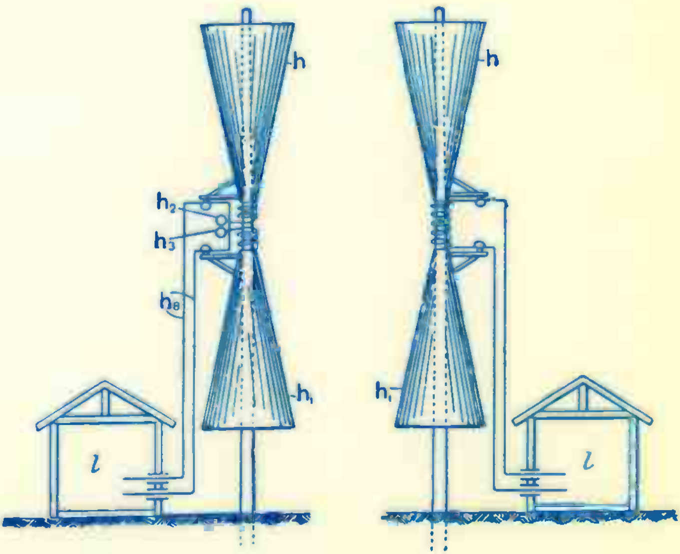
OLIVER LODGE AND THE INVENTION OF RADIO

edited by

Peter Rowlands and J. Patrick Wilson



PD PUBLICATIONS

OLIVER LODGE AND THE INVENTION OF RADIO

edited by

PETER ROWLANDS and J. PATRICK WILSON

published by

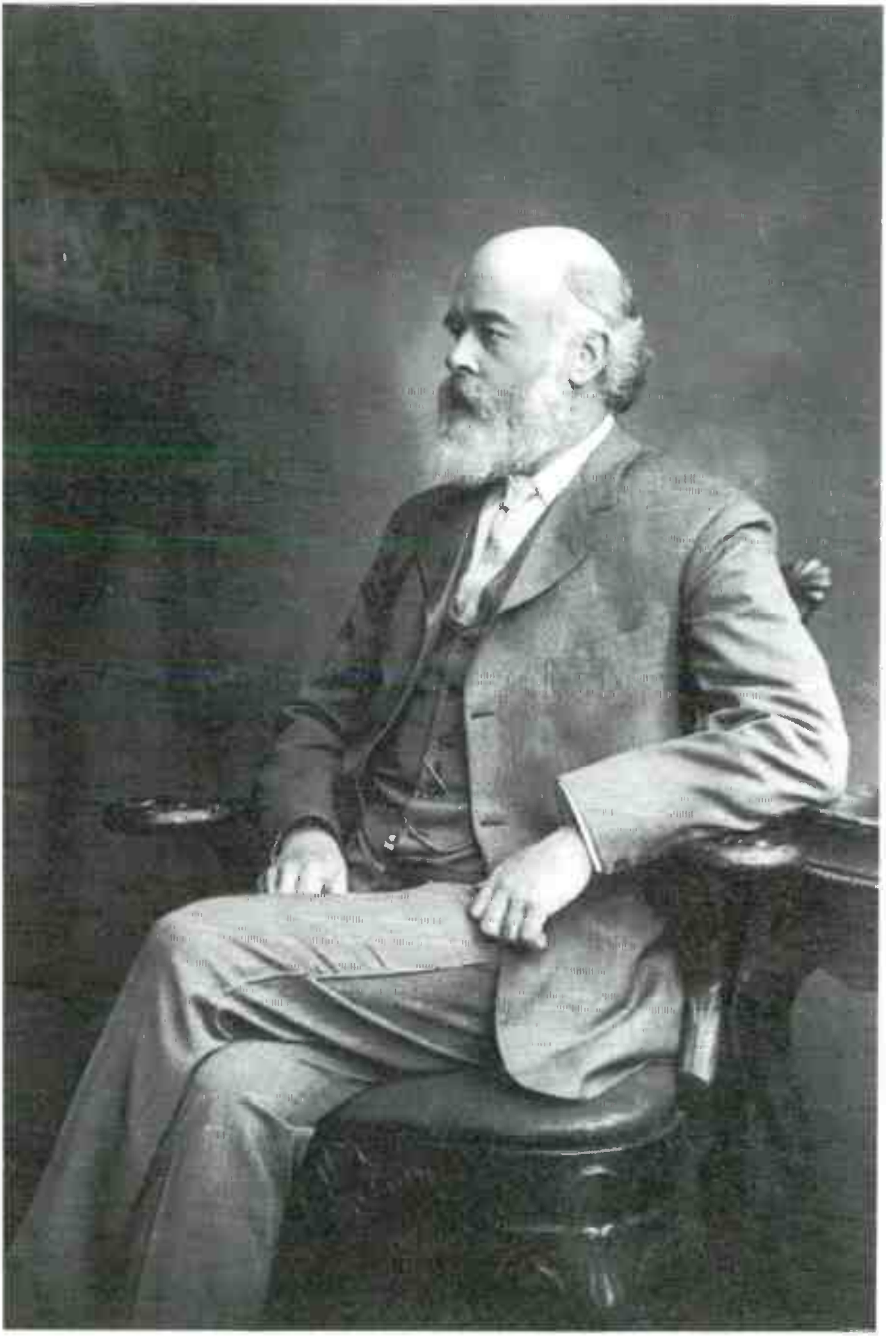
PD PUBLICATIONS

1994

First published 1994 by
PD Publications
4 Ascot Park
Liverpool
L23 2XH

British Library Cataloguing in Publication Data
Data are available
ISBN 1 873694 02 4

Printed by Antony Rowe Limited, Chippenham, England



CONTENTS

PREFACE

The transfer of information using radiowaves was one of the great technological innovations of the later nineteenth century. For largely commercial reasons, however, the history of its origins was distorted from the very beginning, and has been clouded by controversy ever since. In particular, the highly significant contribution of Oliver Lodge, Professor of Physics at University College, Liverpool, though recognised, has not been given its full weight. Lodge, in his lifetime one of the most prominent British scientists of his day, has, for various reasons, been considered a less central figure in the history of science and technology than his actual achievements would seem to merit.

In the field of radio, Lodge was the first to propose that electromagnetic radiation could be generated from electrical circuits, and, subsequently, to discover convincing evidence for them at the same time as Hertz; he set up the first system which could be used for radio communication and used it in the first public transmission of information by radio using Morse code; he developed the method of tuning without which simultaneous communications would have been impossible; and, with his partner Alexander Muirhead, became a successful manufacturer of commercial radio apparatus. The influence exerted by Lodge's lectures and published works was widespread and was widely recognised by other radio pioneers; important legal judgments recognised the validity of his patent claims. He was also a pioneer of radio astronomy in that he attempted to find both the ionosphere and radio emission from the Sun. That these achievements have not led to popular recognition is a fact which deserves investigation.

The authors of this book propose to put Lodge's contribution to the technology of radio into its proper perspective. They aim to illustrate the pattern of influence linking his work with that of the other radio pioneers, in particular with that of Guglielmo Marconi with which it will always inevitably be compared; to show the exact nature of his technical contributions to radio, together with some account of other significant developments with which he is associated; and to explain how and why the early history of the subject came to be so distorted as to make him a peripheral, rather than central, figure. In the process they have uncovered a great deal of new manuscript material, never before quoted, as well as providing previously unpublished photographs and oral information from family recollections to illustrate the more personal side of the story. While each chapter has been designed as a free-standing piece of research, the authors have worked closely with the editors and with each other to ensure that the overlap of information has been kept to a minimum and that the book can be read as a coherent whole. They have aimed at consistency of fact while allowing for variations of interpretation.

The contributors felt that such an important innovation as the invention of radio required a proper centenary celebration and so arranged an international conference, in collaboration with the Institution of Electrical Engineeers, the Institute of Physics History of Physics Group and the International Union of Radio Science, which was held, with full media coverage, in the Barkla Lecture Theatre, at the University of Liverpool, on 11 July 1994, one hundred years after Lodge's first public demonstrations of the new technology. Lectures were also given at the IEE History of Technology Weekend immediately preceding the Conference and at the annual URSI meeting immediately after; and then, in September, at the BA meeting in Loughborough.

The Conference was accompanied by a 5-day exhibition of manuscripts, apparatus, photographs and other memorabilia relating to Oliver Lodge and the invention of radio. A special event station was set up by Liverpool and District Amateur Radio Society, under the organisation of Geoff Southern, with call sign GB0OL. Running parallel with these events was a Schools Programme, organised by Phil Pennington, with a specially designed information pack and prize competition. Schools Lectures were given at the Barkla Theatre on 12 and 13 July during the University's Open Days, and visitors were encouraged to view the exhibition and the special event station. An event of this magnitude naturally required a great deal of organisation and cooperation from many people, and we are particularly grateful to Mike Houlden and to David Bamber who organised much of the publicity. The whole event was an enormous success and did much to increase public awareness of the importance of science and technology to our society.

The contributors would like to express their gratitude to all those organisations and individuals who lent materials for the exhibition or for their research, in particular, the Science Museum, London; Birmingham Museum of Science and Industry; Birmingham University Library; Stoke-on-Trent Museum; the Library of University College, London; the Walker Art Gallery Liverpool; Liverpool University Library's Special Collections; Liverpool University Physics Department; the members of the Lodge family; and the staff of Lodge-Sturtevant and Morgan Matroc. J. H. Andrew of the Birmingham Museum of Science and Industry and Susan Stead of University College London Library were especially helpful. The organisers of the conference and exhibition would like to thank the technical staff of Liverpool University's Physics Department for their cooperation, and the Universities of Liverpool and Keele and the British Association for their generous financial support. Finally, this book could not have been produced without the patience and good humour of the staff of PD Publications.

Peter Rowlands, Liverpool
J. Patrick Wilson, Keele

Illustrations

Between pages 192 and 193

Between 200 and 201

Sources of illustrations

Birmingham University Library, Heslop Collection, 40; Birmingham Museum of Science and Industry, 55; Deutcher Museum Berlin, 19(b); Dr D. N. Edwards, 13; *The Electrician* 1896, 29; G. F. FitzGerald, *Scientific Writings* (1902), 19(c); Dr Nicholas Godlee, 1(b), 1(c), 2, 3(b), 7(b), 10, 12, 14; *Harmsworth Wireless Encyclopedia*, 44, 57; IEE Archives, 19(a), 19(d), 41(a), 41(b); *Journal of the Society of Arts*, (1888), 20(a), 20(b), 20(c); Keele University, Warrilow Collection, 3(a), 4(a), 5(b); Liverpool University, 15, 16, 58; Liverpool University, Sidney Jones Library, Special Collections, 21, 22, 27, 28, 37; *Liverpool Echo* (1896), 23; *Modern Wireless* (1930), 11; O. J. Lodge, *Past Years*, 25; O. J. Lodge, *Signalling Through Space Without Wires*, 30, 31, 32, 42; O. J. Lodge, Patents, 47, 51; Mr O. R. W. W. Lodge, 1(a); Lodge-Cottrell archives, 52, 53; Lodge Plugs archive, 48, 49; *Proc. Roy. Soc.* (1909), 43; Dr John Ross, 17, 18; Science Museum, South Kensington, 26, 45(b); University College London Library, 33, 35, 36; Dr J. P. Wilson, frontispiece, 1(d), 5(a), 6, 7(a), 8, 9, 41(c), 41(d), 45(a), 46, 47, 50, 54;

Chapter One
OLIVER LODGE: A SKETCH OF HIS LIFE

by J. Patrick Wilson

Although the name of Oliver Lodge is well known it is not one which is strongly associated with a specific discovery or theory. He was a physicist with very broad interests who could be relied on to interpret the latest scientific findings in a form accessible to the layman. His interest and writings on psychic matters also guaranteed public attention. He was, however, instrumental in the development of many ideas, particularly the work of Clerk Maxwell on electromagnetism, as well as in bringing new discoveries of science into practical application for the benefit of mankind. This can be seen to stem from his background and training which will be outlined here and expanded in later chapters.

Oliver Joseph Lodge was born on 12th June 1851 at Penkhull, Stoke on Trent, the first son of Oliver Lodge (the 3rd) and Grace Heath. Although many of the Lodge forebears on both sides were professional people his father had given up training as a doctor, with his elder brother Charles, to become a cashier on the North Staffs Railway at Stoke. Later he took on an agency from B. Fayle & Co. for the supply of china clay and other pottery materials. He was enthusiastic and successful in business and this enabled the family to live in steadily increasing grandeur. In spite of their comparative affluence the family of eight boys and a girl was raised with very little domestic help even though their mother assisted in the business and found time for such hobbies as painting and wet-plate photography (the photograph of Moreton House (Fig. 3) may be one of hers). Two of Oliver's brothers and his sister, who was eighteen years his junior, also had illustrious academic careers.

