HISTORY OF THE HOUSE OF SIEMENS

GEORG SIEMENS

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VOLUME I

THE ERA OF FREE ENTERPRISE

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A. F. RODGER

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PREFACE

The idea of writing this book in its present form was only conceived after the close of World War II, at a time when the combined archives of the various Siemens undertakings were either destroyed or in a state of great disorder. Thus only inadequate use could be made of this valuable source material, and it is mainly due to the fact that the Author was able to make a series of extracts from the archives whilst engaged on other research at an earlier date that he was able to undertake the task at all.

This work seeks to combine the salient features of the "popular" presentation with those of the scientific exposition; it is intended to be easily comprehensible after the style of the former, without lapsing into the unpretentiousness of a picture book, yet to maintain something of the critical objectiveness of the latter, whilst dispensing with the cumbersome ballast of bibliographical data generally associated with this type of literature. It is for the critics to decide what measure of success has been achieved. The difficulties described above will no doubt be taken into consideration.

The Management of the Firm generously permitted the Author full use of such archives as are already accessible again, without seeking to influence him in any way. On the contrary, the Author was granted complete freedom in all matters concerning both the selection of suitable material and the mode of representation, for which he alone bears full responsibility.

Überlingen (Germany), 12th October, 1947 — Georg Siemens

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I.

THE TELEGRAPH WORKSHOP

It is no longer possible to say exactly when the phrase: "A People of Poets and Philosophers" first came to be used, but there are good reasons for assuming it to have originated rather more than one hundred years ago. For then it was that Germans commenced to regard the particular kind of poetry to which the phrase refers as classical, in contrast to that other which, in the name of "Young Germany," laid claim to its heritage. By philosophers, on the other hand, were meant those exponents of philosophic idealism, whose line began with Kant and ended with Hegel. During the mere half-century of its existence this intellectual movement had evolved with the force of an eruption, to soar finally into the blackness of inscrutable night, there to be extinguished in a final burst of flame. But this epoch, too, was now definitely closed and lay behind the spectator. A deep and widespread conviction prevailed that a complete and drastic change was imminent.

There can be little doubt, although unbeknown to the contemporaries of the age, that a part was here played by the same mysterious forces which influence the lives of communities, as they do the individual works of Nature. This reaction grew the more in violence, as the new generation became increasingly conscious of the grave neglect of vast and important opportunities. Whereas other peoples had achieved nationhood and become decisive factors in world affairs, Germany, hamstrung by the particularism of her dynasties, had remained a geographical concept; whilst other countries enjoyed an animated political life, in which domestic issues and the principles of good government were contested, Germany, as Heine has said, could be heard snoring. And whilst enlightenment had elsewhere resulted in fostering the study of mathematics and natural science, thus laying the foundations of the impending technical age, Germany—as many thought—had been wasting her time in idle speculation. The way in which the new alliance of philosophic materialism and natural science overthrew philosophic idealism bore something of the character of a revolution, the former potentates

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being overthrown and routed almost over-night. The vehemence with which, from the second half of the nineteenth century onwards, the German people threw itself into the pursuit of natural science, as well as of technical and commercial activities, has often astonished the world by its inconsistency with the previous conception of Germany as a People of Poets and Philosophers. In reality, however, it is quite easily explained as a natural reaction, which was possibly more violent in the case of the Germans than it would have been with others, owing to a certain national proneness to overshoot the mark.

If one insists on fixing the time at which this reversal in the intellectual interests of the German people became manifest, it can be taken—somewhat symbolically—to be the year of Goethe's death (1832); in any case, it was during the two decades following this event that the great transformation took place. From now onwards, in marked contrast to earlier times, German names began to figure more and more frequently in the annals of the exact sciences; the name of Gauss heads a brilliant succession of mathematicians, which, carrying on the tradition of the great Frenchmen, includes such names as Jacobi, Riemann and Weierstrass. Prominent in the field of Physics were such men as Doppler, Dove, Kirchhoff, Ohm and Wiedemann; in Chemistry Bunsen, Liebig and Wöhler gained world renown, and Robert Mayer was the first to state the fundamental law of modern physics relating to the conservation of energy.

Running parallel to this evolutionary wave were the political currents striving to eradicate the particularistic absolutism of the Princes with their fear-ridden government by police and bureaucrats, and to create instead a unified federal German State founded on the self-government of free citizens. Then again, there was the material distress of the uprooted masses who had deserted the land during the agrarian crisis of the 1820's in favour of expanding industry, and who now had found their champions in the persons of a few intellectuals. These lived under the impression of the far greater misery which had overtaken England a few decades earlier, due to the same causes, and expected things to take a similar course in Germany. It was at that time, too, that their most outstanding protagonist, Karl Marx, a former pupil of Hegel, laid the foundation of the sociological doctrine which still bears his name.

Thus, this epoch conveys the impression of a general transition; Society has quitted its accustomed haunts and has set out in search of new objectives; according to temperament, people look back on the past with sadness, restrained irony or cynical contempt. But one thing is common to all—viz., unlimited optimism and unswerving belief in "Progress," in all departments of human endeavour. For Marx, too, the iron law of wages

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and the class struggle were only a passing phase, leading to the ultimate triumph of a new and better society. Progress was the "religion" of the later nineteenth century; it was believed in by the Age in the same way that the early Middle Ages believed in the Gospel; it was permissible to be sceptical about everything, but not about progress.

Werner Siemens was a true child of this age, and it is not without justification that he has been considered to be one of its most typical representatives. This is particularly evident in the light of his subsequent development, but was already foreshadowed in his early aptitude for the natural sciences, linked, as appeared later, with a technical ability bordering on genius. As the eldest son of the leaseholder of an estate in Mecklenburg, a man with a large family and many responsibilities, he travelled to Berlin at the age of 17½ with a view to enrolment as an officer cadet in what was then known as the Engineer Corps. His early wish to study Architecture at the Academy could not be fulfilled owing to financial considerations. The Engineer Corps, however, was unable to accept him, on account of a redundancy of applicants, so, armed with a letter of introduction, he applied to Magdeburg and was installed there in the autumn of 1834 as an officer cadet in the Artillery Corps. One year later he was transferred in the usual course to the Artillery and Engineers School in Berlin, where for three years he received a thorough training, above all in mathematics and the natural sciences, in which he took an absorbing interest. The next few years he spent in Magdeburg and Wittenberg, doing the monotonous routine duty of a young garrison officer in a provincial town. In his spare time, therefore, he occupied himself with all manner of studies and experiments in chemistry and electricity, in the course of which he discovered the galvanic method of gold-plating from hyposulphurous salts. On being transferred in 1842 to the Artillery Workshops in Berlin, these pursuits grew in diversity. Not only was he impelled by his unusually marked inventive ability, but also by anxiety on account of his younger sisters and brothers, for whom he felt himself responsible after the early death of their parents. As regards his brothers, he commenced by taking a special interest in Wilhelm, his junior by six years, whom whilst in Magdeburg and later at Göttingen he had had trained for a technical career, as far as was possible in those days. Having barely attained the age of 21, Wilhelm went to England to exploit his brother's gold-plating process, and had the good fortune to dispose of it for quite a considerable sum, which relieved the two brothers for a time of their most pressing financial embarrassments. In the course of 1846 Werner Siemens, still a Lieutenant at the Artillery Workshops, Berlin, had also come

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into contact with electric telegraphy, which happened just then to be of interest to the General Staff, the Government, and also to the Railway Companies, which were then in the course of formation. This contact with electric telegraphy was to be of decisive influence in his life.

About the middle of the eighteenth century men had begun to study more closely what had been known since the days of classical antiquity, but regarded merely as a curiosity, viz., the electrical phenomena observed when two insulating bodies were rubbed together. So-called "Electrical Machines" were constructed, the electricity thus generated stored in condensers, in those days known as Leyden Jars, and all kinds of experiments made, e. g., by allowing the condenser battery to discharge through a large circle of people holding hands, in order to demonstrate the immeasurable speed of the discharge. These and similar demonstrations were given at Court, in the Salons of the leading circles and before learned societies, and stimulated all manner of speculations and phantastic ideas, without leading to the formation of any clear conception of their true significance. This state of affairs did not change until 1799, when Alessandro Count Volta correctly interpreted at Padua the observations made by Galvani on convulsions in the hind legs of frogs.

The opening of the nineteenth century marked the commencement of a lively period of discoveries. Scientists observed the development of heat in solid conductors, the chemical action in fluids, in particular, the decomposition of water and the phenomenon of the passage of electric current through air, which was termed the arc, discoveries largely connected with the name of Humphrey Davy. Georg Simon Ohm discovered the law governing the interrelation of potential, current and resistance which we call Ohm's law. Above all, however, it was the relationship existing between current and a magnetic field which was studied by men like Oerstedt, Ampère, Arago and others, until Michael Faraday, that unrivalled genius in the art of systematic experimentation, besides stating the fundamental laws of electro-chemistry, coordinated the whole complex of electro-magnetic phenomena into a closed system. This culminated in the perception that every current creates around itself a magnetic field, and that the growth or fading of a magnetic field generates a current in neighbouring conductors. With Faraday's presentation of this phenomenon, lucidly illustrated by the conception of the lines of magnetic force, this stage of development was for the time being brought to a certain finality (about 1835). It was from about this same period that it is possible to date the intellectual revolution in Germany.

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Progress has been described above as the "religion" of the nineteenth century. However, this "religion" could only unfold the full wealth of its riches provided there existed within its individual communities and across their boundaries a lively exchange of news, people and goods. Commerce is one of the most important means of promoting the general wellbeing; it is the most obvious sign of progress and, as it were, symbolic of the blessings showered down by the "religion" of progress. This, in turn, was concomitant with a strong desire to conquer space and time which, indeed, was characteristic of the general frame of mind of the period, and has led many interpreters of the closing western cultural epoch to speak of a Faustian aspiration, finding its expression in an urge to perfect the means of communication. Hence the fact that Railways and Telegraphs, habitually mentioned in one breath, together became the two great symbols which dominated the new age.

Behind these general yearnings, of course, there were very material political forces. Every well-organized government must have a strong interest in the means of communication of the country, both as regards transport, and perhaps even more the dissemination of news. The first World Power of Antiquity, the Persian Empire, besides possessing an extensive road network, already operated a high-speed news service with couriers, alarm-posts and beacons. The use of beacons, by means of which, incidentally, according to Aeschylus, news of the fall of Troy was transmitted in one night from Asia Minor to Argos, was fairly widespread throughout the early ages. The Greeks even had a properly organized torch-telegraph system for any kind of communication, which, for example, was abundantly used in the Peloponnesian war; the fortified Roman frontier against Germania, the Limes Romanus, also made use of beacon fires for signalling. So it came about that these were used throughout the Middle Ages for military purposes, above all, in mountainous country. At the same time plans and suggestions were constantly under consideration for the introduction of optical signals which, by mechanically operated means, such as flags or beams, should form signs for transmission from one look-out post to the next. However, it fell to the first modern State of the new era, the Republic of France, born of the great revolution, to embody this principle in a durable and practicable apparatus. In the year 1792 Claude Chappe proposed to the National Convention the use of a "Tachygraph", which comprised a trestle of some five metres in height carrying a two-limbed rotatable lever, each limb furnished with a jointed signal arm. With this it was possible to make 86 different signals. The signalling posts erected at intervals of seven to ten kilometres, according to the features of the

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countryside, formed a continuous line, along which a signal, repeated from post to post, could be transmitted at a speed which for those days was remarkable. By such lines, having a total of 534 signalling stations, the Capital was eventually connected with 29 towns. The installation came to be known as the "Telegraph". Its success led Great Britain to equip similar optical telegraph lines, and finally, in 1832, the Prussian State Government to install a telegraph line from Berlin, via Magdeburg, Paderborn, Cologne, Coblenz to Treves, the military object of which was obvious.

Under these circumstances it was natural to enquire into the possibility of using continuously flowing electric current, which had meanwhile become known, for the transmission of messages; the incredibly rapid propagation of the electrical effect through a metallic conductor seemed to be a direct challenge. And actually, it was not long after the discovery of further properties of electricity that attempts were made from time to time to utilize it for the production of a telegraph.

In 1833 Gauss and Weber in Göttingen connected up the Observatory and the Institute of Physics by twin wires and exchanged signals. The receiver consisted of a horizontally suspended heavy magnet rod which was able to oscillate freely round its vertical axis, and was encompassed in a wooden frame wound with many turns of wire. A current flowing in these coils caused the magnet to be deflected from its position of rest, i. e., North-South, in the one or other direction of rotation, according to the direction of the current. By suitable combination of the deflections it was possible to represent every letter and every digit by four current impulses at the most.

Out of this rather awkward arrangement, the purpose of which had originally not been a device for news transmission, but for the measurement of electricity, grew others. Thus Schilling von Canstadt, Steinheil and, somewhat later, Wheatstone developed the much handier instruments known as "Needle Telegraphs", some of which had as many as five magnet needles. The object in view was to produce the several needle movements which represented each symbol simultaneously instead of consecutively, and thus to reduce the time required for transmission. Of course, this meant that a separate wire was required for each needle.

As compared with the needle telegraph, the operation of which was nevertheless still very troublesome, the invention of the dial telegraph by Cooke and Wheatstone was a decided advance. In the form which it assumed about 1840 after some preliminary experiments on the part of the two inventors, the dial telegraph consisted essentially of an electromagnet, the movable armature of which was connected to a clock-

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work mechanism by a balance wheel. As is generally known, the balance wheel of a clock is the last wheel with the one-sided teeth, which gives motion to the pendulum by means of the so-called escapement. In the case of the Wheatstone-type instrument, the place of the pendulum is taken by the armature of the electromagnet, and this drives—in the reverse order—the clockwork through the balance wheel, no further drive being necessary. Each current impulse coming from the other station attracts and releases the armature, thus moving the balance wheel forward by one tooth (step-by-step switch). A pointer connected to the clockwork thus remains stationary at the division of the dial which corresponds to any particular number of current impulses.

A number of the Wheatstone instruments were brought to Berlin about 1842, where a certain Hofrat Soltmann spent several years testing and introducing them. Owing to Soltmann's son being a regimental comrade of Werner Siemens, and on friendly terms with him, it was possible for the latter to take part in experiments undertaken in the summer of 1846 in Soltmann's garden with the object of testing the apparatus. In witnessing this demonstration, Werner Siemens saw that the current impulses produced by turning a crank handle were too uneven to ensure reliable action of the apparatus, and that they should preferably be produced by clockwork. A clockmaker of the name of Leonhardt, who had been commissioned by the General Staff to install an experimental line between Berlin and Potsdam, and who knew Werner Siemens from the Polytechnic Society, undertook to carry out the improvement.

Over long distances, however, this arrangement was also unsatisfactory, and Siemens proposed to Leonhardt an entirely new construction which he had evolved in the interval.

When the armature of the electromagnet for the stepwise balance wheel movement is attracted, it interrupts its own circuit by means of a special contact, and in so doing falls back, thereby again restoring its circuit, again falling back, and so on, repeating the cycle. By suitably dimensioning and adjusting the parts, it is possible within limits to set the apparatus to operate at a definite cyclic frequency, and thus at a definite rotational speed of the pointer. Thus, when the operator at the transmitting station closes the circuit, the pointer of his instrument commences to rotate, and since the instrument at the receiving end is fed by the same impulses, the pointer of that instrument will rotate at the same speed, i.e., in synchronism. The dial of the instrument is surrounded by radially arranged keys, each one of which corresponds to a section of the dial. If one of these keys is depressed, the pointer of the transmitter

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instrument is mechanically arrested and the circuit interrupted. This, however, causes the needle of the receiving instrument to stop simultaneously and at the same point.

Werner Siemens explained his idea to Leonhardt, who at once expressed his agreement in enthusiastic terms, although, as later became apparent, he never really understood the inherent principle of the invention. It was agreed that Leonhardt should manufacture instruments on the Siemens principle and pay Siemens a certain share of the profit. It was evident, however, that Leonhardt was unable to cope with the task; in any case he left his client in the lurch and a dispute ensued, which at the close of the year 1846 led to the annulment of the agreement. Werner Siemens, on the other hand, was now determined to give up the rather aimless pursuit of all sorts of inventions, and to concentrate exclusively on electric telegraphy, which he considered to have a great future.

The ultimate Authority in Prussia for technical questions concerning telegraphy was the "Commission for the Undertaking of Experiments with Electromagnetic Telegraphs," briefly known as the Telegraph Commission. With this Commission Werner Siemens had previously come into contact, having already made a name for himself through lecturing on Telegraphy before the Physical Society and the Polytechnical Association. The first step now was to gain the approval of the Commission for his new design. Having severed his connection with Leonhardt, Werner Siemens found two mechanics, Boettcher and Halske, partners in an engineering workshop, who were prepared to build a trial instrument to commence with. On 8th July, 1847 after extensive experiments and repeated modifications, it was at length possible to demonstrate the instrument to the Telegraph Commission on the Berlin-Potsdam line, which had meanwhile been completed. The simplicity of the apparatus, as also the speed and reliability of its operation, gained for it the unanimous approval of the Commission, and on the basis of a report by the technical deputation, which included a number of the members of the Telegraph Commission, a Prussian patent, for which Werner Siemens had applied, was granted to him on the 7th of October, 1847 for eight years.

Werner Siemens' spell of duty in the Artillery Workshop was at an end; on October 1st, 1847 he was due to return to his Regiment at Wittenberg. Since this was very much against his inclinations, he was thinking of resigning his commission, when the Chief of the Prussian Telegraphs, General O'Etzel, proposed his being posted as a senior staff member to the Telegraph Commission. Siemens accepted the post, but,

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as he himself wrote, he found himself in a rather peculiar position, as he had meanwhile persuaded the mechanic Halske to leave his partner and, together with Siemens, to found a Telegraph Construction Co., as they planned to call it. A cousin of Werner, Georg Siemens K. C., in Berlin, had offered to advance the necessary capital of 10,000 Thalers, becoming in this way a sleeping partner in the new venture. The net profit was to be shared in the ratio of $^2/_5 : ^2/_5 : ^1/_5$. Georg Siemens was to subscribe his capital in three equal instalments, the final one payable in the spring of 1848, but owing to the turmoil of the revolution, the last instalment was never received, so that actually only 6,843 Thalers were paid in, which, as Georg's share, had grown by 1st January, 1855 to 60,000 Thalers. The K. C. then withdrew from the business, after arranging for repayment of 10,000 Thalers per annum from the above date for six years. The two active partners in the new private trading firm rented premises at Schöneberger Strasse 19, in the vicinity of the Anhalt Railway Station, where they set up house, Werner Siemens on the ground floor and Johann Georg Halske on the second floor, whilst on the first floor they equipped a workshop of about 150 square metres area with three lathes, and engaged an initial team of ten men. They commenced operations of the 1st October, 1847, which is, therefore, the foundation date of the Firm of Siemens & Halske.

More or less contemporaneously with the development of his telegraph apparatus, Werner Siemens had been studying the question of conductors. The task of insulating a metallic conductor from its surroundings had been occupying many brains for half a century and had brought forth, amongst others, quite a number of very curious suggestions. Nevertheless, Sömmering had produced a cable consisting of several cores as long ago as 1809, the insulation consisting of india rubber which had been dissolved in ether, and Schilling von Canstadt had in 1812 used a cable of this kind to detonate under-water mines. In 1837 there had been some talk in America about laying insulated conductors underground in iron or lead pipes, and Cooke and Wheatstone were granted a British Patent for such an arrangement in the following year.

In 1842 an English physician in Singapore, Dr. Montgomery, became acquainted with guttapercha. He sent samples to London and, somewhat later, consigned a considerable quantity to England. In this way Wilhelm Siemens became acquainted with the new material, and sent a quantity to his brother Werner, who in the spring of 1847, suggested using it for the insulation of electrical conductors. In August of the same year Werner contracted with the Indiarubber Works of Fonrobert & Pruckner in Berlin to supply two 3.7 kilometre lengths of copper wire

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insulated with guttapercha, which he installed alongside the Anhalt Railway line, and in the following spring extended it by 18 kilometres to Grossbeeren. In the first instance, the insulation of the copper wire consisted of two guttapercha strips, each of which was pressed round half the circumference of the core, thus forming two seams. As this arrangement did not prove to be durable, especially when the wires had to be bent, Werner Siemens in the autumn of 1847 designed a model press for encasing the conductor in a seamless sheath, which he demonstrated to engineering circles in the spring of 1848. It was thus that the first really serviceable cable came into existence, and optimists were already prophesying that the cable was the thing of the future, and that overhead transmission lines, which had hitherto been used but were very liable to failure, would soon disappear.

That Siemens, now that he was a partner in an engineering business and a contractor for the manufacture and installation of telegraph equipment, did not retire from the Civil Service, was probably due in the first place to his desire to see how his new undertaking was going to develop. In the second place, he had not yet definitely decided to become a manufacturer on his own account, but was rather counting on the possibility of being offered an important post in the Government Telegraph Administration and of handing over the engineering business as a family concern to one of his younger brothers. Friedrich at that time had just commenced to make himself useful in the workshop as a draughtsman. Of course, the young Firm at that time had few orders, and was mainly engaged in producing demonstration models. At Werner's suggestion, the Telegraph Commission had thrown open to public competition the submission of the most suitable design for a telegraph apparatus for the State Telegraph Service, the trials in connection with which were to begin on March 15th, 1848.

Three days later, however, revolution broke out in Berlin, the immediate effect being to disrupt the functions of government. Hardly had things begun to settle down, when the Elbe Dukedoms of Schleswig and Holstein rose in arms against the contemplated annexation of Schleswig by the Danes. The German Confederation decided to support the insurgents, and despatched an expeditionary force to the seat of war under Prussian leadership. Werner Siemens' brother-in-law, Himly, who was a professor in Kiel and a member of the Provisional Government, appeared in Berlin and solicited the co-operation of his brother-in-law in the defence of Kiel harbour by electrically detonated submarine mines. Since Prussia was for all practical purposes at war with Denmark, Werner was granted the leave for which he applied to enable

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him to participate in the German-Danish war. Full of enthusiasm he threw himself into the adventure, whilst Halske remained in the workshop and with circumspection commenced to stock-pile telegraph apparatus.

Johann Georg Halske was actively engaged in the undertaking which he had helped to found for a period of only twenty years, but his name has graced the style of the Firm for a hundred years, and with every justification, for the tradition he created lives on to this day. As a skilled mechanic, his technical qualifications placed him between the clockmaker and the mechanical engineer; from the former he had inherited patience and from the latter sound engineering principles. For this type of occupation he was admirably fitted by nature; he was cautious, reliable and thorough, and took the pride of an unspoiled artisan in good work and honest dealings. Not a piece left the workshop before he had convinced himself that he could let it go on its way with a good conscience, no matter how much he might be pressed from outside. Halske's "artistry" was occassionally a source of annoyance to Werner Siemens, when it resulted in prices being too high or deliveries too long, but he (Siemens), on the other hand, felt bound to acknowledge what a priceless Works Manager he possesed in the person of his partner. It was a rare stroke of fortune which had brought together the wealth of ideas of the gifted inventor, and the sterling incorruptibility of the mechanic.

When in the course of the summer of 1848 the war appeared to be drawing to a close, Werner Siemens retired from the service of the Provisional Government and returned to Berlin. Here, one or two changes had occurred in the meantime: the Telegraph Service, which had hitherto been a military concern, was now attached to the Ministry of Commerce (Board of Trade); in consequence, the Telegraph Commission had been dissolved. Before this actually took effect, however, the Commission had arrived at a decision in the matter of the public competition which had been planned for March. Its verdict had been different from that for which Werner Siemens had hoped, he having in all probability expected to be the sole prize-winner. The Commission, on the contrary, had taken the view that full-scale tests should be undertaken with three of the equipments submitted, by installing them in the new lines which were due to be laid in the near future; the apparatus submitted by a certain Dr. Kramer, a schoolmaster in Nordhausen, on the line Berlin—Cologne. This apparatus was a combination of the Siemens & Halske model and that of Wheatstone; the line Berlin-Frankfort was to be equipped with the Siemens self-interrupting dial telegraph and with a novel type of instrument which recorded the message, an instrument which Werner Siemens at its first appearance was not inclined to take quite seriously. It came from the United States of America and was sold in Europe by a certain Mr. Robinson; the inventor was stated to be a painter by the name of Morse.

As long ago as 1837, Samuel Finley B. Morse had developed a telegraph apparatus which he had intended to enter in an open competition advertised by Congress for a mechanical-optical telegraph. In this apparatus the armature of an electromagnet was moved horizontally to and fro when the magnet was excited by impulses of shorter or longer duration. The armature carried a vertical lead pencil, beneath the point of which a strip of paper was drawn by means of clockwork at constant speed at right angles to the direction of movement of the armature. A short impulse produced a triangular projection in the pencil line on the strip of paper, whilst a longer impulse gave rise to a trapeze-shaped projection. Morse had used a combination of these short and long impulses to form an alphabet.

The inventor took out an American patent for his apparatus, but failed in spite of personal efforts to obtain a patent in any European country. On the other hand, his friends in Congress succeeded in obtaining a grant of 30,000 Dollars to equip an experimental line between Washington and Baltimore to test the invention. The first telegram was transmitted by this line in May 1844. On the basis of the experience gained in the following two years of operation, Morse modified the apparatus in such a way that the pencil, being moved in a direction at right angles to the surface of the paper, made longer and shorter strokes on the strip. Moreover, he added the automatic release of the clockwork at the commencement of reception, and developed the instrument, still known as the Morse key, which is used for creating the impulses. It was in this state of development that Robinson—actually against Morse's will—brought the apparatus to Europe, trying in vain to introduce it into England or France, until in 1847 he succeeded in getting it accepted for the equipment of a new telegraph line between Hamburg and Cuxhaven for reporting the movements of shipping. Following this, he took part in the Berlin Telegraph Contest, and although his apparatus was inferior in execution to the self-interrupting dial telegraph of Siemens & Halske, the Commission decided in favour of undertaking large-scale experiments with the Morse telegraph. This resolution was strongly supported by Nottebohm, a Government Assessor, who was the Director-designate of the future Prussian Telegraph

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Department. Whilst he was not a telegraph engineer, he made up for it by possessing a considerable amount of sound common sense.

Since it was thought that, in the discovery of guttapercha, the ideal material had been found for the insulation of underground conductors, the general opinion amongst experts was against the construction of overhead lines if they could possibly be avoided. Actually, too, the first results with overhead lines were not encouraging. In the opinion of the masses, the purpose behind the construction of telegraph lines by the Government was to enable it to deploy troops against insurgents without loss of time; they were therefore an instrument for the suppression of the liberties of the people, and as such the target for attack by numerous saboteurs. It was therefore decided in the case of the Frankfort line to lay guttapercha-conductors in the ground alongside the railway line. On sections where the railway line was not yet in existence, as between Frankfort and Cassel, the overhead construction was retained, for which Werner Siemens introduced porcelain pin insulators in place of the glass insulators used in America.

The laying of the Frankfort line, which Werner Siemens superintended in person, was pushed forward rather too hurriedly, owing to the fact that the so-called Federal Parliament, from whose deliberations and decisions on the shaping of the future Germany far-reaching effects were awaited, was in session in Frankfort. The consequence was that the trenches were neither of sufficient depth nor adequately covered, and that the marking of the position of the conductors and the joints was insufficient to meet the demands which later experience showed to be essential in work of that kind. Furthermore, following the principle of the vulcanization of rubber, introduced by Goodyear a few years earlier for the purpose of rendering the rubber tougher and more weatherproof, sulphur was added to the guttapercha. This combined with the copper of the conductor to form cuprous sulphide, which gradually destroyed the guttapercha sheath and rendered the insulation illusory. The experience gained from the laying of this first line was to some extent turned to account in later undertakings, but vulcanized guttapercha was retained for the insulation, as it was only very gradually that its evil effects became manifest.

On the conclusion of six months' operation of the Frankfort line and the completion of the Cologne line, Werner Siemens requested his discharge from the Civil Service. He believed himself to have gathered sufficient experience to enable him to set up for himself as an independent manufacturer of telegraph apparatus. In the meantime, too, the Workshop had received so many orders for telegraph apparatus that

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the question of extensions had to be considered. In addition to Government Departments, the Railways now appeared as prospective customers, planning to use the telegraph for train control. Moreover, the Railways had a large demand for so-called electrical bell-ringers, which Siemens & Halske had developed in a spirit of friendly collaboration with their one-time competitor, Dr. Kramer. A heavy clockwork, after the fashion of a turret clock, with weight-drive and bell-hammers, was mounted in a cylindrical sheet-iron housing at each railway station, and remotely operated by current impulses from the previous station to signal the departure of a train. As a matter of fact, quite a crop of technical queries had arisen, such as the testing of conductors during manufacture and laying, the construction of suitable measuring instruments, the question of static charges in conductors laid in the ground and other matters, so that it had become impossible to deal with them as side issues. This business was no longer that of a small workshop like so many others, which could be established and then perhaps left as a going concern in the hands of a manager to be administered in the interests of the family; it required the concentration of the whole of the personality of the founder.

One of these new questions was the appearance of the Morse telegraph. Nottebohm had arranged for the apparatus, in the primitive form supplied to Robinson by a Hamburg workshop, to be set to work on the Frankfort line alongside the Siemens dial telegraph. The result was that the Speech from the Throne of the King of Prussia opening the Diet in Berlin was transmitted by the Morse apparatus in 1¼ hours, whereas transmission by the dial telegraph took 7 hours. This was so decisive that Nottebohm refused to listen any longer to the initial objection that the American apparatus involved the engagement of skilled operators. He called for Halske, and asked him whether he were willing to manufacture this apparatus for the Prussian State Telegraphs, enumerating at the same time the modifications required in the new apparatus.

Siemens & Halske thus commenced to manufacture the new telegraph and, thanks to the high quality of their workmanship, remained sole suppliers to the Prussian Telegraph Administration until further notice.

However, the victory of the Morse Telegraph was not achieved in 1848. The Prussian Telegraph Administration continued to order dial telegraphs from Siemens & Halske; in December, Halske went to Oderberg to instal the one hundredth apparatus. A few months earlier, an envoy of the Russian Government, Captain Lüders, had come to Berlin to study the German telegraph system. He also called at Siemens &

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Halske, and the dial telegraph which was demonstrated to him won his approval. However, no business resulted.

On 1st January, 1850, the young firm issued its first balance sheet, which thus covered a period of 2 1/4 years. It must be confessed that this was not a balance sheet as we understand it, but rather a kind of profit and loss account with a somewhat peculiar arrangement of the accounts. As a matter of fact, the two partners understood just as much about book-keeping as about theology, and this was evident from a glance at the balance sheet. This much could be gathered, however, that in the period named the turnover amounted to the round figure of 32,000 Thalers, of which roughly half remained as gross profit. The number of employees had meanwhile risen to 32.

At the beginning of the year 1850 Werner Siemens undertook the first business journey for his firm. He travelled first to Brussels, where he had the opportunity of lecturing before the King and Court on electric telegraphy, in this way becoming known to the public. But his hopes of obtaining a substantial contract from the Belgian Government for telegraph apparatus were disappointed, owing to the stubbornness of an old physicist, who had been called in by the Government as an expert, and whose prejudice in favour of the old needle telegraph could not be broken down.

Werner then proceeded to London to visit his brother Wilhelm, who had endeavoured, without much success, to establish himself in England as a Consulting Engineer, unless it be regarded as an asset that he had taken an active part in the proceedings of the learned and technical Societies of the country, and had in consequence acquired a certain reputation. The two brothers now agreed that Wilhelm should represent Siemens & Halske in England. He was granted an advance of £ 210, and it was agreed that he should receive one third of the net profit on business which he introduced; furthermore, he was empowered to add 12 1/2 per cent to the prices of Siemens & Halske on apparatus sold by him. He commenced his new activities by making preparations for Siemens & Halske's participation in the World Exhibition planned in London for 1851.

Werner now turned to Paris with a view to creating a basis for further activities, and followed up his London talks by negotiations with L. Bréquet, the manufacturer of the telegraph apparatus used by the French State Telegraphs. The discussions were unfruitful but as the guest of the Academy of Science, he submitted a paper: "Mémoire sur la télégraphie électrique." This opportunity of appearing before such a

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Forum reinforced the authority which he had already acquired in the few short years of his activities.

When Siemens & Halske drew up their second balance sheet at the close of the year 1850, the figures confirmed the favourable impression which had been formed of its development as time went by. Turnover was 81,000 Thalers, gross profit 26,700 Thalers, i. e., no longer half, but only one third of the turnover, which reflected the closer calculation of prices which had become necessary.

For the time being, orders continued to be received in such a volume that the workshop was strained to the limit of its capacity. Thus, for instance, an order was received from the Russian Captain Lüders, as the result of his earlier visit, for 75 dial telegraph instruments for the St. Petersburg—Moscow line. In addition to their demands for telegraph apparatus, the Railways were large users of electrical bell-ringers, and the Berlin Fire Brigade placed an order for an extensive "Fire Station Telegraph" installation, the first of its kind in history, and which has become a model for all subsequent fire-alarm services. If it was intended, in the face of this situation, to plan for a further expansion of the business, there was no option but to move into larger premises, since there was no further possibility of extension in the Schöneberger Strasse. Siemens & Halske therefore acquired a property at 94, Markgrafenstrasse, not very far from the former headquarters, for the sum of 40,000 Thalers, comprising a roomy, 3-storey house fronting the street, an extensive courtyard and land on which suitable workshops could be built at an estimated cost of 10,000 Thalers, whilst the 3-storey house provided room for the accommodation of the partners and for the necessary offices.

Meanwhile, a serious technical crisis had developed concerning the telegraph wires of the Prussian State Telegraph Network. The vulcanizing of the guttapercha proved to have been a disastrous mistake, and the wires had not been laid at a depth sufficient to protect them from mechanical damage. Above all, however, the repair and maintenance services were in their infancy and their organisation totally inadequate. Thus the number of faulty lines continued to grow, as also the time spent in repairs in consequence of progressive deterioration of their condition, until, finally, it came to pass that on certain lines the state "out of order" became the rule, and "in working order" the exception. The public seized on the scandal, especially as Reuter had handed in an angry complaint concerning this intolerable state of affairs. The hard-pressed Prussian Telegraph Administration was probably not altogether unconnected with the sudden clamour which accused Werner

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Siemens of having recommended the use of underground wires and guttapercha insulation. Thus attacked, Werner Siemens defended himself in a pamphlet entitled: "Short Account of the Working of the Prussian Telegraph Lines with Underground wires," in which he endeavoured to prove that pure, unvulcanized guttapercha was an excellent insulating medium, and that underground wires would most certainly give satisfactory service, provided that they were laid in a suitable manner, and not—as had been the case—hurriedly and with a view to saving expense, and that they were adequately maintained. Nottebohm regarded this pamphlet as a criticism of his administration, and since in any case relations between himself and Siemens & Halske were strained by reason of what he considered to be a lack of deference on their part, he made use of the incident to sever the connection with the Firm entirely. He cancelled the whole of the orders from the Prussian Telegraph Administration, and handed over the Siemens & Halske apparatus to other firms to be copied.

For the young firm this stroke meant not only the loss of its largest customer, but also the one who was most punctual in settling accounts, and a heavy blow had been dealt to their credit. True, the order book contained numerous orders from other Telegraph Authorities and Railway Companies, but with these they might easily have to wait a long time for payment. What Siemens needed, however, was cash, ready cash. The granting of the French patent was conditional on the manufacture of the apparatus in France, a circumstance which led to a revival of the plan to start a factory in France in collaboration with Bréquet in Paris. Karl, the brother next to Friedrich, who till then had been occupied in the family factory without special functions, was instructed to take the necessary time to come to an understanding with Bréquet. But Bréquet was in no hurry; he was only interested in the venture on condition that the Germans provided the finance. After months of negotiating, the point was reached where Karl Siemens was able to submit to Berlin a draft agreement, which involved the advance by Siemens of a considerable sum of money. Since this could not be raised, Halske was compelled to abandon the scheme and, in consequence, to allow the French patent to lapse. Halske considered this attitude to be the more justifiable, as the removal to the Markgrafenstrasse had meanwhile taken place—in the summer of 1852. In itself, it was quite time to move into larger premises, since orders had come in from Russia, for very early delivery of course, with a promise of further orders to follow. At the moment, however, this meant the engagement of further hands, who expected punctual payment of their wages, and the purchase of further

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raw materials, for which only short-term credits were obtainable. And when would the Russians pay? It frequently happened on pay days that Halske had to borrow Thalers by the hundred.

After the good start in 1850, the result for 1851 had been poor; that for 1852 was even much worse, if the figures which had just been compiled, were to be believed. They were not reliable, as the books were in a state of great confusion, but that things were not going well was evident to Halske from the fact that there was never any cash in the safe.

He could have got on quite well with his partner Werner, had it not been for the brothers. To begin with, there was Wilhelm in London, the only result of whose activities thus far was the bronze medal awarded to the Firm in connection with the International Exhibition in London. On the strength of this Wilhelm troubled Halske with incessant modifications of a water-meter which he had invented and in which he expected to do an extensive business in England. Karl, again, had spent nearly a year in Paris without the slightest success, having cost the firm 3,000 francs in expenses. No wonder that Halske was annoyed and that he regarded the future with the deepest concern.

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II.

EUROPEAN BUSINESS

At this critical period, Werner, although only recently married, spent long months travelling, mostly in Russia, for as a result of the reconnoitory visit of Captain Lüders in 1850, a close business connection was soon to develop between Siemens & Halske and the Russian Government. The vast Russian Empire was ruled over by Nicholas I, a suspicious and brutal despot, employing the technically backward devices of the omnipotent police State. That meant that in all matters except those, which by reason of their outstanding importance required the personal sanction of the despot, decisions were taken as seemed most expedient to the bureaucracy. This soon became evident to Werner Siemens, following his arrival in St. Petersburg early in 1852 to negotiate the construction of a telegraph line St. Petersburg—Oranienbaum—Kronstadt. At the middle of last century, Railways and Telegraphs in Russia were still in their infancy. About 1850, in this land of enormous distances, there existed a total of 600 kilometres of railway track, as against 10,600 kilometres in the small area of Great Britain; the proportion of telegraph lines was similar. In spite of his deep-rooted dislike of any greater freedom of intellectual development, which according to the conception of the nineteenth century should go hand in hand with scientific and technical progress, the Tsar fully realized that railways and telegraphs were important instruments in the maintenance of his rule. He had therefore decided in principle, next to ensuring the safety of the Gulf of Finland, to link up the Capital by State Telegraphs with the two border areas most subject to political unrest—Finland and Poland.

Railways and telegraphs belonged to the department of the Minister of Public Works, Adjutant General Count Kleinmichel, a replica on a smaller scale of the ruling despot. He commenced by keeping the German Industrialist waiting in order to "soften him up." The consequence was that his first journey, in the course of which, incidentally, Werner became seriously ill, did not lead to business. On a second visit in August 1852 some contact was made, more particularly as in the

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meantime Halske had signed a contract with Representatives of the Governor General of Poland for the construction of a telegraph line from Warsaw to the German border, but it took a third visit at the commencement of the following year to conclude an initial contract for the line St. Petersburg—Oranienbaum—Kronstadt. These journeys, which in those days still had to be performed by road under the rigours of the Russian climate, imposed the severest demands on Werner's physical and mental resilience; nor could he remain absent from the factory repeatedly for months at a time. He had, on the other hand, gained the impression from his negotiations with Kleinmichel that it was now necessary for someone to be permanently in St. Petersburg, who was not only capable of superintending work in progress, but was also in a position to follow up and conclude further business. In agreement with the Adjutant General, therefore, he transferred his brother Karl, who since his unfortunate debut in Paris had been stationed in London as assistant to Wilhelm, to St. Petersburg as permanent representative of the Firm. Karl was still very young when he took up this responsible position, but his sound common-sense and pleasant manner quickly secured him in the good graces of Count Kleinmichel, and enabled him to make a success of his mission. Although the Russian Government had been determined, from the time of the initial contact with Siemens & Halske, to proceed with the development of the telegraph network, it was impossible to have foreseen the delays which were to be imposed by political events. The war with Turkey in 1853 on account of the Moldavian Principalities had led, in consequence of the support given to Turkey by England and France, to the outbreak of the Crimean War in 1854: what seemed at first to be a larger kind of colonial war had grown into a European war, which threatened the standing of Russia as one of the great powers. The military and political importance of speedy communication with the seat of war was so obvious, that for the Government the question of expense played an entirely subsidiary part. Siemens & Halske were known to be efficient, since they had laid the telegraph line St. Petersburg—Oranienbaum—Kronstadt, with a cable supplied by Newall & Co. in England, crossing the Gulf of Finland from Oranienbaum to Kronstadt, and in spite of enormous difficulties and obstacles had handed over the line in working order in a comparatively short period of time. The line from St. Petersburg to Warsaw had been commenced. In view of the speed at which action had to be taken, there was hardly any other firm available, so that the Government entrusted to Siemens & Halske the execution of the whole development plan. Contracts were offered to the Firm for a line from Moscow to Kiev,

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and shortly afterwards for lines from Kiev to Odessa and St. Petersburg to Helsinki, always, of course, with impossible stipulations as to time of delivery. The contract in each case was to comprise the complete equipment: poles, insulators, wire, apparatus, including installation in working order. Then, however, and this was new and unexpected: the Russian Government demanded the acceptance of a so-called " Remonte," i. e., a maintenance contract, under which, against payment of a fee, the telegraph lines were to be kept in a constant state of repair and working order. The partners, Werner Siemens in particular, stubbornly resisted the pressure to accept these maintenance contracts, as there were too many unknown factors which influenced the costs. It was not until after lengthy negotiations that Siemens & Halske, with grave misgivings, declared their readiness to accept, for at this point a Russian outsider seemed ready to accept the contract. This could not be tolerated under any circumstances, however, since the competitor would attribute every failure to inherent defects in the line, and not to the maintenance, thus seriously endangering the reputation of the Firm.

The obligations to Russia into which Siemens & Halske had entered in this year of 1854 were immense for such a small undertaking. They had contracted to build telegraph lines to the tune of about half a million Roubles, and in addition accepted maintenance contracts of an annual value of about a quarter of a million Roubles for a period of twelve years. A stream of orders for apparatus poured into the Berlin workshop, which was unprepared for such a sudden deluge; within a year the number of hands had to be approximately trebled. But above all, it had become necessary to create an organisation in Russia to supervise the construction and maintenance of the telegraph lines, which were to stretch from the Gulf of Finland to the Black Sea. This meant the engagement of senior staff, or "officials," as they were then called. Up to that time the Firm had not had "officials" of this type in their employ—the Principals were their own designers, managers and correspondence clerks; the one exception was the accounts, for which Mr. Fiedler had been engaged, and in which connection it was debatable whether his inexperience, or the want of instinct of the Partners for good commercial practice, was more to blame for the indisputable confusion in the books. The time had thus come to engage staff. As a preliminary, it was decided to part company with one who was felt to be no longer anything else than a drag. This was Georg Siemens K. C., with whom it had become impossible since the crisis of 1853 to maintain harmonious relations. At the end of 1854, he was therefore given notice of termination of his partnership, with the provision that he was to be

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paid as his share of the capital the sum of 60,000 Thalers in six annual instalments of 10,000 Thalers; the Firm was now in a position to make this generous settlement. His place as Partner in the Firm was taken by Karl Siemens. Karl's contribution to the capital was a capacity for work which had shown brilliant results in Russia at a decisive juncture. It was agreed to share the profits between Werner Siemens, Halske and Karl in the ratio $^{2}/_{5} : {}^{2}/_{5} : {}^{1}/_{5}$. The opportunity was taken of striking a balance at the end of 1854, which showed the capital of the company to be 262,159 Thalers. Since it must be assumed, on the basis of the meagre records available, that the capital at the close of 1853 was 60,000 Thalers, it follows that in this one year a net profit had been made of roughly 200,000 Thalers, the greater part of which had flowed from the Russian orders, and this notwithstanding the fact that a large part of the Russian contracts had not yet been executed, much less invoiced. To handle the Russian business a branch of the Firm with autonomous accounting was opened in St. Petersburg, with Karl Siemens as manager.

Notwithstanding the increased business activity, the Works in Markgrafenstrasse was still only a workshop, not a factory. Apparatus and instruments continued to be manufactured individually under Halske's supervision. Although at that time such ideas as interchangeability and serial production were quite unknown, there were nevertheless already certain branches of the metal-working industries on the borderline between machine construction and instrument making where the beginnings of rational mass production could be observed. In the manufacture of small arms and, a little later, of sewing machines, it had already become the standard practice to clamp a number of identical parts together and to plane, bore or mill them together in one operation. Of course, this necessitated the use of machine tools with power drive from shafting. In the background of a works of that kind there was always the steam-engine. The shops in Markgrafenstrasse had no such equipment; the only machine tools were lathes and a small drilling machine, both for manual operation; it was not until 1863 that a steam-engine was installed. The mechanics employed were also not just operatives, but "artists," as Werner would occasionally remark with bitter sarcasm. In this respect he did not see eye to eye with Halske, who invariably took the part of the workers, and whose ideal was to have a splendidly equipped workshop, but on no account a factory.

The impulse, which originated in the rapid expansion of the Russian business, led the Partners to engage two assistants, who were destined to play a material part in the history of the House. One was Werner's old school-fellow and regimental comrade, William Meyer. In Meyer,

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Werner Siemens had found a collaborator whose disinterested fidelity to the ideals of the Firm created a tradition, which has remained a force through succeeding generations. The second was the Senior Accountant Karl Haase. He joined the Firm at an early age, and brought with him something which it had not possessed until then, viz., a system of book-keeping which brought order and clarity into its complicated transactions. For here was the unfolding of a type of business undertaking, for which no precedent had hitherto existed; it was therefore necessary to organize and present the accounts in a manner which was entirely new. The Russian business was the first touchstone of Haase's abilities.

It had not taken long to become used to big figures. In 1855 the turnover from the laying of new telegraph lines was about three quarters of a million, that resulting from the maintenance contracts about two hundred thousand Roubles. One year's working in Russia had thus resulted in a total turnover of nearly one million Roubles. In the following years the turnover from new construction was not so high, since after the cessation of the Crimean War the pace of development of the telegraph network was slowed down considerably. Moreover, quickly following the death in March 1855 of Tsar Nicholas there had been a comb-out of the leading ministerial posts, to which the Minister of Public Works and patron of Siemens & Halske had also fallen a victim. The new minister regarded the transactions of his predecessor with great suspicion, the more so, as he had discovered that the banker Kapherr, whom the Firm had appointed as their representative on first coming to Russia, had received a commission of 10% on the first and subsequent contracts. ("What a profit these people must have made to be able to pay such commissions!"). What the outsider did not appreciate, was that the two brothers had walked into the net of the crafty financier and had rather thoughtlessly agreed to bind themselves for a number of years. As a matter of fact, the bulk of the profit was not made on the construction of the lines, but on their upkeep, and in this connection Siemens & Halske could say with a clear conscience that it was not they who had invented this form of contract, but that, on the contrary, they had resisted it to the best of their ability, and had only given way to extreme pressure. As a matter of prudence, a reserve fund had been created, to which a third of the income from the maintenance business was posted annually, from which to meet the cost of the inevitable renewal of the telegraph lines in due course. But in spite of these burdens, the maintenance contracts proved, in the twelve years of their existence, to be a brilliant piece of business. The total net profit, includ-

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ing the deductions for the reserve fund, amounted to approximately two million Roubles, of which, unfortunately, about half a million was lost in needless and foolish speculation on the part of Karl.

Seen from the outside, the Firm of Siemens & Halske appeared, in fact, to be nothing more than a profit-making enterprise of the Siemens Brothers, a family dinner-table at which the courses followed in continuous succession. Werner had no fewer than seven brothers: in order of age, Hans, Ferdinand, Wilhelm, Friedrich, Karl, Walter, Otto. Of these the two eldest had made their own way at a comparatively early age, the former as a distillery owner, the latter as a farmer. Wilhelm, Friedrich and Karl, on the other hand, were at first connected in one way or another with their brother's firm as his assistants, and on Friedrich striking out for himself as a glass manufacturer, the two youngest threatened to move in as members of the family. Apart from the fact that Werner had promised his mother on her deathbed to be a father to his younger brothers and sisters, he was by nature endowed with a strongly developed sense of family, which made it appear to him the most natural thing in the world to offer his younger brothers a home in the house which he had built. Notwithstanding his friendship for his partner, Halske could not contemplate the consequences of Werner's attitude without a certain amount of apprehension. Together with his partner he had founded a telegraph construction workshop, and not an undertaking for the maintenance of the Siemens family, in which all manner of speculation was being practised which had nothing to do with the objects for which the Firm had been founded. In the case of Wilhelm in London this was an old weakness, but Karl was now following in his footsteps, which was the more serious, as Karl, in contradistinction to his brother Wilhelm, was a partner in the Firm. As he quite openly admitted, Karl had begun to tire of the telegraph business in Russia. New orders were much less frequent than during the Crimean War, and raised very few new technical problems, whilst the major source of revenue, viz., telegraph maintenance, practically took care of itself. Karl, who had meanwhile married the daughter of the banker Kapherr, and had to some extent become accustomed to live in the manner of well-to-do Russian society, had bought a large estate in the vicinity of Lake Ilmen, and there erected a glass works, while at another place he operated a sawmill. Both undertakings, the glassworks in particular, were for years a source of worry and loss.

Wilhelm Siemens in London had meanwhile endeavoured to introduce the products of the firm he represented to the English market, but had not made much progress. His restless spirit did not take kindly

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to the methodical activity of a representative. He was essentially creative, and happiest when inventing. For a considerable time past he had been concentrating on the problem of the water meter. Following on the erection of the first water works in England and on the Continent, usually by English undertaknigs, it was very soon realized that the supply to the individual consumer must be measured, since every lump-sum tariff favours the thoughtless and extravagant user at the expense of others, and robs the economically minded consumer of the fruits of his virtue. The object in view, therefore, was a small metering apparatus which could be fitted in the supply pipe of every consumer, and produced in large quantities at a reasonable price. The most obvious solution, and the one adopted by numerous inventors, was to introduce a miniature water turbine into the supply pipe, the number of revolutions of which, being proportional to the flow of water, was transmitted through gearing to a counter. That sounds very simple, and Wilhelm Siemens had developed a water meter along these lines in collaboration with a certain Mr. Adamson, and had succeeded in persuading his brother to manufacture the apparatus in the Berlin workshop. But production turned out to be more difficult than had been anticipated, and at the finish the apparatus was so expensive that Wilhelm decided to have it made in England on the basis of the Berlin model. In Berlin the workmanship of the English meter was pronounced wretched, but the water works over there evidently didn't mind—Wilhelm sold his water meters, for his own account, of course. Having become thus far involved, and probably because of a certain liking for the idea, it was at length decided by the Heads of the Firm in Berlin to develop and manufacture a water meter of their own, the more so, as for years past Werner had been a prey to the idea that the telegraph business was of limited duration, and that it was advisable to take up the manufacture of other products in good time.

Now that the initial technical difficulties of the telegraph service had been overcome, it became possible and necessary to turn attention to the commercial efficiency of its operation, and voices were soon heard demanding the transmission of several telegrams simultaneously over one line. The simplest case to solve was the despatch of two telegrams at the same time over the line in opposite directions (duplex operation). Following on an imperfect phantom connection proposed by an Austrian telegraph engineer by the name of Gintl, a method of connection was invented in 1854 about the same time, but unknown to each other, by a telegraph engineer in the service of the Hanover Telegraph Administration, C. Frischen, and by Werner Siemens. This connection,

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which is called after the two inventors, solved the problem in a manner which was as simple as it was elegant.

A further problem arose out of the increasing distances which had to be bridged. It was not only the increase of electrical resistance which weakened the telegraph current, but the loss by leakage, which mounted up as the cable increased in length owing to the imperfect construction and inadequate insulation of those days, and placed a limit to the distance which could be covered. At the beginning of the 'thirties, i. e., in the infancy of telegraphy, Wheatstone had amplified the excessively weak incoming impulses by taking them to a sensitive electromagnet instead of to the telegraph receiver. The light armature of the magnet had only a contact to operate. This contact, on the other hand, closed the circuit of a battery which was powerful enough to actuate the receiver reliably. For this principle Wheatstone adopted the term in common use in the coaching days for fresh horses, viz., the word "Relay." Out of this simple or neutral relay Siemens & Halske developed as a first step a precision apparatus of very high sensitivity.

In telegraphing over long distances, however, difficulties arose in spite of the relays, due to charging of the conductors by the signalling current, in consequence of which the individual current impulses arrived blurred instead of clearly distinguishable. This Werner endeavoured to counter by the use of short, sharp impulses such as result in suddenly making and breaking the magnetic field of a coil of wire, i. e., by so-called induction. They can be generated, for instance, by mounting two coils on a common iron core and exciting the one, the primary coil, by impulses from a source of direct current—a battery, say—produced by alternate making and breaking of the circuit. The resulting sudden formation and interruption of the magnetic field of the secondary coil induces in it the desired sharp current impulses. Alternatively, a coil can be rotated by a crank mechanism in the field of a permanent magnet. In either case the result is an alternating current, each impulse having the opposite direction to that of its predecessor.

Werner Siemens applied the first of these methods to the Morse telegraph, and called the resulting telegraph system the Recording Induction Telegraph. However, the neutral relay hitherto employed could not be used in this case, since each time the primary circuit was made and interrupted by the Morse key, representing a dot or a dash, two impulses of opposite direction were produced in the secondary circuit, which would have attracted the armature of the relay twice, thereby making two dots. He thus produced the polarized relay, numerous modifications of which have been employed in all subsequent telegraph systems.

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The second method, the movement of a coil in a magnetic field, had hitherto only taken shape in a number of very imperfect forms. Siemens & Halske placed several powerfully magnetized, horseshoe-shaped steel laminations parallel to each other, and made a bore through the pole-shoes, just large enough to allow a cylindrical body of soft iron, the armature, to rotate with a small air-gap. Two broad, deep slots were milled in the cylinder, parallel to the axis at diametrically opposite sides, and a coil wound into these with its turns likewise parallel to the axis, until the slot space was completely filled. In this way the coil rotating with the armature was fully immersed in the magnetic field of the poles, and attained a maximum of induction. This armature, known on account of its shape as the "Double-T Armature," has remained the basic form of armature for the alternating current machine to this day.

Early training in the exact observation of the workings of nature had brought Werner Siemens to realize that penetration into the mysterious realms of electrical phenomena is only possible by the method of experiment and measurement, and that this is conditional on the creation of units of measurement. Now, Gauss and Weber at Göttingen had, of course, already enunciated the so-called system of absolute measurement, based on the three fundamental units centimeter, gramme and second, but the electrical units thus determined were only theoretically defined. Reproductions having any claim to exactitude were therefore exceedingly difficult to fashion. Consequently, there was in practice no generally accepted standard, such as the Paris Standard Metre, for the most frequently occurring quantity: electrical resistance. Every scientist created his own unit as suited him best. In his search for unit, Werner Siemens reflected that by reason of their crystalline structure none of the metals which could be used for a standard were immutable; depending on their previous history as regards refining, melting, casting, rolling or drawing, they would have different basic values. It was therefore necessary to fall back on the only metal which occurs in a liquid state at room temperature, viz., Mercury. A column of mercury of a cross-section of one square millimetre and a length of 100 centimeters retained one and the same electrical resistance at any given temperature, and was easily reproduced. This resistance value Werner Siemens chose as a standard, and caused sets of wire-resistances to be prepared in accordance with this standard, after the fashion of the sets of weights customarily used for scales. With these units, in conjunction with sensitive galvanometers, he created the basis of the exact measurement of electrical quantities as, indeed, of the scientific approach to matters electrotechnical in general. The "Siemens Unit" of resistance, as it was now called, was retained as the

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international unit until the Paris Congress of 1881, when having regard to the adoption of the "Volt" as unit of pressure and the "Ampère" as the unit of current, it was replaced by the "Ohm," which was defined as the resistance of a mercury column of one square millimetre section and 106.3 centimeters in length.

For Siemens & Halske, the decade from 1850 to 1860 thus embraced a sum of carefully handled theoretical and practical problems, in which in each case the initiative and, above all, the scientific development doubtless fell to the first of the two partners. The part played by the second has to a great extent remained hidden from subsequent generations which, however, have good reason to assume that his share of the credit was considerable. None of these labours was of revolutionary significance in the manner of a great, sensational invention, but taken together, they provided a considerable impulse in the further development of telegraphy and of electrical engineering, which grew out of it.

Now that the first great links of the European and North American telegraph networks had been completed, this development gained further momentum from the submarine cable. As long ago as 1837 Wheatstone had suggested a cable between Dover and Calais, a plan which was investigated by a Parliamentary Committee. It appeared, however, that the difficulties of insulating the cable against sea-water were as yet insuperable. Ten years later Jacob Brett, who had already made a name for himself as a designer of telegraph apparatus, founded an undertaking in association with his brother, John Watkins, for the establishment of telegraph communication with France and America, and acquired the landing rights for telegraph cables from the French Government. The Brett brothers employed 1.8 mm diameter copper wire pressed round with guttapercha, which had meanwhile become known, and laid it on 28th August, 1850 between Dover and Cape Gris Nez, weighted every hundred yards by lead plates, but without further mechanical protection. Brett sent his wife a congratulatory telegram from Calais, the first overseas telegram in history, but already in the following night a Boulogne fisherman lifted the wire with his trawl, and thinking it was a deep-sea monster, cut off its "head." Brett now instructed R. S. Newall & Co., Rope Makers, of Gateshead-on-Tyne, to manufacture a "telegraph rope," as it was then called in Germany. This consisted of four guttapercha covered copper conductors which were stranded together and provided with wire-armouring consisting of ten 7.5 mm diameter steel wires. This cable with a total length of 41 kilometres was laid on 25th September, 1851 between St. Margaret's Bay, near Dover, and Sangatte near Calais and opened for public service on the 13th November. Telegraphic communication

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was thus established between England and France, a fact which gave rise to great enthusiasm in both countries. Brett and Newall were the heroes of the day, and the Cable Company which was then founded paid a regular dividend of 16—18% until taken over by the British Government. It was not surprising that a veritable cable fever now broke out, particularly in England.

For the time being, the lead was maintained by Brett and Newall. In 1853 they laid a second cable between England and the Continent from Ramsgate to Middelkerke (Ostend) and had several other schemes in preparation, such as the founding by Brett of the Mediterranean Extension Telegraph Co. Within the next few years, others laid cables between England and Ireland, Holland, and in 1858 the first cable to Germany. And as early as 1854, Cyrus West Field, an American business man of rare tenacity, had founded the New York, Newfoundland and London Telegraph Co., which secured the sole rights for 50 years to land cables in Newfoundland and Labrador. After an unsuccessful attempt in 1855, the Company laid a cable in the following year of 150 km length across the Gulf of St. Lawrence, and thus linked up New York with Newfoundland as a first step, preparatory to risking the crossing of the ocean.

One of the partners in the Newall Company was a certain Lewis D. B. Gordon, Professor of Engineering at Glasgow University, with whom Wilhelm Siemens had become friendly through the learned societies. From his conversations with Wilhelm, Gordon had formed a favourable impression of the scientific way in which Werner habitually endeavoured to approach all technical problems, and the rough-and-ready manner, in which it was then usual in England to brush aside such considerations, did not appear to him to be applicable to cable problems. At that time Newall & Co. were confronted with the task of laying a cable between Cagliari (Sardinia) and Bona (Algiers), two previous attempts by Brett in the two preceding years having failed. In view of the foreseeable difficulties, Gordon suggested to his partner that he request the well-known German telegraph engineer to supply the apparatus for this line, and to supervise in person the laying of the cable planned for the summer of 1857, in order to keep watch on the electrical condition of the cable during laying. Werner Siemens agreed, and travelled with a number of his staff and the necessary instruments to Sardinia. Even before the commencement of laying operations, it was evident to Werner that Newall and his men had no more chance of succeeding than had Brett. So far, they had only had experience of laying cables in the shallow waters around England and were now pretty helpless in dealing with the Mediterranean and its depths of over 3,000 m.

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In order to appreciate the fundamental difficulty involved, the following must be realised: The cable was then, as now, enclosed in large tanks which occupied the whole width of the ship. In the process of laying, the cable is paid out of the tank via guide blocks and a brake drum over the stern of the ship and into the sea. The correct running speed is imparted to the cable by means of the brake, this speed depending on the speed of the ship, the depth of water and the weight of the cable. If the brake is too slack the cable will be unwound too rapidly, forming serpentines on the bed of the sea and running out before reaching the opposite coast; if the brake is kept too tight the cable will part. In the shallow waters thus far experienced it was possible to arrive at the correct brake pressure, which was only very moderate, by trial and error; at great depths, which also fluctuated disconcertingly near the coast, this method was very dangerous. To be on the safe side, therefore, Newall applied only slight brake pressure with the result that, having covered one fifth only of the distance, he found that he had used one third of the cable. Although the actual laying operation was no concern of Werner Siemens, he had already developed a theory in accordance with which he had suggested the calculation of the necessary brake-force, but had been politely ridiculed by Newall and his men. They now turned to him for help, and he undertook to lay the cable on condition that his instructions were implicitly obeyed. By controlling the brake pressure in accordance with his formula, so that the cable was brought to lie taut on the bed of the sea, he just succeeded in landing the end of the cable on the opposite shore.

This success of Siemens enormously raised his prestige in England. For the cable from Cagliari via Malta to Corfu, which it was planned to lay in the same year, Newall & Co. asked him to furnish the supervisory staff, and shortly afterwards proposed that Siemens & Halske should act as their Telegraph Consultants. In June 1858, after much indecision, Wilhelm as intermediary finally negotiated an agreement, under the terms of which Siemens & Halske placed their services at the disposal of Newall for the duration of five years. Siemens & Halske reserved the right to lay cables on their own account, but undertook to purchase them from Newall.

Now that Siemens & Halske were compelled in view of the agreement to maintain personnel, stores and a small workshop in London, it was no longer adequate to be represented merely by an agent. In consequence, the Firm of Siemens, Halske & Co. was founded in London. The partners were Wilhelm Siemens, who had meanwhile become a British subject and was engaged to Gordon's sister Anne, Siemens & Halske and,

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with a small interest, Newall & Co. Under Wilhelm's management the Firm maintained a repair shop, and a staff of engineers and mechanics for cable-laying under an engineer named Loeffler. In the same year, the new firm was engaged in three cable-laying expeditions of Newall in the Mediterranean, and the year following in laying the cable between Suez and Aden through the Red Sea. In view of the importance of the undertaking, Werner Siemens took part personally in the laying operations, in order to carry out the control measurements and fault location. As a result, he was able to inform his Principals that in consequence of its poor condition the cable could not be expected to last any length of time. On the homeward journey from Aden to Suez, the steamer in which the members of the cable expedition had taken passage was wrecked on a deserted rocky island considerably off the course, and the whole company would have perished miserably if Newall had not ventured out in a small boat, and had the good fortune to sight an English warship which rescued them at the last moment. In the autumn of the same year the cable was extended as far as India, on which operation the Siemens & Halske team was led by William Meyer. In all these joint undertakings, however, there had been continual friction between the Newall and the Siemens & Halske men, so that it was mutually decided by the Principals in 1860 to cancel the agreement before its due date; Newall & Co. left the Firm, Siemens & Halske paid them a forfeit of one thousand pounds and permitted them the continued use of the Siemens & Halske method of testing.

For Siemens, Halske & Co. this collaboration with Newall had not been so unsatisfactory from a financial angle: in 1859 the Firm had made a net profit of 36,000 Thalers, and in the year following of 80,000 Thalers, and had also gained considerable experience. It was thus not surprising that William Siemens, as he now called himself, looked around for further cable business, especially as the telegraph business on land did not appear to offer any great prospects. His brother in Berlin, too, had become a victim of a curious wave of pessimism concerning the future of telegraphy; on the other hand, his keen intellect was occupied with all manner of technical problems and industrial schemes. William's undeniable success with his melting furnaces, and Friedrich's success in applying them to glass manufacture, had fired his imagination again and again with the vision of the Siemens brothers founding a kind of industrial family concern with centres in Berlin, London, St. Petersburg, and possibly also in Vienna and Dresden, as the Rothschilds had done in finance. Compared with this, the Telegraph Workshops would have been only the kernel, which would disintegrate gradually with the

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growth of the tree which had sprung from it. In one of these moods, Werner wrote at the beginning of 1861 to his brother in London that, taking a long view, he no longer believed the telegraph business to have a future; in particular, as far as the British market was concerned, his hopes of gaining a good connection had been disappointed. In view of the agreement with Halske and the Russian maintenance contracts, the Berlin Telegraph Workshop must, of course, continue in being until 1867, but after that only if William so wished for the sake of English business; should William desire to continue in business entirely on his own account, he was at liberty to do so. He, Werner, was thinking of starting a brass foundry and rolling mill, or a glass works for the manufacture of cut and ground plate glass, or perhaps also an engineering works where he could build hot-air engines among other things. Would William be good enough to express his candid opinion on these plans.

In view of such statements from Berlin, William Siemens was not to be blamed if he did his best to free the English House, whose Principal he was, from the Berlin tutelage.

Cyrus Field and Brett had by October 1856 succeeded in interesting a sufficient number of financiers to enable them to form the Atlantic Telegraph Co., which in August 1857 began its activities with the laying of a cable from the Irish island of Valentia across the Atlantic. After having covered a distance of 618 km the cable parted in 3,600 metres of water. Two further attempts in June of the following year, commencing from the middle of the ocean and working in each direction, were likewise unsuccessful, but a fourth, proceeding in the same manner, was commenced on 28th July, 1858 and brought to a successful conclusion. The completed cable transmitted the first telegram across the Atlantic on 5th August, 1858, an event which gave rise to an amount of excitement which it is difficult to visualize to-day. Unfortunately, the rejoicing was premature; after the transmission of 366 telegrams, the insulation of the cable, without having torn, had deteriorated to such an extent as to be useless. The Cable Company, however, refused to abandon the plan; after a lengthy, but fruitless search for the cable, it was decided to try again with a new cable of improved construction based on the experience gained, but the outbreak of the Civil War in the United States put a temporary end to the undertaking.

Deeply impressed by the tenacity of these venturesome business men, William Siemens chafed more and more at the brake placed upon his spirit of enterprise by the cautious Berlin partners. Since he had continually been met with the objection that he must not incur the risk of laying cables which had been manufactured by others, he succeeded at

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length in obtaining sanction for Siemens, Halske & Co. to put up a cable factory of their own at Charlton, near Woolwich. Now, of course, it became necessary to look for orders for the new factory, and although it was still unfinished, negotiations were entered into with the French Government in January 1863 for a cable between Cartagena in Spain and Oran in Algeria. The French had chosen this route as the distance across the Mediterranean was only 220 km, whereas a cable from the South of France to Algeria would have had a length of over 700 km. William had introduced a new design for this cable to protect it from boreworms. The external armouring consisted of copper strips overlaid after the fashion of scales, whilst mechanical strength was contributed by a spun layer of Manila hemp. The laying of the cable was planned for January 1864, a very unfavourable time of the year, and although filled with dark forebodings, Werner Siemens would not be denied personal participation in this first cable-laying operation of his firm. All went well at first and it was thought on all hands that laying would be completed on time when the cable parted. Since under the terms of the contract the cable-maker was responsible for handing over the cable in working order, a new cable was manufactured which William undertook to lay in September of the same year. This he did, but only a few hours later the cable parted, having evidently been suspended under water between two rocks, and had to be abandoned. Thus was lost a sum of about £ 15,000, approximately half the capital of Siemens, Halske & Co.

As far as Halske was concerned, the Cartagena—Oran cable was the last straw. Immediately after the signing of the contract, even, he had announced his intention of withdrawing from the London firm on account of the speculative nature of the cable business. He now confronted his Partner with the terse refusal to collaborate further with William in any form whatever and demanded in consequence that Siemens & Halske should withdraw immediately as partners in Siemens, Halske & Co. in London. In any case, stated Halske, he had intended to terminate his connection with Siemens & Halske in 1867, particularly in view of the fact that Werner had on several occasions spoken of his intention to close the Telegraph Workshops in that year. He was willing to wait until then, so as to avoid causing the firm embarrassment by the premature withdrawal of his capital.

This prospect made Werner Siemens not a little unhappy. He had a genuine feeling of friendship for Halske; the use of "thou," the intimate form of address, which had bound the two men together soon after the launching of their common venture, had been no empty form, and Wer-

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ner knew very well how much he owed to the industry, conscientiousness and great mechanical talent possessed by his partner. On the other hand, Halske had become a typical example of the worthy Berlin middle-class citizen, with a seat in the Town Council. Having become well-to-do, he lived in perpetual fear of the loss of his hard-earned fortune, and his frail health had turned him into a hypochondriac. By contrast, Werner Siemens was anything rather than a "middle-class citizen;" he was much too highly spirited and intellectually restless. His was the typical spirit of enterprise, with the love of adventure in his veins. Halske would never have said that the telegraph business had become stale—in fact, he was annoyed when his partner said so. The money which had been earned with comparative ease in the course of the last ten years, chiefly from the Russian maintenance contracts, had only to a lesser extent been put into the Berlin workshop—in view of its small compass and slow development, the workshop could not have absorbed more—and had sought other outlets. Werner bought shares in the Stettin Vulcan Works in 1864, and together with his brother Karl, bought an old copper mine at Kedabeg in the Caucasus Mountains. The idea originated with Walter, the second youngest brother, who had for some time been Manager of a branch in Tiflis. Although suspicious at first, Werner allowed himself to be persuaded by the brilliant report of a German expert who just then happened to be there and bought the mine. "Your mining speculation can be a success," wrote William to his brother, "but it would have been at least as safe if you had put the money in an Atlantic cable." Of course. But Werner took no pains to disguise the fact that in buying the mine he had Walter in mind, for whom provision would thus be made for life. For Halske this was one more reason for insisting on a clear distinction being made between this new venture and the Firm of Siemens & Halske, and incidentally, for preparing for his final separation from the Siemens family.

The first step in this direction was the winding up of the Firm of Siemens, Halske & Co. in London, their legal successors being a new Company under the name of Siemens Brothers.

Partners in the new Firm were Werner and William Siemens, the former contributing that part of the capital formerly held by Siemens & Halske, viz., 80—90% of the whole, from his own personal account, at the same time conceding, as was his generous way, one half of the profit to his brother as Managing Director. The new Company commenced its career on 1st January, 1865. Wheter the Telegraph Workshop, founded more than seventeen years before by Werner Siemens and Johann Georg Halske, was destined to outlive the year 1867 appeared to the two

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partners to be increasingly problematical. Halske regretted it, but declared that it was no fault of his. He stated that, in his opinion, an industrial undertaking must always be based on a good factory; this was the nucleus around which all other things must group themselves, and finally, the manufacturer should stick to his trade, of which he could claim some knowledge. If, however, he simultaneously traded in wood, invented furnaces, melted glass, laid cables and now wished to run a copper mine, he need not be surprised if telegraphy no longer showed a profit.

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III.

TRANSCONTINENTAL TELEGRAPHY

There was certainly no denying the fact that as far as Siemens & Halske was concerned, telegraphy, or rather the further development of the technology of telegraphy, had made but scant progress for several years prior to the critical year 1867. This was no doubt due in the first place to Werner Siemens' preoccupation with scores of plans, enterprises, journeys and worries—amongst others the fact that his wife had become ailing without hope of recovery—which left him neither the time nor leisure to devote to telegraphy. It must be remembered that at that period he was still his own chief planner, designer and draughtsman and that no one can exercise these functions adequately as a side line and by spasmodic fits of attention. Even constructive ability and inventive genius can take a wrong turning and become bogged down if there is insufficient time to survey the ground and form a considered estimate of the overall situation. This Werner Siemens had to learn to his cost.

As early as the commencement of the 'sixties he had resumed his efforts to produce a printer telegraph, i. e., an apparatus which could print the message in type, so as to obviate the tiresome work of translating the Morse signs. Even if a telegraph of this kind should be somewhat slower in operation than the Morse telegraph, it seemed quite possible that the lost time could be made up by the reception of an immediately readable telegram. Soon after the completion of his first dial telegraph, Werner Siemens had coupled it with a type disc with a number of radial slots, which gave it the appearance of a star with a number of flexible rays. Fixed at the end of each of these rays, or spokes, was a letter of the alphabet. When the letter arrived opposite a strip of paper which was moved forward in a series of impulses, an electro-magnet caused the letter to strike the paper, thus causing an imprint. In its original form the design was rather clumsy, but had meanwhile been improved to such an extent, as to be seriously considered capable of use in the telegraph service. With his sanguine temperament Werner was already dreaming of "gaining control of the whole of the submarine

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lines" and thought of selling the apparatus in England for £ 1,000 apiece. However, there appeared on the scene an apparatus invented in the United States by a certain Mr. Hughes, which had meanwhile been introduced into France. From all one heard, this apparatus was considerably speedier than the Siemens model, and after a year's trial had been spoken of in the highest terms by the French Government Telegraph Administration.

This apparatus had a peculiar history. David Edward Hughes, an Englishman by birth, had at an early age emigrated with his parents to the United States and had taken a good deal of interest in telegraphy. He became involved in a dispute between the largest telegraph company of those days, the American Telegraph Co., and the American Associated Press. The American Telegraph Co., possessing monopoly rights in the use of the Morse apparatus, was taking an undue advantage of the Press in the matter of telegram rates. The other telegraph companies, to whom the Press turned for support, were not in a position to compete with their slower dial telegraph. The Associated Press thereupon invited Hughes to New York and on the strength of his experimental work furnished him with the means of completing his apparatus and of putting it into practical operation. Having completed this task to the satisfaction of his Principals, Hughes came to Europe to exploit his patent, and being unsuccessful in England, went on to France, where the State Telegraph Administration purchased the system for 200,000 francs.

The great success of the Hughes apparatus was not merely due to the saving in time and money resulting from the delivery of messages in readable print, but also to the high speed of transmission. As is always the case with important technical inventions, the working principle was very simple. Transmitter and receiver were combined to form one whole. As in all later-day telegraph systems, the transmitter also writes its own telegram as a check. The transmitter has a keyboard with 32 keys after the manner of a piano. If, for instance, the transmitter key "X" is pressed, the tape is caused to strike a revolving type-wheel at the instant the letter X has reached the lowest point, where the printing mechanism is located, and thus prints the letter. A brief current impulse has the same effect at the receiving end.

But this short description hardly gives an impression of the complicated but ingenious mechanical and electrical layout of the Hughes telegraph. Having decided to give up the attempt to develop a telegraph apparatus of their own Siemens & Halske purchased the manufacturing rights for 15,000 Thalers, and set themselves to apply the great skill of the Telegraph Workshop to the manufacture and improvement of the

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Hughes apparatus. As the only manufacturers in Central Europe who were for the time being capable of producing the complicated apparatus in a really reliable state, Siemens & Halske contributed in a major degree to its widespread use.

It has already been said that, about that time, Werner Siemens devoted special attention to the technical science of electrical measurement. Here, he enjoyed the great advantage of being an adherent of the new school of experimental physics, which looked upon experimental measurement as the basis of progress in physics, as opposed to the speculative contemplation of Nature formerly practised in Germany. Electrical science, slowly assuming form and substance, was itself a veritable challenge to proceed by measurement, as it became evident that its methods of measurement were superior to all others hitherto known. Up till that time the most sensitive instrument known to researchers was the balance; it celebrated its triumph contemporaneously with the flourishing of chemistry, as whose symbol it was justifiably designated. There now arose a new symbol of exact research, more sensitive and more revolutionary in effect: the galvanometer.

The galvanometer is the primary form of all electrical measuring instruments. It originated from observing that a compass needle is deflected from its North-South direction, if an electric current is caused to flow in a wire placed parallel and sufficiently close to the needle, for the current creates a magnetic field which surrounds the conductor and influences the needle. It was soon discovered that the effect could be intensified by winding the wire into a coil of numerous turns and placing the needle within the coil with freedom to move. With a view to weakening the effect on the needle of the Earth's magnetic field—which, of course, is the force which causes the needle to take up the North-South direction—and thereby increasing the sensitivity of the instrument, two parallel compass needles were coupled together in reverse, so arranged that one was inside the coil and the other either above or below it. The whole system had to be suspended by a thread. Attached to the moving system was a tiny mirror, in which from a distance of about 2 metres the reflection of a horizontal scale could be seen through a telescope with reticle. With this arrangement it was possible to measure deflections of the system so small as to be barely perceptible to the naked eye.

The inventor of the mirror-galvanometer, William Thomson, afterwards Lord Kelvin, himself did not regard it so much as a measuring instrument than as an instrument for indicating very weak telegraph currents. This was equivalent to returning to the primitive method of

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telegraphing practised exactly twenty-five years ago by Gauss and Weber on the occasion of their celebrated experiment in Göttingen. There was little choice in the matter, for when Cyrus Field laid his first transatlantic cable in 1858, the unsuccessful attempts of the previous year had already demonstrated that ordinary apparatus and instruments were of no use.

The submarine cable is the equivalent of an enormous condenser, one coating of which is the conductor, the other being the sea-water, the two separated by the dielectric of the guttapercha insulation. The quantity of electricity flowing into the cable at the transmitting end serves first of all to charge the condenser, hence the quantity flowing out at the receiving end depends on the state of the charge at the moment, and therefore reproduces the impulse, i. e., the signal, only imperfectly and indistinctly. In order to overcome this difficulty, the Morse alphabet was built up of opposing current impulses of even length, since positive and negative impulses are more easily distinguishable than short and long, whilst the current was cut to the extreme limit by reducing the battery voltage. This, in conjunction with the high cable resistance, produced very weak current variations at the receiving end, which could only be followed by means of the mirror galvanometer. That its use was extended to checking the condition of the cable during laying and in service and that it rapidly found its way into the laboratories is not at all surprising.

Such was the state of things when Werner Siemens took in hand the further development of the galvanometer as an instrument specially adapted to the requirements of telegraphy, which called less for sensitivity than for an adequate degree of accuracy. Thus he invented among others the so-called hairpin galvanometer, in which a sheet-iron bell was provided with wide slots at two diametrically opposite points. A vertical section through the bell had the appearance of a hairpin, hence the name. When magnetized, the two halves showed opposite polarity. The very low rotational inertia of the system enabled it to adjust itself speedily and thus to follow rapid fluctuations of the current without difficulty. It was thanks to this instrument that it was possible to follow, measure, and interpret the complicated phenomena occurring in the working of a long transatlantic cable.

Even at the time he founded his firm, Werner Siemens was already held in high esteem by the German telegraph engineers of the day—albeit relatively few in number. This reputation was soon to extend beyond the limits of the Berlin circle, and thanks, no doubt, to the support of his brothers in Russia and England, to spread to countries abroad. It

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was less the inventor that impressed the professional world—the fortunate inventor is popular with the masses, as is seen in the case of Morse—nor the scientific researcher (in his command of the physical and mathematical sciences he was, without a doubt, inferior to William Thomson) and not the man of enterprise as such—Cyrus Field was much more spoken of—but that curious combination of creative, technical imagination, scientific spirit and commercial daring of which he was the first, and almost the only, example in the history of the nineteenth century. This personality, which had hitherto passed unnoticed, began within ten years of the commencement of his activities to attract the attention of many unbiassed observers, until ultimately the Berlin University took the occasion of its 50th anniversary celebrations to confer upon him an honorary Doctor's Degree, in those days a most uncommon distinction for an industrialist. But was he really an industrialist? Judged by the standard of the workshop in Markgrafenstrasse, employing at that time about 100 workmen and hardly deserving to be called a factory, certainly not. In those days, Berlin could boast of works, such as Borsig's, which were on a very different scale to the modest workshop of Siemens & Halske, quite apart from Krupp at Essen, who in the early 'sixties employed more than 2,000 hands. Krupp was at that time regarded as the foremost industrialist in Germany, but he was a one-sided specialist, almost exclusively wrapped up in what he conceived to be his life's work and, as a man, rather unpleasant. He was not to be compared with Siemens, who was open-minded and a man of wide interests, regarding the world and men without prejudice, and of kindly instincts. As a young officer he had incurred the serious displeasure of his military superiors for having taken part in a harmless free-thinker demonstration, and in the revolution of 1848 he had made no secret of the fact that his sympathies were on the side of the people and against the "Reactionaries." Throughout his life he continued to take a lively interest in the political movements of the day.

This became particularly evident when, following the formation of a Regency Council for the ailing King of Prussia in 1858, the hitherto existing political apathy commenced to lift. Siemens joined the National Association, which had been founded by the liberally minded Duke Ernst von Coburg-Gotha, and also took part in the founding of the German Progressive Party. The new party soon found itself in lively opposition to the Government when the Regent, having ascended the throne as Wilhelm I on the death of his brother, appointed Bismarck as Prime Minister with the object of forcing through Parliament an increase in the size of the army, doubling its strength, as planned by

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the War Minister von Roon, against the opposition of the House of Representatives. It was in these circumstances that Siemens was approached with a request to stand as Progressive candidate for the Solingen-Remscheid constituency. After some hesitation because of his other activities he consented, and was in due course elected. The conflict between the Government and the parliamentary majority increased to such a pitch that Siemens quite seriously considered resorting to a refusal to pay taxes. Siemens & Halske were not suppliers of armaments like Krupp, but they were also Contractors to the Government on a considerable scale, and Werner Siemens was personally not unknown to the King. At the outbreak of the Crimean War, Werner had been in St. Petersburg, and was being pressed by Count Kleinmichel to stay on against his will. Difficulties had been created in obtaining an exit visa, and as the Prince of Prussia happened to be in St. Petersburg to discuss Prussia's attitude to the Crimean War, Siemens had requested and obtained an audience of the Prince, who had promised him the desired assistance, and chatted with him on the subject of telegraphy. A few years later, during this period of Parliamentary conflict, the Prince, now King, was shown a model of the high-speed printer telegraph, and on being told by Chauvin that Siemens was the inventor, he remarked irritably: "I don't know a Lieutenant Siemens." Quite evidently, he was personally offended by his former Lieutenant's antagonistic attitude. But that did not trouble Siemens much and whoever would have attempted to induce him to bargain his political convictions against business considerations, would probably have received a rough answer.

Where Bismarck was concerned, however, he found himself in much the same case as the majority of his countrymen. When Bismarck again faced the House of Representatives after the two successful campaigns of 1864 and 1866, and was wise enough to furnish it with a means of retreat in the shape of the Indemnity Law, the temper of the House changed completely. Success had been so decisive, so quick and had been won at so small a sacrifice that criticism of his methods subsided. Above all, however, the yearning after the unity of the German peoples was obviously near to fulfilment, although in a different form from that dreamed of in 1848. The transformation of the political atmosphere is intelligible, especially when the simultaneous intellectual development in Germany from idealism to positivism, from humanism to realism, from Goethe to Wagner, is taken into account, or as was said by a witty historian: from Fichte & Hegel to Siemens & Halske.

Thus it happened that Werner Siemens also made peace with Bismarck, not from opportunist motives, but in consequence of an inward change

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of conviction. He had, however, lost taste for politics, the more so as he did not see eye to eye in the matter of export policy with the business men of his constituency, and concentrated his attention henceforth on his business.

In the meantime this business had received a fillip from various sources. One of the most important of these had its origin in a plan, the beginnings of which went back a long way.

For two hundred years India had been England's most important colony; the wealth and might of England were to a considerable extent founded on the Indian trade. And this in spite of the fact that up to 1869 the sea voyage to India was long and arduous, and the maintenance of an up-to-date overland news service through barren and uncivilized regions practically impossible. The opening up of a cable route to India was therefore one of the foremost objectives of the British submarine cable technicians. The cable laid through the Red Sea in 1859 was intended to meet this urgent need, but, as will be remembered, it failed soon after completion. As a result, attempts were soon made to reach India by telegraph overland. Following on the extension of the Russian telegraph network through the Caucasus to the Persian frontier, the English had also begun to install telegraph lines in Persia. The first of these connected the capital, Teheran, with Bushire on the Persian Gulf, where it connected with the line from Aden to Karachi in India, continuing from Bushire to the borders of Asia Minor. A further line was constructed from Teheran to Julfa in the Armenian Highlands with a view to linking up with the Russian network. At that time it was therefore possible to reach India from England by overland telegraph by two routes, i. e., via Russia and Asia Minor, the two joining in Teheran. In reality, however, the route via Russia existed on paper only, for the Persians had allowed the section from Julfa to Teheran to fall into a state of decay, and although the Russian Government, having an interest in maintaining telegraph communication with Teheran, placed materials for re-equipment to the value of 100,000 Roubles at the disposal of the Persians, they allowed the material to lie unused. The other Persian lines, which were used by the British-Indian Telegraph Administration by virtue of an Anglo-Persian agreement, were also in poor condition consequent on the difficulties of maintenance in these barren and trackless regions. The same applied to the telegraph system in Turkish Asia Minor, so that, all in all, telegraph communication with India was very uncertain. To add to the difficulties, the distances over which through-traffic could be maintained were very short, with the result that the message frequently had to be transcribed and re-telegraphed. In view

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of the fact, however, that the operators were in many cases familiar only with their own native tongue, each such operation was a source of possible error, and it was therefore not surprising that on reception after many days delay the telegrams were mutilated to the point of being unintelligible. Anyone cabling to India needed to be lucky!

Under these circumstances, those circles on either side which had the political and economical interests of the Country at heart, felt this state of affairs to be both damaging and humiliating. William Siemens, who was following developments attentively, had more than once spoken to Werner and Karl, and the three had discussed various schemes culminating in a plan for a direct overland telegraph line to India. An obvious condition of operation was that telegrams should not be passed from one network to the next regardless of the various technical and operational peculiarities of the several systems, but that they should be despatched via one through trunk line, operated throughout on the same technical system under one and the same management. As things then stood, that could only be a private undertaking—as nobody in those days had ever thought of a supra-national organization.

The three Siemens brothers had already made considerable progress with their plan when the Austro-Prussian war broke out and with its aftermath called a halt for the time being. In October 1866, however, von Lüders, meanwhile promoted to General, became Director of the Russian Telegraphs and this gave the enterprise a new impulse. Since his first visit to Siemens & Halske in 1850, von Lüders had been very favourably disposed to the Firm, and as Werner Siemens was sure of the support of the Prussian, now North German, Director of Telegraphs, Col. von Chauvin, he paid a visit to General von Lüders in March 1867 and propounded the following plan. Linking up with an Anglo-German cable, a direct cable line was to be laid through North Germany, Russia and Persia to Teheran, to connect there with the cable system administered by the British-India Authority. Prussia desired to construct that section of the line within its own frontiers, and to place it at the disposal of the Company which would be formed to operate the cable. On Russian territory the cable was to be provided by the Company, likewise in Persia, since the existing section between Julfa and Teheran was useless. The plan having been sanctioned in principle by the English and Prussian Telegraph Administrations, everything now turned on obtaining corresponding concessions from Russia and Persia, while the latter, in turn, was hoping for Russian support. Lüders declared himself satisfied, and as a result, Champain, the Director of the British-India Telegraph Administration, von Chauvin and von

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Lüders met in St. Petersburg at the end of April, and concluded a Russo-Prussian Agreement on the basis of Werner Siemens' proposals. It was not until the autumn, however, that everything was settled in detail, and that the Siemens brothers received the Prussian and Russian concessions for the complete undertaking. The dues payable to Prussia for the provision and maintenance of the cable line were 2 1/2 francs per telegram of 20 words; to Russia—merely for permission to construct and operate the line—the dues amounted to five francs.

To lay a cable of their own from England to Germany was not possible, as Prussia had granted an English telegraph company, The Electric Co., the exclusive right for a number of years to land cables on the Prussian coast, while a similar contract existed with Reuter in respect of the former Hanoverian territory. An agreement was concluded with the Electric Co. and Reuter which secured to the new Company the right to participate in the use of the existing cable between Lowestoft and Emden. For this and for a special line from London to Lowestoft the dues were 4 1/2 francs per telegram.

The Persian concession had now to be negotiated. Conditions in that country were very confused. As was generally the case at that time in the Near East, the country was governed by a despotic but weak central Authority based on the arbitrary rule of an intrigue-ridden Court, whilst the provincial governors were in a state of latent rebellion, and were made use of in the North by Russia, and in the South by England for the furtherance of their own ends.

The telegraph system was also an object of political rivalry, besides which, it was looked upon by the Shah and his relatives as their personal perquisite. They received their share of the dues, but omitted to pay their officials and withheld payment to the foreign Powers for equipment supplied, which they then allowed to decay—in fact it was in a state of chaos, unfathomable to any beside those immediately concerned. It thus became a necessity to study matters on the spot, in order to gain sufficient insight into affairs to provide a basis for negotiating a concession.

Walter, the second youngest of the Siemens brothers, had for some time past been stationed in Tiflis, where he watched over his brothers' interests, partly in the Branch Office there, and partly in connection with the Kedabeg copper mine; in addition, he had been appointed German Consul. He was less talented than his elder brothers, a gay young fellow, but of good presence and by no means unskilled in his approach to men. He was therefore instructed to travel to Teheran to see what he could do.

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Having already acquired some experience of oriental business methods in Tiflis, he equipped himself accordingly, being primed at the same time by his brother Karl, who had also some experience of Persian practices. Karl's opinion was, in effect, that the avarice and corruptness of the leading people there was fabulous and that "in any case, Walter must open the negotiations with presents on a corresponding scale."

Under such auspices Walter journeyed to Teheran about the middle of October, and remained until the middle of January, having succeeded after long and hard bargaining in obtaining the concession about the turn of the year. This permitted the Siemens brothers to build and operate a new telegraph line from Julfa to Teheran alongside the original line, now derelict. As consideration, Persia retained the right to use the line for internal traffic, and was to receive dues not exceeding 10 1/2 francs per telegram.

It was thus possible at the beginning of 1868 to proceed with the formation of the company, and it was decided to form an English Limited Liability Company, with headquarters in London, but to place about half the capital on the Continent.

To begin with, the public subscribed readily in Germany, but more tardily in England, since the submarine cable, being entirely under British control, was regarded as the natural solution of the problem. It was also known that the newly formed British-Indian Telegraph Co. was laying a new cable line through the Red Sea with all speed and at great expense; it had been stated that the monster ship, the "Great Eastern," the eighth wonder of the world, had been chartered for the laying of the cable. But ultimately, the capital was subscribed. Each of the Siemens brothers participated, as stipulated, with a one-fifth share of the capital, and on April 8th, 1868 "The Indo-European Telegraph Co. Ltd." came into existence. To it were transferred the concession rights, in consideration of which the Siemens brothers received the order for the construction and laying of the cable at a cost of £ 400,000, as also the maintenance contract for £ 34,000 per annum. This was the largest transaction so far handled by Siemens & Halske and Siemens Bros.

It was now possible to commence the constructional work. In preliminary discussions it had been agreed that the cable should follow the route London—Lowestoft—Emden—Berlin—Thorn—Warsaw—Jitomir—Odessa—Kertch—Suchum—Tiflis—Julfa—Teheran, a distance estimated to be 6,000 kilometres. Of this, the Company had to provide the section between Thorn and Teheran, a distance of approximately 4,700 km. There were two wires of 6 mm diameter which had to be carried

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on approximately 70,000 supports, which were planned as spruce poles in Poland, oak poles in southern Russia and iron poles in the Caucasus and Persia. Opinions differed as to the best route between the Crimea and the eastern end of the Black Sea. The mountains in this area were almost trackless, and certainly without anything deserving the name of a road. In addition, they were rendered unsafe by the presence of numerous bandits; in the coastal region the mountains extended to within a short distance of the sea, in places rising precipitately out of the water in towering buttresses where, according to classical legend, the Father of the Gods had Prometheus chained to the rock. On making enquiries, it transpired that at such points, where wintry storms drove the frozen spray against the rocky coast, covering everything with a coating of ice, there could be no question of proper maintenance of the line. With a heavy heart Werner acquiesced in William's suggestion to by-pass this coastal section by a submarine cable; the recollection of former experiences still haunted him. If a cable, then let it be armoured with stout steel wire to give it adequate strength. But William insisted again on using his copper-scale armouring, to which in the end his brother reluctantly agreed.

In itself, the provision of a continuous line from London to Teheran was not the whole solution of the problem, since, whether with a Morse or a Hughes telegraph, it was equally impossible to bridge a distance of 6,000 km in one span. But in this case Werner Siemens wanted to demonstrate "what telegraphy could do." It was now that he reaped the benefit of the experience he had gained in his many unsuccessful attempts to make a high-speed printer telegraph. He designed a special type of Morse telegraph which worked after the fashion of a polarised relay, and by reason of its sensitiveness was able automatically to transmit the incoming message to the next section of the line, at the same time writing down the message as a check. For transmitting he used the punched tape; the transmitter through which the tape was drawn was so arranged that current impulses of alternating direction produced by an inductor with double-T armature synchronised exactly with the contact impulses resulting from the punched tape. Apart from this kind of mechanical transmission, however, the apparatus could also be operated by means of the Morse key in the usual way.

Werner Siemens knew from experience that in constructing such long telegraph lines, particularly in desolate regions, the major difficulty is the question of transport and he devoted special attention to this in consequence. Climatic conditions were also a decisive factor where erection schedules were concerned. In Poland, Central Russia and

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especially in the Caucasus, it was only possible to work in summer, and in Persia, owing to the summer heat, only during the winter. The oak logs used in the Russian section could only be floated down in springtime; other transport across the steppes was best undertaken in winter on sleighs.

The greatest difficulty was to get the materials to Persia. They had to be shipped from England to St. Petersburg, forwarded from there by rail to Nijni-Novgorod, transferred to barges and taken down the Volga to the Caspian Sea, and again loaded on board sea-going vessels for the journey across the whole length of the Caspian Sea to Resht. From here, the materials were to have been loaded, as was the custom in these parts, on mules for the journey across the trackless Elburz mountains to the Iranian Plateau. Instead, axles and cartwheels were sent in advance to Resht, and waggons—75 of them—of a type suitable for the rough mountain tracks, since 500 tons of wire had to be provided for the Persian section alone, not to speak of the heavy iron poles. Three sections were at work simultaneously, the Russian, the Caucasian and the Persian, each under its own superintendent, who was to a great extent autonomous. Their instructions were: "We have provided you with the best materials, and expect you to combine this with the best workmanship, for failures of any kind will later be charged to our account; for the rest, it is your business to get the job done." They got it done.

At the height of the summer of 1868, when work was in full swing, the Representatives of the Telegraph Union met in Vienna. This had been founded three years previously in Paris, for the study of technical questions and the fixing of telegraph rates. Amongst other subjects the Conference entered into a discussion of the affairs of the Indo-European Telegraph Co., and there were found to be a number of critics who were obviously dissatisfied because direct communication between England and India was no longer to pass over their systems. Werner Siemens had attended the Conference with a view to explaining the new telegraph system to be used on the India line, as also the mercury unit of resistance. Since both gained the unanimous approval of the telegraph experts, and the "Siemens Unit" was adopted as the standard of the World Telegraph Union, it is not surprising that he returned from the Conference with a feeling of satisfaction, and in the belief that the Indo-European Telegraph line had nothing more to fear. Shortly afterwards, however, Lüders turned up in Berlin, and calmly announced that new maximum rates had been fixed in Vienna for the Indian telegraph services, and that the 20-word telegram was henceforth to cost 71 francs, as against 87½ francs hitherto. In addition, Persia was to receive a royalty in

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respect of the section Julfa—Teheran of 5 francs and the British-Indian Administration for the section Teheran—Bushire a royalty of 8½ francs.

Werner Siemens was thunderstruck, for this spelt the doom of the undertaking which had been launched with such high hopes. On the basis of these rates and royalties, there was as good as nothing left for the Company. Hundreds of thousands of pounds worth of material had meanwhile been purchased and sent forward, a considerable staff had been engaged and obligations of all kinds undertaken—and now this! It was a catastrophe.

Lüders, now somewhat subdued, offered to try to get the Russian royalty reduced by 1—1½ francs, but that was of little use. The Siemens brothers realized that since it was no longer possible to alter the new rate, everything depended on wresting from the Persians the 5 francs per telegram which, contrary to the terms of the concession, they had arranged for the generous competitors of the Indo-European line to grant them in Vienna. But Walter Siemens was no longer alive; six months after his return from Teheran he had met with a fatal accident in Tiflis; and Karl, too, who had been living for some years in the Caucasus Mountains, had been compelled by the state of health of his wife to leave the district. It was absolutely essential, however, that someone should go to Teheran.

The choice fell on Georg Siemens, the son of the former Partner in the Firm, and now Secretary of the Company, who had shown his negotiating skill in connection with the founding of the undertaking. His mission was not only to negotiate with the Persian Government, but to assist the Superintendent Engineer, who was apparently not quite a match for the tricks of the local rogues, great and small.

In the year that had passed since Walter's negotiations in Teheran telegraph affairs had become more tangled than ever. Observing the exertions of the German concessionaires, the rulers in Persia had concluded that there must be a lot of money to be made out of their telegraphs, and English telegraph circles had become very nervous. Whilst they had hitherto endeavoured to create the impression that the expiry of their concession in 1872 was a matter of complete indifference to them, they were now unable any longer to conceal their concern. Both the British and the Russian governments had promised the Indo-European Telegraph Co. their support in its claims against the Persian government, but in view of the British-Indian Telegraph Co., the British promise was probably not intended to be taken too seriously, and Russian support was also lukewarm. When approached by Georg Siemens, Her Britannic Majesty's Ambassador regretted, on principle, that he was without

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instructions, and the Russian Ambassador responded only when he thought that, by so doing, he could damage British interests.

Georg Siemens remained in Persia for eight months, firmly resolved not to depart before having attained his object. Since it had been clear from the outset that the Persians would never relinquish the advantage granted them in Vienna without a quid pro quo, it had been planned to offer them instead a fixed, but of course, smaller sum. Moreover, a suggestion was put forward for a new telegraph line from Shiraz to Bandar Abbas; this permitted a nearer approach to India by land, and avoided the use of the cable across the Persian Gulf with its heavy dues.

After months of exhausting and fruitless negotiations, Georg played his last trump, which he had hitherto held in reserve. He made an offer of sale to the British-Indian Administration of the line between Julfa and Teheran which was just then under construction. Before the English had had time to consider their attitude, the Persians got to know—Georg had arranged for this—and were highly alarmed. They had been so glad to deal with a harmless, half-German private Company instead of two antagonistic Great Powers, whose every move was bound up with open or concealed political extortion, that this new prospect appeared highly questionable. Georg Siemens retorted with a shrug of the shoulders that it was their stubbornness that had driven him to this act of desperation, and that the Indo-European Co. was in no mind to allow itself to be crushed out of existence by their greed. The stalemate was broken and negotiations again got under way. Finally, it was agreed that Persia would drop her claim to the notorious five francs against an annual payment of 12,000 Tomans and would award the concession Shiraz—Bandar Abbas to the Indo-European.

The victory had been won after an intense struggle and at a heavy cost, for Lüders was furious when he learned that the new telegraph line, although in the Russian zone of influence, had nearly been sold to England by friends, on behalf of whose interests he had, not without difficulty, interceded with his Government. Werner Siemens, who thereupon paid him a visit in St. Petersburg, finally succeeded in pacifying him by pointing out that it was due to his, Lüders', negligence in Vienna that the Company had been placed in such a difficult position, from which it could now only hope in the course of time to recover by reason of increased traffic due to the lower telegraph rates.

After much laborious work and after overcoming many difficulties, construction of the telegraph line was completed at the beginning of 1870. The laying of the cable under the Black Sea, this time without incident,

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had been personally supervised by William Siemens. But the inauguration of the line was held up for some considerable time. Breakages kept occurring, conditions being aggravated by the abnormally cold winter; the personnel was as yet untrained, the "stations quarrelled," but above all, the telegraph instruments did not appear to perform as their designer had expected. The fact was that he had intended them to operate at the permissible limits of sensitivity, but was only to learn by bitter experience how to keep such delicate products of the electro-mechanical art in reliable operation. At that time Werner Siemens devoted several hours almost every day to personal instruction of the operators in the Berlin telegraph room, from where he also exercised the telegraphists of the whole line. Here he would receive reports from Jitomir, Kertch or Tiflis of peculiar technical phenomena and unexpected difficulties, and issue the necessary instructions for dealing with them. This state of affairs lasted many weeks; his brothers and the staff began to lose heart, the public was waiting and rumours began to get about; the shares fell in value. In the end, Werner was the only one to keep his head. With exemplary determination he worked on—it had to succeed, his honour was engaged.

In the meantime, the "Great Eastern" had successfully laid the cable through the Red Sea and landed the final section of the direct submarine cable from England to India at Aden, to the accompaniment of much Press rejoicing, and a short time later the first cablegrams were passing from England to India by the submarine route. It had to be admitted that transmission was rather slow and cumbersome, due to the necessity for repeated readings of the mirror galvanometer, but it worked, and was obviously quite reliable. The shares of the Indo-European Company slumped badly.

By this time, however, Werner Siemens had also surmounted the last of his difficulties. His brother William invited General Sir Wm. Baker, a member of the Government of India in London, with whom he was acquainted, and a number of other well-known people to a reception in the Telegraph Room of the Company in London, and requested him to send a cablegram to India. The General sent a message to his friend Colonel Robinson in Calcutta, and in the course of an hour received a reply. The distance from London to Calcutta, measured along the telegraph line, was more than 11,000 kilometres, i. e., more than a quarter of the Earth's circumference. Up till then, this was more than anyone else had succeeded in doing.

On looking through the newspapers a few days later, Werner Siemens found that he had become famous; his fame had been honourably won.

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Unfortunately, the rejoicing at the final triumph of the Indo line was not of long duration. In consequence of an earthquake on the 1st July, 1870, the Black Sea cable broke in several places simultaneously, and was found after close inspection to be irreparable. The question thus arose whether to lay a new cable, or to make use of a new road which had meanwhile been built across the mountains. The decision fell in favour of the latter alternative, as it was held that in consequence of the frequency of earthquakes in those regions, a coastal cable would always be exposed to falls of rock. After six months of strenuous work the Indo Line was once more ready to resume operations and, with the exception of a break from 1914 to 1921 due to the first World War, was in uninterrupted service for 60 years, until 1931, with the reputation of being one of the speediest, most reliable and most profitable of the World's great telegraph lines.

Mathilde Siemens, Werner's wife, had died of an incurable disease in 1865. It affected him deeply, as he was truly devoted to her, and was imbued with a deep sense of the blessings which happy family life bestows. Left with the care of the four youngest children, as yet under age, there was an added anxiety concerning the future of the business, which although outwardly flourishing, was now, in 1867, heading for a dangerous internal crisis, due to Halske's earlier announced intention of severing his connection with the Firm in that year. Furthermore, illness had struck down Werner's friend and collaborator, William Meyer, to whom he had been greatly attached, and the loss of whose wise counsel and organizing talent seemed irreparable. Meyer's death early in 1868 was therefore one more heavy blow.

Discussions between the three brothers concerning the carrying on of the business after the expected retirement of Halske had been in progress—mainly by correspondence—for two years. Matters had become complicated by the fact that as concerning Siemens & Halske, Berlin, the Partners were Werner and Karl, apart from Halske, whilst as regards Siemens Bros., London, the Partners were Werner and William. The Caucasian copper mine was run by Werner and Karl in partnership, with a ten per cent share of the profits for Walter. William, on the other hand, in addition to his interest in Siemens Bros., had an extensive practice as a Consultant for hot-air engines, furnaces, steel production and water meters, as well as interests in other directions. Werner was broad-minded and generous, always having the common weal at heart; William, self-centered, wilful, incalculable; Karl adaptable, jovial but sometimes rash. For Werner it was no easy task to weld this mixture of warring interests and temperaments into an orderly foundation. On the

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other hand, he saw quite clearly that things could not continue as they were. In his opinion, therefore, Halske's retirement would have to be the occasion for making the necessary adjustments. At last, he became so impatient of the interminable exchange of views, that he requested his two brothers to come to Berlin for a round-table discussion. They succeeded in August 1867 on the following basis:

For accountancy purposes a "Consolidated Account" was opened, which embraced the Balance Sheets of Siemens & Halske, Berlin, and Siemens Brothers, London. The Works at St. Petersburg ranked as a branch of the Berlin Company and was styled "Siemens & Halske, Kommanditgesellschaft." The net profit shown by the Consolidated Account was divided between the three Partners, Werner, William and Karl in the ratio of 40%, 35% and 25% respectively. The Works at Kedabeg in the Caucasus, which were the joint property of Werner and Karl, remained outside the scope of the arrangement, likewise William's Consulting business and other interests in London. On his retirement Halske made a loan of 360,000 Thalers to Siemens & Halske, bearing interest at 5%, and also received 10% of the profit; leading officials received a bonus, which counted as a first charge on the profit, only the balance ranking for distribution amongst the shareholders.

At the beginning of January 1868 Werner Siemens gave a farewell dinner in Halske's honour in his newly-built house in Charlottenburg. Deeply moved, the retiring Partner promised to preserve his interest in the Firm and his goodwill towards its leading officials, and, in fact, the two founders of the Firm remained sincere friends until Halske's death in 1890.

It was at this period in his technical and scientific research work that Werner Siemens made a discovery, the great significance of which he was quick to grasp, although its revolutionary influence on engineering science as a whole only gradually became apparent, viz., the discovery of the electro-dynamic principle. The event is mentioned at this point merely for the sake of chronological order; a fuller appreciation must be deferred until its discussion at a later date in another connection.

The loss of Meyer and Halske had left painful gaps in the ranks of the senior staff of the Firm which were by no means easy to fill. Notwithstanding his astounding capacity for work, Werner Siemens was so overburdened by his travels—twice to the Caucasus—reorganisation of the Firm, construction of the Indo-European telegraph, scientific studies, domestic cares and occasional illness, that he had to give serious consideration to the infusion of new energy into the business if it were to continue prosperously.

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IV.

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Karl Frischen, at that time a telegraph engineer in the Administration of the Hanoverian State Railways, had already made a name for himself by the invention, at practically the same time as Siemens, of the telegraph circuit named after both, which permits the simultaneous transmission of two telegrams over the same wire in opposite directions. More than once the Siemens brothers had discussed the idea of securing Frischen's services for the Firm. Meanwhile, he had become Senior Telegraph Engineer of the North German Federation but, tiring of the Civil Service, he gladly accepted the offer, which Siemens & Halske eventually made to him in 1869, to join the Firm. His first assignment was a tour of inspection of the Indo-European telegraph line, then approaching the critical stage prior to setting-to-work, with full powers to "get things going." After this, he took over the management of operations in Berlin.

Two years previously a young engineer by the name of Friedrich von Hefner-Alteneck, a member of a distinguished Aschaffenburg family, had applied to Siemens & Halske for a post, but was refused on the ground of lack of experience. Nothing daunted, he managed to get a job with the Firm as a mechanic (engineers in those days having usually qualified as skilled workers prior to their academic studies) and as such was posted to the experimental and calibrating room, then known as the "Regulating Room," where his talents were soon discovered. In the course of a few years he became Head of the design department, on which for two decades he impressed the stamp of a personality which was both versatile and flexible, although very self-willed.

In 1873 the first physicist and academician to cross the Siemens threshold joined the Firm in the person of Dr. Oscar Frölich, a Swiss by birth.

It is strange that Werner Siemens hardly expected such men to make useful assistants. It would seem that, as time went on, he had become unable to divest himself of the idea, doubtless quite sound during the first twenty years of the Firm's activities, that for the scientific working-

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out of the day-to-day problems one head was sufficient, viz., his own. Perhaps, too, like many self-made men, he was distrustful of those who, by reason of their academic training, might lay claim to qualifications which only subsequent achievement could prove. He took to Hefner, because he was modest. But he was sorely in need of assistants and decided, therefore, to give Frölich a trial. Times had changed profoundly in more than one respect, and the great dividing-line between the periods was the Franco-German war.

To the commercial world of those days, the idea of a war between two first-class European Powers conveyed a sense of economic catastrophe, and in this it was surer in its instinct than its descendants. It saw visions of financial stringency, soaring rates of interest, collapse of credit, tumbling share prices, insolvencies, unsaleable stocks, increased sales resistance, works closing down and unemployment. The only ones to gain by a war were a few armament firms—to be counted on the fingers of one hand—and a few particularly cunning speculators; the rest had to suffer. And thus it was that from a business point of view Werner regarded the rather sudden outbreak of war with France with apprehension, whilst, of course, also participating in the wave of patriotic enthusiasm which swept the nation.

The first few days of war seemed to confirm Siemens' forebodings; money was not available at any rate of interest, communications were blocked in consequence of the movement of troops, the workshop was depleted by the calling-up of numbers of men. Then suddenly things changed: the army telegraph department placed large orders for existing types of apparatus, at the same time pressing for the manufacture of new types. A portable army telegraph which had been designed some time previously, the so-called "patrol telegraph," which was furnished with a thin, steel-armoured cable of high tensile strength (field cable), was in immediate demand in great numbers. The fear of a coastal invasion called for hastily organized defence measures, for which range-finders, mine detonators and extensive communication gear was required. The Workshop had to endeavour to close the gaps in its personnel, and received the assurance of all possible consideration in the calling up of reserves. In a word, the Firm found itself overnight in a very different situation from that anticipated, and one which gave a mild foretaste of the demands to be made in a full-scale war on the more important manufacturing industries, in consequence of the transformation of civilisation by technical science.

The war and, in particular, the mobilisation, which involved the rapid transfer of troops from the eastern provinces to the western frontier,

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had disclosed serious shortcomings in the German Railways. This applied especially to the heterogeneous signalling and safety devices in use. Whilst this could be explained as a consequence of the gradual fusion of the private and State railway systems, such a state of affairs could no longer be tolerated in view of the heavy increase in the volume and speed of long-distance traffic. As a result of the experience gained during mobilisation, arrangements were made to hold a conference during the war of representatives of all German Railway Administrations to discuss the standardisation of safety regulations.

The ultimate purpose of railway safety regulations is to prevent collisions between trains. The fundamental solution had been applied at an early date in England and consisted in dividing the line into individual sections, so-called blocks, and making it a rule that only one train be allowed in a block at a time. The junctions of the blocks A, B, C... are guarded by signals. In the double-line track, which predominates, each line corresponds to one direction of travel. A train II travelling in this direction from block A is not allowed to enter block B until the previous train I has left it, i.e., has passed the signal between B and C. The signal B/C is now put at "danger" and not until then is it permissible to put the signal A/B at "clear" and to give train II the right of way from block A to block B. To enable this to be done, the man at the block-junction A/B must know what is happening at B/C.

Up to that time the English railways had been content to provide telegraph lines between the block points, by means of which the signalmen could communicate by simple signs. At Frischen's suggestion, however, Siemens & Halske had developed a system which would render communication between signal boxes as simple and automatic as possible. This system was demonstrated to the above-mentioned conference, which put forward a number of further requirements. At a second conference in the course of the following year, the modified design was approved in principle. The "Siemens Section Block," as the system came to be called, proved to be the foundation of an extremely extensive business, since it has been adopted in the course of the intervening years by the majority of the railways of the European Continent.

The fact that the system necessitated the use of mechanical transmission between block apparatus and signals—later the points were also incorporated in the system—led Siemens & Halske to take up the manufacture of all the purely mechanical accessories at that time required for railway signalling and point control. In so doing they developed systematically the entire field of railway safety measures, and acquired the character of a signal construction works. The consequence was that,

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under Frischen's energetic leadership and materially assisted by the increasing use of the Siemens section block at home and abroad, they quickly created a new, extensive and important market.

The strong fillip given to the manufacturing side by the block signaling business soon resulted in increasing congestion in the workshop. Obviously, premises and equipment which had sufficed during the years of gradual growth would be considered a few decades later to be inadequate for precision engineering and instrument making. The shops were dark, with low ceilings and insufficient ventilation and were, for the most part, overcrowded. They had no railway siding; incoming and outgoing goods entered and left by the main doors on either side of the works, which were situated between two main streets. Heating was by means of iron stoves, lighting by paraffin lamps and gas. Such was the overall picture in the early 1870's when employment was given to 350—400 hands, approximately half of them fitters and mechanics, the remainder clock-makers, turners, cabinet-makers and semi-skilled men. Without exception they were content with their lot, for they were paid well and treated well, but not spoilt.

The increasing flow of orders, and in particular the increasing frequency of orders for large quantities of the same product, raised anew the problem of rational manufacture. Werner Siemens had often discussed this theme during the 'sixties in letters to his brothers and had laid it down that customers who accompanied their orders by special stipulations as regards execution must be notified that the apparatus in question could only be supplied in one particular form, and that in the event of this being unacceptable, the order should be respectfully declined. This, however, was more easily said than done, since the manufacturer was, after all, dependent on the goodwill of his customers and one or two smaller competitors had appeared in the meantime. On the other hand, customers themselves, in particular the recently formed State Telegraph Administration, had begun to realize that standardisation was in their own interest. An important step in this direction was the introduction of the Standard Ink Recorder, which had been developed by Siemens & Halske, after years of experimentation in collaboration with the Post Office, and which was intended as *the* Morse Apparatus to be used throughout the German telegraph network. Other countries followed suit, with the result that sufficient orders were assured to make quantity production not only feasible, but essential.

In German engineering practice the first example of mass production of articles of the same kind was the sewing machine; here, in truth, the product was not "built," but "fabricated" (in the original meaning of

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the term). In his early years Ludwig Loewe, later to be appointed Kommerzienrat (Councellor of Commerce), had spent some time in U.S.A. studying quantity production methods, which in that country were the natural outcome of economic conditions and the inventive genius of the manufacturers of sewing machines, small arms, agricultural machines and machine tools. Loewe had established a sewing machine works in Berlin in 1869 embodying these American principles. Owing to insufficient turnover, however, the enterprise was not a success, and Loewe conceived the idea of applying for a very large contract for modifying the sights of Chassepot rifles captured in the war. This venture proved completely successful and highly profitable. Werner Siemens had met Loewe frequently in the course of his political activities, had been attracted by the evidence of a clever brain, and had consulted him on engineering matters. Loewe introduced him to an American engineer who had played an outstanding part in the development of the new-type machine tools in America, and who had come to Berlin to introduce them into Germany. Siemens & Halske purchased a number of these machines and installed them in one of the newly acquired shops, which from that time on became known as the "American Shop." It commenced operations in 1872 with a complement of two heavy and six light milling machines, four multi-speed drilling machines and a number of planers.

The introduction of American methods into the workshop was the equivalent of a revolution. From the older hands it encountered embittered resistance. Up till then they had been accustomed to fashion each individual component of an apparatus, e. g., an ink recorder, and then to assemble the parts; now it was proposed in this new shop No. 30 to clamp a quantity of identical parts together and to mill, plane or drill them all in one operation. The parts were then to proceed to an assembly room, where, with others which had been produced elsewhere, they were assembled by someone who had had no part in their manufacture, and could therefore accept no responsibility for their workmanship. That was not the kind of job for a skilled mechanic, quite apart from the fact that the man now being taught to operate the machines had never learned how to file or turn. Moreover, in this connection there rose again a bogy which, notwithstanding repeated sorties, had hitherto always been successfully warded off: Piecework.

Hitherto, Siemens & Halske had engaged their skilled workers at a fixed weekly wage, which was paid on Saturday; in the event of men leaving before the end of the week or losing time, the wage was calculated according to the number of hours worked. In the latter half of

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the 'sixties the wage varied according to age and skill between four and five Thalers, quite a comfortable income under the conditions of those days, even allowing for the fact that the cost of living in Berlin has always been higher than in smaller provincial towns.

The sub-division of labour consequent on the introduction of American machine-tools was followed almost automatically by the introduction of piecework. This system of payment is based on the manufacture of parts of which the worker produces large quantities in a comparatively short time; for complicated products, on which a man may work for weeks, it is not easy to fix a piece-rate. Piece-rates were commonly settled on the basis of a suggestion by the foreman on the one hand and a (higher) counter-suggestion by the worker on the other; agreement was eventually reached and a trial made, from which it soon became manifest whether the estimated rate was approximately adequate, or whether a correction was necessary. The ultimate piece-rates were entered in a large book after the style of a ledger, and reviewed from time to time in the light of experience. Two results accrued from the division of labour and the introduction of piecework: the prime cost of the products was reduced, and the worker's weekly earnings were considerably increased. This latter was certainly necessary, since the close of the war ushered in a period of high prices, goods being scarce and money plentiful. As a result, the prices of many goods in daily use, above all foodstuffs, rose within a few years to almost twice their former level. But under the piecework system the pay level of Siemens & Halske workers rose still faster. In 1876 ten to twelve thalers per week could almost be counted an average, and in certain departments, more particularly block signals, there were individual pay packets as high as eighteen thalers. In those years Siemens & Halske were reckoned amongst the best paying employers in Berlin, and a job with Siemens was keenly sought.

Piecework, however, also placed a greater strain on the worker. To begin with, the time spent on the job was much shorter than formerly under day-wages, when the worker could afford now and then to enjoy a short rest. Again, piecework was inherently more tiring. The old-style worker, who retained a job in his hands from start to finish, grew into his work; it took possession of him and he could forget the time. Now, with this monotony, this eternal repetition of the same sequence, the glance at the clock became more and more frequent, and the time spent in the factory, although agreed to be a necessity, engendered a depressing sense of compulsion. It speaks for Werner Siemens' human understanding of the worker that he was one of the first amongst the German

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employers to compensate the introduction of piecework by a reduction in the number of working hours. At the Siemens & Halske Works the hours were from 7 a. m. till 6 p. m. with a total interval of two hours, making a 9-hour day and 54-hour week. It was not until twenty years later that, under pressure of the Government welfare policy and the Social Democratic Party, which had meanwhile grown enormously in power, the majority of German industrialists followed suit.

It was also due to the influence of the Principal that a number of other social services were introduced in the interests of the workers. In the course of his political activities, Werner Siemens had made the acquaintance of Schulze-Delitzsch, many of whose ideas he had adopted and endeavoured to apply in his own Works. This eminent and well-known social reformer was a true liberal, who did not believe in State-dispensed welfare, but advocated a welfare system based on the principle of contributions by the workers themselves. State-aided health insurance was not then in existence; the employees of Siemens & Halske, the majority of whom, including their Principal, responded to the influence of liberal circles, thereupon inaugurated a private sick-fund with the full support of the management, who arranged for the deduction of the contributions at the source. A Cooperative Society was also formed, for which the Firm provided the necessary offices and services free of charge. Years ago, Werner Siemens had issued clear factory regulations which he was in the habit of amending from time to time, as experience showed desirable, as in his opinion this was the best protection against arbitrary decisions of minor officials. At the close of the financial year, it was his custom to explain the Firm's balance sheet to a meeting of the employees, and to distribute to those workers who were not engaged on piecework a so-called stock-taking bonus, the amount of which was governed by the result of the year's working and represented a small share of the profits. Finally, on the occasion of the Firm's twenty-fifth anniversary in 1872, an "Old Age and Sick Pension Fund" was inaugurated with an endowment by the Firm of 180,000 Marks. This completed for the time being the series of welfare measures initiated by the Firm. It was on this occasion that the custom originated for the Principal of the Firm to invite the office staff, foremen and older workers on Ascension Day to a garden party at his Charlottenburg Villa, where ultimately he entertained as many as 400 guests.

The gradual expansion of the Block Department into a Signal Construction Works had caused an increasing demand for cast-iron parts, and since the dependency on outside suppliers was becoming increasingly irksome, the Firm decided to do its own casting. In 1870, there-

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fore, a foundry for iron castings was established in Markgrafenstrasse, Berlin, where there had already been a yellow metal foundry in operation for a number of years. It was soon found, however, that the cramped site with its scattered buildings was little suited to the purpose, particularly in view of the fumes and risk of fire inseparable from casting. Within a year or two it became an urgent necessity to move the foundries to a site outside the city.

The foundry was not the only Works' department to have migratory yearnings. In the early 1860's, when Karl Siemens was beginning to find the Russian telegraph business "boring" and was taking an interest in all kinds of other schemes in consequence, he learned of an invention by a Pole of a relatively simple method of registering the alcohol content when distilling brandy. As Werner Siemens was just then on the lookout for new lines of manufacture, he took up the idea and constructed a suitable apparatus. By the commencement of the '70's sales had attained such proportions that the alcohol meter business threatened to bring about the final disruption of the chronically overcrowded Markgrafenstrasse Works. More and more, the new line came to be looked upon as an intruder, since, following on some hesitancy in earlier years, the factory had come to be definitely accepted as a "Telegraph Construction Works," albeit in the wider meaning of the term.

In order to be prepared for developments, Werner Siemens had in 1862 acquired a large building site on the Salzufer Bank of the Spree in Charlottenburg, and it was therefore decided, in view of the above-mentioned conditions, to build a new factory on this site, to be devoted basically to the manufacture of alcohol meters. The factory was segregated from Siemens & Halske and taken over by the Firm of Gebr. Siemens & Co., one of whose partners was a distant relative of the brothers.

In this way space was gained for a time in Markgrafenstrasse, but it was not long before it became necessary to commence building again, as Siemens & Halske found themselves faced with a new demand: the manufacture of cables.

About the beginning of the 1850's the enterprising firm of Felten & Guilleaume in Mülheim on the Rhine, founded in 1826 as wire-rope makers, had commenced the manufacture of electric cables, and after initial failures, had produced designs which appeared to be sound. The basic principle was, as usual, quite simple; the secret lay in the process of manufacture, and in this respect the Firm was able to turn to account its long years of experience of wire-rope manufacture which enabled it to modify the processes and machines hitherto employed and to adapt

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them for their new purpose. At the turn of the 'seventies Felten & Guilleaume felt justified in submitting definite proposals to the State Telegraphs for the construction of an extensive German telegraph cable network; they applied for and received a contract for an experimental line from Berlin to Halle. Stephan, the Postmaster General, who was convinced of the feasibility of the scheme, submitted the necessary resolution to the legislature for the granting of the very considerable expenditure. The proposed network was to comprise approximately 5,500 km of cable, the greater part of which was to consist of seven cores, in the arrangement of a central core surrounded by a circle of six outer cores, in order to obtain a circular cross-section overall. Each core was embedded in a double layer of guttapercha insulation, the seven cores stranded together and again covered with guttapercha. This stranded core was provided with a covering of hemp as a cushion for the armouring of galvanized iron wire, which was again protected from rust by an asphalt-impregnated outer covering of a mixture of jute and hemp.

The Post Office was in no doubt as to the inadvisability of placing this large order with one single firm, but was not prepared, on the other hand, to accept the tender of Siemens & Halske, who proposed to supply the cable from their Woolwich Works. The cable had to be manufactured in Germany, so Siemens & Halske promptly undertook to build a cable works of their own in Berlin. The complete contract was thereupon awarded to Siemens & Halske and Felten & Guilleaume jointly, and the two partners agreed between themselves that each should supply one half of the cable, delivery to extend over a number of years; in the event of one of the partners exceeding his quota, he was to pay to the other a penalty amounting to 7½% of the value of the excess delivery. Thus came into being the first cable ring (Kartell) contract, a form of association which was to be extensively copied and expanded in later years.

In the autumn of 1876 equipment of the cable works was begun on the Markgrafenstrasse site, and in the following year it was working at full pressure, not without having undergone extension in the meantime. Cable manufacture needs a great deal of floor space, so that in spite of repeated acquisitions and extensions, lack of room continued to hamper the work. The laying of the cables of the Grand Telegraph Network had been planned to take five years; work was completed in 1881. This network gave service for more than fifty years, until it became obsolete only by reason of the further development of telegraph technique. When certain sections were dug up and tested in the 1930's, they were found to be scarcely affected, and in every case in good operating condition.

At the time it was built, in 1863, the Woolwich Works of Siemens

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Bros. did not quite justify the use of the term "Cable Works." Manufacture did not commence with the making of the copper wire, but consisted in stranding already insulated wires purchased from outside, the cable then being armoured and finished. Shortly before this period, their main competitors, Glass & Elliott, had amalgamated with the Gutta-percha Co. to form the Telegraph Maintenance & Construction Co. which had a practical monopoly of the buying and processing of gutta-percha. They were, moreover, in possession of certain secret formulae, and William, as Manager of Siemens Bros., was not anxious to enter the lists against the monopoly, more particularly as he was at that time deeply immersed in his plans for steel-making and other inventions. All this changed, however, with his brother Karl's arrival in London in 1869. Karl had returned from the Caucasus to look for a new field of activities, and at Werner's suggestion, had agreed to devote himself to the affairs of Siemens Bros., London, which needed the drive of an energetic personality, and of one whose attention was not diverted by other interests. It so happened that the telegraphs in England had just been nationalized; the predominance of the Electric Telegraph Co., particularly on the railways, was thus at an end, and for an active concern there appeared to be a promising future in the English telegraph business.

Karl seized the opportunity with both hands. In the first place, he said, Woolwich must have the additional equipment to make it a complete cable works, and despite dissuasion on the part of Werner—who still had a horror of submarine cables—he carried the day and Woolwich was completed, beginning manufacture in 1871. At first, it seemed as if Werner's doubts were justified, for the hoped-for flow of business did not mature, and the cable works lay idle for most of the first two years following its completion. It was absolutely essential to find work for the factory and the only possibility seemed to be a transatlantic cable. William hesitated at first at the idea of such an adventure, influenced by Werner's urgent dissuasion. Who was to supervise the laying of the cable? "I" replied Karl with disarming confidence. Of course, he needed for the purpose a proper ship, built specially for the job and incorporating the sum of past experience. Why should not Siemens Bros. possess their own cable-laying ship? He succeeded ultimately in interesting his brother in the plan, and since William had already paid for his experience, he knew how to plan a cable ship which was adequate for the difficult task. The ship was of 5,000 gross tons, i. e., a respectable ocean-going steamship, and cost £ 158,000. At the launching in 1874 it was named "Faraday," as a mark of gratitude to the great physicist for the

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unselfish support accorded to William at all times in the development of his ideas.

At that time three cable lines were in operation between Europe and North America, viz., the cable laid by Cyrus Field, Brett and John Pender in 1866, which had been the first permanent link between the two Continents. Secondly, there was the cable which had parted during the laying a year before, but which had later been raised, repaired and put into operation. Finally, a cable had been laid in 1869 by a French financial group from Brest to St. Pierre in Newfoundland, with an extension to Cape Cod in Massachusetts. There could be no doubt that there was a demand for further cable links between the old and the new world, and this was also acknowledged by the group operating under the leadership of John Pender. From the beginning, however, this group had shown monopolistic tendencies, and had used every means to keep competitors out of the business. After the pattern of the ruthless American railroad magnates, whose aims were also monopolistic, they planned to create a giant concern, characterized by the word "Globe," to cover both the operation of overland and submarine telegraph lines, as also the manufacture of the cables and telegraph apparatus. Karl Siemens' proposal to his brothers was to equip a telegraph line to America, independent of the Pender group.

The "Direct United States Telegraph Co." was formed for the purpose, and placed an order with Siemens Bros. for a transatlantic cable costing £ 1.1 millions to be laid between Ballinskellig's Bay in Ireland via Newfoundland to Torbay in Nova Scotia and thence to Rye Bay in New Hampshire, and to be the first assignment of the newly completed cable ship "Faraday."

The difficulties and anxieties accompanying such an enterprise in those days are graphically described by Werner Siemens in his memoirs: "...brother Karl assumed command (of "Faraday") during the actual cable-laying, I considered Karl to be particularly suited to this task, since he had a habit of calm consideration, was a keen observer and definite in his decisions. I was not to be gainsaid in sailing with the Faraday with its load of deep-sea cable as far as Ballinskellig's Bay on the west coast of Ireland, where the cable was to enter the water, and supervising operations at the land station during laying.

The weather was reasonably good and all went well. The steep drop of the Irish coast into deep water was successfully negotiated and the condition of the cable, as proved by electrical tests, without a flaw. Then, suddenly, there appeared a small insulation fault, so small that only extremely sensitive instruments such as we possessed could have detected

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it. In the light of existing cable-laying experience this fault would have been disregarded, since it did not interfere in the slightest with the transmission of signals. However, we were anxious to have a cable without any flaw whatsoever and decided, in consequence, to lift it again as far as the fault, which could not be far from the ship. According to records telegraphed from the ship, all went well at first, in spite of the great depth of water of 18,000 ft, when suddenly the scale of the galvanometer was jerked violently out of view—the cable had parted! And this at a depth from which the recovery of the broken end seemed quite impossible . . ."

Contrary to expectation they succeeded after three days of arduous searching in locating and raising the broken end and were able to complete the laying of the cable in due course, though two further expeditions were necessary to eliminate minor defects which pride of manufacture would not permit to remain.

Considering the interest taken by the whole civilized world in the laying of these first Atlantic cables, it is not surprising that the names of the three brothers were on all lips, especially as the new cable proved to be several times faster in operation than those hitherto existing. Werner's status, also in the world of science, found acknowledgment in his election as a member in ordinary of the Berlin Academy of Sciences, an honour accorded only to scholars of distinction. He delivered his inaugural address on the 7th July, 1874. His friend, du Bois-Reymond, who was Secretary of the Mathematics and Physics Division, in a reference to the Indo-European Telegraph Line and the Transatlantic cable, greeted the new member with the words: "Your telegraph wires encircle the globe; your cable ships sail the oceans." Werner heard these words with somewhat mixed feelings, for just prior to coming to the meeting he had been handed a telegram which stated that the "Faraday," which was on the point of completing operations on the new cable, had been crushed by icebergs and had gone down with all hands. In a frame of mind which can be imagined he had to give his address without betraying his emotions. The only uncertain thing was the source of the news, which was obscure—it was still possible to hope. A few days later news was received from the "Faraday" herself, that she had entered Halifax safe and sound; she had been held up by dense fog—actually in the iceberg zone. It would appear that the false news was the work of "friends" who were unable to forgive the Siemens brothers their success.

The Cable Company was not a commercial success, especially as the Pender group and their associates did all they could to make things difficult. After languishing for a period of years, during which an

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attempt at reconstruction under the style "Direct United States Cable Co." was also a failure, the Company capitulated and was absorbed by the Pender ring.

Siemens Bros. had meanwhile received an order from the Companía Platino Brazileira for a cable from Rio de Janeiro to Montevideo. Since the "Faraday" was still engaged in the North Atlantic, a ship was chartered for the laying.

During the operation this ship ran on a sandbank and went down with about one fifth of the cable. A second ship with replacement cable was caught in a heavy storm in the Bay of Biscay and foundered—this time actually with the loss of the whole crew. It was only at the third attempt that the expedition finally succeeded. It had to be admitted that Werner was not far wrong in his doubts about the submarine cable business.

In France, there was a good deal of annoyance at the British cable monopoly, taking advantage of which an alert financier, M. Pouyer Quertier, succeeded in forming the "Compagnie Française du Télégraphe de Paris à New York," with the object of laying a new French cable over the route of the old one. The order was placed with Siemens Bros. and completed in 1879 without material incident. But the British financiers were tougher than the French capitalists; soon after the inauguration of the cable, the Compagnie Française was also in the hands of the British cable ring.

In the United States, particularly since the civil war and the following boom, a class of speculators had come to the fore, whose aim was the consolidation of the railway undertakings into vast networks, and the pursuance of a policy, often by the most ruthless methods, of economic expansion. One of these "Railway Kings" was a certain Jay Gould, who controlled an extensive railway system in the Middle West and was also connected with telegraph interests. He was attracted by the transatlantic cable business and founded the American Telegraph and Cable Co. He approached Siemens Bros., and promptly placed with them a telegraphic order for two cables. Delivery and laying of these cables was effected in 1882; shortly afterwards, Gould leased the two cables to the Western Union Telegraph Co., in which he also had an interest, and who, in turn, entered into a pool agreement with the Pender group, so that for all practical purposes the monopoly remained intact.

In the following year Sir William Siemens, as he now was, having been created a British Baronet, died rather unexpectedly of heart trouble. His death called forth numerous expressions of sorrow in the United Kingdom, which had become proud of its adopted son. Since he died

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without issue, the greater part of his fortune reverted to his brothers. It has been said of him that he amassed three fortunes in his lifetime: the first he lost, the second he gave away and the third he bequeathed.

He was not destined to witness what was, for some time, to be the last big success of the branch of the House he managed. The very existence of the cable ring was a continual challenge to attempt to break it. With this end in view, two American business men, J. G. Mackay and J. G. Bennet, the first of whom was more than usually enterprising, founded the Commercial Cable Co., and had two cables laid by Siemens Bros. from Waterville in Ireland to Halifax and thence to New York. They then engaged in an embittered rate-war with the Pool, which continued until amicably settled in 1888.

And thus it was that within a period of ten years, apart from numerous smaller enterprises, Siemens Bros. laid no fewer than six cables across the Atlantic and by their achievements, turnover and international prestige, dwarfed the parent Company in Berlin; "Faraday" had shown the flag of the House of Siemens on all the seas. But the day of these large transactions was drawing to a close, and in Berlin developments were in progress which were destined to usher in a new epoch.

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V.

THE BIRTH OF POWER CURRENT

In the early 'thirties, Faraday had concluded his basic study of the relationships between current-carrying conductors and magnetic fields. He had demonstrated, in particular, that the movement of a conductor in a magnetic field at right angles to the lines of force produces an electric potential. Inventive minds set to work to turn this knowledge to practical account. In 1832 Pixii in Paris constructed an apparatus, which may be considered to be the first electrical machine. A horseshoe magnet was arranged to rotate in front of two series-connected coils placed side by side in such a way that the lines of force from the north to the south pole of the magnet passed through the space enclosed by the coils when the magnet poles were opposite the centres of the coils, whereas on being rotated a quarter of a turn, the line connecting the magnet poles was at right angles to that joining the coil centres. Half a turn of the magnet reversed the position of the poles, and a further half-turn restored the original position and the cycle was repeated. The rotation of the magnet thus caused the lines of force to cut the turns of the coils, thereby creating in them, in accordance with Faraday's experiment, a periodically variable potential which reversed its direction at each half-turn of the magnet. Joining the ends of the coils caused a current to flow in them which was proportional to the potential.

It was obvious that the current attained its maximum value when the magnet poles were opposite the centres of the coils, dropping to zero after a quarter of a turn, here reversing its direction and regaining its maximum, but this time negative value after half a turn, and so on. A current of this kind was called an "alternating current."

In 1836 Saxton and Clarke improved on the Pixii machine by arranging for the heavy magnet to be stationary and allowing the lighter coils to rotate. Of course, this involved the provision of means for collecting the current from the rotating coils. Two slip rings were therefore mounted on the rotating spindle, insulated from it and from each other, each slip ring being connected to one end of the coils. A spring contact known

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as a "brush" was made to bear on each slip ring and formed the point at which the current was collected and conveyed to the terminals of the machine.

It was also possible to do with only one slip ring by cutting it diametrically into halves, which were insulated from each other, and each connected to one of the coil ends. If the brushes were then placed in the so-called neutral zone, i. e., the position in which the reversal of the current took place after completion of the first quarter of a revolution, the passage of the brushes from one half of the slip ring to the other simultaneously reversed the connections to the beginning and end of the coils, again causing the current in the outer circuit to change its direction. In contrast to the original design of the machine, the current always flowed in the same direction, although pulsating twice in the course of a complete revolution between zero and maximum. To distinguish it from alternating current, this kind of current was called "pulsating continuous" current. In the course of one revolution of the machine this pulsating current therefore had two "beats." The bisected slip ring, which converted the alternating current produced in the coils of the machine into the pulsating unidirectional current flowing in the outer circuit, became known as the commutator.

It had come to be realized that a device which, when driven mechanically, produced electrical energy in the form of a pulsating continuous current, i. e., worked as a generator, must also be able to operate as a motor when fed with continuous current from an external source, such as a battery. Whereas, however, there were certain limited practical uses to which a generator could be put, motors were looked upon merely as scientific toys; consequent on the low output of the galvanic cells and the poor efficiency of the motors, it was as much as could be expected if the motor ran at all—there was no question of its giving any appreciable output. In those days, incidentally, the machines were not called motor and generator, but electromagnetic and electrodynamic machines. These terms were not exactly logical, but they had come into common use.

In experimenting with "electromagnetic" machines it had occurred to Pacinotti in Bologna to improve on the irregularity of the torque of the motor in the course of one revolution by increasing the number of coils. In the hollow cylindrical space between the magnet poles he placed a ring, on which were wound a number of coils placed side by side until the whole of the ring was covered—in one example, of which he published details in 1863, there were 16. For these he should really have employed eight split slip rings; however, he conceived the happy idea of using only one, which he split up into sixteen mutually insulated segments. The end

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of one and the beginning of the next coil were taken to one common segment of the commutator; all of the coils were thus connected in series and the current fed to the two brushes distributed itself in parallel to the two halves of the ring, quite independent of the position of the ring, resulting in approximate uniformity of the torque throughout each revolution.

If the process was reversed and the machine operated as a generator, the sum of part-voltages of the individual coils in each half-ring formed the terminal voltage of the machine; likewise the current, which deviated the less from a constant value, the greater the number of coils. This achievement was so much nearer to the ideal of the really continuous current obtainable from galvanic batteries as to be sufficient for all practical purposes.

The machines, known until then as electromagnetic or electrodynamic machines, were either scientific apparatus for demonstration or test purposes, or they were small telegraphy generators, in either case of a size which, when driven by a hand-crank, were scarcely equal to delivering the mechanical output of which a powerful human arm is capable over a limited period. True, in the early 'fifties a machine designed by Nollet, a professor at the Military Academy in Brussels, and built by a firm by the name of "L'Alliance," was intended to give a greater output. A large number of powerful horse-shoe magnets were arranged on a framework in star-fashion, with their poles pointing to the centre and forming a hollow cylindrical space, in which a ring of flat coils rotated past the magnet poles.

The complete machine was so large and heavy that a small steam engine was required to drive it. The current was used primarily for operating arc lamps in certain important lighthouses, in place of the oil lamps hitherto employed. After overcoming initial difficulties, these Alliance machines, as they were generally called, gave many years of good service in a number of lighthouses.

None the less, they were of rather unwieldy design. The great masses of steel which gradually lost their magnetism, necessitating re-magnetisation, bore no comparison to the output of the machine. It was but a short step to the idea of replacing the steel magnets by electromagnets. This step was taken at the beginning of the 1860's by Henry Wilde of Manchester, who generated the current required for exciting the electromagnets by means of a special magneto-electric machine which was driven simultaneously with the main machine and, like the latter, was equipped with an H-shaped armature. Such machines were built with ratings up to quite a considerable level.

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In the autumn of 1866 Werner Siemens was also considering ways and means of dispensing with the use of steel magnets in electrical machines. The solution which had been adopted by Wilde was, in reality, no solution, since the excitation of the electromagnet of the main machine necessitated the use of an auxiliary machine, which in turn had a steel magnet. In his laboratory in Markgrafenstrasse Werner had constructed an experimental machine with a double-T armature and an electromagnet in place of a steel magnet. This machine was fed from a battery and ran, therefore, as a motor, the battery, electromagnet and armature being connected in series in one circuit. The current from the battery excited the electromagnet, flowing then by way of the split slip ring into the armature coils, where it produced the torque. If this motor was braked down to rest, the current increased considerably. Siemens found the correct explanation: when rotating, not only by reason of an external drive, but also under its own power, the armature always generates a potential, which in this case is opposed to that of the battery and therefore reduces the current; if the armature is forcibly held, the counter-potential disappears. If the armature was rotated in the reverse direction, the potential reappeared, but likewise in the reverse sense; adding itself to, instead of opposing, the battery voltage, thus causing a further increase in current. It was now possible to short-circuit the battery and to take it out of the circuit altogether without materially affecting the arrangement; the machine, no longer running as a motor but as a generator, was supplying itself the current required for the excitation of its electromagnet.

Even after stopping the machine, the iron core of the electromagnet continued to exhibit a certain weak magnetism, the so-called residual magnetism. When the machine was started up again this sufficed—the battery was no longer connected—to generate a weak current in the armature coils. This strengthened the magnetism, which in turn reacted on the current and so forth, until within the space of a few seconds the machine was self-excited and had regained its full potential and current. It was also soon discovered that the residual magnetism necessary to start this chain did not require to be produced by an initial powerful magnetisation, but that it was present in all iron, which, if only very weakly, is magnetised by the magnetic field of the Earth. If properly designed, the electrical machine would always be capable of exciting itself, building up from its residual magnetism.

These two interconnected discoveries—that an electrodynamic machine could excite its own electromagnet, and that the all-pervading presence of residual magnetism was sufficient to start the process of self-exitation—were termed by Werner Siemens "the electrodynamic principle."

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When the physicists of those days spoke of a "principle" which they claimed to have discovered, they meant a discovery of fundamental importance; the principle of Virtual Displacement, of the Smallest Effect and of the Conservation of Energy, were basic discoveries of this nature. From the outset, Siemens was in no doubt as to the enormous significance of his discovery. As early as December 4th, 1866 he wrote to William in London: "This matter is capable of great development and can usher in a new magneto-electric era..." And three months later, more definitely: "This apparatus will be the pivot of a great technical revolution, which will raise electricity to a new place in the scale of elementary forces..." Impelled by the idea of establishing the priority of his discovery before a recognized body of scientists, he presented a paper to the Berlin Academy of Sciences in December 1866 entitled: "Concerning the conversion of power into electric current without permanent magnets." The paper, which was read on January 17th, 1867, summarized the results as follows: "Technical science now has the means of generating electric current of unlimited strength, cheaply and conveniently, at any place where driving power is available. This fact will prove to be of considerable importance in several directions." At his brother's request, William also read a similar paper before the Royal Society on February 14th, 1867, when he gave a demonstration by means of a model machine. At the conclusion of William's lecture Wheatstone, who was due to read a paper a fortnight later, rose and stated that he had had the same idea—a statement which can be accepted. About that time there was obviously something in the air, for as it transpired later another Englishman of the name of Varley had lodged a patent application on December 24th, 1866 which was based on essentially the same claims. The only difference was that Werner Siemens, as opposed to his competitors, at once realized and publicly foretold the technical revolution which the use of the electro-dynamic principle would bring in its train. Thus he is justificably regarded by the world as the discoverer of the principle, and the 17th January, 1867, when it was first announced to the world with its consequences, as the date of the birth of power current engineering.

The new-born babe began life with child-like ailments, which for some considerable time retarded its growth. Even in his first experiments with the machine, Werner Siemens had noticed that the iron of the rotating part, i. e., the armature, became very hot. After a lengthy period of operation the overheating became dangerous. These large quantities of heat also had to be furnished by the driving power and were lost as far as the generation of current was concerned; it was just

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as if part of the driving power were consumed in heavy friction and converted into heat. The cause of this phenomenon was at first obscure. Werner Siemens surmised that it was the perpetual reversal of the magnetism in the iron, consequent on its rotation in the magnetic field, which produced the heat, since in those days it was held that reversal of the magnetism involved a movement of the smallest particles in the iron. In actual fact this phenomenon, known to-day as hysteresis, is the cause of a certain power consumption and consequent generation of heat. By comparison with the total power losses, however, it only accounts for a small proportion. The main cause is to be found elsewhere. The iron body of the armature with its insulated conductors, in which current is to be generated, is itself a conductor, in which the generation of currents is not desired, but nevertheless occurs. These currents flow in the massive iron of the armature in paths parallel to the insulated conductors and can form unlimited numbers of circuits of exceedingly low resistance, attaining considerable strength and heating up and retarding the rotation of the armature in consequence. For the time being, no better means of overcoming the heating could be devised than by cooling the armature with running water. This resulted in a complicated construction and meant that a considerable proportion of the mechanical power supplied to the machine was running to waste instead of being converted into electric current. It was similar to a doctor fighting a fever without understanding the cause.

In considering the uses of the new machine, the first thought was electric light. As a matter of fact, Werner Siemens had already spoken of the possibility of power transmission, but for this the time did not yet appear to be ripe; the question of electric lighting, on the other hand, was a matter of keen public interest.

The arc lamp had come to be known as the result of Davy's experiments in 1809. If a closed electrical circuit was broken at any point, provided the potential and current were high enough, the spark which is always produced at the point of interruption was not extinguished at once, but continued to bridge the gap, if it was small enough, forming a continuous flow of current through the air. This "arc," which developed a hitherto inconceivable heat, consisted of the high-temperature gases given off by the melting and vaporizing ends of the conductors, and emitted an intensely bright light, the bluish-white colour of which varied somewhat according to the material of the conductors, or so-called electrodes. The rapid consumption of the electrodes, however, rendered the process somewhat irregular; it became technically feasible only through the use of electrodes consisting of a material which

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would conduct the current without melting, viz., pure carbon, such as was found as a residue in gas retorts. Prismatic rods of this carbon formed the electrodes of the first electric arc lamps.

In view of the heavy power consumption, by comparison with telegraph apparatus, of even one single arc lamp, the idea of using galvanic batteries for electric lighting was quite out of the question. Now, however, since the discovery of the electrodynamic principle, the way seemed open for the application of arc lamp lighting on a large scale.

The first to take note of this new possibility was, as usual, the Army. Already during the siege of Paris, the French had endeavoured to protect the approaches to the bitterly contested Mont Valerian against surprise attacks in the dark, by floodlighting them with arc lamp searchlights. All the major Powers now began to equip themselves with portable lighting plant for army and coast-guard use, consisting usually of a locomobile, a generator and an arc lamp.

As yet, of course, these lamps were pretty unreliable. The carbons did not actually melt in the heat of the arc, but vaporized, or "burned away," as it was termed, and had to be continually replenished in order to maintain the proper length of arc, which would otherwise be ruptured, i. e. extinguished. Endeavours were made to feed the carbons to the lamp by clockwork devices, but these were unable to take account of the accidental factors influencing the rate of consumption. In lighthouses and military installations it was possible to provide for an attendant to be permanently on duty; in ordinary civilian service this was out of the question. Eventually, in accordance with a suggestion of Foucault, the clockwork was combined with an electromagnet connected in circuit with the current. If the current became excessive due to insufficient distance between the electrodes, the magnet would draw these apart, thus maintaining a certain degree of equilibrium. This made it possible to maintain satisfactory operation where one arc lamp was concerned. All attempts to operate a number of lamps in series from one generator, however, were unsuccessful, as the lamps interfered with each other. As was said at the time, electric light was not divisible.

Not long after the introduction of the electrodynamic principle the Compagnie L'Alliance found it expedient to abandon the manufacture of machines with steel magnets, as hitherto employed for lighthouses and similar duties, in favour of the new system. A very active employee of the Company, a certain Théophile Gramme, conceived the idea of using the Pacinotti ring armature with a multi-segment commutator in the construction of an electrodynamic machine. As the result of the initial experiments it was not long before a machine was produced, to

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the accompaniment of considerable publicity, as the "Gramme Ring-Armature Machine," which thanks to its indisputable constructional advantages soon made its mark.

Von Hefner-Alteneck, who had meanwhile become chief designer of Siemens & Halske, now turned his particular attention to the design of a machine which would preserve the advantages of the double-T armature as against the ring winding, whilst incorporating a large number of coils with correspondingly subdivided commutator. For the ring winding had one disadvantage: those parts of the coils which were inside the ring were ineffective, they were simply ballast, merely increasing the resistance of the circuit. Hefner therefore returned to the solid body of the double-T armature, which had no internal surfaces, but dispensed with the two deep slots which had hitherto accommodated the windings and wound a large number of coils over the surface of the cylinder in such a way that the turns of each coil lay parallel to the axis of the cylinder; the coils then crossed each other at the two cylinder ends. At one end was placed the multi-part commutator; the two ends of each coil were taken to two diametrically opposite segments of the commutator. To distinguish it from the ring winding, Hefner called his arrangement, which was first produced in 1872, the drum winding; for the following twenty-five years this came to be accepted as the standard form of winding for all electrical machines.

The excessive heating of the armature and consequent waste of energy, to which reference has already been made, continued to be one of the greatest defects of the electrodynamic machine. Designers had gradually come to realize that the root of the evil lay in the eddy currents circulating in the iron of the rotating armature. At that time these currents were called Foucault currents, after the physicist who was the first to observe them. Von Hefner-Alteneck resorted to a drastic experiment: the iron of the armature was held stationary, and only the coils and commutator allowed to rotate between the poles and the armature cylinder. This was a somewhat difficult feat, for the now hollow wire cage had to rotate at high speed in the narrow annular gap between the poles and armature drum. However, the experiment proved satisfactorily that it really was the eddy currents which were the cause of the trouble; the iron armature remained cold, and the power consumption of the machine was considerably lower for the same electrical output.

The suggestion was now made in several quarters to retain the rotating iron armature but to subdivide it at right angles to its axis of rotation and to the direction of the eddy currents, with a view to blocking their path. To this end the iron body of the ring or drum was built up

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of thin wire, individual turns of the windings being insulated from each other by a thin coating of varnish. In this way the eddy currents were confined to the short distances represented by the thicknesses of the wires and their injurious action suppressed. Admittedly, this construction lacked mechanical strength, embodying, as it did, such elements as wooden supports, string and glue. Electrical machine construction continued for a long time to suffer under such disabilities, and it was only as the result of much bitter experience and many failures, that it learnt to master these problems with existing and new materials to a degree that justified reference to an electrical machine as a "sound engineering job." An important step in this direction, which was taken soon after the introduction of the wire-wound armature, was its supercession by the laminated construction. Depending on whether the armature was of the ring or drum type, corresponding rings or discs of thin sheet iron were packeted together, insulated from each other by a layer of paper which was pasted to one side of each sheet and pressed firmly together by powerful bolts. This resulted in a rigid body which could be mounted securely on the machine shaft and provided with electrical windings. In the plane of the sheet-iron there was nothing to obstruct the path of the lines of force, but at right angles to this plane the spread of the eddy currents was arrested. Thus originated what are still known to-day as dynamo-sheets, which continue to play an important part in the production programmes of ironworks, in the iron-distributing trade and the economic statistics of many countries.

In designing a new machine, there were no previous calculations available and each machine of larger size than its predecessor had to be approached and developed empirically; if the windings became overheated, heavier wire was made, and this applied throughout. Demonstrations were invariably accompanied by incidents of various kinds; even the journal bearings, which appeared to be one of the simplest constructional elements imaginable, repeatedly gave rise to trouble which had to be combated by repeated applications of the oil-can, or in critical cases even by dousing with water. It is highly amusing to read, in the memoirs of the old campaigners in the early battles for the introduction of electric lighting on special occasions, such as illuminations, exhibitions, festivities, etc., how each of these demonstrations was an ordeal of fear and trembling for all those who were in the know. At any rate, this much is certain, that, for the first decade following the discovery of the electrodynamic principle, there could be no question of the manufacture of electrical machinery on an industrial scale, nor even of any influence of the new idea on the economic outlook. All that can

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be recorded is groping and experimenting on the part of the engineers, and astonishment on the part of the public at occasional sensations.

A period of searching and rumination of this kind usually gives birth, in the minds of various individuals, to all manner of ideas and proposals, which mature about the same time and result in a sudden brisk acceleration of the pace of development. Such an epoch had arrived about the year 1878, which heralded in a period of several years of rapid advance in the field of power current. Werner Siemens and his chief designer, von Hefner-Alteneck, regarded it as one of their main tasks at this time to devise a regulating mechanism which would make it possible to control several lamps in a common circuit.

In an ordinary arc lamp the regulator consisted of an electromagnet connected in series with the main current. The tips of the carbons were pressed together by a spring controlled by clockwork. When the current was switched on, the magnet drew the carbons apart against the pressure of the spring, separating them farther as the current increased. If, however, the variation of the current was caused by a second arc lamp in the circuit, the magnet endeavoured to regulate its own lamp, which was obviously wrong and rendered simultaneous operation impossible. But the state of the arc is governed by a second characteristic besides the current, viz., the voltage, which—a peculiarity of the arc—drops with increasing current and vice versa. If, then, the spring is replaced by a second electromagnet fed from the voltage of the arc, or shunt connected, as it is termed, the result is a force which varies with the arc voltage instead of the constant pressure of the spring. This system is in equilibrium when the forces of the two magnets balance each other, i. e., at a certain ratio of arc voltage and current. The system was so designed as to keep this ratio constant, thus rendering the lamp independent of what was happening in other parts of the installation. Since the force which was effective in adjusting the carbon was the difference between the forces of the two magnets, the inventors of this construction called it the "Differential Lamp." It embodied the long-sought solution of the problem of the divisibility of electric light, as far as large units were concerned, in almost ideal fashion.

A first public trial with the new lamp was undertaken by Siemens & Halske in the so-called Kaiser Arcade at the crossing of Unter-den-Linden and Friedrichstrasse in Berlin, where they installed twelve lamps of this type. The generating plant was accommodated in a shop which happened to be unoccupied; the power drive was furnished by one of the new gas engines manufactured by Otto.

The installation attracted a good deal of attention, as it was situated

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at one of the busiest spots in Berlin, and it was not long before orders were received for equipment for lighting the Berlin railway stations, the Houses of Parliament, the Royal Palaces, large office blocks and individual factories. Each separate installation was furnished with its own generating plant, which was usually driven by a gas engine. By present-day standards the technical fittings and, in particular, the wiring were exceedingly primitive. Switchgear was almost non-existent, likewise measuring instruments, and the voltage was adjusted in terms of revolutions of the generating set and judged by the brightness of the lamps.

To make them burn steadily was at first a matter of considerable difficulty. The carbons, which up till then had been cut from retort carbon, were square in section. It was soon discovered that a carbon of round section was greatly superior as regards steadiness of burning. It therefore occurred to Siemens & Halske to grind the raw material, and after mixing it to a paste, to press it into round rods and fire it. Since the premises in Markgrafenstrasse were unsuitable for work of this kind, Gebr. Siemens & Co. in Charlottenburg were instructed to erect the necessary plant on their land; attention was given, in particular, to the building of suitable furnaces, and in spite of great initial difficulties, the manufacture of arc lamp carbons was commenced with great zeal under the direction of the Engineer, Mr. Viertel. It was Hermann Viertel who conceived the idea of assisting the steady burning of the arc by boring a hole lengthwise through the carbon and introducing a filling of the nature of waterglass; thus originated the cored carbon which proved to be the starting point of an exceedingly fruitful development.

In 1879 the city of Berlin held a trade fair, in the grounds of which Siemens & Halske built a small railway having the dimensions of a good-sized toy. The total length of track was approximately 300 metres, the gauge half a metre, i. e., about one third of that of a standard gauge railway. Five to six small open cars with lengthwise seats, from which the passengers' legs dangled almost to the ground, were drawn by a miniature electric locomotive, on which the driver sat astride. The locomotive was equipped with a three horse-power motor, from which power was transmitted to the driving wheel through a reversing gear (for changing the direction of travel). The motor was supplied with continuous current at 130 volts through an iron bar laid on a special longitudinal sleeper between the rails, whilst the return circuit was completed by way of the rails. Given dry weather—on wet days the railway did not run in any case—the insulation thus achieved between the outward and return circuits was sufficient. This was the world's first electric railway.

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Werner Siemens evinced a boundless enthusiasm for the idea of the electric railway. As many as twelve years previously he had spoken occasionally of the "electric carriage" which he intended to build very shortly. Now that this small-scale demonstration had proved successful and had taken the popular fancy, he desired to experiment on a larger scale. He procured a licence to operate a public tramway between Lichterfelde Station (Anhalt Railway) and the Main Military Academy in the town. The tramway had its own track, and as the intention was to use it as a pattern for the Berlin elevated railway, a scheme which was already in preparation, it was considered adequate to use the insulated rails to carry the feeder and return current, especially as the working voltage did not exceed 180 volts. The tramcar was of the same type as those hitherto used for horse-drawn trams; the underframe carried a motor with a rope drive to the main axle of the car, and electric reversing gear. Siemens & Halske opened this line in 1881 for their own account, and were able over a period of several years to gather their own experience in its operation.

Soon after the machines of Gramme and Hefner-Alteneck had become known, engineering circles in the United States of America began to turn their attention to the question of electric light. William Wallace, a smelter of Connecticut, was the first in the United States to build a dynamo, which it was his intention to use in electrochemical processes at his works. At the same time he also commenced to make arc lamps for lighting his premises. Thus inspired, others commenced to build dynamos, amongst them Charles Brush, who in 1878 originated a rather peculiar type, which was to be much used in the years to come. As in Europe, individual installations came into existence for lighting railway stations, factories and public squares. Presently, this new and promising group of activities became an object of speculation.

A number of observers in the United States, foremost among them lecturers on physics and technical sciences at the universities, were of the opinion that the arc lamp could not be the final solution in the use of electric current for lighting. Again and again a comparison was made with gas lighting, which furnished a small and comparatively economical illuminant for each individual house. The well-known inventor Edison had also expressed himself along similar lines.

Edison's idea was to produce a lamp with a wire-like conductor which would be heated to the point of incandescence by the electric current. This was a problem on which all manner of people had been concentrating for some considerable time, and it had come to be recognized that the wire could not glow in the air, as it would soon be consumed by

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reason of the oxygen. Either the wire would have to be surrounded by a chemically inert gas, such as Nitrogen, or—simplest of all—enclosed in a vacuum. Twenty years previously, an immigrant clockmaker from Germany, by the name of Goebel, had introduced platinum wires into a barometer at a point above the mercury and had brought them to incandescence by means of the current of a galvanic battery. He had used a number of these lamps to illuminate his shop-window in New York, and had thereby obtained a certain amount of publicity, but the device had meanwhile been completely forgotten. Edison also commenced by experimenting with platinum, but did not get very far as he had to remain below the melting point of the metal, which was 1715°C, too low for the production of an economic light.

Thus he and his assistants—the number of which had soon grown to more than forty—again returned to carbon, to face the task of enclosing a thin filament of chemically pure carbon in an evacuated glass vessel. To produce this filament, some organic substance had to be carbonized under vacuum in such a manner that the resulting product possessed sufficient mechanical strength to withstand the process of transference to the glass vessel without breakage. All the materials imaginable were tried out in turn, and Edison must have been driven by a kind of frenzy to carry on as untiringly as he did with his endless search, rather than abandon it as hopeless. At length he succeeded in preparing a bow-shaped filament made from paper pulp, which burned for about forty hours in a vacuum. In the course of further experiments he hit upon bamboo fibre, and, since plants belonging to the Bamboo family are indigenous to numerous parts of the tropics, he despatched—in truly American fashion—expeditions to India, China, Central and South America to look for the type of material best suited to his purpose. Finally, it transpired that a Japanese variety was the most promising, and long-term contracts were therefore made with local plantation owners to secure the supply of raw materials for large-scale manufacture.

Hand in hand with the endeavour to produce the incandescent lamp, consideration was being given to the provision of suitable accessories and to the overall arrangement of the installation. Assuming that it was required to be able to install a lamp at any desired point and replace it in the event of failure by a new one, all lamps would have to be made for the same voltage; on the other hand, this voltage would also have to be available at every point where a lamp might be required. Each lamp would then bridge over, as it were, the difference in electric potential between two main conductors, in the same way as the rungs of a ladder span the distance between the uprights. This parallel connection of all

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consuming apparatus across a constant potential is to-day a matter of course, but it was not so then. Edison was more or less forced by circumstances to adopt this arrangement, as, unlike his predecessors, he was planning to operate many, in fact, a very large number of individual lamps independently of each other. He found the most suitable supply voltage, expressed in present-day units, to be 110 volts. It was high enough to keep current and cross-section of the conductors within limits which were considered acceptable, whilst it represented the limit up to which he could make his bamboo filament.

To enable the lamps to be exchanged easily, they were furnished with a new screw cap with the well-known Edison thread, by means of which they were screwed into a corresponding socket. The sockets were provided with a tap-type switch after the pattern of the gas tap, by means of which the light could be switched on and off as desired. Lamps installed at a height could be controlled from a small switch on the wall. Edison was assisted in the development of these parts by a collaborator of earlier days, a German by the name of Sigmund Bergmann, who had meanwhile settled in America and started a factory of his own, in which he manufactured the accessories for the new lamp. Edison joined his friend as a partner in the business.

In Edison's laboratory at Menlo Park, attempts had been made to keep the work on the incandescent lamp as secret as possible, the more so, as the first patent applications at once encountered opposition. But the number of assistants had meanwhile grown to more than one hundred, and pressmen were so inquisitive that in the course of time quite a lot of information had leaked out. Edison therefore resolved to invite the entire Press and other interested parties to Menlo Park on New Years Day 1879, in order to demonstrate to them what had so far been achieved. Up to that point he had incurred in experimental work an outlay of 45,000 Dollars, but added immediately that this was by no means the end.

Eighteen months later, the first Electrotechnical Congress met in Paris, in which scientists from all over the world came together for the purpose of agreeing on an international system of electrical measurements. Units were agreed, which had hitherto been derived from the so-called absolute system of measurements familiar to physicists. Above all, the three basic units of potential, current and resistance were laid down, and called after the names of meritorious researchers. In so doing, the hitherto commonly used unit of resistance introduced by Werner Siemens was dropped in favour of the Ohm, having regard to the latter's close connection with the other two units. But the originator of the Siemens

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Unit had the satisfaction of seeing his method of reproducing the resistance unit adopted by the Congress without alteration.

The Congress was made the occasion for holding an International Electrotechnical Exhibition. In addition to their telegraph and block signalling equipment, Siemens & Halske had on view several continuous and alternating current dynamos, as well as various types of the differential arc lamp, steel-melting in a small electric furnace in which an arc burned between an adjustable carbon electrode and a graphite crucible placed beneath it; the Firm had also installed an electric railway, which plied between the Place de la Concorde and the Exhibition. Current was fed through a conductor encased in a slotted tube, arranged above rail level and collected by a contact shoe. This was, of course, not a complete solution of the current feed, since neither points nor crossings were possible with such a system, but it at least enabled electric traction to be shown.

The greatest attraction to Exhibition visitors, however, was the illumination of the buildings by incandescent electric lamps introduced from America, and demonstrated now in Europe for the first time by the Compagnie Continentale Edison in Paris. It must be confessed that Werner Siemens and those around him regarded the innovation with some scepticism; possibly they may have been somewhat irritated by the extravagant publicity in the American Press for the inventor Edison. To the layman it might appear as if Edison had "invented Electricity." There was another visitor to the Exhibition, however, who was well acquainted with Werner Siemens and the capacity of his Firm, holding both in high esteem, and who was greatly impressed with Edison's achievement. Wide prospects affecting the economy of the future opened up before his eyes. He was a mechanical engineer by profession and had not had anything to do with electricity hitherto; what he saw in Paris awakened in him the resolve to give careful study to the possibilities inherent in the incandescent electric lamp.