Oliver started at a Dame school in Penkhull and at the age of 8 went as a boarder to Newport (Salop) Grammar School where he had an unhappy time both at the hands of the staff, one of whom was an uncle, and the other boys who were all older. At 12 he went to complete his studies privately with this same uncle when he was appointed Rector of Combs in Suffolk. At about the same time, however, he fell under the influence of his Aunt Anne who enthused him in science during her visits to the family home and on his return visits to her in London. At the age of 14 he finished schooling to join his father in business travelling around the Potteries, and occasionally further afield, tending the horse and carriage in the yard whilst his father was doing business in the office. He did, however, continue to study science in his spare time and enrolled in various courses at the Mechanics Institute in Hanley, the Wedgwood Institute in Burslem and the Athenaeum in Stoke-on-Trent. His enthusiastic participation in these activities soon got him noticed and he was invited to assist in the preparation of some of the demonstrations by one of the lecturers, Mr Angell, who had to travel from Manchester to give his lectures.

The Science and Art Department of South Kensington, who were responsible for many of these provincial classes, were at that time offering government assisted courses for teachers at South Kensington and when a teacher at the Wedgwood Institute was unable to accept such a place Lodge was able to go as substitute. Here he studied chemistry under Professor Frankland and enrolled in further classes at King's College in maths, mechanics and physics eventually coming joint-first in the exams. After this he had to suffer a further period of drudgery in his father's business relieved only by his private study and experimentation in the laboratory he had built up in his home at Chatterley House. It would have been here that he would have constructed the induction coil now at Birmingham Museum of Science and Industry (Fig. 5), and where he gained practical understanding of the properties of self-inductance. During this period, after returning from London, he became very aware of the unhealthy environment provided by the smoke of the potteries (Fig. 4) and of the social conditions in which people worked and lived. He saw electricity as a clean source of power and resolved to do what he could to bring this into being. Later he saw a similar potential for nuclear power long before it was a practical possibility. But he also felt that social changes were necessary and did not support his mother's views that servants were better uneducated.

Eventually his hard won studies gained him matriculation to London University for a BSc. For the latter he took courses at the Royal College of Science, King's College, and University College in chemistry, physics, mathematics and biology. During this time he exchanged his comfortable family home for a bed-sit at 62, Delancey St., Camden Town (Fig. 6), where with the aid of food parcels and the generous hospitality of Aunt Anne he deluded himself into believing that he was living on £50 a year! For this princely sum he was working as an assistant to Professor Carey Foster at University College on a variety of electrical measurements including plotting lines of equipotential on a conducting plane, and on the question of whether a magnetic field would deflect a current free to take any path within a plane. In that experiment he unfortunately failed to discover the Hall effect but went on to make measurements on electrolytes, metallic conductivity and thermoelectric effects. This work was written up for his DSc, which was awarded in 1877, and published as several papers in the *Philosophical Magazine*.

1877 was also the year he married Mary Marshall the daughter of family friends in Newcastle-under-Lyme. Brampton House (Fig. 6) had been a second home to him from about the age of 12 until long after his own parents had died. To obtain consent from Mary's stepfather, William Tomkinson, he had to supplement his research assistant's income by lecturing to the ladies of Bedford College in physics and later in chemistry as well and by marking innumerable examination papers. He moved from his modest bed-sit to a small house in Kentish Town. During this time in London he gained his first taste for public lecturing by a highly successful demonstration of one of the first Edison phonographs to reach this country. He was also greatly interested in the newly invented telephone.

In 1881 he was appointed as the first Professor of Physics at University College Liverpool. It was here during the next 20 years that most of his scientific work was done and his international reputation established through publications and papers presented at various scientific societies, and the British Association in particular. It was here also that 12 of their 14 children were born, although two died in infancy. Contrary to the implications of his autobiography, that 6 girls neatly followed 6 boys, their eldest daughter, Violet, preceded their youngest son Raymond. Their growing family demanded moves from 26 to 21

Waverley Road and then to 2 Grove Park, all near Sefton Park and about a 12 mile walk to his laboratory. Throughout his life he always chose to walk to work whenever possible .

His first task at Liverpool had been to supervise the conversion of an old lunatic asylum into a laboratory, and while this was being done he toured Europe in search of ideas and equipment for his new laboratory. At that time the concept of laboratory classes was new in England. He felt that much of the German apparatus was better designed for science, lacking decorative features quite unnecessary to its function. It was during this time that he first met Helmholtz and his young assistant Hertz. Much of his heavy teaching load in Liverpool was to medical students and it was not until later that he had his own students in physics.

His research work was done with the help of a number of able scientific and technical assistants including Benjamin Davies and Edward Robinson, who continued to collaborate with him for the rest of his life on an occasional basis, and J. W. Clark who sadly committed suicide, and Charles Wood who had the misfortune to be heavily exposed to X-rays in the days before their danger had become apparent, first with Lodge and then as radiologist at Liverpool Infirmary. The respect and loyalty in which he was held by his assistants was demonstrated by their long service and continued correspondence after retirement and by his mechanicist, Cyril Franklin at Birmingham, who was instrumental in getting much of his scientific equipment preserved for posterity by Birmingham Museum of Science and Industry.

During his time at Liverpool Lodge did research and consulting on a large number of topics including ionic conduction, electric storage batteries, photoelectricity, dust and thermal and electrostatic precipitation (Clark obligingly providing the smoke from his cigars!), sparks and lightning conductors, electromagnetic waves along wires, coherers as detectors of electromagnetic radiation and a long and expensive series of experiments on aether drag which arose out of the Michelson-Morley experiment. He considered this to be his most important fundamental scientific achievement and obtained funds for it from the Liverpool shipping magnate, George Holt. This involved spinning two huge steel discs at enormous speed to see whether their moving mass was able alter the speed of light beams traversing the slot between the discs.

In 1894 he gave the first public demonstration of wireless telegraphy during a lecture in memory of Hertz and attempted to detect radio waves from the sun. This really formed the culmination of many related experiments on the properties of electricity and magnetism and his correspondence with many other scientists, including G. F. FitzGerald in particular, on the theories of Maxwell. He was quick to take up and publicise the work of others such as Röntgen on X-rays and Rayleigh on argon and drew enormous public audiences for lectures on these topics. It was also during this period that he started to become involved in psychic research, although his interest had probably been first stimulated by his mother-in-law's premonition of her first husband's death. He also invented and patented the moving coil loudspeaker, although without electrical amplification this invention was premature.

Through his publications in the scientific and popular press, lectures to scientific societies and particularly to the British Association and Royal Institution, he became very well known so that he represented an obvious choice for the post of Principal at the newly constituted University of Birmingham. He did, however, ascertain before accepting it that he would be free to continue researching and writing on psychic matters which even in those days was considered not entirely respectable. He was not, however, alone among the scientific community in this interest, as Sir William Crookes and Lord Rayleigh were also involved. Furthermore it had provided the route for many of his social contacts among government and the aristocracy. He clearly relished such associations in spite of his socialist leanings and he had a wide circle of friends of all political persuasions. He particularly enjoyed his occasional rounds of golf with the Prime Minister, Arthur Balfour, and in another direction, his long correspondence with John Ruskin. His wide interests in the arts and literature as well as politics and science were clearly fundamental to his views on education. His ambitions for Birmingham, which included broad curricula and wide access and the involvement of students in university policies, he was never able to fully realise. Coming from a family with many intelligent and capable women he was always keen to support their full involvement in education, politics and all other activities. As Principal he left the day to day running of the university in the hands of administrators and concentrated on gaining support from local benefactors and local and central government to build up and staff the university. His office and laboratory were based centrally in the original Mason College rather than at the present site in Edgbaston.

Apart from the first year, he lived in a large house Mariemont, on the Edgbaston side of Birmingham, which was ideal for the many social and official gatherings that his post required and with extensive grounds suitable for the frequent family sporting activities such as tennis and football. He claimed not to like foreign travel and when on holiday always seemed to end up visiting some scientific colleague or psychical researcher. He did, however, always enjoy a game of golf and liked walking holidays sometimes going with his sister Eleanor.

Although Lodge was no longer personally involved in teaching physics he retained a laboratory staffed by Davies and Robinson, who moved from Liverpool and Cyril Franklin a mechanical engineer. The work was now more heavily directed towards practical applications and served the function of setting up his sons in engineering businesses. His eldest son, Oliver had however already established himself as a writer and artist. These developments will be considered in more detail later.

During the war his son Raymond was killed and he and the rest of the family became convinced that they were able, through mediums, to communicate with him. He wrote this up as a book with the intention that it should help the many thousands of other families suffering bereavement. At the end of the war he felt that so many changes would be necessary at the University that it would be appropriate to retire and leave the reorganisation to a younger man. Retirement was not to relax, however, but to have more time for the many things he wanted to write. His publication list, which includes many books, runs to well over a thousand items.

Leaving Mariemont, however, presented something of a problem as many of the family were still living at home. In 1919 however, with the help of psychic guidance he and his wife found for themselves Normanton House not far from Stonehenge whilst Lionel, Noel, Honor, Norah and the twins, Rosalynde and Barbara, moved to The Wick, Barnt Green. The twins married and left but the other four remained there for the rest of their days, Norah being the last of the generation to go, in 1990. Their mother had died in 1929 and Sir Oliver in 1940. His secretary during his retirement period, Helen Alvey, then went to assist the remaining family at The Wick until her own retirement.

Chapter Two
PERSONAL REMINISCENCES

MY GRANDFATHER AND HIS FAMILY

by Oliver R. W. W. Lodge

The habit in my family of naming sons Oliver is a strong one. In an unbroken line of Olivers, which has to date extended for seven generations, my grandfather was the fourth. But there were Olivers in the Lodge family before the first of those seven. The habit started in the seventeenth century in Ireland, where members of the family were among the English adventurers and soldiers who received grants of land from the Cromwellian government in the 1650s. Initially, no doubt, the name Oliver was given to mark the esteem in which the family held the Lord Protector. However, Lodges endeavoured to live at peace with their Roman Catholic neighbours and it is told in the family that, when a Lodge ancestor was asked by a suspicious Roman Catholic why he called his son Oliver, he replied, with more tact than truth, "After the Blessed Oliver Plunket of course".

My grandfather's grandfather was a clergyman of the Church of Ireland. He was born in Kilkenny in 1765, graduated at Trinity College, Dublin in 1784 and appears to have been ordained deacon in the same year, well below the prescribed minimum age of 23. To his clerical function he added that of a farmer and also, briefly, that of a soldier. A testimonial records that, on the outbreak of the Rebellion of 1798, the Reverend Oliver Lodge "had taken up arms in the defence of the County, uniting himself for that purpose to a military corps". In 1807 he came to England and was for some 27 years curate-in-charge at Barking in Essex. For the last nine years of his life he was rector of Elsworth in Cambridgeshire. He married three times. His first wife died childless; his second wife had nine children; his third wife, Anne Supple, had 16. He died in 1845 aged 80. She died in 1867 aged 81.

My grandfather's father was the twenty-third child of the Reverend Oliver. He was born at Barking Vicarage in 1826 and was called Oliver by way of replacement for a half-brother who had died. As a young man he became an assistant cashier in the offices of the North Staffordshire Railway Company while its line was still under construction. He was what we would nowadays call a workaholic. When another man was absent from the office he delighted in doubling his duties and thereby extending his knowledge of the business. He would happily work far into the night. In 1849 he married Grace Heath, the daughter of a clergyman schoolmaster. Their first home together was in a small house, called, I think, "The Views" at Penkhull above Stoke-on-Trent. It was there that their eldest child, my grandfather (to whom I will hereafter refer simply as "Lodge"), was born on 12th June 1851.

Shortly after his marriage, Lodge's father left his employment with the railway company and built up a business of china-clay merchants at Hanley which ultimately became known as "Oliver Lodge and Son". The "son" of that title, however, was not Lodge but his brother Frank. The business flourished and it was not long before Lodge's parents and their growing family moved to a larger house, Moreton House at Wolstanton. In about 1869 they moved to Chatterley House, Old Hall St., Hanley. When this later became a doctor's house and surgery, it was found to be "riddled with wires" from his youthful electrical experiments. In early 1876 they moved yet again, this time to The Watlands on Port Hill, Wolstanton. This was a sizeable property, the house standing in some 25 acres of park-land with lodge gates at each end of the drive. It is thought to have been the original of a house called "Hill Port" depicted by Arnold Bennett in his novel *Helen with the High Hand*.

Four of the children of Oliver and Grace Lodge attained academic distinction. These were Lodge himself, his brothers Alfred and Richard and his sister Eleanor. Alfred became Professor of Mathematics at the Royal Indian Engineering College. Richard became Professor of Modern History, first at Glasgow and then at Edinburgh (I suspect the last Englishman to hold either of those Chairs). Eleanor, the only daughter and youngest child, was another historian. She became the first woman D. Litt. at Oxford, Vice-Principal of Lady Margaret Hall and latterly Principal of Westfield College, London.

When aged only three or four Lodge was taught by his maternal grandmother, not merely to read but the art of reading aloud, an exercise he enjoyed throughout his life. The first few years of his life were happy but the clouds came down when, at the age of eight, he was sent as a boarder to an old-fashioned grammar school at Newport in Shropshire, where an uncle by marriage was the second master. For four years he remained there, having Latin beaten into him in the school-room and being bullied in the dormitory. When he was twelve his uncle became Rector of Combs in Suffolk and the young Lodge's so-called education was continued there for the next two years. In later life he wrote to John Ruskin saying, "My school days (from 8 to 14) were the dullest and most miserable that I can easily picture to myself without thinking of actual Dotheboys Halls and suchlike hells".

At 14 Lodge was taken away from the Combs Rectory and put to work to help in his father's expanding business. He found this work entirely uncongenial. He told Ruskin that, "In the soul-destroying work of calling on Staffordshire potters and selling them clay and materials for certain shippers and manufacturers, I spent seven good years of my life – only squeezing out of the evenings and train-waitings such opportunities for reading and study as I could". This was something of an overstatement for, when he was 16, his Aunt Anne came to visit his parents and, considering that her nephew's spiritual and mental needs were being neglected, persuaded his father to allow him to spend the winter with her in London, where he would be prepared for confirmation and would attend lectures and classes. Aunt Anne was a remarkable woman. She held the position of Woman of the Bedchamber to Queen Adelaide, the widow of William IV, and she was interested in education, politics, the Church and social work. She was an important formative influence in Lodge's early manhood.

That winter visit to London was a turning-point in Lodge's life for, among the lectures he attended was a series of six on the subject of heat given by Professor Tyndall of the Royal Institution. That was his first introduction to physics. Until he was 20 or 21 Lodge continued to work in his father's business but was able to make occasional visits to London to attend lectures at the Royal Institution.

In 1874, at the age of 22, Lodge, in spite of paternal disapproval, started as a student at University College, London. He was there paid

£ 50 a year to help Carey Foster, the Professor of Physics, with his classes and in his laboratory. On the strength of that income he took lodgings in Camden Town.

In the spring of 1876 Mary Marshall, a young lady of the same age as Lodge, who lived with her mother and step-father at Brampton House, Newcastle-under-Lyme, went to London to study at the Slade School of Fine Art. Lodge had known her as a neighbour since they were both aged 12 but, in London, their friendship deepened into love and he spent as much time as his work would allow in seeing her. He was assisted in his courtship by Aunt Anne who frequently invited Mary to her house on Sundays. In that year Lodge graduated BSc and, in the Long Vacation, went with his brother Richard to Heidelberg. He spent much time there thinking and dreaming of Mary Marshall but nevertheless managed to complete the reading of Clerk Maxwell's two volume work on *Electricity and Magnetism*.

On Boxing Day 1876 my grandparents became engaged to be married. At supper that evening at The Watlands there was ginger wine to drink and, in consequence, it is now the custom in our family on Boxing Day to drink the toast of "Father and Mother" in ginger wine, each of us drinking to his or her own parents, whether living or dead.

Getting engaged was one thing; getting married another. Mary Marshall's parents said they could not part with her until Lodge was earning £ 400 a year. At the time his earnings amounted to only £ 150 a year but he obtained promotion at University College from the position of Demonstrator to that of Assistant Professor and, by taking on additional teaching, was soon able to show earnings not of £ 400 but of £ 800 a year. In June 1877 Lodge became a DSc and, on 22nd August of that year, Dr Oliver Lodge married Mary Marshall at St George's Church, Newcastle-under-Lyme, which is directly opposite Brampton House.

In 1881, at the age of 30, Lodge was appointed Professor of Physics and Mathematics at the newly founded University College, Liverpool. There then remained to him nearly 60 years of life and, with hindsight, those years fall broadly into three 20 year periods. From 1881 to 1900 he was at Liverpool; from 1900 to 1920 he was Principal of Birmingham University; and from 1921 until his death in 1940 he lived in retirement near Amesbury in Wiltshire.

It was at Liverpool that Lodge established his reputation as one of the leading scientists of the day. His principal experimental work there was in the field of electromagnetism, a subject with which I am not competent to deal. I understand, however, that it was that work which led to the event, the centenary of which this book celebrates, namely the first public demonstration of wireless telegraphy. Lodge was elected a Fellow of the Royal Society in 1887 and was awarded its Rumford Medal in 1898. In 1899 he became President of the Physical Society.

It was at Liverpool also, in 1884, that Lodge became a member of the Society for Psychical Research. At that time there was general interest in psychic matters and the Society had among its distinguished members Professor Henry Sidgwick, Arthur Balfour, J. J. Thomson, Lord Rayleigh, John Ruskin, Lord Tennyson, the artist G. F. Watts and the Rev. Charles Dodgson, better known as Lewis Carroll. On the death of F. W. H. Myers in 1901 Lodge became President of the SPR and held that office for three years. I am not concerned here to express any view as to the value of psychical research save to venture the opinion that the experiments carried out by Lodge and others in the late nineteenth and early twentieth centuries were praiseworthy attempts to apply the scientific method to a subject which we may now think is not susceptible of such treatment. I am, however, concerned to take this opportunity of stressing that Lodge became interested in the subject in 1884 or earlier and that his approach was that of disinterested scientific inquiry. I have too often heard it suggested that his interest in psychic matters arose only when his youngest son, Raymond, was killed in Flanders in 1915. That suggestion is not only demonstrably false but is damaging to Lodge's reputation, as it casts doubt on the objectivity of his research in this field and imputes an unscientific motive for undertaking it.

My grandparents already had three children when they moved to Liverpool and nine more were born while they were there. They had in all six sons and six daughters who survived infancy. However, only two of the sons and four of the daughters married and there were only 12 grandchildren. The last survivor of my grandparents' children was Norah Lodge, who died in 1990 at the age of 95. She was an outstanding personality, greatly loved and latterly the lynch-pin of the family. While at Liverpool my grandparents' home was first at 26, and then 21, Waverley Road, and then at 2, Grove Park.

Lodge's researches in electromagnetics resulted not only in important developments in wireless telegraphy but also, more prosaically, in the patenting of a B-spark igniter for use in motor cars. This was exploited commercially by two of his sons who subsequently diversified into the manufacture of Lodge sparking plugs. Two other sons formed a company to manufacture equipment for the deposition of smoke and dust particles, this also being derived from experimental work carried out by their father. This was later combined with American interests to become Lodge-Cottrell.

Notable among Liverpool magnates who supported University College in Lodge's time were William Rathbone and the Holt brothers, who were shipowners and engineers. One of these, George Holt, financed Lodge's experiments designed to ascertain the properties of the ether, which, before the days of Einstein's theory of relativity, was assumed to be the medium which carried electromagnetic waves.

In 1900, at the instance of Joseph Chamberlain, Lodge was offered the post of Principal of the newly founded University of Birmingham. He accepted the offer after hesitation only on condition that he would be provided with his own research laboratory, could bring two scientific assistants with him from Liverpool and was permitted to undertake psychical research. He was to be free of routine administration so that he could concentrate on schemes for the development of the university. In 1902 Lodge received a knighthood in the Coronation Honours of Edward VII. This helped him in his task of establishing the standing of the young university.

While at Birmingham, Lodge and his family lived in a fine large house in Edgbaston called Mariemont which is, alas, no longer standing.

From the outset there were women students at Birmingham and the first Warden of the women's hall of residence was Margery Fry, sister of Roger Fry. She described Lodge as one of the most formidable people she had ever met, though she also thought him kind. He was undoubtedly a man of extraordinary energy. Even at Liverpool he took an active interest in educational progress and social reform in addition to his other work. At Birmingham he necessarily cut down on his teaching and experimental work but became deeply involved in the politics of education. Though he avoided overt involvement in party politics, he nevertheless assisted Sidney and Beatrice Webb with their work on the

Poor Law and corresponded on social and educational issues with, among others, the Conservative Prime Minister Arthur Balfour and the Liberal statesman James Bryce. He was in constant demand as a public speaker and was a frequent broadcaster. His output of books and pamphlets on a variety of subjects was prodigious. He was President of the British Association in 1913 and was awarded the Albert Medal of the Royal Society of Arts in 1919.

When Lodge retired in 1920 he and his wife moved to Normanton House at Lake, near Amesbury. This was a comfortable and attractive house built of Wiltshire flint. His retirement was not an idle one. Between 1922 and 1927 he published ten books and his correspondence was so voluminous that the Post Office enlarged the letter box in which it was posted. In 1931 Lodge published his autobiography, *Past Years*, and his last major work, called *My Philosophy*, appeared in 1933. In 1932 he was awarded the Faraday medal of the Institution of Electrical Engineers. He was greatly helped in his retirement years by the devoted services of Walker, his chauffeur/valet, and Helen Alvey, his secretary. Both remained with him until his death.

Lodge remained physically as well as mentally active during his retirement. Though he gave up golf he continued to play tennis and I remember watching him playing badminton with Walker on the court belonging to his neighbours at Wilsford Manor.

In his old age my grandfather was often referred to in the newspapers as “The Grand Old Man of Science”, largely no doubt because of his tall but stooping figure, his high, domed forehead and his white beard. To my youthful mind there was a natural correlation between my grandfather, King George V and the First Person of the Deity; all patriarchal figures and the heads respectively of the Family, the Nation and the Universe.

In 1927 my grandparents celebrated their Golden Wedding but in 1929 my grandmother died. Thereafter one or more of their daughters would stay at Normanton to look after their father. My own visits there were fairly frequent. On one such visit I remember my grandfather showing me a globe of the world and, on my pointing to the Antarctic regions, he told me of the bravery of Scott and his companions. On another visit, when aged 7 or 8, I was allowed to stay up until after dinner so that I might listen to my grandfather reading to the assembled family the account of the trial in the case of *Bardell v. Pickwick.*

Not long after that event my grandfather gave a lecture to some part of London University in a building on Campden Hill in Kensington, called, I believe, Queen Mary's Hostel. We lived nearby and my grandfather came to have supper with us beforehand. I was dressed in an Eton suit for the occasion with an uncomfortably stiff collar. Before the lecture began my grandfather introduced me to Sir John Reith, the Director General of the BBC, who was taking the chair. I well remember Sir John's grave courtesy and his soft Scottish accent. I do not remember much about the lecture itself but it must have had to do with gravity or magnetism, for in the course of it my grandfather told us that, if free-moving in space and unaffected by the gravitational pull of larger bodies, even the glass water jug and tumbler on the table would be attracted towards each other.

My grandfather died at Normanton aged 89 on 22nd August 1940, the 63rd anniversary of his wedding day. I was then aged 17 and, as my father was at the time in Canada, I represented him at the funeral, which took place at Wilsford Church, about half a mile from Normanton. We walked from the house to the church behind the coffin which was on a handcart pushed by the undertaker's men. After the service my grandfather's body was buried in the same grave as his wife against the south wall of the church. When the family returned to Normanton we sat in the hall to hear my grandfather's will read aloud, the only occasion on which I have known this to be done.

OLIVER LODGE AT HOME – SOME RECOLLECTIONS OF MY GRANDFATHER

by Nicholas Godlee

My grandfather died in 1940 in his ninetieth year during the Battle of Britain. I was only twelve at the time, and although my personal memories of him are those of his old age, I have been able to build up a picture of him at home from others who knew him, including my mother and my aunts.

His daughter Lorna lived about a mile from his house in Wiltshire, and whenever I stayed there with my aunt, we used to ride over in the donkey cart for lunch, to be greeted by his secretary, Helen Alvey. Soon my grandfather would appear, tall and benevolent and, to my eyes, immensely old, but ready to do his best to put a small boy at his ease. In one of the barns he had fitted up a gymnasium with a fine assortment of exercising equipment, a punch ball, weights and pulleys, Indian clubs, chest expanders, and an intimidating machine which shook one violently when the motor was switched on. I remember being rather scared when I first encountered this machine, despite my grandfather's reassurance.

Throughout his life regular exercise was important to him. In his younger days he had been an enthusiastic golfer, and frequently played tennis. Sawing logs for firewood was a favourite activity, and even in the last years of his life he went for a vigorous walk each day with Helen Alvey to a hill overlooking Stonehenge.