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VI.

THE STRUGGLE FOR LEADERSHIP

At the time he began to take an interest in incandescent electric lighting at the Paris Exhibition, Emil Rathenau was 42 years old.

He was quick to accept the American conviction, voiced in particular by Edison himself, that the incandescent electric lamp was destined to take the place of gas as illuminant in every house, office, factory and warehouse. To this end it was necessary to erect large, centrally-placed generating stations in the towns after the pattern of the gas works, to provide extensive distribution networks in line with the public thoroughfares and squares and then to sell the electric supply to consumers at a fixed charge. It would, of course, be necessary to obtain a licence from the local Authorities, and would involve a large expenditure of capital which would exceed the means of the ordinary person. It therefore amounted to finding financiers who were prepared to advance money for such schemes.

These hesitated at first. Werner Siemens and his Firm, who were regarded as the supreme authority in all matters concerning electricity, had not expressed themselves too favourably in the matter of the incandescent electric lamp. In this they seemed to have the same experience as with the telephone, which had shortly before been introduced into Germany from America. An enormous American publicity campaign in the Press was not taken seriously to begin with; however, as the first consignments of telephones arrived and proved their value with such startling effect, the popular humour suddenly changed to one of wild enthusiasm, fanned by a Press which made up in boundless optimism what it lacked in scientific knowledge. Numbers of people began to busy themselves with the new possibilities; one heard of workshops which were to concern themselves exclusively with electrical manufacture, covering dynamos, arc lamps and telephones—all in accordance with their own inventions, of course—and were on the look-out for capital. Little they knew of the countless difficulties which the original engineers had had to surmount in order to reach the point

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where they now stood. These engineers could with difficulty suppress their annoyance at the swarms which now seemed to have been released to gather in the harvest of their wearisome labours. Not only that, but the ignorance of these folk was accompanied by the danger that by their activities they would bring discredit upon all that had been built up with such endless effort. People were warned to take note of the situation in England, where a similar movement had degenerated into a gigantic fraud, involving the public in acute losses, with the result that in 1881 a sharp Act of Parliament—the so-called Lighting Act—was passed, the effect of which, incidentally, proved to be highly unfortunate for the electrical industry in England. It was as the result of all this that as far as Siemens & Halske were concerned, the new American achievements were met with scepticism.

In spite of these difficulties, Rathenau had ultimately been successful in awakening interest in his plans on the part of the Jacob Landau Bank in Berlin and the Gebr. Sulzbach Bank in Frankfort, who were then joined by the Nationalbank für Deutschland. Together with these banks, he founded a Company in the summer of 1882 for the purpose of studying the operation of electric lighting with incandescent lamps in a number of large-scale installations, and of gaining experience. He himself contributed a share of the working capital. An early opportunity of staging a demonstration of this kind presented itself at the Electrotechnical Exhibition in Munich in 1882, and the results of the extensive installation were very well received. The Manager of The Royal Residence Theatre in Munich, von Perfall, was so pleased with what he had seen that he replied to Rathenau's suggestion for the electric lighting of the theatre out of hand with: "Carry out the job at your own risk; if it's a success, I'll keep it, otherwise it's just too bad for you." The Manager kept the installation, and his example was soon followed by others.

Edison had assigned the exploitation of his European patents, not only those covering the manufacture of the electric lamp, but also the details of a current distribution system and designs for installation materials, to a Company founded in Paris for the purpose, viz., the Compagnie Continentale Edison. As a matter of fact, these patents had been vigorously opposed from the outset, but it had not appeared to Rathenau to be advisable to be drawn into these confused legal battles; he preferred to operate under licence from Edison, profiting by the latter's experience, a course which had the complete approval of his backers. Another query bearing on his plans for the future was his relationship to Siemens & Halske. It appeared hopeless to launch a new undertaking with an inherent bias against the Firm of Siemens & Halske, which for all

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practical purposes exercised a scientific and technical monopoly, at least in Germany. In negotiating with Werner Siemens and his deputy, the engineer Lent, Rathenau therefore proposed that in converting his Exploration Company into a regular manufacturing concern he would work hand in hand with Siemens & Halske. His part would be to procure contracts from the municipalities for lighting, for which he would erect and operate the necessary plant. The equipment, in particular the electrical machinery, cables and installation material, he was prepared to purchase from Siemens & Halske at fixed prices, with the exception of the incandescent lamps. These he wished to manufacture himself, as he was under obligation to operate the Edison patents. Siemens & Halske had meanwhile commenced the experimental manufacture of incandescent lamps according to a process suggested by Swan in England.

Rathenau's proposals were approximately the same as those which had been under discussion between Werner Siemens and his Assistants for some time past. From the time that electric lighting had emerged from the stage of tentative experiments and had begun to gain economic significance, Siemens & Halske had received an increasing number of suggestions and invitations to take up the supply of lighting installations. But it was only in exceptional cases that the interested parties were prepared to purchase and operate the installation themselves; in the majority of cases, their proposals amounted to the provision by Siemens & Halske of the equipment at their own expense, and to charge for the electricity consumed at an agreed tariff. Now, it was hardly practicable for Siemens & Halske to concern themselves with undertakings of this nature, unless they were prepared to see their staff and capital frittered away, and endless complications introduced into their accounts. The only acceptable expedient would have been to form a separate operating company, organized along lines specially designed to handle this type of business. For a time this idea received serious consideration, but negotiations already on foot in this direction again broke down and Werner Siemens finally lost taste for plans of this kind. He was now in his sixty-sixth year and had had enough of new flotations.

In view of this frame of mind, Rathenau's proposals would appear to have been well timed. Why shouldn't he (Rathenau) try his luck? If the scheme proved successful, Siemens & Halske would have a regular customer for their machines and apparatus without incurring any financial risk whatever. If the scheme didn't work—well, in the words of Herr von Perfall: "It's just too bad for you."

Thus it came about that on the 13th March, 1883 an agreement was

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signed by Siemens & Halske and Rathenau, with provision for its adoption by the Company which the latter was yet to form. In accordance with the agreement, Siemens & Halske renounced the right to solicit lighting contracts, undertaking, in fact, to pass on any offers of such business to Rathenau, whilst Rathenau undertook to purchase the whole of the equipment required for such installations from Siemens & Halske, with the exception of the incandescent lamps. Armed with this Agreement, Rathenau had no difficulty in attracting the necessary capital, and on the 19th April, 1883 he converted the Exploration Company into the "Deutsche Edisongesellschaft für angewandte Elektricität" ("German Edison Company for Applied Electricity"), with a share capital of five million Marks, which for those days in Germany was very considerable.

Conditions in the Siemens & Halske workshops in Markgrafenstrasse had again become intolerable. As long ago as December 1881, i. e., before the launching of the Deutsche Edison Co., in order to avoid having to pay royalties to Edison, Siemens & Halske had tentatively commenced the manufacture of electric lamps by the process of the Swan United Electric Light Co., which exploited the method proposed by Swan in England about the same time as Edison had developed his in America. Consequent on the chronic overcrowding at Markgrafenstrasse, the manufacture of electric lamps had been temporarily consigned to a room under the hay-loft of the packing department. It was possibly due to these uncongenial working conditions that results were unsatisfactory and that in consequence, shortly before the founding of the Deutsche Edison Co., a decision was taken to acquire a licence from the Compagnie Continentale to manufacture incandescent electric lamps under the Edison patents. Production was also to be undertaken on a larger scale and with more suitable equipment. As this was impossible in the Markgrafenstrasse premises, the only other solution was to remove to the Charlottenburg Works of Gebr. Siemens & Co. The manufacture of cables had meanwhile expanded very considerably in consequence of the development of the national telegraph network; of the Firm's total turnover, which had bounded up in 1880 to 6,350,000 Marks, approximately four millions were on account of cable orders. And now power cables were claiming a share of the output of the winding, spinning and stranding machines. With the increasing numbers of electrical installations, the conviction had gradually asserted itself that the existing primitive methods of wiring, hitherto so much in favour, must give place to something more substantial; wiring installed in engine rooms and public streets was now required to be insulated and protected against mechanical damage, as far as possible by laying it underground.

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In doing so, the discovery was made that the guttapercha insulation hitherto used for telegraph cables was quite unsuitable for power cables. Guttapercha is very sensitive to heat; its otherwise excellent properties began to deteriorate appreciably at temperatures above 30° C. But power cables, as opposed to telephone and telegraph cables, frequently became warm in operation, partly due to the heating effect of the current at higher loads and partly due to the heat radiated in engine rooms from the steam plant. In the search for other means of insulation, the Manager of the Siemens Cable Works conceived the idea of utilizing as insulation the fibrous material which had hitherto been employed as packing between the guttapercha and the wire armouring, by impregnating it with a mixture of insulating fluids such as bitumen, turpentine and paraffin. Acting on a suggestion by Werner Siemens, the materials were impregnated under vacuum, in order to ensure the expulsion of any residual air or moisture. With a view to preventing the evaporation of the impregnation and re-entry of moisture, the cable cores were encased in a seamless lead sheath; this process followed the pattern of the method of seamless enclosure of copper conductors in guttapercha proposed by Werner Siemens in 1847. The lead sheath of the cable was given a further covering of jute fibres and overall armour protection which, unless special tensile strength were called for, consisted of two layers of strip iron wound spirally round the cable. This type of construction was protected by several patents taken out in the early 'eighties, and was known as "Patent Lead Cable."

The continued expansion of the power current business had now reached a point where, with the best will, the demands on floor space at Markgrafenstrasse could no longer be met. If, as was to be expected, the Agreement with the Deutsche Edison Co. was soon to be followed by considerable orders for dynamos, cables and other accessories, a solution had to be found, and quickly.

This was done just in the nick of time. In the immediate neighbourhood of Gebr. Siemens & Co., Charlottenburg, the engineering firm of Freund & Co. owned a piece of land and buildings, comprising Nos. 11 and 12, Salzufer, which Siemens & Halske were able to acquire in 1889. Including the factory buildings, the purchase price was 650,000 Marks. The first step, therefore, was the transfer to these works of the manufacture of the Edison-type dynamos, the supply of which the Deutsche Edison Co. had made a condition of contract, to be followed by the remaining dynamos and, after a further brief period, the whole of the cable production. Four years after this initial land purchase, Siemens & Halske were able to acquire from a farmer the vacant piece of

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land, Nos. 13 and 14, Salzufer, adjoining the plot originally bought from Freund. The remainder of the power current departments hereupon removed to Charlottenburg, where power current manufacturing was now able to begin an independent existence, under the management of von Hefner-Alteneck, in what came to be known as the "Charlottenburg Works," whilst from now on the workshops in Markgrafenstrasse was called the "Berlin Works."

The Deutsche Edison Co. had commenced its activities by supplying a few small lighting installations, such as had already been carried out by Siemens & Halske and others; amongst the first installations of the new Company were the lighting of the Union Club in Wilhelmstrasse and the "Ressource" in Schadowstrasse. They then advanced a step further, and succeeded in interesting groups of consumers occupying the same block of buildings, which rendered it possible to arrange for the current supply without touching the public streets. The most familiar example was a block situated between Unter-den-Linden and Friedrichstrasse, of which Café Bauer was the chief consumer. In dealing with these lighting contracts, Rathenau experienced in full measure the joys and sorrows of the current supplier. Despite the difficulties attending the installation and operation of steam plants in the heart of the most densely populated area in the city, he was determined from the outset to avoid the use of gas engines as prime movers for his generators, saying, quite logically, that in endeavouring to replace gas-lighting by something better, he must avoid the use of gas in doing so. However, these small steam plants proved to be most uneconomical, added to which there was constant friction with the Authorities in connection with the bye-laws concerning the operation of steam boilers. A check of the results of the first few months' working showed that the income from the sale of current barely covered the cost of fuel, not to speak of the remuneration of the Staff, overhead charges and a reasonable provision for interest and amortisation of the capital. In addition, there were claims for damages on the part of Café-lessees for losses incurred when failure of the lights resulted in an angry stampede of the guests, many of whom would forget to pay. It was an enterprise which offered no scope, and expansion was possible only by generating current on a large scale for a large number of consumers, as had been recommended by Edison from the outset. From the experience thus gained, Rathenau realized that a large-scale experiment of this kind could only be made in Berlin. Here he was at home and familiar with the psychological atmosphere; here he could keep the object of his experiment under continual observation, which was an obvious condition of success.

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After lengthy negotiations with the Berlin Municipality, an agreement between the Corporation and the Deutsche Edison Co. was finally signed in May 1884. This conferred upon the latter the sole right to the use of the public thoroughfares within a certain specified area of the city for the distribution of electric current and to the sale of current to all and sundry at fixed prices. On the 8th May, 1884 the " Aktiengesellschaft Städtische Elektrizitätswerke" (Municipal Electricity Works Ltd.) came into being with a capital of three million Marks, half of which was taken over by the Deutsche Edison Co.

The initial current supply was to be taken from a power station in Markgrafenstrasse, which was completed and put into service in the following year. In view of the high price of land, the station was designed as a two-storey building. To conform with the Police Regulations, the boilers were on the upper floor and the machines on the lower. These comprised twelve dynamos of the Edison type, belt-driven in pairs by six vertical steam engines. The total output of the generating plant was 540 kW, which would correspond to a driving power of the steam engines of about 900 horsepower.

At that time electrical engineers had not yet learnt to operate a large network as a unit, into which current was fed from numerous generating stations, and from which it was supplied to all consumers. It was not very long ago that one generator had been used to feed a single arc lamp, and although some progress had been made in the meantime and the Edison distribution system was explicitly based on parallel connection of the lamps, it was still the custom to keep the arc lamps electrically separate from the incandescent lamps and to operate the former in a large number of separate circuits in order to confine possible disturbances within as close limits as possible, especially as parallel operation of the generators as yet constituted a serious difficulty. Thus, there was the strange sight in those days of power stations comprising a large number of small, high-speed generators driven by slower, but still comparatively fast-running steam engines with flapping belts, purring like spinning wheels, while a bluish-green line of sparks under the commutator brushes showed that the " dynamo was producing current."

To the professional mechanical engineer, and thus to Rathenau, this sight was an abomination. As he correctly maintained, based on his own sound knowledge of engineering, economically operating steam engines must be large, slow-speed units with gradual expansion of the steam in several consecutive cylinders and subsequent condensation by cooling water, equipped with precision valve gear, preferably of the Corliss type recently introduced from America, and reliably controlled by a

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governor. The dynamo must be adapted accordingly; what was required, therefore, was large slow-speed dynamos for direct coupling with the steam engine, not these small, "purring spinning wheels" with bearings eternally overheating due to the belt-pull. But it was impossible to make the electrical people understand, as they were not mechanical engineers.

Indeed, in its early days, Rathenau did not derive much satisfaction from the Berlin Municipal Electricity Works at all. The chief consumer was the Royal Play House at Gendarmenmarkt, which only required current during performances, but then in such bulk that the supply to other consumers had to be cut, a state of affairs which was quite out of the question as a permanency. All kinds of breakdowns were daily occurrences; experience had to be gathered the hard way: minding the generating plant, supervision of the electrical network, the rapid clearance of faults, for all of which there was at first no trained staff. The responsible director, who had been forced on him by the banks, was an ex-civil servant, a timid bureaucrat with no confidence either in himself or in the future of the undertaking. At times, Rathenau himself was in danger of losing his courage.

But in other respects, too, the Deutsche Edison Co. had to contend with considerable difficulties, although the manufacture of incandescent lamps, commenced in 1885, had developed quite satisfactorily. Apart from those consumers who were connected to the still very limited municipal supply system, there were two groups of potential customers, viz., those who already possessed a lighting installation, and those who were anxious to have one. The latter had gradually come to be the larger and more important group. To satisfy them simply by selling them an installation was against the Agreement with Siemens & Halske, and since this Firm could not keep up with the surging demand, the business was lost to outsiders. Meanwhile, the technical staff of the Deutsche Edison Co. was growing, and it was their duty to learn from the experience gained in Berlin and to break new ground. This body of men, with Rathenau at their head, had formed their own ideas about the planning and operation of electrical installations, but could make little headway as long as they were unable to convince the Siemens & Halske engineers of the correctness of their views. Psychologically, it is easy to see how difficult it was for the Deutsche Edison men to prevail against their senior professional colleagues of Siemens & Halske; an attitude of superiority and feelings of jealousy on both sides rendered collaboration exceedingly difficult.

At the Berlin Municipal Electricity Works, matters had meanwhile reached a crisis. The Municipality was under pressure from public

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opinion to extend the still very limited area of electricity supply, and plans and suggestions were being submitted in increasing numbers by people who imagined themselves as capable as Rathenau or more so. Fierce battles were being fought backstage. Siemens & Halske had also become involved, as at the suggestion of Lent, who had risen to be Head of the department dealing with Electricity Works business, they had submitted an offer to the Municipality to operate the electricity undertaking for the city in the event of the city wishing to purchase it, as it was being urged to do. In this dangerous situation Rathenau acted immediately. He bought up the whole of the shares of the Municipal Electricity Works on the open market, to the tune of 1½ million Marks, on behalf of the Deutsche Edison Co. and, having succeeded in persuading the Municipality to drop the idea of purchasing the Electricity Works, founded a new company in 1888, the "Berliner Elektrizitätswerke A. G.," to take the place of the hitherto existing undertaking. The new company covered a much larger territory and had a working capital of six million Marks. In addition to Rathenau, the Board of Management comprised Felix Deutsch and an old colleague from the Deutsche Edison Co., Oscar von Miller—who replaced the inefficient and meanwhile indemnified director. In 1886 he already had another power station in Mauerstrasse with a capacity of 285 kW, and now a third was being built in Spandauerstrasse with an output of 1,700 kW. By this time he was getting the kind of machines he wanted.

Von Hefner-Alteneck had taken Rathenau's criticisms of existing electrical machinery to heart. Together with Karl Hoffmann, who had commenced work with Siemens as a turner, and had worked himself up by dint of his exceptional talent to be a first-class designer, he created a slow-speed continuous current dynamo suitable for direct coupling to a steam engine.

This "internal pole machine" was bold in conception and difficult to manufacture; it could only be produced in a shop with sound experience of precision manufacture at its command. But it was the first to solve the problem of the large dynamo, and while resulting in radical changes in power station design, was one of the material factors contributing to the expansion of public electricity supply. Its advent was the saving of the "Berlin Electricity Works," technically and thus also commercially. In the decade dominated by the successful design, Siemens & Halske supplied more than five hundred of these machines, which were usually of quite large size, and in consequence of their manufacture the Charlottenburg Works underwent considerable expansion, both as regards area and numbers employed.

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Notwithstanding the favourable development of the Berlin Electricity Works, Rathenau had other worries. In buying up the shares of the electricity undertaking, the Deutsche Edison Co. had overstrained their resources, and were, for the time being, not in a position to finance the extensions due to be carried out under the new licence. Moreover, the ties binding them to the Compagnie Continentale Edison were felt to be irksome. The Edison patents did not hold what they promised. The legal proceedings jointly undertaken by Siemens & Halske and the Deutsche Edison Co. in defence of the incandescent lamp patent in Germany had, after a bitter struggle of several years duration, been brought to a formally successful conclusion. A decision of the Supreme Court, however, had limited the scope of the patent to such an extent that it covered only one definite process of manufacturing the carbon filament lamp, and could thus be circumvented with ease by a different process. The consequence was that several factories now started to manufacture carbon filament lamps in Germany, competition which could only be met by raising the lamp production of the associated firms to the highest pitch of efficiency. As for the remaining Edison patents, the position was similar: they were more or less worthless, since they offered no adequate protection, but cost large sums in renewal fees which had to be paid to the Paris Company. The satisfaction of all these demands called for money, a great deal of money, and this was not forthcoming as long as there was no settlement of the differences with Siemens & Halske.

At the commencement of the winter of 1886, Rathenau therefore opened negotiations with Siemens & Halske with the object of withdrawing from the Agreement of 2½ years ago. At first, Werner Siemens rejected this proposition energetically, suggesting that the difficulties —which were undeniable—could be solved most easily by Rathenau's adherence to the original agreement. Meanwhile, however, Rathenau had gained the support of men of considerable influence. Henry Villard, the well-known American railway magnate, appeared as Edison's representative. On the other hand, Villard was on intimate terms with Georg Siemens, as a Director of the Deutsche Bank, who in this way was drawn into the discussions. The result was that the son of the former Partner in Siemens & Halske, who had earlier acted as Secretary to the firm in Persia and London, convinced his cousin that it was preferable to come to an agreement with Rathenau, and to endeavour by capital investment to gain an influence in his undertakings.

Werner Siemens reluctantly gave his consent. In view of his years he was thinking of retiring, and was anxious that his sons should not have

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to take over an obscure tangle of affairs fraught with danger and strife. Siemens & Halske therefore undertook as a first step to release the Deutsche Edison Co.—which preferred for the time being to remain in the background—from its ties with the Paris company by purchasing the whole of the rights and claims of the Compagnie Continentale Edison in Germany for 800,000 Marks; of this sum the Deutsche Bank and the Deutsche Edison Co. refunded Siemens & Halske one third each. The Deutsche Edison Co. then went into voluntary liquidation and transferred its assets and liabilities to the " Allgemeine Elektricitätsgesellschaft," which had just been established with a capital of twelve million Marks, of which Siemens & Halske contributed one million. A new Agreement dated 23rd May, 1887 sealed the partnership and required the Allgemeine Elektricitätsgesellschaft to purchase all equipment for installations exceeding a total output of 100 h. p. from Siemens & Halske, and also all cables. Siemens & Halske, on their part, undertook to give the AEG the option of carrying out, or refusing, any lighting contracts of over 100 h. p. which might be offered to them. In all other respects the parties possessed freedom of action; the AEG was at liberty to manufacture, and Rathenau at once commenced to build a large factory for dynamos and motors. The Chairman of the Board of Directors, however, was Georg Siemens.

From the time that the first power stations commenced to operate, the question of how to measure and charge the electricity supplied to customers had been a burning problem. At first, an attempt was made to charge up lamp hours, but the method was too primitive, as it depended entirely on the honesty of the consumer. An apparatus had thus to be found which was able to measure the electricity supplied. In the case of continuous current, the electric power supplied to the consumer is equal to the product of current, voltage and time, and since the electrical quantities, in particular the current, can vary, the process of measurement must be imagined as being the addition by the apparatus of a sequence of individual measurements, each over a sufficiently short period of time.

Amongst the large number of proposals and experimental apparatus produced by inventors was one suggested in 1884 by Aron in Berlin, which appeared to be the most serviceable; it was quickly adopted at the Berlin Electricity Works and within a few years came to be widely used. Aron fitted a clock pendulum with a magnetised steel weight and caused it to swing above a coil, the axis of which coincided with the zero position of the pendulum. The coil was in circuit with the current to be metered and brought about an acceleration of the pendulum

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which was proportional to the current and additional to that of gravity. This reduced the period of oscillation of the pendulum, as compared with that of a second pendulum of equal length but without a coil, which was mounted beside the first. The difference in the number of beats of the two pendulums was registered by a counter.

Besides meters, it was essential to have measuring instruments at the generators and distribution points to indicate the prevailing values of voltage and current, and it was Siemens & Halske who were first in the field with suitable types. Instruments developed from the original galvanometer with freely oscillating magnet, the so-called Bussole or compass types, were useless in power current installations, owing to the interference of the strong magnetic fields set up by the conductors assembled in the switchboard, which rendered anything in the nature of an accurate measurement impossible. Frölich, of Siemens & Halske, however, had recourse to an idea which had been suggested by Wilhelm Weber as long ago as 1841. A rotatable coil is mounted within a stationary coil in such a way that, when at rest, the axes of the two coils coincide. If the same current is made to flow through both coils, the movable coil is deflected from its zero position by a force which is equal to the square of the current. If the rotatable coil is turned back into its zero position against the power of a spiral spring, the replacement angle is a measure of the current. These instruments, known as "Torsion Dynamometers" could be built as ammeters, voltmeters or wattmeters, depending on how they were to be connected in the circuit, and in view of their accuracy soon came to be widely used. Later, a need was felt to be able to read off the values of the current, etc. from a continuously indicating pointer instead of first having to carry out a manipulation. The stationary coils therefore began to be replaced by the field of a steel magnet, within which the moving coil with pointer was free to rotate in opposition to the torque of a spring. For measurements in which a lesser degree of accuracy was sufficient, an instrument was designed in which an iron core was drawn into the interior of a stationary coil against the pull of a spring, and the movement transmitted to the pointer by a system of levers. Thus there emerged alongside the large electrical manufacturers, frequently with its roots in the University workshops, an independent industry of electrical instrument-makers.

Besides Siemens & Halske and the rapidly expanding AEG, there was a third firm in Germany which in the space of 15 years had grown from almost insignificant beginnings. Sigmund Schuckert had learnt his trade as a mechanic in his native town of Nuremberg, and had then started out in accordance with existing custom as a journeyman. In the course of his tra-

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vels he had also worked for a time in 1866 in the Siemens & Halske shops in Berlin. Finally, he landed in the United States and was employed by Edison in Newark. He had not been at all averse to settling in America altogether, and had only returned to Nuremberg in 1873 for the purpose of finally striking his tents. Family affairs caused him to remain, however, and in August of that year he opened a small workshop in the "Schwabenmühle" on the Pegnitz, where he repaired sewing machines and made electrical apparatus of all sorts. He soon came to be known for his quick grasp of essentials and skilled workmanship, and the small business prospered rapidly, so that in 1878 he was forced to move into larger premises in Schlossäckerstrasse, which again had to be extended after a short time. He was now making dynamos which were fundamentally based on the Gramme design, but superior to these by reason of an improved type of ring armature which economised material. He also built switchgear of all kinds, arc lamps of his own design and, above all, searchlights. The parabolic mirrors of these he ground and polished by a process jointly patented by himself and a certain Professor Munker in Nuremberg. As regards parabolic mirrors his workshop long had the reputation of being the finest in the world. As his representative for Central Germany, he had secured the services of Alexander Wacker, a very active and enterprising business man, who in 1884 came and settled in Nuremberg, became Schuckert's partner, and by his enterprise contributed greatly to the rapid expansion of the undertaking. Four years later Schuckert & Co. became a "Kommandit" Company with Schukkert, Wacker, Hugo Ritter von Maffei, the "Maschinenfabrik Augsburg-Nürnberg (M. A. N.)" and the "Schaffhausensche Bankverein" as shareholders and with a capital of more than two million Marks. At that time they turned over this capital approximately twice a year, and employed about five hundred hands.

Schuckert & Co. were probably also the first firm in Germany to realize the importance of the accumulator battery in connection with public lighting. In the first few years of public supply, it had been customary to close down the power stations at a certain hour in the evening, as it was too expensive to keep a machine running for the sake of the few lamps required. Tis was where the accummulator could be fitted in; in cases of breakdowns to the generators, too, it could be useful. In 1888 Schuckert & Co. therefore equipped the Barmen power station, which they had built, with an accumulator battery and thereby brought this innovation to the notice both of the engineering world and of the public.

The principle of the accumulator had been discovered by Planté as long ago as 1859. He immersed two lead plates in diluted sulphuric acid,

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and observed that when an electric current was passed through, the plate on the incoming side (anode) acquired a deposit of lead oxide. When after a period the current was switched off, the two now differently constituted plates had been converted into a galvanic element, capable of supplying current in the opposite direction. This condition continued until the original state of the plates was restored by re-formation.

However, in the state of technical development prevailing in those days, nobody was interested in the practical application of this principle. Then Faure demonstrated in 1881 that the process could be rendered much more efficient by making the anode in the form of a grid, and filling the spaces between the ribs at the outset with lead oxide. A few years later this idea was taken up by the Tudor brothers in Rosport, Luxemburg, considerably improved upon, and applied to the manufacture of accumulators on a large scale.

In Hagen (Westphalia) a certain Adolph Müller was in business as a heating engineer, trading as Büsche & Müller, when he happened to make the acquaintance of the Tudor brothers in Brussels. He decided to represent them in Germany, closed down his existing business and established a new Firm under the style of Müller & Einbeck, opening up with an unusually convincing advertising campaign to the effect that nothing that had been said against accumulators in power station service applied to the Tudor accumulator—that this was the accumulator of the future. Since this publicity roughly coincided in point of time with the movement initiated by Schuckert's action, it was a great success, and in the following year Müller acquired the Tudor patents for Germany and equipped a Works of his own in Hagen for the manufacture of these accumulators. Soon after, he was flooded with orders to an extent which completely overtaxed the capacity of the still comparatively small undertaking. Seeing this, Georg Siemens, Chairman of the Board of Directors of the AEG, approached Siemens & Halske through the Deutsche Bank, which he controlled, with a suggestion to participate jointly with the AEG and the Bank in a scheme for placing Müller & Einbeck on a broader basis. The result was a Partnership Agreement concluded between Siemens & Halske, the AEG and Müller & Einbeck in June 1890, in accordance with which Müller & Einbeck brought in their factory as their share in a new Company known as the "Akkumulatorenfabrik Aktiengesellschaft," in which the two other partners had a substantial interest. Müller became managing director, and the vigour with which he had hitherto conducted his advertising campaigns increased almost to the point of brutality in combating the competitors now commencing to appear in various quarters.

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Thus, in spite of many disappointments and reverses and the advent of powerful competitors, the penultimate decade of the century had witnessed a further vigorous expansion of Werner Siemens' untertaking, due chiefly to the rapid development of the electricity supply. Admittedly, this expansion was more or less confined to business in Germany; in the subsidiary Companies abroad the picture was not always so bright.

From the time that Karl left Russia to settle in London, in 1869, the existing stagnation had given place to indubitable retrogression. Practically the only customer for the Firm's telegraph products was the Government, who, having completed the equipment of the State telegraph network and the most important railway lines, did very little more for the improvement of communications. Notwithstanding this, a well-managed Branch of the size of the Petersburg Office should have been able to live on the income from general sales, had it not been for the fact that the Chmelewo Glass Manufactory, of unhappy memory, had meanwhile been converted into a porcelain factory, for the main purpose of supplying insulators and other porcelain accessories. Economically and financially it proved to be a worthy successor to the glass factory, showing as it did, for the period 1872—1880, an aggregate loss of 600,000 Roubles, thus swallowing up the greater part of the profits from the regular business of the Petersburg House. On returning from London to St. Petersburg in 1880, in order to take over anew the control of the Russian House, one of his first acts was to remove the cancerous growth by a decisive operation. His next step was to carry out a thorough reorganisation of the Concern, both financially and as regards the staff. He then purchased a sizable piece of land in the "sixth line," on which he commenced to build a factory for machines and apparatus, whilst on a second fairly extensive estate at the mouth of the Neva, which had been purchased a year earlier, Karl now erected a cable works. He had decided to risk these large investments, firstly because Russia had meanwhile raised the import duties on electrotechnical goods, in particular cables, to such an extent that supply from Germany was almost impossible, and secondly in view of assurances from Court Circles, to whom he was known from former times, on the strength of which he believed he could build up a business. Of course, the backward state of the Russian economy retarded the growth, but even so, the turnover in dynamos, apparatus, arc lamps, filament lamps and cables gradually assumed quite respectable proportions. Shortly after manufacture commenced, Siemens & Halske acquired a licence for the electric lighting of the city of St. Petersburg, and established a company known as the "Company for Electric Lighting of 1886." Three years previously they

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had already commenced with the electric lighting of individual thoroughfares, in which cases they had accommodated the small generating plants in iron barges on the Neva. In Moscow and Lodz they were also successful in obtaining lighting contracts, for which they were able tc build power stations of their own. The weak current side of the business also developed satisfactorily, particularly the railway section, so that at the end of the 'eighties Karl had reason to be satisfied with his ten years' activity.

For Austria-Hungary a branch had been established as early as 1858 in Vienna (Apostelgasse), mainly for the railway business. After six years of unsuccessful efforts to get business going, the Branch was closed down in 1864, mainly at Halske's instigation, and the Austrian business entrusted to an agent. In 1879, however, Werner Siemens decided, in view of the advent of power current business, to re-open the branch in Vienna at the same address as a "Technical Office," with a small factory attached. To begin with, considerable orders were received for railway signalling apparatus which had to be manufactured in Vienna owing to congestion in the Berlin Works. In consequence, the Vienna shops began to expand rapidly. They went on to smaller, then larger, lighting installations, took up the manufacture of dynamos, apparatus and arc lamps, until at the close of the 'eighties they were commencing the erection of three large public generating stations on their own account.

About that time, the Municipality of Vienna was particularly interested in the construction of a City Railway on the model of other Capitals. It was to be steam-operated, as was then the custom. Vigorously supported by Georg Siemens and his bank, Siemens & Halske introduced into the ensuing discussions the idea of electric traction, or the combination of a steam railway and electric feeder lines. As a result, the negotiations between the Authorities, the interested banks and the suppliers were prolonged over a number of years without reaching a conclusion. This was due, on the one hand, to the unconvincing state of technical development and, on the other, to the slowness of Austrian officialdom. Again and again, Siemens & Halske submitted new proposals and plans, many of which were latterly the work of an engineer (Regierungsbaumeister) by the name of Heinrich Schwieger, who had joined the Firm in 1885. Meanwhile, the Municipality of Budapest had begun to take an interest in the Vienna proceedings, and it was possibly due to a certain spirit of rivalry in the second Capital of the Dual Monarchy that Schwieger there found greater willingness to listen to his ideas. In the upshot, the Budapest Authorities placed an order for the equipment of an electric tramway system with underground current supply, the

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first section of which was in service in 1887, the whole being completed two years later.

This was followed in 1896 by the inauguration of an underground line in Budapest, in which current was fed to conductors mounted on the roof of the tunnel, and which could be regarded as a successful small-scale experimental model of the much larger and more difficult undertaking which was commenced about the same time in Berlin. These activities led to the formation of a "Department for Electric Traction" in Vienna, with Schwieger in charge, on the pattern of the department of the same name in Markgrafenstrasse. The two groups together, under common management, were the first example of a business department which was no longer just the sales department for a corresponding manufacturing group of the works, but a consulting department, with functions covering designing, planning and negotiating with customers, until it finally ordered from the Works the equipment required for the installations.

In France, following on the Franco-German war, there appeared, in view of the national antipathy to everything German, to be little prospect of business for a German firm. However, as it became evident towards the end of the 'seventies that a keen interest was being taken in electric lighting, it was thought in Berlin that the risk of establishing a Branch on French soil was justifiable. A certain measure of compulsion was exerted in this respect by French Patent Law, which stipulated that articles protected by French patents must be manufactured in France. With a view to keeping the German character of the establishment as far as possible in the background, it was launched from London by Siemens Bros.; the new Firm was accordingly styled Siemens Frères and it was planned that it should be managed from London. For a time there was talk of Karl moving to Paris, in order to superintend in person the equipment of the Works. A carefully planned and well-appointed Works was opened in Passy in 1879, and all the signs for its future operation appeared to be auspicious. But in 1880 Karl decided for other reasons to return to St. Petersburg; the management of the undertaking was placed in the hands of an employee in Paris, no one in London took any interest in it, and Berlin had trouble enough of its own. For the reasons already stated, moreover, Berlin was holding back as far as possible. To the Compagnie Continentale Edison, who were in possession of the whole of the patents concerning incandescent lamps, Siemens Frères had found no approach. The Edison Company was stated to have infringed the Siemens patents; they had been sued and had succeeded in prolonging the lawsuit for a number of years. And so there had been very little

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business done; the expenses soon exceeded the modest profits, whilst negotiations—latterly conducted in Berlin—with the object of inducing the Edison Company to take over the unfortunate Company, fell through. Weary of it all, Werner Siemens decided in 1886 to wind up the Company which had been floated with such high hopes. A considerable loss to Siemens & Halske and Siemens Brothers was the result.

A few years later, arising out of a feeling that it was wrong to abandon the French market entirely, a decision was taken to make a fresh effort in another direction. In connection with the construction of an electrical power station in Mulhouse (Alsace), Siemens & Halske had established friendly business relations with the Elsässische Maschinenbau-Gesellschaft, which was domiciled there. In 1889 the two Companies concluded an agreement covering the establishment of a Trading Company under the title "Société Alsacienne des constructions mécaniques (service électrique)" in Belfort. The business of the Company was the construction of power stations in France, above all, public supply stations, for which it would purchase the electrical machines and apparatus from Siemens & Halske, whilst the Elsässische Maschinenbauanstalt would itself supply the boilers and steam engines. At the same time, the two Partners, conjointly with Siemens Bros., London, founded the Société Alsacienne des constructions mécaniques (Usine de Belfort) with a capital of 900,000 francs to operate a cable works in Belfort. In this way, a modest but at least definite share of the French business seemed to have been secured.

In those years, however, Werner Siemens' greatest source of worry amongst the Branches of the House abroad was the once proud firm of Siemens Bros., London. Whoever had known this Firm in the early 'eighties, when it was laying the great Atlantic cables described in a previous chapter, and which, in the brilliance of its engineering feats, its commanding financial position and international reputation had almost eclipsed the parent Firm, would never have believed what a sad decline was in store for it. But as long ago as 1880 a gentle creaking might have been heard in the timbers. Karl Siemens, to whose energy the successful cable-laying had been mainly due, had lost interest in his work. He was annoyed at Loeffler, who was constantly endeavouring to push himself into the foreground as William's deputy; he often disliked the dubious practices of the circles with whom the financing of these large undertakings brought him into contact, and he was tired of always playing second fiddle to his elder brother, who, after all, had practically ceased to take any active part in directing the affairs of the Firm, and now devoted his time solely to his technical hobbies. He therefore declined

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the offer to take over the management of the newly formed Paris Branch, as he would again have been subordinate to London, i. e., to Loeffler, and decided to return to St. Petersburg, where he would be his own master.

Under these circumstances, and notwithstanding his dislike of Stock Exchange transactions, Werner Siemens assented to the proposal as shareholder, since it appeared to be the only way to achieve a clean separation between the Firm and William's private business, which was becoming increasingly involved as time went on. In December 1880, accordingly, Siemens Brothers & Co. Ltd. was registered with a share capital of £ 500,000. Since English Company Law specifies a minimum number of seven shareholders at the time of registration, it was decided, in addition to Werner and his two sons, Karl and his son and William, to allot to Loeffler 100 shares out of the total of 5,000, to give him a stake in the prosperity of the Company. Various clauses of the agreement between the new Company and Siemens & Halske were ambiguous, in particular those relating to working territory. Amongst other things it was stated that they desired to avoid competing with each other "as far as possible." Furthermore, in spite of all the earlier unhappy experience, there was no clear definition of "prime cost," at which one partner could purchase from the other. Werner Siemens had not considered it necessary to go into such exact detail in these matters, as he would always be able to smooth out any serious differences with his brother. But William died in 1883, and difficulties now arose with Loeffler. William's brothers, as his heirs, considered that they were acting as he would have wished, in offering Loeffler a further 1245 shares from William's inheritance. In addition, Loeffler bought up a number of shares which were owned by employees of the Firm, having done which he found himself in possession of nearly one third of the share capital and in a strong position as Director. In this capacity, he endeavoured to prevent Siemens & Halske from concluding contracts overseas, and even in European Countries such as Holland, claiming these to be within the territory of the English House. On the other hand, he did nothing to secure such business for himself, at any rate as far as power current installations were concerned, but considered it solely from the angle of the specialized cable manufacturer in its relation to cable orders, forgetting that the hey-day of cable-laying had meanwhile come to an end. Neither did he realize the possibilities inherent in power current engineering, since its exponents were to be found in Germany and the United States, but not in England. Little had therefore been done to develop these possibilities, and though Siemens Brothers had for years

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been considered to be the leading electrical engineering firm in England, the market in Britain and its Dependencies soon fell to American competitors. Moreover, the growing pressure of German competition was making itself felt in overseas business, independent of Siemens & Halske, in those very lines from which Loeffler in his jealousy was attempting to debar them. This state of affairs had gradually become intolerable, and cast a shadow of great bitterness over the closing years of Werner's business life.

Matters had reached such a point that Siemens & Halske resolved to consider the sale of Siemens Bros. and to entrust Loeffler with the preliminaries. But it proved impossible to find a buyer; the undertaking had been allowed to run down too far. After several fruitless attempts on Werner's part to win Loeffler's co-operation by friendly persuasion, Siemens & Halske brought an action against him in 1890. Realising that he would be the loser, Loeffler decided to resign his directorship. Alexander Siemens, a distant relative of the brothers, who had been with both Siemens & Halske and Siemens Bros. for a number of years, was entrusted with the task of restoring the business to health and prosperity.

Thus it happened that the last few years had brought the founder of the House of Siemens a crop of troubles, disappointments and reverses. The feeling that the development of the electrical industry, to a great extent the fruit of his own activities, had attained dimensions and a pace which appeared to threaten the commanding position of that which was really his life's work: the Firm of Siemens & Halske; the unedifying dispute with the AEG; the losses and failures in France; the hopeless relations with the English House and its decline: all this was not calculated to give him much pleasure in the day-to-day conduct of business. Several times already he had declared, usually as the result of annoyance, that he was not prepared to carry on any longer, and now his human body would remind him occasionally that he had crossed the boundary-line of the biblical age. In 1889, in his seventy-fourth year, he finally decided to hand over the control of affairs to others. In accordance with his very pronounced hereditary instincts, these successors could only be members of the family. Four years after the death of his first wife, he re-married, and of his second wife he records in his memoirs: "she has again brought warm sunshine into my rather darkened, toilsome life." By his second marriage he had two further children, so that, in addition to the two sons of his first marriage, Arnold and Wilhelm, there was a third son, Karl Friedrich, who at this time, however, was only in his eighteenth year and due in a short time to commence his studies.

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Before the business could be handed over, a few legal changes had to be effected in the structure of the Company. As from 1st January, 1890 the hitherto Private Trading Firm of Siemens & Halske was converted into a Company ("Kommanditgesellschaft") with a declared share capital of fourteen million Marks. Principals of the Firm and personally liable were Karl Siemens and Werner's sons Arnold and Wilhelm, whilst Werner remained a sleeping partner with a capital investment of 6,200,000 Marks. He naturally made it a condition that he should continue to be consulted in connection with all important decisions. He exchanged, as it were, the day-to-day management for a seat on the Board of Directors, since for anybody with a temperament such as his, it is impossible to sever at a stroke the connections he had himself built up. But his desire was to be free from the daily routine, and to gain perspective to review the balance sheet of his life.

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VII.

THE ALTERNATING CURRENT REVOLUTION

When Werner Siemens looked back over his life from the reflective seclusion of his Harzburg retreat, he could scarcely reproach himself with having been merely an inventor and a man of business, e. g., on the pattern of an Edison. Neither did he belong to that class of successful men, who pursue their own interests first, and later, having attained a state of esteem and wealth, remember that a certain amount of patronage is expected of them. His interest in matters of public concern already became evident at an early age. When at the beginning of the 'sixties he plunged into politics, he did so at the expense of his business, from which he not only alienated part of his energies, so that the resulting damage was almost immediately reflected in the suspension or failure of certain development work, but he also placed himself in opposition to the Powers-that-be, of whose material good-will he could not be quite independent. The possibilities inherent in such a situation had been demonstrated in the Nottebohm crisis. He withdrew, then, from active politics, because he was no longer willing to participate in the pursuit of petty interests as desired by his constituents. In seeking a substitute in some other form of public service, he threw his energies in the first place into work in connection with the revision of the Patent Laws.

Following on the foundation of the Reich, attention was turned to the question of a new Patent Law for the whole of Germany, and Werner Siemens took an active part in the debates which ensued. Whilst a majority of the Reichstag urged the passing of a comprehensive law, voices began to make themselves heard in the Bundesrat (Federal Council) under the influence of the Prussian Government—contrary to the attitude of almost all other industrial countries—calling for the abolition of patent protection, as being inimical to the freedom of economic life. This challenge was met by the formation, at Werner Siemens' instigation and in collaboration with the Institute of German Engineers, of a "Patent Protection Association." Thanks to the lively agitation

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of this body the resistance of the no-patent fraternity was broken and a Patent Law passed, which substantially covered all which Siemens had conceived as desirable. His object, as he had repeatedly stressed, was not so much the protection of the inventor and his interests, but of invention itself, since the creation and exploitation of as many inventions as possible is the surest way to encourage technical and industrial progress, and thus to raise the standard of living. The passing of the Patent Law was followed by the establishment of the Reichs Patent Office, of which Werner Siemens was appointed a member.

Now that the matter of Patent Law in Germany had been disposed of to the extent that it was no longer a burning question, Siemens turned his attention to a new task of public importance. From an early age he had been convinced that progress in the experimental sciences is dependent on the accuracy of the methods employed in measuring: hence his keen interest in all efforts to establish electrical standards which are reproducible. At the beginning of the 'eighties, therefore, he pondered the question of founding a state-controlled institute, which should be intermediate between a scientific standards bureau and a research institute. On the one hand, it would certify gauges and precision apparatus, and on the other, develop new methods of measuring, thus leading to the continual refinement of the art of scientific measurement. In this way, he believed, an independent state-supported institute could exert an educational influence on such sections of industry as were based on physical and technical foundations, and in this way contribute to the national well-being. Along with a few others he advocated this idea with great tenacity, and meeting with no response from the Prussian Government, he endeavoured to interest the Reich. With a view to imparting drive to the movement he declared himself willing in 1884 to make a personal contribution of half a million Marks, either in the form of land or in cash. His plan was strongly supported by Crown Prince Frederic, thanks to whose energetic intervention the ship, which had stranded on the reefs of the Bundesrat (Federal Council), was floated again. After long delays the Bundesrat, in consequence, voted the sum of 300,000 Marks as a first instalment for inclusion in the budget for 1887/88 and, as the Reichstag concurred, the creation of the Physikalisch-Technische Reichsanstalt (National Physical-Technical Institute) was achieved at last. It has become the model of similar institutes in other major countries.

Crown Prince Frederic, son-in-law of Queen Victoria, had a strong personal liking for Werner Siemens. Himself liberal-minded, he thought highly of this outstanding representative of the body of capable citizens,

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the importance of which for the future of the Nation he placed much higher than that of the old military aristocracy. If there was to be a nobility, then at least not one confined to a caste whose interests did not extend beyond Agriculture, the Army, the Civil Service, or attendance at Court, and which in consequence never ceased to provoke the scornful opposition of the intellectually independent Prince. His English brother-in-law had once told him of a conversation with Gambetta, in which the Prince of Wales had replied with disarming frankness to the old revolutionary's criticism of the French nobility by saying: "Why don't you do as we do at home? We select those who have distinguished themselves in Industry, Science, Literature, Trade, etc. and raise them to the ranks of the nobility, which in consequence always remains a real aristocracy." On coming to the Throne, Frederic, a dying man, proceeded, as one of his first official acts in accordance with the above principle, to create a small number of nobles by way of a desirable replenishment of the ranks. Amongst these was Werner von Siemens.

Thus his profession had brought him not only abundant material success and inward satisfaction, but also many outward honours. His personality, well-known at home and abroad, imparted to the House which he founded an eminence seldom possessed by industrial undertakings of the nineteenth century. But in a time of stormy advance, such as that of the young electrical industry at the turn of the 'eighties and 'nineties, authority is a very doubtful asset. This was also to be the experience of the "Past-Master" who, although retired, was occasionally drawn into arguments, and whose judgment was now lacking in that directness which springs from the daily handling of the problems of creative production.

One of the problems that had been becoming increasingly urgent, to the ultimate temporary exclusion of everything else, was the distance limit to the transmission of electrical energy. As long as activities had been confined to the building of plants for the generation and distribution of electric light in the heart of the most densely populated cities, everything seemed to be comparatively plain sailing. Even so, there were already those who criticised the contemplated erection by the Berlin Electricity Works of the fourth power station within their comparatively small supply area. Was it not possible, they asked, to centralize more? The range is not large enough, came the reply.

In order to appreciate this, it must be remembered that the work of the electric current per unit of time, i. e., the output, is represented by the product of two factors: the voltage and the current. If, as is often

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done with advantage, an electrical circuit is likened to a water supply, the voltage represents the water pressure, while the current is the equivalent of the volume of water flowing through the pipe per unit of time. As in electricity, the output of the water pipe is equal to the product of the water pressure and volume.

The inevitable losses in both types of power transmission represent power which is converted into heat and dissipated; in the case of the water pipe line it is the product of pressure-loss and volume, and in the electrical system, the product of the voltage-loss and current. Voltage-loss, again, according to Ohm's Law, is the product of the conductor resistance and the current times the current, or in other words the product of conductor resistance and the square of the current. This means that if it is desired to double the amount of power transmitted over the same conductor at the same voltage, the current must be doubled, resulting in fourfold losses; if the power is to be trebled, the current must be trebled and the losses will be ninefold. There is thus only one effective way of reducing the losses or of confining them within reasonable limits, and that is to keep the current as low as possible, i. e., to raise the voltage as much as possible.

All this had reference to the actual transmission line. With the already available or procurable means of insulation, the raising of the voltage —within limits, of course—presented no insuperable difficulty. As regards the generators and consumer apparatus, however, matters were very different: a possible voltage increase was confined to fairly close limits. Thus, in the case of the incandescent lamp, a voltage of 110 volts was for long held to be the maximum for which a lamp could be manufactured. In any case, the distances separating the current-carrying and earthed parts of machines and apparatus, which were exposed to accidental contact on the part of the attendants, were too small to permit the use of materially higher voltages. Both machines and apparatus, on the contrary, can usually be built economically for higher currents. The ideal solution thus appeared to be to generate a powerful current at low voltage, to transform it before transmission into a low current at high voltage and before feeding it to the consumer apparatus to re-transform it back into the original state. This, of course, was not possible with continuous current.

It was a relatively small group of mostly youngish men of various nationalities who helped to prepare the great technical revolution of the 'eighties of last century, an event which ushered in a new economic epoch. The majority of them came from the ranks of the physicists; but there were others amongst them who had scraped their knowledge

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together from promiscuous sources, and now spent their time theorizing and conducting electrical experiments.

The eldest of them, born before the middle of the century, were Galileo Ferraris, Professor of Mathematics and Physics at the Turin University, and Marcel Depréz, an engineer by profession, later Professor at the Conservatoire des Arts et Métiers in Paris. Roughly ten years their junior was Nicola Tesla, a Croat by birth, who had emigrated in 1889 to the United States, and was one of those prolific inventors whose destiny it is to experience to the full the dark aspects of an inventor's career—quite in contrast to his contemporary Elihu Thomson, who, born in England, came as a child to the United States, qualified as an engineer and quickly achieved considerable business success. A peculiar destiny was the portion of Karl Steinmetz, born in Breslau in 1865 of parents in modest circumstances. As a student of mathematics he was dubbed Proteus by his fellows. As a confirmed socialist he did not feel happy in his own country, emigrated to the U.S.A., and died there as Charles Prot. Steinmetz after a long and successful career, laden with honours, as the Nestor of American electrical engineering. Of the same age was Sebastian Ziani de Ferranti, equally gifted as an inventor and man of the world, who attained to similar eminence in his English home. Belonging to the same generation were André Blondel, originally an engineer, later Professor of Electrotechnics at the École des Ponts et Chaussées, and Charles Eugène Lancelot Brown, who was a native of Switzerland, where he played a leading role as an engineer and industrialist; further, Gisbert Kapp, who was an equally distinguished theoretical researcher and practical organiser in his capacity as the first Secretary General of the Verband Deutscher Elektrotechniker (Association of German Electrical Engineers). From the foregoing, it is evident that the movement was international in character. It also found energetic sponsors in Hungary, the Scandinavian Countries and Holland, whom it is not proposed to name individually here. About the middle of the 'eighties the eldest of those mentioned would be approximately forty years of age, the youngest just out of their twenties.

At the instigation of Werner Siemens, Chairs of Electrotechnics had been installed at a number of the German Technical Universities; the first to begin lecturing was Dietrich in the summer term at Stuttgart, followed within six months by Slaby in Berlin and Kittler in Darmstadt. Of these, Erasmus Kittler, formerly a private lecturer on Physics at Munich, and now thirty years of age, was the most active and successful, as in a short space of time he had rejuvenated a dying University of only 137 students, and infused into it new and vigorous life. At the

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outset he founded a special electrotechnical department, the foremost of its kind in Germany, and his electrotechnical laboratory was without parallel in the world. A large number of gifted students emanated from his institution, amongst them many foreigners, and formed a phalanx of youthful pioneers of the new science.

The idea of electrical power transmission, i. e., the transmission of mechanical output over long distances by means of electric current, had begun to exercise men's minds at the beginning of the 1880's. It was realized, also, that this was only practicable by raising the transmission voltage to a multiple of the value hitherto employed in electric lighting. The only difficulty was how to cope with the problems rising from the use of such high voltages at the machines. Oskar von Miller was at that time (1881) a young assistant in the Public Works Dept. of the Bavarian Civil Service, and had been entrusted with the organisation of the first German Electrotechnical Exhibition in Munich. He recollected a suggestion, made a year previously by Marcel Depréz in connection with the Electrotechnical Congress in Paris, to the effect that it must be possible to transmit any output over any distance through conductors of small section. Von Miller invited Depréz to undertake a joint experiment to prove the correctness of this theory. They made arrangements to install a specially-built d. c. generator for approximately 1.5 kW and 1,500—2,000 volts in a coal mine at Miesbach, and to drive it by a small steam engine. The current was conveyed over a distance of 35 miles through standard telegraph wires to the Exhibition in Munich, and there fed to an electromotor of the same type as the generator. This motor drove a centrifugal pump which supplied a waterfall of approximately 6 ft. 6 in. height. This caused a big sensation, but von Miller related 50 years later:

"On that occasion I declared: This hour has given us the inspiration to transmit electric current to whole provinces and countries, even though the experiment may be found to have many technical shortcomings.

The technical and commercial shortcomings soon made their appearance. Inadequate insulation of the machines, particularly the commutators, gave rise to many interruptions. Of the twelve days during which the plant was in service, it was running for, perhaps, four days and out of operation for eight. The Assessment Committee, which I had set up to judge the exhibits, found the efficiency of the plant to be only 22 % . . ."

Von Miller's enthusiasm proved to be premature. Admittedly, Depréz repeated the experiment in the following year in Paris with larger machines, and over a greater distance with more success, and persuaded

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Thury in Geneva to continue along the same lines, which he did by connecting a number of machines in series, both at the generator and the consumer end, so that each machine only had a fraction of the total voltage to carry. In the course of years, Thury built quite a number of high-tension d. c. plants on this system, but on the whole, it proved to be too troublesome and unwieldy to be regarded as the final solution of the transmission problem. It was obvious that other ways must be found. The aforementioned group of youthful engineers concentrated, therefore, on the investigation of the possibilities inherent in alternating current.

One of the most important features of alternating current, demonstrated by Faraday, is that a variable current gives rise to a variable magnetic field around the current conductor, and that this field, in turn, produces an electrical potential in an encircling conductor. By this "inductive" action, therefore, it was possible to transmit electrical energy from one conductor to another which was adjacent but not in metallic contact with it, provided that the action was variable in point of time. Physicists had already made use of this knowledge when they mounted two metallically separate coils on a common iron core, and connected one of them to a regularly intermittent, i. e., variable continuous current supply; the result was an alternating current of the same frequency at the terminals of the other, "secondary" coil, the voltage of which was in the same ratio to that of the first coil as the number of turns of the two windings, whilst the currents were in inverse ratio.

Apparatus of this type, in which the primary coil possessed only a few turns of heavy wire, the secondary coil a large number of turns of thin wire, were usually known as Spark Inductors, as they were employed by physicists, on account of the very high secondary voltages, to investigate the properties of long sparks and of discharges in rarefied atmospheres. Now that alternating current was being given more serious consideration, it was not unnatural to use it, instead of intermittent continuous current, for energising the primary coils of these inductors. The first to make extensive use of the idea were the British engineers Gaulard and Gibbs, who, as opposed to existing designers, made the spark inductor with an almost closed iron path for the magnetic lines of force. They connected the primary coils of a number of these inductors in series at the end of a high-tension line, and supplied separate circuits from the secondaries. In this way they were able, as they demonstrated at an Exhibition in Turin in 1884, to transmit an output of 20 kilowatts over a distance of 40 kilometres with a voltage of 2,000 volts.

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In Budapest in those days there existed the engineering firm of Ganz & Co., in which three young engineers of the new generation, viz., Déri, Blathy and Zipernowsky, had met, and who were happily complementary to each other. They seized on the idea of Gaulard and Gibbs and considerably improved on it, making the apparatus at the end of the transmission line mutually independent by connecting the primaries in parallel. Moreover, they provided a completely closed iron circuit for the magnetic field, and gave the apparatus a constructional form which it has retained substantially to this day. They called it a Transformer, the name by which it is still known.

The Budapest triad was very enterprising, and induced Ganz & Co. to carry out quite a number of high tension transmission schemes. In the space of two years they had installed two dozen such lines with surprising success, and in 1890 they submitted a scheme for the supply of electricity to the city of Rome from the water-power at Tivoli over a distance of 17 miles at a tension of 5,000 volts, which was put into effect two years later.

As in all these schemes the main object in view was electric lighting, the supply of alternating current was quite acceptable. Alternating current was generated at a voltage which was convenient and safe from the point of view of the machines, and in any case it was not necessary to be so cautious as with continuous current, since there was no commutator, the most sensitive part of the d. c. generator, to worry about. The generator voltage was then transformed up to the transmission voltage, which was chosen according to output and distance, and then stepped down to the distribution voltage at the consumer end. In this way it was easy to bridge any distances occurring in large towns, and it was also possible, in contrast to continuous current plants, to choose a site for the power station quite independently of the locality of the consumers, and solely from the point of view of the most economical operation, cooling-water disposal, coal supply and storage.

There now came to be direct current and alternating current parties who fought each other bitterly whenever a new municipal supply scheme was mooted. The case for alternating current has already been stated: independence in the choice of site for the power station, whilst the question of the current conductors, which in view of the rapidly increasing outputs seemed to be approaching deadlock as far as d. c. was concerned, solved itself for alternating current in a manner which was as simple as it was elegant. Adherents of the d. c. party, finding their absolute domination seriously threatened, pointed out that alternating current precludes the use of accumulator batteries, which were

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indispensable as equalizers and a stand-by in case of breakdowns. But above all, there was no serviceable motor for alternating current.

The "old" firms, led by Siemens & Halske, belonged to the direct current party, although as long ago as 1883 Wilhelm Siemens, Werner's son and youthful assistant, had read a paper, in the course of which he had made a suggestion involving, in principle, the idea of alternating current distribution in conjunction with transformation, for which a patent application was made two years later. That matters did not progress beyond the theoretical stage, is to be explained in part by the then existing connection with the power supply business of the AEG. This firm refused point blank to consider the use of alternating current: the Berlin Electricity Works were based on direct current, and were a fount of knowledge and experience for the AEG engineers. Added to this was the fact that Edison, whom the AEG still regarded as an authority, would have nothing to do with alternating current. Schuckert also maintained a suspicious reserve towards the innovation. The whole of the hitherto existing authorities were thus opposed to the idea of alternating current.

On the other side were, to begin with, the members of the Budapest group, who were able to point to indisputable successes, and with the excessive zeal of youth branded the others as technical reactionaries. It so happened, too, that they had recently received reinforcements in the shape of a firm in Cologne, which had grown from very small beginnings. This was a manufacturer of telegraph apparatus, founded in 1882 under the original title of "August Berghausen," and converted in 1884 into the "Helios A. G. für elektrisches Licht und Telegraphenbau in Ehrenfeld und Köln," with a capital of one million Marks. The Principal was not an electrical engineer by profession, but one of those mechanical engineers who, like Rathenau, were dissatisfied with the mechanical constructions of the young electrical industry, and turned to the manufacture of large slow-speed machines. He had come into contact with Ganz & Co., and had acquired their patents, thus becoming the advocate of the alternating current system in Germany. Helios, as a local firm, had no difficulty in securing the contract of the city of Cologne for its new electricity works, so that Cologne became the first large German city to build an electrical power station on the alternating current principle.

For some time past the city of Frankfort/Main had also been considering the establishment of a municipal electricity works, and was already negotiating with a number of firms for the erection of a direct current plant, when the Cologne decision came to be known. This caused the

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Authorities to hesitate. Ganz & Co. and their allies Helios at once attacked the breach, and for a time it appeared as if Frankfort was going to follow Cologne's example. But the direct current party did not remain idle, and Werner Siemens himself joined in the argument by pointing out that the "battle for the city of Frankfort" involved a decision on a matter of principle. As a matter of fact, the dispute was no longer confined to the technicians, but had engulfed wider circles. The Lord Mayor of the city was an outstanding and widely known administrator, and amongst the townsfolk there was a considerable number of people whose intelligence and business experience considerably exceeded the average. Thus the dispute called for a decision in principle which went far beyond the confines of communal policy. Amongst those earnestly endeavouring to further the interests of their city was Leopold Sonnemann, banker, M. P., and founder of the "Frankfurter Zeitung," a most striking personality. He did not understand the technicalities of the argument, of course, but his common sense told him that these objective arguments, advanced with such vehemence, were a screen for very substantial commercial interests. In consequence he suggested to Oscar von Miller, who had meanwhile relinquished his directorship of the AEG, retired from the service of the Berlin Electricity Works, and set up himself as a Consulting Engineer, to hold an Electrotechnical Exhibition in Frankfort, in which the alternating current people should have an opportunity of vindicating their system by demonstrating a power transmission installation over a fairly long distance. Miller seized on the idea with gusto, particularly as he had had previous experience of organizing exhibitions, and the notion of transmitting electrical energy over long distances had since then left him no peace. An opportunity presented itself in the construction of the Lauffen dam across the Neckar, already sanctioned, from which it was proposed to operate a power plant in Heilbronn. Miller suggested erecting a transmission line from this station to Frankfort, to carry sufficient power to cover the requirements of the Exhibition.

The weightiest challenge of the direct current people to the use of alternating current had always been the fact that there was no serviceable a. c. motor. Theoretically, of course, it was possible to run any d. c. motor of the usual type on alternating current, since when the direction of the current reversed in the armature, it also reversed in the windings of the magnets, thus reversing the direction of the magnetic field, with the result that the direction of rotation remained unchanged. In practice, however, it did not work, since the rapidly changing magnetic fields caused trouble at numerous points, particularly in the reversal

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of the current at the commutator, so that it was found to be impossible to run a direct current motor satisfactorily on alternating current. Not until very much later was it discovered how to design machines so as to overcome these difficulties, but even to-day the alternating current commutator motor in its various forms is a very sensitive machine. In those days, however, the engineer found himself confronted with a hopeless task.

The solution came from a quite different direction. In 1885 Galileo Ferraris in Turin had already experimented with two independent alternating currents which were of the same strength and frequency, but which differed in phase, inasmuch as they did not attain their peak and zero values at the same instant. Ferraris discovered the peculiar phenomenon that, in exciting a system of fixed and immovable coils by two alternating currents of equal frequency but of differing phase, a magnetic field is created which rotates in space with a speed depending on the frequency of the two alternating currents, exactly as if it had been caused by a rotating magnet. When Ferraris introduced a conducting, rotatable body, such as a copper cylinder, into this field, a current was caused to flow in the metal body in consequence of the relative movement between itself and the rotating field. The mechanical force resulting from the interaction of the current and magnetic field caused the cylinder to rotate in the same direction as the field. It was as if the cylinder was chasing the field without ever being able to catch up with it, for then there would have ceased to be any relative movement between the two and, consequently, no induction of current and generation of motive force.

Ferraris was not at all clear as to the significance of what he had discovered. He allowed three years to pass before publishing an admittedly very careful description entitled: "Electrodynamic Rotation caused by Alternating Currents." In this he commented that the experiment could not have any industrial importance, since a motor built on this principle could in theory convert only half of the electrical input into mechanical output.

Independently of Ferraris, and before the above publication, Tesla had conducted similar experiments, and in 1887 had applied for a United States patent for an arrangement which was substantially the same as Ferraris'. After further consideration, it occurred to him to use three alternating currents instead of two, with the phases of each separated by one third of a period. Whereas four conductors were required in the case of two-phase current, six should properly have been used for three-phase current, a circumstance which would have seriously limited

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its usefulness. Further investigation, however, disclosed a remarkable feature of the three-phase system, viz., that the current in each phase is always equal to the sum of the currents in the other two and directionally opposed to them, and can therefore be regarded as the return current. By suitably interlinking the three coil pairs, e. g., by connecting their incoming ends together, and their outgoing ends to the transmission line, it is possible to transmit current with only three wires. This discovery was the seed from which electrical power transmission as we know it to-day was born.

It is remarkable that almost simultaneously with Tesla, and unbeknown to him, two other inventors were following the same line of thought. One of these was F. A. Haselwander, an engineer in Offenburg, Baden, who chanced to make the discovery when rebuilding a direct current machine. Following up the idea to its logical conclusion, he produced a corresponding motor which he set to work in Offenburg in October 1887. The other was Bradley in the United States, who, likewise in pursuing his study of two-phase current, made the discovery of the three-phase system.

Thus it happens that, for one of the most important and portentious inventions, the prize cannot be awarded to one single individual. It was the period, obviously, at which the idea was ripe for materialization, resulting in the simultaneous ignition of the mental spark in several places. The patent situation was in consequence pretty obscure, particularly in Germany, and neither Tesla, who had disposed of his American patents to the budding electrical manufacturing concern of George Westinghouse in Pittsburgh, nor Haselwander were able in consequence of the existing legal confusion to reap the harvest which they really deserved.

Such was the state of affairs in the summer of 1890, when Oscar von Miller undertook to organize an Electrotechnical Exhibition in Frankfort in the following year. Of three-phase current, little more was known than what was contained in the early patent descriptions and other publications. However, if it were the case, in spite of Ferraris' pessimistic attitude concerning the motor efficiency, that the problem of the a. c. motor had been basically solved, it would be definitely worth while to use this three-phase alternating current[1] for the power transmission from Lauffen to Frankfort. The distance was approximately 110 miles, the maximum load 240 kW; for this a potential was chosen

[1] known in German-speaking countries as "Drehstrom," a term neatly coined at the time by von Dolivo-Dobrowolsky and meaning "Rotary current."

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of 15,000 volts, which could be raised to 25,000 volts. The hazard was unprecedented; no one had hitherto dared to consider such voltages, loads or distances; furthermore, existing ideas on the design of the generators, transformers, the insulators for the overhead transmission, but above all, of the motors, were fairly hazy. But von Miller's unconquerable energy did not recoil in the face of these difficulties. He arranged for the generators and transformers to be supplied by the Swiss firm of Oerlikon, the electrical department of which was under the able management of Brown. In this connection, oil was used for the first time as an insulating and cooling medium. The AEG, although originally an adherent of the direct current party, were persuaded to commission their Engineer, von Dolivo-Dobrowolsky, with the design of the motors, which was obviously the most difficult part of the task, since except for the working principle nothing was known of their construction.

The insulators were supplied by the porcelain manufacturers H. Schomburg & Sons to their own designs, and the Post Office undertook to erect the masts and the overhead transmission line. Everything had to be ready by the middle of August 1891, i. e., in one year's time. Miller was an unrelenting taskmaster.

As the preparations were nearing completion, it transpired that the main difficulties were not in the scheme, but with the Authorities. The supposed dangers of the installation evoked a flood of safety requirements and stipulations, which more than once endangered the completion of the work. On the 25th August the Exhibition grounds were bathed in a flood of light from innumerable electric lamps, the novel electric motors hummed, and large posters announced to visitors that all this energy was coming from Lauffen on the Neckar over a distance of 110 miles. On the previous day the Assessment Committee had issued a public caveat to the effect that their willingness to carry out technical measurements did not warrant the conclusion that they were convinced of the feasibility of the scheme. Their tests, however, disclosed an efficiency of transmission of 75 %.

The sensation in the engineering world was enormous. Professional men from all countries, particularly the United States, flocked to Frankfort to see the almost incredible with their own eyes. A veritable revolution broke out in the ranks of the electrical fraternity, and the 25th August, 1891 has for them become a Day of Remembrance, as it were the storming of the Bastille. The door to a new world had been thrust open and a mighty industrial transformation begun.

It is not so easy to imagine what Werner Siemens may have thought of this latest development, and what may have been his feelings. His

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colleagues, in particular the older generation, continued to extend to him the respect and veneration to which his life's work entitled him. This respect had once more been given public expression in connection with the Frankfort Exhibition, of which he was offered the honorary Chairmanship. The younger generation at home and abroad may, of course, have felt that it was time for Age to stand down and make way for them. But that had always been so since time began, and must be accepted as inevitable. More keenly felt, no doubt, was the fact that his own Firm no longer occupied its former commanding position, but that could be accepted when it was remembered that, as business continued to expand, it was neither possible nor desirable to retain a monopoly. But that in a number of respects the technical leadership should have slipped out of the Firm's hands, as the Frankfort Exhibition had revealed, could not but appear to those who had witnessed the early developments of electrical engineering in the service of the Firm as a highly deplorable state of affairs.

His Life's Balance Sheet, which Werner Siemens intended to draw up in his years of leisure, had meanwhile taken shape in his "Lebenserinnerungen"—Life's Memories. The book, which appeared in 1892, has been published in a considerable number of editions, and later in several "popular" editions, a proof of its favour with the reading public. It is written without any attempt at ingenuity of style, but with warmth of feeling, and captivates as much by the content of the narrative as by the natural and spontaneous manner in which it is presented. It has thus popularized the name of the Author, and the House which he founded, to an extent which would have been impossible otherwise. It is not the custom, nor is it perhaps possible, to take up literary productions as assets in balance sheets, but if this had been done on drawing up the first balance sheet of Siemens & Halske after the death of the founder, the book could quite easily have been entered amongst the assets at a value of several millions of Marks. As the Author lay on the sick-bed from which he was to rise no more, the first copy of the printed book was placed in his hands. It was the last service he was able to render to his Firm; shortly afterwards, on the 16th December, 1892, he closed his eyes for ever. He was borne to the grave like a prince.

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VIII.

THE TELEPHONE

In his will, Werner von Siemens had provided that his share of the capital should be transferred in equal parts to his six children. Of these, four, viz., the two sons Arnold and Wilhelm and the daughters Anna and Käthe, were children of his first marriage, whilst Karl Friedrich and Hertha sprang from the second. Those of them who were sleeping partners only, which applied to the four younger children, increased their share of the capital from their other means. Werner's widow Antonie simultaneously contributed a corresponding share. In addition to the three partners who were personally liable, therefore, the Kommanditgesellschaft now comprised five shareholders with a total capital of twelve million Marks. The working capital of the three personally liable Principals can be assumed to be at least equal to that of the sleeping partners, so that the Firm would dispose of a capital of at least 24 million Marks. However, it was about this time that, due to the growing prevalence of company promoting and the founding of large enterprises on the pattern of the AEG, capital requirements in the Electrical Industry began to increase rapidly. Thus, in October of the same year, Siemens & Halske found it necessary to raise a loan of ten million Marks at $4^1/_2$% against the security of a mortgage—the first external capital since the founding of the Firm.

Of the three Principals, Werner's brother Karl had become Chairman and as such had removed from St. Petersburg to Berlin. Belonging to an earlier generation than that of his two nephews, he soon came to limit himself to the performance of the more formal duties of his office, although, of course, in certain matters of a general nature, especially questions of finance, he was able to give valuable counsel. Of the two brothers, Wilhelm, the younger, was by far the more active, although this found its expression less in external characteristics than in a constant struggle against certain inhibitions which were part of his nature. His elder brother was also subject to these inhibitions (as long as they lived, both had to overcome a certain natural shyness when

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required to appear before a large gathering and carry their point). Wilhelm also took a greater interest in matters of a technical and scientific nature—if Fate had not ordained otherwise, he would probably have become a scientist—with the natural consequence that, in a firm which had grown from technical roots, he found himself thrust more and more into the foreground. There were certain to be many in German Industry who envied him his position and the task unfolding itself before him, but he himself by no means felt his lot to be enviable. With his somewhat phlegmatic temperament, given to ruminating, it could not have escaped him that all was not well with the parental heritage, and that every effort would be required to prevent it from continuing down-hill. The Frankfort Exhibition had, of course, only been like a searchlight beam which had rested for a short while on a section of the scene of action, throwing up manifest defects into strong relief. But also in other directions, things did not look too well. These were matters in regard to which it was impossible, notwithstanding the glamour of inheritance, to be under any delusion.

When Wilhelm von Siemens studied the figures for electrical manufactures published in 1891, i. e., two years earlier, on the basis of a private census, he found that the total production for Germany in 1890 was estimated at 45 million Marks. In that year the AEG had declared its turnover to be 11 millions, and although in consequence of its company-promoting activities, some values were included which did not represent electrical manufactures in the meaning of the census, the figure nevertheless showed the considerable share of the market which the AEG had already captured. Schuckert declared his turnover as 5 1/2 millions; Siemens & Halske still accounted for a good third of the total production. According to the same statistics, the total number of employees in the electrical manufacturing industry was about 17,000; of these about 2,500 were accounted for by Siemens & Halske and about 2,000 by the AEG. Since these figures represented the position of three years previously, they were sure to have undergone a change which was relatively unfavourable to Siemens & Halske, since the rate of expansion was greater for the AEG than for his own Firm. It was almost possible to plot in advance when Siemens & Halske would at length be overhauled.

The parent Company, Siemens & Halske in Berlin, owned the so-called Berlin Works in Markgrafenstrasse, which was also the seat of the administration, the Charlottenburg and the Vienna Works. It also owned the subsidiary company in St. Petersburg, which operated as an independent Firm. The Siemens brothers also owned the majority of the shares

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of the Limited Company of Siemens Bros. & Co. in London, as well as the Company known as Gebr. Siemens & Co. with works in Charlottenburg for the manufacture of arc lamp carbons and alcoholometers, and, finally, the Siemens & Halske Electric Company of America in Chicago.

What the Firm obviously needed most was young engineers who were capable of dealing with the technical and scientific problems set by the increasing application of electricity. The old Guild which had grown up in Werner's school, overshadowed by his sovereign personality, were lacking in the faculty of independent thought. Above all, however, as purely practical men without any early theoretical training, they had grown too old to be able to find their way unaided in the strange new realm of alternating current electricity. And it really was strange ground which opened up before their astonished eyes, with its inexhaustible profusion of extraordinary and complicated phenomena. It required a fundamentally new method of approach, a familiarity with certain mathematical conceptions and novel methods of graphic presentation, to enable the essence of a problem to be grasped and the solution found. Articles on electrical subjects, which now followed each other in rapid succession in the technical periodicals, were almost beyond the ability of these older men to read, patent claims were unintelligible, and the path of future development undiscernible. The electrical streamlet released on the opening of the sluice-gates at the Frankfort Exhibition was rushing on with thundering eddies to join the waterway of the Future. It was calling to the new generation. Wilhelm von Siemens did not hesitate to open wide the doors of the Charlottenburg Works, which soon echoed with the pleasant stir of enterprising technical youth.

Uncle Karl had no great opinion of the future of the Russian business, and since he had twice in his life—in the early days of his career and again quite recently, before returning to settle in Berlin—been in charge of it, his views concerning future prospects were bound to carry weight. In its hey-day, between 1855 and 1868, Russian business had consisted primarily of erecting and maintaining installations for one client, viz., the Government, whose requirements now seemed to have been satisfied for some considerable time.

The advent of power current was followed by corresponding developments, the workshops were greatly extended and subsidiary companies formed, but to Karl it seemed that it would be a long time before the fine prospects existing in Central and Western Europe could come to fruition in the economically backward realm of Russia; he also looked upon Russian business as a considerable risk. By comparison with the

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thriving state of the electrical business in Germany, which Karl was now able to observe at close quarters for the first time, the image of the St. Petersburg Branch grew somewhat dim. It therefore came as a surprise to his nephews when Karl one day proposed to them to sell the whole of the Russian business, since in view of the anticipated further rapid expansion of the German market, the proceeds could very profitably be invested in the electrical business in Germany.

Strangely enough this "Russian" prejudice of Karl's extended to the Vienna Branch, which he wished to include in his sale plans. Actually, there was no occasion for this, since the Vienna business had developed quite satisfactorily in recent years. It comprised a "Dynamo Works" for generators and motors, a general engineering and mechanics' shop which would nowadays be called an "Apparatus Works," and a "Cable Works." In an electro-chemical department, which had acquired a reputation for its systematic scientific research work, parts were electrolytically plated for the other departments. About one third of the total output was for railway signalling equipment, which had been highly developed at the Vienna Works, and enjoyed a kind of monopoly with the Austrian State Railways. At that time the Vienna Branch gave employment to 700—1,000 workers and was thus quite a sizable undertaking.

However, the personal relationships between the Works' Management and the departments in Berlin, such as the Department for Electric Traction, who were keenly interested in developments in Vienna, were anything but good, and the continual friction which had to be smoothed out by the directors no doubt contributed to Karl's aversion to the Vienna Branch. After one of these discussions with his uncle, Wilhelm recorded in his diary: "Our intention is to develop Berlin, London and Chicago first."

"Chicago" referred to the Company with the pretentious title: "Siemens & Halske Electric Company of America," which had been a source of worry to its promoters for a year past. In accordance with frequent earlier deliberations, which had always been adjourned, Arnold von Siemens visited America in company with a senior member of the Firm at the turn of 1891/92, the immediate purpose being to study the question of the exploitation of certain patents. As the result of discussions with interested American circles it was resolved to found a Limited Company in which Siemens & Halske would have an appropriate interest, and to build a factory in Chicago. An American by the name of Meyenburg became President, while Dr. Berliner of the Charlottenburg Works was appointed Works' Manager.

Not even a year had passed since the formation of the Company before

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rumours reached Berlin of serious differences between the President and the Works' Manager, as also of business reverses. Since, moreover, the World Exhibition was due to be held in Chicago that year, Wilhelm von Siemens decided to go there himself to look into the affairs of the Company.

He found himself confronted with a very unedifying situation. The Company had assumed obligations which were far beyond its modest capital resources of half a million Dollars. Meyenburg suffered from a lack of self-control, and was prone to ill-temper and acts of brutality toward the Staff. After a short period of collaboration with Dr. Berliner, who was not exactly conciliatory by nature, violent quarrels had occurred between them, in the course of which Meyenburg had dismissed his colleague on the spot. After protracted discussions Wilhelm came to terms with the Americans in Chicago, under which it was agreed to double the capital, to be shared by the two parties in equal amounts, hoping thereby to have overcome this post-natal crisis.

What impressed him most in America, however, was the manner in which new electrical problems were grasped and solved. He recollected that according to the private statistics referred to earlier, the total electrical production in Germany for 1890 was 45 million Marks; now, for the same year, the Americans calculated the production of their electrical industries to be 100 million Marks. In the United States the first electric railway was put into operation in 1885, whereas Siemens & Halske had opened their well-known experimental electric tramway service at Lichterfelde four years earlier. But in Germany hardly anything further had been done until 1890; now, at the time of Wilhelm's visit, there would be, on an outside estimate, perhaps thirty electric railway services in operation or under construction in Germany, whereas in the United States the number was over three hundred. Likewise, there were at least ten times as many public electric generating stations as in Germany.

But all this, striking as it was, receded in face of the extraordinary development of the telephone in the U. S. A. Germans did not cease to point out that Philipp Reis, a Nassau schoolteacher, had effected the "transmission of the voice by electrical means" as long ago as 1861, but the invention was hardly noticed, especially as it was not of practical use in the form presented by Reis, and was soon completely forgotten. When, therefore, Alexander Graham Bell, a linguist and deaf-mute teacher in Salem, near Boston, who had made a close study of phonetics, applied for a patent in February 1876, entitled "Improvement in Telegraphy," which embodied, inter alia, the claim: 'to cause by means of sound the vibration of a membrane mounted in front of an electromagnet, using the variations of the magnetic field thereby produced to generate alternating electric currents which in an identically constructed receiver must re-transform themselves into sound waves, the patent was granted him on the 7th March of the same year.

The first Bell telephones appeared in Europe in the summer of 1877 and caused quite a stir, also in Germany. Everybody was talking about them and wanted, if possible, to have a couple of these instruments as experimental playthings. As the German Patent Law did not come into force until the 1st July, 1877, Bell had not been able to obtain a German patent. The manufacture of the apparatus in Germany was thus free for all, and Siemens & Halske were unable to cope with the demand, so that Werner Siemens spoke in his letters of 'this telephone racket which is making life a burden.' He also improved the original form materially by replacing the rod magnet used by Bell by a horseshoe magnet, and he devoted considerable study to the theory of the instrument, insofar as it was possible to speak of a theory up to that time. But otherwise, as far as the broad masses were concerned, the telephone just remained a joke, and also became a favourite target of the comic papers.

In contrast to this attitude, Bell acted immediately on the conclusion of the first promising tests with his invention and, with the assistance of two moneyed friends, founded a company with the object of building and operating telephone exchanges, and renting the connections to subscribers. Thus, a telephone exchange was opened in New Haven (Conn.) in January 1878, which was the first in the world. Of these first exchanges with which the Bell Telephone Co. began its activities, visitors were told amusing stories. The incoming lines from the subscribers terminated on a switchboard in sockets with corresponding drop indicators. A call signalled by the dropping of the indicator was answered by an operator, who contacted the subscriber by plugging a cord into the corresponding socket. The required connection was then made by the "switchman," who joined the two subscribers together by means of a cord with two plug-ends which were inserted into the two sockets. These "operators" were usually half-grown youths who stood in front of the switchboard, the cords not in use at the moment slung round their necks, shouting the subscribers' instructions at each other. Telephone numbers did not yet exist, and the youths had to call out the subscribers by name. That was how it began in America, but it worked. It worked so well, that by the time the first telephone exchange was opened in Berlin in 1881 with 48 subscribers—some only after per-

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sonal persuasion by the Postmaster General, Stephan, others declining roundly to have anything to do with this American humbug—the United States had no less than twenty large local exchanges in operation, with a number of trunk lines.