He and his wife had moved to Wiltshire when he left Birmingham on his retirement in 1920. The house they found – Normanton House – was an old farmhouse in the Avon valley on Salisbury Plain. It was built of stone and brick, with plenty of oak beams, and with most of the rooms facing south. It suited them perfectly, but before they could move in, the roof had to be raised to provide an extra floor to house all his books.

seventy, but retirement did not mean any lessening of his literary activities. Helen Alvey became his resident secretary, and he continued to write as much as ever, pouring out articles, keeping up a huge correspondence, and producing a dozen more books. In fact about a third of all his writings was published in the years after he went to live in Wiltshire.

After the First World War, he became increasingly well known through his books, his popular journalism, and later from his broadcasts. He was by then something of a national figure, and was greeted with acclaim wherever he went. Large crowds attended his public lectures, sometimes spilling out into the street and disrupting the traffic. On a few occasions he had to give the same lecture twice when the hall was not large enough to accommodate everyone. His fame and success as a popular speaker must have antagonised some people in the scientific world, but anything he did made news for the papers, and his name must have appeared in the press hundreds of times each year.

Once he had the unusual experience of reading his own obituary. This followed the disastrous Carr Bridge train crash in the Scottish highlands when a railway bridge collapsed in a violent storm, and one of the coaches to the Glasgow to Inverness train was completely destroyed in the raging torrent beneath. In a recent account, L. T. C. Rolt says that "no coach in railway history has ever disintegrated more rapidly and completely". It therefore took some time to recover all the bodies of the victims, but among the wreckage was a suitcase labelled "Sir Oliver Lodge". The case was later claimed by his eldest daughter, Violet, who was travelling alone and who by a lucky chance was in the dining car at the time of the disaster.

He and his wife celebrated their golden wedding in 1927. Eighteen months later she died, and for the remaining eleven years of his life he was looked after by Helen Alvey and by Leslie Walker, his chauffeur/valet. During this time there seemed to be no let up in his activities, and he continued to write, travel and broadcast and go for daily walks. Only in the last few years did he slow down; then he gradually settled into a quiet old age and died in 1940 at the age of eighty nine.

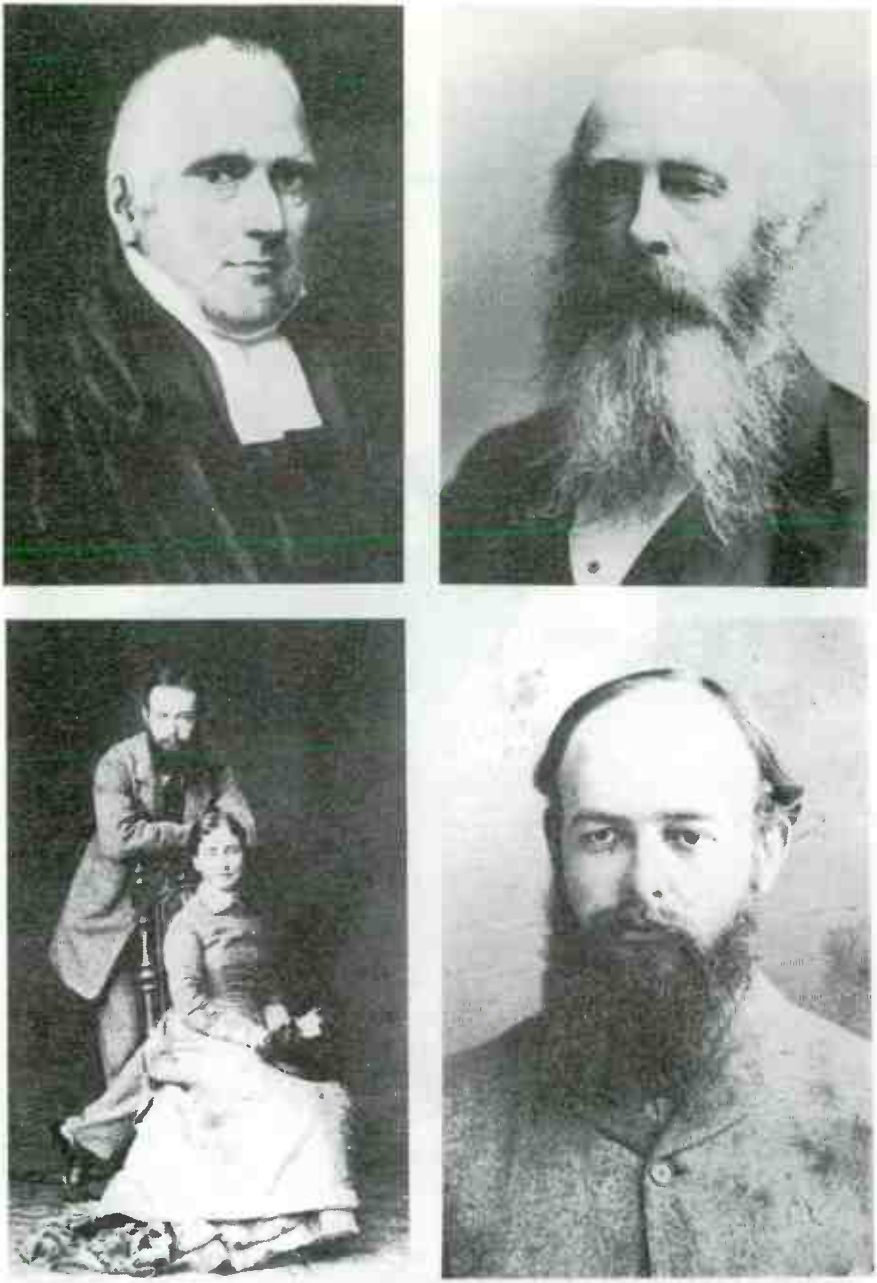


Fig 1. The Rev Oliver Lodge (2nd), grandfather of OJL; Oliver Lodge (3rd), father of OJL; Oliver and Mary Lodge in Heidelberg; Oliver Lodge (4th) in 1882.

Fig 2. Oliver and Mary Lodge and their young family (Oliver, Lionel, Alec and Brodie).

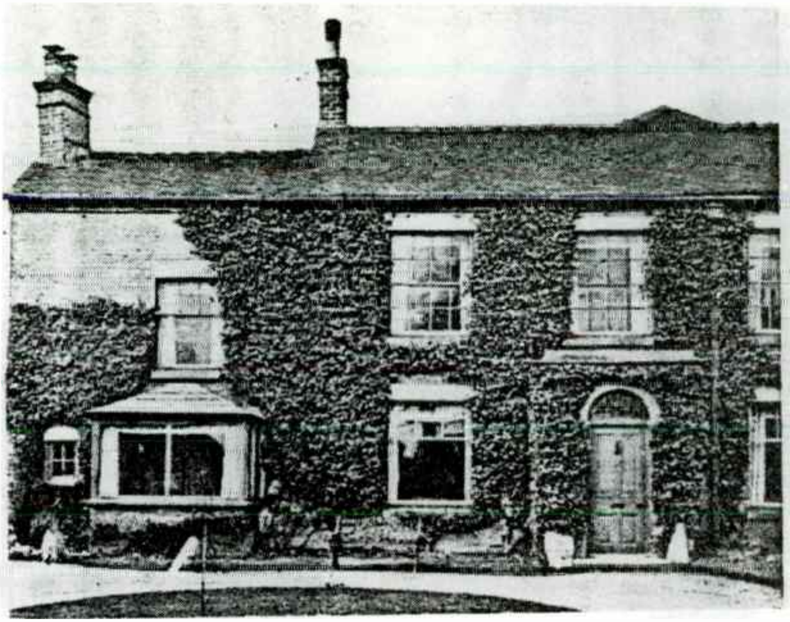


Fig 3. The Views, Penkhull; Moreton House, Wolstanton.

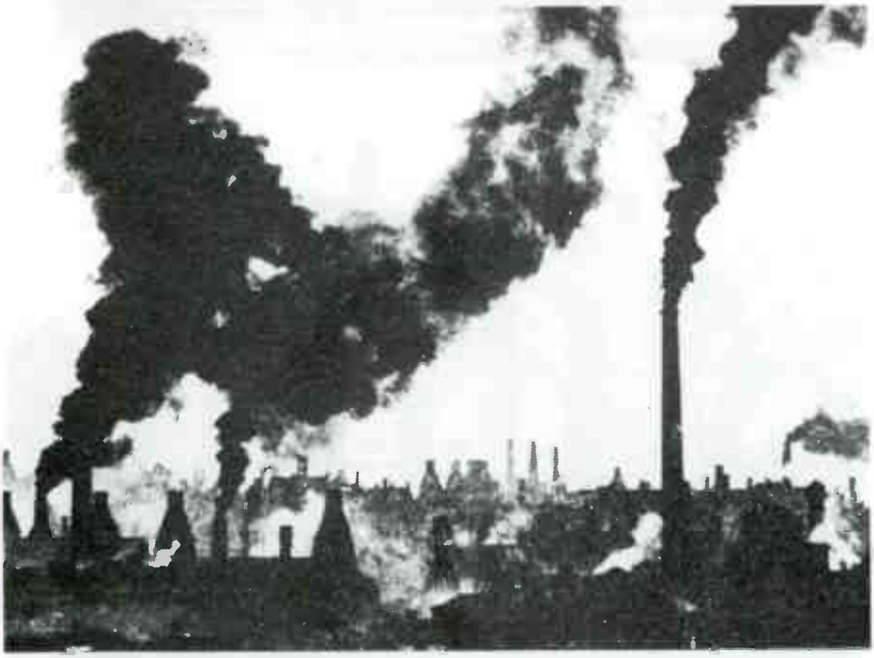
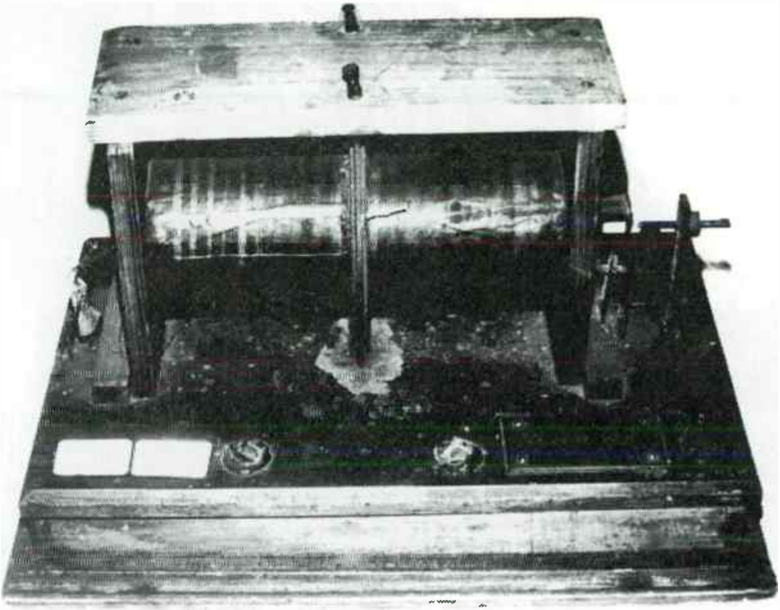


Fig 4. Chatterley House, Hanley (the two dark buildings to the right of the chapel); Smoky Potteries c1900 by W. J. Blake.



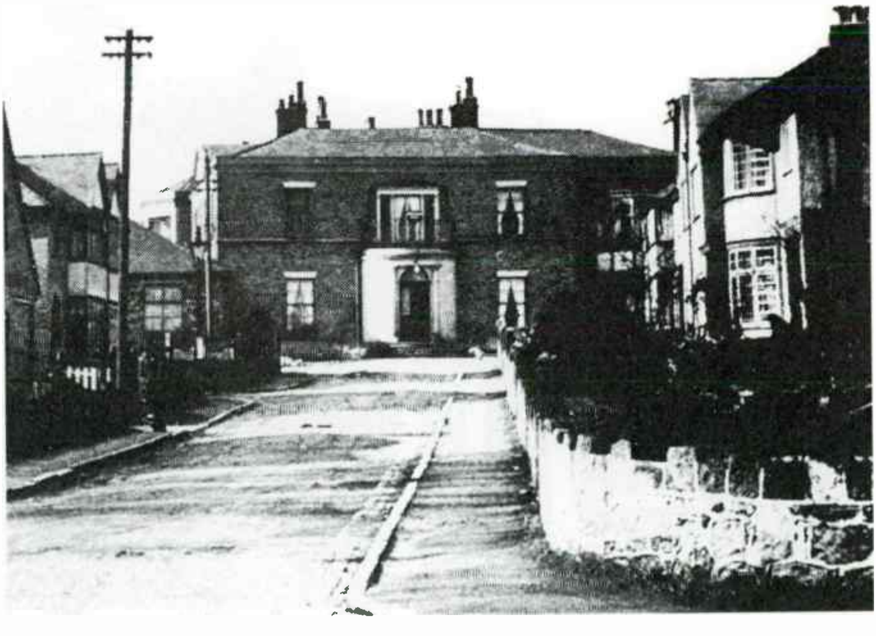


Fig 5. Induction coil constructed by OLJ in his youth; The Watlands in 1940, demolished 1951.