But it was not merely the incredible urge to get things going manifest in the American spirit of enterprise which impressed Wilhelm von Siemens; the fact was that, hitherto, the state of development in the field of telephony had been years in advance of that in Europe. The microphone had been introduced in America as long ago as 1878, whereas in Germany it was not used until 1887. In 1881 the Americans had commenced to operate on the two-wire system; in Germany it was still impossible to foresee the end of the wrangle with the Post Office on this grievous subject, despite the fact that with the increasing numbers of electric railways, telephoning over a line with earth return was already torture. Above all, however, multiple connection systems had been in use in America since 1879, whilst their introduction in Germany did not begin until 1887. Their originator was Scribner, the inventive Chief Engineer of the Western Electric Co., Chicago, who thus mastered the first technical crisis with which the excessive rate of expansion had threatened to overwhelm the new means of communication.

The drop indicator board, the switchboard on which the connections were made, permitted the making of only a limited number of connections. If the board was increased in size, it became too large to operate and supervise. At first it was endeavoured to overcome the difficulty by subdividing the exchange into several boards, each with its own operator. However, when a subscriber on board A wished to speak to one whose connection was on board C, boards A and C had to be connected together whilst the operator of A called out the subscriber's number to the operator of C. During busy hours this arrangement proved to be unworkable, on account of the noise it occasioned. Scribner now joined up the various boards into one unit and repeated in a multiple field on each board the connections of all the others by means of throughgoing lines. As these connections did not require to have drop indicators, they could be mounted with their jacks close together, the corresponding indicators being on the boards (outside the multiple field) to which they belonged. Since every subscriber had a multiple jack on every board, he was easily accessible to every operator. It might happen, for instance, that a line was engaged on board B when a subscriber from D wished to speak to him. To enable the operator of board D to know when the required line was free, Scribner devised a simple test-procedure. Operator D touched the connection of the required line in his multiple field with the tip of his calling jack. If he heard a crackling sound in his earphones, the line was still engaged.

To complete the survey of the position in Chicago, discussion included the Chicago firm: The Strowger Automatic Telephone Exchange Co The story went that Strowger was a funeral undertaker in Kansas City, who was annoyed at the poor and unreliable telephone service on the part of the exchange in handling long-distance calls. In consequence, he designed an automatic device to take the place of the operator, and had it covered by patents. In conjunction with a commercial traveller called Joseph Harris, he then founded the above-mentioned firm to exploit the patent. According to reports, the two had already equipped the first public exchange with this system in 1892. Admittedly, Wilhelm's informants were inclined to be sceptical as to its ultimate success, but the affair shows the various categories of people in the United States who were concerned with electrical inventions: deaf-mute teacher, traveller, undertaker—and Edison, for that matter, had no better training.

When Wilhelm von Siemens returned to Berlin and, fresh from his travels, entered the well-known precincts of the Berlin Works in Markgrafenstrasse, it seemed to him that it was high time for the windows to be thrown wide open. Undoubtedly, much good work had been done there, and as regards certain departments, this still applied. Railway signalling, to which the Partners had always devoted special attention, appeared to be imbued with new life following the engagement a year ago of the twenty-eight year old engineer (Regierungsbaumeister) Pfeil, who in a manner rarely observed in technicians, combined extraordinary constructive talent with a rare ability for convincing presentation of his ideas, which spoke well for his further prospects. Following the general electrical expansion, the output of incandescent lamps was increasing from year to year, but this department of manufacture was in reality alien to the Markgrafenstrasse Works; if things continued in this way, it would be necessary to consider the building of a separate Lamp Works. Water meters were an old established, smoothly running line of manufacture, offering little prospect of excitement or technical laurels. But now came the dark spot, the Telegraph Department, the nucleus, round which the firm had once been formed.

The fact that for several years past electric telegraphy, in the narrower meaning of the term, had been in a trance-like condition was, of course, not wholly the fault of the department, since nothing had been heard from other sources, either at home or abroad, of any material developments in this field. All the same, those in charge might occasionally have considered the possibility of exploring other avenues of progress. And as

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regards telephony, it had to be acknowledged that in comparison with the example set by the Americans, the position of Siemens & Halske was very bad indeed.

What was the Firm supplying in this connection to its chief client, the German Post Office? Small numbers of a drop-type switchboard, 1882 Model, which continued to be used in minor exchanges, small quantities of telephone sets, and a certain amount of repair-work—that was all.

In the meantime, however, the Post Office had begun to equip the larger towns with modern exchanges, i. e., with multiple boards. Since Siemens & Halske had nothing suitable to offer, the Post Office had found other suppliers, in some cases having actually trained them. In the latter half of the 'eighties, a certain Fr. Welles in Berlin had established a "Telephone Apparatus Factory" under his own name, which could be considered to be the German Branch of the Western Electric Co., Chicago, since it made full use of the Scribner patents, manufactured in accordance with the Western Electric designs and employed a number of American engineers. This firm was transferred to an engineer by the name of Zwietusch, born in Milwaukee of German parents and trained in Chicago, who had then joined Welles. He showed great ingenuity in adapting the American designs to German conditions and to meet the special requirements of the Post Office, with the result that he received the orders for the first two large multiple connection boards for the Post Office Exchanges in Berlin and Hamburg almost without competition.

A former employee of Siemens & Halske, a tool-maker by the name of Stock, had set up for himself as a manufacturer of small parts on entirely new principles, which he had evolved as the result of his workshop experience. His former workmates at first ridiculed his products as "stamped thin stuff," but were soon compelled to admit that in view of the enormous quantities of identical parts required by these large telephone exchanges, the existing practice of fashioning each part individually was no longer feasible. Having no American connections, Stock had contacted the Swedish telephone engineer Ericsson, who was glad to have an outpost in Germany to supplement his flourishing home business. Since the Post Office was anxious not to be dependent on Welles/Zwietusch as sole supplier, Stock found no difficulty in obtaining Post Office orders. The Post Office was so pleased with his work that, in 1893 alone, he was awarded the contracts for three large exchanges.

The private trading company of Mix & Genest, founded in 1879, had commenced by specializing on tele-communication apparatus for large-

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scale private installations, such as factories, mines, offices, banks, hospitals and hotels. For these it developed a number of special designs which were well received. Particular attention was devoted to good workshop organisation, and this enabled good work to be sold at reasonable prices. Having secured the services of a Swedish engineer who was a first-class designer and electrician, the firm applied for and was successful in obtaining orders from the Post Office.

The Post Office now had a wide enough choice of manufacturers to select from, and was no longer dependent on Siemens & Halske. 'A pity for the good old Firm,' may have been the thought of many an elderly Civil Servant who had known the former times.

Such then was the scene as it presented itself to Wilhelm von Siemens on taking stock of the situation in relation to the flourishing telephone industry. Truly, the position was humiliating.

The director of the Berlin Works who was actually responsible for this state of affairs was Hermann Siemens, a nephew of the Louis Siemens who was active in founding Gebr. Siemens & Co. and was their Works Manager for many years. At first, Hermann Siemens displayed a certain amount of energy in the discharge of his duties, but illness befell him, undermining his vitality; it was probable that he would be compelled to retire ere long. A younger man would have to be put in his place and, in fact, it was evident that the whole works was in dire need of a blood transfusion.

Through the recommendation of a friend, Wilhelm von Siemens became acquainted with Dr. August Raps, a private lecturer on Physics at the Berlin University, who expressed his willingness to join the Firm, at first, in the capacity of Assistant to the Chief of the Telegraph Department. While inspecting the apparatus in course of manufacture in the shops, Dr. Raps noticed the speed-governor of the Hughes Apparatus, the purpose of which was to maintain synchronism with the speed of the corresponding apparatus. Although all sorts of people—and other firms—had endeavoured to improve the construction of this apparatus, it continued to be very cumbersome and unreliable. In the course of a few months Raps produced a new construction of astonishing simplicity and elegance, which was destined to be the foundation of an exceedingly lucrative business. Above all, however, it laid the basis of the reputation of the new man inside and outside the House; almost in a trice he had solved the problem which had been engaging the attention of numerous specialists for years with little result.

Simultaneously with this work Raps, meanwhile promoted to Chief Draughtsman and Chief of the Experimental Laboratory, had

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been taking steps in various directions towards the systematic improvement of certain component parts. He redesigned the measuring instruments, developed a new microphone, and re-modelled the existing clumsy telephone instrument to render it lighter, cheaper and more efficient. At the same time he designed new telephone stations, which in consequence of improved manufacturing methods were cheaper to produce. Two years after joining the Firm he was made Head of the Department; he now attacked the hard core of the telephone problems, viz., to devise a multiple connection system suitable for large exchanges.

When he informed his assistants that the first thing to do was to carry out a systematic search in the patent literature, above all, the American, he was met by blank looks. Never before had this sort of thing happened in the Berlin Works. The result was not encouraging. Almost every conceivable avenue of approach to a solution seemed to be blocked by patents, above all, those of Scribner. In that case, said Raps, a commencement should be made with the systematic redesign of all undisputed components, of all those small parts which in their hitherto existing form had been taken for granted, but which were capable of being made simpler, smaller, more compact and more easy to handle, always bearing in mind the rationalization of the manufacturing process. The outcome was a host of new ideas concerning assembly and interconnection, from the combination of which the possibility emerged of creating a new multiple connection system which would avoid infringing existing patents, and was itself characterized by a number of patentable features.

As the result of their labours, the Siemens & Halske stand at the Berlin Industry Exhibition of 1896 included a telephone exchange for 10,000 subscribers which was a decidedly original and clever solution of the problem, and attracted a corresponding measure of attention on the part of the telephone experts. Amongst these was the Postmaster General Stephan, who visited the stand, conducted by Wilhelm von Siemens, and had the telephone exchange demonstrated to him. "Very nice, very original..." he commented, then, turning to the Under-Secretary accompanying him: "...but I don't think we require any at the moment?" "No, your Excellency," was the reply. A week later Stock & Co. received an order for several large exchanges to the value of three million Marks. Wilhelm von Siemens was furious—this man had once called himself a friend of his father! But this was one of the results of long neglect.

Since business with the Post Office appeared for the time being to be hopeless, contact was sought at the beginning of 1897, through the intermediary of the Vienna Works, with the Austrian Ministry of Commerce,

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which was just then engaged in the modernisation of the Vienna telephone system. Some exchanges had already been converted by the Americans to multiple connection operation. Siemens & Halske received a trial order to equip one exchange on their new system, further orders to depend on the result of the trials.

It was made a condition that the new system should be capable of operating together smoothly with the already converted exchanges. After difficult and extensive development work the equipment was delivered, but it was found to be unable to meet all requirements. Numerous hitches occurred, caused, in part, by the fact that the Siemens & Halske system called for different manipulation from that to which the operators were accustomed, in consequence of which the personnel of the various exchanges was not immediately interchangeable. After six months' operation the equipment had to be withdrawn; the experiment had cost 300,000 Marks, and the whole of the million-Mark order went to Welles.

Naturally, the news of this failure had spread quickly in technical circles and the Bavarian and Wurttemberg Post Offices, which at that time were still independent of the Reich, resisted every effort to persuade them to experiment with Siemens & Halske apparatus. Several large orders of these clients again fell to competitors.

Wilhelm von Siemens was in doubt as to whether he could justify the sinking of further money in this obviously hopeless enterprise, especially as investment business on the power current side was placing a continuously increasing strain on the Firm's resources. Imprudently—as he thought—the Firm had competed in Rio de Janeiro not only for the electric power station contract, but simultaneously for the contract covering the supply and operation of the municipal telephone system, and had been successful in obtaining the order against the competition of the American Telephone and Telegraph Co. In the light of recent experience he was very much inclined to renounce the contract, but at Raps' request agreed that it be transferred to the "Brazilian Electricity Co.," a company founded jointly with the Deutsche Bank, which then ordered the telephone equipment from Siemens & Halske. In this way one remained master in one's own house, and could gain experience quietly without its being broadcast to an unsympathetic public. The lessons learned proved to be very valuable for the future.

In 1896 Raps had acquired the services of a new assistant in the person of Dr. Adolf Franke, whom he soon made his deputy. Franke was a physicist by training, and commenced his professional career in the then existing Telegraph Engineers Department of the Post Office. The

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department was at that time engaged in systematic research into the part played by electricity in telecommunication, both in the transmitter and receiver, as well as the wires, and in the scientific presentation of its findings. This was a task, the fundamental significance of which had up to now only been realized in England, whereas in America they had been content to work to rule of thumb, which, considering the history of electrical development in that country, was not surprising. Siemens & Halske had also done practically nothing in this direction. Having now perceived that the time sequences of the electric currents which transmit the human voice in telephoning are, or should be, a true replica of the speech oscillations, it was clear that these currents could be pictured as being composed of a number of simple, regular so-called harmonic alternating currents of various strengths and frequencies, and that the composition was a different one for each sound, and peculiar to it. If, therefore, it was desired to study the laws governing the propagation of speaking currents in instruments and conductors, it was first necessary to produce these elemental currents, and to be able to vary them as required. For this purpose Franke designed an alternating current generator which, as opposed to the machines hitherto used in power current engineering, was not built for one frequency, but for the whole range of frequencies occurring in human speech, capable of infinitely fine variation and adjustment as a function of the time. This machine, named after him, proved to be a most valuable auxiliary in the study of these complicated phenomena, and led to Franke becoming well known in professional circles. He was barely a year the junior of Raps, and by contrast with the latter's lively Rhenish temperament, was a thoughtful Lower Saxon, so that the two complemented each other in ideal fashion. Their relations remained harmonious throughout the twenty-three years of their collaboration.

Raps had found a further assistant in the person of a young technician, whom he discovered in the drawing office soon after his own instalment there. Georg Grabe was not only a very intelligent but, above all, a very energetic person, who did not in the least mind if he got on the nerves of less active and easygoing people. Telephone manufacture had at an early date indicated the development of mass-production methods, and it will be appreciated that workshops thus organized are particularly sensitive to being upset by experimental work and call for modifications. In this case, however, it was essential to turn to account every bit of experience, and all the setbacks, for the improvement of circuits and designs, and it happened more than once that Grabe drove the Workshop Management to the verge of desperation.

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The Americans had meanwhile replaced the drop indicator as call-sign by a signal lamp, which economised space, and had, of course, covered the design by patents. But the so-called spring indicator, which Siemens & Halske presently developed, proved in consequence of its compact design to be even superior to the lamp as regards space requirements. The use of the automatic clearing signal to indicate the close of a conversation, indispensable for the speedy dispatch of traffic, and which the Americans had also attempted to bar by patents, was rendered possible by an astonishingly neat solution invented by Siemens & Halske. The Firm had meanwhile also covered itself by a network of patents, some of which could hardly be circumvented. In addition to this, the work which Raps put into the improvement and re-design of the components when he took up his duties, was now beginning to bear fruit. Telephone orders were received from clients at home and abroad in increasing numbers—even the Post Office began to introduce certain types of instruments as Standards, and to conclude contracts for a year's supply of large quantities. Thus encouraged, Siemens & Halske decided to approach the Post Office with the request to give the Firm an opportunity, when next requiring a large multiple-connection exchange, of demonstrating their ability. With unexpected promptitude came the reply: An invitation to equip the new Exchange Berlin VI to be built in Lützowstrasse in accordance with the Siemens & Halske system. "The Post Office reserves the right to retain or return the equipment until after conclusion of the trials."

The practice in cases of this kind was to set up the new exchange complete by the side of the old one. On a Sunday, taking advantage of the hours of night, the whole of the connections were transferred by means of parallel conductors to the new board, and the old ones disconnected. On Monday morning everything was required to operate smoothly under the new conditions—a nerve-racking experience for all concerned. To add to the tension in this case, there was, on the one hand, the highly strung Berlin public, and on the other, distrust on the part of the Post Office, some of whose engineers would have been glad to see things go wrong. Failure, coupled with the return of the equipment, would have meant not only a loss of at least half a million Marks, but a business catastrophe. "If there is a repetition of what happened in Vienna," said Wilhelm von Siemens gravely, "the consequence will be incalculable."

"This time it will be different," said Raps.

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IX.

INVESTMENT BUSINESS

As far as power and lighting are concerned, it can be said that present-day electrical engineering practice was moulded in the twelve years between the Frankfort Exhibition and the economic crisis shortly after the turn of the century. The impetuous economic expansion seen in the so-called "promoter years," and the successful solution of the ensuing electrotechnical problems reacted to their mutual fructification. In the meantime, of course, much thought has been applied to the improvement of machines and apparatus, leading to the creation of fundamentally new types. Although outputs, voltages and dimensions have increased enormously, the fact remains that electrical engineering practice in power and lighting attained its present-day shape about the year 1903. This development has been built up on the understructure of three-phase current, successfully demonstrated for the first time at the Frankfort Exhibition. The three-phase alternating current generator, commonly called alternator, very soon acquired a characteristic form, consisting of a rotating wheel—the rotor—on the periphery of which are mounted a number of poles with windings excited by direct current, and arranged as north and south poles alternately. The rotor revolves with a small air-gap within a stationary ring, which is built up from numerous pieces of thin iron sheet separated from each other by paper insulation. On its inner circumference, facing the poles, the ring is provided with a large number of axially disposed parallel slots which carry the well insulated conductors. The sheet-iron ring is supported by a cast-iron ring or steel housing, both together known as the stator. The alternating magnetic flux created by the rotor poles generates an alternating potential in the conductors in the stator slots.

A generator of this kind can also be used as a motor, but only if it has been brought up to its full speed to commence with. If it is then connected to the supply, it will continue to run at synchronous speed, i. e., the speed corresponding to the frequency of the alternating current

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supply and the number of poles of the stator. For this reason a motor of this type is called a "synchronous motor." It is unable to start by itself, and it requires direct current for its excitation.

Since both these conditions are very irksome, electrical engineers reverted to the solution already indicated by Ferraris when he discovered the rotary field. Ferraris had placed a rotatable metal drum in the centre of a rotating field, and had found that the drum commenced to rotate, due to the interaction of the rotary field and the currents induced by them in the drum. Proceeding on this principle, the pole-wheel of the synchronous motor was replaced by an improved Ferraris drum. In place of a solid cylinder, the rotor is built up of sheet laminations in the same way as the stator. The cylindrical periphery is likewise provided with axial slots enclosing the conductors, which are connected to form closed circuits in which the rotary magnetic field induces current. For this to take place, however, the rotor must always lag slightly behind the rotary field, as otherwise there is no relative movement between them. As opposed to the synchronous motor, therefore, the other behaves "asynchronously." But this enables it to start by itself and to dispense with d. c. excitation.

Many millions of these three-phase asynchronous motors, commonly known as induction motors, are at work the world over, from the smallest dentist's motor to the heaviest motor for the propulsion of a battleship. Together with the petrol engine, it has become the most indispensable machine that man has made. Of all electrical machines it is the simplest and most reliable, but the theory of the induction motor is anything but simple. Dozens of keen brains spent years on its study, until they succeeded in unravelling and co-ordinating the complicated phenomena sufficiently to present them clearly and make them amenable to mathematical calculation. The engineers of the Charlottenburg Works played a prominent part, not only in the practical development of the induction motor, but also in the theoretical formulation of its problems.

By the end of the last century the transmission voltages of three-phase installations had increased to about 10,000 volts. The voltages of the generators, however, were kept timidly below the 1,000 volt limit, so that the potential had to be transformed up and then down again. The transformers employed for that purpose already possessed all the essential features of the present-day types; oil-cooling, in particular, which had already been employed in Frankfort, became universal. A special problem was that of the high-tension switchgear. The simple interruption of the electrical circuit by means of a hand-operated switch

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was found to be out of the question on account of the dangerous arc. This led to the extinction of the arc under oil, and the development of the oil circuit-breaker, in which breaking of the contact takes place in an oil tank—a type of circuit-breaker which is still in extensive use for medium outputs and voltages. With a view to keeping high voltages away from the measuring instruments, dangerous voltages and currents were reduced to safe values by means of special small transformers with a high accuracy of transformation-ratio, so-called "instrument transformers," whilst the corresponding measuring instrument was calibrated for the true values. In order to bring about the automatic interruption of the line in the event of short-circuit or other excessive increase of current, so-called "automatic circuit-breakers" were designed, the contacts of which were opened instantaneously by the action of a spring on the withdrawal of a latch by an electromagnet; the electromagnet also came into action if a certain predetermined current was exceeded, or if a serious voltage drop occurred. The whole of this apparatus, together with the instruments for a generating station, transformer substation or a distribution point, was then combined in a switching plant, consisting in the early stages of a single switchboard and developing gradually from individual enclosed cubicles into extensive switchgear houses. To this must be added the development of starters and speed regulators, control-gear for cranes and traction motors, lighting installations for large suburban areas, railway yards and harbours, as well as for large-scale indoor illumination and stage-lighting, the development of wiring accessories for workshop, office and domestic use, which was greatly accelerated by the invention of the insulated conduit, in which the wiring could be carried beneath plaster. From this it is possible to gather some idea of the magnitude of the tasks which were accomplished by the pioneer designers of those days.

Having learnt how to measure the individual electrical quantities: voltage, current, output, resistance and frequencies, and to improve the standard of accuracy of the measuring instruments, it was a short step to testing the finished products, machines in particular, under various conditions of load before leaving the works. This was an innovation by comparison with existing mechanical engineering practice, in which large machines were habitually assembled for the first time on site. On the mechanical side, too, the methods of testing were comparatively rough and ready. The electrical machine, with its purely rotary motion, was easy to assemble and test in the manufacturer's works. In this way it was possible, not only to satisfy oneself that possible guarantees would be fulfilled, but to gain important insight into the performance of the

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machine as a guide to future development. In this way the so-called "test-beds" came into being, which were at the same time invaluable training schools for the younger generation; with these, electrical practice has set an example to the whole of the producer-goods industries.

At that time and for a number of years to come, the relationship between manufacturer and customer was very different in power business as compared with communication engineering. The users of light current products and, in particular, the most important clients, were large organisations, government telegraphs, cable companies, railways, etc. These had built up what might be termed a "technical tradition;" they had their own skilled personnel, were in a position from long experience to pass judgment in technical matters, and in most cases knew exactly what they wanted and what they could demand. Components in common use had in many cases been standardized by clients themselves, who then placed annual bulk orders for these parts. And when it was a question of a new installation which they allowed the contractor to erect, as in the case of the early multiple connection exchanges, they would be standing by as critical experts, and do the looping-in to the existing system themselves. Propaganda for new types had thus to be confined to drawing attention to their advantages as compared with earlier types: Expert was speaking to expert. How very different were things in the realm of power and lighting engineering. Here electric light was competing with gas—the public was interested. Or the electric motor was struggling for the mastery over the gas-engine or small steam-engine—the user, the works manager and the accountant were all involved. In another case the electric drive was endeavouring to oust the traditional hydraulic drive for a crane or hoist—this concerned the machine designer, the harbour master and steel-works manager or hotel proprietor. The building of an electric power station or the electrification of the tramways was not only a technical question, but also a matter of municipal policy, in which all manner of interests, but primarily the rate-payers, wished to have a say. But apart from these diverse interests which the presentation of a new scheme involved, every large contract had to pass first through the quotation stage, meaning that details had to be set out on paper, showing the costs, with technical explanations and guarantees. And when the order matured, everything had to be drawn up and stipulated in the form of a contract. Erection on the site was the obligation of the supplier, since only he disposed of the necessary skilled personnel. In those days even large customers had none, whilst small firms have none even to-day.

All this led to the need for an increase of personnel, in addition to

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those in the calculation, design and testing departments, who were engaged on the development and gradual standardization of machines and apparatus—assistants whose function it was to select from the available types those which were most suitable for a particular job, to suggest modifications, if necessary, and skilfully to combine the whole to form a uniform installation, and on this basis to prepare a quotation to the client, negotiate the order and follow it through with the works. The wide scope of this task necessitated the employment of technical staff on an ever-increasing scale. These, in the course of their duties, gained experience by observation of the behaviour of the machines under working conditions. Whereas at first the technical staff was still a part of the works, the ever-expanding application of electricity and its penetration into industry and the public services resulted in these engineers being detached from the works, and becoming an independent unit of the organisation.

This detachment of the engineering staff from the works and its formation into a separate unit, is a development which took place in the electrical industry for the first time in industrial history, and is symptomatic of the rôle it was destined to play. After lengthy preparation, the new organisation was finally introduced at the Charlottenburg Works in the autumn of 1894. An Estimating and Sales Department was formed, incorporating the various quotation departments which had meanwhile come into being, each handling a different section of the business—the sections in most cases representing industries. The new department also carried the responsibility for the erection of the plant on site, and for the training of its erectors. It devolved on this department, moreover, to report on suitability and performance of the Firm's products, and to make timely suggestions for alterations and improvements, where necessary, to the Design and Development Departments. The organisation provided further for the establishment of a network of Branches for direct contact with clients, and for the issue of directives and instructions to the Branches for their propaganda and sales activities.

After some time the Estimating and Sales Department was separated entirely from the works' organisation of the Charlottenburg Works, and became an independent department. To distinguish it from the already existing "Department for Electric Traction," it received the name "Department for Lighting and Power." It prepared complete tenders for public and private generating stations and undertook their erection, including the buildings. The actual building work and the supply of transport equipment, water piping, boilers and the prime movers had to be placed by the department with sub-contractors, but the responsi-

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bility to the customer for satisfactory operation of the complete plant remained with the Department for Lighting and Power. On the other hand, it was the task of this department to study the manifold possibilities of electric driving, to introduce it into the mining industry and to adapt it to the special requirements of mining duty; to develop electric driving in the textile, paper and leather industries; to familiarize electrical practice with the difficult conditions prevailing in the chemical industry; to design suitable electric drives for machine tools; to introduce electric operation into steel-works, and—a most important objective—to electrify the almost limitless host of hoisting and transport machinery from passenger lifts to bulldozers. This task continued to grow in scope, and was met by Siemens & Halske—not exclusively, of course, but to a certain degree—by intensive development work, the pace of which during the last decade of the nineteenth century was positively tempestuous, and which occupied an ever-growing number of capable engineers. Under this system, in which the Head of the Works was responsible not only for the manufacturing side, but also for the staff of engineers intermediary between works and customers, the Works Manager had to be a personality whose field of vision extended beyond the merely technical sphere. The pure technician could even be a danger to the works if, as so often happens, he allows himself to become absorbed in the development of his own pet ideas. A case in point was von Hefner-Alteneck, without a doubt a remarkable brain and a man with outstanding services to his credit during the years he was guided by the overriding authority of Werner Siemens. On Werner's retirement, however, he considered that he had a claim to a partnership in the Firm, and on this request being refused, he brusquely handed in his resignation. This showed that he was deficient in those qualities which are essential for collaboration in a large organisation. It thus became necessary, after an interregnum, to look for a new manager for the Charlottenburg Works.

For the same reasons as those which led to the choice of Raps, a search for a suitable personality was made outside the ranks of the Firm's own staff. For some considerable time past, both Wilhelm von Siemens and his father had known Dr. Emil Budde, who 20 years ago had commenced his career as an unpaid lecturer on Physics at the Bonn University. He was living in Berlin as a private tutor, and was just engaged in negotiations for an appointment with the State Physical-Technical Institute, when he received Siemens & Halske's invitation to take over the management of the Charlottenburg Works.

The detachment of the Estimating and Sales Department from the works had, however, already taken place before the developments at Charlottenburg and in a branch of Siemens & Halske's activities which, in the closing decade of last century, was destined to be of considerable public interest. After the first demonstration of a small electric railway at the Berlin Trade Fair in 1879 and the opening of the experimental tramway service in Berlin-Lichterfelde in 1881, Siemens & Halske had electrified a mine railway here and there. They had also experimented at Westend, near Berlin, with a double-pole overhead-wire installation with trailing current collector, but, on the whole, progress in this department, as in so many others, had given way to stagnation. Things only began to come to life again under Schwieger's influence. He spent most of his time in Vienna with a small staff of assistants, working out plans for a number of electric tramways with underground current supply for the city of Budapest. These duly came into operation in 1889.

In the United States, on the other hand, the electrification of "rail-cars" had proceeded at a very different pace. From the very earliest days of electric services, no objection had been taken to the alleged spoiling of the appearance of the streets by overhead wires. Nor had anything been thought of spanning great bundles of telegraph wires and telephone cables across the roofs, or of erecting poles in the streets to carry power cables, so that nobody minded the conductors for the tramways being slung on cross-wires over the centre of the rails. In accordance with a design of Sprague's, current was taken to the motors by means of small contact rollers, so-called trolleys, held in contact with the overhead conductors by means of poles mounted at a slant on the roofs of the cars. Sprague—a second Scribner— had altogether quite a number of patents on the electric equipment of rail-cars, amongst which was one particularly important patent covering the mounting of the motor in the car. When, therefore, Siemens & Halske began about 1890 to give serious attention to the construction of electric railways, they found themselves in a similar situation to that which confronted them in the case of the multiple connection telephone exchanges. The AEG had secured the selling rights for Germany on the whole of the Sprague patents, was thus relieved of development work and in a position to proceed with the equipment of actual installations. For the first large-scale trial the AEG selected the municipal horse-drawn tramways in Halle, which were leased to a private company. The AEG took over the lease through a syndicate, and converted the tramways to electric operation. The results were, generally speaking, satisfactory, the installation attracted considerable attention, and became a pattern for a number of further conversions. Apart from the technical

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side, however, the transaction at Halle was a characteristic step on the way to investment business, in which the AEG now commenced to deal on a large scale.

This investment business, originally concerned solely with the building of public generating stations, found itself faced by a different set of conditions when it proceeded to attract the tramways into its sphere. When building a power station, a licence had first to be obtained from the landowner—in the majority of cases the municipality—to use the public thoroughfares for cable laying, this licence being implimented either by the manufacturing firm itself or by an associated company. In larger towns, however, which were usually the first to consider the installation of electric tramways, a licensee was as a rule already in existence, viz., the horse-drawn tramways. These were either owned by the municipality, and in that case usually leased to an undertaking, as in the case of Halle, or there was a separate company whose licence would still have several years to run, in which case the town had usually reserved the right to take over the tramways on conditions which necessitated their being completely written off beforehand. If it was therefore desired to acquire the licence, it was necessary to get possession of the licensee, i. e., to buy up his shares. A majority vote would then secure the passage of a resolution to convert the tramway undertaking to electrical operation, with a provision that the work be carried out by oneself, or an associated company. Competition in tramway electrification thus often amounted to a fight amongst purchasers for share control. Siemens & Halske frequently voiced their strong aversion to this type of transaction, but if tramway business was to be secured at all, they had no choice but to participate, and Schwieger proved himself equal to handling this business with enthusiasm and skill.

Unfortunately, these business matters increasingly diverted his attention from technical development, which was rendered very difficult not only by reason of the Sprague patents, but also by those of the American Thomson Houston Company. However, he was fortunate, like Raps with Grabe, in having an assistant in the person of the young engineer Reichel, whose energy and gift of original design quickly rendered the Firm independent of the foreign patents. By experimenting on the Siemens & Halske tramway in Lichterfelde (Berlin) he found that, contrary to the accepted opinion, a simple bow collector was quite capable of conducting the current from the overhead wire and feeding it to the motor. He soon succeeded in imparting to the collector a shape which made it a simple and reliable component, with the great advantage over the trolley of simplifying the installation of the overhead

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wires. The order for an electric tramway for Genoa provided the occasion for intensive study of the method of transmitting the power of the motor to the driving wheel of the car. Originally this had been effected by means of worm gearing, which was satisfactory but rather expensive. Further reflection and experiment suggested a solution similar to Sprague's German patent. Continued development work on the design and connection of the remaining electrical equipment led to the discovery of new solutions, so that about the middle of the 'nineties, Siemens & Halske were practically independent of the American patents, and in a position of offer to clients their own simple and reliable system of electric tramway equipment.

Enquiries and orders continued to be received by this department in increasing numbers as time went on, and as soon as the first few successful installations had shown the new means of transport to be reliable, every large city was wanting to have its electric tramways. In the end, competition among manufacturers, carried on a wave of popular enthusiasm and Stock Exchange speculation, gave rise to a veritable tramway fever. The staff of the Electric Traction Department increased by leaps and bounds. Apart from design-development work, it was above all the quotations, which were unavoidable even in cases where the prospects of receiving the order were remote, as also the civil engineering work, which weighed heavily. Tracing the line to be followed had to be carried out on site, land bought, power stations put up, rails purchased and laid, standards erected for the overhead wires and in many cases, even, paving to be put down or made good. To look after all this, it was essential to have a local office, which often enough could not even be closed when the job was completed. It frequently happened that the contract provided for a period of supervision, or that the tramways had barely commenced running before enquiries were received for extensions which continued to occupy the office for an indefinite time. These developments were not confined to the homeland, although, of course, the home demand constituted the solid core of the business. But when the enquiry list of one single year contains, apart from numerous German cities, the names of Basle, Schaffhausen, Davos, Liège, Ghent, Rotterdam, Paris, Rome, Genoa, Turin, Naples, Palermo, Catania, Madrid, Barcelona, Valencia, Malaga, Saragossa, Oporto, Stockholm, Gothenburg, Copenhagen, Moscow, Warsaw, Buenos Aires, Montevideo, Caracas, Johannesburg, and Colombo, and even allowing for the fact that only a minor proportion of these enquiries matured into orders, some impression is conveyed of the amount of work which this department of business involved.

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Among these enquiries was one of almost venerable age, which in the course of time had undergone various changes, viz., the Berlin "City Railway," as it had been called, a normal-gauge railway with its own permanent way. The first plans submitted in 1880 by Werner Siemens, providing for an overhead railway along Friedrichstrasse on the New York model, but on a centrally supported gantry, fell through due to a combination of opposition and indifference on the part of those concerned. Neither the time nor, may it be said, the plans were at that period ripe for such an undertaking. Nevertheless, Werner Siemens clung with great tenacity to the idea of a City Railway, and reverted to it repeatedly. At his instigation, the Firm submitted a plan in 1891 to the Authorities for an East-West connection to supplement the more northerly City Railway, and to open up the southerly and south-westerly urban districts, which had come into being in the course of the last two decades. The original plan provided for an overhead line throughout, but it was eventually decided to build the western section of the line underground. Werner Siemens also succeeded in interesting the Deutsche Bank in the financing of the scheme, and in obtaining its agreement to take part with Siemens & Halske in the construction in the event of the plans being sanctioned. Werner Siemens did not live to see the materialization of his idea. It was not until September 1894, after long and difficult negotiations with the various departments, that an affirmative resolution was passed by the Berlin Municipal Council, and the way thrown open for a considerable engineering undertaking of several years duration, which was to enhance the reputation of the Firm and to prove a commercial success.

In the German electrical industry a movement had meanwhile set in which was without precedent in economic history. Even at the founding of the AEG there could be observed a distinct, if incipient, tendency to create a demand by making the Firm at one and the same time a manufacturing concern, an electricity supply undertaking, and a bank. Not only had this device been developed to perfection by its inventor, but it had been imitated by others. In the stress of competition it had been so overdone, that whoever got caught in the whirlpool had little chance of extricating himself. Transactions offered themselves in all manner of forms, but in the end it always came to this, that the goods were supplied on credit in the first place, payment being accepted ultimately in securities, which were sold at a profit. Provided all went according to plan, a profit was made, first, on the goods, secondly, on the sale of the securities, and very frequently, finally, from the running of the newly founded undertaking. Provided all went according to plan.

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In view of their agreement of the 27th of May, 1887 with the "German Edison Company for Applied Electricity," which later became the AEG, Siemens und Halske had assumed that the AEG would launch intensive propaganda for the building of large generating stations, from which Siemens & Halske would expect to benefit by substantial orders for machinery. This turned out to be a vain hope. The AEG were very reserved, and after the completion of the Berlin Electricity Works, built only one more large power station, viz., that in Madrid, and confined themselves to putting up small stations, in regard to which they were not under any obligation to their Partners. On the other hand, they were very active in the tramway business, which had appeared to be of little importance when the agreement was negotiated, and for which, therefore, no provision had been made.

This and various obscure passages in the agreement soon led to friction, which became so acute that it was decided to refer them to a Court of Law. At the suggestion of the banks, however, parallel negotiations for an amicable settlement were continued, and resulted in 1894 in a new agreement. This cancelled the former agreement, and conferred full freedom on the AEG as regards their manufacturing programme, with the sole exception of cables, which they were not to manufacture until the 1st of January, 1898, the expiry date of the original agreement, but to buy from Siemens & Halske.

Georg Siemens had been particularly active in his endeavours to bring about a settlement between the AEG and Siemens & Halske. But the agreement, which meant the final separation of the two firms, at the same time put an end to one of his favourite ideas. The linking up of a finance corporation (AEG) with a manufacturer (Siemens & Halske) had taken place in quite a different way from that which he had visualized, since the AEG embodied both of these in itself. This was far from what he had intended seven years ago, when he lent Rathenau his assistance. Apart from this, there were no other ties which bound him to the AEG, whose departmental Heads regarded him with distrust on account of his "relatives." He therefore resigned his Chairmanship of the Board of the AEG in 1896, and severed all connection with that Company.

In the meantime, it was the tramway business which, having been omitted from the 1887 agreement, had now become the medium for the development of the new AEG policy. In Dortmund, a Company known as the "General Local Railway and Tramway Company," which had been in existence since 1881, had operated fairly extensive horse-drawn tramways in Dortmund, Duisburg and Chemnitz. The AEG

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acquired the majority of the Company's shares, and transferred its Head Office to Berlin for the sake of closer liaison between the managements.

Firms like the "General Local Railway and Tramway Co." and the "Electricity Supply Company," whose primary object was the management of the parent Company's tramways and generating stations, and to bring in new business, have been called "Operating Companies." These Operating Companies, the majority of whose shares belonged to the parent Company, obtained the capital necessary for financing extensions by the issue of fixed interest-bearing debentures. Occasionally, there would be a fair-sized public issue when one of the undertakings under their management had grown to be large enough to be a separate Limited Company, with shares dealt in on the Stock Exchange.

In a different category from the Operating Companies were the so-called Trust Companies. One of these, viz., the Bank for Electrical Undertakings in Zurich, was founded by the AEG in 1895 to assist in the financing of large projects abroad. The Bank was domiciled in Zurich out of regard for possible national prejudices, and the easier provisions of the Swiss share laws. The Bank was also to take over such of the AEG shareholdings as the Company for any reason did not wish to retain in its own portfolio, and to participate in share deals in which the AEG was interested. Since the Bank in turn was in a position to provide large amounts of ready cash by the issue of debentures, its capital resources represented a considerable increase in the financial power of the AEG.

The amounts involved can be gathered from the fact that the original share capital of the AEG of five million Marks had increased to twenty millions in 1890, and in the course of the next ten years to sixty millions. At the turn of the century, the capital of the Bank for Electrical Undertakings was thirty-three million Swiss Francs, that of the General Local Railway and Tramway Co. more than fifteen million Marks, whilst that of the Electricity Supply Company exceeded five million Marks. And it has been estimated that, in the development of the Berlin Electricity Works, whose share capital in 1900 was 25.2 million Marks, the AEG had up to that time earned 13 1/2 million Marks by the exercise of its right to purchase these shares, a further 15 millions in profit on supplies, 3 1/2 millions on Stock Exchange deals and 2 millions on administrative services, i. e., thirty-four million Marks profit in fifteen years on one client alone!

It would have been difficult enough for Siemens & Halske to hold their own against the competition of the AEG, operating with all the modern devices of expansion, but this was not the only competitor.

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Encouraged by the good reputation of their products, Schuckert & Co. had begun to follow the example of the AEG. Already in 1888 the Partnership Schuckert & Co. had been converted into a Company, of which Sigmund Schuckert, the founder, undertook the technical and Alexander Wacker the commercial management, whilst Hugo Ritter von Maffei, the "Maschinenfabrik Augsburg-Nürnberg" and the "Schaffhausensche Bankverein" were the sleeping partners. Continued expansion of the business caused the partners to convert it on 1st April, 1893 into a Limited Company with the title of "Elektrizitäts-Aktiengesellschaft vorm. Schuckert & Co." with a capital of 12 million Marks. In each of the four years from 1896 to 1899, the share capital was successively increased, so that in the year 1900 it stood at 42 million Marks. In 1895 Schuckert further founded the "Continental Company for Electrical Undertakings" in Nuremberg. This was neither a pure Operating Company nor a pure Trust Company, but a combination of both types. In its capacity as a Trust Company, it not only held the shares of undertakings founded by Schuckert, such as the Hamburg Electricity Works and others, but it also took over the management of other concerns. It went so far as to draw up plans for the projected "Suspension Railway" from Barmen to Vohwinkel, and to equip a department of its own for the construction of electric tramways. In addition to the "Continental," Schuckert formed the "Elektra A.G." in Dresden on the same lines, to cover the territory of Saxony, and the "Rheinische Schuckertgesellschaft für elektrische Industrie" in Mannheim, which was not only the Operating Company for Schuckert in South Germany, but also acquired licences, held shares in subsidiary companies and a lease of a major generating station. The organic structure of the Schuckert group was not clearly planned and had been built up somewhat hastily, but for the time being it continued to expand rapidly.

At the beginning of 1892 the machine-tool manufacturers Ludwig Loewe & Co. in Berlin, the Engineering Concern of Thyssen & Co. in Mülheim (Ruhr) and the Thomson Houston Co. of America formed the "Union Elektricitäts-Aktiengesellschaft" in Berlin with a capital of $1^1/_2$ million Marks. Eight years later the share capital of the Firm had grown to 24 millions. Based on the experience of the American parent company, the "Union" dealt chiefly with tramway business. It formed a Trust Company called the "Gesellschaft für elektrische Unternehmungen" in Berlin.

After acquiring the Tesla patents for the three-phase system of current generation in 1892, a minor firm in Cologne by the name of "Helios Aktiengesellschaft für elektrisches Licht und Telegraphenbau" also had

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the courage to plunge into investment business. In the course of six years it increased its capital from 1 to 16 million Marks. In due course it also founded its Trust Company.

In 1890 the engineer W. Lahmeyer in Frankfort founded a company in his own name, which was converted shortly afterwards into a Limited Company. The "Deutsche Gesellschaft für elektrische Unternehmungen" was formed to take charge of the investment business, and in a few years its capital had risen from 2 to 15 million Marks.

The "Aktiengesellschaft Elektrizitätswerke (vorm. O. L. Kummer & Co.)" was formed in Dresden in 1894 with a capital of 1 1/2 millions to take over a small partnership firm; six years later the capital had reached the figure of ten millions. By establishing its own Trust Company, the firm was able to participate more or less at random in the seemingly inexhaustible investment racket.

Evidently, then, the credit-fostering policy of Emil Rathenau, the founder and guiding star of the AEG, had found numerous imitators. But Rathenau had wielded with consummate skill the instrument with which he built up his edifice, and despite all his initiative and daring had always remained a prudent man of business. He had invariably taken care to ensure that his Firm stood on its own feet, and had never allowed the banks to acquire a dominant influence over his affairs. This did not apply to his competitors to the same degree. At that time it seemed to be such an easy matter to obtain orders and float companies, since every little country town wanted to have its electric power station and its tramways. In barely ten years 750 power stations had been built in Germany, and on an average every town of 40,000 inhabitants had at least one line of tramways. The capacity of the market for absorbing electricity shares seemed to be inexhaustible; in the year 1897 alone, the seven large electrical manufacturers issued shares and debentures to the value of approximately 40 million Marks, whilst the equivalent issues of their finance companies amounted to nearly 90 millions. Electricity shares were extremely popular. When the "Continental" (Schuckert subsidiary) offered 10 million Marks' worth of new shares in 1895 at the price of 142%, they were sixteenfold over-subscribed, whilst in the previous year an issue of 2 million Schuckert shares at 140% was forty-two times over-subscribed. Thus, in those days Schuckert could have had as much money as he wanted. Who can therefore be surprised that the Principals of some of these undertakings exhibited symptoms of something akin to megalomania?

Not many years after the death of their founder, Siemens & Halske found themselves caught up in just such a mad whirl of flotations, spe-

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culations and risky deals. Everything appeared at first to be successful, and if they did not want to be hopelessly left behind, they had to participate in some way and could not stand completely aside. In any case, as the only private company amongst a host of public companies, they appeared to many to be something of an anachronism. Owing to the form of the Company, it was becoming increasingly difficult to keep step with the others. The type of transactions which were now so popular demanded financial resources which were much greater than could be provided out of the manufacturing profit. The latter barely sufficed to cover extensions of the works which were necessary from time to time. What was now required was someone to advance considerable capital sums, to guarantee rates of interest or stand security. In such cases the Limited Companies simply offered their debentures to the market and the money came pouring in. Siemens & Halske were dependent on bank credits.

Part of the money, of course, could be obtained from subsidiaries. An Operating Company could be formed, in the first place, to relieve the parent Company of the administration and day-to-day running of these enterprises. Thus in 1896 the "Siemens Elektrische Betriebe, G. m. b. H." came into existence with an initial capital of 2 million Marks. In view of its expansion it was converted in 1900 into a Limited Company with a capital of 5 million Marks. It further seemed desirable to have a Trust Company, particularly in view of the overseas enterprises. A company was consequently formed in the same year called the "Schweizerische Gesellschaft für Elektrische Industrie," with registered offices in Basle, originally with a capital of 10 million Swiss Francs, which was doubled in 1898. At the same time debentures were issued which totalled 30 million Francs up to 1899. Finally, under pressure from the Deutsche Bank, the "Elektrische Licht- und Kraftanlagen A. G." was founded in Berlin in 1897, which was a combination of an Operating and Trust Company. This Company commenced business with a capital of 30 million Marks from the outset. Thus equipped, things could have carried on for some time, had it not been for other considerations, which called for a change in the structure of the Company.

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X.

THE LIMITED COMPANY

As long as Georg Siemens was Chairman of the Board of the AEG, he had refrained for obvious reasons from interfering with the financial structure of Siemens & Halske. Shortly after his resignation in 1896, however, it occurred to him that Werner Siemens had stipulated that in the event of his (Werner's) premature decease, Georg should become the guardian of his sons. This did not happen, however, as the sons were already of age, but now and again it seemed as if Georg did imagine himself to be their guardian. On more than one occasion this elderly cousin, once removed, had reminded the brothers that a bank cannot advance millions of Marks to an industrial company unless it has a clear picture of that company's financial status, which is only possible in the case of a Limited Liability Company, with representatives of the bank on the Board.

There were, moreover, other reasons in favour of the conversion of the Firm into a Limited Company. Werner Siemens had left six children, the whole of whose fortune was in the business; besides these, there was Werner's brother Karl, also with children. Then there were grand-children, and would be more; to tie up the interests of all these, in particular, those of the female descendants, with the business in such a way that at any given moment the whole of these resources were available for financial transactions, was bound to become increasingly difficult. In the case of a Limited Company, a settlement of pecuniary differences between descendants was easier to arrange, especially if care were taken to prevent shares from getting into undesirable hands. Above all, however, it was easier to attract outside capital, not only in the form of shares but also debentures, and still to remain master in one's own house, if means were exercised to ensure that a majority holding remained in the hands of representatives of the family.

That which gave the final impulse to come to a decision, however, was a plan of Rathenau's which amounted to an amalgamation of the AEG with the Union Elektrizitäts-Aktiengesellschaft. The Siemens brothers

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learned of this intention at the close of 1896; the effect of its materialization would have been to withdraw from Siemens & Halske the support of almost all the Berlin banks. The Deutsche Bank let it be known that it was prepared to wreck the plan by refusing to collaborate, but on condition that Siemens & Halske now assume the form of a Limited Company, which alone would guarantee the Firm permanent access to the capital market. This being so, the Siemens brothers and their uncle Karl decided in the spring of 1897 in principle to convert the Firm into a Limited Company. The change was made formally on the 3rd of July, 1897, with effect as from the 1st of August, 1896, by a resolution transferring the whole of the assets of the hitherto existing Company, viz., the factories in Berlin, Charlottenburg and Vienna, the Branches, all land belonging to these, buildings, machines, machine-tools, and apparatus, undertakings, either as going concerns or in the development stage, securities, bank deposits, all cash and debtors, reserves, welfare arrangements, the goodwill of the Firm and its clients, to Siemens & Halske Aktiengesellschaft, and the Limited Company also took over all liabilities of the old Company, which was allotted, as consideration for the transfer, 28,000 shares of a nominal value of 1,000 Marks each. The Siemens family took over a further 7,000 shares of the same denomination against cash. The initial capital of the Limited Company was thus 35 million Marks, all of which was in the hands of the Siemens family.

The Articles of the new Company, as entered in the Commercial Register of Berlin, sought to define the respective powers of the Board of Directors and the Managerial Board. It is the basic conception of German Company Law that the Management transacts the business of a Limited Company, whilst the Board of Directors is merely invested with certain supervisory powers, which it exercises in the interests of the shareholders. Of course, the boundary line between transacting and supervising business is very flexible; some would, therefore, allocate to "transaction" what others would consider as coming within the sphere of "supervision." In practice, the result is likely to be different, according to whether the shares are widely distributed, or held by a few persons in large blocks. In the former case the Board of Directors will confine itself to a general supervision, and leave the day-to-day conduct of business to the Management; in the other case, individual directors may be keenly alive to the fact that their fortunes depend greatly on whether the Company is flourishing, and not unnaturally wish to take a hand in achieving this object.

In the case of the Siemens brothers, these considerations were strengthened by the feeling that it was in the tradition of the parental

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heritage, that the Firm bearing the family name should never be allowed to fall under the determining influence of strangers. Accordingly, Article 22 of the Company endowed the Board of Directors with fairly wide powers. Among other things it was made incumbent on them to lay down principles for the engagement and dismissal of staff and workers, to determine the rates for profit-sharing and bonus payments, to sanction in each individual case the appointment by the Managerial Board of Sub-Managers and Heads of Departments, the opening of new Branches, and the extent of the Branch Manager's authority, moreover, the purchase, sale or mortgaging of all land. In addition, Article 25 laid down that: "The Chairman of the Board of Directors at all times has the authority to supervise in every respect the conduct of business by the Management and, accordingly, to inspect the whole of the books and documents of the Company. The Board of Directors is also empowered to delegate the exercise of the foregoing functions, as also of other special duties, to individual members and to other authorized persons outside the Management, and to fix their remuneration." This provision was expressed in a draft, which clothed a "Committee of the Board of Directors" with far-reaching authority.

Georg Siemens was indignant when he read the draft, which was submitted to him for his opinion. Cunningly devised, to be sure! On the one hand, a Limited Company is formed in order to attract outside capital, but the Management is not really responsible for the conduct of business. Instead, responsibility is vested in a "Committee of the Board of Directors," in which, of course, the family would be "amongst themselves" and able to do what they pleased unchecked. Admittedly, Rathenau's control of his undertaking was also pretty autocratic, and the banks represented on the Board of Directors had little to say, but as Chairman of the Board of Management and by his signature as Managing Director, he stood in the full glare of publicity, quite apart from the fact of his being a financier of renown and, as such, commanding the respect of the banking world. But here... The Director of the Deutsche Bank sent his cousins, by way of reply to their draft, an expression of opinion which was by no means lacking in candour: "I have never yet seen such a brake as this provision." By law, he said, it is the duty of the Board of Directors to supervise, but here the Board has the power to interfere in everything without bearing responsibility. The Management is degraded to the level of clerks. "Under all circumstances the Manager must be in authority over the personnel. They can be prevented from engaging personnel but must not be denied the right of dismissal." The Committee must not have the right to interfere in technical

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matters, or it must be laid down that its members must all be technicians. He claimed for the Deutsche Bank a seat on the Committee, as otherwise the corresponding section of the share capital would not be represented. "A right of the Committee to issue instructions to individual departments is inadmissible. Communication between the Board of Directors and the departments is only permissible through the medium of the Managers. Preferably there should be no such communication, as discipline is otherwise undermined . . . The personal conduct of negotiations is prohibited by law. The Committee would thus become the Managerial Board. If such personal negotiations are desired, the particular member of the Committee must first resign from the Board of Directors and become a Manager... Quite in general, I would say that I doubt whether any self-respecting Managerial Board would accept such instruction. I am also dubious as to whether a share in such a company would be worth having. From the point of view of the Deutsche Bank, I would warn against entering into long-term engagements with an institution which is run on these lines."

In Germany, in those days, the Director of the Deutsche Bank was a powerful man, and the threat conveyed in the last sentence was not to be overlooked. In this controversy Georg Siemens nevertheless lost the battle, for the Siemens brothers stuck to their guns, and in this argument about the constitution of the Company the elder brother, in particular, exhibited a degree of toughness and obstinacy that one would never have expected in such a quiet man. As a marginal note he wrote on his cousin's angry letter: "Since we represent the major part of the Company's capital, we claim the right to control, not only the administration, but also the technical progress, on which the future of the undertaking and the value of our property is essentially based." It happened, too, that the timing of Georg's attack was badly chosen. In the prevailing mood of the public, money was available in abundance for investment in electrical shares, so that, if necessary, they could do without the Deutsche Bank. There were enough people to whom the Siemens & Halske A.G. need only drop a hint, if they wished to form a syndicate for the emission of further shares. In the upshot, therefore, the draft remained unchanged in its essentials, and Wilhelm von Siemens retained the virtual control of the Firm in his hands.

This created a precedent in German economic history. Here was the spectacle of a Company, whose shares were soon to become one of the most important and representative of the stocks on the Exchange, and which was controlled by one family with a Head, much as in the case of a hereditary monarchy. With this system there was, of course, the danger

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that the Management, as Georg Siemens had said, would be degraded to the level of clerks. It was impossible to brush aside his misgivings, which amounted to the anticipation that capable men would not be willing to work under such a system. The danger could only be countered if the monarch possessed an abundant gift of tact, which preserved the managers from ever experiencing the feeling of being clerks. And in the German economic life of the day, tact was a commodity with a high scarcity-value (nobody knew this better than Georg Siemens). But in this case he was in error; the monarchs of the House of Siemens have shown that they possess the necessary tact.

The Principals of the Firm issued a notice in which they assured the employees that the conversion of the Siemens & Halske organisation into a Limited Company would not bring about any fundamental change in their mutual relationship. It was nevertheless unavoidable that in their dealings with staff and operatives, the Firm should now be represented by a Board of Managers which in the parlance customary in those days in large firms was known as the "Directorate." It was quite natural that the Managers of the largest and most important sections, i. e. Budde of the Charlottenburg Works and Fellinger of the Vienna Works, should be appointed to the Managerial Board. The Berlin Works, however, was not represented on the Board at that time, since Raps, who had in the meantime been made a Works Manager, was still considered to be too young for this honour; he had to be satisfied, meanwhile, with a deputy membership of the Managerial Board. Schwieger, the Chief of the Traction Department, on the other hand, was given a seat on the Board as a mark of recognition of his work. Beyond these, two representatives of the Dynamo Works, two of the Vienna Works and one from the Traction Department were appointed deputy members of the Managerial Board. The prestige of the light current department as represented by the Berlin Works, was obviously not very great.

The Managerial Board now had to have a Chairman, but the choice was a matter of some difficulty. On his merits, Budde would have been the right person for the office, but his selection would most likely have given rise to jealousy on the part of his two colleagues who had both been much longer with the Company. Above all, however, the Deutsche Bank had its own ideas on this point, and drove the Siemens brothers in a direction which was quite contrary to the tradition of the Firm.

At the suggestion of the Bank, the appointment fell to a high state official and pure administrator, in the expectation that, in virtue both of his high rank and his personality, he would exercise the necessary authority in the affairs of the Board.

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As Chairman of the Managerial Board of Siemens & Halske A. G., the former President of the Ministry of Insurance, Dr. Tonio Bödiker, Wirklicher Geheimer Rat, found himself from the outset in a difficult position. In all the history of the Firm, the Engineer had been in command. The founder had looked upon himself as an engineer and had always stressed this in all his dealings; Wilhelm von Siemens had been brought up in this tradition and the Works' Managers, now members of the Management Board, were definitely engineers by training and in outlook. By reason of the immensely rapid development of electrical science in those years, technical matters entered into nearly every business decision, and it was very unsatisfactory when the Chairman was unable to give an informed opinion. It would have been a different matter if he had spent a number of years in the shops in some non-technical occupation where he could have gained a smattering of technical knowledge, which, of course, would not have qualified him to form an independent judgment, but would have enabled him to grasp the significance of the judgments of others. As it was, he had to confine himself to taking the Chair at Board Meetings and, for the rest, to the management of the so-called "Central Department."

This Central Department was a commercial department, and an old established feature of the organisation. It was responsible for the management of finance, accountancy, cash transactions and invoicing, control of the money circulation, financing of subsidiaries, dealings with banks, ministries and competitors, the conclusion of the more important commercial agreements, the launching of new enterprises, company flotations, the preparation of the Annual Balance Sheet and Report, statistics and legal matters. In this department Bödiker found work with which he was familiar. The organisation of the Firm was a rather irregular growth; some Branches, which were not so well developed as others, seemed to have become somewhat wooden in their structure, whilst others flourished luxuriously on self-evolved principles. Above all, there was no uniformity in dealing with the personnel. Such matters as staff regulations, authority to sign, holidays, travelling expenses, staff patents, resembled a patchwork design. With a certain amount of pedantry Bödiker created the necessary uniformity. The Concern had now become so large and geographically dispersed—the Traction Department alone was in the habit of opening a further technical office every few months—that the introduction of certain bureaucratic regulations coupled with the use of printed forms, became unavoidable. It did not, of course, require a Managing Director to bring about this unification, but it had to be a man with a sense of order, and equipped with the

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requisite authority over the departments. Bödiker's work in this connection was so thorough and sound, that it lasted unimpaired for more than a generation. Moreover, the uniform pattern compelled all the branches of the tree to grow in one direction, to form a crown which could be seen from afar as a sign of its vigorous life. But the gardener with his shears made himself very unpopular; he could do nothing but prune, they said, and often enough cut away fruit branches with the others. His opponents were everywhere, not excluding the Board.

It was here that differences of opinion found expression, particularly in the case of Schwieger, the Manager of the Traction Department, and Dr. Berliner, who had taken charge of the "Department for Lighting and Power" and had meanwhile been appointed a deputy member of the Managerial Board. In the ordinary course of business these two, in particular, frequently clashed with the Chief of the Central Department who, amongst other things, was responsible for the provision of finance. It was they whose activities primarily consisted in the promotion of investment business, and they came to the Board Meetings with schemes and plans, of the importance of which they were convinced. It was not unlikely that they subsequently exchanged opinions about the timid bureaucrat, who had understood nothing of what it was all about. Raps, on the other hand, seldom appeared at the meetings of the Managerial Board, and the Berlin Works and its affairs were rarely discussed. It was almost surprising that the Annual Report for 1898/99 made reference to a large Berlin telephone exchange which was shortly due to be put into operation.

Raps had proved to be justified in his optimism concerning the opening of the No. VI Exchange in Berlin, inasmuch as there had been no set-backs of a dramatic nature. The newly designed spring-indicators proved to be generally suitable, when given proper attention by the station mechanics, who, of course, had to be given the necessary instructions. Siemens & Halske had to devote much attention to this point, since in certain departments of the Telephone Administration there seemed to be a prejudice against them. Amongst the lower grades were those who had become accustomed to working with other firms, and who allowed themselves to be incited against the competitor with his new designs. These, they said, could only disturb the course of smooth development, and result in much more work for the maintenance staff. The increasing number of solutions of the multiple switchboard problem was an argument used against Siemens & Halske by certain of the more highly-placed officials, whose word carried weight. Amongst them were those who had made an intensive study of the technical and economic

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aspects of the question, and who considered that it was at least necessary to decide as soon as possible on one uniform system for the country's telephone service—this system to become the standard, to which manufacturers would be required to conform. Many even seriously thought that the Post Office could then manufacture the instruments in its own workshops. An end was put to these speculations, however, by the appointment about 1900 of the former Cavalry General von Podbielski as successor to the Postmaster General Stephan, who was retiring after many years of service. There was considerable public indignation, at first, at the idea of a former cavalry officer administering a department of such a highly technical nature. But the new man grappled with the telephone question, in particular, with remarkable fearlessness. Amongst other things, the long overdue introduction of the two-wire telephone system was at length agreed to; further, a regulation was passed sanctioning the manufacture of extension line instruments by industrial firms and their sale or renting to subscribers. Von Podbielski had no prejudice against Siemens & Halske; in particular, the Manager of the Berlin Works was a man after his own heart.

The requirements of the German Post Office in complete telephone stations and other equipment had meanwhile reached such proportions, that they could no longer have been satisfied by home manufacturers without the active participation of Siemens & Halske. The turbulent expansion of business in those years of plenty found itself handicapped by means of communication which were much behind those of other countries, and especially those of the United States; their development was therefore a matter of urgency. The orders received at the Berlin Works alone for components for delivery against annual contracts, such as microphones, telephone instruments, bells, inductors and even complete stations, by far exceeded the capacity of the workshops, despite the continual acquisition of more room and fighting between departments for every inch of space. In addition to these annual contracts, which enabled manufacture to be distributed fairly evenly over the various months, there were the multiple connection boards, which always gave rise to congestion in the shops. Moreover, the Post Office had now prescribed the general use of the automatic clearing signal invented by Siemens & Halske. Other firms desiring to supply equipment to the Post Office had to pay considerable royalties to the originators of the device, which was unprecedented. Many people inside and outside the Post Office considered that Siemens & Halske were doing much too well, and would have been glad to see them taken down a peg or two.

As a matter of fact, there was no longer the same trepidation when

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setting new exchanges to work as formerly, when such days used to be a trial of nerves of the first order. Now, two years after the much-feared inauguration of the Berlin Exchange No. VI—although everything went well, after all—a new Exchange, No. IV, with 10,000 subscribers was ready to go into operation. This was the largest of its kind, hitherto.

The usual procedure had been followed: after checking and counter-checking, the lines had been switched over on Sunday to the new exchange, to await the opening of business on Monday morning. Although it was understood, of course, that in consequence of the many new developments in the exchanges, the old Post Office wiring system could not be equal to the more modern requirements as regards insulation and cross-talk damping, the resultant risks had not been taken too seriously. Moreover, everything went well at first. But as the morning wore on and the hour of maximum traffic density approached—dreaded by telephone engineers and known as the "rush hour"—it became evident that the operators, not being familiar with the new apparatus, were unable to cope with the traffic. The calls piled up and the wrong connections multiplied, while the faulty cables occasioned cross-talk to add to the confusion. By about eleven o'clock some thousands of inherently nervous Berlin business men had become little short of raving mad, and the telephone operators had lost their heads. Suddenly, one of the operators tore her 'phone-set from her head and fell into hysterics, an example which was infectious. A few minutes later the room was a mass of screaming and howling women, some of whom jumped up from their seats and rushed out. In the midst of the tumult the Director of Telegraphs stood with arms raised to heaven wailing: "My poor girls! my poor girls!"

Grabe, who with a few of his men had hitherto been watching operations, here and there lending a helping hand, at once realized the dangerous significance of this occurence. The touchy Berlin public was like a beast of prey, and a section of the Press in the Capital was always on the look-out for a scandal such as this as suitable fodder. This type of newspaper would place its columns at the disposal of certain experts who had known that this was bound to happen and had not ceased to utter warnings . . . Without further ceremony Grabe seized the wretched Telegraph Director—who was demanding the immediate restoration of the exchange to its former state—by the arm and led him out of the room. Here, Grabe declared that he was himself assuming command for the time being, as also the responsibility. He then instructed his men to take over the switchboards, at the same time calling for reserves to be sent by cabs from Markgrafenstrasse. The mechanics spoke to sub-

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scribers good-naturedly in their home dialect, and with the aid of a little persuasion and a Berlin joke or two succeeded in calming the storm.

By the afternoon, the situation had been so far restored to normal that it was possible for the operators to take their places again, and as everybody, from the Director downwards, was rather ashamed of the morning's performance, things went not so badly at first, and afterwards quite well. After a few days the crisis had passed.

Meanwhile new developments began to make their appearance in telephony. Hitherto, every line had required to have its own small microphone battery (local battery), usually consisting of a few dry cells. However, in 1892 telephone engineers of the Western Electric Co., U. S. A., had conceived the idea of replacing all these local batteries by a central battery, to be installed at the exchange, and of feeding the whole of the subscribers' microphones through the same wire as that which was used for speaking. This d. c. circuit would then be used to give the call signal to the exchange, thus enabling the inductor hitherto required for every station to be dispensed with—likewise that interminable grinding with which impatient subscribers were wont to relieve their feelings. The telephone station thus became much simpler and cheaper. In view of the millions of instruments involved, the economy was enormous. Of course, the introduction of the central battery system, as it was called, was not possible without a redesign of the multiple-connection boards; in a word, modifications and no end. However, Siemens & Halske had now recovered the lead in telephony, a fact which the Post Office could no longer dispute; it had taken ten years of effort and struggle, but the goal had been reached.

Apart from this progress, new developments had begun to appear in certain branches of telegraphy. In speaking of telegraphy, it is usual to think of the transmission of messages consisting of words, so that the message has to be spelt out. However, it is also possible to telegraph signs, each of which represents, not a single letter, but a complete message, e. g., a report or an instruction. Thus one stroke of the bell of a colliery winder can mean "raise," two strokes "lower" and three "halt." The scope of signalling can be increased by causing a pointer to move over the scale of a circular instrument comprising a number of sectors, each containing a message or instruction. The first dial telegraphs worked on this principle, except that the sectors represented letters only. Whole messages can be transmitted in cases where the same set of operations is continually repeated. The telegraph between the bridge of a ship and the engine-room is a case in point (engine-room telegraph).

In telegraph installations of this type, it matters less about restricting

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the wiring to a two-wire line between transmitter and receiver, since the distances to be covered are, as a rule, not great, than that the signals should be received immediately, and absolutely reliably. A receiver embodying these qualities had already been designed by von Hefner-Alteneck in the early 'eighties and a patent applied for. The principle on which it was designed was retained right into the first decade of the twentieth century. Known as the three-, and later six-roller system, it formed the basis of a flourishing business, and met all requirements of a dial telegraph for short distances.

The attitude of mining and marine engineers to electricity was similar, in that their general conservatism in technical matters led them to adopt a negative attitude to electric signalling. In view of the relative proximity of the stations involved, they were of the opinion that they could continue to use the existing means of signalling, and save themselves the trouble of learning a new technique, which appeared to be obscure, sensitive and unreliable. It had to be admitted that by involving exposure to widely fluctuating temperatures, attacks of salt water ranging from mere dampness to complete flooding, incrustation by coal dust and oil, coupled with rough treatment, the operating conditions presented the young electrical industry with problems which often seemed insoluble. And since, in mining and shipping, absolute reliability of the signalling equipment is a sine qua non, the early refusal to consider electric signalling was comprehensible.

For transmitting the orders and cyphers necessary for the training of the guns, stationary artillery such as is installed in forts had been in the habit of using the same simple methods as the mobile artillery. However, with the increasing calibre of the guns, the correspondingly greater distances between individual guns and between them and the firing base, coupled with the introduction of covered-in turrets, the transmission of orders by optical or acoustic signals became more and more difficult. The greater range necessitated the use of special devices for range-finding and calculating the data for training the gun, which could not be left to the gunner to operate. Finally, it was a natural requirement that it should be possible to control a number of guns from one point, but this was feasible only with the help of special means of communication. The words "Fire Control Station," as the expression of this desire, cropped up at an early stage of the development work to be described later. With the introduction of the practice of mounting the heavy guns of large battleships in revolving turrets instead of casements, this desire for centralized control was extended to the marine artillery. Thus it came about that a second point of contact was made between shipping

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and electricity, but with the difference that this time it was the artillerymen who expressed a desire for electrical means of communication.

Discussion between the Inspection of Marine Artillery and the Firm led in 1892 to the equipment of an experimental station on Heligoland, and as the tests proved satisfactory, it was decided to equip a complete battery of heavy artillery on the island in the same way as the test set. Instead of allowing the pointer of the instrument to move across the scale, the dial was made to rotate and the appropriate sector appeared at a window in the casing. In the case of the cypher instruments, the dial carried the numbers 0 to 9; all three-figure numbers could therefore be indicated by three instruments placed side by side. Three such groups of three each, could provide all the numbers required by one gun for elevation and lateral training of the barrel; a further instrument was needed for such orders as "fire," "interval," "live shells," etc. By means of separate sets of instruments, certain specific messages could be transmitted in the reverse direction, i. e., from the guns to fire-control. It is obvious that the equipment was rather clumsy, but the Navy was satisfied, and at once ordered two further sets, one each for Cuxhaven and Wilhelmshaven.

In the case of warships, the problem was considerably more difficult to solve than for coastal batteries. Space was very restricted, both in the control rooms, and, more particularly, in the turrets. The wiring had to be laid beneath the armoured decks and was mostly taken through narrow passages or vertical ducts, where the air temperature was very high. The earliest of the cables used for these installations were similar in construction to the submarine cables, with guttapercha insulation and steel wire armouring. The stiffness of the armouring rendered laying a very difficult matter, and guttapercha was in no way suitable to withstand the high temperatures; it just rotted and lay like tinder in the junction boxes. Approximately five years after equipping the first ships —a whole squadron— their cable networks were totally useless and had to be re-laid; meanwhile, it had been learnt how to manufacture cables with strip-iron armouring and impregnated cotton insulation. Some of the connections had to be provided in the form of detachable plugs, so as to be prepared for varying types of action (bow, stern, port or starboard broadside engagements), in which case transmitters and receivers were to be combined in appropriate groups by means of the plug connections. This primitive arrangement was, of course, not satisfactory. The loose ends of the cables with the plugs sustained damage, which resulted in their replacement by fixed change-over switches. Eventually, this led to the development of so-called "artillery switchgear."

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Most inconvenient of all, however, were the instruments and apparatus, by reason of their bulkiness. The commander found himself surrounded at his action station by a battery of circular drums, so that he could hardly move. Hand-in-hand with the Navy, therefore, and retaining the six-roller system, apparatus was designed in which an endless strip moved up and down in a narrow, vertical column with a frontal window, thus making it possible to accommodate a great number of figures or instructions in a single receiver. Simultaneously, the transmitters were better adapted to the unavoidably rough treatment to which they would be subjected in a naval action.

Now that the Artillery had smoothed the path of electricity to the warship, Navigation followed in its wake. After the pattern of the original dial instruments, but with the necessary modifications, there came in succession the engine-room telegraph, linking engine room with the commander on the bridge; the boiler-room telegraph, for the control and adjustment of the steam supply to suit prospective requirements; the rudder telegraph for transmitting orders to the helmsman, and the rudder indicator instrument for checking back. Finally, too, the telephone was added to facilitate communication between different stations on the ship. It was only in the rarest cases, of course, that the telephone could be used in the form familiar on land. On warships, the telephone instrument had to be water-tight, constructed of metal throughout, and with earpieces of sound-proof construction for excluding extraneous noises, such as the unavoidable noise of battle, and so designed as to leave both hands free when speaking. There was also a demand for loud-speaking telephones. As there were no such things as amplifiers in those days, special microphones were used which were capable of carrying a heavy current, and a number of telephones were connected together in a group with their receiver caps directed to one common earpiece. Thus, whilst the application of power current in warships had been confined in the first place to lighting, a veritable network of many-cored cables was installed for communication purposes.

In the sphere of power current, Siemens & Halske had to hold their own not only against the six other large electrical manufacturers, but against a whole series of specialist competitors, amongst which were firms of considerable repute. In telephony they likewise had to fight hard for their share of the market, but as regards the Navy they enjoyed a virtual monopoly. The Admiralty took a keen interest in these matters, and accepted the unavoidable initial failures and disappointments as part of the bargain. It assisted the development work undertaken by Siemens & Halske in every possible way, so that their common labours

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soon engendered an atmosphere of mutual trust. Since the Navy was satisfied with Siemens & Halske's efforts, and was not of the opinion that prices were too high, it did not feel called upon to approach the Firm's competitors, particularly as none of them had made any serious attempt to produce this class of equipment. In the interests of national Defence, it also appeared to be desirable to restrict the circle of those engaged in this work to as few as possible. At the same time, Raps personally was intensely attracted by the technical possibilities inherent in the further development of fire control. He did not confine himself merely to the search for solutions of the problems immediately to hand, but took a wide interest in the general problem of shooting at a moving target whilst the gun itself is not only travelling, but at the same time heaving and performing a kind of corkscrew movement in common with the ship on which it is mounted. However, whilst the physicist and mathematician Raps was captivated by the problem of "Shooting with Moving Guns," to quote the title of his memorandum to the Admiralty, the Works Manager Raps had to wrestle with the still more difficult problem of how to deal with the orders resulting from the Navy's extensive construction programme in the face of the insufferable congestion prevailing in the Berlin Works.

Some considerable time before this, plans had been laid to relieve this situation by the removal of the Incandescent Lamp Works to other premises. Although up till then no radical change had taken place in the manufacture of the carbon filament lamp, the annual production figure increased from half a million in 1890 to about two millions in 1898; added to this from 1895 onwards was the rapidly expanding manufacture of Röntgen tubes, and the news of the invention of the Nernst Lamp indicated that things were stirring elsewhere, and that the days of the comfortable manufacture of the old-fashioned carbon filament lamp were drawing to a close. Research was needed with a view to discovering means of improving on the existing principle of the filament lamp, or of replacing it by something different. This necessitated the equipment of new laboratories and testing stations, as well as new manufacturing plant; in other words, it was time to prepare for a future which was probably not very far off. It was therefore decided to build a spacious new factory on the site in Helmholtzstrasse which had been acquired in 1893 and was in the immediate neighbourhood of the Charlottenburg Works. In the spring of 1899 the new factory was taken over by the Lamp Works, which at the same time became an independent unit.

Like the Lamp Works, the Railway Signalling Department had gone the even tenour of its way for some time past. It had specialized on one

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particular line to such an extent as to become a distinctly separate group. During this period, the technique of railway signalling had passed through a phase of lively development. At the commencement of the 'nineties the construction of the section block equipment had pointed the way to an innovation which turned out to be very fruitful. A danger zone in railway traffic had always been the beginning of a block section, e. g., the exit of a train from a large station. The departure signal, which allows the train to enter the first block section, must be returned to "danger" immediately the train has left. But there is no compulsion to do so, as would be exercised on the open road by the previous section. If, therefore, the signalman forgets to change the signal to "danger" or delays this movement too long, a second train could enter the section before the first had cleared it. To prevent this happening, Siemens & Halske inserted an electromagnetic coupling between the signal arm and the wires which actuate it. This coupling only connected the two parts when current was flowing through the electromagnet. By breaking a rail contact the departing train interrupted the electric current, the electromagnet released the coupling and the signal fell back to "danger." Before the signal could again be moved to "clear," the signalman had to carry out those operations which he had forgotten or thought of too late, and the following block station had to operate its block apparatus as the train passed.

Since the section block system had rendered it possible to interlock the functions of two posts which are remote from each other, it was natural to apply this system to the control of train movements in large railway stations; this resulted in the "station-block." The related functions differ, however, in this case from those on the line. In order to select a particular route for the arrival and departure of a train in a large station, for instance, and to keep it free during the passage of the train, it is necessary to separate the function of setting-up from that of clearing. A block instrument F is provided at the setting-up point, and a block instrument A at the clearing point, the two being interconnected. When the signalman at F has set up the route, he must block it to A and is only then in a position to operate the signal for the train to enter the sector. In doing so, however, he has, as it were, simultaneously cut off his retreat, for the sector can no longer be cleared by himself alone. The interlocks are not released until A, who alone can judge whether this is permissible, has blocked back to F. Innumerable station blocks can be built up on this principle, and the operation of large stations would be impossible without them. The pioneer work carried out in those years by Siemens & Halske laid the foundation for subsequent developments.

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Small electric motors had meanwhile been designed which could be run from accumulator batteries and, when suitably enclosed, mounted on the track for operating points and signals in place of the long rods and wires used hitherto. In 1895 the Firm succeeded in persuading the timid Prussian Railway Authorities to place an order for an experimental electrically operated signal box for Westend Station, Berlin, comprising 16 points and 4 signals. The trials were successful, and with improvements added in the light of further experience, others of the Federal German States, as well as numerous foreign railway authorities, commenced to take a keen interest in electric signalling, leading to numerous enquiries and orders. Amongst others, the States of Bavaria and Württemberg each ordered a large electrical frame for Munich and Untertürkheim, both of which were in operation by the spring of 1897.

In this branch of engineering Siemens & Halske undoubtedly held the lead in Germany. They consequently had not only a privileged position in the home market, but enjoyed a deservedly high reputation amongst the countries of the European Continent. No wonder that, as the turnover increased from year to year, the framework of the old Berlin Works was in danger of being strained to bursting point. To add to the strain, there were the insistent demands for more and more space for the manufacture of multiple-connection telephone equipment, and the rising sales in almost all the departments with which the Berlin Works were concerned. A basic solution of the space question was imperative. The decision was therefore taken to build a new Works on the still available land adjoining Helmholtzstrasse in Charlottenburg, alongside the recently erected Incandescent Lamp Works. The former "Block Department" of the Berlin Works took up its quarters in the new building in 1900. It became a completely independent unit with the name of "Block Works," with Pfeil as Works Manager.

The Berlin Works, it should be said, was not the only one which was suffering from congestion; the Charlottenburg Works was also beginning to feel cramped on its fairly extensive site. In the early 'nineties the Works' Management at Charlottenburg had commenced to transform the empirical methods of manufacture to something more akin to workshop science. This reform was the work of Karl Dihlmann, who had come to the Firm in 1884 as a young engineer, and after a short period had been promoted to Manager of the Estimating Department for power station construction. His talent for Works organization led him over to the manufacturing side, and amongst other problems, it was cable manufacture which, by reason of its increasing demands on floor space, was giving him serious trouble. The turnover in cables had

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increased enormously. On the one hand, the continual opening of new power stations and electric tramways, as also extensions of existing ones, called for more and more power cable. On the other hand, the Post Office had begun to replace the overhead telephone wires by underground cables, in order to improve the appearance of the streets, reduce losses in stormy weather, and to screen the cables more effectually from disturbance caused by the electric tramways. Added to these were large orders from abroad, so that it became necessary to enlist the help of the cable works of the Floridsdorf Branch in Vienna to enable Charlottenburg to keep abreast of its commitments. As already mentioned, the use of guttapercha had been discarded as insulation for land cables in the early 'eighties. Instead, it became the practice to use impregnated jute or cotton insulation, which was sealed against moisture by seamless lead sheathing pressed round the cable. The lead sheathing was in turn served with a jute wrapping, outside which was the armouring consisting, as a rule, of two iron tapes wound spirally round the cable. In special cases, where extra mechanical strength was required, the armouring consisted of steel wires, but this rendered the cable much less flexible. At the beginning of the 'nineties it was discovered that certain kinds of paper possessed excellent insulating qualities. In the first place, the paper in strip-form was wound spirally round the copper conductor and the textile insulation applied outside; subsequently the latter was omitted altogether, the only insulation being the paper, which was also impregnated under vacuum and enclosed by the lead sheath. A little later it occurred to someone to take three of these paper-insulated conductors, to strand them together, impregnate them, and enclose them in a common lead sheath. This is the form which three-phase cable has retained to the present day.

Up till this time, communication cable had only differed from power cable by reason of its lower voltages and currents; they thus needed to have only a small cross-section and little insulation. As against this, it was possible to combine a greater number of cores in one cable. With the development of telephony, however, the picture assumed a fundamentally different aspect. For reasons to be discussed later, the most important thing in connection with communication cables was to reduce the feature known as capacitance. It was found to be lowered by omitting the impregnation and using dry paper only for the insulation, which was quite permissible in view of the low voltages. The capacitance became lower still when the paper was folded quite loosely round the wire, just sufficiently to prevent it making contact with the others, the rest of the insulation being provided by the air spaces. Such was the

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gradual development of the telephone cable with loose paper insulation, a type which was to play an important part in the future.

Since the programme of the Charlottenburg Works included the manufacture of all types of cables, but in all other respects catered only for power current users, a special sales office was opened in the Berlin Works for communication cable. The task of this department was not only to deal with sales, but to keep in touch with technical developments and arrange for their application in manufacture. The Manager of this department was Dr. Ebeling, an ambitious and high-spirited personality, whose designs were frequently thwarted by the inadequacy of the manufacturing facilities available in Charlottenburg.

It had now been decided to manufacture insulated wires at Charlottenburg. These wires were in increasing demand for installation work, and had hitherto been supplied from London by the Woolwich Cable Works. They were carried in insulated conduits and later in bare steel tubing. As regards the rubber for the insulation, Charlottenburg was still dependent on Woolwich, as it would otherwise have had to put up its own rubber works, for which there was no room. As it was, the wire required for cables and installation purposes had to be purchased from outside sources. What the Works needed was a wire-drawing plant of its own. Turn which way one would, there was the same crying need for space.

For some time past, the Firm had been on the look-out for building land. Since there was no more available in Charlottenburg, and there was no disposition, having the example of the Berlin Works in mind, to be satisfied with half-measures, the choice fell on a tract of open country to the North of the River Spree, between Charlottenburg and Spandau. Here was an extensive area known as the "Nonnenwiese." That part of it which bordered on the Spree was swampy; from there it stretched away into the sandy pine-woods of the Jungfernheide. As regards communications it was remote from anywhere; the nearest habitations were about three-quarters of an hour distant on foot. It was no easy decision to purchase land in this wilderness, as everything seemed to be against it and only one point in favour: here was room at last! But the chronic state of congestion had worn the Directors down to the point where the advantage of freedom of expansion had come to rank above everything else. In purchasing the first parcel of land in 1897, therefore, full advantage was taken of the possibilities and an area of 200 hectares (approximately 500 acres) secured. The building of a cable works was commenced the following year. Having regard to the advantages of waterborne transport of coal and raw materials, as also the finished

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products of the Works, the factory was located on the banks of the Spree. This rendered it necessary, however, to sink two thousand piles as a support for the foundations of the buildings. The new "Westend Cable works" went into operation in the second half of 1899, thus ceasing to form a part of the Charlottenburg Works and becoming an independent unit.

Somewhat apart from the main stream of electrical development and, therefore, less in the public eye, was the factory of Gebr. Siemens & Co., in Charlottenburg. This operated, formally, as a separate Company, but was in reality a unit of the family concern along with the other Works. The main contribution of the Gebr. Siemens Works to electrical manufacture had been the production of arc lamp carbons, which in 1891 had undergone considerable improvement through the application of the Bremer patents. These covered the addition of certain metallic salts to the cores of the carbons, which produced a coloured light, whilst very materially increasing the brightness. A second important product was the carbon contact, and in particular the "carbon brush," for electrical machines, which began to come into general use about the middle of the 'nineties. These consisted of compressed carbon dust to which metal powder was added later, in order to increase the conductivity. Production increased hand in hand with the general expansion of the electrical industry to such an extent, that it soon became necessary to think about a major extension of the Works. A large piece of agricultural land was purchased north of Berlin, at Lichtenberg, and a new factory for carbon products erected which commenced operations in 1901.

But it was not only the manufacturing side which had needed more room. In the last few years those groups, which have been termed "Staffs" and had detached themselves from actual manufacture, had grown to such an extent that some other provision had to be made to accommodate them. The Central Department and the Traction Department were crammed into painfully tight quarters in the office wing of the Berlin Works, with which they no longer had anything to do; the Department for Lighting and Power was housed in the Charlottenburg Works (where it had originated), which now, however, required the space for its own purposes. It was therefore decided to combine the whole of this office staff in a separate Administration building, which would also make a better impression on the numerous visitors than the old, cramped and dingy rooms in the Markgrafenstrasse building. The Firm succeeded in securing a site facing the Askanischer Platz and opposite the Anhalt Railway Station. The frontage was rather narrow, but the site possessed considerable depth, and here a new building was erected in 1898 in the

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decorative style just then coming into vogue. This then became a Head Office worthy of the Firm.

Thus, in the space of a few years, the Firm had built four new factories and an imposing Head Office. It could cross the threshold of the new century with the feeling that the last decade had been one of solid achievement, and that most of the lost ground had been recovered.

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XI.

THE FRUITS OF THE MAXWELL THEOREM

In 1873, a few years before his premature death, James Clerk Maxwell, Professor of Physics at Cambridge, published a work entitled: "A Treatise on Electricity and Magnetism." In this he set down the results of ideas which had been occupying his mind for nearly ten years. He based himself on Faraday's researches and on the conceptions which had evolved from them. His object was to express these in exact mathematical form. Faraday, although acknowledged to be one of the greatest geniuses in experimentation that ever lived, did not possess the gift of expressing his ideas as mathematical formulae. Faraday was of the opinion that the electrical and magnetic forces which emanate from electrical quantities, electrical circuits and the poles of magnets are not so-called remote effects, which are directed without a medium from the point of origin to that at which they take effect. On the contrary, Faraday held that a medium was essentially connected with the phenomenon, even in cases where its presence was not apparent, as in a vacuum. In this case it must be assumed to exist; space must be invested with special qualities. The path of the electrical and magnetic forces through space had been indicated by Faraday by the lines of force already referred to, which in the aggregate represent an electrical or magnetic field. As the logical consequence of the conception of an effect which is propagated from place to place, it followed that the movement of the field in space must take place at some finite speed. Since it appeared to be impossible to measure it, the numerical value of the speed could only be a matter of conjecture; in any case it was very high.

Hitherto it had been customary to speak of closed circuits, formed by the unbroken connection of conductors, and of open circuits. The latter could consist, for example, of two bodies of opposite electrical charge, which, when connected by a conductor, would give up their charge in a brief surge of current. On the basis of Faraday's conception, Maxwell evolved the idea that such an arrangement was also a closed circuit, and that open circuits did not exist. That portion of the circuit

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which appeared to be missing was present in reality, and consisted of the electrical field. In the example chosen, the lines of force of this field spanned the space between the two charged bodies through the dielectric. When the discharge took place, the field collapsed. A waxing or waning field of this kind, in fact, every variable electrical field, corresponds to a current; Maxwell called it "displacement current."

It had long been known to physicists that an electric current gives rise to a surrounding magnetic field. Moreover, since the days of Faraday's classical experiments, it was known that a variable magnetic field induces an electrical potential in a surrounding conductor, which in turn produces a current. Proceeding from his "displacement current," Maxwell explained electric current in general as a variable electrical field. The two above-mentioned laws then assumed the following general form: A variable electrical field (current) as cause, is surrounded by a magnetic field as effect; a variable magnetic field as cause, is surrounded by an electrical field as effect. This was to apply universally, also in cases where there was no conductor in which the electric field could develop in the form of current as hitherto understood.

The mathematical equations in which Maxwell expressed the two laws each contained a constant c, which indicated a speed. This was the speed at which the reciprocal process of conversion of electrical into magnetic energy and vice versa takes place, and obviously also the propagation speed of the fields in space. For since the magnetic field had always been observed in free space, and the current, as displacement current or variable electrical field, was now no longer dependent on the presence of a conductor, it was possible to imagine, as Maxwell himself said, that the intermingled fields must emanate from a centre of excitation. It was invariably the case in physics that a disturbance was followed by restoration of the original state of equilibrium. When a stone is thrown into a pool of water or the clapper of a bell strikes the rim, trains of waves are caused to proceed in straight lines from the centre of disturbance. Similarly, said Maxwell, a rapidly varying electric field, produced by suitable means, must be the point of origin of "electromagnetic" waves which will spread at the speed c. The constant c could be calculated from Maxwell's equations by inserting suitable values for the other members; for space which is void of all matter, the result was 300,000 km/sec., the accepted speed of light. From this, Maxwell concluded that if electromagnetic waves travel at the speed of light, the ray of light which strikes our eye must be a train of electromagnetic waves.

At first, this electromagnetic theory of light, as it was subsequently

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called, attracted little attention and met with still less credence. The penetration of its mathematical wrappings was only possible to the very few in possession of the highest qualifications, and the predicted electromagnetic waves had hitherto not been observed. Amongst physicists, therefore, the Maxwell Theorem was treated as an interesting, but unproven, speculation, whilst the broad mass of the public had never even heard of it.

In 1889 Heinrich Hertz, who had studied under Helmholtz, was called as Professor of Physics from Karlsruhe to Bonn University. A year previously he had published particulars of experiments which he had carried out with very high frequency oscillations. These occur as resonance of a circuit under the action of its capacitance and inductance. Capacitance is a constant numerical value, which depends on the geometrical arrangement of the system of conductors and the physical peculiarities of the insulating medium which separates them. Capacitance could also be represented as the electrical storage capacity of the arrangement. The inductance is also a constant which determines the magnetic field resulting from the action of the current; in a certain sense it represents the magnetic storage capacity of the conductor. The quantity of electricity stored in the capacitance is discharged in the form of current into the circuit and, together with the inductance, produces a magnetic field. Thus, electrical energy is converted into magnetic, which, in turn, is converted back into the original form, and so on. The action could be compared with the play of a weight which is suspended from a spiral spring. In dancing up and down, the weight transforms its momentum into spring tension and vice versa. In the electrical circuit, the number of oscillations depends on the capacitance and inductance; the smaller their product, the higher the frequency.

In order to produce the highest possible number of oscillations, Hertz employed an arrangement with very low capacitance and inductance, in which two short metal rods or two spheres were arranged in line and interrupted by a small air-gap. The two metal bodies were charged with opposing polarities by connecting them to the secondary terminals of an inductor or transformer. When a sufficiently high value of the potential had been attained, the discharge took place by a flash-over at the air-gap. For the duration of the spark, exceedingly rapid oscillations, as described, would occur in the circuit represented by the two rods or spheres ("dipole"). Although this circuit was apparently open, it was in reality a closed circuit in the Maxwellian sense, in which the missing portion is represented by the lines of electric force stretching between the metallic bodies of the dipole. And as long as the circuit continues

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to oscillate, this very rapidly variable electric field in the neighbourhood of the dipole is, as Maxwell predicted, the point of origin of trains of electromagnetic waves, in that it produces a magnetic field and this an electrical field, and so forth. By using small test-circuits, the natural frequency of which was adjusted to that of the dipole, Hertz succeeded in demonstrating the existence of electromagnetic fields as a consequence of the wave trains at all points of the laboratory. As Hertz was able to show, the waves conformed to the optical laws. They could be diffracted, refracted and reflected, and did not behave otherwise than millionfold enlarged light waves, in the same way as the dipole can be looked upon as a millionfold radiating atom.

In a Paper entitled "Concerning Rays of Electric Power," which he submitted to the Berlin Academy of Sciences on 13th December, 1888, Hertz presented a full report on the results of the experiments performed to-date, which created a tremendous sensation. These experiments were repeated and extended throughout the world, and it was everywhere regretted that Maxwell had not lived to witness the triumph of seeing his electromagnetic light theorem vindicated.

In the eyes of the physicists, this vindication was the most important aspect of Hertz's experiments. Not only did optics become a branch of electricity, but this itself had acquired a new foundation upon which a comprehensive edifice could be built. But it was not long before considerations of a very practical nature began to spring from the knowledge thus gained.

To begin with, it was remembered that years ago, phenomena had been observed on long telegraph and telephone lines, which in the light of Maxwell's theory were capable of a new explanation. As already related, telegraphing over long submarine cable lines met with considerable difficulties due to the charging and discharging of the cable at each current impulse in consequence of its capacitance. As was now realized, a "wave" was propagated in this case, too, from a "centre of excitation" (the telegraphic transmitter) and travelled at a certain very high speed through the cable. In the latter half of the nineteenth century, various researchers had attempted to give precise expression to this phenomenon by means of the "Telegraph Equation," a differential equation, the integration of which was possible in certain cases, depending on the limit values assumed. In the early 'nineties scientists were commencing to apply the telegraph equation to telephone currents, whose function it is to transmit human speech over the line in the form of electrical images. As already stated, they are similar to speech in being a mixture of individual harmonic oscillations, since in speaking, a sound is characterized as

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a sum of individual oscillations which vary considerably as to amplitude and frequency. If they are impressed on the line by means of the microphone, which in this case acts as an alternating current generator, each of the individual oscillations travels over the line in the form of a train of waves, diminishing gradually in intensity in consequence of the unavoidable losses—they become attenuated. The telegraph equation shows that whilst attenuation is caused by ohmic resistance, it is enormously increased by the capacitance of the cable. This explains the earlier experience that cables are so much less suitable for telephony than overhead lines. The reason for the much greater capacitance of the cable is the close proximity of the outgoing and return conductors and the dielectric of the insulating material as compared with the large air spaces of the aerial transmission line. Moreover, attenuation of the high frequencies was greater than that of the lower, i. e., the high-frequency sounds were the first to become indistinct, and finally, the times occupied in the transmission of sounds of different frequency were different, with the result that the sounds were completely distorted in reproduction. It was impossible, in consequence, to telephone over long distances. With the usual core diameters it was impossible to make oneself understood over a greater distance than about 35 km. Using overhead aerial wires of sufficiently low resistance, i. e., of adequate thickness, on the other hand, it was possible to bridge a distance of about 600 km, although disturbance caused by atmospherics and stray currents was considerable.

Oliver Heaviside was an English telegraph engineer with an astonishing gift for mathematics. In following the discussions of the early 1890's concerning the various possibilities of integrating the telegraph equation, he had realized that the inductance of a cable, if great enough, could neutralize the detrimental effect of the capacitance. He therefore suggested inserting coils with iron cores in the line at regular intervals with a view to increasing the inductance. One or two tests were carried out by different people, but without success. Nobody had the slightest idea as to the proper size of the coils or how far apart they should be spaced.

About the turn of the century Michael J. Pupin, a Serbian national, was Professor of Electricity at the Columbia University in New York. He had studied physics in Germany and had for a time been under Helmholtz, from whom he had learned of Hertz's experiments. These had left an indelible impression on his mind. In this way he had familiarized himself with the Maxwellian conceptions, in which he was aided by his outstanding mathematical ability. In any case, he was more of a theoretician than experimentalist. In 1899 he published a work

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entitled: "Propagation of Long Electrical Waves," in which he discussed the telegraph equation under the assumption that coils were inserted in the line at regular intervals for the purpose of increasing the inductance. He also calculated the size and spacing of the coils to produce the desired diminution of the attenuation. Simultaneously, he applied for American and other patents for his idea. The American patent was the first to be granted in June of 1900. It was a curious patent, for it protected in reality nothing more than one integration of the telegraph equation. About six months later it was announced in the German press that Pupin's invention had been sold to the American Telephone and Telegraph Co. for a phantastically large sum.

Siemens & Halske were keenly interested. Raps knew Pupin from his college days, and knew that he was to be taken seriously. Wilhelm von Siemens held the American Telephone Industry in great respect, and was therefore not inclined to listen to voices in Berlin and other circles that spoke of American newspaper humbug. Raps therefore wrote to Pupin, asking for further particulars, as his Firm might possibly be interested in the non-American patents, and in that event, whether he might come and see him. Pupin replied that he had disposed of the American patents to the Telephone and Telegraph Co. for 455,000 Dollars, and that he would be quite prepared to negotiate with Siemens & Halske on a similar basis; in any case, he would be very pleased to see his old college friend again.

On hearing the actual sum from Pupin, the Management of the Firm was startled and their reaction was one of indignation. Some were of the opinion that this represented the figure proposed by Pupin as a basis of negotiations, that the deal was probably not closed, and never would be at that level. How could a charge of this magnitude ever be recovered; where was a telephone administration to be found that would be prepared to face the increased capital cost for the sake of a possible minor improvement in transmission? But at Ebeling's instigation Franke urgently advocated that Pupin at least be approached, for it was pretty certain that the Bell Company had either paid a very high price or were actively considering it, in which case there would no doubt be good reasons for doing so. Wilhelm von Siemens concurred and Raps therefore set out for New York in the spring of 1901.

Pupin's demands were not exactly modest. His price for the patents, which had not yet even been granted, was 1·6 million Marks for the countries outside America, of which 400,000 Marks was to be paid down, and the remainder in ten equal annual instalments; in addition, he stipulated a running payment of one third of the net profit accruing

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from the turnover. He showed Raps his Agreement with the Bell Company, and mentioned that they were hard at work putting his ideas into practical form. Finally, Pupin expressed his willingness to give Siemens & Halske the option, against payment of 60,000 Marks, of considering his proposals until 1st January, 1902, during which time they could carry out their own experiments, whilst he, on his part, promised not to pursue negotiations in any other direction. This gave the Firm six months to consider its position. Raps attended a number of tests, and discussed the position with responsible engineers of the Bell Company. From these he gained the impression that, according to American opinion, the Pupin patents were going to exercise a far-reaching influence on the whole telephone business. With this he departed for home.

Meanwhile they had commenced in Berlin to experiment in the laboratory with artificial cables furnished with coils in accordance with the Pupin formulae, but had not achieved satisfactory results. They therefore requested the permission of the Post Office to carry out experiments on the Berlin-Potsdam telephone cable. This line, with a length of 32 km, represented precisely the maximum limit which it was possible to span with the telephone cables of those days. Of the 28 pairs of cores, fourteen were to be equipped with coils, and the remainder without coils, as hitherto.

The preparation of the coils was a matter of considerable difficulty at first. Pupin certainly had indicated to Raps, and had confirmed in writing, that the iron must be very finely subdivided, in order to suppress the injurious influence of the eddy currents; that the corresponding coils in each branch must have exactly the same values, and that, in fact, everything depended on careful and precise workmanship. Notwithstanding this, however, no one had imagined how sensitive the electrical system would prove to be in consequence of the minute currents involved. At length, the equipment of the experimental cable was completed and at the beginning of March 1902 a party of about 25 German and foreign telephone engineers was invited to a demonstration of the pupinized cable as compared with one of the original type.

The demonstration proved to be a remarkable success. The guests were surprised at the loudness and the quality of transmission. This was especially so when it was shown to them that after cross-connecting the cores, so as to form three or even four times the original length of cable, transmission was still superior to that of the cable in its original state. The Post Office engineers realized that here was the beginning of a revolution in their telephone system.

Pupin agreed to extend the original period of the option beyond

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the 1st of January, 1902, particularly as the German patent had not been granted. On this, moreover, the fate of most of the other European patents depended, since the German examination procedure was known to be the most searching.

The delay was due, in part, to the looseness of some of the claims in Pupin's American patent applications, and, in part, to opposition which had been raised in various quarters, based on Heaviside's work. The opponents were the AEG, Felten & Guilleaume's Cable Works in Cologne and—the Post Office.

Siemens & Halske, who were now fervently hoping for Pupin's success in the struggle, requested him to come to Germany at the earliest possible moment, in order to influence matters in his favour by his personal appearance, to discuss the results thus far achieved in theory and practice, and also to conclude the licence agreement. Pupin arrived in Berlin at the beginning of July 1902. In negotiations and discussions lasting several weeks, the results obtained by Siemens & Halske were compared with the theories and the patent claims put into final shape. Pupin realized that without the assistance of Siemens & Halske he would probably have little chance of success with his claims against the very extensive investigation of the German Patent Office. He therefore agreed to a considerable reduction of his original exorbitant demands concerning the initial fixed payments, whilst his share of one third of the net profit was allowed to stand. Having concluded the Agreement with Pupin on this basis, Siemens & Halske undertook to see the patent through with the Patent Office.

In spite of the three-fold opposition, the patent was granted in May of the following year, but it was not sealed, since the opponents had at once appealed. An embittered legal battle was joined, with experts' opinion on both sides; this lasted until February of the following year, and attracted the attention of the Kaiser. Pupin appeared at the final hearing in person. He had the satisfaction of hearing the appeal rejected, and the patent declared valid. The battle had been won.

The credit for the successful ending was to a large extent due to the energy and tenacity of one man: Ebeling. On the evening of that memorable 5th of February, Ebeling said to the happy inventor: " As far as I know, that is the highest price that has ever been paid for a mathematical formula; it far exceeds the hundred oxen of the late Pythagoras. The Post Office knows very well why it led us such a dance last year, for it is now its turn to pay."

Meanwhile, numerous investigators had been occupied with the further development of Hertz's experiments. As long ago as 1890, the

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French physicist Branly had announced a method of detecting the faint electromagnetic wave fields radiated from the Hertz dipole. He filled an insulating tube with fine metal powder and inserted it in a circuit fed from a source of direct current. Ordinarily, this metal powder section was an insulator, but became a conductor when struck by the electromagnetic waves. In that case, the interstices were bridged by the resulting microscopic sparks, thus causing the particles of the powder to adhere to each other. The non-conducting state could be restored by mechanical shaking. By inserting into the "coherer" circuit a further instrument, such as a galvanometer, an alarm bell or a Morse key, Branly was now able to use the emission of electromagnetic waves for signalling. Meanwhile, of course, the distances could be no greater than those for which propagation of the waves had been detected.

In 1895, the 21-year old Physics student Guglielmo Marconi was experimenting with Hertzian waves at his father's country estate near Bologna. The impulse had been given by his Tutor Righi. Marconi endeavoured to increase the range by making the dipole much larger. To this end, he gave one of the metal bodies the form of a long vertical wire extending into the upper air, whilst the second body was connected to earth. At the receiving end he used the same arrangement, into which he inserted the Branly coherer. The transmitting and receiving wires he called Antennae, corresponding to the belief that insects use the organs to which we have given this name for the purpose of inter-communication. With this arrangement Marconi succeeded in signalling over a distance of several hundred metres.

About the same time Preece, Chief Engineer of the British Telegraphs, was looking for a reliable means of communication with certain of the West Coast lighthouses. These were built on rocky islets, and the telegraph cables hitherto employed to connect them with the mainland had repeatedly been destroyed by the breakers. He endeavoured to use the inductive action of alternating current by spanning a lengthy wire horizontally at both the transmitting and receiving ends, the two lengths parallel to each other, and feeding the transmitter wire with high-frequency a. c. There was actually a weak response in the receiver wire, provided the distance was not excessive. On reading about these experiments, Marconi wrote to Preece to say that using his own arrangement he could undertake to cover greater distances. On the strength of this he was invited to come to England, and in the summer of 1897 experiments were carried out in the Bristol Channel, in which Marconi succeeded with his antennae in telegraphing first over 5.5 km, and later over more than 16 km. The consequence was the founding of the "Wire-

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less Telegraph Co.," a Limited Company with a very youthful Italian Principal, but very powerful English backers.

At the invitation of Preece, these experiments in the Bristol Channel had also been watched by Adolf Slaby, at that time Professor of Electrical Engineering at the Technical University, Berlin. On returning home, he commenced to repeat the experiments and to extend them. He learnt how to tune the antennae to definite frequencies, i. e., wavelengths, by inserting variable coils and condensers, how to increase the energy supply to the transmitter antennae by a suitable arrangement of the spark gap, and how to deal with the very troublesome atmospheric disturbances. Kaiser Wilhelm II took an active interest in these experiments, and placed the services of men and materials from the Army at Slaby's disposal.

Ferdinand Braun, Professor of Physics at Strasbourg University, had also begun to experiment with Hertzian waves. He had very soon realized that, of the energy radiated by a train of waves during the passage of the spark in Marconi's arrangement, the amount for each individual wave was much less than for the one preceding it. The train of waves was thus severely attenuated, a circumstance which greatly impaired the total effect and the range of transmission. He therefore inserted a so-called intermediate circuit between the a. c. power and the antennae as reservoir condenser, which by reason of its high capacitance was able to absorb more energy. Being loose coupled with the antennae circuit, the transfer of energy took place gradually, with the result that the waves were attenuated less, the range increased, and the tuning facilitated. He made the further discovery that, if the point of a wire is brought into contact with a crystalline piece of certain semi-conductors, the arrangement allows current to pass in one direction only. By inserting this rectifier in the reception circuit, he succeeded in charging a condenser by means of the unidirectional microscopic current impulses of a train of waves, and to use its discharge as evidence of their presence. (For this reason the apparatus came in due course to be known as a "Detector".) The cumbersome coherer used by Branly could thus be dispensed with. Based on this and other improvements and special features, Braun, like Marconi and Slaby, evolved a system of wireless telegraphy of his own, so that the Marconi system, which predominated abroad, now found itself in opposition to the two mutually hostile German groups.

The antagonism between the two German groups was considerably heightened by the fact that, on the one hand, Slaby had concluded an agreement with the AEG for the exploitation of his patents and ex-

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perience. On the other hand, Siemens & Halske had come to an arrangement with the not too powerful finance group behind Braun, which resulted in the formation of the "Gesellschaft für drahtlose Telegraphie, System Prof. Braun und Siemens & Halske." The Head Office of this Company was in a rented house in the neighbourhood of the Berlin Works, and was for all practical purposes a department of the Siemens Firm. It carried out for Siemens & Halske all business in any way connected with wireless telegraphy, and was under obligation to purchase all manufactured parts from the Berlin Works exclusively. The atmosphere between the Wireless Company and the corresponding department of the AEG was charged with the antagonism unavoidable between keen competitors, and the patent litigation customary in such circumstances was not wanting.

The first and most important clients to be interested in the new means of communication were, of course, the Army, the Navy and the Merchant Service. Wilhelm II therefore took a lively interest in the further developments, and on several occasions expressed his displeasure that in Germany two groups should be competing with each other. This, he claimed, weakened the German position with regard to the Marconi Company which appeared to be working for a kind of world monopoly. The Kaiser was supported in this attitude by the Authorities concerned, who were anything but happy about the battle of systems between the two groups. They found it difficult to follow the constantly changing technical arguments, and would have greatly preferred to deal with one manufacturer only, who would then have had to carry the responsibility for technical decisions. Added to all this, the technical war had introduced conflict into the ranks of the Forces, in that the Army favoured Braun/Siemens, whilst the Navy held to Slaby/AEG. Thus the pressure on the two groups to collaborate became increasingly strong on all sides.

Siemens & Halske, on their part, were at first not too keen about collaboration with the AEG; the memories of earlier attempts of this kind were not encouraging. Moreover, it was said with justification that it was in the interests of technical progress and of clients that the two groups should compete in producing the best. But as in the case of Schuckert, external influences were mightier than considerations of that kind. The Kaiser patronized Slaby; Rathenau was persona grata. It also happened that Rathenau opened the conversation with Wilhelm von Siemens on the subject of collaboration, with the remark that he had just been stopped by the Kaiser, who was riding in the Tiergarten. On hearing from Rathenau of proposed negotiations with Siemens, the Kai-

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ser had voiced his great satisfaction and expressed a wish to receive a report of what he hoped would be the positive result.

This kind of pressure was difficult to resist. There was the danger that, in the case of the negotiations breaking down, Rathenau, who enjoyed the royal favour, would give the Kaiser an account which placed the blame for the failure on Siemens & Halske. And the Siemens family knew quite well that they were not in favour with the monarch, in spite of—or was it because of—their good relations with his parents.

After some further preliminaries, therefore, a 25 years' agreement with the AEG and the "Gesellschaft für drahtlose Telegraphie, System Prof. Braun und Siemens & Halske" was reached on 27th May, 1903, in which Siemens & Halske did not bind themselves directly to the AEG, but through their "friends." In accordance with the Agreement, a new Firm was founded, viz., the "Gesellschaft für drahtlose Telegraphie m. b. H.," to whom the objects were transferred which they had hitherto pursued separately, together with the register of clients, experience and patents. The new Company was bound by the terms of the Agreement to purchase everything required in the fulfilment of its orders from the two parent Companies. George Earl Arco, hitherto Slaby's assistant, was appointed Technical Director. At that time it had already become the custom to use word-combinations as telegraphic addresses. For this purpose the new Company selected the name "Telefunken," and although Wilhelm von Siemens strongly objected to the word as a linguistic monstrosity, it soon shared the rapidly growing popularity of the new enterprise and became the official style of the Firm. This is just another illustration which shows that the living power which can create—or also deform—a word is greater than all philology.

There were doubtless those in the employ of Siemens & Halske who regretted the departure of wireless telegraphy from the House of Siemens. It is also certain that this was witnessed by Wilhelm von Siemens with a heavy heart, although he would have to admit that until then Siemens & Halske had hardly commenced to give the subject serious attention. But it was not until later that it became evident how mistaken the step had been when viewed from a higher standpoint. The two innovations just reviewed, viz., Pupin's invention as the commencement of long-distance cable-telephony, and wireless telegraphy were both legitimate children of the Maxwell Theorem. They were so closely related as only brothers and sisters can be. The difference: by wire or wireless, proved later to be totally immaterial.

Although not fully appreciated at that time, the history of electricity has shown repeatedly that a new shoot will spring from the common

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trunk and endeavour to develop into a sturdy branch with a life of its own. It was the historic mission of the House of Siemens not to allow these shoots to run wild independently of the main trunk, but to cultivate and shape them to form a common crown, with a view to preserving the organic unity and life of the whole. In this case the opportunity was missed. "High Frequency" became a "special branch," also in the mental attitude of its devotees, which soon lost contact with the remainder of electrical science, much to the detriment of both, and only regained it a full generation later.

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XII.

THE BIG FUSIONS

The developments in communication engineering just described were, of course, very absorbing to those concerned, but the interests of the Firm, as was manifest from the discussions at managerial and directorial levels, were mainly concentrated on power current problems. The building of electric power stations continued to play an important rôle. Some idea of the expansion in this field during the decisive years may be gathered from the fact that, whilst the first Annual Report of the Limited Company for 1896—7 mentioned 18 power stations simultaneously under construction, that for 1901—2 refers to 88. It would not be correct, moreover, to think in this connection only in terms of the old-fashioned d. c. power plants for urban supply. Siemens & Halske built their first three-phase power plant as long ago as 1892, i. e., in the year following the Frankfort Exhibition, at Erding on the Sempt, a tributary of the Isar. The combined output of two generators of 30 kW each was transmitted for a distance of more than 1½ km at 1,500 volts. Soon afterwards the Taunus Electricity Works was opened and supplied as much as 300 kW, which was distributed by overhead lines at 5,000 volts; the total length of the system was 35 km. The Chemnitz Electricity Works was opened in 1894 with an output of 430 kW. Here, for the first time, three-phase alternating current at 2,000 volts was carried by cables; the total length of the system was 8 km. About the same time a power station was built at Wynau on the Aare, in Canton Berne. This was the first investment undertaking of the "Gesellschaft für Elektrische Industrie" in Basle. The station was planned to supply the northern tip of the Canton Berne, as also parts of Canton Solothurn, and in the first stage comprised five alternators of a total output of 3,000 kW driven by water turbines, which supplied three-phase current at 8,500 volts. In the absence in those days of laws governing the erection of poles on private land, the completion of the overhead transmission lines at first encountered considerable difficulties. The local peasantry refused to have anything to do with the undertaking and attempted to pull down

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the poles. As it was, these poles were a source of great trouble in the early stages of overland transmission. In 1895, when the line supplying Grünberg (Silesia) from Eichdorf with about 500 kW at 10,000 volts, three-phase, was put into operation, the result was numerous flashovers at the insulators, which set fire to the poles. The engineer despatched from Berlin to investigate found that the energetic Grünberg fire brigade had meanwhile trained a special squad to keep watch on the line.

About the same time Siemens & Halske began the construction of a power station at Brackpan near Johannesburg, Transvaal, for the Rand Central Electric Works. This was a Company founded in partnership with the Deutsche Bank on the basis of a concession granted to Siemens & Halske by the Boers through the Firm's representative in the Hague. Steam-driven alternators of an aggregate output of about 3,000 kW supplied three-phase current at 10,000 volts across more than 40 km of barren country to the Witwatersrand gold mines. A few years later an undertaking was founded under the title "Alta Italia" for the supply of the city of Turin and industrial environs. The aggregate power of 8,800 kW at an initial tension of 12,000 volts was distributed over a system of a total length of about 40 km. At the turn of the century the voltage was doubled, as planned.

At the time the new century opened, orders were no longer coming in so fast, although, as against this, the size of the machines was increasing continually. Whereas at the beginning of this period, direct current generators of 100—150 kW were considered large enough, their output at the beginning of the new century had risen to about 1,000 kW, whilst at this time three-phase alternators were being built for double this figure. Things reached the point where the output of the generating set was no longer limited by the generator, but by the prime mover.

Alongside the public supply stations, large industrial concerns commenced to build private generating stations, in which the lighting load was greatly subordinate to that of power. It was chiefly the mines and steelworks which soon started competition in the electrical industry, which led to the flooding of prospective clients with schemes, efficiency and cost calculations and trial installations, as a means of overcoming the suspicion and hesitancy of the leading personalities of the heavy industries in the face of untried innovations. However, it is proposed to deal with this aspect later in its own context.

Notwithstanding this lively, often tempestuous, development in the technical approach to electrical operation in the manufacturing industries, it must not be forgotten that in the decade following 1892 the centre of gravity of the application of electricity—and thus of the turnover in elec-

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trical production—lay in electric traction. Traction business far exceeded that of all other departments, also with Siemens & Halske. And of the schemes in hand, one stood out which dominated all the others in size, technical problems and economic importance, viz., the "Elevated and Underground Railway" in Berlin.

In the Traction Department of the Firm the scheme was originally known as the "City Railway." Like the original City Railway in Berlin, the new one was to be an overhead railway, but supported on steel arches in place of the older masonry construction. Those citizens of Berlin who had ever seen and "heard" the elevated railway in New York, might, however, be expected to raise objections. After the plan had received the sanction of the City Fathers, the route agreed and detailed constructional work commenced, these objections began to be voiced. Property owners along the western section, in particular, protested vociferously, as this was a well-to-do residential district. The Authorities themselves were anxious not to see the amenities and architecture of the buildings around the Kaiser Wilhelm Memorial Church spoilt by the structural work of an overhead railway. It was finally agreed to carry out the western section of the railway from Nollendorf Place onwards as an underground line. This necessitated a complete revision of the whole scheme, particularly on the financial and economic side, and delayed the start of work very considerably. Meanwhile, in accordance with the original agreement with the Deutsche Bank, the "Gesellschaft für Elektrische Hoch- und Untergrundbahnen" was founded in April 1897 with a capital of 12$^1/_2$ million Marks. Whilst this Company was nominally responsible, the constructional work was carried out by Siemens & Halske, with the additional obligation of operating the system for a year from the date of opening.

The construction of the railway confronted the Firm with hitherto unaccustomed civil engineering tasks. There was not only steelwork to be designed for station buildings, workshops and power plants, viaducts and bridges (some with considerable spans) but also difficult foundation work, in which the bed of a former prehistoric stream presented problems enough. In particular, however, it was the prevalence of wet quicksand, which made it impossible to follow any previously known procedure in the construction of the tunnels. It was therefore decided to employ an open trench with sheet steel piling, and to lower the ground water level by means of numerous artesian wells with electrically driven pumps. This method, subsequently developed and improved, was so successful that it later became the basis for an important civil engineering undertaking which was formed as an offshoot of the "Traction Department."

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New ideas were also pursued in the design and equipment of the rolling stock. Whilst retaining the standard gauge, considerations of space and a saving in weight led to the profile of the coaches being made smaller than for normal railway stock. The coaches were so arranged as to permit of rapid filling and emptying during rush hours and to have the maximum possible capacity. Trains could be made up in varying lengths, according to traffic requirements, and all motors were controlled from one or other end of the train as necessary. The operating current was direct current at 750 volts, which was fed to the motors by a third rail mounted beside the track. The arrangement proved so satisfactory in every respect that it has become a pattern for all subsequent electric underground railways. With justifiable pride, the Firm was able to state in its Annual Report for 1901—2: "On the 15th February, 1902 the Berlin Electric Elevated and Underground Railway was formally opened with a run from Warsaw Bridge to the Zoological Gardens, and over the branch line to Potsdam Place. Members of the Reich and Prussian Governments, as well as of Local Authorities, participated. The railway has become increasingly indispensable from day to day, particularly on account of its high speed of travel..." And, indeed, the original section has become the nucleus of an extensive Berlin network of high-speed lines, which has been of ever growing importance to the city.

Up till this time the electric propulsion of rail cars had been confined to industrial and mining railways, tramways, narrow-gauge lines and high-speed underground and elevated railways in cities. The application of electric traction to full-scale railways presupposed motor outputs of a different order of magnitude. A locomotive for a heavy goods or express passenger train must be capable of developing at least 1,500 h. p., whilst the output of a good sized tramway motor would amount to about one twentieth of this. At 1,500 h. p., the current required by the motors at the prevailing d. c. voltages could not be carried by overhead wires and the third rail could not be used on main-line railways. The "trolley-wire" voltage would therefore have to be increased to a multiple of what was customary, and this led, as things were then, to the experimental use of three-phase current. As long ago as 1891 Siemens & Halske had developed a three-phase traction motor, which they had built into a locomotive, with which they performed trial runs in the grounds of the Charlottenburg Works. This work had then been laid aside for a few years, as all interest became concentrated on the development of the d. c. system. Towards the end of the century, however, they began to take a renewed interest in three-phase traction. In the meantime, electrical engineers had come to hold the opinion that the success of main

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line electric traction depended on whether or not it was possible materially to increase the speed of travel, since the steam engine had now reached the limits of its capacity. Siemens & Halske therefore set themselves the task of producing a three-phase electric locomotive for high speeds. In order to test it, however, they required a suitable railway line. After some search, this was found to exist in the section Marienfelde—Zossen of the War Office line to the artillery practice grounds at Jüterbog, which the Authorities agreed to place at the Firm's disposal. However, they refused to confer this privilege on one firm alone, as this would have given it an unfair advantage over its competitors. The difficulty was solved by the formation of the "Syndicate for the Study of High-Speed Electric Railways," members of which included several Government Departments and the AEG. For the trials, each of the two Firms provided a large streamlined coach, each running on two six-wheeled bogies and driven by four three-phase motors, suspended from the axles. Current was taken from three overhead wires at 10,000 volts and stepped down to the motor voltage by a transformer in the coach. In addition to this, Siemens & Halske also ran an experimental locomotive in which the motors operated at the high tension supply voltage. In the trials, the speed was successively raised until reaching 160 km per hour, when it became apparent that any further increase was beyond the capacity of the permanent way to withstand. The trials were therefore interrupted for a time to allow rails of heavier section to be laid. On their resumption, a maximum speed of 210 km per hour was quickly attained, this being the target in view.

The public regarded the achievement as sensational, and counted it as one of the great records of mankind. Since the aeroplane was not yet in existence, it certainly was a fact that man had hitherto never moved at anything like a velocity of 60 metres per second. From the point of view of railway engineering it had been demonstrated that, given suitable construction of the permanent way, speeds of this order were feasible with orthodox two-rail rolling stock, and that there was no necessity to have recourse to phantastic constructions, such as suspension railways or monorail lines with gyroscopes. None the less, the practical yield of the experiments was meagre. There could be no question of adopting the arrangement as it stood in practice on account of the three feeder wires at the side of the track, which were impossible at points and crossings. A material increase of existing speeds, moreover, even on selected preferential lines, could not be justified economically on account of the high capital cost and operating charges involved. It had to be admitted that engineering science had once more overshot the mark of

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day-to-day requirements. As far as the Firm was concerned, the chief result of the experiments was a round of very effective publicity, of which it did not hesitate to make full use.

The continued expansion of business, in particular the investment business of the Traction Department, as also the erection of new factories, inevitably called for more capital. Siemens & Halske Ltd. thus entered the capital market only one year after its formation, increasing its share capital by 5 million Marks to 40 millions and issuing debentures to the amount of 25 million Marks at 4%. Part of this loan, however, was to be used for the redemption of the earlier loan of 1893. In the year following, a further share-issue of 5 million Marks was made, and in 1900 the capital was again increased by 9½ million Marks. Of these, 4½ millions were offered to the public, whilst 5 millions were distributed amongst members of the family in exchange for £200,000 worth of shares in Siemens Bros. Ltd., London, and 2 million Roubles in the "Russian Electrotechnical Works Siemens & Halske" in St. Petersburg. This step was also taken with the object of strengthening the ties between the parent Company and its Subsidiaries. A year previously, the Russian Firm had been converted into a Limited Company. In addition to this increase in capital, a further debenture loan was raised at a rate interest of 4½%. Money had become dearer.

At the commencement of the new century the share capital of the Firm had thus risen to 54½ million Marks; that of the AEG at the same period was 60 millions. If a comparison had to be made, this difference of 10% was not necessarily significant. But the AEG now also had more employees. In 1895 Siemens & Halske, with a total of about 7,600—workers and staff, including the Vienna Works—had still been the largest firm of electrical manufacturers. At that time the AEG employed 6,300 and Schuckert 3,100. By 1900, however, the AEG counted 17,300, as against 13,600 for Siemens & Halske and 7,400 for Schuckert. Whichever figures were taken as a basis, the comparison showed in each case that the AEG had secured the largest share of the expansion.

In itself, this expansion was enormous. Between 1895 and 1900 the number of publicly owned electrical generating stations in Germany had grown from 148, producing 34,000 kW, to 652, producing 192,000 kW. The number of electrically operated tramways had increased from 47 with 854 km of track, to 156 with 5,308 km. In the same period the total of electrical manufactures in Germany had grown in value from 155 million Marks to about 270 millions, i. e., an increase in five years of almost 75%.

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Now, the electrical industry was not only a producer, but also a very considerable user of supplies of many kinds. For its investment business it required boilers, steam engines, piping, cranes, traversers, loading tackle, etc. It gave work to waggon-builders, iron foundries, rolling mills, ironworkers, building contractors, and the like. This, in turn, stimulated coal mining, iron production, the metal trades, transport and last, but not least, banking. Finally, the electrical industry was itself a major consumer by reason of the continual extension of its factories, which it often built itself. In a word, the electrical industry was an enormous motor which in those years drove the German economy forwards.

Some idea of the state of industry in Germany in those years may be gained when it is remembered that the annual consumption of iron per head of the population rose from 91.9 to 131.7 kgs. The total consumption of copper increased from 63,800 to 108,900 tons, that of lead from 111,700 to 172,900 tons. The natural consequence of this demand for raw materials was a stiff rise in prices, e. g. cast iron from 64 to 101 Marks per ton, copper from 99 to 160, and lead from 22 to 37 Marks per hundredweight.

When prices are rising, the consumer lays in a stock, fearing that they may go still higher, and thus contributes to the rising movement. He usually continues buying until he finds himself in possession of high-priced stocks, which he is unable to use for want of orders. Raw material prices then slump, with unpleasant consequences. This is what happened then.

Prior to the fall in raw material prices, however, those of manufactured goods had already dropped to lower levels. Even before the turn of the century, the Annual Reports of the electrical manufacturers began to contain complaints of unremunerative prices. This was not to be wondered at. They had one and all built up a formidable organisation to secure business, with the consequence that in many German cities there were as many as a dozen Sales Representatives competing for every order. The really lucrative business was a thing of the past, the cream had been skimmed, and now they fought for the scraps that were left. The last of the horses of the old horse-drawn tramways had passed into the hands of the dealers, and every little town had its electricity generating station. But consumption was unable to keep up with the pace at which development had driven it. The prices of electrical goods continued to fall, likewise the volume of business, and since this always leads to an increase in the cost of manufacture, the ratio of selling prices to prime cost became progressively worse.

It commenced in May 1901 with the insolvency of a few small banks.

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In June the "Aktiengesellschaft Elektrizitätswerke vorm. Kummer & Co." was compelled to declare itself bankrupt, as nearly all the schemes and investments embarked on so light-heartedly had proved to be rotten. Their failure brought down the "Dresdner Kreditanstalt," which in turn dealt a mortal blow to the "Leipziger Bank." The failure of this respected credit institution created a veritable panic amongst the public, especially when it came to be known what risky deals and slovenly practices had contributed to the failure. The consequence was a run on the banks, and a collapse of prices on the Stock Exchange. Schuckert & Co. were glad to seize the occasion to forgo payment of a further dividend for 1900—1, and "Helios" decided to reduce their capital of 20 million Marks in ratio 5 : 1, i. e., to declare 16 million Marks' worth of shares as valueless, well-nigh an admission of bankruptcy. The Lahmeyer Company, too, which had recently appeared to be full of confidence, preferred not to pay a dividend.

In the eyes of the public it was the AEG whose credit in this crisis stood the highest. It was counted as the largest undertaking; in that year of storm and stress (1901) it had still paid out a dividend of 12%. The public confidently expected that the founder of the Firm, as inventor of the investment principle in electrical engineering finance, would succeed in preventing things from getting out of hand. It appeared as if he proposed to master the situation by the fusion of several competitors into a kind of trust. Widespread interest was, therefore, created by a public statement of the advantage of such fusions, in which it was made known that negotiations were taking place between the AEG and Schuckert & Co.

Schuckert & Co. had evidently got into difficulties, but not through the failure of the Leipzig Bank, as was at first insinuated, but due to careless management. Investment undertakings had been floated with little discrimination, especially in the electrical field abroad. The "Kontinentale Gesellschaft für Elektrische Unternehmungen," whose business it was to finance all these flotations, had had to be taken over by Schuckert, who then found themselves saddled with a mass of worthless securities which were a danger to their own solvency. In addition to this, the whole of the Firm's internal organisation seemed to be pretty confused. The agreements with the majority of the Branch Managers were so worded, that these continued to enjoy a substantial income when the Firm was losing money. Briefly, the organisation was haphazard and unsuitable; the most valuable assets were the factories. The first condition laid down by the AEG was to put the accounts on a sound basis in accordance with the AEG's commercial principles.

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This produced the shattering result that before anything else, 18 million Marks would have to be written off. It was the intention of the AEG to create a kind of pool in the first place, but the AEG shareholders believed that an immediate and a complete fusion was the real object in view. In consequence, a hail of protests descended on the Directors from shareholders, who feared that the healthy AEG-shares might be contaminated by the rotten shares of Schuckert. Acting under this pressure, Rathenau raised his demands to a point beyond what Schuckert could concede, and the negotiations broke down.

The AEG now looked round for another partner and found one in the Union Elektrizitäts-Aktiengesellschaft, which had also suffered considerably in the crisis. Of course, the "Union" was not in any real danger, as it enjoyed the support of a very powerful group of banks led by Isidor Loewe. After brief discussion the group accepted the AEG proposals, which again aimed at the conclusion of a pooling arrangement in the first place. The Agreement was inherently justified by the differing spheres of activity of the partners, for whilst the Union had concentrated chiefly on rail and tramway work, this department of the AEG had hitherto not received the same attention, at least, on the engineering side. It was evident and, indeed, openly stated that the Pool Agreement was merely the forerunner of an ultimate fusion.

In view of this development, the question arose for Siemens & Halske as to whether it could afford to continue in the rôle of splendid isolation which they had so recently extolled in their Annual Report, published in December 1902. In spite of the credits which Schuckert had meanwhile managed to obtain, it was hardly to be expected in view of his financial weakness, that he could maintain his independence indefinitely. At this juncture, moreover, "concentration" was in the air; it was in everybody's mouth, and such unanimity of voice is known to possess a great power of suggestion. The question was whether to let things take their course, with the risk of Schuckert ultimately falling a prey to the AEG, or to act immediately.

As regards power current business, Siemens & Halske were not in a good position, either. Although the intention had always been stressed to keep out of investment business as far as possible, this had not always been implemented, and in at least two cases the Firm had badly burnt its fingers. In founding the Bochum-Gelsenkirchen Tramway, the Firm had guaranteed, in addition to numerous other things, a dividend of 6% until such time as this amount had been earned by the undertaking for three successive years. In the case of the "A. G. Berlin Electric Tramways," a guarantee of 5% had been given under the same conditions.

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In one of the crisis years, these carelessly assumed obligations cost the Firm 1 1/4 million Marks. It was impossible to balance losses of this magnitude by economies in manufacture.

However, there was one factor in Siemens & Halske's calculations which the others did not possess, and which proved in these difficult years to be of decisive importance. That was the Berlin Works, so habitually looked down upon by the Power Current Departments. Here were no company flotations, no foolish guarantees, no orders accepted at any price, but solid work and money earned. Who shall say what might have been the fate of Siemens & Halske, had it not been for the work of a few energetic men who, in those ten years, had transformed a sleepy, old-fashioned workshop into a factory with a reputation which was spoken of with respect at home and abroad.

Negotiations with Schuckert were opened in January 1903 and quickly reached a decisive phase. The proposals made by the Siemens brothers were uncommon and not unpleasing to the other side, as they left the individuality of Schuckert unimpaired. The suggestion was to form a G. m. b. H. (Private Limited Company) with the two Firms as sole partners, the Siemens-Schuckertwerke. Each partner would contribute to this his power current interests, i. e., his factories for electrical machinery together with ancillary departments, sales organisations, managerial staff and representatives in Germany. This meant that Siemens & Halske contributed the Charlottenburg and Cable Works, the Traction Department, the Department for Lighting and Power with the technical offices in Germany, whilst Schuckert transferred the whole of his manufacturing facilities, including his sales organisation to the new Firm. Siemens & Halske thus retained the Berlin Works, the Block Works and the Lamp Factory, as well as the factories of Gebr. Siemens & Co. The two partners retained their investment business and financial interests. Schuckert thus became a Holding Company. The capital of Siemens-Schuckertwerke was registered at 90 million Marks, and it was laid down that 45.05 millions should belong to Siemens & Halske and 44.95 millions to Schuckert, i. e., with a small margin in favour of Siemens & Halske. At the end of a transitional period of six years, profits were to be allocated in a ratio of 55 : 45. For the first three years of the transitional period, Siemens & Halske were to receive a fixed payment out of the joint profits of 2 1/2 million Marks; in the three following years there was to be a sliding adjustment of the payments to meet the above distribution ratio. Finally, the Agreement provided that the Chairman of the Managerial Board of the new Company was to be a nominee of Siemens & Halske, and his deputy a nominee of Schuckert.

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Following the ratification of the Agreement by the two Shareholders' Meetings in March, the Siemens-Schuckertwerke came into being on 1st April, 1903. Under the leadership of Siemens & Halske, a group had thus been formed which was fully the equal of the powerful AEG group, and one which could turn its attention, in competition with the AEG, to steering the German electrical industry back into calmer waters.

It will have been observed that whereas hitherto a fusion has meant the amalgamation of two into one, in this case it resulted in two becoming three. It could also be said that whereas one customarily devoured the other, in the present instance a third was born. The difference is not without its significance. It will be understood that in the "married state" a certain amount of friction is inevitable, which could have been avoided by following the usual more brutal procedure. As long as Schuckert existed, i. e., until 1939, arguments arose from time to time between the Partners about the interpretation of the marriage contract, which required ability and good will to settle. On the other hand, these tensions proved to be wholesome, fruitful and a good preventative of stagnation.

When, early in 1903, the plans leading up to the fusion with Schuckert began to take more definite shape, Bödiker decided to retire. For some time past he had felt himself to be the target for increasing criticism, not only on the part of his colleagues, but also of the two Siemens brothers. It had become evident that the Concern had become too self-willed to be governed by the methods hitherto prescribed by the banks. This horse could only be ridden by one who had grown up in the saddle.

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XIII.

ELECTRO-CHEMISTRY

If an acid, an alkaline compound or a salt is dissolved in water, certain reactions point to the conclusion that some of the molecules of the bodies dissolved in each case are split in two. This action is known as dissociation. The proportion of split molecules to the total increases with the weakness of the solution and with rising temperature; with very great dilution the whole of the dissolved molecules are dissociated.

Disintegration follows definite laws. In the case of acids one of the two parts is the hydrogen component, the other the acid residue (the "radical"); in the case of the salts, the hydrogen is replaced by the metal peculiar to the particular salt, according to the acid from which it was formed. Moreover, it is found that the two components carry electric charges of equal intensity but opposite polarity; in the untouched molecule the two charges cancel each other out. The components are known in general as Ions, those of them that are formed from hydrogen or the metallic base and always carry a positive charge being called Cations, whilst the others, which exhibit a negative charge, are the Anions. Dissociation is quite independent of any external electrical forces; the ions are produced in every case by the making of the solution.

If, however, an electrical field is introduced into the solution by means of two metal plates, each connected to one pole of a source of continuous current, the ions commence to travel, the positive cations migrating to the negative plate (cathode) and the anions to the positive plate (anode). Having reached their respective electrodes, they give up their substance and charge. In order to maintain the electrical field, equal quantities of electricity of opposite polarities must be supplied to the electrodes. Thus a current is set up in the circuit, the metallic conductors of which merely serve to carry electricity, while the electrolytic conductor—the solution—also carries material.

Taking a solution of copper sulphate as an example, the result is a deposit of copper at the cathode. The acid radical arriving at the anode, having given up its charge, can no longer exist, and its fate depends on

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the nature of the anode. Should this be of copper, the radical will combine again with an atom of copper, torn from the anode, to form copper sulphate, is again dissociated and serves to regenerate the solution, which thus remains unchanged. Ultimately, the anode disintegrates and appears at the cathode as a deposit of copper.

As long ago as 1833 Faraday had formulated the two laws of electrolysis which bear his name, the first of which lays down that in one and the same process, the weight of material deposited is proportional to the amount of electricity supplied to the bath. The second law says that in different processes, the same quantity of electricity will produce the same equivalent weight of material, corresponding to the atomic weight and chemical valency of the substance. Thus it is possible to calculate the amount of electricity theoretically required for each electrolytic process; in practice, more is always necessary in order to compensate for unavoidable losses, the reduction of which to the lowest possible amount is the task of the electro-chemist.

By choosing suitable salts for the electrolyte it is possible to deposit coatings of various metals on others after the manner described above for copper. It was thus that "galvanic" gold, silver, copper and nickel-plating was practised at a comparatively early period. The Reader will recollect that as early as 1842 Werner Siemens, when still a young officer, discovered the electrolytic process of gold-plating with hyposulphurous salts, a patent for which he sold in England. A few years later, becoming engrossed in telegraph work, he temporarily laid his chemical studies on one side. From the various applications, however, this much had been learnt, that electrolytically produced metal was of a hitherto unknown purity. This is, of course, easy to understand. Taking silver as an example, it should, by rights, only be the silver atom which is deposited at the cathode, so that cathode silver should be chemically pure silver. In practice, this ideal is unattainable by reason of unavoidable imperfections in the process; nevertheless, the metal is still much purer than that obtained by any re-melting process.

As time went on, and the consumption of copper by the electrical industry continued to rise, users began to turn their attention more closely to this most important raw material. They discovered that the essential quality of the metal, its conductivity, depended to a high degree on its purity. Even small inclusions of lead, arsenic, antimony, nickel and cobalt lowered the conductivity to an appreciable degree. The class of copper hitherto supplied by the mills to other users was no longer good enough for the electrical industry.

Towards the end of the 'sixties, Elkington, William Siemens' first

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business connection, had taken out a British patent for the electrolytic production of copper from soluble anodes. The patent did not so much cover the principle, which was already known, as the most important essentials of the method. Since copper is not a precious metal, however, and is required in large quantities, the exploitation of the process broke down at first in consequence of inadequate current supply.

Things assumed a new aspect with the discovery of the electrodynamic principle which enabled engineering science "to generate electric current of unlimited strength cheaply and conveniently at any place where power is available." When in due course the teething troubles of power generation had been overcome, and the first reliable generators put into operation, it was not long before thoughts were turned again to the electrolytic production of copper.

In Germany, a plant of this kind operating with Gramme dynamos had been at work in Hamburg from about the middle 'seventies, being known as the "Norddeutsche Raffinerie." A little later, in October 1877, the Chief Engineer of the Government Ironworks at Oker-am-Harz by the name of Bräuning approached Werner Siemens to enquire whether he would help with the electrical equipment required in the setting up of an electrolytic copper refinery. Werner agreed at once, and expressed his willingness to share the risk of the experiment. Not unnaturally, he took a personal interest in the solution of the ensuing problems and the gradual perfection of the process, for after all, electro-chemistry was his old hobby. Since all electrolytic processes work with a heavy current but at low voltages, the first dynamo supplied to Oker in 1878 was built to generate 1,000 amps. at 3.5 volts. A current of this magnitude had never before been heard of and with the primitive measuring instruments of those days it was one, the value of which could only be ascertained by indirect means. But the plant operated successfully and was soon followed by others. Such was the commencement of the electro-chemical business of Siemens & Halske. Based on the experience gained in Oker, which, above all, pointed to the fact that the electrolytic bath must be kept in motion if a close deposit is desired, Siemens & Halske gradually evolved a process, which has come to be widely known by their name.

Siemens & Halske also installed an electrolytic copper refinery at Kalakent in conjunction with the Caucasian Copper Mine at Kedabeg belonging to Werner Siemens and his brothers. It was here, however, that particular efforts were directed, from the second half of the 'eighties until after Werner Siemens' death, to the development of a process for the electrolytic winning of copper directly from the ore. The founder of the House devoted a large part of his closing years to the study of this

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difficult problem. In "Life's Memories" he writes in connection with his plans in Kedabeg: "Furthermore, preparations are now going forward to operate the process specified by me for the conversion of low grade ores, which are not worth smelting, into refined copper by purely electrical means without the use of fuel. With this in view, large turbines of over 1,000 horsepower will have to be installed in the neighbouring Schamchor valley to drive dynamos to generate the necessary electric current. This current must be carried over the 800 meter ridge which separates Kedabeg from Schamchor to the foot of the ore mountain, where the copper will be extracted from the powdered ore and galvanically precipitated . . ."

In order to understand what this means, one must visualize the following: the copper deposit at the cathode is brought about by the adherence of the copper ions held in suspension in the electrolyte. The latter would therefore soon lose its copper, and the process would cease, if it were not for the fact that, due to the action of the acid radical, the anode dissolved and released new copper ions. If the anode is made insoluble, other means must be taken to regenerate the bath, e. g., by the continuous addition of fresh electrolyte containing copper ions. This fresh electrolyte can acquire its copper content directly from the ore. Werner Siemens had evolved a process suitable to meet these conditions and was granted a patent in 1886 and later, two patents of addition.

He was highly confident of the future of the process and visualized the beginning of a new age in electro-metallurgy. From the passage of "Life's Memories" cited above he is seen to be fully convinced of success, extensive laboratory tests having proved satisfactory. However, the first full-scale trials under operating conditions disclosed a number of serious defects. Items which seemed so simple in the laboratory, such as the design of the pumps and agitators, the water-tight seals between moving parts, the partitioning of the bath by a durable diaphragm, the filtering out of the ore from the lye—all these at that time were fraught with well-nigh insurmountable difficulties for the chemical engineer. As Werner Siemens reprovingly remarked, the people at Kedabeg were bent on making money right away with a fully operating plant, whereas he claimed to have had only an experimental installation in view. However, referring again to the above extract from "Life's Memories," it must appear doubtful whether Werner was justified in his censure. With that determination which was a part of his nature it is possible that he might have succeeded in spite of all reverses in nursing his favourite child back to health and vigour, but his death intervened. The various departments concerned with electro-chemistry were now left without

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definite leadership, particularly as at that time Wilhelm von Siemens had more pressing worries.

In the second half of the nineteenth century the consumption of copper had increased enormously, and when the beginning of the twentieth brought the additional demand of the rapidly expanding electrical industry, European production lost practically all significance by comparison with that of overseas suppliers. In the meantime, the Americans had commenced to work the enormous deposits at Lake Superior; California, Australia and Chile entered the field as competitors, and already there were encouraging reports of prospects from the southern provinces of the Congo, which were later to rank as amongst the richest copper-bearing areas in the world. The copper mined in the U. S. A. was electrolytically refined on the spot, so that the building of such plants in Europe almost ceased to have any importance.

In Chile, incidentally, there had been a renewal of efforts to win copper directly from the ore by an electrolytic process. Although the abundant deposits of oxidic copper ores in the most northern province, the Atacama Desert, have a content of not more than 1½ to 2% of copper, they are more easily mined, and are more suitable for simple electrolytic treatment than the sulphidic ores, with which all experiments had so far been fruitless. In view of this, the Chile Exploration Co., a Company under British management, commenced in 1913 to erect an electrolytic plant at Chuquicamata, which was capable in the first stage of converting 10,000 tons of ore daily into 125—150 tons of electrolytic copper. Electric current was generated in a steam-driven power plant situated for convenience of fuel transport at the coastal town of Tocopilla. The output of 40,000 kW was transmitted to the copper works over a distance of 150 km at 110,000 volts, stepped down to 5,000 volts and converted into direct current of 235 volts for the electrolytic baths in seven converters of 2,500 kW each. As will be seen, the output involved was large by comparison with earlier installations. Although the details of the process and equipment of the baths and accessories were worked out by the customer to the exclusion of Siemens & Halske as electro-chemical engineers, the contract for the supply of the whole of the mechanical and electrical equipment was awarded to their sister Firm, Siemens-Schuckertwerke, in keen competition with British and American Manufacturers. The contract involved much work of a new and interesting type. The House of Siemens in this way reaped a modest reward for the unsuccessful efforts of its founder to solve the old problem, viz., to extract the red metal from its ore by electrical means.

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At the same time as the electrolytic refining of metals, the so-called alkali-metal-chloride processes began to acquire commercial importance. The electrolytic decomposition of a solution of sodium chloride (common salt) or potassium chloride in water is accompanied by the formation of three products, viz., chlorine gas at the anode, hydrogen at the cathode, and either sodium hydroxide (caustic soda) or potassium hydroxide (potash lye) in the solution. If it be desired to procure these separately, a porous partition (diaphragm) must be inserted between anode and cathode, with the result that chlorine alone collects in the anode compartment. If the diaphragm is omitted, a further reaction immediately sets in, viz., the chlorine combines in part with the sodium of the sodium hydroxide to form common salt. In so doing, the chlorine on the one hand reverses the electrolytic process, and on the other expels the hydrogen from the sodium hydroxide, usurping its place and giving rise to sodium hypochloride which is known in the trade as Eau de Javelle.

This sodium hypochloride and its opposite number, calcium hypochloride, usually called chloride of lime, have been used for centuries past as bleaching agents for fabrics of all kinds in the textile industry and in the paper-making industry. In consequence, attention began as far back as the 'eighties of last century to be directed to the electrolysis of salt solutions, and a considerable number of inventors took up the study of the resulting problems. However, it transpired that it was not merely a question of applying the simple principles enunciated above. It was discovered that every electrolytic process is accompanied by all manner of subsidiary reactions, which, unless neutralised, render its commercial utility doubtful. The aggressiveness of chlorine, moreover, introduced a further complication.

In 1884 three Chemical Works in Germany: Matthes & Weber, Duisburg; Kunheim & Co., Berlin, and the Griesheim Chemical Works, Frankfort on the Main, had collaborated in the development of a diaphragm process for the manufacture of chlorine, hydrogen and potash lye. This led to the erection of a sizeable plant in Griesheim. In the same year the "Chemische Fabrik Elektron A.G." was founded in Frankfort under the ægis of the AEG for the exploitation of its own patents. Since, however, it was ultimately considered by the AEG to be more economical to use the cheap fuel of the Central German lignite coalfields, the main factory was transferred to Bitterfeld; as Holding Company for this and other undertakings for the manufacture of aluminium and carbide—which will be discussed later—the AEG established the "Elektrochemische Werke" in Rheinfelden and Berlin. In 1898 Griesheim and Elektron were amalgamated to form the "Chemische Fabrik

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Griesheim—Elektron," and the AEG leased to this Company the Bitterfeld and Rheinfelden plants, which were owned by the Elektrochemische Werke, for the purpose of producing alkali-metal-chloride products. It was evident that a Concern of no little importance was already taking active shape in the field of electro-chemical production.

In Vienna, a certain Dr. Kellner carried on an electro-chemical laboratory which had been granted numerous patents, and about the turn of the century it happened that contact was made between this laboratory and the Vienna Works of Siemens & Halske. These Works also included a chemical laboratory, which had originally been intended merely to cover internal requirements, but had shown itself capable of pursuing independent research. Development work had been carried out under the Kellner patents on "bleaching-electrolysers" for the production of sodium hypochloride, with sheet platinum electrodes of a special shape. A few of these electrolysers were sold to interested parties.

Schuckert, too, had been giving this subject attention for some time past, and an electro-chemical working party, led by Hess, had succeeded about 1898 after prolonged experiments in producing a bath in which a thin platinum foil anode was suspended between two graphite cathodes. This design proved to be quite practical, and became increasingly popular, especially as it had the advantage that the lye was fully usable after only one passage through the bath. Whilst this work was proceeding, Schuckert was also studying the electrolytic decomposition of water. In view of the increasing interest being taken in various countries in hydrogen for military airships and captive balloons, its production by the electrolytic process appeared to have a promising future.

It is possible to decompose water with the addition of a little sulphuric acid (H_2SO_4) by an electric current. Hydrogen is collected directly at the cathode, whilst the acid radical SO_4 appears at the anode, and separates the hydrogen from the water, re-combining it into sulphuric acid to liberate oxygen. The disadvantage of this process, however, is that the electrodes must be of platinum or a similar chemically inert metal, since iron is attacked by the sulphuric acid. It is thus preferable to use caustic soda or potassium lye. Their disintegration also gives rise, by the secondary processes described, to the separation of the water into its two constituents, and it is possible to use inexpensive iron electrodes. In view of the dimensions attained by such apparatus for larger outputs, this is quite a consideration. The main difficulty is to draw off the two gases without their mixing, for this results in the formation of oxyhydrogen gas, which is highly explosive. In the last two decades of the nineteenth century various inventors abroad took out patents for arrange-

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ments which usually amounted to the provision of suitable diaphragms.

In 1898 Hess, of Schuckert, designed an arrangement which dispensed with a porous diaphragm. He fitted a number of parallel sheets of iron into a large bath, connecting them alternately with the positive and negative poles of the supply. Over each of the sheets he placed a sheath-like cover, which was suspended from an insulator, and had a pipe outlet in its upper part for drawing off the gas. The hydrogen obtained in this way contained not more than 2 to 3% of oxygen, which was acceptable for most purposes; if required, it could be eliminated by electric ignition. Schuckert received orders from the War Ministry for numbers of these decomposition units, in particular, two for Kehl and Metz. The combination of hydrogen and oxygen, moreover, came to be used for autogenous cutting and welding, for melting precious metals and quartz, and for other industrial purposes.

The pursuit of this and other problems by Siemens & Halske had suffered for want of a definite working plan. Originally, during Werner Siemens' lifetime, such matters had been allocated to the general laboratory in Markgrafenstrasse under Frölich's management. Frölich, who was a physicist, had a young assistant, Dr. Erlwein, a chemistry graduate, who was highly gifted and full of ideas, but queer and self-willed and very difficult to fit into the organisation of a large Concern. Apart from the Markgrafenstrasse laboratory, there was an experimental station at Moabit, known as Bohneshof, where the laboratories could carry out large-scale test series under working conditions. The respective spheres of operation and competence of the two departments were not clearly defined. Frölich, in particular, consequent on Raps having taken over the Berlin Works, found himself increasingly alienated from his former development work. He became engrossed in all kinds of side lines, chief of which was the application of ozone to a multitude of different uses. Finally, on finding himself pushed rather to one side, he retired, and for some years lectured at the Berlin Technical University. His department was dissolved, and it was now intended that Erlwein should preside over the whole of the electro-chemical activities of the Berlin Works. However, notwithstanding his ability and fertile scientific imagination, he was by no means the equal of Raps and Grabe in a wider sphere, viz., that of leadership with authority. To make matters worse, he had a competitor in Vienna, the Electro-chemical Department under Engelhardt. Moreover, on the founding a year later of the Siemens-Schuckertwerke, the Electro-chemical Department of Schuckert, not being attached to any of the Works, remained outside the new combination and represented a third organisation of this kind within the Concern.

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With a view to sparing Schuckert's feelings, no doubt, Wilhelm von Siemens had not insisted on the Nuremberg Electro-chemical Department being combined immediately with that of Siemens & Halske, especially as the organisation of the latter could hardly claim to be exemplary. He decided, rather, to put his own house in order first and took advantage of the removal of the Berlin Works to Nonnendamm in 1905 to transfer the Vienna Electro-chemical Department to Berlin and amalgamate the two. Here, again, however, personal susceptibilities were allowed to stand in the way of clear assignment of authority. The new "Department for Electro-chemistry" was launched with two chiefs, Engelhardt and Erlwein, formally of equal status, each with a section of his own. As time went on, however, the stronger personality of Engelhardt proved more effective in the internal management of the department.

Amongst the assets which Engelhardt brought to the new establishment in Berlin, the most important was his connection with the business of alkali-metal-chloride electrolysis. Dr. Kellner, with whom he had collaborated in the production of sodium hypochloride in the so-called bleaching electrolyser, had meanwhile died. During his lifetime, however, his assistant, Dr. Billiter, had made a close study of how to produce caustic soda or potassium lye in addition to chlorine gas and hydrogen, since the former were even then in demand as basic substances for other chemical processes, e. g., soap manufacture. As already mentioned, the electrolytic bath must have a diaphragm to prevent the chlorine from combining with the caustic soda, to enable the chlorine to collect at the anodes whilst, in addition to the lye, hydrogen is formed at the cathodes. It was a very difficult matter to find a suitable diaphragm, as evidenced by the large number of patents on the subject. The large industrial plants at Griesheim, Rheinfelden and Bitterfeld operated with diaphragms of cement. This worked, but the baths were complicated in their structure, operation and maintenance. Billiter hit upon the idea of placing the diaphragm horizontally, with the anodes above and the cathodes below. He stretched across the bath a partition of close-meshed wire netting, which he strewed with asbestos fibres or baryte-meal. This layer, the thickness of which could be varied as required, represented the diaphragm, whilst the wire netting was the cathode, the diaphragm thus lying on the cathode. Carbon anodes were immersed in the liquid in the upper part of the bath, which was continually replenished with fresh salt solution, the caustic soda or potassium lye being drawn off at the cathode chamber. Here, too, the hydrogen was collected, whilst the chlorine was drawn off from the upper chamber. Mixed with milk-of-lime in spray towers, it furnishes chloride of lime, which is most useful as

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a loosening and bleaching agent. The problem of the alkali-metal-chloride electrolyser had thus been solved in exemplary fashion by the Siemens-Billiter cell, as it was now called, which gradually superseded the older processes. It became the foundation for an important extension of the potassium industry, and a source of lucrative business for the House of Siemens.

Many years before the establishment of the new department, attention had been given in Berlin to another matter, the origin of which dated back to one of Werner Siemens' earliest inventions. It is usually classified as belonging to the field of electro-chemistry, although, strictly speaking, it has nothing to do with a chemical process, but with the borderland between physics and chemistry: the production of ozone, a particular modification of oxygen. Ozone differs from the atmospheric oxygen which we know, by reason of the fact that its molecule consists of 3 atoms of the element (O_3) instead of two (O_2) in the case of oxygen. Oxygen in this state is more aggressive than ordinary oxygen, a feature which is shown by its greater power of extermination of bacteria. In addition to being a by-product of certain chemical processes and of ultraviolet radiation, ozone is produced primarily by electric discharges in the air. Actual sparking is not essential, the preliminary silent discharge suffices; for technical reasons the latter is even preferable. On this basis, Werner Siemens had built an apparatus for making ozone as long ago as 1857.

For a long time Siemens & Halske looked upon ozone as a kind of universal agent. All kinds of processes, particularly in organic chemistry, were thought to be improved. Frölich, in his closing years with the Firm, made a close study of its bleaching properties, its effect on starch, its neutralisation of evil smells as also the creation of artificial perfumes, the extraction of nicotine from tobacco, and the ageing of alcoholic drinks. However, these investigations were not productive of business on any appreciable scale, although certain useful properties of ozone were not to be denied. Precious time was wasted in profound investigations in company with learned outsiders, who afterwards proceeded to publish equally learned articles in the journals, until one day, just at the turn of the century, big business rose above the horizon: The sterilization of drinking water.

In those days it was common for larger towns with water works of their own to use surface water. Mountain springs and ground water streams only began to be used in more recent times. The water was therefore rarely free from germs, and cholera and typhoid epidemics were always a latent danger. Based on a very favourable opinion of the

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National Health Office on a large-scale experimental plant built by Siemens & Halske, discussions were proceeding with the cities of Wiesbaden and Paderborn concerning the erection of ozone-water works. Paderborn was particularly interested by reason of the annual typhoid epidemic, which it suffered in consequence of its bad water supply. A plant was erected in which the water trickled down from towers of approximately 4 metres in height in counterflow to a stream of ascending ozone gas. The arrangement appeared to be an immediate success, and the future of the ozone business on a large scale secure.

Appearances, however, were deceptive, for in contrast to Paderborn, the installation at the Schierstein water works of the city of Wiesbaden was a total failure. The water there contained a good deal of iron, and it was not known that iron in water is precipitated by ozone as a thick brown sludge. Siemens & Halske were now expected to supply a further, fairly expensive plant to eliminate the iron from the water in advance. This they refused to do, stating that the original samples of water had given a misleading impression of the actual conditions. In the ensuing heated argument each side laid the blame on the other. The local Authorities, feeling that they had had a raw deal, lost faith in the whole idea, and warned other municipalities not to have anything to do with it. As it so happened that the water works as a body had just come to the conclusion that the safest way to obtain pure water is to tap ground water streams, the further pursuit of the idea of ozone-water works proved to be pretty hopeless, at least, so far as Germany was concerned. A modest turnover in water-sterilizing apparatus appeared to be possible in particular cases, amongst others portable equipment for fortresses and for the Navy. In addition there was a prospective field for the use of ozone for such purposes as air-conditioning theatres and assembly rooms, for neutralizing odours in covered-in markets and refrigerating rooms, in connection with the live transport of fish, and the treatment of cereal fodder to prevent it from sprouting. However, these and other similar applications were more a source of trouble than profit.

The year 1908 witnessed a cholera epidemic in St. Petersburg, which persisted for many months. The frightened public attributed the outbreak—no doubt quite rightly—to the use of water from the Neva as drinking water, and compelled the Municipal Authorities and the Council to put in hand a scheme for the ozonization of the water which had been prepared some considerable time before by Siemens & Halske. The value of the contract, which was placed jointly with Siemens & Halske and two other Firms specified by the Russians, was 2.3 million Roubles. The works were built in accordance with the Contractors'

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plans, and were in every respect a success. The rumour now spread that the St. Petersburg installation was only the first and most urgent of several similar schemes, and that it was intended to install equipment to the value of 22 million Roubles; moreover, it was said that Siemens & Halske were negotiating with the city of Paris concerning a similar scheme which was to be carried out in instalments. The result was that the AEG suddenly commenced to take an interest in the ozone business. After discussion with the departments, Wilhelm von Siemens decided that, having regard to other interests, it would not be politic to rebuff their competitor. It was therefore resolved to meet the AEG half way by founding the "Ozongesellschaft m.b.H.," in which Siemens & Halske by virtue of their years of pioneering could maintain the leadership. The new partner derived but little satisfaction from the association. The Paris contract was concluded in good time with French interests participating, and the Russian scheme of many millions, after interminable delays, was brought to a sudden end by the first World War.

In 1879 William Siemens was awarded a British patent for an electric melting furnace; the patent drawings have been preserved and illustrate two alternative forms. In both cases the furnace consisted of a crucible of refractory material which widened conically towards the top, and was provided with a cover. In the first form two horizontal electrodes were introduced through the furnace wall; the arc burning between them melted the surrounding charge. One of the electrodes was of carbon or graphite, the other of metal, and water-cooled. This was evidently intended to be the negative electrode, whilst the positive carbon electrode burned away. As in an arc lamp, a current-controlled regulator maintained the correct distance between the electrodes. In the second arrangement the electrodes were vertically above each other; the upper, movable electrode entered the furnace through the cover, the lower, stationary electrode being fitted in the base of the crucible. In this case the arc was intended to burn between the upper electrode and the charge, which, therefore, had to be able to conduct the current. Somewhat later, William Siemens gave a working demonstration of this furnace at a lecture. One pound of broken files was deposited in the crucible and the charge melted with a current of 70 amps. in 13 minutes, so that it could be poured off. In a hot state of the furnace, the second charge was melted in 8 minutes.

It was, of course, quite clear to William that there was nò question of working this process on an industrial scale. In steelworks, output is measured not in pounds but in tons. For full-scale production, therefore, the size of furnace and the amount of electricity required were at that

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time beyond contemplation. Incidentally, William and his brother Friedrich had just developed the regenerative gas furnace, which had then been introduced into full-scale operation by the two French steel makers Martin, father and son. Since then, the method employed in the production of steel in these furnaces has been known as the Siemens-Martin process. In those days, any kind of electric furnace, even if it could have been made large enough, would not have been able to compete with the Siemens-Martin furnace. In the laboratory, of course, for melting and alloying small sample quantities, the arc furnace was very serviceable. It therefore came to be used for all kinds of research work, which called for very high temperatures, such as could be produced by no other means.

One of those who made a special study of ways of utilizing the heat of the electric arc was the French chemist and later Nobel Prize winner, Henri Moissan. He caused the arc to burn in a very small chamber of refractory material, and succeeded, amongst other things, in transforming carbon in minute quantities into the crystalline form of the diamond, and in forcing it to form other, hitherto unknown, compounds.

Amongst the inorganic carbon compounds was a group, the so-called carbides, which had attracted considerable interest since 1862, when Wöhler succeeded in producing calcium carbide, CaC_2, by melting coal in the presence of an alloy of zinc and calcium. It was discovered that the addition of water to calcium carbide generated acetylene gas, which could be used, not only for lighting, but also in the place of hydrogen in oxyhydrogen gas for autogenous flame-cutting and gas welding. As yet, however, industrial exploitation was not to be thought of, since the quantities produced were too small.

In December 1892 Moissan announced that he had succeeded in producing calcium carbide by melting lime and coal together by the electric arc. This announcement coincided roughly in point of time with a report from the U.S.A. that an American electrical engineer by the name of Wilson, with little knowledge of chemistry, had been endeavouring to make metallic calcium in an electrically heated aluminium furnace. Wilson had melted lime and carbon together, but instead of producing calcium, as expected, he obtained to his disgust a blackish-brown mass, which he tipped out in the yard. Presently it commenced to rain, and then, when by chance a lighted match was thrown on the wet heap, it began to burn, and was identified as calcium carbide. Whereas the Americans took immediate steps for the industrial exploitation of this discovery by establishing the Carbide Company, Moissan's further research between 1892 and 1894 furnished European

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industrialists with the technical conditions which had to be fulfilled in order to produce a usable carbide. Immediately afterwards, the great "Carbide Run" set in all over the world.

For this, large arc furnaces were required. The arc was produced by alternating current of about 100 volts and, at first, about 1,000 amps.; later, the electric input was raised a hundred-fold. To enable these enormous inputs to be fed to the electrodes without heavy losses, each furnace was provided with its own transformer, which was placed as close as possible to the furnace. To commence with, single-phase alternating current was used, and the electrodes were arranged similarly to those in William's experimental furnace. Later it became customary to use three-phase alternating current, with the three electrodes projecting vertically through the furnace roof. The triple arc was united in the charge. This consisted of a mixture of ground anthracite and burnt lime, which combined to form calcium carbide, whilst the oxygen liberated from the lime combined with one part of carbon to form carbon monoxide, which escaped through the vent together with dust and other residual products as a yellow-brown cloud.

Thus it happened that between 1895 and 1905 carbide factories sprang up all over Europe where there was suitable hydraulic power, and the "Founder Fever," which at that time had also taken possession of the electrical industry, fastened, in particular, on this branch of it. Between 1896 and 1898, i. e., within two years, no less than a round 500 patents were issued in connection with details of the carbide process. At the instigation of Alexander Wacker, Schuckert led the van in the matter of carbide flotations. He acquired rights in the development of hydraulic power at home and abroad; reference has already been made to his undertakings in Norway. Siemens & Halske also contributed their share in the equipment of carbide factories. Shortly before the close of 1900 they built a carbide factory in conjunction with the large electric power station at Wynau on the Aare; three years after commencing to work, this factory was destroyed by fire; a little later a factory was built for the Lonzawerke at the foot of the Lötschen Valley in Wallis; this was followed by several others, some of them in Italy. The AEG also did not hesitate to use its electro-chemical experience as a stepping stone to the carbide business, not to mention numbers of foreign firms. In the picturesque Swiss valleys the air was darkened and polluted by carbide factories.

In consequence of the precipitate establishment of new works, it is not surprising that carbide became a glut on the market. It had been intended to use it for the production of acetylene gas, mainly for light-

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ing, but with the gradual extension of electric lighting, electricity became the murderer of its own offspring. As early as 1900 Siemens & Halske decided not to rebuild the carbide factory at Wynau, and the fact that Schuckert got into such difficulties in 1902 was due, inter alia, to his speculation in carbide factories. It was therefore not surprising that the interested parties began to investigate the possibility of using the existing furnaces for other purposes. For a long time past Ironmasters had experienced a call for certain alloys of iron, such as ferromanganese, silicon and chromium, which require very high temperatures for their formation, and could be produced in electric furnaces, in similar fashion to carbide, from the same constituents as were used in blast furnaces. The Ironmaster uses these ferro-alloys as an addition to the molten steel in order to purify it by de-oxydisation, and, in exact doses, to impart certain qualities to the steel. Some of the carbide factories were therefore converted into ironworks for ferro-alloys, whilst others were built specially for this purpose later on.

In this way, the carbide furnace came to be the prototype of the electric arc furnace in general. This was particularly so as regards the solution of special electrical problems, such as the manufacture of transformers for very heavy secondary currents, the carrying of these enormous currents to the adjustable electrodes by flexible conductors and the connection of the leads to the electrodes. For all these tasks the carbide furnace has been the pattern, not forgetting, also, the development of the electrodes.

Siemens & Halske were in the fortunate position of having in Gebr. Siemens & Co. a factory of their own, in which the manufacture of furnace electrodes more than compensated for the shrinking demand for arc lamp carbons, due to the gradual supersession of the arc by the incandescent lamp. The furnace electrodes were compounded of anthracite, coke, tar and pitch which were worked into a mouldable mass and pressed into the desired shape, upon which they were gas fired at about 1,100 ° C. The electrodes of the early carbide furnaces measured only a few centimetres across, gradually attaining the thickness of substantial poles, and finally of tree trunks of half a metre diameter and more than two metres in length, weighing 12 to 14 cwts.

The field of application of these large carbon electrodes had lately been widened by the development of a new electro-thermal process, which had meanwhile acquired great importance, and to study which, it will be necessary to look back a little.