Fig 6. Lodge's bedsit in Delancey St, London; Brampton House, Tomkinson home.

Fig 7. 21 Waverley Road, Liverpool; 2 Grove Park.

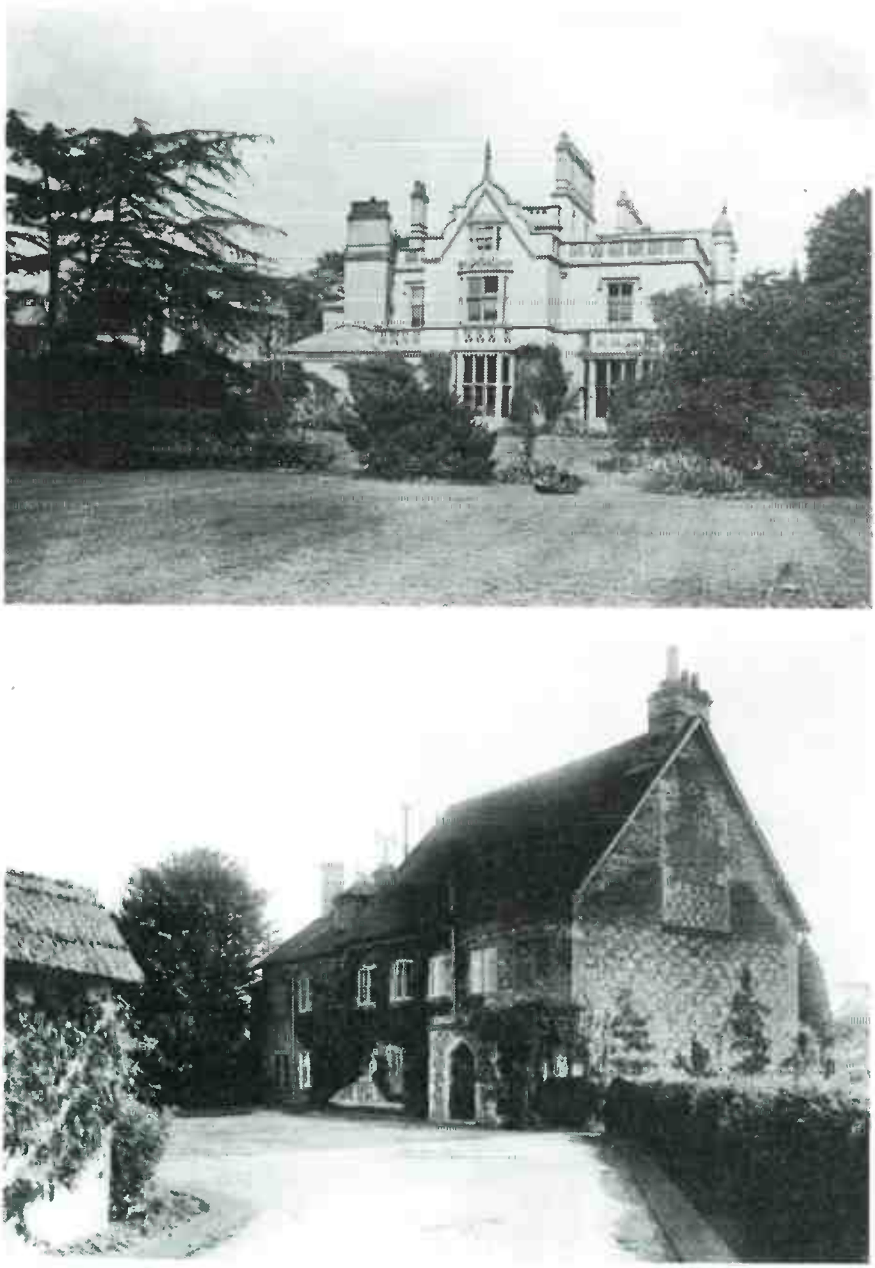


Fig 8. Mariemont, Edgbaston; Normanton House, Wilts.

Fig 9. Lodge and his family at Mariemont c 1910 (*left to right* Oliver 1878-1955, Alec 1881-1938, Honor 1891-1979, Lorna 1892-1987, Raymond 1889-1915, Barbara 1896-1983, Lionel 1883-1948, Violet 1887-1924, Lodge, Rosalynde 1896-1983, Winifred (Mrs Brodie), Mary, Norah 1894-1990, Brodie 1880-1967, Noel 1885-1962).

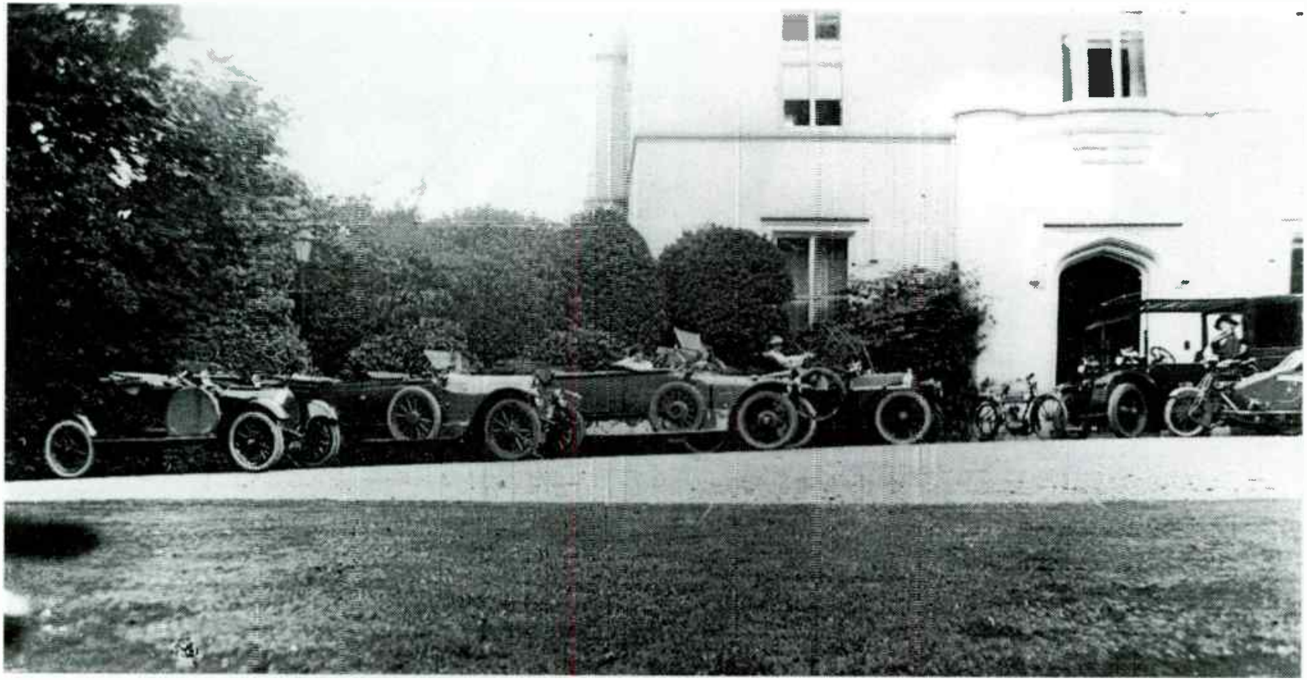


Fig 10. The Lodge family cars c 1910.

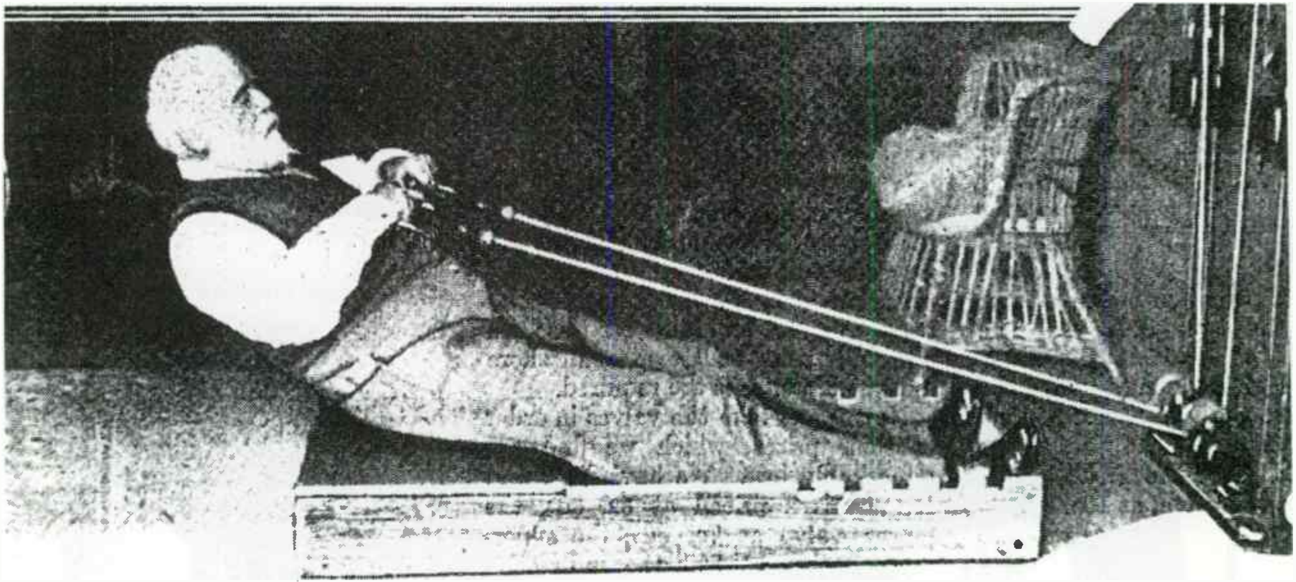


Fig 11. Lodge exercising in his gymnasium at Normanton House.

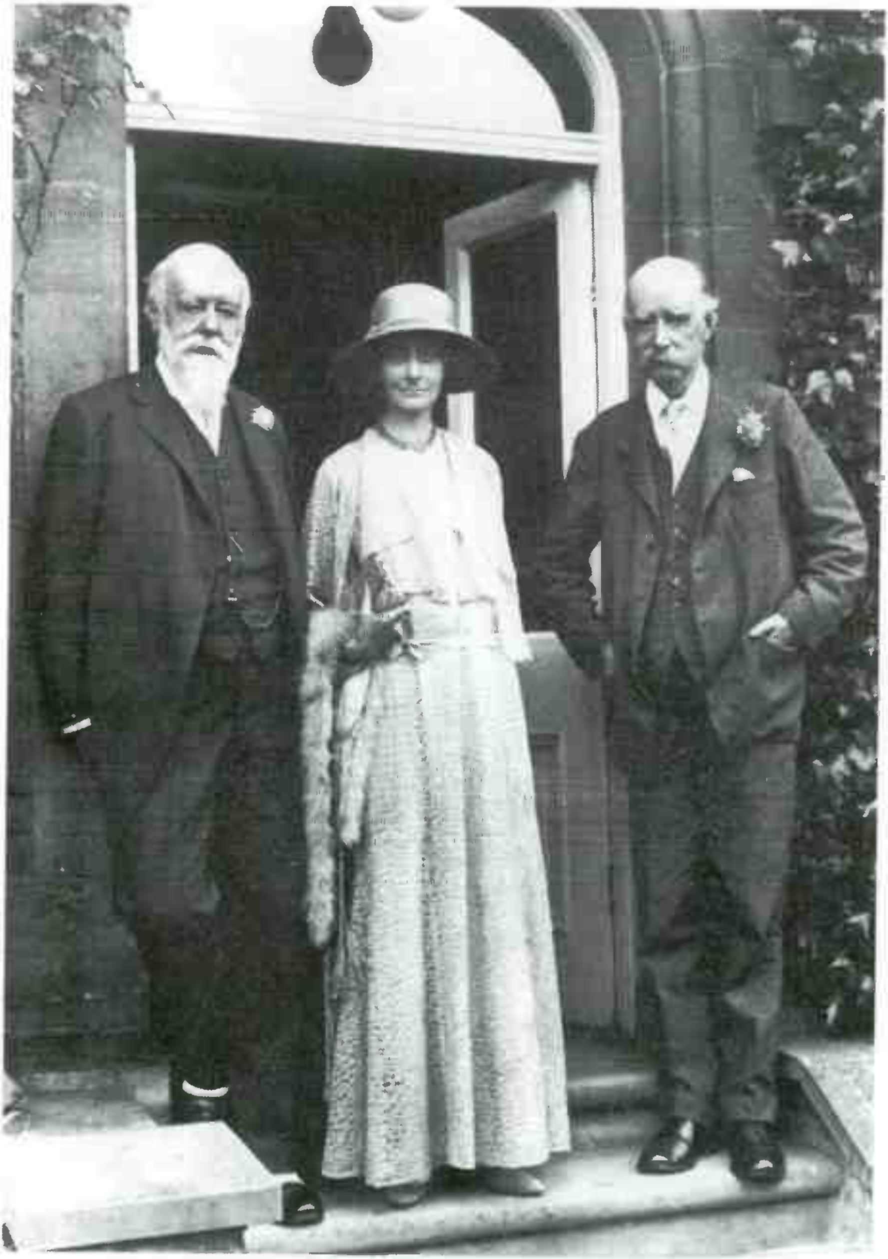


Fig 12. Sir Oliver, Dr Eleanor and Sir Richard Lodge.

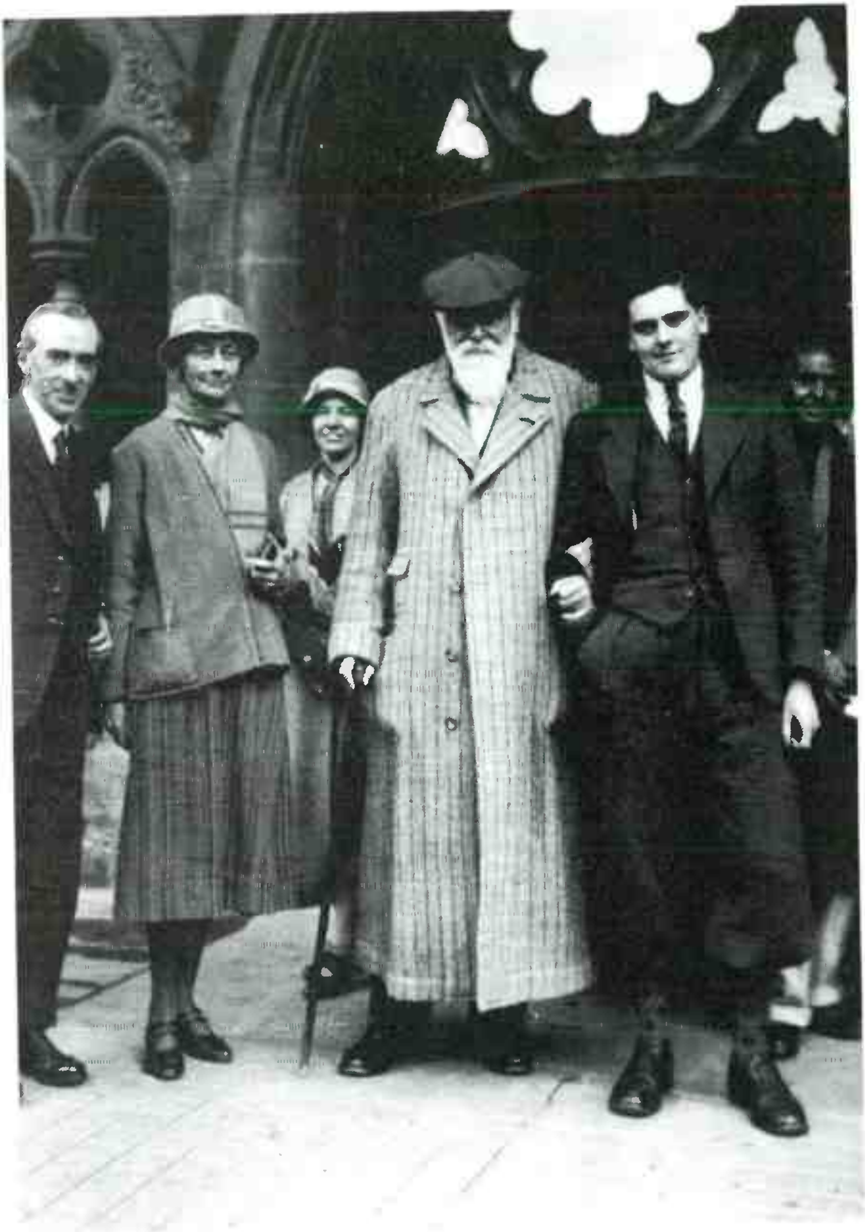


Fig 13. Sir Oliver with Eleanor and Helen Alvey at Aberystwyth in 1930.

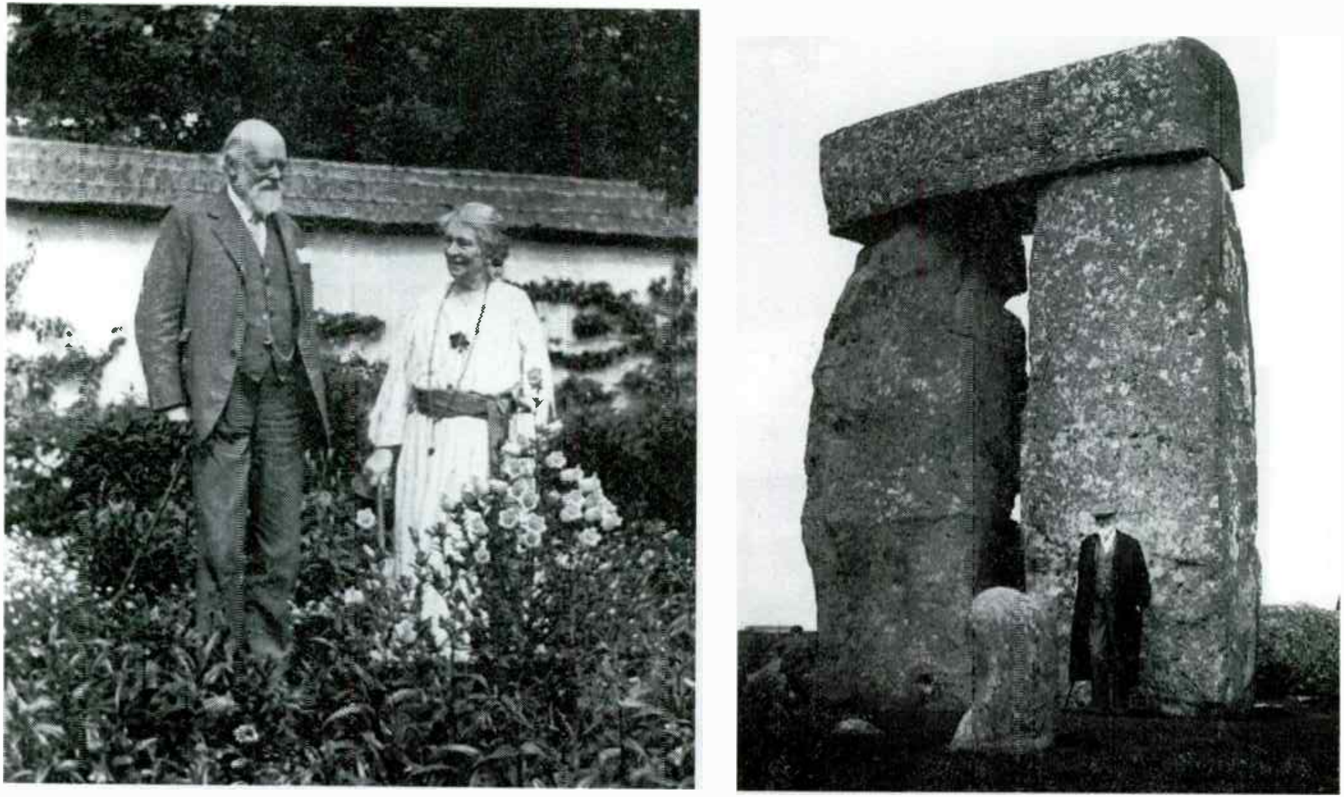


Fig 14. Oliver and Mary just before their golden wedding; Lodge at Stonehenge.

Chapter Three
A VICTORIAN POLYMATH

by David Edwards

In many ways Oliver Lodge was the archetypal Victorian; he sired a huge family and, by dint of natural abilities and hard work, rose from humble beginnings to become a "Pillar in the Land". The twelve children were a fact and 'hard work' and 'abilities' were certainly present in considerable quantities but a closer examination of the rest of this opening sentence raises issues that make him, I believe, an even more interesting person than most of his contemporary eminent Victorians. The 'humble origins' described so vividly in his autobiography were relative. His father, after a stint as a railway clerk, had set up in trade as a supplier of china clay to the Staffordshire Potteries. Undoubtedly the early years of the business would have been a struggle but by the time Oliver reached his 'teens the family fortune was well established. The family conflict which threatened Oliver's education was due to his father's natural desire that his eldest son should join, enhance, and eventually inherit the business; maybe his father suspected, rightly as it transpired, that too much learning would entice Oliver away from the firm.

Oliver would have been well aware of the educational opportunities he was missing. His father's temporary lack of funds was in part due to his being the 'drop out' in the previous generation. Oliver's father had been 23rd of a brood of 25 many of whom had reached high positions in the Church, education and commerce.

In his autobiography, the octogenarian Oliver recalled his formal education with simmering horror.[1] The vacuous learning by rote, the teachers beating Latin grammar into reluctant schoolboys by liberal and arbitrary use of the cane, the older boys' traditional dormitory bullying – even a hint of worse – left Oliver with a lifetime's interest in progressive education and a determination to save his own offspring from the Dickensian regime his kind and caring parents had provided. His mature views on the role of tests and examinations in education would be regarded as *avant-garde* even today.[2]

Oliver was always grateful for the timely intervention of his maternal Aunt Anne, one-time Woman of the Bedchamber to the Dowager Queen Adelaide, who rescued him from the drudgery of the firm and took him to London where he attended lectures on chemistry, geology and physics which awakened his natural curiosity in general science. His specialisation in physics was triggered by these teenage attendances at Tyndall's lectures at the Royal Institution and richly confirmed by his first meeting with Clerk Maxwell at the 1873 British Association Meeting in Bradford. Oliver must have been particularly pleased that the talk immediately before Maxwell's lecture on 'Lightning' at the 1876 BA meeting in Glasgow was one on a working mechanical model illustrating the famous Maxwell Equations by a "Mr. Oliver Lodge". The annual meeting of the British Association for the Advancement of Science was for Lodge, as for most of the scientists of his generation, the most important event of the year. Old friends, old enemies and old controversies were dusted off each summer, fiercely debated and provided the stimulus for research over the next twelve months. When, through illness, Lodge had to miss the BA meeting in 1935 he wrote apologetically that he had attended well over 50 of the annual jamborees; he gave a vote of thanks at what was to be his last meeting in 1936. He was particularly pleased to have been able to attend the centenary meeting of 1931 held, exceptionally, in London.

His Aunt Anne also introduced him to astronomy which became a life-long interest;[3] his teenage notebooks describing the construction and use of a telescope have survived.[4] Later, when the professor at Liverpool, Lodge gave a popular course on the Lives of Great Astronomers and acquired for the department a large $6\frac{1}{2}$ inch Cooke refracting telescope, although there is no evidence that he ever used it professionally. He became a Fellow of the Royal Astronomical Society in the mid 1880s and would have mixed with several astronomers within the Liverpool Physical Society, like W. E. Plummer and George Higgs. The teenage experimenter acknowledged the *English Mechanic* as the source of many of his projects[5] but that magazine would have provided little help in Oliver's accidental discovery of self-inductance.[6] "At Hanley [he wrote] I . . . became acquainted with self-inductance, and devised a method of measuring it, though we had no units in those days in which to express it. I observed that, when measuring the resistance of wire on an electromagnet, by means of a Wheatstone bridge, a balance could not be got unless the galvonometer circuit was closed after the battery circuit. If it was closed before, there was a kick each time the current was put on and each time it was put off." The hours spent investigating and eventually mastering self-inductance were to bear fruit in his acrimonious clashes with the Engineer-in-Chief of the General Post Office, William Preece.

Oliver's formal education was unusual in that he was in his twenties before he started his BSc studies at University College, London. Many of his undergraduate lecture notes have survived.[7] He was only able to finance his studies by Carey Foster offering him £ 50 per year to mark exercises and assist in his laboratory. By 1876 Oliver was also giving lectures at Bedford College, then an institution for young ladies only: he said that he knew he had given an interesting lecture when the chaperones stopped knitting!