Ever since the researches of Sir Humphrey Davy at the commencement of the 19th century, a metal had been known to exist, which Davy

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had called "Aluminium," but which no one had ever succeeded in producing. It was not until 1827 that the labours of Friedrich Wöhler yielded very small quantities of an apparently grey powder, from which he was then able with considerable effort, to knead the silvery solid metal in a mortar. In 1854 St. Claire-Deville and Robert Bunsen, independently of each other, endeavoured to produce the metal electrolytically from its chlorine salts. As the result of fruitless experiments with an aqueous solution, they found that the liquified salts had become dissociated, and that they must therefore respond to electrolytic treatment. The high temperature of the melt, however, produced secondary reactions, which stood in the way of complete success. Deville, therefore, simply treated the molten salt bath—without electrolysis—with metallic sodium, and was able in this way to produce aluminium, although at a cost of 50 francs per kilogramme.

In 1886 Charles Martin Hall, at that time a student in Oberlin, Ohio, conceived the idea of improving the molten flux electrolysis by melting the basic material, e. g., aluminium oxide (alumina), in the flux of another material, of which the electrolytic decomposition voltage is higher than that of alumina. By this means only the latter would be decomposed. To this end Hall used a bi-fluoric compound of aluminium and sodium, known as kryolith. It was found that with this arrangement electrolysis proceeded at much lower temperatures, and the results were altogether surprising. Hall was also able to confirm what his predecessor, Bradley, had noticed, viz., that the heat of the current was sufficient to keep the bath molten, so that no additional heating was required. These discoveries laid the foundation of the present-day aluminium industry, and in the United States it was not long before moves were made to give them practical effect.

Quite independently of Hall and a few weeks before his first publication, a French patent had been applied for, covering the same subject matter, i. e., the same object by the same means. The applicant was Paul Héroult, a French Metallurgist, who, not finding any interest for his process in France, entered the services of the Swiss Metallurgical Company in Neuhausen near Schaffhausen, as Consultant. This Company owned the hydraulic power rights of the Rhine Falls and decided to test Héroult's process at their Works.

A year later than Hall and Héroult, a chemist in the employ of the AEG, Martin Kiliani, had also experimented with the production of aluminium by molten flux electrolysis, and had learned how to control the temperature, current density and composition of the bath in order to obtain practically pure aluminium. Together with the Swiss Metal-

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lurgical Co. and other Swiss interests, the AEG now in 1888 founded the "Aluminium Industry A.G." in Neuhausen, where operations were soon commenced on a considerable scale. The AEG itself took over the sale of the aluminium products in Germany and Russia in order to popularize the new metal with users.

Héroult returned to France and, with the experience gained, built two Works, the second of which by 1895 was already dealing with an output equivalent to a consumption of 10,000 kW, which was no mean achievement for those days. France, in fact, was at that time the country with the highest aluminium production, being followed by Switzerland and England. For the year before the outbreak of the first World War the production figures for these three countries were 14,500, 10,000 and 7,600 tons respectively; the German output was a mere 1,000 tons.

At first, Siemens & Halske took little notice of the activities of the AEG in the matter of aluminium production. It was the period in which the management of the Berlin Works was somewhat out of gear. However, when it became apparent in the second half of the 'nineties that the white metal had come to stay, Erlwein was seized with a desire to make a contribution to the production of new materials, especially as the manufacture of carbide, which had then begun to assume importance, was not originally the work of Siemens.

The compound of one carbon atom and one atom of nitrogen is known to the chemist as cyan. It is not a body which is capable of existing in itself, but a constituent, similar to the acid radical, which requires hydrogen or a metal to enable it to form a stable chemical compound. Such combinations of cyan with a metal are termed cyanides, the best known of which is cyanide of potassium. Up till the year 1890 the use of this chemical was confined to a few rarely-worked processes, but suddenly consumption increased rapidly due to the discovery of a method of extracting gold and silver from their respective ores with its help. Siemens & Halske had already been engaged for some time past on experiments in the electrolytic production of gold from ores and sand, in which they employed cyanide of potassium. In this, their interests ran parallel to those of the "German Gold and Silver Refinery" in Frankfort on the Main, whose activities caused them to take a keen interest in the manufacture of this commodity. After joint deliberations and experiments with a view to producing potassium cyanide synthetically from potash, coal and nitrogen in an electrically heated pit furnace, the results of which were not entirely satisfactory, Erlwein was offered a patent in the names of two chemists, Dr. Adolf Frank and Dr. Nikodem Caro.

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As long ago as 1895, these two had ascertained the fact that at higher temperatures, atmospheric nitrogen associates with the carbides, i. e., the carbon combinations of the so-called earth-alkali metals. Earth-alkali metals are the oxides of the three metals calcium, barium and strontium, and of these it was calcium which was of most interest, since its carbide was already being manufactured. In the course of the experiments Dr. Fritz Rothe, a young assistant of the two chemists, had noticed that the desired chemical reaction, the association of the nitrogen with the carbide, occurred at a particular temperature, which in the case of calcium carbide was between 1,000 and 1,100 ° C. A process had, therefore, to be evolved in which this temperature was maintained. Of course, the immediate result was the production of calcium cyanide; from this it was a comparatively simple matter to obtain the required cyanide of potassium.

At the suggestion of the Deutsche Bank, "The Cyanide Company" was formed for the development of the process. Partners were Siemens & Halske, the Gold and Silver Refinery, and Frank. The experiments were carried out in the laboratories of the Gold and Silver Refinery. It was found that while, in accordance with Rothe's suggestions, the combination of calcium carbide and nitrogen produced potassium cyanide, carbon was also liberated. This carbon combined with the hot mass of the cyanide as it gradually cooled, forming a new compound known to the chemist as calcium cyanamid. Since it contained both lime and nitrogen, it occurred to one of the assistant chemists that it must be quite useful as a fertilizer. Tests carried out by agricultural consultants confirmed that this was the case.

Meanwhile, however, the Gold and Silver Refinery was becoming impatient: these experiments were leading nowhere! After all, the object in view was cyanide of potassium, not fertilizer, and since a simpler and purely chemical process for winning cyanide of potassium had meanwhile been discovered—or so it was thought—the Refinery declared its intention of leaving the Cyanide Company. In so doing, it found the support of a number of kindred spirits amongst the higher management of Siemens & Halske, who had begun to be critical of the whole business. With the carbide crisis at the turn of the century in mind, they pointed a warning finger at the Schuckert speculation, and professed to have had enough of electro-chemical experiments for a while.

At this juncture, Erlwein came forward with a suggestion which, in its way, was ingenious. As a chemist of many interests and with a very active brain, he was quite au fait with the endeavours which had been afoot since the days of Liebig to apply the essential mineral fertilizers

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to the hard-worked soil of countries with a high population density. Plant life requires potassium, lime, phosphoric acid and, above all, nitrogen in assimilable form. The only nitrogen fertilizer hitherto available was sodium nitrate (saltpeter), which was found in enormous deposits in Northern Chile, and had led to the growth of a thriving import trade centred in Hamburg. Then there was ammonium sulphate, a by-product of the coking ovens, but in totally inadequate quantities. However, the newly discovered "calcium-nitrogen," as Erlwein called it, was capable of becoming a first-rate mixed fertilizer, provided its production in bulk from calcium carbide was found to be economical. This could, in fact, be the salvation of the calcium carbide business. Withdraw from the Cyanide Company? No, on the contrary, if the Refinery insisted on doing so, take over their shares, and, as the majority shareholder, ensure that the experiments are carried through to the finality of a full-scale manufacturing process!

Erlwein's enthusiasm finally overcame Wilhelm von Siemens' doubts, particularly as the Deutsche Bank was persuaded to take over half of the Refinery's shares. He now applied himself with burning zeal to the search for the basic conditions for the production of calcium cyanamide on a commercial scale. He lined a large circular iron tank with refractory material, and filled it with finely ground calcium carbide. As the experiment proceeded, it was found that it was advisable to add some finished calcium cyanamide and 1—3 % of fluor spar as a catalytic agent. A narrow cylindrical shaft was left free in the centre of the charge into which a carbon rod was introduced (this was the later arrangement proposed by Erlwein's Assistant, Voigt). The nitrogen was introduced from below, being extracted from the air by the Linde process. By means of a suitable current the carbon rod was heated to a bright red, and "azotisation" began, i. e., the adherence of the nitrogen to the carbide. Once the process had started, the electric current could be switched off, since, as an "exothermal" reaction, the process generated its own heat. The azotisation proceeded from the centre of the tank towards the periphery, and in from 24 to 28 hours the whole tank was filled with calcium cyanamide, which could be tipped out. Each charge amounted to 900—1,000 kilogrammes of the finished product. Various details of the process were covered by patents, and Erlwein's experience was somewhat of a parallel to that of the earlier Böttcher, who set out to make gold and invented porcelain.

Whilst this development work was in progress, other research workers had turned to an old suggestion of Werner Siemens, who had observed that electric discharges in the form of sparks or arcs cause a part of the

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two gases which comprise the air to combine in the form of nitric oxide (NO). The phenomenon is not fully understood to this day, but it is certain that the high temperature is not the only cause of the reaction, but that intermolecular electric processes also play a part. Werner Siemens said at the time that the phenomenon should be chemically exploited, but the necessary quantities of electrical energy were not then available. About the turn of the century the idea was pursued again by the Norwegian scientist Birkeland who, jointly with an engineer by the name of Eyde, built an apparatus, in which a large high-voltage arc burned in a chamber. Atmospheric air was forced through the chamber, where nitric oxide was formed, although it only amounted to $1^1/_2$% of the volume of air. The resulting hot air was used for heating boilers, whilst the nitric oxide was collected in special chambers, where it assimilated oxygen from the air, becoming nitric dioxide. This was passed through towers of granite, where it was sprayed with weak nitric acid which, in mixing with the nitric dioxide, was converted into concentrated acid. Mixed with carbonate of lime, the resulting product was nitrate of lime, $CaNO_2$, which was later called Norge-Saltpeter. This was thought to be the solution of the nitrogen problem as regards soil fertilizers.

The matter was not to be dismissed lightly, since, although the consumption of electricity was very high by comparison with the yield of nitric oxide, that was evidently of no consequence in Norway. As a matter of fact, it soon became known that, based on the Birkeland-Eyde patents, a Company had been formed to operate the process in Notodden in Telemark with an installed electrical output of 40,000 kW. In view of this, Siemens & Halske, in order not to neglect any possibility, turned their attention to the experimental production of nitric oxide in the arc furnace; at the same time they speeded up their efforts to perfect the calcium cyanamide process.

The Cyanide Company now prepared a number of schemes for calcium cyanamide factories on the basis of carbide production, and submitted them to likely clients. Since everything was dependent on water power, and in the light of experience, Italian workers were most suitable for the difficult operation of the furnaces, it was decided to build the first factory in Italy. A contract was concluded with the "Società Italiana per la Fabbricazione di caburo di calcio" in Piano d'Orta, near Rome, as licensees, where the first calcium cyanamide factory was set to work in 1905 with an annual production of 3,750 tons of fertilizer. The satisfactory results were reflected in the keen interest taken by Italian economic circles, especially as the new process was held to strengthen the country's industrial position. Almost immediately the

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"Società Italiana per la Fabbricazione de Prodotti Azotati e altre sostanze per l'agricultura" was established in Sebenico on the Dalmatian Coast, and the equipment ordered from Siemens & Halske. The latter were content with the not inconsiderable royalties coming in under the contracts, but the Italians were the keener business men. They endeavoured to persuade Siemens & Halske to join hands with the Cyanide Company in forming a new undertaking, the "Società Generale per la Cianamide," in Rome. This Company was intended to be a Holding Company for national cyanamide undertakings in Germany, Austria, Hungary, Switzerland, France, Spain, Norway and even the U. S. A. The new process was to be introduced everywhere, and a world Concern of enormous dimensions built up. Siemens & Halske became a little nervous at the dizzy prospect, and Wilhelm von Siemens and his immediate advisers experienced a distinct malaise at this speculation fever on the part of the Italians. In Germany, it would appear that authoritative circles considered the Norwegian nitrate of lime process of Birkeland-Eyde to be more promising, for it became known that the "Badische Anilin- und Sodafabrik," the "Elberfelder Farbenfabriken" and the "Aktiengesellschaft für Anilinfabrikation," i. e., the three most powerful chemical undertakings in Germany, had acquired an interest in the "Norsk Hydro-Electrisk Kvaelstof Aktieselskab," at the same time contributing a new type of arc furnace designed by Schönherr. The plan was to harness the Rjukan Falls in Norway, thereby raising the output available (including the Notodden Plant) for working the process to 200,000 kW. This would be a power plant, the like of which was not yet in existence, and additional details of the chemical apparatus, such as the spraying towers 20 metres in height and consisting entirely of granite, also gave some indication of the scale on which the plant was designed. Under these circumstances Siemens & Halske decided not to join the Società Generale directly, but only to maintain a loose contact through the Cyanide Company. This connection resulted in the formation of the "Bayrische Stickstoffwerke A.G." with the participation of the Deutsche Bank, and the establishment of the Cyanamide Works in Trostberg on the Alz.

At first, events seemed to justify the maintenance of a certain reserve. The hastily-built factories of the Società Generale frequently began operations without observing the production rules carefully worked out by Erlwein on the basis of his exhaustive experiments, but which the local Works Managers appeared to consider superfluous. It frequently happened, in consequence, that the quality of the final product was below standard, and the situation became critical, with numerous

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reverses and individual failures, before it was restored to sanity. But finally it was mastered, and at the close of 1912 the Management of the Wernerwerk, in a retrospect of the cyanamide business prepared for the Managerial Board, was able to state: "The Cyanamide Industry, with which we are now only indirectly connected through the Cyanide Company, would seem to have overcome its initial difficulties, and to have become a factor of immense economic importance. Factories are in operation and under construction representing a production of about 200,000 tons of cyanamide yearly to the value of approximately 40 million Marks. The German Sales Syndicate has orders for 50,000 tons as compared with 22,000 tons in the previous year.

The severe competition expected from the Birkeland-Eyde process, which is jointly operated in Norway on a large scale by the Badische Anilin- und Sodafabrik, the Elberfelder Farbwerke and the Berliner Anilin- und Farbenfabrik, has not matured, and results do not appear to have come up to expectation, since the Firms in question have withdrawn from the venture with a loss of several millions. Only the synthetic ammonia process of Haber, which the Badische Anilin- und Sodafabrik is developing on a large scale, appears to be a formidable competitor."

Thus Siemens & Halske, as inventors of the cyanamide process, could have earned many millions if they had only had the courage to handle the product commercially, either directly or through a fully-controlled subsidiary. They had relinquished the trump cards to a vast business, and later were to see Frank and Caro (the latter a man of doubtful scientific integrity), allowing themselves to be acclaimed as the inventors of the process. Perhaps, however, it was better after all that the Firm instinctively remained faithful to its true mission. Who knows, whether the millions would have brought them luck!

Héroult's restless spirit was unable for long to be satisfied with his success in the field of aluminium. Now that the carbide and cyanamide processes had demonstrated the practicability of building and operating large electric furnaces, he turned his attention to the application of the arc furnace to steel manufacture.

It had gradually been realized how it came about that crucible steel was of such consistently high quality, although the raw material was not by any means always good: the steel boiled in the crucible. The gases still in solution in the steel were thereby driven off, useful reactions set up between the remaining inclusions, and a high degree of homogeneity achieved.

Molten steel commences to boil at about 1,700° C, depending on its composition, and that was also about the upper temperature limit of the

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flame-fired furnaces of those days. For the electric arc, however, such temperatures were child's play, and Héroult therefore resolved to boil the steel in an electric furnace. As raw material for this, he had no need to use the old-fashion cemented puddle steel, he could take good-quality steel scrap and a corresponding slag, adding alloying ingredients such as chromium and nickel, the significance of which had recently been discovered. The most important thing, however, was the boiling.

Héroult, therefore, built a furnace consisting of a round crucible with a cover and pouring spout, and arranged for tipping and emptying through the spout like a coffee-pot. The three electrodes for three-phase operation entered the furnace through the cover; the three arcs were united in the charge. Generally speaking, Héroult followed the pattern of the carbide furnace. He had his design covered by several patents, under which he granted licences, amongst others, to the AEG. The first furnaces were built for charges of only a few hundredweights, but these increased rapidly to several tons. These developments stimulated others, amongst them Girod, to take up electric furnace building. Girod introduced one electrode through the furnace bottom into the charge; in the Stassano furnace, the three electrodes entered through the side walls of the crucible above the level of the bath, so that the arc heated the charge by radiation only.

A furnace designed by a Swedish engineer Kjellin was founded on a totally different principle. If the secondary of a transformer is made to consist of one turn only, short-circuited in itself, a current will be produced of low voltage, but of very heavy amperage, which will overheat the winding and eventually burn it out. Kjellin applied the primary winding to one limb of the transformer, which possessed the usual two limbs and an upper and lower yoke to form the customary closed magnetic circuit. Around the primary winding he arranged a circular open crucible of refractory material, into which he poured the molten steel from above. The furnace was attractive on account of its high efficiency and the excellent results in refining the steel. Since Siemens & Halske had "missed the bus" with regard to the Héroult furnace, they decided to acquire an exclusive licence for Germany, Austria-Hungary, Luxembourg, and Russia on the Kjellin patents. An already existing connection led to close collaboration with the "Röchlingsche Eisen- und Stahlwerke" in Völklingen, where one of the engineers named Rodenhauser devoted special attention to the introduction of the furnace to the iron and steel industry, and effected a number of important improvements.

The joint labours involved in this experimental work led in 1906

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through the initiative of Siemens & Halske to the founding of the "Gesellschaft für Elektrostahlanlagen," in which, apart from Kjellin and Röchling, interests from Lorraine and Luxembourg were represented. Within the next few years the use of the Röchling-Rodenhauser furnace had become so extensive, that in Germany the arc furnace could at first make little headway. Even during the first World War the bulk of the greatly increased demand for electro-steel was met by the induction furnace. It was not until later, after the expiry of the patents, that the arc furnace came into its own in the form originated by Héroult. This was in large part due to the greater simplicity and versatility of the arc furnace. Meanwhile, however, the induction furnace had proved to be a very profitable line, and up till 1911 Siemens & Halske had installed fourteen of these plants.

As far as the House of Siemens is concerned, the history of electrochemistry up to the outbreak of the first World War is hardly likely to satisfy the materialist. However, Wilhelm von Siemens was not always just a cool calculator but, like his father, looked upon this branch of the business as a kind of moral obligation on his House; it most definitely was a branch of electrical engineering. Then, finally, it was now surely within the capacity of the House of Siemens to harbour a few expensive guests, and to engage the services of a number of learned men, whose names were mentioned with respect at home and abroad.

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XIV.

THE DEVELOPMENT OF POWER CURRENT PRACTICE

In the majority of electrical power stations about the turn of the last century, the prime mover which drove the generators was the steam engine. Hydraulic power stations had already been built, of course, and in the 'nineties the possibilities of comprehensive utilisation of "white coal" had already been the subject of lively discussion. However, it so happened that, in the industrial districts of Upper Silesia, the Ruhr, the Saar, Lorraine, Luxembourg, Belgium, Northern France and Great Britain, as well as the great cities and harbours on the European coast, there was no water power of any magnitude. In Europe, it was only to be found, at first, in the Alps and Scandinavia, where, on the other hand, there were no consumers of any size. Although a beginning had been made in long-distance power transmission, as we have already seen, it was still a long and arduous way from the solution of a technical principle to its operational and economic mastery. At the opening of the twentieth century, therefore, the preponderance of thermal over hydraulic prime movers in power stations was undisputed, both as to size and output, and predominant amongst the former was the reciprocating steam engine. Gas engines were only to be found in the generating stations of Iron Works.

During the nineteenth century the improvement of the steam engine had been the object of much ingenious thinking. The expansion of the steam in various stages in as many consecutive cylinders, the heating of the cylinder walls by a steam jacket, the increase of the steam pressure, the perfection of the valve-gear had all contributed to the raising of the efficiency. As compared with a steam consumption of a medium-sized engine about the middle of last century of about twelve kilogrammes per horsepower/hour, the corresponding figure for the largest machines in the early twentieth century was about five. This, however, also represented a certain limit, both in steam consumption and in the size of units. A steam engine of about 7,500 horsepower, corresponding to an

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electrical output of the driven generator of 5,000 kW would appear to have been about the largest ever built. Beyond that, manufacturing and operational difficulties became excessive.

It is said that Heron of Alexandria had built another kind of steam engine. According to this report, he used a closed copper boiler filled with water and arranged for heating from underneath, which he fitted with a vertical steam pipe. Across its upper end the pipe carried a second, arranged after the fashion of the cross-member of the letter T, and which was able to rotate. The ends of the rotatable pipe were bent sideways, and when steam issued from them, the pipe turned in the opposite direction to that of the steam-plow. The principle employed was the same as that of the well-known lawn-sprinkler, which rotates in a direction counter to that of the water-jet. In the absence of water pressure at the point of exit, the pressure against the walls of the pipe predominates (principle of the reaction turbine). Heron's device, of course, if ever actually made, could only be regarded as an ingenious toy.

It was, of course, possible to revert to the form of prime mover, typified by the water wheel, which had been in use from earliest times. In this, a stream or jet of water struck paddles which were fitted round the circumference of a wheel, converting its kinetic energy into pressure on the paddles. Of course, this age-old arrangement, in which the stream of water fell vertically on to flat paddles, made very poor use of the available kinetic energy, since this energy is only converted into pressure on the paddles by forcibly changing its direction, i. e., by diverting the stream of water. The action of the vertical stream striking the flat paddles is, however, very irregular and accompanied by heavy losses. Realising this, Euler had in principle converted the simple water-wheel into a turbine with curved blades as early as 1754. By means of suitable guides the water entered at the incoming edges of the curved blades in an almost tangential direction, practically without impact or loss, its direction of flow being changed gradually by the curvature of the blades until it issued at the outgoing edges with energy and velocity almost completely spent. Thus it was that the old water-wheel with its flat paddles and splashing water-flow was replaced by the wheel with a guided water-flow, the laws of whose motion were amenable to mathematical calculation.

Towards the end of the 'eighties, a Swedish engineer, Carl Gustaf Patrik de Laval, decided to apply this principle to the construction of a steam motor for driving his recently developed milk centrifuges. He directed steam issuing from a nozzle on to a circle of curved blades

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arranged around the circumference of a wheel. The jet blew just past one edge into the hollow of the blade, was diverted by the curve in such a way that it emerged at the other edge with very little velocity and in almost, but not quite, the opposite direction. The diversion brought about the conversion of the kinetic energy of the jet into mechanical pressure on the blades, with the consequence that the wheel was set in rapid rotation.

The speed of the turbine blades must be in a certain ratio to the velocity of the steam or water jet. The optimum value, as a simple calculation will demonstrate, is half the steam velocity.

When issuing from a container at higher pressure the velocity of steam is exceedingly high. In exhausting steam of only 12 atmospheres, which in de Laval's time was the maximum pressure, into a vacuum of 90%, the calculated velocity of the steam was about 1,150 metres per second. Even if, having regard to the unavoidable losses, the speed of the turbine rotor remained lower than half this value, de Laval arrived at a rotational speed of his comparatively small machine of approximately 18,000 r.p.m., which in those days was unheard of. He built a special train of gearing by means of which he reduced the speed to about one tenth. With these he was able to drive not only his milk centrifuges, but small electric generators, which in those days were still in the spinning wheel stage. The arrangement, however, was never widely applied, as in its original form the de Laval turbine consumed too much steam.

A few years earlier, it had occurred to a gifted young engineer, Charles Algernon Parsons, of wealthy English parentage, that the velocity of the steam could be reduced by causing it to pass through a number of separate pressure stages. Instead of the one nozzle employed by de Laval, he arranged a rim of "guide-blades" around the circumference of a stationary wheel. By its passage through the guide blades the very high initial pressure of the steam was greatly reduced, although it still remained considerable. In this way, a moderate velocity, corresponding to the pressure drop, was imparted to the steam impinging on the blades of the rotor. The active inner surface of each blade which caused the change of direction of the steam flow, combined with the back of the adjacent blade to form a compartment, similar to those between the blades of the guide wheel, in which further expansion of the steam took place. In the rotor blading, therefore, the energy of the steam was converted into mechanical output, not only in consequence of the change of direction of the steam-flow, but by reason of its expansion to a lower pressure at the exit than at the entrance of the blade, thus producing a reactive effect, as with the motor of Heron of Alexandria.

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On leaving the rotor, the steam passed through a second system of stationary guide blades, in which it expanded further, thus acquiring new velocity, entered a second system of rotor blades and so on through a large number of stages, each consisting of guide blades and rotor blades. The rotor blades were mounted on one common drum, whilst the guide blades were attached to the internal surface of the cylindrical casing of the turbine in which the rotor revolved. Between the guide blades and the rotor blades was a narrow annular gap.

To give practical shape to the idea proved to be a matter of considerable difficulty. The gap between the stationary and rotating parts was required to be very narrow, especially as there was a pressure drop in the rotor blades between the inlet and outlet sides, which led to "gap losses." Variations in the temperatures due to load changes could result in the rotor blades scraping the stationary ones with disastrous results, and the high rotational speed of the drum was fraught with the risk of out-of-balance vibration. No experienced manufacturer would have accepted an order to build such a phantastic machine.

Fortunately, Parsons was again an independent manufacturer, after having had to withdraw in 1889 from the firm he had helped to establish, and to renounce the ownership of his patents, thereby being condemned to five years of inactivity. In 1894 he re-acquired the old patents and turned to the realisation of his ideas. Judged by the workshop standards of those days, the demands on the accuracy of the workmanship were enormous. After a series of preliminary tests and small experimental machines, he supplied two steam turbines of 1,000 kW each to the Elberfeld Municipal Electricity Works in 1900/1901. At home nobody was prepared to risk the experiment. The steady, vibrationless operation of the machines, their reliability, small space requirements and low steam consumption caused a sensation. Above all, it was the modest floor space, a fraction of the foundation surface of a reciprocating engine of the same output, which was remarkable. As in Frankfort nine years before, the numerous visitors to the Elberfeld Power Station could not help feeling that a new era had commenced in power current generation. Thus it is justifiable, in spite of de Laval's earlier contribution, to consider Parsons as the real inventor of the steam turbine. He was fortunate, in that—as opposed to many others—he lived to see his life's work expand to undreamt-of dimensions.

In 1891, following the close of the successful Frankfort Exhibition, G. E. L. Brown, to whom and to whose machines a large share of the credit was due, entered into partnership with another engineer, Walter Boveri. Like himself, Boveri was an employee of the Maschinenfabrik

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Oerlikon, and a man whose enterprising spirit was no longer satisfied with the status of a mere employee.

They founded the Brown, Boveri & Cie., Kommanditgesellschaft in Baden (Switzerland), and in view of Brown's reputation as the result of the Frankfort Exhibition, were awarded the contract for the Frankfort electrical power station in the face of the keenest competition. They expanded their business rapidly by taking part in the development of Swiss water-power and by the equipment of several of the mountain railways which have been made popular by tourist traffic. In 1900 the Company was converted into a Limited Company, and a second factory built in Mannheim. This step was taken in view of the award of the contract for the electricity works by the Authorities of that city. Here they established the Head Office of the German branch of the firm, which also took the form of a Limited Company. The firm also acquired manufacturing rights in the Parsons patents, and commenced to build steam turbines and the accompanying generators, commonly called "Turbo-generators."

Now that, in consequence of the Frankfort Exhibition, alternating current, at first single-phase, then soon in its three-phase form, had come to be the current used predominantly for major supply and transmission undertakings, the construction of the electrical generators came to be standardized. The conductors, in which the tension was produced by the rotating magnetic field, were placed in slots in the inner circumference of a cylindrical ring, the "stator," which was built up of laminated sheets with a view to preventing eddy currents. Rotating with a very small air-gap within the stator was the "rotor" carrying the d. c.-excited poles which produce the magnetic field. With this arrangement, the number of pairs of poles follows from the desired frequency of the current and the rotational speed of the pole-wheel; it is the quotient of the frequency and speed when both are related to the same unit of time. Accordingly, with the frequency of 50 cycles per sec. most commonly used in Europe, the number of poles corresponding to 100 r.p.m. is 60; for 125 r.p.m. 48, and for 150 r.p.m. 40. These figures give an approximate idea of the most frequently occurring speeds and numbers of poles for the large slow-speed steam-driven generators of those days.

The steam turbine, however, demanded much higher speeds. Although Parsons with his clever solution had succeeded in reducing the impossible de Laval speeds very considerably, the fact remained that he still required speeds of at least 750 r.p.m., preferably 1,000 or still better 1,500 r.p.m., which corresponded to a generator rotor with 8, 6 or 4 poles. This was where trouble commenced with the turbo-generator.

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A rotor with 6 or 4 poles is really no longer a wheel, but a six- or four-pointed star. Imagine a hub, to which six or four heavy masses of iron are attached, each carrying its excitation windings of thick copper wire, the whole rotating at high speed and exerting centrifugal forces of several tons which endeavour to burst the hub asunder. In the event of an accidental increase in speed, caused, for instance, by suddenly disconnecting the generator from the network, there is a risk of the hub being fractured and of the poles being hurled through the room as by an explosion, threatening everything with destruction. Several occurrences of this kind had served to draw attention to the danger.

For this reason, Brown designed his turbine rotors as solid cylinders of alloy steel in which a number of slots were milled parallel to the axis to receive the d. c. excitation windings. These were secured in position by long wooden strips of swallow-tail section, which were inserted into correspondingly milled grooves in the upper part of the slots. The end connections between the conductors in the slots, which made them into closed coils, were protected by bronze caps. The resulting construction was not only mechanically rigid, but had the advantage from the electrical point of view that, in consequence of the even distribution of the excitation windings around the rotor, the intensity of its magnetic field was graduated from the centre outwards, a feature which has always been sought after by reason of its favourable influence on the shape of the voltage wave.

Brown, Boveri & Cie. built these turbo-generators, which they had protected by several patents, in the same works as the turbines under the Parsons patents, and were thus in a position to test them together in the presence of customers. In this way they stole a unique march on their competitors on the European Continent, which they as skillfully turned to account.

The problem of the steam turbine had meanwhile attracted numerous inventors and designers. In the U. S. A., de Laval's original idea of allowing the steam to expand completely in one stage in a single or a few parallel nozzles had again been taken up by Curtis. The conversion of the steam velocity, however, he distributed over two, three or four rows of blades on the same wheel, thereby reducing the speed of rotation to one half, one third or even a quarter of that of the de Laval turbine. This led to more acceptable conditions (Principle of Velocity Stages). Auguste Rateau in Paris, on the other hand, suggested stepping down, not the velocity but the pressure, in stages, i. e., not expanding the steam completely in one set of nozzles or guide blades, but only to an intermedial stage, imparting the velocity thus gained to the rotor. As opposed to

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Parsons, however, this was not to be accompanied by further expansion. A second expansion stage was to follow in a further set of guide blades, and so on. This idea was seized upon by Zoelly, Chief Designer of Escher Wyss & Cie., in Zurich, and developed (Principle of Pressure Stages). There remained the possibility of combining the systems, as far as was permissible in view of the somewhat confused patent situation.

One of the first German industrialists to grasp immediately the vast possibilities inherent in the steam turbine was Emil Rathenau. It was not for nothing that he was heart and soul a mechanical engineer, nor that he had struggled unsuccessfully for years with the problem of mating the steam engine and the electrical generator. Here, at last, was a congenial partner. Without hesitation he made arrangements, helped by his American friends, with the builders of the Curtis turbine, which had meanwhile been further developed, and now comprised two to three pressure stages (Rateau) in conjunction with two to three velocity stages each (Curtis). As opposed to the Parsons turbine, this resulted in a comparatively simple and short machine, with a somewhat higher steam consumption, but an excellent reputation for reliability. The AEG decided forthwith to manufacture these turbines in their own workshops, and for this purpose built a new factory in Berlin—the AEG Turbine Works—which, even in its external appearance, at once impressed one with the idea that it was intended by its owners to be one of the centres of gravity of their future activities.

These developments took the House of Siemens somewhat by surprise, the more so, as they materialized just as the Siemens-Schuckertwerke had been established as the new focus of power current interests in Germany. The fusion was barely accomplished, and the new regime just beginning to function, when the question arose, whether to follow the example of Brown, Boveri & Cie. and of the AEG, whose plans had meanwhile become known, and to build a turbine works. For a number of reasons the question could not be answered in the affirmative. However, at the instigation of the Siemens-Schuckertwerke a syndicate was formed in 1904 to build turbines on the lines originally proposed by Rateau and materially improved by Zoelly, incorporating subdivision of the pressure stages without reaction in the rotor blading. The "Syndicate for Steam Turbines" comprised, apart from the Siemens-Schuckertwerke, five large German and one important Swiss engineering Works, in addition to two "Corresponding Members," viz., the Maschinenfabrik Lang in Budapest, and Auguste Rateau in Paris.

In this joint undertaking Siemens-Schuckert took the leading part inasmuch as it was they who furnished the designers with the require-

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ments and problems arising in power station operation, and who distributed the turbine orders amongst the members of the syndicate. Conversely, member firms receiving orders for complete turbo-generators were under obligation to place the order for the generator with Siemens-Schuckert, except where a customer had specified a generator of another make.

Siemens flattered themselves that this move was an effective tit-for-tat to the two most dangerous competitors, the AEG and BBC. The fact of being allied to a whole number of firms of high reputation, it was said, was a strong point in favour of the collective enterprise as against their competitors, each of which had to work alone. The assumption proved to be correct, and during the next few years Siemens-Schuckert succeeded in securing an important share of the market. As early as the year following the formation of the syndicate, there was already talk of orders received for turbines of 10,000 h. p., corresponding to a generator output of 6,750 kW. The widely varying experience, and the greater numbers of designers working from different angles towards a common target, were further points in favour of the new organisation. However, it had one grave disadvantage, viz., the turbine and generator were not built in the same Works, whereas with the AEG and Brown, Boveri & Cie. the two components, although not made in the same workshop (which was unavoidable), were assembled as complete units in the Works and tested together, mechanically and electrically, which was not possible with the machines of the syndicate. In this case, turbine and generator met for the first time on site. It was as if a couple contemplating marriage were to meet for the first time on the eve of the ceremony. The consequence was that adjustments which, in the case of the others, would have been effected at the latest prior to testing, had, in the case of the syndicate, to be carried out in the course of erection on site in full view of the customer, which was not always desirable.

The steam engine, whether of the reciprocating type or turbine, is only a part, although perhaps the most conspicuous, of the means of converting the energy contained in the coal into mechanical output; further essential links are the condensation plant, the boilers, the re-coolers for the condenser cooling water, the pumping systems, the preparation of the supplementary feed water, the bunkering and transport of the coal, ash disposal, the difficult constructional work called for in building the foundation piers for high-speed turbines, and the accommodation between the piers of the condensation plant. Consequent on the subdivision of industry into turbine works, boiler makers, pump manufacturers, pipe manufacturers, mechanical handling equipment

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makers, and general building contractors, there was really only one central control point, from which all these activities could be supervised and directed. This was the big electrical manufacturer. Of these there were in Germany—and thus in Europe—only two, who were capable of fulfilling these functions, viz., the AEG and the Siemens-Schuckertwerke. Each of the two competing firms established a department for the construction of electric power stations on the lines of engineering consultants. These departments built up a staff of assistants, which were not only capable of dealing with every detail of the extensive problem as competently as the specialist firms, but were ambitious to urge forward the scientific and technical development of power station design as quickly as possible. They did not confine themselves to generating stations for the public supply, but applied the lessons there learnt to the design and installation of industrial power plants of ever increasing size. The Siemens-Schuckert department, known since its establishment in 1895 modestly as the "Maschinentechnisches Büro," but now of considerable size, was in charge of Hermann Tonnemacher. In his young days Tonnemacher had gained much experience in power station construction as a Superintending Engineer for Siemens & Halske. Now, he was also Secretary of the Steam Turbine Syndicate.

On the one hand, the impulse given to electricity by the introduction of the steam turbine was enormous. On the other hand, the new prime mover necessitated a radical departure from existing generator design. Machines now had to be built for outputs and speeds hitherto not dreamt of. As a consequence of the increasing size of individual machines and thus of the power stations, it was natural to concentrate the generation of electricity at a few favourably situated points, and to close down the small uneconomical plants of earlier days. Moreover, these were usually direct current stations, whereas modern plants, with their long-distance transmission systems, were almost exclusively three-phase works. On the other hand, it was impossible to change over forthwith the old systems from d. c. to a. c. operation, on account of the arc lamps and d. c. motors and meters which would only run on direct current. A change-over, therefore, had to be effected gradually after step-by-step replacement of such units. Certain supply systems had perforce to remain on direct current, e. g. tramways and some sections of dock-yard and factory networks, since in those days d. c. motors were superior where speed regulation was required, as for cranes and machine tools. However, to build new d. c. steam power stations or even to continue to operate existing ones for these special requirements would have been senseless. When necessary, new a. c. power stations could include a d. c. generating set. In the

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majority of cases it was found preferable to convert the a.c. supply to d.c. in special convertors. Apart from this technical revolution, however, the economic foundations, on which power current investment business had hitherto been based, had undergone a change.

In spite of the lively pursuit of export business, it was essential that the centre of gravity remained in the home market. In Germany, however, every large city meanwhile had its own electricity undertaking and tramways. The most that could be expected would be the extension or re-building of out-of-date installations. In any case, the decision lay with the Municipal Authorities, based on the legal rights of the communities. Even where communities had not refused at the outset to have anything to do with the investment system, as had frequently happened in West and South Germany, it was made evident by the terms of the operating licences in nearly every case, either expressly or by implication, that it was intended that the community should ultimately become the owner of the undertaking. This also accorded with the general trend of political thought at the time—development in the opposite direction would have been unimaginable. It must also be remembered that many of the higher communal officials were chafing at the fetters frequently placed on their freedom of action by the provisions of the licences. Finally, a weighty argument in support of the licence system had now ceased to apply, viz., the want of competent staff in the service of the Municipalities. This was now available. By reason of the economic crisis, many of the large manufacturers had cut down staff, who now sought employment, in addition to the annual contingents from the technical colleges. Then there were many Superintendent Engineers who, with the consent of both parties, took over the management of the new undertaking when completed. Having sufficient expert personnel of their own, the Municipalities were no longer prepared to be held in tutelage.

What the farmer—and particularly the cottager—really wanted, was countries which were industrially less developed and financially weaker; in Europe to Spain, Italy and the Balkans; overseas to South America. Here it found itself confronted with the traditionally active British capital market, and with rapidly growing industrial competition from the U.S.A. In Germany itself, investment business soon dwindled to the point of insignificance. The further development of electricity in the service of the national economy was taken over by other hands.

Not unnaturally, the smaller towns and villages were anxious to enjoy the amenities of electric power and lighting as soon as possible, but the provision of the sums necessary for the interest and amortisation of the

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capital outlay presupposed a consumption of electricity which could hardly be expected. Appeals were made to farmers and, in particular, to the big landowners, to consider driving their machines by electricity, having the plough in mind in the first place. As long ago as 1880 Werner Siemens had experimented with an electric plough, in which he adopted the well-known Fowler arrangement for steam ploughs, viz., a multi-share plough is drawn backwards and forwards between two locomobiles placed opposite each other at the two outer edges of the field. The locomobiles are moved forward as ploughing proceeds. Owing to technical difficulties, Werner's experiment, in which the locomobiles were replaced by mobile electric motors, was not a success. Amongst other obstacles was the current feed to the mobile motors. Fifteen years later Siemens & Halske returned to the attack, the transmission of current at high tension and its transformation to a suitable working voltage on site having meanwhile become common practice. Two new experimental ploughs were equipped at selected spots, one in Pomerania and the other in the province of Saxony, but the results were still not satisfactory; the equipment proved to be too complicated and expensive. Even the electric drive of threshing machines, pumps, centrifuges, chaff-cutters and winches made only slow progress, notwithstanding efforts made to encourage it by the provision of mobile and portable motors. What the farmer—and particularly the cottager—really wanted, was electric light. The same applied in small towns; the demand for light far exceeded the propaganda-inspired calls of small craftsmen for electric drives, and the many applications of electric heating were at that time unknown. Unfortunately, electric lighting is the least desirable form of load for any generating station. In the winter it is confined to a few hours morning and evening, and in the summer, particularly in the country, it vanishes almost entirely. In villages and small towns, again, there are no large consumers such as department stores, assembly rooms, theatres, large railway stations, street-lighting, factories and offices. In the drastic terms of those days: you can't build a generating station just to light the way for the milkmaid for half an hour in the morning and evening in the winter.

Matters might assume a different aspect if it could be arranged to provide a feeder from the supply system of a neighbouring municipal power station. In such cases it was sometimes found convenient for the communities, in order to relieve the power station of the necessity for meter-reading at remote points, to form a kind of local Consumers' Association, which proudly called itself " Electricity Works," although it had nothing to do with generating, but merely re-sold the current re-

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ceived. Often enough, it was possible to combine a number of such communities into one group attached to a common supply station; they then became G. m. b. H.'s (the approximate equivalent of Limited Companies), purchased the local supply networks and undertook their operation.

When the electricity supply had expanded in this way over a large enough area, there was usually little difficulty in persuading one or other of the local industrialists, such as the miller, brewer, timber merchant or small factory-owner, to connect up to the power network. The reason was that businesses such as these frequently had small power units of one kind or another which were uneconomical in operation. In this way and with the active support of Local Government Authorities, an electricity supply network (although somewhat widely meshed at first) was gradually extended into the rural areas adjacent to the large generating stations of the big towns. This applied particularly to districts between cities which, in consequence of their industrial character, were thickly populated. Cases in point were Upper Silesia, Central Germany, and above all, the Ruhr.

Now that electric supply had succeeded at several favourable points in stepping beyond the confines of the Municipalities and spreading into the country districts, efforts began to be made on all hands to extend it at the public cost to less densely populated and less important areas. In South Germany there was already serious talk of the development of potential water-power. In Bavaria and Baden the respective Governments called upon the communities not to waste their efforts on small individual plants but to collaborate with the Government in working out joint plans for regional hydro-electric supply. The pre-1914 statistics of electricity production in public generating stations in Germany are not very reliable, as at that time several units were not clearly defined; a certain amount of estimating and interpolation is therefore necessary. It is, however, possible to estimate the net value of the electricity consumed, i. e., the amount generated minus the unpaid losses in transformers and transmission, with reasonable accuracy for the years 1904, 1907, 1910 and 1913, as follows: 550, 900, 1,450 and 2,300 million kilowatt-hours. That means that the consumption of electricity at the end of the nine years in question was quadrupled, an increase which even in those years of economic expansion had not been attained by any other commodity.

This could never have been achieved by the mere increase in the number of generating stations of the same approximate size and technical development. On the contrary, it was only possible as the result of the

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enormous increase in the size of the stations and their distribution systems, which, in turn, was the fruit of the technical revolution brought about by the steam turbine and the development of power current practice. Chiefly involved were the two "modern" industrial countries, the U.S.A. and Germany, and in each case the pressure was increased by the competition of the two largest electrical manufacturers, and further augmented by the strenuous efforts of the medium-sized and specialist firms. This, in itself, is an interesting example of the beneficial effect of free competition on the general economy and technical development of an industrial country.

The founding of the Siemens-Schuckertwerke and the pooling of the experience of the two partners in the design of large power stations found its expression in works of an increasingly ambitious character. In the case of the Adige Station for the supply of Bolzano and Meran, the voltage was only 10,000 volts, and the power was transmitted by cable, for those days a daring, but successful venture. For the three hydro-electric stations built shortly afterwards for the Sociedad Hidroelectrica Iberica, Bilbao, with a combined output of 11,000 kW, the tension was raised to 33,000 volts. In 1906/07 two power stations were built simultaneously for operation at 50,000 volts. In one of these, the hydro-electric Moosberg Station for the supply of Munich from a point 50 km downstream on the Isar, transformers of 3,000 kVA individual output were used for the first time. The second 50,000 volt plant concerned the extension of the supply system of the Aktieselskabet Glommens Traesliberi, initially built ten years earlier by Schuckert & Co., and comprised the interconnection of the large generating stations at Hafslund and Kykkelsrud by an overland line at 50,000 volts. In the following year, when it was decided to supply Madrid, Valencia and Cartagena from a power station owned by the Sociedad Hidroelectrica Española at Molinar, on the Jucar, Siemens-Schuckert, as Contractors responsible for the complete plant, decided to use 70,000 volts, since there were portions of the transmission line up to 240 kilometres in length. Individual transformer outputs had meanwhile grown to 6,750 kVA.

In view of these successful progressive increases of the transmission voltage, it no longer seemed too audacious to consider a jump to the thousand-fold value of that employed by Edison twenty-five years earlier for his first distribution systems. An experiment of this kind had already been made in the U.S.A. with transmission lines at 110,000 volts, admittedly under very favourable climatic conditions. None the less, the venture had succeeded. In Germany, therefore, the "big firms" commenced by research and experiment to prepare to follow the American

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example. All that was now wanting was a customer who was willing to participate.

It was not long before one was found, viz., the Lauchhammer Ironworks in 1911. This Concern owned four Works, each remote from the other, situated in the Saxon Lignite Coalfields. The two most distant Works, Lauchhammer and Riesa on the Elbe, were rather more than fifty kilometres apart. Since lignite was mined at Lauchhammer and steel rolled at Riesa, the obvious thing was to generate electric power at the mine, and to transmit it to the rolling mills at Riesa. It was, of course, necessary to obtain the consent of the local Authorities to the erection of the transmission line across their land. It so happened, however, that they were planning to build an overland power station of their own; they were, nevertheless, persuaded without much difficulty to relinquish the idea and to tap their requirements from the ironworks line for distribution through their own network. With the aid of a competent and experienced consultant the ironworks placed the contracts for the whole of the equipment, distributing them amongst suppliers who were themselves customers of the ironworks. Siemens-Schuckert received an order for a turbo-generator, the majority of the transformers of 6,260 kVA each, and the switchgear for one end of the transmission line. This enabled them to get experience concerning the most difficult part of the equipment, i. e., the transformers, which inevitably accompanies the breaking of new ground.

In progressing thus to successively higher voltages, it soon became evident that the transmission equipment had three critical points, viz., the transformers, the switchgear and the insulators for the overhead line, the latter, at first, giving the designers the greatest trouble. The insulators originally used for overhead lines had been porcelain insulators of the type employed on telegraph lines but with slightly larger dimensions. Up to tensions of a few thousand volts this worked satisfactorily, but, as has already been described in the case of the Grünberg transmission line, trouble began as the voltage approached 10,000. About 1897, in response to a suggestion by Robert M. Friese, at that time in charge of the Alternating Current Dept. of Schuckert & Co., the Hermsdorf Porcelain Manufactory introduced a new and patented insulator which, owing to its outward appearance, was named the Delta insulator. It had been found that large ribbed insulators of porcelain were difficult to manufacture to exact dimensions without developing fine cracks, through which the high tension penetrated to the point of flash-over. Insulators were therefore built up of several hollow cones with rounded points, placed inside each other. The uppermost and also shortest cone

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spreads its wide skirt over the lower ones, protecting them from rain; the lowest and inmost cone, widening slightly in a downward direction, was moulded around the iron pin which carried the whole insulator. Thus the voltage had a long distance to creep from the conductor at the head of the insulator over the surfaces of the various skirts until it reached the earthed pin at its lower end. This insulator provided an ample degree of safety, even under pretty bad atmospheric conditions, for tensions up to 50,000 volts. Beyond that, the Delta insulator became too cumbersome.

For this reason Hewlett in the United States abandoned the Delta type in 1906, in favour of the suspension insulator. This consisted of a number of thick porcelain plates, dished after the manner of soup plates. The bottoms of the plates on both sides were provided with a number of bosses pierced with holes, by means of which short pieces of wire rope were attached. In this way three, four or five plates were suspended beneath each other with the hollow face downward to form a string, the upper end of which was secured to one of the cross-arms of the tower, whilst the lower carried the overhead conductor. Later, the arrangement was improved by drawing down the edges of the plates to form bells. A long iron clapper in the bell was connected at its lower end to a socket in the cap of the next porcelain bell. With suspension insulators of this kind it was possible to transmit current at 110,000 volts with safety, provided the necessary care was observed in the manufacture of the insulators. Above all, they had to be free from cracks in the glazing.

Originally, it was assumed that the voltage drop of, say, 100,000 volts in the case of a string of five units would be equally divided as between the units, i. e., 20,000 volts for each. Measurements, however, demonstrated that the unit next to the conductor is by far the most heavily stressed, making an even subdivision of the stress out of the question. This very complicated phenomenon was first recognized by Reinhold Rüdenberg, one of the most capable of the young science Assistants of Siemens-Schuckert, who presented it in clear mathematical form. Since then, many volumes have been devoted to the mathematical treatment of the nature of the electrical field in the neighbourhood of the string of insulators, and it has been shown how to shape the individual units in order to equalize the potential drops and so increase the permissible transmission voltage. The ordinary man, whose eye chances for a moment to rest on the string of insulators of a high-tension transmission line, has little conception of the amount of mathematical and physical speculation which has gone into the making of these porcelains.

A very high proportion of the electrical energy thus generated and

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transmitted was used for motor drives. It was not surprising, therefore, that the group formed by Siemens & Halske as early as 1894 to deal with these questions was called the "Power Transmission Department." This eventually became the largest of the departments, a development which followed from the increasing penetration of electricity into industry, and the seemingly limitless diversity in the types of specialized electric drives. This survey must therefore be confined to a few of the more prominent examples.

In the middle 'nineties it began with underground water drainage in the mines. The long steam pipes which had to be laid and maintained down the shafts and into the pump chambers were a source of trouble and annoyance; the three-phase motor solved the problem in simple and elegant fashion. Though the drainage pump was usually the first large consumer of electricity in the mine, it was often the only one for some time to come. It not infrequently happened, therefore, that at first only one electric generator was installed above ground, to which the pump motor was electrically coupled. In order to keep the speed of the motor low, the generator was often designed to give such a low frequency as to cause the light to flicker, so that it could not be used for lighting. The result was two different supply frequencies in the mine. It was not until later that the standard European frequency of 50 cycles per sec. was also established in the mines.

Pump driving is a simple task for the three-phase motor, inasmuch as the speed usually remains constant for long periods. With many other drives this is not the case. In rolling metal, the speed increases as the section decreases; in driving machine tools, textile, paper-making and printing machinery, variation of the speed is often required over a wide range; in lifting and transport, small loads are handled at higher speeds than heavy ones, quite apart from the necessity for smooth starting and stopping. All this means that the speed of the driving motor must be "variable."

This presents no great difficulty in the case of the d. c. motor, which runs faster or slower according as the magnetic field of the poles is varied by weakening or strengthening the excitation current, an operation which is not attended by any appreciable losses. The three-phase a. c. motor, however, is a different proposition in this respect, and it was for this reason that in those days many preferred to retain their d. c. supply system, by converting the three-phase supply, as received, into direct current before feeding it to their own distribution network.

The first method of conversion employed was to drive a d. c. generator by a three-phase motor. A set of this kind was called a motor-genera-

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tor. The process was simple, but had the disadvantage of being accompanied by rather heavy losses, expressed in the heating up of the two machines. Electrical energy was first converted into mechanical and then back into electrical, so that the losses occurred twice. It was then remembered that every d. c. machine was primarily an a. c. machine and that the current supplied is first rectified by the commutator. By tapping the rotor winding at the end opposite to the commutator at two or three symmetrically situated points, and connecting these to two or three slip rings, it is possible to obtain single or three-phase alternating current. The generator will therefore give a simultaneous supply from the same windings of direct current at one end, and alternating current (three-phase, if three slip rings are provided) at the other. Conversely, if three-phase current is fed to the slip rings from an outside source, and the rotor arranged to run at a speed corresponding to the frequency of the three-phase current and the number of poles, this current will be converted—by the commutator—into direct current. The power consumed is only that which is required to keep the machine running, and is taken from the alternating current supply. This type of machine is the single-armature converter, more commonly known as the " Rotary Converter." The voltages of the three-phase and d. c. sides of the converter are in a fixed ratio to one another, and since the d. c. supply voltage is also a fixed value, it is necessary to insert a transformer on the a. c. side to adapt the voltages to that of the d. c. system. Notwithstanding the transformer, the efficiency of the rotary converter is considerably higher than that of the motor-generator, and it was for this reason that the converter soon found widespread application, particularly in traction work, following on the closing down of the old railway power plants and their substitution by converter stations. A considerable share of the ensuing work fell to Siemens-Schuckert.

In 1891 the American engineer Ward Leonard had obtained a patent on the arrangement of a single d. c. motor fed from a special converter of the motor-generator type. The voltage of a generator can be varied as desired by varying its excitation, with the consequence that a motor supplied by the generator can be made to run at any desired speed.

Not only is the speed of the d. c. motor dependent on the voltage of the supply, but a reversal of the voltage will reverse the direction of rotation of the motor. Here, therefore, was an almost ideal solution of the speed regulation problem, albeit at considerable cost, since three machines were needed in place of one, and a fifth or even a quarter of the energy taken from the supply was lost. This was probably the reason why the arrangement did not at first find favour, and which led Ward

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Leonard to abandon his German patent in 1902, after it had—nearly been forgotten.

About the turn of the century electrical engineers found themselves confronted with the task of providing reversing drives: in mines for the main winding, and in ironworks for the ingot mills. In both cases it is required to run quickly up to maximum speed from rest, to maintain this speed for a short period, to brake down to zero, and to repeat the cycle in the opposite direction—and so on for many hours, it may be even months, without ceasing. The maximum speeds required were not particularly high. In the case of the winding engine the steel rope of several inches diameter, to which the cages were attached, was passed round a Koepe pulley of 6 to 8 metres diameter, so that one revolution of the pulley per second was sufficient to impart the speed of an express train to the cages in the shaft. Of much the same order of magnitude is the speed of the rolling mill rolls which grip the red-hot ingot and draw it through, to feed it back through the rolls at the next pass in the reverse direction and with a reduced section. The driving power thus fluctuates continually within the space of a few seconds between zero and a maximum value which, in the case of the ingot mill, can approach that of the engine-power of a medium-sized warship.

For this duty the Ward Leonard drive seemed to be exactly what was required, except for one point: the reaction on the supply network of the fluctuating load. In view of the comparatively small capacity of the power stations of those days, there was the risk of the voltage becoming so unstable as to render proper operation of the system impossible.

This difficulty was met by a Consulting Engineer named Karl Ilgner with an arrangement, for which a patent had been applied for, in which the Ward Leonard converter was coupled to a heavy flywheel, the kinetic energy of which would take over a part of the load peaks, the flywheel being "re-charged" from the electricity supply during the braking and rest periods. The significance of this invention was realized by Karl Köttgen, one of the young engineers who had joined the Charlottenburg Works in 1894, and who soon came to be recognized as one of the most capable. Köttgen did not rest until Siemens & Halske had acquired a licence from the owners of the patent, the Donnersmarckhütte. In competition with the AEG, who likewise had a licence, Siemens-Schuckert developed the details of the main winding engine and reversing rolling mill drives to a degree of excellence which won them the admiration of engineering circles, and in a large measure contributed to the victorious advance of electricity in the heavy industries. Materially, the effort was equally successful. Between 1902, the year of the licence, and

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the time of its expiration no less than 141 electric winding engines were supplied, having a total value of 30 million Marks. In the same period a number of large rolling mill drives were installed, each of which as a rule represented a capital outlay of a million Marks.

For smaller and medium-sized motors the outlay for Ward Leonard equipment was out of proportion to its usefulness, but in view of the great advantages of three-phase as compared with direct current, in particular the simplicity and reliability of the three-phase motor, users became resigned to the less efficient speed regulation of the latter. In consequence, it was the three-phase motor which in those days gradually came to be the dominant electric drive, even for lifting equipment for which continuously changing speed is essential. It can in fact be stated without fear of contradiction that modern lifting gear is the product of the electric drive. This applies particularly to the travelling crane, to be found to-day in every factory of appreciable size. Even at that time it was the commonest form of lifting gear, but besides these there were large loading bridges for bulk transport of materials in the open, gantry and floating cranes in harbours and dockyards, cranes of special design for ironworks, furnace hoists, tongs for handling the red-hot billets, charging machines for the melting furnaces, lifting magnets for pig iron and scrap, lifting and tilting equipment for reversing rolling mills, live roller trains for these, then excavators and stacking machines for lignite coal mining, not to mention passenger and goods lifts of ever-increasing efficiency. In a word, continually expanding spheres of application, which made it essential for the electrical engineer and the manufacturer of the mechanical part to cooperate, in order to make certain that the electrical portion of the equipment was exactly fitted to its task, but also to mould the mechanical part to meet essential electrical requirements.

The above group of applications may serve to indicate the multifarious problems which arose where electric driving was required—and where was this not the case? It was the task of the electrical engineer to study the industrial process, to analyse it, to determine its essential characteristics, and if necessary, to suggest modifications, where these would lead to a closer adaptation of the electric drive to the technological process. The sum of creative work accomplished by the electrical engineer of those days is truly immense.

Immediately after the founding of the Siemens-Schuckertwerke, the question presented itself as to how best to distribute the manufacture of the various classes of electrical machinery amongst the several available works. The Schuckert factories in Nuremberg had always enjoyed a high

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reputation for the excellence of their small and medium-sized machines —mostly motors. It was therefore decided to allocate to the "Nuremberg Works" the manufacture of those machines which were to be found in the printed price-lists, and were usually manufactured in large batches. The manufacture of transformers was also concentrated in Nuremberg. The plan provided, on the other hand, that the Charlottenburg Works should manufacture those machines which were built individually, such as steam turbo-generators, large hydro-electric generators, Ward Leonard sets for winding engines and rolling mills, and also traction motors. The management of the Works was placed in the hands of Robert Friese, a former pupil of Kittler. Friese had originally intended to follow an academic career, and about the turn of the century had been a Lecturer at the Technical University of Munich. However, he returned to Schuckert & Co., in whose service he had already been for a brief period, and on the founding of the Siemens-Schuckertwerke, was elected to their Board of Management. The Board was of the opinion that the management of the Charlottenburg Works, in particular, should be placed in the hands of this most scholarly, although rather quiet and reserved man. A circumstance contributing to this decision was the fact that the Charlottenburg Works of those days was in the nature of a herbaceous bulb, which in addition to sustaining its own plant, from time to time develops new bulbs, which in turn produce new plant growth.

By comparison with the Nuremberg Works, the Charlottenburg Works were out-of-date; the continual growth in the size of the large generators necessitated the use of machine tools and transport equipment which could no longer be accommodated. It had been decided in principle that the whole of the Berlin factories should be concentrated in the spacious territory situated between the lower Spree and the Jungfernheide. The plan had begun to take effect about 1900/01 with the building of the new cable works and the occupation in 1905 of the new Wernerwerk, of which a description will follow in its place. Having made further considerable land purchases, it was decided in the same year to build a "Dynamo Works" which, in the height and spaciousness of its shops, would be adequate to meet any foreseeable requirements of electrical machine construction for many years to come.

The first large salient pole machines for the Berlin Electricity Works, the largest generators of those days, had an output of approximately 250 kW at 63 r.p.m., and weighed about 25 tons. On account of their size they had to be assembled for the first time on site. Now, however, an order was received for generators for water-turbine drive, to have an output of 7,000 kW at 250 r.p.m. They weighed nearly 130 tons, more

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than five times the weight of the first-mentioned. It was only with difficulty that the workshops could keep up with the pace of this development; in 1910, only four years after its inauguration, the dynamo works had to be considerably extended.

The manufacturing programme of the Charlottenburg Works covered, in addition to arc lamps, switchgear and swichboards, starting and control gear and speed regulators, the construction of small machines, practically all motors, and no generators. These motors, however, developed in a direction which was quite different from that of the larger machines.

It would happen, of course, that the motor, like the large ones, would be manufactured as an individual unit, and the method of driving the production machine left to the customer. In the early days of electric driving that was the general practice. Now, however, there began to be an increasing number of cases, particularly where small motors were concerned, in which the designer had to take thought for the best way of fitting the motor to the machine. For example, the motor is required to drive a small pump. The obvious thing was to couple pump and motor directly together, but in view of the high speed of the motor the pump would have to be of the rotary or centrifugal type. But by a skillful combination of parts common to both, such as bearings, endshields, etc., it was possible to assemble the components in such a way that the layman would be unable to distinguish where the pump ended and the motor began. This type of construction, however, presupposed that the complete unit was made in one and the same Works. The same applied to fans, compressors and air pumps. Electrically driven fans were made for indoor use in living rooms and concert halls, for use on board ship, in factories and mines, for exhausting air in many industrial processes, for use as hair-driers and vacuum cleaners, the latter having come to represent a very considerable and lucrative item in the manufacturing programme. A further step in the development of what might be termed the motorized machine, was in the sphere of small machine tools. From an early date efforts had been made to construct an electric drill for coal and stone, in place of the compressed-air drill. This was a difficult problem, which had occupied Siemens & Halske for a long time! The difficulty in drilling stone is that a hammer action is required in addition to the rotary, an obstacle which had thus far baffled the designers and raw material experts. For drilling in metal the rotary motion is sufficient, but the speed of the drill is low as compared with that of the motor, which necessitates at least a single, if not a double, gear reduction. The combination of the drill with the motor finally led to the

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portable electric drill. This had the great advantage that it was no longer necessary to carry the work to the drill, a point of particular importance in building construction. It is no exaggeration to say that the rapid completion of many steel structures and ships would not have been possible without the electric hand-drill.

It would occupy too much space to quote at length all the types of small motorized machines, such as sewing machines, household appliances and office machines, which made their appearance. It will be realised that a branch of electrical development had come into being which was continually putting forth new shoots. In most cases, too, the new products were required in large quantities, which called for mass production. For this the odd shops of the Charlottenburg Works were totally unsuitable, apart from the fact that they were not large enough. On the other hand, a bare ten years' experience had shown the cable works at Nonnendamm to be no longer adequate. The main reason for this was the decision to carry out the melting, rolling and drawing of yellow and white metals on the premises, i. e., to establish a metal works to produce the bare wires, cables and cords as a feeder for the actual cable works, and to render it independent of outside suppliers. However, as the land surrounding the existing cable works was too restricted to permit of such extensions, it was decided to build a new cable works in Gartenfeld, on land adjoining the existing works on the North-West, but large enough to permit of any foreseeable extensions, and to include the metal-works just mentioned. The space thus vacated in the old cable works was taken over in due course by the "Small Motor Works," the offshoot of the Charlottenburg Works which was to manufacture the class of motorized machines and appliances referred to above.

A certain transition from the above-mentioned tasks, which were mostly concerned with industrial production, to the sphere of transport, which was the concern of the Traction Department, were the—usually—narrow-gauge railways for the conveyance of goods between departments of the same works. Amongst these, the so-called mining railways gradually began to acquire special importance. In the coal and ore mines it has been the custom from earliest times to convey the product in a train of tubs to the foot of the shaft, whence it is wound to the surface. These railways were usually operated by pit ponies. On rare occasions electric traction had been tried, as at the Saxon coal mine at Zauckeroda, where Siemens & Halske successfully installed the world's first electric mine railway in 1882. Developments, however, were very slow at first, especially since the introduction of petrol and compressed-air engines, which the miner regarded as simpler to operate than the electric motor.

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It was not until the first decade of the 20th century, when the German coal mining industry in Upper Silesia and the Ruhr commenced to meet the rising demand by sinking new shafts and developing existing ones, that a need was more pressingly felt for efficient large-scale transport facilities below ground. This being so, Siemens-Schuckertwerke addressed themselves intensively over a period of several years to the task of developing electric mining railways, rolling stock and equipment adequate to the severe working conditions of coal mining, and of the Rhenish-Westphalian deep mines in particular. They had the satisfaction of seeing the hesitant mining industry gradually becoming accustomed to the new technique, leading eventually to the development of extensive and profitable business which has well repaid the initial outlay.

In other respects, too, the character of the business dealt with by the Traction Department had meanwhile undergone a considerable change. Whilst up to now it had been the equipment of electric tramways, together with the construction of the Berlin Elevated and Underground Railway, which had occupied their whole attention, new tasks began to make their appearance. In Germany, the electrification of the tramways was practically complete; business consisted in the main in the supply of spares and in extensions. Foreign business was shrinking and came mostly from European countries, whilst overseas business was increasingly subject to the pressure of American competition.

In the same way that the first of the grid power stations grew out of municipal electricity works which had extended individual feeders of their system into rural districts, so also did the tramways develop. Undertakings with an originally municipal character built extensions which opened up the more thickly populated areas in the neighbourhood of large towns. In this way networks had already come into existence during the founder period which, whilst being in the nature of tramways, maintained a regular service between adjacent towns. Progressing step by step, these undertakings had acquired the ownership of the permanent way outside the urban limits, which enabled them to operate at higher speeds. From this it was only a short step to the establishment of railway undertakings, which were usually financed by the interested towns and Communal Authorities, and whose object was the linking up of two or more towns. Whilst they confined themselves to passenger traffic, they operated not merely single cars but trains consisting of several motorized units and trailers. In the towns they used the public streets, and picked up and set down passengers in the same way as the tramways, thus not requiring station buildings. Outside the towns, on their own permanent way, they attained speeds comparable with those of the

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railways. In contrast to the U. S. A., the development of these undertakings was hampered by their being subject, as light railways, to State control. This was exercised by the Railway Authorities, and was not always free from an unconscious, or even conscious, element of rivalry.

There followed the metropolitan railways, the only example of which in Germany, as yet, was the Berlin Elevated and Underground Railway. Its great technical and economic success quickly led to extensions, which enabled Siemens-Schuckert to profit by experience in the introduction of improvements in matters of detail relating, in particular, to the rolling stock.

In planning the Berlin Elevated and Underground Railway, as also in carrying out the high-speed railway tests of 1903, Walter Reichel had specially distinguished himself. It would be fair to regard him as one of the best representatives of the University-trained engineers in the House of Siemens at that time. He combined a thorough scientific grounding with a very constructive imagination, and was eminently practical. In consequence, when it was a case of undertaking trial runs, he would not hesitate to take up an exposed or even dangerous post, to enable him to observe the working of particular parts. In short, he was attached to his work with a devotion which was as sincere as it was remarkable. At the conclusion of the high-speed trials, he accepted a call from the Berlin Technical University to the Chair "Electric Railways," without completely severing his connection with "the" firm, but although he proved to be a highly successful and inspiring Lecturer, he returned after a few years to his "first love." He was appointed to the Managership of the dynamo works, which was just then in process of rapid expansion. From this position he exerted a special influence on everything in any way connected with railway electrification, and was untiring in his efforts towards its furtherance.

The Prusso-Hessian Railway Administration had for some time past maintained a negative attitude towards all suggestions to electrify its railways. For one thing, the Army was against it for military reasons; in the second place, the controversy in the electrical world as to the most suitable type of current supply was by no means settled.

To use d. c. at 500 volts, which had been so successful in the case of the tramways, appeared to be out of the question for the railways, where the transmission of very much larger outputs was involved. A tramcar would probably consume about 50 kW, a small express locomotive at least ten times as much. For the tenfold current, however, there was no reliable bow collector; in any case the voltage losses would have rendered the attempt uneconomical. The alternative was to raise the voltage, and

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1,000 volts were at first proposed. Here the difficulty was with the commutators, due to the risk of flashing over between the live and earthed parts of the motors.

Two motors were therefore connected in series, in this way halving the voltage drop of each. Further, by suitable design of the parts the risk of flashing-over was reduced. With motors incorporating these and similar improvements Siemens-Schuckert equipped the "Rhine Bank Railway" between Cologne and Bonn in 1905. It was one of those railways with several well-appointed coaches for linking up two cities and soon became very popular. The railway was operated with d. c. at 1,000 volts, power being taken from a converter station situated at the load centre of gravity, an arrangement which proved to be perfectly reliable. In the following year Siemens-Schuckert supplied to the Rombach Ironworks in Lorraine a narrow-gauge railway for ore transport. This was built for 2,000 volts, and also operated without a hitch. In the U.S.A. and France, d. c. traction voltages were in use as high as 3,000 volts. In America there was no attempt to devise a uniform system on which all the railways in the various States, or possibly the whole world, could operate, but each case was dealt with on its own merits, and equipped in accordance with the latest principles applicable to the given circumstances. Railway electrification in America commenced with the underground approaches of the main lines to the centre of New York, in order to eliminate the smoke of the steam locomotives in the tunnels. As the distances were short, the existing d. c. voltages were adequate, especially as the trains did not travel fast. A further typical case was the crossing of the Rocky Mountains by the Chicago-Milwaukee Railway. The output of the steam locomotive is limited by the boiler, or, it may be said, by the performance of the stoker. The result was that the speed of the steam trains on the long, steep gradients was so low that it was decided to electrify the line. The electric locomotive is not tied down to the size of the boiler, but takes the power it requires from the trolley wire. The tension chosen for the steep sections of the line was 3,000 volts d. c., and the scheduled time was shortened considerably. Steam traction was retained on the level stretches, as there was no compelling reason to make a change. In view of the fact that in France, too, several lines had been converted to electrical operation at 3,000 volts d. c., there was an increasing number of those who were of the opinion that this was the solution in principle of the electrification of the complete railway system. They admitted, of course, that a considerable number of converter stations would be required, distributed more or less closely, according to the traffic density, and with personnel to operate them.

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In view of the scarcity of coal in Italy, and, on the other hand, the abundance of water power in Northern Italy, it was not surprising that thoughts turned to the electrification of the railways in the mountain valleys. In this connection there were many points of contact with Switzerland, where certain of the mountain railways had been successfully converted to three-phase electrical operation by Brown, Boveri & Cie. The Italian State Railways therefore decided to adopt this kind of current for its experimental lines. In favour of the three-phase motor was its simplicity and robustness, but a disadvantage was that it was confined to one speed only. The attempt to regulate the speed was attended by the difficulties already described. The direct current traction motor, on the other hand, in which the magnetic field and armature are connected in series and traversed by the same current, possessed the series characteristic essential in all traction work. This type of motor has the advantage of slowing down as the load increases, with the consequence that the output, which it takes in the form of electrical energy from the supply, does not rise so steeply when travelling up a gradient, as if it were to maintain a rigidly constant speed. With the three-phase system there was also the difficulty of feeding the three "phases" to the motor. If the rails were used for one phase, it still was necessary to provide two overhead conductors, which were a source of trouble when it came to points and crossings. These conductors also placed limits on the supply voltage; it was not considered advisable to go beyond 3,000 volts owing to the danger of short-circuits. The result was that the same number of feeder points had to be provided as with d. c., the only difference being that these consisted of static transformers which required no attendance. Nevertheless, the solution was not ideal.

For a long time past the question had been in the minds of those who, like Siemens, were concerned with the development of alternating current, as to whether it was not possible to produce a simple single-phase motor on the same lines as the d. c. motor. If it were made with solid poles, the same thing would happen as occurred in the early dynamos: the eddy currents would convert a considerable proportion of the electrical input into heat. Moreover, two of the commutator segments and the corresponding armature windings are always short-circuited by the brushes as the armature rotates. It is this which, in d. c. machines, gave rise to sparking at the brushes. The task of confining this sparking within harmless limits occupied the best brains for a period of nearly three decades. When, however, a short-circuited rotor coil is subjected to an alternating magnetic field, a considerable potential and corresponding current is induced, giving rise to "fireworks" under the brushes and

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making operation of the motor impossible. The only way to produce a serviceable traction motor, therefore, was by reducing the normal frequency of the current of 50 cycles to one half, or even better, one third, since the voltage produced by the alternating field increases with the frequency. It was a weighty decision, for it was not only the injurious voltages which were reduced, but also the useful ones. The consequence was that the transformers had to be larger, heavier and more expensive. Having a frequency of its own, the railway system could not be fed from the ordinary supply, but had to have its own power stations with large and expensive low-frequency generators. Obviously, however, there was no other solution.

As opposed to the three-phase system, this arrangement only needed one overhead wire and the voltage could be much higher. It soon became standard practice to adopt 15,000 volts, and one third of the otherwise normal frequency, i. e., $16^2/_3$ periods per sec. In the locomotive itself the voltage was reduced by a transformer to about 300—400 volts. A number of tappings and a step switch were provided on the low-tension side of the transformer, for connecting the motor to lower voltages for starting and speed regulation.

After some time, Siemens-Schuckert succeeded in finding a suitable standard-gauge railway on which to try out the single-phase a. c. system, viz., the branch line from Murnau to Oberammergau, which was not without a certain importance on account of the tourist traffic. It was found that the service of this quiet little line could be maintained without difficulty, and it proved to be very useful as a source of further experience.

Encouraged by the results, the Baden State Railways decided to electrify a second experimental line, viz., that between Basle and Schopfheim, the so-called Wiesental Railway. On this line, for the first time, goods traffic played an important part, and it was in consequence decided to employ locomotives.

Hitherto, the motors of the tramways had been of the underslung, axle-suspended type to ensure positive transmission of the power from the motor shaft to that of the vehicle. This was particularly important owing to the presence of spur gearing. On one side, therefore, the motor rested on the axle, and on the other on the underframe of the car. Since springs are interposed between the underframe and the axles, a certain amount of movement takes place between the two when the vehicle is in motion, so that about one half of the weight of the motor is sprung, but not the other. As far as tramways were concerned, this was quite satisfactory, especially as speeds were not high. In railway operation,

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however, much heavier weights rested on the axles, and the speed was from two to three times as high. It was generally feared, in consequence, that heavy hammer-blows would occur at every rail-joint, which would be a source of danger to the track and vehicle. The expedient was therefore adopted of mounting the motor high in the locomotive, so that the springs became fully operative also in regard to the motor. Thus arranged, one or two motors sufficed for a locomotive; they could be of the open-type, and accessible for inspection during operation. The transmission between the motor shaft and driving axle was by means of duplicate connecting rods arranged outside the underframe.

Work on the Wiesental Railway took longer than had been anticipated, and there had meanwhile been a good deal of discussion in technical circles about this, the first real electric railway in Germany. Furthermore, there was talk of plans on the part of Bavaria for the electrification of the Salzburg-Reichenhall line. Finally, a number of influential people in Prussia, Members of the Lower House amongst them, began to criticize in public the policy of procrastination of their Ministry of Railways, thereby encouraging a number of higher officials to present anew plans which had previously been rejected. As a matter of fact, these same officials had already had tests undertaken by the two large electrical firms with single-phase motor rail coaches on a branch line in the vicinity of Berlin, with very good results. Under these circumstances the Ministry of Railways decided to apply to the Prussian Diet for a credit to cover the electrification of the line between Dessau and Bitterfeld as an experiment.

The order covered seven locomotives in all, two each for the "Big Two," and one each for Brown, Boveri & Cie., the Bergmann-Elektrizitätswerke and a new firm, the Maffei-Schwartzkopffwerke, a fusion of two locomotive builders with an electrical department attached, who were also to be entrusted with a share. Siemens-Schuckert were the first to be ready, and they also appeared on the scene with one of the locomotives for the Wiesental Railway which could not just then be used at its real destination.

Whilst the performance of the Siemens-Schuckert express locomotive as built to the Dessau-Bitterfeld specification was very satisfactory, developing a speed of 130 kilometres per hour in the open, the other locomotive, built somewhat earlier for Wiesental, was a great disappointment, in fact a catastrophe. On attaining a certain speed, it commenced to vibrate and oscillate to an extent that was totally unacceptable. Much alarmed, the Authorities found that the other locomotives, although in varying degrees, exhibited the same suspicious

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motion, and when it was attempted to run the Siemens-Schuckert goods locomotive at full speed, the connecting rods broke and the locomotive was wrecked. The matter was a complete mystery; all kinds of theories were advanced as to the cause, and Doctor dissertations were written on the theme, which for a time filled the pages of the technical journals. The cause of the trouble proved to be the connecting rod drive, which required a degree of accuracy in machining which was at that time unknown in locomotive building. As it was, relatively small inaccuracies coupled with the heavy rotating masses served to produce rapidly alternating forces in the driving rods, which were transmitted as vibration and oscillations to the frame of the vehicle. When those on the electrical side asserted that precision must be ensured in manufacture by current workshop practice and maintained in service by adequate repair shops, they were told that they knew nothing about railway engineering. In the Prussian Ministry of Railways there were even those who wisely nodded: Didn't I tell you?

Reichel, with indestructible optimism, combated the embarrassment which was beginning to be felt within and outside the firm at the result of this first experience with the Railways. The Tramways, he said, were also not conquered in a day, and steam locomotive construction was still a pretty rough trade; steps would be taken to introduce the precision methods employed in electrical engineering. Of all the German firms it was Siemens-Schuckert who were the stoutest advocates of the electric railway and the single-phase a. c. system. In addition to other commitments in this direction, they had meanwhile accepted a large contract from the Swedish State Railways which had been awarded them as the result of successful trials, and which was now causing them some uneasiness.

The Kiruna Mines in Swedish Lappland produced a particularly high-grade iron ore which was conveyed by a single-track railway in a north-westerly direction across the Norwegian border to the harbour of Narvik. This involved crossing the frontier mountain range of over 500 metres in height across barren country north of the Arctic Circle, subject for most of the year to raging snow storms. Steam locomotives of the heaviest type struggled up the long gradients of 1 in 100 with ore trains of up to 1,400 tons. A pilot engine was required for the last and steepest section to Riksgränsen, notwithstanding which, the speed was not more than 10 kilometres per hour. To add to the difficulties and expense, the coal for the locomotives had to be hauled over the same line. As against this, Siemens-Schuckert suggested utilizing the water-power of the Porjus River to the South, and taking the electrical current

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at 80,000 volts to the railway, where it would be stepped down to 15,000 volts in a number of transformer stations to feed the overhead line. The question was whether the rather sensitive single-phase motor would be equal to the inevitably rough treatment aggravated by climatic conditions? Was it reasonable in these barren tracts, far from civilisation, to expect for the equipment that amount of care and maintenance which it would hardly receive even in Germany? Moreover, the Firm had entered into fairly extensive guarantees. If the venture was to be a success, everything, and the locomotives in particular, would have to be up to a standard such as had never yet been called for at home. Reichel did not fail to impress his assistants with the full seriousness of the situation.

The "Riksgränsen" Railway commenced operation in 1914 and proved to be a resounding success. In spite of the rigours of the Polar climate, the locomotive performance was better than guaranteed; they hauled loads of 1,500 tons up the snow and ice-covered gradients at 30 kilometres per hour, and required little in the way of repairs. In course of time the electrification of the line was extended to Lulea, on the Gulf of Bothnia, and to Narvik on the Atlantic coast, thus completely crossing the Scandinavian Peninsula. For a considerable time the railway was looked upon as a masterpiece of engineering, and one which had made an important contribution to the modernisation of the railways. Its doughty locomotives had not only broken the ice on the up-hill tracks, but also the prejudices of Railway engineers at home and abroad.

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XV.

THE DEVELOPMENT OF COMMUNICATION ENGINEERING

Observing certain shortcomings in the operation of the Hughes telegraph apparatus, Émile Baudot, an untrained and unassuming official of the French Telegraph Administration, began early in the 'seventies of last century to develop a new telegraph system. With the support of the Ministry and in untiring labour extending over a generation, he succeeded in making one improvement after another, until by the turn of the century, he came to be acknowledged and honoured as one of the great pioneers of telegraphy. He reverted to an idea which had already been suggested, viz., that if, in sending a number of symbols over the line, it is desired to shorten the time for each as much as possible, all the symbols must be of equal length. This could be achieved by using current impulses of equal length but opposite direction, and by composing symbols of the same number of impulses, but differing in the order in which the opposing impulses occurred. Since it is possible to operate a telegraph system with about 30 symbols, it follows according to the law of permutations that the number of opposing impulses must be five, for $2 \times 2 \times 2 \times 2 \times 2 = 32$. This, incidentally, was the system on which Bacon invented a secret code in the seventeenth century. Thus was born the five-unit alphabet, upon which all modern telegraph systems are based. Baudot produced the combination of current impulses required for each letter by pressing several of the total of five keys, and ensured the maintenance of the exact time sequence of the impulses by means of a distributor disc with contact segments and a set of rotating brushes. Each revolution of the brushes therefore sent an accurately built-up symbol into the line.

At the receiver end the series arrangement of the impulses was converted into a parallel by a second distributor which rotated in synchronism with the first. According to the sequence of the impulses, the armatures of five electromagnets took up positions which copied those of the keys of the transmitter. A complicated piece of apparatus, the translator

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ascertained the symbol corresponding to the position of the magnets, which was then printed on a tape in the usual manner.

The fact that translating and printing occupied a certain amount of time—although very little—during which transmitting had to be interrupted, led Baudot to divide the distributor discs into two sectors each, and to arrange the transmitter contacts within the area of one sector. In this way he was able to feed two transmitters and two receivers from each distributor, and had two sets of apparatus operating over the same line. Whilst one set was transmitting and receiving, the other could be translating and printing, and vice versa. Operating at a speed of 180 r.p.m., which was half as high again as that of Hughes, Baudot could transmit 360 cyphers per minute, and with a second distributor and four transmitters and receiver as many as 720 symbols. Of course, this also meant twice or four times as many operators.