Lodge's appointment in 1881 to become the first holder of the Lyon Jones Chair of Physics and Mathematics has been linked to the change of regulations requiring physics in the London External degrees taken by students in the long established Liverpool Medical School[8] but recent work has indicated that the need for physics tuition was simply the excuse to found a physics school in the University College, Liverpool.[9] He initially applied for the chair in Owens College, Manchester. Other contenders were J. J. Thomson and Arthur Schuster, the latter of whom got the job – not only was he prepared to work without salary, but he would also finance a Reader and a technician from his own pocket! As Oliver had carefully prepared his CV, he submitted it to the less desirable Liverpool College and, as there was no competition, he was appointed at £ 400 p.a. plus two-thirds of the students fees. Nobody had envisaged how much this dangerous contract would spur Lodge into initiating courses and his income quickly rose to an embarrassing £ 1200, much more than the Principal's. So his contract was re-negotiated to be £ 600 p.a. plus one-third of the fees – he soon overtook the Principal again.

As well as lecturing to the medical students and building up his physics Honours school, Lodge cornered the market in 'electrotechnics' – what we would now call electrical engineering. There were also several series of lectures open to the general public at sixpence a time: he also started in 1892 four Christmas lectures on 'Electricity' for school children at five times that price. In 1897 his Christmas lectures were on 'Wireless'. By the mid-nineties Lodge's typical academic work load was 10 lectures and five laboratory supervisions per week; this, with the administration of the department and normal College committees, make it difficult to see how he achieved so much personal research. He was a workaholic but somehow fitted in an active participation in evening societies like the Fabians, the Liverpool Lit. & Phil., the Medical & Surgical Society, the Liverpool Physical Society and even a local apiary society! When asked by the editor of *Modern Wireless* to contribute an article on 'At Work and Play' on the occasion of his 79th birthday, Lodge recalled that he always found it easier to Work than Play. In his younger days he relaxed by playing tennis, dancing or cards. His active sports of badminton and golf were extended in his retirement by a specially equipped gymnasium in a barn near Normanton House. Photographs in the article of a punch-ball and a rowing machine show that he took his fitness seriously.

Lodge's involvement with politics was typical of his awareness of the imperfections of even the enlightened society of the Empress of India. He had been deeply impressed by his hero Tyndall's defence of biological evolution at the Belfast BA meeting of 1874 and Lodge often used the language of evolutionary change in his scientific writings. It was natural, therefore, for him to find kindred spirits in that precursor of the Labour Party, the Fabian Society. He was a proponent of Proportional Representation throughout his life.[10] His most influential political work was a tract 'Competition v Co-operation' for the Liverpool Fabian Society[11] setting out his views on relative remuneration, taxation and inheritance which drew an appreciative letter from Keir Hardie[12] and established friendships with the Webbs and George Bernard Shaw. The latter was a frequent speaker to the Liverpool Fabians and stayed with the Lodges but was distracted by the dozen children galloping around the house. "We will talk," he said, "when the party is over and the children have gone home." "They are home," came the reply.

Oliver was aware of the appalling living conditions in the slums of

Liverpool and encouraged the College to set up two settlements for a scientific study of the causes and possible amelioration of the poverty. He argued that these settlements "are to the School of Economics what the laboratory is to the scientist or a hospital to the Medical School". He wrote several letters to the press on the topics of pollution and slum-clearance.

Whilst still a student Lodge was offered a prize by the Telegraphic Engineers and chose a leather-bound edition of the works of John Ruskin whom he later got to know well. By 1885, his friend Ruskin was suffering acute mental ill-health and Lodge organised an anonymous collection of both financial and spiritual aid from like-minded people. The appeal and the covering letter are reproduced and show his tactful regard for colleagues.

With his carefully balanced family of six boys and six girls, it is no surprise that Lodge was an early advocate of equality for women. He spoke to the Midland Women's Suffrage Society in 1901 (his friendship with the Webbs would have led him along such a path). After Christabel Pankhurst's meeting was broken up by an angry mob Lodge offered the sanctuary of Birmingham University to the speaker; indeed he chaired the meeting in December 1907. A generation later we find him writing letters to support the foundation of the League of Nations and he wrote several articles for the League of Nations Union. He spoke and wrote German well and offered his home to scientists fleeing the Nazis; he also used his influence to get the often penniless refugees positions in British universities.

When Lodge described the telephone as "the fundamental invention of the latter half of the nineteenth century",[13] he was blissfully unaware of the havoc Graham Bell was causing to future historical scholarship. The postal service at the height of the Victoria period enabled, in major cities at least, a budding Romeo to bombard his Juliet with four or five sequential letters and get replies the same day. Lodge and his friend G.B.S. were maybe the last historical figures whose surviving correspondence is measured in thousands; a study of Oliver's 965 letters to his technician Ben Davies over a period of 50 years would provide a fascinating insight into his working methods and their evolution.[14] Lodge took a keen interest in the subsequent careers of his assistants and students and we can sometimes trace correspondence over a period of forty years or more.

Lodge wrote profusely not only to every important scientist of his age but also to such lesser known scientists as Sir Edward Elgar and Elizabeth Bowes Lyon (the present Queen Mother). As well as the letters to individuals we have the letters to newspapers and periodicals. Besterman's 1935 compilation, approved by Lodge, listed some 1154 books, papers and letters to newspapers; after his retirement, the setugenarian Lodge averaged one publication a week on a great variety of subjects from a calculation of the mass of a black hole to the standardisation of Summer Time, from London traffic to the origin of the solar system. The range, number and quality of his writings justifies the status of polymath.

Lodge did not consider himself amongst the very top flight of physicists, deferring to the more mathematical Kelvin, Thomson and FitzGerald, but he was acutely conscious of his own superiority as a 'communicator'. From his first lectures at Bedford College he commented on the audience reaction and regarded all his time and effort in preparing both the text and the demonstrations as being justified by their reception. Throughout his life he was in constant demand for public lectures and his second Liverpool lecture on the new X-rays of 3 February 1896, when the doors had to be closed with over a thousand (paying) customers inside the Arts Theatre,[15] he could still recall with great pleasure a generation later.[16] A year before, on 25 February 1895, he had drawn an audience of 700 people prepared to part with sixpence to hear about Rayleigh's discovery of argon.

Lodge's principal forum for communicating both his own ideas and for the presentation of important discoveries of others was the annual meeting of the British Association for the Advancement of Science. From its foundation in 1831, the BA was the powerhouse for the display of the works of professional scientists and their dissemination to a wider audience. This audience consisted of the rapidly expanding articulate middle class of Victorian society and, more importantly, the fellow scientists in different fields; the lay audience were all experts in something else, even if it was palaeontology or embroidery. The annual meeting moved around the principal provincial towns generally on a North-South basis with occasional sorties to the old Dominions and the 1896 meeting was held in Liverpool so Lodge was able to exert an even more dominant presence than usual.[17]

With the coming of BBC radio in the mid-twenties Lodge found a way to reach a wider, more general audience and he was a frequent broadcaster speaking on a wide variety of topics. It is typical that the advent of 'talkies' found the eighty-three year old enthusiastically embracing its potential in one of the series of films of eminent scientists made by the IEE. The circumstances in which the ailing Lodge was cajoled into what must have been something of an ordeal are described by V. J. Phillips in the April 1992 *Engineering Science and Education Journal*.

Lodge wrote some forty books roughly equally divided between science and spiritualism and many of them were translated into several languages. He was particularly honoured that his *Modern Views of Electricity* was translated into German by the wife of von Helmholtz, as Lodge had travelled to Berlin in 1881 to discuss the design of his proposed new laboratory in Liverpool. Apart from his early text-book on *Elementary Mechanics* of 1879 his scientific books were aimed at the enlightened general reader and, after his retirement from Birmingham in 1919, he worked intermittently on what he hoped would be the culmination of his work in education, the book *Physics for Everyman*. In 1924 he accepted a commission from Dents to write a non-mathematical compendium explaining the whole of natural phenomena in layman's language.[18] The manuscript was essentially finished by 1929 and a complete set of line drawing commissioned from Gwen, the artist daughter of his technician Ben Davies, but after adverse comments from some of his trusted ex-students, Lodge decided to abandon the project in 1935. This is particularly sad as the manuscript has many innovative ideas and the field was later shown by Lancelot Hogben with his *Mathematics for the Million* (1936) to be ripe for such a text.

Lodge took a life long interest in education, seeing its spread as an instrument for social change. After his first visit to Germany he strongly advocated both 'technical highschools' and the shorter doctorate, the Ph.D. He was frequently consulted by professional bodies to advise on training programmes. It is perhaps significant that for a representation of 'education' on the plinth of the Victoria Monument in Liverpool the sculptor should have chosen Lodge demonstrating a gyroscope to two young students.

The foundation and evolution of the Liverpool Physical Society provides a good example of Lodge's ideas of involving the (rich) layman in the spread of scientific ideas to provide financial support for further experiments.[19] The inaugural members of 6 November 1889 can be grouped by occupation. We find:

12 college staff	13 teachers	8 engineers
8 BSc unspecified	6 cashiers	2 watchmakers
8 analytical chemists	4 medics	8 managers
3 patent agents	3 lawyers	15 gentlemen

Students in general were actively discouraged from joining the Society by the annual subscription of 7/6 – equivalent to about forty pounds today. Some of the subscription money went to providing visiting speakers expenses; we know that FitzGerald reluctantly accepted £ 3 3s and Rutherford, less reluctantly £ 5; Poynting negotiated a fee of £ 10 **plus** expenses which even Professor Wilberforce, Lodge's successor at Liverpool, thought a bit excessive.

What did the founder-members expect to get out of their society? About half were professionally connected to some aspect of physics either in a teaching role or in the rapidly expanding service industries of electrical generation, telephones or transport. The other half were amateurs who probably subscribed to some of the soft-science weeklies and monthlies which started up in profusion in the late Victorian era. These were non-mind-taxing versions of *Scientific American* with articles on astronomy, anthropology, ornithology and, very occasionally, real physics. The best example of these journals was *Knowledge*, whose astronomy correspondent was a leading Liverpool amateur astronomer, Isaac Roberts, and whose physics correspondent from 1904 was Arthur Porter, one of Lodge's students.

Oliver Lodge gave the inaugural Presidential Address on 16 December 1889. It gave an overview of the then state of science in general and of physics in particular; it was printed in the first volume of *Proceedings of the Liverpool Physical Society.* Thereafter, the Society rapidly degenerated into anarchy. People who promised talks did not deliver; even worse, sometimes when they did talk – on banalities – it would have been better if they hadn't; so Lodge and his assistants, James

Howard and Ben Davies, soon found themselves running the show. At the end of the first year, Lodge ousted the secretary and installed Howard, also establishing him in the post of honorary demonstrator.

The Society was then moulded by Lodge into a genuine research orientated group; I will mention a few of the ideas which first saw the light of evening at society meetings – often reappearing in modified form in later scientific literature.

(a) George Higgs was a watchmaker by trade who had a jewellers shop in Tuebrook, Liverpool. He was also a gifted astronomer, becoming the President of the Liverpool Astronomical Society in 1909. He made his own telescopes and fitted a spectrograph to photograph the Sun's rays at mid-day and late in the evening when the light had traversed the greater thickness of our atmosphere. He was thus able to distinguish between absorption lines from the Sun's atmosphere and the Earth's. Then he measured the Doppler shift of the Sun's lines from the edges of the disc and deduced the rotation speed of the Sun.[20]

(b) G. F. FitzGerald was a personal friend of Lodge who arranged for him to become an early external examiner for the College. FitzGerald first proposed the contraction to explain the null Michelson-Morley experiment (1887) on a visit to Lodge in 1889, not, as text-books intimate, as an *ad hoc* proposition but by derivation from the Heaviside theory of matter and Maxwell's equations. Later, FitzGerald gave a lecture on 'Flight' but, alas, he died before the Wright brothers made it a reality.

(c) Lodge's contribution to the ether controversy then prevalent was to perform the Ether Drag Experiment, arguing that the null result of Michelson-Morley might have been due to the ether sticking to the Earth as it travelled around the Sun like a viscous layer. We can follow the evolution of what Lodge regarded as his most important scientific work by reference to the minutes over several years, from vague concept, through construction, to data, and, eventually, publication. Lodge used two rapidly rotating steel discs to simulate the Earth's motion and studied the speed of light travelling in various directions with respect to that motion. He did not discover ether drag but seems to have discovered sponsorship; the whole experiment was paid for by Mr George Holt, a local shipping magnate who gave at least a thousand pounds (seven years salary for a lecturer) to finance the work. This series of experiments was to become an important ingredient in Einstein's Special Theory of Relativity.

(d) The Zeeman Effect was published late in 1896 and within a couple of months was demonstrated to the Society by Ben Davies. Because Zeeman's apparatus had poor resolution he was only able to see the broadening of the spectral lines; but, in May 1897, having acquired the $4\frac{1}{2}$ inch Rowland grating used by Higgs in his solar spectroscopy, Lodge and Davies were able to demonstrate the actual splitting.