Apart from France, the Baudot Telegraph Apparatus soon gained a footing in the countries of Western Europe, and the German Post Office began to use it on some of its trunk lines. It proved to be a most important step in the acceleration of telegraph communication. In view of this state of affairs, Wilhelm von Siemens was of the opinion that it was time for Siemens & Halske to concern themselves with the development of a high-speed telegraph. A task of this kind was congenial to him, inasmuch as he needed a "change" from time to time from administration, organising and finance. Not having a very high opinion of the inventive talent of his telegraph department, Wilhelm von Siemens transferred Dr. Franke and an engineer by the name of Erhardt to his private laboratory, where he spent many fruitful hours with them in stimulating discussion.

In November 1903 Wilhelm von Siemens himself presented the newborn babe in a lecture to the "Elektrotechnischer Verein" in Berlin. By way of introduction he reviewed the reasons which had been responsible for the existing stagnation in the field of telegraphy. Part of the blame for the unsatisfactory situation in telegraphy was attributed by the lecturer to the absence of that close contact between the designer and user which prevailed in power current practice. The result was that numbers of ingenious constructions and ideas had been relegated to the shelves of the museums. Should, however, a high-speed telegraph apparatus make its appearance which were equal to all demands, there would be little doubt but that telegraph would adapt itself to the improved methods of working. On this basis he, the lecturer, therefore hoped that the new apparatus about to be demonstrated would not end in a museum.

The new apparatus, a high-speed telegraph for 2,000 symbols per

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minute, ran counter to most of the ideas introduced by Baudot, and struck out on original lines. It employed a type-wheel revolving 33 times per second, corresponding to the above telegraphing speed (since each cypher required one revolution of the type-wheel). With the size of wheel selected, the velocity of the rim carrying the letters was 16 metres per second. At such a speed, printing as hitherto understood was, of course, out of the question, so a photographic process was introduced. The 45 cyphers for which the apparatus was designed, were arranged in small windows around the periphery of the type-wheel in the form of silhouettes capable of casting shadows. An electric spark was caused to discharge at the instant the required cypher passed in front of it, projecting the shadow on to a strip of sensitized paper, and thus effecting an instantaneous exposure of one millionth of a second. The paper strip then passed through a tiny dark-room, where it was automatically developed and fixed. Nine seconds after the exposure, the letter appeared on the strip, which could then be handled in daylight.

Relative to the state of the art of instrument-making at that time, the apparatus was of outstanding merit, an achievement of which the inventor could be justly proud, and for which a number of patents were granted. Nevertheless, it did not find favour with the Authorities, who feared trouble with the complicated mechanism and the photographic process, with which they were unable to deal in the event of a breakdown. Moreover, there was no doubt that with its enormous speed the apparatus had really overshot the mark. Even when its use was confined, as was the intention, to overworked lines, it frequently happened that the operatives, whose duty it was to prepare the punched strip, paste up the finished telegrams and enter the official remarks, etc., were only intermittently occupied. The new apparatus had drained the line dry. Above all, however, it could hardly be used on cable lines owing to the blurring effect of the previously discussed capacitance on the precise timing of the current impulses, on which the correct transmission of the symbols depended. As had come to be generally recognized, however, the cable was the thing of the future, especially for busy trunk lines. It became evident that Baudot had been right after all, when he laid it down that all symbols must be of equal length, from which followed the five-unit alphabet. After some years of unsuccessful effort to establish the high-speed telegraph apparatus, it likewise ended its days in the museum.

Wilhelm von Siemens was not a little annoyed on realising that his pet child had proved a failure, but since he was unable, in view of his other duties, to continue to devote precious hours to the high-speed telegraph,

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he put Dr. Franke in charge of the further development work. Unlike his chief, Dr. Franke was not given to ruminating, but was a practical man of business, who did not see why he should avoid a certain line of approach to a subject merely because others had already trodden it. Surely it had to be admitted that Baudot was right in his idea of the five-unit alphabet, and of the basic design which followed from it. What were they aiming at—to invent something at all costs, or to produce a serviceable high-speed telegraph? In following the Baudot principle, it was still possible to develop quite a number of original ideas.

It was not until May 1913, after several years of study and experiment, in which the Principal of the House maintained a continual interest, that Franke introduced the product of his labours, the Siemens High-speed Telegraph, to the general public, in a Paper read before the "Elektrotechnischer Verein" in Berlin. Unlike its predecessor, the apparatus was limited to a speed of 1,000 symbols per minute, which were printed in the usual manner by a fast-rotating type-wheel on a strip of paper, the printing speed having meanwhile been successfully raised to this level. The symbols were transmitted by means of a paper strip, in which holes had previously been punched by a kind of typewriter in five parallel lines in accordance with the five-unit alphabet. Each row of holes—or blanks—in the direction across the strip represented a symbol. Of the corresponding row of five feelers, these made contact with the drum where the strip had been punched. As in the Baudot apparatus, the rotating brush-arm of a stationary distributor-disc commuted the positions of the feelers into the sequence of current impulses. At the receiving end, the impulses were freed from any distortion suffered in transmission by a brush rotating on the face of a distributor disc in synchronism with the transmitter brush. Thus corrected, the impulses were taken to five respection relays, which copied the positions of the transmitting feelers by corresponding positions of the armatures. The fundamental transmission of the symbol was thus achieved. The translation into print was effected by an ingenious switching device coupled with the type-wheel, which caused the paper strip to strike against the wheel at the instant that the letter corresponding to the position of the relays was in the printing position.

Essentially, the Siemens high-speed telegraph was an improved version of the Baudot apparatus. Instead of hand-operated keys, it employed a punched paper tape, and instead of the exceedingly complicated and sensitive translator mechanism, the simple and neat electrical solution. Both these modifications made for a high working-speed, and rendered the idea of connecting more than one piece of apparatus to

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one line superfluous, thus saving personnel. With its assembly of wooden cases and interconnecting cables, the Baudot apparatus rather gave one the impression of a patriarchal collection; the Siemens high-speed telegraph, on the other hand, was compact and business-like in its external appearance. In operation, it was all it promised to be. There were hardly any of the usual ailments of childhood; both in design and workmanship it proved to be a masterpiece of precision engineering, the Halske tradition had once more scored a success. At last the battle was won. A telegraph apparatus had been evolved with a performance superior to anything hitherto known, which, as it transpired, held this world record for a considerable number of years. As has always been the case with regard to telegraphy in the House of Siemens, however, this was not the outcome of a stroke of genius, but the fruit of painstaking, scientific plodding and unsurpassed workmanship.

Almost thirty years before the appearance of the first high-speed telegraph, in the early 'seventies, certain American apparatus had given Werner Siemens the incentive to design a so-called tape machine. In consequence of the brisk speculation prevailing in the large cities of the U.S.A., above all New York, a need had soon come to be felt for a means of transmitting the share and commodity prices to brokers and others in the shortest possible time. The result was a service which telegraphed the same information from a central point to a large number of subscribers. The receiver instruments required no attendance; the message was read on the tape, which was automatically set in motion with each new message. The Americans called these machines "Tickers." They were one of the early objects with which Edison as a young man won his spurs as an inventor.

The first tape machine made by Siemens & Halske was designed on some of the basic principles of the pointer telegraph. In both instruments, a spindle rotated in the transmitter in unison with a spindle in the receiver. By pressing one of a set of keys, similar to those of a typewriter, the rotation of the transmitter was momentarily interrupted. At that instant the same letter of the receiver presented itself to the printer. The longer current impulse consequent on stopping the machine excited the pointer magnet, which struck the tape against the type-wheel. Printing was thus not carried out with a flying type-wheel, as in the teleprinters of those days, but the apparatus was stopped in each printing operation. This resulted in a relatively low working speed, but speed was not of such importance in this case.

This apparatus, with occasional improvements, served its turn for twenty-five years without finding any considerable sale in Germany.

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Neither at home, nor in other countries of the European Continent, was there much call in those days for tape machines. In England, on the other hand, business was rendered impossible by the strained relations with Siemens Bros. The decision had almost been reached to give up the manufacture of the telegraph apparatus altogether, when it became known (1898) that an inventor by the name of Bernhard Hoffmann had produced an apparatus called the "Telescripteur." The design embodied little that was novel, as became evident when the patents were offered to Siemens & Halske with a view to their joining a "Telescripteur-Syndicate." The novelty lay in a suggestion to establish a network on the pattern of the telephone system, to which private subscribers (primarily large firms) could be connected with the object of communicating with each other telegraphically without the necessity of using the services of the Post Office. An obstacle in the way of fulfilment was, of course, the Post Office telegraph monopoly, but the idea had been conceived of forming a Company with the participation of the Post Office, from which the Company would rent the necessary lines. After some hesitation the Post Office agreed to the suggestion, and became a partner in the "Ferndruckergesellschaft m. b. H." (Teleprinter Company Ltd.), which was to commence operations in Berlin by way of a trial. Siemens & Halske had meanwhile commenced to design a suitable apparatus, which followed the general lines of the ticker machine, making use of the experience since gained. In contrast to the ticker, however, every subscriber—as in telegraphy—had to be able to transmit as well as receive. The task of designing the new apparatus was placed in the hands of Carl Schwennicke, who had joined the Firm as a young mechanic as far back as 1859, and had grown up, under the tutelage of Werner Siemens and von Hefner-Alteneck, to the status of an experienced designer with special knowledge of telegraph accessories. Instructions were given that Schwennicke was to work out the design in his experimental laboratory, particularly as he had had earlier experience with the ticker machine. Again—as in the case of the high-speed telegraph—the so-called "Telegraph Department" was by-passed, an undoubted mistake, for which both the department and the object under consideration were to suffer. The seemingly simple problem proved to be much more complicated than had been imagined. Two unforeseen difficulties cropped up. In the first place, a cable network had to be used which was not laid out for telegraphy. The cores of the urban telephone cables, which had to be used because of their ease of access, were of insufficient cross-section for telegraphy. When the telegraph voltage was raised in order to limit the current, the consequence was unbearable interference with conversa-

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tions over neighbouring cores. Moreover, now that the telegraph apparatus had to be used by all and sundry, it was necessary to make it foolproof, which was no easy matter with such a complicated apparatus. Schwennicke spent years of Sisyphean toil till he was able to write in his last report: "...The work of the laboratory on teleprinter systems is thus at an end. In the course of six years, without the help of drawings of any kind, it has carried out the design, construction, assembly and also the manufacture of the most important components of this apparatus. During this period, approximately 500 teleprinters have been made and installed, which should be sufficient proof of their commercial efficiency." It certainly was a proof of Schwennicke's tenacity and endurance, but it reflected little credit on the way in which work on the problem had been organized.

About the same time, the towns were beginning to take an interest in fire alarm telegraphs. In itself, this was nothing new as far as Siemens & Halske were concerned, the Firm having been requested shortly after its foundation to prepare a scheme for the Berlin Municipal Authorities. The system was to provide for a number of public fire alarms, from which it was possible by one manual operation to call the Fire Brigade, at the same time letting them know whence the call emanated. Siemens & Halske arrived at the following basic solution: the whole of the fire alarms were connected together by a single cable; in the fire station the two ends of the "loop" (in extensive systems there might be several loops) were connected through a relay to a source of current. Normally, current flowed continually through the circuit (closed-circuit connection), and the alarm signal was given by interruption of the current. When this took place, the armature of the relay dropped and closed a local circuit which operated the alarm. The closed-circuit connection was chosen in order to ensure that an alarm was sounded also in the event of the circuit being interrupted unintentionally. Whereas, in this case, the signal was a continuous one, that belonging to an intentional alarm was intermittent, the number of beats indicating the number, i. e., location of the fire alarm. The fire alarm was fitted with a clockwork mechanism, which was set in motion by pressing a button after breaking the glass cover. The clockwork then interrupted the electrical circuit according to the pattern peculiar to the particular alarm. If, for instance, the signal corresponding to the contact breaking was xxx xxxxx, it indicated that alarm No. 35 had been operated. Each alarm thus telegraphed its number automatically.

Seeing that in the course of nearly fifty years, not more than a few large towns had adopted this equipment (which, of course, had been improved as time went on) and, moreover, that only one home and one

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foreign competitor had succeeded within that period in obtaining an order, it was not surprising that Siemens & Halske lost interest in the business. Shortly after the turn of the century, however, the issue was taken up again at the instigation of an energetic engineer by the name of Bügler. It was decided to take the alarm business from the Telegraph Department, where it had been dealt with as a side line, and to form a new independent department. The design of the various components was now improved and rendered more efficient; various systems were developed to suit fire alarms differing in scope and principle; apparatus was designed for registering the alarm calls and the exact time of reception, for the automatic operation of temperature-sensitive indoor alarms. In some cases, the apparatus so designed could be applied to the solution of kindred problems, e. g., checking the watchmen on their rounds, protection of pay-offices, safes and store rooms against burglary, and finally, communication with the police. Well-organized publicity on the part of the Firm drew attention to the importance of protecting national property from fire and theft, and based on the sound design and adaptability of the equipment, it was not long before a remunerative business had developed, of which Siemens & Halske held a practical monopoly in Germany and in the greater part of the European market.

At a comparatively early date, the idea had cropped up of using electricity to synchronize smaller or larger groups of clocks. In the first place, it was the Railways which were interested in the solution of this problem in view of the closely spaced stations of the metropolitan railways, which compelled running to a rigid timetable. This made it essential that the clocks on all stations should keep uniform time, a condition which was impossible of fulfilment with the existing mechanical clocks. The solution was to install a master-clock, equipped with a contact system, by means of which a current impulse is sent out at regular intervals, e. g., one minute, to all the secondary clocks connected in circuit. The current impulse energizes a magnet in the secondary clock, causing it to advance by the amount of the interval, in this case one minute. The secondary clocks thus require no movement of their own, and can be of exceedingly simple construction. They are all connected in series in one circuit, and are thus similar to the fire alarms, with which they have many points in common. A number of the larger cities decided to install public electric clocks, an example which was followed by numbers of large firms having extensive offices and factories. Siemens & Halske attached the rapidly expanding Clock Department to the fire alarm group, but not as a monopoly, for in this branch of the business there was no dearth of active and efficient competitors.

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In the course of his visit to Chicago in 1892, Wilhelm von Siemens had learnt about Almon B. Strowger and his ideas in connection with automatic telephony, for which he had obtained a basic patent in the preceding year. The Strowger Automatic Telephone Exchange Co., in Chicago, was just then engaged in equipping an experimental exchange in La Porte (Ind.) on this system. In the experiments which led to the grant of his first patents, Strowger set himself the task, in the first place, of enabling a subscriber to call any one of a hundred other subscribers. To achieve this, Strowger connected the ends of the hundred lines to flat contact pieces, which he arranged in ten horizontal groups of ten each, placed above each other, and projecting from the inside of a semicircular surface. A rotatable contact arm was connected to the subscriber making the call, and could pass along the surface of each of the ten horizontal contact groups. If the subscriber wished to call Nr. 57, he first sent out five impulses by means of a suitable mechanism. These caused a "lifting magnet" to raise the contact arm, one step at a time, to the fifth horizontal row of contacts. A further series of seven impulses operated a "turning magnet," which rotated the contact arm until it reached the seventh contact in the fifth row. He was now connected to No. 57. Strowger thus succeeded in producing a very compact assembly, which was also essential, since there had to be one of these "selectors" for every subscriber, and the corresponding contacts of each selector had to be interconnected as in multiple operation, to enable every subscriber to call every other.

To produce the current impulses required for selecting, the Strowger Co. invented in 1896 the now well-known number-plate and finger-operated rotating dial, which transmits the impulses on its return to zero.

In the early days, the subscriber had to dial zero after each number before the selector could pass on to the next. The current impulses produced by the dial were also used directly for energizing the lifting and turning magnets. This meant fairly heavy currents, with their resulting interference with other cores in the same cable, as in the case of the teleprinter equipments. It was not until later that the idea was conceived of transmitting weak impulses, and of amplifying them in the telephone exchange by relays to the strength necessary for operating the magnets. It eventually became the general practice to use large numbers of relays and complicated connections to control the change-over of the selectors from "lifting" to "turning," for testing whether a line was free or engaged, and for making the final connection.

In the example considered, the number of subscribers was one hundred. If this number were increased, the process of selection had to

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be divided into several stages. The selectors in the first stage were called "group selectors," as they were not directly connected to the subscriber lines, but to another selector group known as "line selectors," to which the required subscriber was connected, provided that the exchange did not comprise more than 1,000 subscribers. If a subscriber called the number 467, dialling of the figure 4 would cause his group selector to rise to the fourth horizontal row of contacts. To these were connected the line selectors of the hundred subscribers whose number begins with 4 ("fourth hundred"). By passing over the contacts of this fourth horizontal row, the group selector searches out the first line selector of the fourth hundred which is not engaged, and connects up to it. The same procedure is then repeated in the line selector in selecting the last two digits. By thus connecting various selector stages in series on the decimal principle, it was possible to build exchanges for any desired number of subscribers.

As far back as 1898 the Strowger Automatic Telephone Co. had extended feelers to Europe. In Berlin they had made the acquaintance of three enterprising business men: Philipp Mosino and the brothers Salo and Siegfried Sachs, who introduced them to the Ludwig Loewe group. The latter controlled the "Deutsche Waffen- und Munitionsfabriken" with Works in Karlsruhe. Although equipped for the manufacture of cartridges, there seemed in those peaceful times to be nothing against using the machinery for other precision work in mass production. The Post Office was persuaded to build an experimental exchange for 400 subscribers in Berlin, to which a number of ministries and large firms were connected, with a view to gaining practical experience of the working of the new system. The equipment was ordered from Chicago, as Karlsruhe was not yet ready for production. Siemens & Halske learned of the order, and the Management enquired reproachfully from the Post Office whether even telephone equipment was now to be bought in America. The evasive reply, mentioning experimental work, merely served to confirm the fact that, as far as telephones were concerned, the Post Office still had insufficient confidence in the Firm's ability. It was the period in which the Firm was fighting bitterly for re-consideration as suppliers, meanwhile, of hand-operated multiple-connection switchboards. Prior to serious participation in the tasks involved in the introduction of automatic telephone exchanges, there certainly was a good deal of preparatory work to be done.

Following these preliminary negotiations and arrangements, Ludwig Loewe & Co. signed an agreement with the Strowger Company in June 1901, in accordance with which they took over the American firm's

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patents in Europe with the exception of England and France. Four weeks later, Ludwig Loewe concluded an agreement with the German Post Office, in which they bound themselves against payment of a pretty stiff royalty to grant the Post Office the use of all existing and any future Strowger patents.

Following on the extension of the Berlin experimental exchange and its modification in the light of experience gained, the Post Office decided in 1905 to convert the Hildesheim exchange, which was in any case ripe for replacement, to automatic operation, and to order the equipment from the Deutsche Waffen- und Munitionsfabriken in Karlsruhe. Three years elapsed before the exchange was ready for working, as a multitude of details originating in American practice had to be adapted to German conditions. Once in service, however, this first public automatic exchange in Europe operated to the satisfaction of the Authorities and the public, and attracted a stream of visitors from all parts.

In spite of the success, however, one of the participants was not satisfied, viz., Ludwig Loewe & Co. As a business proposition, the result looked much less attractive than that which the firm had pictured to itself when operations commenced. At the outset, there had been frequent talk of precision work, for which the factory at Karlsruhe was stated to be equipped. But the demand really was for precision mechanics in conjunction with electrical engineering, the latter necessitating development work on a colossal scale. There were complicated connections to be devised, which were hardly understood by the usual power current electrician. Hundreds of relays had to be calculated and adjusted to work in unison to control the interplay of electrical operations, in which time was counted in milliseconds. There were difficult magnetic materials to be dealt with, puzzling contact phenomena to be cleared up, as also the influence on the operation of the automatic telephones of the microphones, repeater coils, batteries, wiring and cables. Then there was the Post Office with its requirements and conditions. Its representatives were competent telephone technicians, and inevitably appeared to the inexperienced Ludwig Loewe staff in the light of schoolmasters. Obviously, it was necessary to have more than the American patents. Either one had to decide to establish an extensive special telephone division, or even a separate electrotechnical Works with laboratories and research departments or . . . . . . Loewe decided in favour of the alternative and notified the Post Office that he had little interest in proceeding with this line of business.

Something like this had been foreseen by the Post Office; already in the previous year, following a hold-up in the work at Hildesheim, they

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had been wondering whether to carry on. With the help of one of their experienced engineers, however, the difficulties had been overcome. Why were Siemens & Halske standing aside all this time? The Firm to-day was very different from the firm of the same name ten years ago. In the development of the multiple connection boards it really had won the race, thus acquiring unrivalled experience and building up the most extensive manufacturing capacity for telephone equipment in Germany; backed up with the Pupin patent, it had secured the lead in all questions of long-distance telephony. It could boast of having a larger staff than the whole of its competitors taken together, and it even seemed to have been quietly studying the problem of automatic telephony, judging by several patent applications and patents granted. Really, when it came to the universal establishment of automatic telephony in Germany, which was the ultimate goal of progressive Post Office engineers, it appeared nonsensical not to avail oneself of the services of such a firm.

Based on these considerations, therefore, the Post Office took the occasion of a critical situation in Hildesheim in 1907, to suggest that the Firm should participate in a Study Group with the original interested parties, i. e., Mosino, the Sachs brothers and Loewe. Siemens & Halske accepted the suggestion with the one stipulation that the technical leadership of the "Gesellschaft für automatische Telephonie" should be in their hands. As soon as Hildesheim had resumed operations, the Post Office requested Grabe to call on them, and informed him of their large-scale plan for the conversion of the German telephones to automatic working, in connection with which—especially as regards development work—they counted on the co-operation of his Firm.

In this situation, it was only natural that the Management of the Firm, i. e., Wilhelm von Siemens, Raps, Franke and Grabe, should experience a feeling of justifiable triumph. How, a decade ago, the Firm had begged the Post Office in vain for orders for telephone exchanges, only to see them placed with small specialized competitors, who had thereupon fastened their teeth into the lucrative business of supplying hand-operated multiple connection switchboards! The strange thing was that Siemens & Halske had nothing to show in the new field of development; obviously, it was just the fact that the Post Office trusted the ability of the Firm that had led it to take this step. However, the proffered hand was firmly grasped, and nothing allowed to betray past feelings of bitterness. The "Gesellschaft für automatische Telephonie" had thus really become meaningless, particularly as the Loewe group had let it be known that they had no further interest in manufacture, and the financiers who had established the original contacts had request-

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ed and received repayment of their money by Siemens & Halske. The Firm sent a working party under Raps' leadership to America, where the Strowger Company, after acquiring further capital, had meanwhile been converted into the "Automatic Electric Co." in Chicago. The Americans returned the visit and were shown over the Wernerwerk, which, together with the many examples of Siemens telephone products, caused them some little surprise. A new and extended agreement was made with them on the lines of that concluded with the "Gesellschaft für automatische Telephonie," which provided for comprehensive technical co-operation of the contracting parties. Having taken over the technical staff of the telephone department of the Deutsche Waffen- und Munitionsfabriken, Siemens & Halske proceeded with the further development of the automatic system. On the basis of a patent, the principles of which were worked out by Grabe and his assistant Tanke, they did away with the costly luxury of providing a hundred-line selector for every subscriber. In its place they substituted a small ten-line "pre-selector," which automatically selected the first group selector which happened to be free when the receiver was lifted. Local batteries for subscribers also disappeared, and were replaced by the central battery system. The subsidiary stations were adapted to work on the new system, and solutions found for hundreds of other queries. Germany thus became the first country to witness the triumph of automatic telephony under Siemens & Halske leadership.

The development of the telephone business with the Navy, which commenced after the resumption of the Firm's telephone activities about the middle 'nineties, took a very different direction. In an earlier chapter, developments had been followed up to the establishment of fire-control stations, and the provision of suitable marine telephone equipment for the transmission of information and orders.

Urged on by Wilhelm II, Germany had embarked on an extensive plan of naval construction. In this the Kaiser had found a supporter, as tactful as he was forceful, in the person of Admiral Tirpitz, whom he had appointed First Lord of the Admiralty. Increased building activity in the Navy had hitherto always had to face the difficulty of persuading a reluctant Parliament to vote the necessary means, a procedure which had to be repeated from year to year. Tirpitz hit upon the idea of securing parliamentary sanction for a constructional programme extending over a number of years, to which any later Parliament, possibly of a different composition, would also be bound. With the aid of clever publicity, the scheme was brought to fruition in 1900, when Parliament approved the plan of building a Home Fleet comprising 28 ships of the

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line, 12 large and 38 small cruisers within a period of 17 years, the above to be complementary to existing units. Six years later an additional plan was sanctioned to build an Overseas Fleet; simultaneously the life of the battleships was reduced from 25 to 20 years.

This new order of things meant for the Navy that it had money to spend; not that it would be in favour of irresponsible wastefulness, but the overall plan had been sanctioned, the money voted. Now it would be spent, most certainly after careful consideration, but always on the side of having the best, not the most economical. If, for instance, some promising innovation made its appearance during the construction of a vessel, it was installed, even although the apparatus it replaced might have just been fitted, and regardless of the cost.

Siemens & Halske thus found that their old client, with whom they had worked harmoniously for many years, now had an enormous building programme of many years' duration; that he could dispose of practically unlimited means, was determined to have the best of the latest, and trusted the Firm to supply it. A client like this is not found every day, and Siemens & Halske established a special department—the Marine Department—to deal with this business.

The constructional unit, upon which all tele-transmission apparatus, whether for board-ship or for the artillery, was based, was the so-called six-roller system, already mentioned in a previous chapter. In the course of time, it had been considerably improved in the light of experience gained, but had retained the fundamental defect that in the event of an involuntary interruption of the current, transmitter and receiver fell out of step, and had to be re-synchronized by some means or other.

About 1905 Siemens & Halske engineers chanced to remember a phenomenon which had been observed some years earlier by their colleagues on the power side, but which they had not been able to turn to account. If two small three-phase motors of the same size and type are connected to the same supply with the slip rings electrically interconnected, and the rotor of one held stationary, the rotor of the other motor will continue to turn until it has reached the same relative position to the stator and will then stop rotating. The reason is that in different relative positions of the two rotors their slip ring voltages are different. This voltage difference causes a current to flow in the circuit of the two rotors, which turns the "free" rotor until the voltages coincide. In that position the voltages cancel each other out, current ceases to flow, and the torque vanishes. If the first motor is looked upon as a transmitter and its rotor turned again through a certain angle, the same thing repeats itself until the receiver rotor has again reached the corresponding position.

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The receiver therefore follows every movement of the transmitter, and copies its movements.

Having designed a suitable and reliable apparatus on the above principle, thereby eliminating the troublesome necessity of readjustment inherent in the d. c. six-roller system, Siemens & Halske demonstrated the new model to the Admiralty at the beginning of 1906, where it was received with the keenest interest. It was immediately decided to re-design the fire-control equipment completely. In place of the existing apparatus, in which endless tapes ran in chimney-like superstructures provided with windows, through which the figures on the tapes were visible, the new receiver consisted of a motor, the spindle of which carried a light wheel with figures arranged on the periphery. The motor was placed in a housing with a window, through which the figures could be read. Having learned, meanwhile, to produce motors no larger than a medium-sized fist, and by the ingenious utilisation of space, it proved to be possible to combine within the compass of a medium-sized box, suitable for mounting near to the gun, all the data required in gunnery, such as range, lateral training, lateral correction and general instructions. The transmitter was similar in appearance and had become a compact and handy piece of apparatus, which no longer interfered with the freedom of movement of the commander. The final arrangement was, of course, the result of innumerable experimental models, modifications and sea-going trials on various ships. At length, agreement was reached in respect of a standard form, which was then installed in all the larger vessels of the continually expanding fleet. In addition, there was special equipment for mobile and semi-mobile posts for smaller ships, etc. etc.

The function of existing fire-control equipment had been restricted to advising the head gunner of the distances as measured at the control post, leaving the rest to him. It was, of course, also possible to calculate the elevations at the control post and to telegraph them. To achieve a further saving of time, a rather more powerful receiver could be used to adjust simultaneously the telescopic sight. The gunner then would have nothing more to do than get the target in his sight and fire. It was a regulation in the Navy, however, that the adjustment of the telescopic sight must take place in such a way, that a uniform variation of the distance in the sight would correspond to a uniform motor speed, and thus to the same distance variation in the transmitter. This meant a complicated mechanism, which in a certain sense introduced the values from the firing-table as a variable ratio into the transmission from transmitter to telescopic sight. After intensive study and many practical experiments on board ship, the Siemens & Halske engineers, who by this

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time had almost become marine artillerists and ballisticians, incorporated the mechanism in the transmitter, thus enabling all receivers of the same calibre to receive the correct value simultaneously. To do this, they meanwhile relinquished the idea of electrical adjustment of the telescopic sight, but merely indicated the correct position on a scale. A second pointer on this scale was mechanically coupled with the telescopic sight, and it was the task of the gun-trainer to adjust this sight until the two pointers coincided, thus bringing the telescopic sight into the correct position to give the gun the elevation corresponding to the distance of the target. After installation in its final form on several ships, the Admiralty placed an order with the Firm in 1913 to equip the artillery of 21 ships of the line and 5 large cruisers with this type of fire-control, a contract running into millions of Marks.

The range of a target at sea is found by means of the so-called base range-finder, which works on the same stereoscopic principle as the eyes. Using a binocular, the target is sighted from two points at a certain distance from each other (the base). If the two images are then brought into register, the amount of the necessary movement is a measure of the range. Depending as it must on subjective factors, this procedure is not without a certain inherent inaccuracy, and it soon became the practice on large ships to install binoculars at several points, making observations simultaneously, and comparing results. When the measuring device was coupled to an a. c. transmitter it was found that the transmitters of the various instruments could be connected in series. By addition of their voltages they automatically formed the arithmetical mean, which was much more accurate. This was then transmitted by the telescopic sight telegraph, to indicate finally the required elevation of the guns. In this way more and more complicated transmission and conversion apparatus came to be developed, incorporating bevel gears, cams, worm and planetary gears.

Raps, who had gradually come to be possessed of a real passion for this technical sport, also directed his attention to the problems facing the artillerist in consequence of the rolling of the ship. He dreamt of a battleship whose massed guns lightly followed the sighting telescope, and at the touch of a press-button, covered the enemy with a broadside. Corresponding designs were in preparation when the 1914 World War broke out, rendering the big ships of the fleet for the time being unavailable for further experiments.

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XVI.

THE WERNERWERK

Soon after the founding of Siemens-Schuckert, the Siemens & Halske Management had come to realize that something decisive must be done to relieve the eternal congestion in the Berlin Works. It was decidedly unfair to consign to the fate of a Cinderella that section of manufacture which had contributed so materially to the strong position of the Firm in the negotiations with Schuckert. In consequence of unparalleled expansion due to the successful opening up of ever new fields of activity, it was now unable for want of accommodation to do itself justice, either from a manufacturing or a social point of view. Notwithstanding the removal of the Railway Signalling and the Incandescent Lamp Works, as well as the Head Office, the Berlin Works had overflowed into five separate former dwelling houses in the neighbourhood of Markgrafenstrasse, all leased, with the exception of the old original property. The struggles of the departments for every square inch of space assumed the most ludicrous forms. Now that an extensive acreage of building land was available at Nonnendamm, where the Cable Works and an adjoining Work's power station were already established, it was decided to erect a factory behind this group (as seen from the River Spree). The new Works could cover the foreseeable needs of the departments of the Berlin Works, essentially the Tele-communication and Measuring Instrument Departments, and at the same time be a worthy symbol of the importance of this side of the Firm's activities.

The building plan embraced a complete scheme, of which only two thirds were carried out in 1904. The necessity to give effect to the whole plan arose sooner than had been anticipated, and the building was therefore completed in two stages in 1908 and 1912. It took the form of a six-storey, pilastered structure of square shape and a length of sides of 153 metres. The internal quadrangle was subdivided in the North-South direction by two, and in the East-West direction by three intersecting wings, resulting in the formation of twelve courtyards of approximately 20×35 metres. The regular spacing of the pilasters of $2^3/_4$ metres

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rendered it easy to divide the interior into rooms of any required size by the erection of light partition walls, which could as easily be shifted or removed. The rooms were light, not only by reason of the ample size of the windows, but as the result of the facing of all courtyard walls with white tiles, whilst the four outer walls of the building were finished with dark red bricks. The only break in the otherwise smooth frontage was an octagonal tower adjoining the west wall of the building, which carried a large water tank to provide an adequate supply for the calibration of water meters. In addition to 18 staircases, communication between the seven storeys (including the basement) was provided by 17 lifts, 12 of which were designed for goods traffic. On the level, inter-departmental goods transport was dealt with by hand trolleys ot numerous types. Extensive loading ramps were erected on the east side of the building to connect up with the railway sidings. The piping for water, gas and compressed air, as also the cables for electricity supply, was laid in accordance with a carefully thought-out plan to render them easy to follow and easy of access; this applied with special force in the case of the water supply for fire-extinguishing. The offices were located mainly on the northern side with a frontage looking onto a newly made street, but also spread to some extent into the wings of the building, gradually merging into the workshops in a way which was typical of the close liaison of the two. The removal from Markgrafenstrasse to Nonnendamm was completed early in April 1905. Thus the Firm left for good what had been the seat of its activities for more than fifty years. It was nevertheless hardly possible to give way to feelings of sadness for the old home when contemplating the mighty new structure, which was without a doubt the best and most modern example of factory design which the age could offer. The property in Markgrafenstrasse was sold soon afterwards. It fell to the new factory to carry on the tradition which the founder of the House had begun in Markgrafenstrasse. For this reason, and in contrast to all the other factories, it was given the name "Wernerwerk."

Advantage was taken of the removal, of course, to undertake a thorough overhaul of manufacturing methods. For a number of years past Alfred Hettler, Manager of the Berlin Works since 1904, had been compelled to set aside planned improvements, partly owing to space restrictions and partly in view of the prospect of better working conditions. It was now possible and essential that these ideas be put into practice. First and foremost, a more distinct separation was made between the manufacture of components and their assembly, and advantage taken of every means of extending rational mass production. This

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rendered necessary the use of large numbers of new machines, amongst them some that had been designed and built within the Firm for specific operations. It could have been expected that these changes would result in a reduction in the number of workers, but the influx of orders was such that the payroll continued to rise in spite of rationalization. The numbers as at the end of July were 2,164 in 1903, 2,673 in 1904 and 3,841 in 1905. Here it is noteworthy that the numbers of female workers included in these figures were 272, 410 and 878. In 1905, therefore, they amounted to 23% of the total labour force, which is an obvious pointer to the advance of mass production. Wages varied considerably: the daily earnings of a turner on piecework rate in 1905 was about 6.40 Marks, those of a fitter 5.60 Marks, of a patternmaker, who represented the highest category, about 8.10 Marks. The women workers, on the other hand, seldom exceeded a daily wage of 3.00—3.10 Marks, even on piecework. In comparison with later times, it must, of course, be remembered that the worker of those days found practically the whole of his wage in his pay packet, since deductions for sickness and insurance benefit were trifling, and there was no income tax to pay. For a week's wages the turner could choose a suit of clothes of good woollen material to his own taste in any Berlin clothier's, and the woman worker could buy a frock and some underclothing. If she had to keep herself, she could live on her wage without privation. The Wernerwerk workers were thus by no means badly off, especially when it is taken into account that they could buy a hot midday meal in the Works' canteen for 30 Pfennigs, and that their working conditions in the newly equipped shops were ideal. Indeed they had every reason to be satisfied. Their only complaint was the long journey every day.

The new factory had at length provided with adequate space one department which had been cramped in its development since its inception, viz., the Department for Measuring Instruments. Since there has so far been no mention of this section as a separate entity, it is necessary at this point to turn back a little into the past.

In consequence of the vigorous growth of electricity supply in the last decade of last century, the demand for electricity meters, the introduction of which can be credited mainly to the successful design by Aron, had come to exceed all limits. It was consequently of the utmost importance to have an inexpensive meter. If it was necessary to install a meter in every consumer's premises, every shilling saved on the price of the meter was equivalent to a reduction in the cost of the supply, since someone, whether the electricity works or the consumer, had to pay for the meter, and this was reflected in the price of current. On the other

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hand, the meter had to be reliable, as otherwise one or other of the parties would suffer. The Government had in consequence begun to move along the lines adopted for the setting up of official standard weights and measures. Meter design therefore came to assume an importance which placed it in a class above that of other electrical measuring instruments.

The motor-meter designed by Werner Siemens as long ago as 1884 suffered, apart from unsuitable damping, like all similar instruments from the disability that it only gave a correct reading at one particular value of the load. Below this value, the meter registered too little owing to excessive internal friction. Siemens & Halske consequently gave up the manufacture of this type of meter, and turned their attention to the development of another suggestion of Werner Siemens', viz., the principle of step-wise metering. In this, the momentary values of the electricity were ascertained by measurement at regular intervals, picked up by a sabre-shaped lever with finely spaced teeth, and added up progressively. Schwennicke spent years in making improvements on this "Sabre meter," and in its final form it was reliable, but easily put out of order, and expensive. Raps made further improvements by replacing the sabre-lever by a heavy balance-wheel and spring, as used in a watch. This "balance-wheel meter" owed its success to the excellence of its workmanship.

About the same time Sigmund Schuckert was taking an interest in meters, and had the good fortune to find a very capable engineer by the name of Hummel to take charge of his laboratory. Hummel returned to the motor-meter, which had been abandoned by others on account of its unfavourable error curve. He realized that the first thing to do was to avoid the use of iron in any form, which had hitherto been used as a path for the magnetic flux between the fixed and moving coils. The first result of allowing the flux to find its own way was that the instrument assumed ponderous dimensions, but Hummel soon succeeded, by a re-arrangement of the parts and clever utilization of space, in reducing the dimensions to a reasonable order. It then occurred to him to compensate the friction of brushes and bearings by the addition of a further small coil which he connected in the armature circuit. The result was a meter which had approximately the same small error at all loads. Braking was effected by steel magnets, which created eddy currents in an aluminium disc mounted on the armature spindle. This was the year 1894—alternating current was in its infancy—and here was a motor-meter for direct current which could claim to be the best of its day, and which for many years remained a pattern for numerous other instruments of its kind.

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Siemens & Halske now turned their attention again to the motor-meter, for which they had in the meantime acquired a promising patent from Peloux. The design was quite ingenious, but it was unable to hold its own in competition with that of Hummel.

It was not necessary to have all the experience which Raps had had with the development of the d. c. meter, for him to realize that something fundamental had to be done in the matter of measuring instruments as a whole. Very soon after joining the Firm he had seen only too clearly that in this respect, as in many others, all was not as it should be in the Berlin Works. To make matters worse, there were signs that specialist competitors, such as the very active and well managed firm of Hartmann & Braun in Frankfort on the Main, were getting a hold on a line of business which Siemens & Halske were allowing to go by default. To Raps it appeared necessary to make a radical change, and in this he knew that he had the support of Wilhelm von Siemens.

Measuring instruments had already been designed on various systems, suitable for switchboard mounting, with a pointer playing freely over a scale to indicate at a glance and without further manipulation the momentary value required. As already mentioned, one of these consisted of a current coil which drew a soft-iron core into its interior against the pull of a spring. The distance of travel, which was a measure of the current, was transmitted to the pointer by a suitable mechanism. Instruments of this type were termed "soft-iron instruments," and could be used for both direct and alternating current. Whilst not particularly accurate, they were adequate for most purposes, and were inexpensive and robust. A further system, similar to that of the old torsion dynamometer, consisted in arranging a movable coil within a stationary coil, both being traversed by the same current. As opposed to the torsion dynamometer, however, the coils were allowed freedom of movement against the tension of a spring. In accordance with an earlier suggestion by Deprèz, the field of a permanent magnet was substituted finally for that of the stationary coil; the movable coil rotated in the circular bore of the magnet poles. Instruments of this type, known in contrast to those of the first group as "precision instruments," were, of course, only suitable for direct current. They were also closely guarded in principle by a number of patents of the inventive American engineer Weston.

The prime necessity, meanwhile, was to produce switchboard instruments along the lines indicated to meet the requirements of the rapidly expanding electric generating stations and industrial undertakings, viz., adequate, although not extreme, accuracy, insensitiveness

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to supply disturbances and rough handling; in particular, however, sufficient damping to prevent troublesome oscillation of the instrument pointer at every small fluctuation of the measured value, without impairing the accuracy. As a result of four years' assiduous development work, a number of designs were produced which represented a remarkable step in advance, both in outward appearance, efficiency and production costs, and which recalled the most fruitful period of collaboration between the two founders of the Firm. Whereas the soft-iron instrument was evident in large numbers of switchboards, the precision instruments, after overcoming the Weston hurdles and finding a limited field of usefulness on switchboards—for d. c.—discovered a new sphere of application, viz., that of portable instruments for laboratories, test-beds and erection shops. Here, the essential thing was the difficult combination of accuracy, sturdiness and simplicity, but the early instruments supplied by Siemens & Halske became so popular with users, that they long remained standards upon which it was found difficult to improve. Soon afterwards, the working principle of the precision instruments was applied also to alternating current measurement and brought to the same degree of perfection. Parallel with the instruments went correspondingly sturdy and handy resistances in the most diverse combinations, thus providing both the generating and manufacturing electrical industry with an accessory for every requirement.

Based on these successes, Raps had meanwhile advanced to become a deputy member of the Board of Management. He prevailed upon Wilhelm von Siemens, soon after the conversion of the Firm to a Limited Company in 1897, to combine the various groups hitherto working loosely together, under the flag of the Telegraph Department, on measurement problems, to form a separate Measuring Instrument Department. It was the object of the new department to take charge of all matters concerning electrical measurement within the Firm, including those which had meanwhile sprung up in the Charlottenburg Works. Here, however, the organizers found themselves confronted at first with certain difficulties, which take us back again to the electricity meter.

In the last five years of the nineteenth century, when the supremacy of direct current was seen to be succumbing to the attacks of alternating current, attention had to be paid to the provision of an alternating current meter. The Aron clock meter was suitable only for d. c., whereas the motor-meter was capable in principle of being adapted for alternating current. But considerations similar to those which had led to the development of the three-phase induction motor, pointed to the desirability of an induction-motor meter, i. e., of a meter in which a simple

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cylindrical metal disc of copper or aluminium rotated in a rotary field, as in Ferraris' classical experiments. A rotary field could also be produced in a simple alternating current circuit by splitting the phase into two circuits with a phase difference of exactly one quarter period. This accuracy was at first difficult of attainment, and it was not until 1897 that the penetrating intellect of Görges, who had played a major part in the development of electrical theory in the Charlottenburg Works, succeeded in finding a particularly simple and neat solution, which was capable of being raised to any degree of accuracy.

Hans Görges had the retiring disposition of the scholar, and in spite of a successful career and brilliant prospects, preferred to leave the Firm in 1910 in order to take up a professorship at the Technical University at Dresden.

His younger assistant, Schrottke, on the other hand, was one of those pugnacious spirits, who, especially towards outsiders, were much given to laying stress on the importance of their own activities.

Görges and Schrottke had been engaged in the Charlottenburg Works in applying the principle of the Ferraris meter to other instruments. If, instead of allowing the aluminium disc to rotate, the torque were balanced against that of a spring, it was found that the corresponding output could be directly indicated by a pointer mounted on the spindle in front of a suitable calibrated scale. With instruments built on the same principle and with corresponding arrangement of the connections, it was possible to measure voltages and currents. These "Ferraris instruments" proved to be very sturdy, since they required no current connections to the moving system, and above all were not sensitive to short-circuits. In consequence, they quickly came to be looked upon as ideal switchboard instruments for the rapidly multiplying industrial power stations. The Charlottenburg Works, therefore, commenced the manufacture of Ferraris meters and Ferraris instruments, since in their opinion the people at Markgrafenstrasse had no notion whatever of alternating current. This opinion was not so far from the truth.

Whoever was desirous of investigating and measuring the conditions prevailing in an alternating current system, had to be at home in this world of discovery, and the newly established Instrument Department was thus confronted by the necessity of making a substantial advance beyond existing thought, before attempting to deprive the Charlottenburg Works of the fruits of its labours in instrument making. Shortly after the turn of the century, however, the necessary progress had been made, and the newly established "Alternating Current Laboratory" of the Berlin Works had learnt the lesson that further success also depended on close collaboration with its colleagues on the power current side.

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By the time the union with Schuckert took place in 1903, the reputation of the Instrument Department of the Berlin Works was so high and its performance so convincing, that the concentration of the sum of the measurement problems of the combined undertaking within the one department was no longer seriously opposed. Schuckert's contribution in the sphere of measuring science was not important—with one exception. In the early development period, Schuckert was generally acknowledged to have performed valuable pioneer work at least in connection with the d. c. meters, and the manufacture of these in the Nuremberg workshops had achieved a remarkable degree of rationalisation. By comparison, the spreading of meter manufacture by Siemens & Halske over two Works had as yet rendered rational production impossible, if only in consequence of space problems. It was therefore resolved to concentrate the whole of the meter production in Nuremberg.

The opening of the Wernerwerk made it possible to provide large and properly equipped laboratories for measuring instruments. This was of the greatest importance, since it is precisely in the manufacture of measuring instruments that the most important development work takes place in the laboratory. Now, included in his work was the design of the so-called instrument transformers for a large part of the alternating current instruments. In those days the three-phase transmission voltages for small outputs and short distances were 2,000, 3,000 and 5,000 volts, rising to 10,000 and 20,000 for medium and as high as 35,000 and 50,000 volts for high outputs. All potentials above 500 volts, however, had to be isolated from instruments incorporated in the switchgear and open to contact. Small transformers, known as instrument transformers, thus had to be provided, to step down the potential at each instrument to a safe value; the scale of the measuring instrument was then calibrated as if the latter were directly connected to the high tension. The transformers for voltage measurement were miniature replicas of the large so-called power transformers, the high-tension windings consisting of many coils of fine wire, and the low-tension windings of a few turns of heavier wire. The transformers for current measurement, on the other hand, had to have a primary winding which formed part of the circuit of the current to be measured. In consequence, only a few turns were permissible in order not to increase unduly the resistance of the circuit. The secondary winding, to which the instrument was connected, consisted of numerous turns of small section in order to obtain a flow in spite of the low magnetisation of the core. In all instruments it was essential that, in spite of fluctuations of the primary values, the error in the transformation ratio of voltage or current should remain unchanged within certain small

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limits. To attain and guarantee this degree of accuracy was the art of instrument transformer manufacture, without which the best of instruments were of no use.

Having thus learnt how to reproduce the complete high-tension system on the smaller scale of the measuring circuits, it was natural to turn to the relays. As automatic control switches for limiting the excessive rise of the current or fall of the voltage, these had hitherto been connected in the high-tension circuits, but were now connected with their trip-coils in the metering circuits. In this way they could be kept under observation and adjusted during operation, quite apart from the fact that, being separated from the high tension, they could be made much more accurate and reliable. From these, there was gradually developed a complete system of automatic supervision and control.

Quite a long time ago a demand had been expressed for electrical instruments with automatic recording apparatus to enable the progress of the measured values to be followed over a certain period of time. The endeavours of the various manufacturers to provide the instrument pointer with a pen, which was arranged to write on a paper chart stretched between two drums, found little favour at first. Siemens & Halske therefore employed a wide coloured ribbon, similar to the typewriter ribbon, which was fitted underneath the chart, and caused the point of the flexible needle to be pressed down on the paper at regular intervals. The resulting coloured dots, visible through the paper of the chart, enabled the course of the measurement to be followed without difficulty. A clever designer then conceived the idea of converting the circular motion of the pen into a straight movement. With a strengthened mechanism it was possible to return to the "ink-recorder," which provided a continuously written chart of any length and a high degree of precision. If the values to be measured were subject to rapid fluctuations, the drum of the chart had to rotate rapidly to spread out the graph, in which case the pen would cease to write. Siemens & Halske therefore devised a recorder in which minute electric sparks were projected on to a rapidly rotating paper drum, which was thereby punctured. The clockwork of all these recorders, in contrast to that of time-pieces, was required to transmit quite an amount of power and still to keep accurate time. This called for no mean standard of workmanship in the shops, especially as the instruments soon came to be required in large quantities.

For dealing with very rapidly variable phenomena, however, such as the course of the alternating current commonly employed in power practice, which completes fifty full periods in the space of every second,

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not to mention the oscillations in telephone circuits with a five to twenty-fold frequency, the spark recording instruments were no longer adequate. For plotting the course of such phenomena a suggestion put forward by André Blondel, and first given practical shape by Hornauer of Schuckert, proved to be very useful. A rotatable wire loop, mounted in the field of a magnet on the Depréz principle, carries a tiny mirror instead of the usual pointer. The mirror reflects a sharply focused beam of light on a wall of the instrument, so that at that point a bright spot of light becomes visible. An electric current passing through the loop deflects it, and with it the spot of light, in an upward or downward direction, depending on the direction of the current, and to an amount which is proportional to the current. If the wall of the instrument consists of photo-sensitized paper, and is made to travel horizontally at a uniform speed, the path of the light-spot will appear after development of the paper as a graph of the current variation in relation to the time, which is capable of exact measurement. By means of suitable devices, the process can also be rendered visible whilst in progress. This instrument, known as the Oscillograph, was at first taken over with its inventor, Hornauer, by the Charlottenburg Works soon after the founding of the Siemens-Schuckertwerke. It was then further developed by the Wernerwerk into a much admired work of art of maximum precision, particularly as the Works had succeeded in arranging for several loops to write simultaneously on the same recorder chart. This enabled several phenomena to be dealt with together, and their values compared. Since it is a simple matter to represent mechanical or acoustic phenomena by electric currents or voltages, the oscillograph became a universal research instrument, which opened the way to all manner of hitherto inaccessible phenomena from mechanics to music. As a "time microscope" it has speeded the advance of research in numerous fields of science.

In making its entry into the physics, chemistry or technical laboratory of a University or Research Institute, the oscillograph almost always found examples of instruments previously purchased from the home factory. The modern mirror galvanometer on the Depréz principle (moving coil in a stationary magnetic field) was to be found in numerous variations, also iron-clad galvanometers of the Dubois type, with highly sensitive iron-clad vibrating needle movements, proof against disturbance from stray fields; standard resistances, the reliability and constancy of which had been raised to the utmost limits. Whoever required anything special in electrical measuring equipment turned to the Wernerwerk—even the newly established Bureau of Standards in Washington, the

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American counterpart of the Physikalisch-Technische Reichsanstalt. Siemens & Halske had thus gradually accumulated such a fund of knowledge of the requirements for laboratories and Institutes, as also for the lecture theatres of Universities, etc. that they were in a position to suggest and supply the complete electrical equipment required. The essential thing was to provide a suitable selection of variable machines and flexible arrangement of distribution gear, so that any required current and voltage was conveniently obtainable at all cardinal points with a minimum of wiring and without mutual interference on the part of the various operators. The building of a whole series of new Institutes led to a considerable volume of orders.

Meanwhile, it had been discovered that electrical quantities could be measured with a degree of ease and accuracy which was unattainable in respect of the units of most other departments of physics and science. Endeavours were therefore made in an increasing degree to convert the latter quantities into electrical equivalents, one of the first being temperature and, in particular, its higher ranges, where the mercury thermometer fails.

The thermo-electrical effect has been known since Stribeck's discovery in 1823. If two conductors of different metals are connected together with a good joint, preferably by soldering, and heated at the point of connection, an electrical potential will appear between the ends of the wires, which is a function of the temperature of the joint. If, therefore, a circuit is provided through a measuring instrument, a current will flow. Both the voltage and current are small, and fairly sensitive instruments are required to detect them. The thermo-electric voltage is approximately proportional to the temperature, especially when a pure metal is jointed to an alloy. Thus a suitable "thermo-couple" for the range of 100 to 500° C has been found to be copper and constantan, an alloy of copper and nickel. A thermo-couple of this type in conjunction with a galvanometer would reliably indicate the temperatures inside a steam-pipe or gas exhaust. For greater convenience, the scale of the galvanometer would be calibrated in degrees of temperature. For higher temperatures it is usual to employ a combination of nickel and nickel-chromium, and for the highest temperatures ordinarily occurring, the couples consist of platinum and platinum-rhodium. Having been tested out in the laboratories, the next step was to render these so-called Pyrometers fit for industrial use by suitable design and, if necessary, the provision of sheaths to protect them against the vapours, gases and rough working conditions of industrial furnaces. Above all, of course, it was essential to produce suitable galvanometers, not with mirrors, of course,

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but with pointers. These instruments had to be capable of withstanding conditions in boiler-houses and chemical or steel works, without early failure. The Wernerwerk took up this task with enthusiasm, and was soon able to register a satisfactory turnover.

Following the introduction of electrical thermometers for high temperatures, users soon began to call for electrical instruments for temperatures within the range of the ordinary mercury thermometer. Werner Siemens had already suggested utilizing the fact that the resistance of a conductor increases with the temperature. A suitable conductor, usually a thin platinum wire, was arranged in "resistance-thermometer" connection and caused the alteration of the resistance to be indicated by a galvanometer, the scale of which was again calibrated in degrees of temperature. The not unnatural desire to see the temperature indications recorded on a roller chart, in the same way as in the recording ammeters, voltmeters and wattmeters, could not at first be fulfilled, as the delicate movement of the galvanometer was unable to overcome the pen-friction. The earlier solution was therefore taken up again of allowing the pointer to play freely over the chart, and depressing it at regular intervals by a chopper bar mechanism, to make a dot on the chart. In consequence of the comparatively slow progress of all temperature changes, the series of dots could easily be made to form a complete curve. To give practical shape to these ideas and embody them in reliable and sturdy instruments called for much thought and experiment, as also workshop practice of the highest possible standard.

As far back as the middle of the nineteenth century, physicists had studied the phenomena resulting from the passage of high-tension electricity through spaces with rarefied atmosphere. Hittorf and Crookes found that if the gas pressure in a discharge tube were low enough, rays emanated from the negative pole of the electrical connection—the Cathode—which were soon recognized as a stream of minute, negatively charged particles, the so-called electrons. These were hurled at great speed in a straight line from the cathode, and gave rise to a lively fluorescence of the glass at the point of impact with the wall of the tube. In accordance with their point of origin, these rays were known as Cathode Rays.

In 1895 Röntgen, at that time Professor-in-Ordinary of experimental physics at the Würzburg University, was making a study of these phenomena. He found that at the point of impact of the rays with the tube, or still more plainly noticeable on impact with a metallic obstruction (the so-called anticathode), the bombardment of the electrons gives rise to the emission from the surface of the anticathode of a new kind of

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ray with very extraordinary properties. Röntgens' immediate conjecture was that these new rays possessed a wave-form similar to that of visible light, as opposed to their progenitors, the cathode rays, which resembled a bunch of fast-flying projectiles. This proved to be correct. The new rays differed from light rays only in having a much shorter wave length, in consequence of which they made no impression on the retina of the human eye. Their existence could only be inferred from the fact that, in common with light, they blackened a photographic plate, and caused certain metallic salts, when finely divided, to fluoresce. In consequence of their short wavelength, these rays penetrated in principle all physical matter, there being no such thing as transparent and opaque matter, as with light rays. The inevitable loss of radiation energy was merely proportional to the density, i. e., the specific gravity of the material. If, therefore, an opaque object was composed of parts of varying density, or, in other words, if a mass of relative homogeneity contained inclusions of greater density, these would appear on the photograph as dark shadows. In the shadowgraph of the human hand, for instance, the bone structure is clearly visible.

Röntgen described and elucidated his discovery in three consecutive publications in such detail, that it was more than a decade before it became possible to attach a new significance to his conclusions. Röntgen called the new rays X-rays, but in Germany grateful contemporaries and posterity have not hesitated to couple them with his name. Being an unselfish man of science, he took out no patents, but released his discovery to the world for general exploitation.

Three days after Röntgen's first publication he had a call from a representative of Reiniger, Gebbert & Schall. This firm, established in 1877 and domiciled in Erlangen since 1886, was engaged in the manufacture of electrical apparatus, in particular apparatus of a medical character. The firm had already had dealings with Röntgen, and now wished to know what he thought of the further development of the procedure in the interests of medical diagnosis. Based on the information received, Reiniger, Gebbert & Schall speedily designed a number of electrical generators, tubes, tripods and other accessories, and launched a publicity campaign with demonstrations in all the larger cities in Germany, which awakened the lively interest of the medical profession and greatly contributed to the popularisation of the discovery.

For some time prior to Röntgen's discovery, Siemens & Halske had been manufacturing so-called spark inductors for use in Physics Institutes. These consisted of the usual arrangement of two concentric coils with a common iron core, the inner coil having a few turns of coarse

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wire, and the outer coil a large number of turns of fine wire. This arrangement has already been mentioned as the prototype of the transformer. The physicist fed the primary coil of the apparatus with continuous current, which was finely chopped up by means of an automatic interrupter, and took from the secondary coil a high-tension alternating current which discharged at the terminals, spaced at from 8—20 cm., in a crackling stream of sparks. Of course, this alternating current was not symmetrical, as is that in commercial use, in which the positive half-wave is the duplicate of the negative. The wave resulting from the making of the primary circuit was considerably smaller than that resulting from the breaking, and could be still further suppressed by suitable means. In this way one arrived at a generator which produced current impulses of one direction only, this being the underlying assumption in speaking of the anode and cathode in the case of a discharge tube.

Spark inductors of this kind, therefore, were used for operating Röntgen tubes, since they required a voltage between cathode and anode of at least 30,000 to 40,000 volts. The tension, or the electrical field thereby generated, is that which imparts to the electrons torn from the cathode the velocity necessary to enable them to produce the Röntgen rays at the anticathode. It was soon found that the penetrative power of the Röntgen rays increased with the voltage, and every effort was therefore made to raise the voltage of the inductors. Having manufactured inductors from the early days, Siemens & Halske were also runners in the competition. The department involved was Measuring Instruments and it thus came about that a separate group was formed in this department for electro-medical apparatus.

Strenuous efforts were directed simultaneously to the perfection of the Röntgen tube. The crucial spot in the tube was the anticathode, the source of the Röntgen rays. Röntgen himself had discovered that aluminium, the material originally used for the anticathode, was the worst possible choice, since the utilisation of the energy transmitted in the electron bombardment of the anticathode, and there converted into Röntgen rays, increases with the specific gravity (to be more precise: the ordinal number in the periodic system of elements) of the material. Moreover, at the very best, it is only a sorry fraction of the total energy which is utilized; the bulk of the energy of the bombardment is converted into heat, and it can happen that the anticathode becomes white-hot and melts. It is best, therefore, to employ a heavy metal with as high a melting point as possible.

Having experimented for some time with platinum, Siemens & Halske applied in 1904 for a patent for anticathodes of tantalum, followed in

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the same year by an application covering anticathodes of niob and wolfram (tungsten). Wolfram was included in the second patent at the instigation of Fischer, the Head of the Department, in spite of an objection in other quarters on the grounds that no living being had thus far ever succeeded in producing a piece of wolfram of the size required. But Fischer had his way, and the patent was granted, notwithstanding the fact that the design of the apparatus was incapable of execution.

For use with the Röntgen apparatus, accessories had to be provided to enable the doctor to arrange the patient and apparatus in the correct relative positions, and in this way the Firm began to find itself treading strange ground, viz., that of diagnostic and surgical equipment, in which they first of all had to learn to find their way about. Essential, again, was the reliable protection of the doctor, medical personnel and patient from undesirable effects of the rays, the very dangerous nature of which only gradually came to be realized. It was learnt, for instance, that it was the so-called scattered radiation which had to be avoided; it was this, incidentally, which spoilt the sharp outlines of the shadowgraph. Every object which is struck by the "primary" rays emits a "secondary" radiation, which scatters in every direction. It is easily understood that it also strikes the photographic plate and causes halation in the manner so much feared by amateurs in photographing against the light. The first effective remedy was the diaphragm known by the name of its inventor, Dr. Bucky M. D., the patent for which was acquired by Siemens & Halske.

Whilst the doctors and engineers were thus engaged together harmoniously on the perfection of this new aid to the healing of suffering humanity, a new customer appeared on the scene. He called for portable apparatus, as far as possible proof against bad roads and rough handling, and in large quantities. This customer came not only from Germany, but also from other "civilized" countries, as he is always among the first to be attracted by new technical developments, and "money is no object." Above all, he works into the hands of the doctors.

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XVII.

NEW LIGHT

In speaking in the early 'nineties of last century of the battle of gas and electricity with regard to lighting, it was not intended to mean that the individual German citizen was called upon to decide which of the two sources of energy he wished to have in his household. In the first place, about half of these citizens still lived in small towns, or on the land. Secondly, in the larger cities, where for the most part gas works were already in existence, and electricity undertakings were yet to be established, the older dwelling houses usually ceased to count, as they were not wired for electricity, and its subsequent installation would have involved considerable disturbance and expense. Apart from a few wealthy exceptions, therefore, the citizen continued for the time being to use his paraffin lamp. Gas and electricity competed, meanwhile, in public buildings, the larger hotels and inns, theatres, places of amusement, halls, schools, barracks, factories, offices and railway stations, but, above all, in the public thoroughfares. Since street lighting was a matter for the local Authority, which was also usually owner of the gas works, the struggle for electricity was particularly severe. The Municipality had already sunk a considerable capital in street lighting, which, of course, it could hardly be expected to write off by a stroke of the pen.

In its external appearance, however, the gas lamp compared badly with the incandescent electric lamp, not to speak of the arc lamp. The gas streamed through a slot in the end of the pipe (the so-called slot-burner), and formed a flat, fan-shaped flame. Out of doors this flame had to be protected from atmospheric influences by a globe. Indoors, it was often allowed to burn without protection, unless the nature of the room architecture called for cylinders and globes. As regards efficiency, i. e., the relationship between the amount of light produced and the volume of gas consumed, there were very few who gave the matter a thought.

For the electrical technician, however, the lamp was a consumer of

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energy like any other, which had to give account of its efficiency. With this end in view, the first essential was to be able to measure its light output, which in turn presupposed the existence of a unit of light. It is characteristic that it was von Hefner-Alteneck, a pupil of Werner Siemens, who introduced this unit. As did the master in defining the unit of resistance, he proceeded from the basic principle that a luminous flame unit must be so defined as to be capable of reproduction. In 1882 he therefore proposed as the unit of light, that of a lamp which, when fed with Amylacetate, produced an exactly adjustable flame of about the same output as that of an ordinary stearin candle. This unit, which quickly found international favour, is known as the Hefner unit. With the help of the subsequently developed photometric method, it was now possible to state the total light output of an incandescent or arc lamp in terms of these units, and also to determine the electrical output required by any particular lamp per unit of light. Measurements showed that, for an arc lamp of the usual type, the consumption of electricity per Hefner unit was about 1/2 watt; in the case of the carbon filament lamp, on the other hand, the consumption was more than seven times as great.

In the meantime, however, quite a number of people had been studying methods of improving the efficiency of gas lighting, amongst them the Vienna chemist Karl Auer von Welsbach, who was a pupil of Bunsen. Even in the days when he was an assistant in the Heidelberg laboratory of the great scientist, Welsbach had devoted time to the study of rare earths. Amongst the oxides of these were to be found some which, when heated, radiated a brilliant light. After a good deal of deliberation and experimenting, Auer decided to soak a piece of loose cotton fabric in a solution of thorium nitrate with the addition of a little Cer. He then carbonized the cotton and placed the charred network, subsequently known as the "mantle," over a Bunsen burner, the non-luminous flame of which caused the mantle to emit a brilliant light. In 1892 Welsbach publicly demonstrated the new "incandescent gas light" for the first time to a gathering of the gas and water engineers in Kiel, and it was very soon obvious to those present that electric light was faced with a dangerous rival. The incandescent mantle supplemented the fishtail burner almost immediately for street lighting. Although estimates of the working costs of lighting installations, as worked out by the protagonists of gas and electricity, were often based on hypotheses and assumptions which were debatable, it could not be denied that in most cases gas lighting was the cheaper. The advantages of electric lighting lay elsewhere: it was not so dangerous, it did not pollute the air, it generated less heat and was simpler to manipulate. The decisive factor,

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however, was the cost, and if electricity wished to gain the lead, it had to produce an incandescent lamp with a lower consumption than the 3½ watts per candle-power of the carbon filament lamp.

In principle, there had been no change in the lamp during the last two decades of the century. Manufacturing methods had, of course, been considerably improved. For a time it had been the practice to manufacture the filaments from Edison bamboo fibre, although in view of its irregular supply, this could scarcely be regarded as a reliable source of raw material upon which to base mass production. It was then learnt how to mix cotton or cellulose with a suitable solvent into a pulp, which was then pressed through fine nozzles. The resulting filaments were then carbonized in a vacuum and introduced into an atmosphere of hydride of carbon, where they were maintained at a red heat by the passage of electric current. Small irregularities in the diameter of the filaments produced differences in temperature, this being highest where the filaments were thinnest. At such points a maximum of carbon was liberated from the gas and precipitated on the filaments. In a short space of time the filaments were "equalized," i. e., brought to an even diameter throughout, which contributed materially to the uniformity of the lamps and their useful life.

If the light emitted by one of these lamps, i. e., that portion which is visible to the human eye, is compared with the total radiation, the result is the so-called optical efficiency of the lamp, a quantity which is as surprising as it is saddening. The efficiency of the carbon filament lamp is about 0.5%—incidentally, about 0.2% in the case of the incandescent gas lamp. The reason for this is that, at the temperatures of the luminous materials of these lamps, the bulk of the radiation energy lies within the range of wave lengths which are invisible to the human eye, viz., the ultrared and long-wave heat rays. In consequence, all these lamps, paraffin lamps and incandescent gas and electric lamps, are more of the nature of heaters than illuminants. As the temperature rises, the maximum of the radiation energy advances towards the visible spectrum, but it is not until the temperature reaches 5,500° C (that of the sun's surface) that this maximum coincides with the centre of the visible part. Our illuminants should therefore have this temperature if they are to be optically economic, and in that case their effect on colours would be the same as that of daylight. However, with the means at our disposal today this is unattainable.

These considerations pointed in any case to the conclusion that the temperature of the incandescent filament must be raised above the maximum of approximately 1,900° C of the carbon lamp, if the efficiency

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was to be improved. A metal or other suitable material was required which had a melting point appreciably above 2,000° C.

Auer von Welsbach had transferred his patent rights to the "Deutsche Gasglühlicht A. G.," a Company formed for the purpose of their exploitation. However, he was far-sighted enough to surmise that the electrical industry would still have something to say in the matter. He therefore took up the pursuit of a metal to take the place of the carbon filament. He reflected that the three precious metals, platinum, iridium and osmium form a closely related group with similar characteristics, and melting points of 1,764, 2,360 and 2,500° C respectively. Iridium, commonly used as an alloy with platinum, proved to be so brittle that Auer immediately turned to Osmium, especially as it possessed the highest melting point of the three. After laborious experiments with this almost equally brittle material he succeeded in producing a filament. He first ground the material to a powder, mixed it with a glutinous paste containing carbon, and pressed it through fine dies as a filament. This was then annealed in a suitable protective gas, in the process of which the carbon disintegrated and the powdery particles of the metal sintered together. This baking together of the filament from granules was its weakness; it broke easily, but there was no other way of making it.

In 1902, as the result of five years of labour, the Auer-Gesellschaft introduced the Osmium lamp, thus presenting to the world the first metal filament lamp to be produced by manufacturing methods. Since the glass bulb must of necessity have approximately the same dimensions as that of the carbon lamp which it was intended to supplant, the filament was made up of several hairpin loops of Osmium wire connected in series. In one case, the total length of wire of a thickness of $^{9}/_{100}$ millimetres was about 28 centimeters, subdivided into several loops. Each lamp was dimensioned for connection to 37 volts, so that with a supply pressure of 110 volts three lamps had to be connected in series and burn together, which was a serious handicap. Even so, the filament became so soft that it had to be supported at the apex by small hooks. Moreover, the lamp had to be mounted in a vertical position, as otherwise the softened filament would part under its own weight. The energy consumption was 1.5 watts per candle power, i. e., less than half of that of the carbon filament lamp. All in all, the Osmium lamp was an experiment which pointed the way to further progress, but no more.

Towards the end of the 1900's Siemens & Halske had also set out to find a metal which could take the place of the carbon filament in the electric lamp. Wilhelm von Siemens took a keen interest in the matter, since to improve the incandescent lamp and secure for it its proper place

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in the electric supply systems, had been one of the first tasks entrusted to him by his father on joining the Firm. His chief assistant in handling this aspect of the problem was Dr. Werner Bolton.

This young scientist was born in Tiflis as the son of the one-time manager of the Siemens Kedabeg copper mine, and came to Berlin at an early age. The gifted boy awoke the interest of Werner Siemens, who equipped a small chemical laboratory for his protégé in Markgrafenstrasse, and kept watch over his progress. Bolton afterwards went to study under Ostwald in Leipzig, and on completing his studies, joined Siemens & Halske as a chemist. He was furnished with working quarters in the Bohneshof Laboratory in Berlin-Moabit, and instructed to search for the required filament metal.

Bolton was one of those natural scientists who rely on their intuition. On contemplating the periodic system of elements, it was suddenly borne in on him that tantalum, by virtue of its position in the system, must possess the desired characteristics, viz., high melting point, low vapour pressure and good malleability. The existence of tantalum had been known for 100 years; it had been discovered as a component of several rare metals, and identified as a metallic element. However, it had as yet been impossible to present it in a pure state. That which the great French chemist Henri Moissau had claimed to be tantalum, with a specific gravity of 12.8, turned out later to be tantalum hydrate. As the result of arduous experiments Bolton succeeded at last in producing fairly pure tantalum, but again, as is the case with all these rare metals with high melting point, in the form of a powder. Why was it not possible to smelt these substances from their ores, as had been done formerly with the old-time metals, when at the conclusion of the process, the molten metal set at the bottom of the crucible as the compact, shiny mass of the regulus, the name by which it had been known since the days of the alchemists.

Bolton was for giving up the struggle, when Wilhelm von Siemens took him by the lapel. Having succeeded in producing metallic tantalum in powder form, it must also be possible to produce a regulus. The expense incurred in further experiments was immaterial.

Bolton now decided to base his further researches on a tantalum-oxygen combination, viz., tantalum pentoxide, which had cropped up in the course of his experiments. The method hitherto generally followed in metallurgy, of offering the oxygen an element such as carbon, for which it has a greater affinity, in order to release the metal, failed again and again due to the tendency of tantalum immediately to form a carbon or hydrogen combination (a carbide or hydride). At length, the researcher

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conceived the idea of melting the tantalum pentoxide in the electric arc, thereby dissociating it as in an electrolytic bath, and endeavouring to precipitate the pure metal at the cathode. For this purpose he built an arc furnace with water-cooled nickel electrodes. The chamber surrounding the arc was evacuated in order to draw off any oxygen which might accumulate. Considering the endless difficulties attending the operation of a vacuum arc furnace with the means available in those days, the feat can only be acknowledged as worthy of the alchemists, and as calling for the highest standard of experimental practice and ingenuity. Little did those engaged take account of official working hours. Bolton, Erlwein and, later, other assistants with special talents had their own ideas on the matter of working hours, and would not hesitate to turn night into day and vice versa. Wilhelm von Siemens was in the habit of allowing his assistant considerable licence in this respect. Late one night in 1902, exactly one hundred years after the discovery of tantalum, Wilhelm von Siemens looked in at the laboratory when Bolton handed him a small piece of silver-grey metal, which proved to be malleable in a cold state. It was the tantalum regulus.

The Siemens & Halske Electric Lamp Works under the able management of Otto Feuerlein, who had meanwhile become Works Director, now became the centre of feverish but secret activity. The filament, now a genuine wire, produced from rolled and drawn metal, was pretty long by comparison with that of the carbon lamp, since the specific conductivity of tantalum is much higher than that of carbon. Even with a diameter of only $^5/_{100}$ of a millimetre, i. e., considerably less than that of a woman's hair, the filament corresponding to a supply pressure of 110 volts would require to have a length of two thirds of a metre. A framework was therefore set up in the glass bulb of the lamp consisting of a central glass stem, to the thickened ends of which metal spokes were attached top and bottom. The filament was wound up and down between the spokes of the framework, thus accommodating the required length of filament without difficulty. The arrangement was covered by patents which were to be found extremely important as time went on. Manufacture commenced, and the lamp was subjected to endurance tests of the most rigorous nature. Improvements were made, both in the design of the lamp and manufacturing methods, until, finally, the stage was reached that the plant was working for stock. It was not until production was running daily at about one thousand lamps packed and delivered, and backed by a considerable stock pile, that the moment was considered ripe to raise the curtain with a fanfare of trumpets. In January 1905, the "Tantalum Lamp" was thrown on the market with

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a current consumption of 1.5 watts per candle-power, available for all customary voltages and current supplies, shockproof, capable of burning in any position, even in tramcars. It was a world sensation, especially for power station managers, who at first pulled a long face when they wondered what was to become of their electricity accounts with the current consumption for lighting barely half its former figure.

At this time there was to be seen on the hoardings in Berlin and other cities a poster depicting a naked, bearded man standing up to the chest in water and vainly stretching his arms upwards to the fruit-laden branches of the tree. The fruit was pears, but glass pears, in the interior of which the zig-zag lamp filament was clearly visible. The picture came in for criticism by Siemens employees as well as others. A few severe judges considered it "high-brow," others thought it witty and quite effective, and a third group, mostly of the older generation, dubiously shook their heads: Just like advertising champagne and chocolate! So it has come to this. If the Old Man knew of this, he would turn in his grave!

The fairly high price of the tantalum lamp as compared with that of its carbon filament rival was against a rapid expansion of the former's sales. The manufacturing capacity of the lamp works was nothing like fully engaged. An urgent proposal of the lamp works to reduce the price of the tantalum lamp by almost half was carried against stiff opposition. This was a rather risky experiment, since on the basis of existing sales, the prime cost of the lamp was higher than the new sales price. A subsequent price increase would be impossible, should the experiment fail. However, the speculation was a complete success. The Works was soon compelled to introduce extra shifts to meet the demand, and sales and profits rose steeply. Very soon it was clear to all those in the incandescent lamp industry that the days of the carbon lamp were numbered. In consequence of the large sums invested in this industry and its existing manufacturing plant, a desperate contest broke out amongst those who did not wish to be drawn into the vortex by the sinking ship. The search for other materials for the metal filament lamp became feverish.

Even at that time tungsten (wolfram) had the reputation of being the most difficult amongst the rare metals to melt, although its exact melting point was not known. For some considerable time past Dr. Fischer, the head of the combined Patent Departments of the Siemens Works, had been pressing Bolton to take tungsten in hand. Others had already succeeded in obtaining pure metallic tungsten from certain material by first producing tungsten acid in a solid state, and reducing it by hydro-

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gen to metallic tungsten. Of course, the metal thus produced was again in powder form, and the most strenuous efforts to convert this into a regulus were of no avail. In consequence, the Auer Company resolved to apply to tungsten the experience gained with the osmium lamp, by mixing the tungsten powder and carbon to a paste, from which filaments were extended. The filaments were subjected to a complicated annealing process, by which the carbon was driven off, leaving a cohesive filament of pure metal. Of this, loops were formed and connected in series as in the osmium lamp. As early as 1906 the Auer Company placed the new lamp on the market under the name of the "Osram Lamp," which was intended to indicate the manner of its origin. For a considerable time the Osram lamp proved to be very delicate, and it took several years of intensive effort before attaining a longer life and a greater capacity to withstand day-to-day treatment. In view of the higher melting point of tungsten (3,370° C), however, it was possible to operate the Osram lamp at higher temperature than the tantalum lamp, in consequence of which the current consumption of the Osram lamp was little higher than one watt per candle-power. In this respect, therefore, the tantalum lamp was beaten, and was able to hold its own solely by reason of its superior robustness.

Siemens & Halske were quick to grasp the situation, especially as the AEG now commenced the manufacture of tungsten lamps with extruded and sintered filaments. Since Bolton would hear nothing of tungsten, and until his untimely death in 1912 continued to pursue the unsuccessful chase after other materials, Dr. Fischer had been instrumental in having investigations into the production of tungsten wire carried out, under the superintendence of Feuerlein. These investigations, which commenced prior to the official introduction of the tantalum lamp, led to the addition of nickel to the tungsten powder, which resulted in an alloy with a lower melting temperature, from which a wire could be drawn. This was wound on the glass frame mentioned above, and the nickel volatilized by an annealing process. The result was tungsten filament which, although rather brittle, was mounted on its final seating. The new type was placed on the market under the name of "Wotan Lamp," and customers had the choice between the more robust tantalum lamp and the more economical Wotan lamp.

Meanwhile, the Americans had not been idle; in particular, the General Electric Co. spent large sums in their laboratories at Schenectady to ensure the independence of the American market from Europe in the matter of electric lamps. In long series of tests, Wm. D. Coolidge had succeeded in developing a process in which tungsten powder was con-

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verted into a wire of considerable strength, and capable of being drawn. In this process the powder was first subjected to high temperature and pressure to form a rod which, when cold, was still rather brittle. The rod was then placed at 1,000° C under a high-speed hammer mill with diamond heads until it became ductile and could be drawn, first warm and finally cold, into a wire of great strength. In Germany, however, the manufacture of electric lamps with this kind of wire was blocked by coiling patents which had been taken out by Siemens & Halske in connection with the tantalum lamp. When, therefore, a trade delegation from the General Electric Co. came to Germany to open up the European market for the American lamp, it was made clear to them by the skilful argumentation of Dr. Fischer, that in view of the Siemens & Halske coiling patents any attempt on their part to manufacture a practicable metal filament lamp would be faced by the most serious difficulties. Not only so, but his Firm laid claim to prior manufacturing rights in the Coolidge patent. As he, Fischer, offered to prove from Bolton's earlier Test Sheets, they had succeeded in rolling rods of sintered tungsten powder at red heat, in the process of which elongation had also engaged in the manufacture of tungsten wire. As the Comdead, but his name continued to count. The Americans became uncertain, particularly as the AEG and the Auer Company intervened in the discussions, and were able to show that they had had considerable success in the working of tungsten. As the result of lengthy negotiations an agreement was concluded between the four firms: General Electric Co., Siemens & Halske, AEG and the Auer Gesellschaft, according to which each of the partners had equal rights in the use of the Coolidge patent and the Siemens patents covering the manufacture of metal filament lamps with tungsten filaments.

Independently of these activities, the Berlin firm of Julius Pintsch A. G. had also engaged in the manufacture of tungsten wire. As the Company which had introduced incandescent gas lighting into railway carriages, they, like the Auer Co., had thereby acquired considerable experience in chemistry and physics. In accordance with a patent granted them in 1916, the Pintsch Company was in a position to supply tungsten lamps with filaments of the necessary strength. In the battle of the filaments, tungsten had undoubtedly emerged as the victor; the rest disappeared from the market.

The opinion, at first commonly held by the electricity undertakings, that the introduction of the metal filament lamp would reduce their lighting turnover, proved to be quite erroneous. Precisely the opposite happened. It was not long before the efforts to improve the metal

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filament lamp were so successful, that its luminous efficiency and specific current consumption were equal to those of the arc lamp. There were many cases, however, where the main consideration was "lighting effect," i. e., shop windows, assembly rooms, theatres, etc., but where the arc lamp had never really been liked because of its occasional unsteadiness and constant need for changing carbons. In these cases high-power metal filament lamps were the ideal solution; they bathed the rooms in a flood of light, in comparison with which the former illumination could only be termed dingy. The "spoiling" of the public led to ever growing demands: offices, factories, restaurants and public thoroughfares must be better lit. The arc lamp struggled desperately for existence against the ever-growing pressure of its rival. There were the "big firms," who themselves had brought about this metamorphosis, and were now preparing in cold blood for the liquidation of their former business, but there were also a considerable number of specialist firms, for whom the death of the arc lamp meant the negation of their raison d'être. For a time attempts were made, in preparing estimates for lighting schemes for railway goods yards, dockyards, extensive ironworks and the like, to prove by calculations based on differences of fractions of a farthing the economic superiority of the arc lamp. All this, however, was of no avail; by the end of the 1914—1918 war the doom of the arc lamp was sealed. This oft-quoted symbol of progress in the early days of electric lighting was now left to eke out a modest existence in searchlights, projectors and drawing office printing frames. The incandescent lamp had conquered all along the line.

This also settled the question of lighting in private houses. No longer was it a question: oil, gas or electric light? It could only be the latter. In the large towns in Germany, houses for letting were built exclusively with the installation for electric lighting, and even the smallest villages did their utmost to be linked up to the local distribution system, not so much for the sake of the power supply, but on account of lighting. In every workers' settlement which clustered round the rapidly expanding centres of industry in Upper Silesia, Central Germany and the Ruhr District, electric light in the house was a sine qua non. The incandescent lamp set the pace for the growth of the power distribution systems, as did these, in turn, for a new and higher standard of living of the masses, in many cases being even a condition of their existence. It is possible to imagine a symbol to denote the various epochs of man's existence: the Pyramid, the Trireme, the Sword of the Roman Legionary, the Gothic Cathedral, the Musket, the Locomotive. For the first quarter of the twentieth century it is a small glass globe containing a hair-like metal filament.

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In the early days of indoor electric lighting, the copper conductors used for the wiring were covered with a layer of spun cotton impregnated with asphalt compound. Conductors of this type were laid in wooden beading, or on porcelain insulators. Both types of wiring were rather unsightly, and as the wires carried on insulators dried out in summer and absorbed moisture again in winter, it was risky to touch them at any higher voltage than the 110 volts d. c. originally used.

In the early 'nineties, therefore, Siemens & Halske commenced to improve these wires by covering them with two layers of impregnated cotton spinning and interposing a spirally wound rubber tape between the layers. This type of conductor—known as rubber taped—came into general use, but it transpired that the tape also perished in the course of time. The opening of the new century was attended in Germany by an enormous increase in building, which gave rise to a rapid expansion in the number of lighting installations carried out. This was the opportunity of the cheap-jacks, who used only the cheapest material and installed it without the slightest pride of workmanship or sense of responsibility, until the Electricity Supply Companies stepped in and issued their wiring regulations, which were along much the same lines as those proposed by the Association of German Electrical Engineers (V.D.E.). The inadequacy of the rubber-tape insulation led to the perfection early in 1910, again with the active collaboration of Siemens & Halske, of a new method of insulation. This took the form of a seamless rubber tube which was pressed round the wire and itself protected by a spun layer of impregnated fibrous material. Against the violent resistance of the "Cheap and Nasty" group, the VDE-Association succeeded in getting it laid down that rubber insulated wire of the above type was the only type to be accepted by the Authorities, from 1910 onwards, for installation in living rooms and workshops, except where in view of special operating conditions more stringent regulations were applicable.

The business which Sigmund Bergmann carried on, in partnership with Edison as S. Bergmann & Co., was sold at Edison's instigation to the General Electric Co. After taking up his considerable share of the assets, Bergmann returned to Germany and founded in Berlin the Firm of "S. Bergmann & Co., A. G., Insulating and Wiring Conduit, Specialists in Electric Installations." The title of the firm indicated in the first place his intention to exploit the invention he had made when in New York, and which had proved very successful in the early Edison installations. Instead of attaching the wires to porcelain insulators as others did, he carried them in light brass tubing which was lined inside

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with a layer of thick paper. With the help of a simple but ingenious appliance, this tubing could be bent at right-angles without cracking it, and it could be fixed neatly on the wall or, better still, invisibly under the surface plaster, especially in new buildings. The wiring was drawn into the conduit system after completion of the building work. The soft lining of the conduit protected the wiring from damage to the outer insulation. The use of "Bergmann Conduit" for the wiring installation was certainly much more expensive than the systems hitherto favoured, but its advantages were so obvious, and the pressure of the V.D.E. for a sound installation system so strong, that insulated conduit came into almost universal use. Bergmann's earnings from this source were considerable, and in 1893 he established the "Bergmann Electromotor and Dynamo Works, A.G.," amalgamating his two firms in 1900 to form the "Bergmann Electricity Works, A.G." Thus shortly before the great crisis, there came into being another electrical manufacturer with considerable capital resources and Head Offices in Berlin.

The great success of the insulated conduit naturally stimulated other inventors. An engineer, A. Peschel, posed the question: why an insulated lining in the conduit? If the insulation of the wire is insufficient, say, by reason of having been damaged whilst being drawn into the conduit, the situation will not be saved by the paper lining of the conduit, particularly as it had probably become wet by condensation of moisture. In that case, it is preferable for the fault to show up as a solid earth or short circuit. Peschel therefore designed a protection system consisting of light steel tubing, slit lengthwise to provide a spring connection with unions and junction boxes. The tubing could be laid on or under the surface of the plaster, was neat in appearance and very strong. The Peschel patent was acquired by the newly-formed Siemens-Schuckertwerke and developed into an installation system which found great favour and broke the monopoly of the insulated tubing. A third system was connected with the name of Kuhlo, the Chief Engineer of an electric power station, who pressed a slit brass covering tightly round the insulated conductor, giving it the appearance of a thin cable. This system was found to be very serviceable, especially in cases where the wiring had to be installed subsequently in finished localities. Siemens-Schuckert also took over the Kuhlo patent, and commenced manufacture in their cable works.

It has already been mentioned that in developing his original lighting system together with Bergmann, Edison had already designed the necessary switches, fuses, lamp-holders and connection boxes for the individual branch circuits. It was not long before he found imitators in Germany.

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Heinrich Voigt was one of the younger generation of engineers who had graduated in the electrotechnical colleges of the Technical Universities. In 1885 he founded the firm of Staudt & Voigt in Frankfort on the Main, with the object of manufacturing arc lamps and measuring instruments. In 1887 he developed a small switch with horizontal spindle for wall mounting and operation by means of a small lever. The switch incorporated the principle used in 1880 by Siemens & Halske for small switches, in accordance with which the initial movement of the switch lever compressed a spring. Further movement caused the spring to pull the contacts apart with a snap action, with the object of preventing the formation of an arc (quick-break switch). It is also largely as the result of Voigt's efforts that the moving contacts of these small switches were fashioned as sliding springs, which ensured that the contacts were kept clean by their rubbing action against each other. In 1904, moreover, he made the rotary switch fool-proof, i. e., insensible to turning in the wrong direction. Altogether, his designs, together with the corresponding work of Siemens & Halske, Bergmann and the AEG, can be regarded as patterns for an inexhaustible fountain of inventive activity in this sphere.

A matter of special importance in electrical installations is the fuses. In distribution systems it is essential to insert, at the commencement of all branches having a smaller cross-section, an automatic device which disconnects the branch immediately the maximum safe current is exceeded. For this purpose it had been customary in the early days to use strips or wires of lead, on account of its low melting point. However, as the voltages gradually outgrew the originally standard 110 volt mark, these lead fuses proved to be rather unpleasant watchmen. In the case of a short-circuit, for instance, it is possible that a considerable quantity of energy may be liberated explosively in the form of heat. The surrounding air is expanded, and molten metal is hurled in all directions by the blast.

The first step, therefore, was to fit the fuse wires into vertical tubes which were open top and bottom, and to allow them to blow themselves out. It was possible to put up with this where switchboards were concerned, providing that a free path could be provided for the exhaust; not so in living rooms, however, even when the fuses were small and correspondingly harmless. It was not long, therefore, before Edison and Bergmann hit upon the idea of making the fuse wire of silver instead of lead, as silver is the best conductor of electricity and thus requires the smallest cross-section to carry a given current. For a current of 6 amps., usually the maximum permissible for the outermost branch of the distri-

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bution system, the silver fuse wire would be no thicker than a hair. The two inventors enclosed the silver wire in a hollow cylinder of cement which they filled with fine quartz sand. The miniature explosion was quenched in the sand without the flame penetrating to the outside. These "cartridges," as they came to be called, were fashioned on the model of the cap of the Edison lamp: one of the terminal contacts was in the centre of the cap, the other being the metal thread of the cap. As with the lamp, the cartridge was screwed into a suitable base; when a fuse "blew," all that was necessary was to screw in a spare cartridge.

An extensive distribution system requires a range of fuses, say, for 6, 10, and 20 amps., corresponding to the various cross-sections of the conductors. Were these fuses all identical externally, there would be a danger of one size being mistaken for the other (accidentally or intentionally). In the latter case, a cartridge for a higher current could be screwed into a base for a lower, hoping that the fuse would hold and save one the trouble of searching for the fault. The cartridges were therefore made in various lengths, and with corresponding depths of the recess in the end of the cap. The cartridge for the higher current was shorter and was, therefore, unable to reach the centre contact of the fuse for the lower current. It was, of course, necessary to have separate bases and cartridges for every different current rating.

In Germany, Siemens & Halske had endeavoured to improve on the Edison screw cartridge as a fuse component, and had found all manner of intermediate solutions when their Engineer Klement, meanwhile transferred to the newly established Siemens-Schuckertwerke, put forward a design of a neatness and many-sided applicability which far surpassed anything hitherto suggested. Klement divided the screw-cartridge into two parts, viz., the cartridge proper and the enclosing "screw-cap" which was screwed into the fuse base, thereby pressing the cartridge into contact with the base. Within a certain range, bases and screw-caps were the same for all currents; only the cartridges, otherwise of the same shape and size, differed according to the current rating in the diameter of a gauge pin at one end of the cartridge. This gauge pin carried the foot contact of the cartridge, whilst a gauge ring of insulating material was fitted into the base and carried the counter contact. The gauge pin had to fit into the gauge ring, as otherwise the two contacts would not meet, and since the cartridge for the higher current had a pin of larger diameter, it could not be used with a base for a smaller current. The cartridge fuse is an example of a well-thought-out system resulting in a product of attractive appearance, small space requirements and great adaptability. In addition, the fuse lent itself well to mass production

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and was inexpensive. Protected by several patents and supported by skilful publicity, a turnover running into millions demonstrated how such a business can attain enormous proportions.

It soon became necessary, of course, to extend the manufacturing facilities to correspond. At first the attempt was made to turn out switches, fuses, plug-sockets and junction boxes in quantity by the usual manual methods. The metal parts were made in the Bohneshof auxiliary workshops at Moabit, where they could be stamped, bored, soldered and galvanized or nickel-plated, whilst the porcelain parts, especially the fuse bases, were purchased from Thuringian porcelain manufacturers, primarily Armand Marseille in Neuhaus. The various parts were assembled at the lamp works. As the business grew, manufacture was transferred to the Charlottenburg Works, where it became a continually expanding independent department. Shortly afterwards, however, Klement commenced designing a new system of switchgear, whilst Charlottenburg was instructed to take up the manufacture of Peschel conduit. This rendered it necessary to reconsider the manufacturing programme of the Charlottenburg Works as a whole. The decision was taken to build a new autonomous Works, on the ground adjacent to the Nonnendamm, for the rational manufacture of all these small parts. Shortly after the opening of the Wernerwerk, the "Kleinbauwerk" (Small Accessories' Works) was erected in its immediate neighbourhood. This was a five-storey building with an initial available floorspace of 25,000 sq.m. In keeping with the style of the day, the frontages were divided up by pilasters running the whole height of the building from base to cornice. Twice at short intervals, 1909 and 1912, the building was extended to twice its original size. It was now possible, as in the case of the Wernerwerk, to introduce a considerable degree of automation of the manufacturing processes, making possible the employment of a large proportion of female labour. Simultaneously with the second extension of the Kleinbauwerk, the porcelain works of Armand Marseille was bought up and re-named "Porzellanfabrik Neuhaus," its manufacturing programme being adapted to the requirements of the other works.

As we have already learned from Rathenau's biography, the theatres were amongst the earliest to take an interest in the incandescent electric lamp. Besides the lower fire risks, which are almost nil, provided the electrical installation has been properly carried out, electric illumination can be arranged to produce effects which could not have been dreamed of formerly. On the one hand, it is possible to increase the luminous intensity almost at will, while on the other, the gradual dimming of the light and the changing of its colour, can be little short of enchanting.

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As long as only the arc lamp and carbon filament lamp were available, these possibilities were, of course, very limited. The arc lamp could not always be used, as it was sometimes noisy in operation and the light subject to unforeseen fluctuations, whilst the yellow tone of the carbon lamp did not always fit in with the colour scheme of the stage. In these respects, therefore, the use of the metal filament lamp in stage lighting meant a revolution. The same thing happened as in other parallel cases: the eyes quickly accepted the brighter illumination as a matter of course, and would have rejected a return to the former lighting conditions as "impossible." Behind the curtain and in some cases suspended from the loft, screened from the audience, were lighting fittings of all kinds, such as floodlights, soffit lamps, skylights, spotlights with coloured glasses and colour mixers, but above all with extensive regulators. By means of a resistance in series, the lamps can be dimmed to the point of extinction, a method of operation which was extensively used. Banks of resistances were provided with numerous tappings which were connected to faceplate contacts arranged in vertical columns. A contact shoe was raised and lowered across the contact faces by means of a rope and drum, an operation which could be performed at any required speed. It was thus possible gradually to light up or darken the lamp, or combinations of lamps, as slowly as desired. The rope and drum gear was arranged after the manner of the railway signal boxes, and operated by levers or handwheels. A system on these lines was shown by Siemens & Halske as early as **1891**, in connection with a model stage at the Frankfort Exhibition. Due, probably, to the overwhelming interest taken in the first three-phase power transmission, it did not receive the attention it deserved. However, Siemens & Halske continued to work on the development of stage-lighting equipment, and Siemens-Schuckert followed the tradition. Later on, they were able to point to the fact that nearly all the well-known theatres at home and abroad had been supplied by them with lighting equipment. Of these, five were in Paris alone. The next stage was to couple the operating drums together in groups, thereby determining in advance the lighting changes and colour combinations required for a particular scene. The set was then driven by a variable speed motor. The whole equipment was usually accommodated in a suspended cabin just inside and at one side of the curtain, and operated by a skilled technician, whose job it was to make the sun set or the thunderstorm blow up at the right moment of the play. These lighting effects were rendered the more striking by the advent, about the same time as the metal filament lamp, of the panoramic stage horizon, which replaced the customary fittings and painted wings by a uniform white back-

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ground on which the most deceptive effects could be produced by colours. With this equipment it was possible to portray Macbeth in the witches' cavern, sunrise on the Rütli Mountain, Sarastro's Holy Halls and Shrewsbury Plain with such fidelity, that former stage managers would have paled with jealousy. The effect of the stage setting on the audience depends much more on the lighting than on the scenery.

Here again it is possible to sense the gulf which separates technical Man from his cultural counterpart. The chief beneficiaries of the new stage lighting were the Reviews, at that time in their first hey-day. Shows of this kind would have been unthinkable without spot lights and metal filament lamps, as the exhibition of bare flesh requires good lighting to be effective. The Ghost that paced the battlements of Elsinore at midnight, however, has managed without electric light for three hundred years.

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XVIII.

REPRESENTATIVES AT HOME AND ABROAD

As long as the Siemens & Halske manufactures were confined to the products of the Telegraph Workshop in Markgrafenstrasse, their customers were mostly large Government monopolies such as the Telegraphs and Railways, who negotiated directly with the Works. Beyond these, there were a few Institutes and scientists requiring instruments, who also came or sent their representatives to Berlin to discuss their purchases. For this class of business no intermediary was necessary or would, indeed, have possessed the necessary knowledge.

Things changed as power current began to develop, the incandescent lamp popularized the use of electric current, public supply undertakings extended their distribution systems and numerous workshops of all kinds, large and small, began to install electric driving. For all these clients to negotiate directly with the Charlottenburg Works, as supplier of the machines, apparatus and cables, was out of the question. There arose the necessity of having local representatives.

It has already been recorded that in the 1880's, as power current had begun to develop in earnest, undertakings began to spring up like mushrooms all over Germany, the object of which was one or other of the many applications of electricity. Some of them commenced to manufacture machines; others, switchgear and arc lamps, meters, instruments, wire, installation materials, etc. Among them were a few who have made their way, and have become specialists of repute. The majority, however, some would-be manufacturers included, encountered obstacles, and found it simpler to buy the parts and assemble them on their own account. They therefore turned to the manufacturers for their supplies and, of course, in the first place to Siemens & Halske.

The Firm was therefore confronted with the question as to the best way of dealing with the threatening flood.

As regards power current manufactures, Werner Siemens had already formed a definite opinion. On the 28th of October, 1877 he wrote to a business friend in Remscheid who was desirous of acquiring an export

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agency for Siemens & Halske: "... Unfortunately, however, we shall hardly be able to offer you conditions which you would find acceptable. As we have no patent for our dynamo-electric machine in Germany, we have not fixed the prices for these machines on any higher basis than for our other products. We are consequently quite unable to grant a higher commission on these machines than 10%. On the other hand, we do not consider the dynamo-electric machine a suitable object to be handled as a commercial novelty. We cannot undertake, any more than yourselves, to install the machines and then to enter into correspondence with the customer as to their method of use. This must be left to technical men who buy the equipment, and make their profit out of its installation. According to your last letter, this type of business does not appeal to you. Like ourselves, you prefer straightforward business which, once settled, is settled for good, and does not give trouble with subsequent complaints. The above remarks apply also to our other products. Whilst we appreciate an association with qualified engineers who purchase our products in order to install them, 30 years experience has taught us that Re-sellers and Agents who only want to deal in our manufactures are of no use to us ..."

The first thing, then, was to find technically qualified men who were prepared to buy Siemens material and instal it themselves. The firm was already in touch with one such individual, viz., a certain Dr. Zerener of the Firm of Dr. Zerener & Cie. in Magdeburg. In May 1877, in conjunction with Hermann Gruson, Dr. Zerener had installed two arc lamps with their corresponding dynamos in the former's iron foundry in Magdeburg, this being the first installation of its kind in a German factory. After extensive tests the equipment was finally accepted in December of the same year. Werner Siemens wrote to Dr. Zerener on 15th June, 1878 as follows: "... By way of further explanation of what we have in mind, we would say that we are little interested in a commercial agency in your district based on publicity. We do, however, consider it to be of the greatest importance that our Representative should be able to undertake the independent planning and installation of lighting equipment, and that he should be responsible for the smooth operation of the plant so installed.

Re-sellers of our lighting equipment receive a discount of 5% on the prices in our price lists, and a further 5% (10% in all) if the Re-seller undertake the planning, installation, care and maintenance of the plant, it being understood that the cost of such care and maintenance within reasonable limits is borne by the Purchaser of the equipment.

Our query is now whether you are prepared under the above con-

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ditions to extend your territory beyond the immediate neighbourhood of Magdeburg, and we ask you to state which part of the Magdeburg surroundings you propose to cover.

We would request you to enter the precise limits of this territory in a small map of Germany, it being understood that these limits are subject to our confirmation . . ."

Werner Siemens had, of course, no time to undertake the task of dividing up the country into agency districts, and of settling the details of their agreements with the individual representatives; this he had to leave to his assistants. It was some years after the above correspondence before his two sons joined the Firm, and even then, of course, they had had no business experience. The man most immediately concerned was von Hefner-Alteneck, just recently appointed to the managership of the Charlottenburg Works, but he had not the slightest aptitude for dealing with such matters. It therefore fell to the lot of the senior departmental manager to fill the gap.

Carl Haase had become grey in the service of the Firm. By his honesty, disinterestedness and reliability he had gained the confidence of his Chief to such a degree that after his, Haase's, retirement from the Firm, Werner invested him with full power of attorney in his personal affairs, and as sole executor of his Will. He was a commercial man of the old school, not in the sense of "Big Business," but of the conscientious accountant, becoming a little pedantic as the years went by. Thus he did not stay to ponder whether the original conception of the founder of the House in this connection was still consistent with the great revolution which had set in with the founding of the "German Edison Co.," but simply carried out his Chief's instructions. He therefore allocated a certain geographically defined territory to each Representative, and obtained his undertaking only to buy from Siemens & Halske (providing that the articles in question were manufactured by them) at the prices stipulated by them. The Representative was required to sell to customers at these same prices without increase, but was entitled to receive a commission of 10% for his exertions. He was under obligation to carry out the installation work, for which he was allowed to charge his own prices. If he required the assistance of men from the Works, such labour would be charged to him at specified rates. The commercial risk had to be taken by the Representative.

After a few years, Siemens & Halske realized that this arrangement was unworkable. The Representatives carried out the installation work as well as they could, and when there was trouble with the customer because the machinery did not give the output promised by the Represen-

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tative, or because of irregularities in operation due to unsuitable assembly of the parts, disputes would arise as to who was responsible. As the result of such occurrences, it frequently happened that, when placing the order with the Representative, the Customer would stipulate that Siemens & Halske must guarantee the whole equipment. If it did not want to lose the business, therefore, the Firm was compelled to guarantee work which it had not performed. As things then stood in electrical engineering, it was not possible to have "straightforward business which, once settled, is settled for good, and does not give trouble with subsequent complaints." It was not possible then, and it is not always possible today, when things are in a fluid state of development. In course of time, moreover, numerous specialist firms had come into existence, especially as manufacturers of installation material, who hoped to attain the largest sale for their products by selling them cheaply at the cost of the quality. Notwithstanding their obligation to the contrary, Representatives would include masses of such cheap stuff in the so-called Siemens & Halske installations; who was going to check every detail? Many went so far as to omit to fix the usual Siemens & Halske nameplate—was it not a fact that the work had been done by them? Payments from Customers were often enough not passed on immediately, but used in the Representatives' businesses, and when Siemens & Halske commenced proceedings to enforce payment, it transpired more than once that the Representative was bankrupt. Instead of having many customers of good standing, i. e., a well-distributed risk, the Firm found itself with few customers, of which some were insolvent. This was the reverse side of the simplified procedure.

These were the vexatious circumstances in which Robert Maass found himself involved. He had been recommended to Werner Siemens by a friend in 1882, when he was looking for a private secretary for his library. Werner accepted the recommendation with some reluctance as the young man had no real qualifications. After having studied medicine for a few terms, he had been compelled to break off his studies on account of conditions in the parental home. Werner Siemens soon realized, however, that Maass was too good for the post assigned to him, and sent him along to be an assistant to the Department Manager Vogel. Since Haase's retirement, Vogel had taken his place in the Central Office and had dealt, among other things, with the Agents. Vogel was an engineer by training, but possessed no creative faculty in this sphere. For this reason, the actual engineers of those early days, e. g., Frischen and von Hefner-Alteneck, had formed the habit of passing on to Vogel administrative matters, in which they were not interested. This covered,

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above all, correspondence with the outside world, which as far as power current was concerned, was principally with the Agents. Since Vogel travelled a lot, and had become rather easy-going, Maass, who was both shrewd and ambitious, was not long in tackling the system of representation, and in putting it on an entirely new footing.

Siemens & Halske came to the conclusion that the existing system was not only costly, but put them increasingly at a disadvantage in comparison with alert competitors, especially the AEG. Some Representatives were therefore given notice of termination of their agreement; in this, and other cases where the death of the Representative or some other reason had brought about the liquidation of his business (there were six in all), Siemens & Halske established a local "Technical Office," or in special cases a Branch. In general, the term "Technical Office" was preferred, as the word "Branch" might unintentionally convey the impression that the establishment included a factory. The use of the term "Branch" was therefore confined to special cases, e. g. where the existing agreement still had some time to run. In the early days, these offices were only modestly staffed. Their function was to keep a lookout for new enquiries, to make contact with the prospective client, and to give him the best technical advice, following this up with a quotation based on the client's requirements and special circumstances. If an order matured, the Technical Office had to pass it on to the Works, and was responsible for seeing that the equipment and its installation were as agreed with the Customer. To begin with, invoicing was direct from Works to customer.

The new scheme, launched hesitatingly and with a minimum of expense, proved surprisingly successful. This was mainly because the new Representatives were carefully selected engineers who had grown up in the Charlottenburg Works, thus quickly gaining the customers' confidence. (It had long been the desire of customers to negotiate directly with the Firm). Equally felicitous was the co-operation between the Technical Offices and Works, since the Representatives were familiar with the home atmosphere, and knew just how to proceed to satisfy their own and the customers' wishes. Out of this co-operation, there grew in course of time the "Engineering Sales Department," the origin and functions of which have already been described. Maass was transferred to the staff of this department (1892), and bent his entire energy to the introduction of the new system throughout the whole organisation. In the course of 10 years, he established a further 24 Technical Offices after liquidation of the respective agreements, so that in 1903, shortly before the founding of the Siemens-Schuckertwerke, there were 30

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outside offices of this kind, of which 8 were abroad, viz., The Hague, Copenhagen, Stockholm, Warsaw, Brussels, Milan, Helsinki and Christiania.

In those days, there was no difference between the organisation of the offices in Germany and abroad. To a later generation, having grown up in the shadow of economic nationalism, economic planning, import quotas and currency control, it may seem strange that there could be a country in which the Branch Office of a foreign firm could exist peacefully in competition with home industries, employing natives and foreigners alike, and remitting its trading profits to the homeland. The fact was that in those days frontiers were mere lines of political demarcation, characterized commercially by Customs duties, which with few exceptions were moderate. These frontiers were in no sense barriers, to be crossed by men, money and goods only with the utmost difficulty, and after the discharge of tedious formalities.

In consequence of the rapid expansion of electrical engineering in the decade before the crisis, the growth of the staff of the Technical Offices was very considerable. Many of them had begun their existence as one-man shows, with their further technical personnel, experienced erectors in particular, from the Works. Assistants and clerical staff were recruited locally, and trained as well as possible. It was not long before it also became necessary to engage commercial personnel. It began with store-keeping, wage-accounts and cash transactions, and the posting of order books, whilst the invoicing of the goods supplied and work executed, the current accounts, and the following up of outstanding accounts remained with Head Office. In the offices abroad, the growth of business soon made this arrangement impossible (by reason of the language difficulty alone), so that they were compelled to take over also the latter part of the functions of an independent business concern. Having seen that this was workable, it was decided in Berlin, after some hesitation, to make the German offices also responsible for carrying through all phases of their business. This, of course, rendered it necessary to install a commercial Head alongside the Technical Manager. While in the nature of things the latter had to be an engineer, the commercial man was expected to carry the responsibility for office matters falling within his province. In view of the large number of more or less independent offices, it was not always an easy matter to find suitable candidates for these posts, and it became necessary to make occasional changes until Berlin was convinced that the right man was everywhere in the right place. Members of a staff of specially trained auditors from the Head Office Berlin, visited the outside offices regularly in turn, and satisfied

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themselves by a thorough check in all departments that everything was working in accordance with the fairly strict rules laid down by Head Office.

Maass was no fussy pedant who loses sight of the main principle through attention to detail, but he was relentless in seeing that the machinery was kept in proper working order by his auditors. The complacent attitude of the earlier Representatives in money matters had ceased; every farthing had to be accounted for. In such independent outside offices there is always a danger that, due to frequent absence on travel or to being absorbed in negotiations, those responsible become easy-going towards subordinates, and that the large sums passing through the hands of employees of modest means may become a fatal temptation. This danger can only be warded off by a rigid and lucid system of accounting which, by its mere existence, impresses the individual with the feeling of living in an orderly atmosphere. A major contribution to this orderliness were the reports which the offices had to prepare on the basis of detailed statistics, and send in at regular intervals. In spite of this system, there will never be complete immunity from dishonesty, and when on one occasion Maass in person exposed a case of extensive embezzlement in the Italien office, there was a drastic clearing up.

When it came to establishing the Siemens-Schuckertwerke it was necessary, of course, also to merge the two sets of Technical Offices, which on the Schuckert side were called Branches. As regards size and turnover, the Schuckert offices were in general pretty much on a level with those of Siemens & Halske; in West and South Germany they were frequently even larger. Since Siemens & Halske had undoubtedly taken the lead in the formation of the Siemens-Schuckertwerke, it was natural that their's should be the deciding voice in the planning of the jointly conducted offices. As was to be expected, the territorial boundaries of the two sets of offices did not always coincide, and in many cases the offices for the same district were in different towns. The staffs of the new offices could not be simply the sum of the two hitherto existing staffs of the separate partners, but had to be reduced; two heads had to be transformed into one. In short, there arose a number of difficult problems which had to be solved, with much tact and due regard to touchiness of individuals, by Maass or Dr. Berliner, the newly appointed Chairman of the Managerial Board of Siemens-Schuckert and, in special cases, by Wilhelm von Siemens himself. Some of the Schuckert personnel declined to carry on and left the Firm, a course which was made easier for them by indemnification in the case of long-term contracts. In this connection it was found that Schuckert was in the habit of paying his

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staff, especially those in positions of responsibility in the outside offices, higher salaries than did Siemens & Halske. The Siemens & Halske folk appeared to the South Germans as "Prussians," and there was no denying that the rigid organisation of the Berlin Firm reflected in all its members, from the Manager downwards to the stores-hand, something of the spirit of Prussian officialdom: calm objectivity, discipline and a sense of duty. Notwithstanding lower payment, their attachment to their Firm was greater than that of the others. In some way, the peculiar conception of "The House" was thereby given clear expression. On the part of the outside staffs, this feeling was perhaps even more marked than with the staffs of the Works' and Head Office Departments. Doubtless, in the daily contact of the former with the business world and their constant struggle with competitors, the conception of "The House" had unconsciously become the moral foundation of their work. In later times and under difficult conditions, the outside offices proved themselves to be powerful braces of the main structure.

This was also the obvious opportunity to put the relationship of Siemens-Schuckert to the Weak Current Departments on a new footing. When the Technical Offices were established by the Charlottenburg Works of Siemens & Halske, they were intended to deal with power current business only. The Berlin Works under Hermann Siemens had refused from the outset to participate, since it was accustomed to deal only with Government Departments and other large customers. If only for the sake of the measuring instrument business, however, this point of view could not be upheld in permanence. When, therefore, simultaneously with the founding of the Limited Company, Raps was appointed Manager of the prospective Wernerwerk, he arranged with Maass to transfer a number of his specialists to the Technical Offices to look after the interests of the weak current business, but subject to the supervision of the Office Manager. The arrangement proved successful and was extended, and when the offices became integral parts of Siemens-Schuckert, it was necessary formally to make a new agreement, since juridically two different firms were concerned. It was arranged that these weak current groups should be known to the outside world as "Technical Office of Siemens & Halske A. G.," but that they should continue their existing connection with the Siemens-Schuckert offices, and remain subject to the latter's supervision. This solution avoided a multiplication of staff which would not have been justified by the turnover of those days.

The expansion of business in the decade following the founding of Siemens-Schuckert was similar to that of the 'nineties, but with this difference, that whereas the earlier growth was driven by the investment rush to speculative heights, it now reflected a genuine increase in consumption, and therefore rested on a much more solid foundation. In the business year 1903/04, the first following the foundation, Siemens-Schuckert reached a turnover of 70 million Marks. In 1913/14, the close of which coincided with the outbreak of the first World War, the turnover was 320 millions, i. e., more than four times as great. In these ten years, the number of workers and staff had risen from 14,000 to 42,000, of which the Technical Offices in Germany alone absorbed more than 8,000 employees, i. e., almost one fifth of the whole.

The only other country to record a trade expansion comparable with that of the German Electrical Industry was the United States of America. As has already been mentioned, the boom in the U. S. A. at the beginning of the 'nineties exceeded in various directions that in Germany. Henry Villard né Heinrich Hilgard, from Speyer, on the Rhine, was known by reason of the founding of the Northern Pacific Railroad as one of the most adventurous figures of the American railway world. He was known at the same time to be one of the main shareholders of the Edison Electric Light Co., the Edison Machine Works Co., the Edison Lamps Co. and the Bergmann & Co. factory. With the assistance of a German-American Finance Syndicate, in which both the Deutsche Bank and the AEG participated, Villard merged the above-named Companies in April 1889, to form the Edison General Electric Co. with a capital of 12 million Dollars and himself as President. About the same time, the Thomson Houston Co. had bought up some six smaller undertakings, the most important of which was the Brush Co., who were the first to build a serviceable dynamo in the U.S.A. In 1892, very much against Villard's will, the Thomson Houston Co., a Company with a very active Directorate and an extensive network of Branches, succeeded in bringing about the amalgamation of the two groups to form the General Electric Co., with Head Offices in Schenectady and a capital, meanwhile, of 39 million Dollars. Villard and, under his influence, the AEG thereupon withdrew their shares of the capital. Rathenau nevertheless attached importance to the maintenance of the personal contacts which had meanwhile been effected between the AEG and the G.E.C.

George Westinghouse was originally a maker of agricultural machinery, later becoming famous by his invention of the compressed-air brake for railways. Early in 1886 he established in East Pittsburgh in Pennsylvania a factory for electrical machines. Within a year, he built lighting installations for single-phase alternating current, and in 1895, having acquired and extended the Tesla patents, he built the first power

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station at the Niagara Falls. In contrast to the General Electric Co., which to some extent still lived in the shadow of the Edison tradition, Westinghouse gave preference to the development of single and three-phase alternating current. In 1899, moreover, he acquired a licence on the Parsons patents, and in the following year supplied the first steam turbo-generator in the U.S.A. Thus, by his venturesome technical innovations, he won for himself from time to time an advantage over his competitors, wherewith to counterbalance their greater capital resources. Both firms were engaged, at the same time as Siemens & Halske and the AEG in Germany, in an embittered contest for predominance in electrical power current engineering.

Under these circumstances the Siemens & Halske Electric Co. of America could quite well have had a share of the American business, especially if they had consciously based their efforts on the German patents, designs and experience. Of this, however, following the withdrawal of Dr. Berliner from the Chicago works, there was no longer the slightest chance. In July 1894 these works were entirely destroyed by fire. Six months later Meyenburg appeared in Berlin and proposed to his Partners to buy up the Grant Locomotive Works, in whose shops the Siemens & Halske undertaking had found a temporary home, and to take over its production, i. e., to build locomotives. At the same time, he proposed to increase the capital from one to two million Dollars. Since, however, those responsible in Berlin did not think it possible, in view of the prevailing expansionist drive in the German Electrical Industry, to provide the required additional capital, the Americans undertook the financing alone. Thus, for all practical purposes, the American Branch slipped out of the control of the Berlin Company. In 1897, the capital was increased for the second time, and the undertaking merged with the Pennsylvania Iron Works, thereby being completely alienated from its original purpose. Siemens & Halske began to withdraw their holding, cancelled the Patent Agreement in 1903, and succeeded in the following year in bringing about a change in the name which, for the last few years, had been a mute reproach for an opportunity lost.

The unfortunate result of this experiment was due to the same causes as the failure of the venture in France ten years previously. The lesson which Wilhelm von Siemens had to learn, was that his House could not just establish manufacturing branches in foreign countries, having their own peculiar economic systems, and then leave these branches more or less to themselves. In both cases the management had been placed in the hands of a foreigner, to whom the conception of "The House" meant nothing, and who naturally went his own way. Thus the Branch soon

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lost touch with the parent Company and, as a comparatively small, helpless unit, branded with the stigma of foreign origin, was at the mercy of its powerful competitors. The parent House should have maintained a continual and close exchange of information with the Branches. This, again, would require that the Branches be managed by a suitable personality of the Berlin school with a number of German assistants, after the fashion of the very successful English-owned Gas- and Water works in Germany two generations before. Dr. Berliner would have possessed the necessary qualifications, as was evidenced by his rapid rise following his return from America. Unfortunately, it was omitted to send out anyone in his place, and so the American outpost was lost. The fact was that it had become a law of existence for the Branches of the House abroad: the stronger the influence of the foreign atmosphere, the more deeply the leading persons in the Branches, who constituted the link between parent and child, must be imbued with the conception of "The House." It is not necessary that they should be clearly conscious of this, but only that they should act accordingly. This had been neglected in London and Paris, and now, again, in Chicago. It was not long before the Firm was confronted for the second time, on this occasion in London, with the question as to whether this lesson had at last been learnt.

Having at length got rid of Loeffler in 1891, the Management of the London Firm was, as a first step, placed in the hands of Alexander Siemens, who since his work in Persia in connection with the building of the "Indo-European," was known in the family as "Ali." Notwithstanding the fact, however, that as an engineer Alexander was technically sound and of wide experience, it was thought advisable to give him a commercial man of some calibre as an assistant in the person of Georg von Chauvin, the son of Werner Siemens' old friend. Von Chauvin had lived for many years in the United States, and had learned in the service of Jay Gould's widely ramified telegraph and cable undertakings what the Americans mean by "Big Business." At the same time, he combined shrewdness with diplomacy. The two used every endeavour to regain the territory lost through Loeffler's mismanagement, but made only slow progress.

In 1900, after the Siemens family had succeeded in regaining all the Siemens Bros. shares not in their possession, Wilhelm von Siemens urged the London Management to build a "Charlottenburg Works" in England. Suitable land was therefore acquired in Stafford, midway between London and Manchester, and a substantial factory built for the manufacture of machines, transformers and switchgear. It commenced

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production in 1903. At the same time, Wilhelm von Siemens persuaded his brother Arnold to send their younger brother Carl Friedrich as the Representative of the family to London.

Carl Friedrich was much younger than his two step-brothers (17 and 19 years), and of a totally different temperament. He did not possess their seriousness, tending to melancholy, which with Arnold amounted to shyness, and in Wilhelm's case to occasional hypochondriacal doubts of his own faculties and those of his assistants. On the contrary, Carl Friedrich as a boy had been a breezy, cheeky youngster, fond of practical jokes at the expense of his teachers and tutors. On being sent to Strasbourg University and later to Munich, he approached his studies in the manner common to most young sons of wealthy families, until, on the death of his father, his two elder brothers transferred him to the Technical University at Charlottenburg, so that he should be under their surveillance and at length commence to do some serious work. Before the conclusion of his studies, however, the bird had escaped again, this time to travel, and, among other things, to pay an informative visit to the United States. He did not come to rest until, still under twenty-six, he married the daughter of a wealthy and distinguished Berlin family, thereupon settling down. Shortly afterwards, he decided to join his father's Firm, where he was at first received with some scepticism by his brothers; would he ever become sensible, as they understood the word? Nevertheless, after two years they had formed the opinion that he could be trusted with the London mission.

The intention was that Carl Friedrich should pay particular attention to the power current business, with which neither von Chauvin nor his cousin Ali were so familiar. Since the new Works in Stafford was already taking shape, Carl Friedrich saw that his main task lay in the creation of a sales organization which could provide the factory with work when finished. He established a Head Office in London on the Berlin model, and at the same time a number of Branches in the most important industrial towns in the Provinces. This duly resulted in business becoming more brisk, and within a few years the annual turnover had increased to between three and four times its former value. Meanwhile, Carl Friedrich travelled in England a good deal with his eyes open, and was gifted with the faculty of sizing up men and treating them accordingly. He could not rid himself of a feeling that the output of the Works in Stafford was not of the quality which one was accustomed to expect in Germany as a matter of course from a factory of like standing.

At Carl Friedrich's suggestion, the power current interests of Siemens Bros., together with the Stafford Works, were brought in as the

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assets of a new Company: "Siemens Brothers Dynamo Works, Ltd.," London and Stafford, with a share capital of £ 200,000 and the like amount of Debentures. Siemens Bros. thereupon leased the running of the new Company to Siemens-Schuckertwerke, Berlin, for ten years, whilst a similar lease agreement was concluded with the Wernerwerk in respect of the remaining weak current departments. Carl Friedrich was appointed Managing Director, and requested the visit of a commission of experts from Berlin to ensure that the new organisation was modelled in all respects on the Berlin pattern.

Dr. Berliner summarized the result of this visit at a Board Meeting in Berlin, by declaring the determination to wrest the British market from the American grip, regardless of cost or losses. "Within a year, the English view that Siemens Brothers are not to be taken seriously as competitors must have vanished; on the contrary, the competition of Siemens Brothers Dynamo Works must be accounted the keenest of all."

Procedure on these lines was soon instrumental in bringing about the desired increase in turnover, but also very considerable losses, which under the Agreement had to be borne by Siemens-Schuckert. It also disclosed the fact that the Stafford Works, which was now handling a quantity of orders, some for machines of considerable size, was incapable of manufacturing to the standards with which such work must be expected to comply. It was thus seen to be necessary to give the Works the support of more personnel of the Berlin school; amongst these was Max Kloss, Doctor of Engineering, who soon advanced to Chief Electrical Engineer of the Works, and later made a considerable name for himself as lecturer on Electrical Engineering at the Berlin Technical University.

Wilhelm von Siemens had learnt meanwhile to regard his younger brother with different eyes than hitherto, and having formed the opinion that he could gradually train Carl Friedrich to be his close collaborator, he recalled him to Berlin. This meant that a new Managing Director had to be found for Siemens Bros. Dynamo Works, and one who could successfully wield the sales weapon in the fierce battle with the Americans and now also the British. He would also have to be able to enforce his will in the Stafford Works, since this was obviously the seat of the trouble. Thus he had to be an engineer who could not be imposed upon in technical matters, and at the same time a competent man of business. This combination was not easy to find, since a man is usually either one or the other.

The choice fell eventually on Carl Köttgen, who had entered the Charlottenburg Works in 1894 with the influx of young engineers which gave it new impetus, and was early recognized as being one of the most

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talented. It was no easy task which awaited him in London; in his memories he wrote: "When I came to London I found a large number of deliveries about which there were complaints. It was my first concern to get these plants into working order, as our reputation had suffered badly ... A separate file was started for each of these cases, 23 in all. Amongst ourselves these files were known as the 'damned jobs' ...

In dealing with these 'reparation' cases I proceeded on the principle: act speedily and thoroughly, regardless of cost. In this way we earned the customer's appreciation. In one case this was clearly visible:

For Manchester Corporation we had supplied three turbo-generators for 1,000 kW each with six-pole rotors. They were built in Stafford, in accordance with a Vienna design, with six salient poles, held by pressure plates at the sides. The poles had never been tight from the outset, and rust actually appeared at the joints; it was thus clear that the poles 'worked.' We were summoned to a discussion with the City Council in Manchester. Mr. Kieffer and I were received by the Lord Mayor and four Aldermen in gowns and white wigs in the venerable, panelled Council Chamber. Mr. Pearce, the City Chief Engineer, opened the proceedings with a long statement; they were evidently prepared for a difficult and protracted discussion. When I was asked what I had to say, I replied: 'We are prepared to give you three brand new rotors of a new design.' The Lord Mayor asked me: 'Is that a word?,' to which I merely replied: 'I stand to it.' The discussion was at an end ..."

Having thus restored the reputation of the House and regained the confidence of his customers—albeit at a considerable financial sacrifice—Köttgen soon succeeded in expanding the business. In six years of strenuous work, up to the outbreak of the first World War, the turnover was increased to approximately £ 1 1/2 millions, roughly two and a half times the figure of 1908. In the same period the Stafford Works were extended by one third. Owing to severe competition, however, prices were low and overheads high, and it is a question whether the venture would have been successful without the financial backing of Berlin. The difficulties in the way of achieving a large turnover in electrical business in England are explained in a report which Köttgen sent to Berlin after a year in London, in which the following appears:

"As regards the absorptive capacity of the English market, I do not at all share the optimistic views which were current, more particularly, several years ago, and which doubtless induced the American Westinghouse Co. and the B.T.H. to establish large factories in England. A great deal is spoken about the extraordinary wealth of England. This may be correct, but it is not the case that this wealth is invested in industrial

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undertakings from which we can expect to receive orders. Some time ago Government statistics came to my notice, according to which 55 Milliards of Marks of English Capital are invested abroad, to a great extent in foreign Government loans and in English Colonial Administration, in shares or loans in foreign railways, in foreign, especially South African, gold and diamond mines, in Colonial Companies, etc.

Without a doubt, England is very extensively industrialised; it is characteristic, however, that as compared with Germany and America these industries have undergone little development. In this connection the pig-iron and steel production figures since 1880 in millions of tons are very interesting. (Here follow the well-known comparison tables for Great Britain, Germany and the United States).

These figures indicate that German Industry as a whole has multiplied several times over, whilst Industry in England has hardly grown at all. It is these new undertaking in Germany, however, which provide our Workshops with work.

The output in shipbuilding in England is in itself, of course, much greater than in Germany. The German shipyards, however, were much earlier furnished with modern equipment, in particular, with permanent slipway scaffolding and gantry cranes, than the English yards. It is only recently that the English yards are commencing to move in this respect.

Again, the fact that enormous quantities of German cast steel and cast iron parts are delivered to England, provides an insight into the way the English steelworks are equipped for supplying semi-finished products. We had an order to place for a 40-ton steel flywheel for Skinninggrove, and were able to buy it from the Skoda Works in Bohemia at a price, including delivery to Newcastle, which was 15% cheaper than that of the lowest English tender. We were anxious to place the order in England, but the negotiations disclosed the fact that the English works were not equipped for supplying such castings, much less for machining them. Some time ago the Stafford Works urgently required three heavy turbine shafts. One we ordered in England, the second from Krupp and the third from Bochum. The German shafts were first on the spot; they cost 40% less than the other, including delivery to Stafford, and were more accurately machined. Moreover, it was found in turning the English shaft that it was faulty, and had to be rejected. It is significant that Krupp makes a practice of marking all steel deliveries to England in large letters with the inscription: 'Warranted German Make'."

The intervention of the Consulting Engineer was also found to be a

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great hindrance. On a large new scheme being put up for consideration in Germany, the engineering firms were accustomed to get into direct touch with the client and to submit their proposals. The ultimate scheme was a combination of the proposals of the various competitors and the modifications desired by the client. Here in England, however, the Consulting Engineer interposed himself between supplier and user, preventing them as far as possible from coming into contact, and worked out a specification in which only the prices had to be entered. As a rule, it was the lowest tenderer who received the order. This was a method of tendering which tied down flexible electrical planning to a hard and fast model, and offered no opportunity of considering the merits of other possible solutions. In fact, a certain strain of ponderous inflexibility seemed to have become characteristic of English engineering practice. This was the opinion shared alike by the Germans and Americans.

The Russian Branch of Siemens & Halske had developed very favourably under Carl Siemens' management in the 1880's, and had not failed to provide sufficient work for the two factories he had built in St. Petersburg, the one for machines and apparatus, and the other for cables. When Werner Siemens died, Carl, as already related, returned to Berlin in order to be mentor to his nephews, thus raising the question as to who should succeed him in the management of the Russian Branch. Under the conditions prevalent in Russia, it was felt to be indispensable to have a Representative at the head of affairs who possessed both the necessary personality and energy. On the recommendation of his cousin Georg, the Director of the Deutsche Bank, Carl decided in favour of Georg's brother-in-law, Hermann Görz.

Görz was a pupil of Kittler in Darmstadt, and on finishing his studies had followed his brother-in-law's advice and had entered the service of the AEG. In the opinion of Georg Siemens, who had always been somewhat critical of his cousins, Rathenau was the man in the German electrical industry from whom one could learn most. At the end of a ten years' apprenticeship, Görz had risen to occupy a leading position in the AEG, and Siemens & Halske were now satisfied that they could safely take him, and send him to St. Petersburg. His task there was admittedly very difficult, for Carl, with his intimate knowledge of the Russian atmosphere, and his exceptional dexterity in handling men, was almost irreplaceable.

In the years that followed, the Branch in St. Petersburg was a faithful copy of the parent House in Berlin, only on a smaller scale. The power current side grew rapidly in extent and importance and was at first based predominantly on "investment business." Side by side with the

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vigorously expanding "Gesellschaft für elektrische Beleuchtung vom Jahre 1886" in St. Petersburg, power stations were erected in Moscow, Warsaw, Voronesh, Lodz, Odessa, Tula, Nicholaieff, Samara and Wilna; in addition, a number of electrical tramway undertakings were started. Business was promoted by a Trade Agreement, which was concluded in 1893 between Germany and Russia. This greatly favoured the export of German manufactures to Russia, and enabled Siemens & Halske to supply goods from the St. Petersburg or Berlin Works, whichever was more advantageous. On the other hand, weak current engineering, and telephony in particular, lagged far behind, enabling the Swedish Firm Ericsson to secure a large part of the Russian market for itself. It was only after the re-design of the telephone equipment by Siemens & Halske under Raps and Grabe, that matters mended in Russia and that this section of the business began to share the prosperity of the others. The same applied to the Railway Signalling business. In 1898 the Russian Branch was converted into a Limited Company: "Russische Elektrotechnische Werke Siemens & Halske, A.G.," St. Petersburg, with a share capital of 4 million Roubles, which was raised to 7 millions in 1900, but reduced later to 5.6 millions in view of the sharp depression.

Meanwhile, other German firms had also established themselves in Russia, due to the fact that, on the expiry of the 10-year Trade Agreement, Russia had begun to impose import duties for the protection of its own industries. For this reason, the Union-Elektrizitäts-A.G. had built a factory in Riga, which on the fusion with the AEG was taken over by that Company. Felten & Guilleaume had built a splendid cable works in St. Petersburg. The AEG was also planning the extension of the Riga Works, in the first place for cable manufacture, since the Russian cable requirements promised to be very large. At this juncture the Felten & Guilleaume cable works were destroyed by fire, and as the result of consultations between the interested parties it was agreed to establish a joint undertaking, the "Vereinigte Kabelwerke St. Petersburg," with a share capital of 6 million Roubles. Since Siemens & Halske at the time possessed the best equipment for cable manufacture, they were entrusted with the technical direction of the new undertaking. As time went on, the Works of the other partners were also extended, and production allocated in accordance with technical considerations. As it is most unlikely that there were any other cable manufacturers in Russia, it may be said that the "Vereinigte Kabelwerke" covered practically the whole of the rapidly growing Russian cable requirements.

At the time the new undertaking came into existence Carl von Siemens died. He had been knighted by the Czar in recognition of his services to

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Russian industry. Since 1893 it had only been on rare occasions that he visited the scene of his former activities, but he continued to enjoy the high regard and attachment of those of his former assistants who had known him from earlier days. With him had passed on the last of the three brothers who had laid the foundations of the House of Siemens. Whereas, however, his brother William had become an Englishman, not only outwardly, but at heart, Carl remained inwardly German or rather cosmopolitan, notwithstanding his Russian citizenship. Russia did not possess the same power of assimilation as England, at least not for a Siemens.

As far as Russia was concerned, the only effect of the founding of the Siemens-Schuckertwerke was that, instead of competing, the two partners arranged the allocation of orders between themselves. Although Schuckert had bought up the business of his Russian Representative shortly before the turn of the century, and had since then run the firm in his own name, the turnover was not very significant, as the output of the Russian factory was only intended to supplement the German Works when required. In view of their growing turnover in Russia, however, Siemens & Halske eventually felt the necessity for a clear separation, on the German pattern, of the power current and weak current interests. Alongside the existing "Russische Elektrotechnische Werke, Siemens & Halske," they therefore founded in 1912 the "Russische Aktiengesellschaft Siemens-Schuckert" in St. Petersburg with a share capital of 15 million Roubles. Simultaneously it was decided to build a new Machine Works of substantial size on the pattern of the Berlin Dynamo Works, which was completed shortly before the outbreak of the 1914 war. A network of 24 Technical Offices covered the Provinces.

As regards nationality, the 4,500 employees of the two Siemens Works in Russia (1914) were fairly mixed, particularly in the case of the office staff. Besides the not very numerous Germans there were a considerable number of Balts, Finns, Swedes, and a surprising number of Poles. These latter were useful for their knowledge of foreign languages, for the industry of Czarist Russia was built up by foreigners: the metallurgical industry by the French and Belgians, the sugar industry by poles; the potash mines at Rostov belonged to the Dutch, and the shipyards on the Black Sea coast to the English. One cannot, of course, expect these men of different origin and way of thinking to form a "corps," such as had been gradually built up in Germany, yet it was possible to discern in Russia a faint breath of the spirit of "The House," even then. Leonid Krassin, before the war a Departmental Manager in the St. Petersburg Works, later a Bolshevik Peoples Commissar and Lenin's closest collab-

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orator—even Krassin was unable to suppress a slight "weakness" for his old Firm.

In Austria-Hungary, the situation following the founding of the Siemens-Schuckertwerke differed from that in Russia, inasmuch as Schuckert had already built up quite a good business there. On the other hand, the Vienna Works of Siemens & Halske had consistently expanded under Dr. Richard Fellinger's management. Having for years remained within the confines of the Apostelgasse district, a large piece of building land was acquired in Floridsdorf, to which the cable works was transferred in 1897, to be followed in 1900 by the dynamo works, for which an imposing new building was erected. Owing, however, to the influence of Schwieger, who was Deputy Chairman of the Board of Management in Vienna, the development of business had been rather one-sided, i. e., in the interests of the Traction Department, and fell off very considerably on completion of the large undertakings mentioned in an earlier chapter. As a consequence, the net profit of the Vienna Works in 1903 was only one tenth of that of the previous year. By comparison, the Austrian Schuckert Company had succeeded in earning considerable profits in the building of the Vienna Electricity Works and other enterprises. In 1902, moreover, it had built a factory in Bratislava which was operated by the "Ungarische Schuckertwerke." Soon after the fusion with Siemens, therefore, it was decided to found the "Österreichische Siemens-Schuckertwerke," with 18 million Kronen share capital, to take over the Vienna factories of the two parent Companies, as also the cable works at Floridsdorf. The "Ungarische Schuckertwerke," on the other hand, were appointed sole Representatives of Siemens & Halske in Budapest, with a change of name to "Ungarische Siemens-Schuckertwerke," and a wedding present in the shape of the factory in Bratislava and, in 1912, of a cable works. These undertakings, above all the Vienna factories, grew apace, for the consumption of electricity in Industry and for domestic purposes was also increasing rapidly in Austria-Hungary, although, of course, not at the same rate as in Germany. The weak current side of the business carried on in the name of the old Company, however, lagged behind, and was to a great extent dependent on deliveries from the parent Company.

Whereas the Siemens & Halske agency arrangements in France, based on their connection with the Elsässische Maschinenbauanstalt, were comparatively weak, Schuckert had succeeded in 1897 in founding the "Compagnie Générale d'Electricité de Creil" in Paris, with the participation of French capital and with a factory. It was even stipulated that such parts as the factory could not manufacture were to be supplied

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by Schuckert. This Company was among the assets brought into the new Firm by Schuckert on amalgamation with Siemens & Halske, thus providing the Siemens-Schuckertwerke with an outpost in France, and permitting Siemens & Halske to terminate the association with their former partners.

As business grew, the Technical Offices abroad followed the example of those in the homeland, and equipped themselves with small repair shops, in order to be in a position to help quickly in an emergency. In some cases, depending on the economic state of the country or the Customs Duties, the repair-shop developed into a factory. Where it was found to be the policy of the national economy to erect insurmountable tariff barriers, it seemed advisable to establish the Agencies in the form of a separate Company. A case in point was the Spanish Company, which attained considerable proportions, operated a fairly large factory in Cornella near Barcelona, had a share capital of $4^1/_2$ million Pesetas and a turnover in 1914 of about 9 million Pesetas.

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XIX.

SIEMENSSTADT

Now that the relationship to Siemens Bros. had been put on a new footing, it was also possible to settle the differences which for years past had been an obstacle in the way of export business to overseas countries. It was agreed to install an Export Group each in Berlin and London; the former was to deal with business in Central and South America, the Far East, the Dutch Indies, the Philippines and the German Colonies, whilst the latter covered Canada, South Africa, India, Australia and the British Colonies. Both Export Groups were to be subject to the supervision of the "Overseas Department" under Carl Friedrich von Siemens. By reason of his six years experience in London, he was considered to be best fitted to fulfil the position of Liaison Officer between the groups, and in point of fact the sales organization proved to be extremely successful. In the five years from 1908 to 1913 the value of the orders received was more than doubled, notwithstanding keen international competition, and in 1912/13 exceeded 70 million Marks. At the same time, the House employed about 800 persons in its overseas service.

Alongside the "Department for Electric Traction," the oldest specialized group outside the Works, it will be recollected that an "Engineering Sales Department" (Siemens & Halske) came into being as early as 1894. About 1900 this department, under Alfred Berliner, was re-named "Department for Lighting and Power." Notwithstanding his appointment to the Chairmanship of the Board of Management of the newly-formed Siemens-Schuckertwerke, Dr. Berliner kept the management of this department in his own hands. It was his creation and his pet child, but owing to the continual expansion of business, it had attained such a size as to become difficult to supervise. It was particularly annoying that it was not possible to check the efficiency of the individual groups, as it was impossible to tell, from the overall result, which group had contributed to the final profit, or whose fault it was that the profit was not greater. It was therefore decided to split up the Department for Lighting and Power into a number of smaller

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"Balancing Departments" (i. e. each compiling its own Balance Sheet). It must be admitted that this expression was not quite correct (it was later abandoned), for the groups did not issue Balance Sheets in the usual meaning of the word, but only profit and loss accounts, any profit (or loss) being transferred to the Finance Department. This subdivision, however, enabled the scope and results of the activities of the individual groups to be kept under observation, and corrections to be applied where necessary. The system was applied throughout, beginning with the Technical Offices, right down to the Works. Thus were established the "Central Station Department" for building and extending power stations for public electricity supply and cognate matters; the "Industry Department" for everything which the manufacturing industries require; the "War and Marine Equipment Department," a title which indicates that in those days on the armament side the Navy was also the chief customer for power current equipment. (The requirements of the Mercantile Marine were also catered for by this department). The "Traction Department" took its place in the new system pretty much unchanged. In addition to these existing groups, a new department was established, viz., the "Small Accessories Department," whose province it was to cover the requirements of the contractors and dealers in mass-production accessories, including incandescent lamps and the electricity meters sold in large numbers to the power stations. The overseas business, finally, which had hitherto been handled as something apart, was now brought into the system under the title "Overseas Department." Over everything and forming, as it were, the roof of the structure, was the "Central Sales Administration," whose function it was to summarize and control the combined result.

If things had gone in accordance with Berliner's wishes, he would have continued in the management of the Central Sales Administration in addition to his Chairmanship of the Management Board of Siemens-Schuckert. But a year before the introduction of the new system, i. e., in 1912, he resigned—to all appearances suddenly—from the Managerial Board of Siemens-Schuckert. His transference to the Board of Directors was generally, and rightly, looked upon as a burial with honours.

In 1888, when Dr. Alfred Berliner joined Siemens & Halske as a young physicist, his work, in common with that of the other young engineers, was to deal with particular technical matters. It fell to his lot to handle the designing and calculation of machines, and the planning of complete installations. Although he proved himself to be a thoroughly capable and creative engineer, it soon became evident that his real talent lay in the economic sphere, and in organization. Thus, on his return

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from his unfortunate American adventure, he forthwith found his way into the Department for Lighting and Power, becoming Manager in 1896. From then onwards he had complete control of the Firm's power current business, and with it, virtual control of the Firm itself. It was he who overthrew Bödiker, who was the driving force in the negotiations with Schuckert, and who was Wilhelm von Siemens' closest adviser in formulating the Fusion Agreement. As Chairman of the Managerial Board of Siemens-Schuckert, he was—unofficially—called General Manager, a title he rather liked to hear, but not Wilhelm von Siemens. In many respects he was similar to Rathenau, with whom, over a long period of history, he shared a common ancestry. The fact is that, in the twenty-five years before the first World War, when Germany experienced its marvellous economic rise, a whole number of men of Jewish blood, such as Rathenau, Ballin, Fürstenberg, Loewe and Koppel (not to mention others, who were not in the front rank) played a leading part in that rise, in every case due to their shrewdness, business instinct and energy. Berliner also belongs to this category. His great ability was not in doubt, and was fully appreciated by Wilhelm von Siemens. As time went on, however, Wilhelm became increasingly conscious of certain rough edges in Berliner's nature. To his subordinates Berliner was usually curt and frequently rude, but never unjust, a fact which cannot be repeated too often. Towards others of equal or superior rank, however, he could adopt a sneering manner bordering on impertinence, which to many of his colleagues had become well-nigh insufferable. When one day at a meeting he 'choked off' the Deputy Chairman of Directors and Schuckert Representative, as if he were an office boy, the cup, which was already full, overflowed. Wilhelm von Siemens was sorry to part with him, but realized that he had become impossible. With characteristic generosity, he nevertheless agreed to Berliner's election to the Board of Directors, and to the payment of ample indemnification. Berliner bought himself a large estate, and devoted his energies from now on to agriculture. He also kept up his friendship with Adolph Müller of the Akkumulatorenfabrik, the only one who had invariably paid him back promptly in his own coin.

The succession to the Chairmanship of the Managerial Board of Siemens-Schuckert fell to Carl Friedrich von Siemens. Wilhelm was convinced that he could entrust this responsible office to his younger brother with an easy conscience. He chose Otto Henrich as Chief of the Central Sales Administration and simultaneously of the Industry Department (its largest group). Henrich was one of the group of young engineers (Köttgen, Werner and others) who had entered the Charlottenburg

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Works about the middle of the 1890's. At that time, these were the new generation, which after rather more than a dozen years was now filling the responsible positions, as far as they showed the requisite ability. As regards Henrich, there was no doubt about his ability, provided this was taken to mean a somewhat reckless energy. In this respect he resembled Berliner, and also in his scant regard for the feelings of others. He did not, however, possess in the same degree his predecessor's gift for physical-technical science and his keen, critical intellect.

Many other changes in the Staff took place about this time. Schwieger died in harness in 1911 and was succeeded by Frischmut, who had been his deputy. Budde, who was already beyond middle age when he joined the Firm, retired in the same year when nearing his seventieth year. Due to the numerous new Works built and the many changes which had been made in the manufacturing programme, Dihlmann, who for a number of years had been the actual Manager of the Charlottenburg Works under Budde, had acquired a considerable fund of experience in running factories. With the object of making this experience available to the whole of the Works, especially to those in the planning stage, a "Central Works Administration" was now established with Dihlmann as Manager, supported by a staff of experienced assistants. This tight organization and scientific development of methods capable of general application has materially raised the efficiency of the Works. It bore particularly valuable fruit during that period of rapid expansion.

In the discussions preceding the inauguration of the new Engineering Sales Departments, it was realized that the new system would mean a not inconsiderable increase in personnel. This was accepted, as it was hoped to save the extra cost in other ways in consequence of the greater clarity in the conduct of business. Since 1902, the Department for Lighting and Power, the Traction Department and the other departments of the general administration, had been housed in the building at Askanischer Platz, of which mention has been made in an earlier chapter. Here, the same thing happened as always. The building had hardly been occupied before it was found to be too small. Neighbouring houses were bought or rented, and the offices extended through openings in the partition walls until the whole resembled a bee-hive with innumerable cells, in which a stranger was almost certain to get lost. A further increase of the Staff under such conditions was impossible. Then there was the irksome journey to the Works in Nonnendamm, which was gradually becoming the real seat of the Firm. In 1911 the decision was therefore taken to build a new Head Office in Nonnendamm to replace the existing offices, and to house the whole of the departments with the ex-

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ception of those immediately connected with the Works. The building was completed in 1912, and for many years was reputed to be the largest building in Berlin.

It lay with its south frontage along the Nonnendammallee, the new arterial road to Spandau, and had only three storeys, since there was ample room for expansion in the horizontal plane. The building had several side and cross wings with courtyards. The architectural design, in particular the spacious glass-covered Court of Honour fronting the East, the lecture and meeting rooms, the roomy, well-lit offices, the kitchens and dining rooms for staff and visitors, as also the technical equipment, were witness to the ability and good taste of the architect, Councillor Janisch, and of his assistant Hertlein. The latter was afterwards to become the successful Director of Building of the Siemens Works. As a whole, it was also obvious that Siemens & Halske and Siemens-Schukkert, many departments of which were run by a joint staff and housed under the same roof, no longer found it necessary to count every penny anxiously before spending it.

In a widely spanned, shallow semi-circle stretching from East, through South, to West the individual factories lay around the Head Office, viz., the Block Signal Works, Small Accessories Works, the Power Station, Electromotor Works, Wernerwerk, Automobile Works, Dynamo Works, the Foundry and the new Cable Works. In 1914 the smallest of these Works, apart from the power station, was the Foundry with 220 hands. Next in order was the Automobile Works with about 450 hands. The number on the pay-roll of the remaining Works varied between 2,000 and 3,000, with the exception of the Wernerwerk with 8,400 hands. In that year the total number of employees in all the Nonnendamm Works, shops and offices together, was about 21,000. To these must be added the personnel of the Head Office, comprising about 2,000.

The picture of the factory town was in no way reminiscent of the murky conceptions of former days. The buildings were light in colour and, in spite of their size, of graceful proportions, without chimneys, soot or smoke, and kept scrupulously clean. The individual Works were widely distributed, the intervening spaces being traversed by broad, tree-lined roads, all of which had been recovered from swampy grassland or barren, sandy heath. The factories are now surrounded by modern dwelling houses with shops and inns, a school with a large playground, a day nursery, and a home for women workers. In 1914 the community had a population of about 7,000. All this: roads, squares, factories, houses and public works, were the fruit of fifteen years' labour. On the 4th of September, 1913 the Borough Council of Spandau resolved un-

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animously to legalize what had become common practice for three years past: the name of the new Works' Settlement from now onwards was officially "Siemensstadt."

Several thousand people thus lived there before the war, a considerable number of employees who for some reason wished to live near to their work, then tradesmen and others who are indispensable for the supply of daily necessities. The first residential quarter was a large block of land, subdivided by cross roads, situated between the Wernerwerk and the Head Offices, on the South side of Nonnendammallee. As everywhere else in Berlin, this land had been bought from the peasantry by speculators, who then proceeded to erect tenement houses. As the need for more houses increased, the "Charlottenburg Building Society" established itself on the north side of the Nonnendammallee, opposite the first-mentioned block and put up more tenement houses. Siemens & Halske invested a certain amount of capital in this, but there was as yet no question of a housing policy on the part of the Firm.

This is in strange contrast to the settlement policy in force at that time on the part of the large undertakings in the industrial West of Germany. The influx of new workers which followed the sinking of a new shaft, the extension of a steel plant, or the establishment of a new industry, possibly chemical, and the resulting housing shortage in most cases, caused the firms to build Works' settlements, or "Colonies" as they were termed. The earlier "Workers Colonies," especially those of the mining industry, were, admittedly, pretty dreary agglomerations of dwellings, unimaginatively set out in rows in unattractive surroundings. Presently, however, the owners of the properties and the architects began to be more ambitious, and by the turn of the century there were individual Krupp colonies which were quite presentable while others later on evoked general admiration. Other firms were anxious not to lag behind; town-planners of standing began to take an interest in the problem of the most attractive layout and setting of the colonies in the landscape. At the same time, it was by no means considered necessary that everyone should have a house and garden to himself. Among other examples, the Friedrichshof quarter of Essen, or on a larger scale the factory town of Leverkusen, both demonstrate how large groups of detached dwellings, each housing several families, can be so arranged as to preserve a pleasing appearance and homely atmosphere. True, many of the styles of those days have since been condemned as romantic or sentimental and a new "building sense" proclaimed. (It remains to be seen what our descendants will think of such of the creations of the new "building sense" as have survived the world-war era). However

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much men may differ as to the architectural and town-planning value of those early efforts, it cannot be denied that they were based on an idea and an endeavour. Berlin, however, had no ideas whatever, nor had Siemens. Those of the Berlin architects of repute who specialized in houses built luxury villas for the wealthy, and the rest of the population existed in tenement dwellings. Notwithstanding a notice over the main entrance: "Staircase for Gentlefolk only," they still remained tenements.

Some insight into the ideas held in authoritative circles concerning the relationships between Works and workers can be gathered from a biography of Emil Rathenau, which was published by A. Riedler in 1916. It is here stated that Rathenau purposely remained with his factories as long as possible in the North of Berlin. By way of explanation Riedler writes: "... As soon as a factory employing 100 men opens its doors in a small place, the living and working conditions of that place undergo a change. Consequent on increased production, however, the AEG has on numerous occasions had an intake of 100 workers per day. It is only in the North of Berlin that the labour market can meet such demands immediately; only a few miles away conditions are much less favourable, and even transport of all kinds is unable to make up the difference, at least not at once. Such demands on the labour market were formerly unknown ..."

Terrible: if, therefore, a couple of hundred workers are required, one just scoops up a handful of human "sand" from the North of Berlin; there is enough man-power available there. This shows why there was no housing policy in Siemensstadt before the 1914—1918 war; there was no desire for it, either at higher or lower levels. Later, when an attempt was made to recover lost ground, it was found that much of it was irrecoverable.

If, however, the inference were to be drawn from the restlessness of the average Berliner in the matter of housing, that the Berlin worker was unreliable in his work, this would be a great mistake. A stranger walking along a street in which building-work was going on (and where was that not the case in those days?) could not help noticing how accurately the smallest bit of paving or edging was carried out, even to the hoardings. The building materials were neatly piled up and everything arranged according to a system; the utmost care was taken by the workers in the handling of their tools. It is difficult to point to the fountain of this universally noticeable spirit of cleanliness, care and precision in a community which was constantly being diluted by immigrants from all over Germany, although chiefly from the eastern provinces. The peculiar atmosphere of the city must always have exercised a strong melting

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action on the ingredients which came into its crucible. The training received in the barrack yard, which was doubtless more intense in Prussia than in other German provinces, probably played its part in this moulding of the spirit. In the main, however, it is a strong critical faculty which does not halt even at one's own failings, and exerts a constant check on the quality of the work. It thus came about that when the mechanisation of industry was introduced in the first half of the nineteenth century, the demand for exact methods of work fell on well-prepared ground. In the bright, objective and rational atmosphere of the city, a type of worker grew up which was incomparable in its kind, and has spread the fame of the Berlin metal industry throughout the world. As an individual, Halske could be imagined to exist anywhere; as the Manager of a factory employing hundreds of workers of the same type as himself, he was only thinkable in Berlin.

Numerous artists, both painters and sculptors, have endeavoured to portray the "Worker" of their generation; as models they have usually selected a builder, labourer, miner or steel worker. As yet, however, no one has attempted to present the Berlin metal worker, although by this time he should have had a monument, for instance, in Siemensstadt. It must be admitted, however, that this is no easy task, since the power of the Berlin metal worker does not rest in his muscles, but within his cranium, whilst the ironical twist to the corners of his mouth is more likely to obscure that power than reveal it.

Now, in building up a force of first-rate skilled workers, it is not only their qualifications and ability which count, but also their training. When the first few firms of the Berlin metal industry began to expand, the majority of the workers they required came from the handicrafts, in which they had served the usual apprenticeship. At that stage, it was not necessary to worry about the training of the next generation. The reservoir of local craftsmen would, of course, not be able to supply this need for long, but great numbers of journeymen came to Berlin on their travels, where they sought and found work, many of them eventually settling there. In this way requirements in skilled labour were satisfied for the time being. When, however, the 1890's ushered in the great development of power current engineering, and the Charlottenburg Works was booked up with urgent orders at the time the Raps era was beginning at Markgrafenstrasse, the situation became critical. Workmen were still to be had, but not of the grade required. The reservoir of North Berlin was, after all, not so inexhaustible as Riedler had imagined.

Before this period, Siemens & Halske had been in the habit of engaging

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errand boys, i. e., youngsters fresh from the Boarding Schools and under the necessity of earning money. For a small commencing wage these boys acted as messengers and helped the men in the performance of simple tasks. Such of them as showed aptitude were gradually taught to do more important work, without any formal agreement as to training. An agreement could not be concluded, because it was laid down by the somewhat confused German Trade Law (confused owing to the interpretation being left to the individual Local Authorities), that the training of apprentices be reserved to those trade organs who are members of the respective guilds, and that an employer can only enter an apprentice for his journeyman's test provided that he—the employer—or his representative responsible for the apprentice's training, is himself a master craftsman. The works were able to overcome these difficulties by engaging suitable instructors, and Schuckert had commenced in 1890 to employ apprentices, whose training was systematically planned over a number of years. A little later the Charlottenburg Works followed his example, and the Berlin Works, in spite of its cramped conditions, decided to train its errand boys as apprentices. After the founding of Siemens-Schuckert and the building of the Wernerwerk, the training of apprentices was carried out on the same lines by both firms. The duration of the apprenticeship was fixed at four years. In the first two, the apprentice spent his time in a specially equipped training shop, which formed part of the organization of all the larger works. Here he was trained systematically by a special instructor in the exercise of the various skills, at the vice, anvil and lathe. The apprentice was then drafted into one of the workshop departments, in which he commenced to perform productive work under supervision. In the final three months of their time, the apprentices were taken back to the training shop to receive the final polish, and to produce their journeyman's test-piece. Since attendance at a continuation school is obligatory for all trade apprentices, Siemens & Halske established in 1906 a Works' School in the Wernerwerk for the whole of their apprentices. The school duly received the sanction of the Authorities as a Continuation School. In 1914 Siemens-Schuckert followed suit with a school in the dynamo works. In addition to German grammar, these schools taught sociology, reckoning and simple bookkeeping, elementary technical principles, simple arithmetic, drawing, physics and the knowledge of raw materials and working methods. In addition to having a full-time professional master in charge of the training, the apprentices were also taught by certain of the Firm's engineers who were selected for their pedagogic inclination and talent, and who performed these duties in addition to their normal work. In

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this way the instruction always retained its vital force. It was not long before the apprentices' schools of the various Works began to vie with each other for the first place, the same applying to the two Works' Schools and the corresponding schools in Nuremberg. Thus, and by the force of the old Works' tradition, these schools gradually attained an astonishingly high level. It was a point of honour with the Siemens apprentices to retain the lead in the journeymens' competition, and the test-pieces of some of the older apprentices were, indeed, show-pieces of the first order.

Not unnaturally, of course, some of the young people did not remain with the Firm when their training was finished, but preferred to try their luck elsewhere; Siemens apprentices were sought after. Many succeeded in climbing rapidly in the Works of competitor firms, or other large undertakings using electric power, to positions of trust, such as leading hands, foremen and workshop superintendents. This resulted in occasional complaints from the instructors and foremen in the Siemens training schools: "We are working hard to make it cheaper and more convenient for others." The Management had to pacify them by pointing out that a part of this work accrued directly to the benefit of the Firm, another part indirectly; the training of apprentices, moreover, was the most dignified form of propaganda, and, finally, as a large undertaking, it also had a public duty to perform.

The development of these apprentice training courses was only a small, although characteristic, feature of the overall picture, which showed the House to be resting economically on solid and broad foundations. The figures of a Balance Sheet do not of course provide information about everything of importance to the economic stability of a firm, as much can be hidden in "depreciation" and "reserves." That part of the assets which rests on the name and tradition of the firm, the ability of its employees, and the good-will of its customers, just cannot be expressed in figures. After all, however, the capital on the debit side of the Balance Sheet must have some relationship to the scope and significance of a firm's activities, and in this respect the low figure of the Siemens & Halske share capital was remarkable. In 1900, as already stated, it was 54½ million Marks, and in 1908, in the period of rapid growth, it was again raised by 8½ millions to 63 million Marks, after which it remained stationary. With this Siemens & Halske controlled the half of Siemens-Schuckert, whose share capital was 90 millions, and who had also contracted loans of 25 million Marks from each of the two Partners. In addition, Siemens-Schuckert had issued debentures to the same amount, so that the total working capital of this Firm was 190 million Marks.

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Of this, 70 millions had thus been loaned to the daughter Company by Siemens & Halske, i. e., more than the latter's own capital. Add to these the other subsidiary companies, mostly abroad, and the large capital investments for the Wernerwerk, Signal Works, Lamp Works and others, one cannot help asking where all the money came from.

In view of the comparatively modest capital, the dividend, which seldom exceeded 12%, accounted for only a fraction of the actual profit. The greater part of this disappeared in reserves and depreciation. In spite of continual new purchases it was thus possible, amongst other things, for all machines, fittings and tools to be written down to the value of 1.— Mark. The considerable resources thus liberated were again immediately invested. This policy was rendered possible by the fact that there was no host of dividend-hungry shareholders which might conceivably have forced through an amendment of the dividend resolution, but that the overwhelming majority of the shares were in the hands of one family. Within the family, again, the individual holdings were limited by agreement, so that the father of the family, in this case the Chairman of the Board, was free to dispose of the money as he thought fit. The successive fathers, however, have been in the habit of keeping their families tight: the Firm has always come first, and whatever could be spared has been ploughed back into the business.

Between the great crisis at the commencement of the century and the first World War the expansion of business was enormous in all departments; the greatest and most impressive expansion took place, however, in that section which later was called the Department of Industry. This was due to the circumstance that the general industrial rise in Germany coincided with signal progress in the perfection of the electric drive, and its consequent use in the manufacturing industries. Not only was there a very rapid increase in the number of electric drives (with a corresponding increase in the size of the generating plants and the current supply systems), but in point of output of the individual unit there was a constant endeavour to outdo what had gone before. A typical example: whereas in 1901 a d. c. motor of 420 h. p. for driving a rolling mill was looked upon as something unusual, a reversing rolling mill drive supplied 11 years later to a mill in Dortmund comprised two direct-coupled motors with a combined output of 10,000 h. p., which represents more than a twenty-fold increase in output. These much-discussed prototype machines, which were in due course surpassed by others, were a continual incentive to competition between both manufacturers and users.

Beside these orders for larger or smaller individual machines, business in mass-production goods began to assume increasing importance, and it

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is not surprising that the idea of forming price-rings first occurred to manufacturers of this class, especially as they were numerous. Such articles, moreover, were not, or did not appear to be, subject to such frequent modification as to make standardization and price-fixing out of the question. The classical example of this type of product was the carbon filament lamp. As already mentioned, the expiry of the Edison patents was the signal for a whole crop of lamp manufacturers to start business, each fighting for a share of the market. The result was a drop in the price-level, which was justifiable as long as the prime cost was reduced in consequence of improved production-methods and increased production. As the result of senseless price-cutting, however, things reached such a pitch that lamps which had cost 20 Marks each to begin with, were selling in 1903 for 20 Pfennigs, i. e., one hundredth of the original price. As this could not continue, an Association was formed in 1904 called "Verkaufsstelle Vereinigter Glühlampenfabriken G.m.b.H." (Associated Lamp Manufacturers' Sales, Ltd.) with Head Offices in Berlin, in which Siemens & Halske and the AEG each participated with a quota of 21 % of the total production. The ring was concerned with carbon filament lamps only, and it is thus somewhat paradoxical that it came into existence in the year which saw the birth of the tantalum lamp. In consequence, it lived for only ten years, and was dissolved in 1914, practically unnoticed, for the good reason that there were no more carbon filament lamps to sell.

The longest-lived and most successful of the rings in the German electrical industry was the Cable Manufacturers' Association, the beginning of which dates back to the days when Siemens & Halske and Felten & Guilleaume were jointly responsible for carrying out the large Post Office order of 1876. As the cable makers grew in numbers, such ad hoc agreements gradually came to be consolidated into a permanent association of the power current cable manufacturers, which was supplemented in 1914 by the formation of the "Deutscher Schwachstromkabel-Verband" for the weak current cable makers. The two closely connected organizations are together known colloquially as the "Kabelkartell." This was not a syndicate, but a price and production control association, which left the sale of the products thus controlled to its individual members. In accordance with the procedure laid down, all enquiries and orders were reported to a neutral office, which "instructed" the price to be quoted. This price had to be strictly adhered to, under heavy penalty. The price instruction was the instrument by which business was allocated in accordance with quota. If, in the course of a business year, a member firm had materially exceeded its quota, say, owing to the

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receipt of unpriced orders, it would be instructed to quote such high prices as to render it uncompetitive for the time being. The procedure operated very successfully, as the Association Management worked strictly to rule, and when in doubt, insisted on inspecting the books. Moreover, the cable orders had not the same attraction for the technicians in the price office as for the sales engineers "on the job," with the result that they were less likely to be tempted to infringe the regulations. From time to time, when the Association was due for renewal, it would dissolve in consequence of the perennial bickering about quotas, and there followed a short interregnum of bitter competition until a new basis of agreement was reached.

From the closing years of last century until the present day, the question of price rings has been one of the most disputed themes in the German economic body. On this subject there exist whole libraries of books and mountains of pamphlets, polemical leaflets, learned opinions and official enquiries. Friends and advocates of the rings were attacked by the ranks of embittered opponents, for whom the rings were the root of all evil. In view of this, the Law adopted a waiting attitude, since in some matters the cleavage of opinion ran right across the political parties. Thus, for instance, there were people in the Social-Democratic Party to whom the price rings represented one of the worst excrescencies of a profit-hungry Capitalism, whilst other Socialists maintained that the rings prevented many a savage price war with resulting bankruptcies, under which the workers were the first to suffer. An even greater number may have thought that the rings were the simplest means of educating Industry in the way of planned economy, as the penultimate step to Socialism. One thing is certain, however: the liberal and free capitalist economy as it existed in all countries before the first World War stands and falls with competition. Without competition, it loses its meaning and justification. In this imperfect world there is no ideal system and, in particular, none for the economic body. It will always be a case of choosing the least of several evils. He who considers the ravages and risks of the competitive system to be so great that means must be organized for its suppression, will find that he is offered in its place a system of state-planned and state-controlled economy in which the Head is no longer a man of free enterprise but is supplanted by a clerk, i. e., a Bureaucrat. This is an aspect which was overlooked before the first World War in Germany by those economists whose all-absorbing occupation was the founding of trade associations.

About the turn of 1913 and 1914 Wilhelm von Siemens wrote in his diary, retrospective of the year just passed: "how happy and contented"

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he had felt for some time past. For one with such a tendency to ruminative pessimism, that was quite a remarkable confession. He was approaching the sixties and was thinking of delegating some portion of the daily round to others, in order to be able to give more time to the pursuit of his scientific and literary tastes. Not that he had the intention of retiring altogether; one who has worked constantly at the same task for thirty-five years does not find it easy to give it up. His idea was, however, that he could confine himself to an overall supervision of affairs, and leave the day-to-day guidance to the members of the Management Board, the Works' and Department Managers, the majority of whom now had many years of experience to their credit.

On looking back to the time twenty-four years ago, when he took over the conduct of the Firm from the tired hands of his father, there were two pairs of figures, by which he was able to gauge the progress made in the interval. Then, in the year 1890, the turnover of the Firm was about 16 million Marks, and the number of employees between 2,500 and 3,000; to-day the turnover was 500 millions and the number of employees at least 82,000, of which 23,000 were abroad. On both counts the increase is approximately 30-fold. Wilhelm von Siemens was much too sceptical and modest to imagine that the credit for this was due wholly, or for the greater part, to himself. He was, however, fully entitled to believe that his calm and sober judgment, his wealth of suggestion and criticism, and his cautious hand had, indeed, contributed in a measure to that success. If he looked out of the window of his office, he saw a town which bore the name of his House, and had grown from the swamps in a decade and a half; if he thought of the centres of European trade beyond the borders of Germany, he could see here, too, in spirit, the growth of offshoots of the parent factories; should he let his thoughts wander to foreign continents and islands, finally, the printed table on the desk in front of him listed fifty-eight cities or commercial centres where the sign of the Firm was to be found, viz., twenty-three in Asia, twenty-five in America, seven in Africa and three in Australia. Of Charles V it was said that the sun never set over his empire. Of this empire it was possible to say the same.

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