(e) Ferdinand Hurter was a chemist whose paper in the first volume of the Society Reports shows his interest in the fundamental processes by which light can activate film. He and a colleague, Driffield, produced the first measure of film speed and the 'H and D' was for many years the accepted method of designating film speed, eventually evolving into the DIN and ASA of today.

(f) In early 1896 Lodge was quick to exploit the newly discovered X-rays, tapping the jam-to-jelly magnate W. P. Hartley for the necessary funds. The speed with which he assimilated the ideas and produced radiographs is quite remarkable and we can follow the progress via the Society minutes:

16th Jan 1896:–	Translation of Röntgen paper in *Nature*.
27th Jan 1896:–	"... the new Photographic Discovery ... photographs taken by Prof Röntgen and by Prof Lodge and Mr Robinson were exhibited ... ."
3rd Feb 1896:–	"The attendance numbered nearly 1000 persons and large numbers were again unable to gain admission."
24th Feb 1896:–	"Mr E. E. Robinson exhibited photographs taken by means of Röntgen rays (Radiographs) by Prof Lodge and himself. They represented the wrist of a boy with a bullet lodged between the middle metacarpal and the corresponding carpal bones, and of a woman's hand with a broken needle in it ... ."

The article with the X-ray photograph of the bullet-in-the-hand appeared in *Lancet* only two months after Röntgen's discovery.[21]

Under Lodge's regime the Society was run as a learned body, publishing a learned journal with original research; unfortunately, this is what led to its demise. Liverpool was not big enough to sustain such a Society and the amateurs resigned *en masse*. One letter of resignation bemoans: "what little I understood, I was not interested in".

When Lodge wrote that "in the nineties of the last century my scientific work seemed to reach a sort of climax",[22] he was no doubt recalling his contributions to wireless, the ether drag experiment and X-rays, but his ability to mount these experiments so quickly was in part due to his having, for the time, highly skilled assistants and technical staff; the experiments were 'big physics' for their day. Some of his other experiments which, with hindsight, we might regard as of lesser rank, are also of considerable interest.

Lodge's first scientific publications from Liverpool were in the field of electrical storage batteries. He was by 1882 a consultant to the Electric Power Storage Company and two other firms: Fawcett & Preston, which is still going on Merseyside, and Sellon & Volckman of London. He made many improvements to the design and the production materials used in the burgeoning storage cell industry. For a few months in 1894 the world's first battery powered electric omnibus plied a route which almost passed Lodge's house[23]: we have not yet been able to obtain details.

As the only physicist in the brand-new provincial university college, Lodge had some difficulty in establishing a line of research. All his training was in the fields of magnetism and electricity so it was perhaps not surprising that the first experiments to gain him some international recognition were in those fields. Firstly, in 1884, he studied the decomposition of a dust-ladened atmosphere by an electric field (later to lead to profitable commercial exploitation) and secondly, in 1886, he devised a means of measuring the velocities of ions when a current was passed through an electrolyte showing that the mobility depended on the mass, or size, of the ion. This was to provide a useful tool when atomic structure began to be unravelled after the Rutherford atom had been accepted.

It had been known for some time that above a heated body there was a dust-free zone. Lodge showed that a similar effect could be obtained with an electric field. This developed into the Lodge-Cottrell Company which he set up for his son Lionel with an American called Cottrell. The company had large scale dust recovery plants in smelting works. Lodge tried to interest the Port of Liverpool to invest £ 10 000 to provide a pilot scheme to rid the River Mersey of fog by establishing giant electrodes on the promenade at Wallasey and at Bootle but was unsuccessful. The electric field was to be provided by a Wimshurst machine; Wimshurst was about this time the secretary of the Liverpool Marine Underwriters Association and might have been involved.

Both the work on dust and his understanding of the chemical and physical processes involved in storage batteries were reported at the 1884 BA meeting in Montreal. This was Lodge's first opportunity to address a truly international audience, as many famous American scientists including Willard Gibbs attended, and both his contributions were well received. Indeed, his obvious grasp of the complex issues involved probably led to his being offered the chairmanship of the BA committee on electrolysis for the Aberdeen meeting the following year. To be chairing such luminaries as FitzGerald, Crookes, Lord Rayleigh and Sir William Thomson was a sure sign that the Liverpool professor was accepted by the Establishment – his FRS duly came two years later.

Lodge's work on the Lightning Rod Commission of 1884 would be worth study. His understanding of inductance led to a particularly acrimonious dispute with Sir William Preece and others about the nature of lightning and the design of lightning conductors. This work undoubtedly led to the foundation of the Lodge Sparking Plug Company described in chapter 11.

The finance for Lodge's chair at Liverpool came from a bequest by Lyon Jones, a local shipping insurance broker, who left £ 10 000 to the Royal Infirmary. Lodge gave the opening address at the newly named Royal Infirmary School of Medicine on 3rd October, 1881. He outlined the ways in which he saw medical science benefiting from the new discoveries in the traditional sciences. One of his first publications in his new post with his assistant, J. W. Clark, was on the design of medical equipment like incubators and a device for providing a constant supply of distilled water. With the tragic suicide of Clark, this line of research seems to have stopped.

The early workers using X-rays quickly became aware of the damage caused by over exposure. The "final" plate in locating the bullet in the boy's wrist was of two hour duration – not, it must be stated, due to the inefficiency of the source but due rather to the incredibly low speeds of the film. (In the early days, the "father of British radiology", Thurstan Holland, made contact prints by exposing on the roof of a building for "a day in summer and a week in winter".) To overcome these limitations Lodge and his assistant Ben Davies spent some months improving the technique.[24] Firstly, the very long exposure times were quickly reduced from hours to minutes; in the *Lancet* of May 16th 1896 we read: "We have received from Messrs B. J. Edwards (Lodge's original plate manufacturer) ... new cathodal plates ... in accordance with suggestions made by Professor Lodge. The sensitized film contains a fluorescent substance which greatly reduces the exposure." In an archive letter to an unknown person Lodge describes the method of incorporating the chemical into the emulsion and the compromise between shortening the exposure time and the inevitable loss of definition due to the fluorencent radiation.

Their second line of attack was to improve what would now be called the 'electron' optics of the tube although the discovery of the electron was still in the future. Two of the Lodge and Davies 1896 tubes with focusing cathodes and aluminium anodes were presented to the Röntgen Society and are in the Victoria & Albert Museum, London. But much damage had been done; indeed one of Lodge's technicians, Charles Wood, would earn the doubtful distinction of having his name in the Martyrs' Memorial in Hamburg. Several hundred of the early workers in X-rays perished and one of the first jobs the new Principal of Birmingham University did in 1902 was to launch a Public Appeal for money for maimed radiographers and their dependants. Lodge played an active part in establishing the Röntgen Society, eventually becoming the President, but, more importantly giving a series of six lectures on the basic physics of the new rays. These lectures were published in the *Journal* in 1904.

Lodge believed that the general public had a right to know about scientific discoveries and that it was the duty of the professional scientist to provide that information in a language understandable by the educated layman. A good example of his approach is his popularisation of X-rays; it appeared in two versions, one destined for a learned journal and one published in the *Liverpool Daily Post* of 24 March, 1896 – not that Lodge was talking down here to the general public, but the newspaper article has more background and a little less technology. I list some of the ideas floated in this conjoint:

(a) He described listening to and smelling the X-ray tubes discharge, then tuning them by playing a Bunsen burner on the glass. He incorporated a side tube with suitable crystals to alter the vacuum by absorption of the residual gas.
(b) He recognised the need to train viewers of X-rays, so he started a course for both radiologists and radiographers
(c) He compared the available plates and developers.
(d) He presented a design for a screening box.
(e) He compared different modes of excitation, such as the induction coil and the Wimshurst machine.
(f) He posed the sensible question: do the new rays kill germs?
(g) He conjectured whether the Sun emitted X-rays; Alpine tourists reported the fogging of photographic plates. He planned a specific experiment. (Cosmic rays were discovered a generation later.)
(h) He speculated that the rays are "maybe" light with wavelength comparable to the size of molecules. "Such molecules would be made diffactionally visible." (X-ray diffraction was discovered in 1912.)
(i) He recalled a certain Reverend Frederick Smith of Oxford, who years before, had warned that photographic plates had to be kept well clear of Crookes' tubes or they would get fogged.
(j) He stated that "last month J. J. Thomson showed that X-rays make insulators conduct". The electron was about to be discovered.

The use of the newly discovered X-rays were not confined to humans. In 1898 a Liverpool carter whose horse had apparently swallowed its tracheotomy tube presented a challenge to the rapidly expanding collaboration between the Royal Infirmary and the Physics Department, literally so, for the photograph taken on the lawn between the two buildings shows Prospero Marsden, the pharmacologist from the hospital, supervising Lodge's technicians, the carter and the heavily sedated horse. The varied head-gear reflected the social standing of the participants. A second photograph was described as showing the "setting off an explosion by X-rays", but it was, in fact, a controlled explosion at Beaumaris during the Territorial Army camp of 1907 when Lodge's friend, Dr Robert Jackson borrowed the induction coil used in the X-raying of the horse to trigger the detonation using the wireless waves from the spark discharge. The War Office showed no interest in radio controlled explosions until the outbreak of war in 1914. (I am indebted to Dr John Ross for these photographs.)

In his 1889 Presidential Address to the Liverpool Physical Society Lodge considered the effects of electricity, magnetism and Hertz (or radio) waves on germs, plants and animals (including humans). Whilst doing an experiment involving a magnet on 4 October 1883 we read in his notebook that a fly alighted on the pole piece. He immediately asked: does it experience the magnetic field? And, covering them both with a tumbler, proceeded to look for any sign by switching the field on and off. He concluded, however, that the magnetic field had no effect.

A Norwegian, Professor S. Lemström had claimed that: "In the Arctic the vegetation is taller than you might expect due to the incidence of electrical storms."[25] He hung wires over plant-pots and made claims that wheat, oats and raspberries benefited from positive voltage, whereas legumes, peas and beans needed negative voltage. Repeating Lemström's work in 1890, Lodge also looked for the photoelectric effect from green plants. This work eventually led to the Lodge-Newman company. (See chapter 11.)

George Newman was a farmer in Worcestershire who somehow became involved in Lodge's horticultural experiments. The cost of installation of overhead wires to carry the electric fields was £ 10 per acre and the company sold systems in the "U.K., Europe, Egypt and the U.S.A." It was even stated in 1905 that "electrical stimulation was going to solve the starvation problem". All the trade photographs show that a Lodge Diode Valve was an essential component of each system. This cost £ 4 and was made under licence by Cossar and was in their catalogue as late as 1913.

Oliver Lodge's involvement in wireless arose naturally from his teaching and research work, following his appointment in 1881 as the first professor in the new University College, Liverpool. A perusal of his publications prior to 1894 would have categorised him as an electricity and magnetism man – indeed his DSc degree of 1877 was by examination in electricity. By 1894, when he made his famous demonstrations of radio, the middle-aged professor was already one of the best known scientists in the country. He had become a Fellow of the Royal Society in 1887 and became President of the Physical Society in

1899; the award of Rumford Medal in 1898, partly for work on radiowaves occasioned a civic banquet in Liverpool Town Hall.

The good citizens of Liverpool held Oliver Lodge in such esteem that, after he left in 1900, the occasion of his birthday was regularly celebrated by a short article in the *Liverpool Daily Post*. By 1938 the number of readers who had personally known Lodge must have been quite small but the anecdote told that year can be found in no other source.[26] In the 1860s, some 20 years before coming to Liverpool as Professor, "He landed here from the Isle of Man on a Sunday, out of pocket-money, and had to wait a long time before he could get any. ... Hungry and lonely, he wandered around the streets, and as he once confessed, 'just hated the smug people who were having their dinners, though there was no reason why I should.'"

Lodge's contribution to the invention and development of wireless is covered in other chapters of this book: it is not our intention to cast doubt about Marconi's claims but to present the evidence that Lodge's contribution was at least as important. The British Broadcasting Corporation at any rate marked the centenary of Lodge's birth by a 45 minute retrospective programme on 11th June, 1951. The covering note in the *Radio Times*, probably written by James Sayers of Birmingham, had no doubt about Lodge's importance. "In so far as Lodge was a pioneer in the discovery of wireless waves and the inventor of selective tuning, it is particularly fitting that his centenary should be celebrated by the BBC." It is sad that the selection committee for the Nobel Prize of 1909 did not share that view.

Sir Oliver Lodge was a member of the influential Central Council for Broadcast Adult Education which advised the Director General, Lord Reith, about that part of the BBC's charter other than entertainment. Lodge gave many talks during the late 'twenties on general science, spiritualism and what today would be called current affairs. Sir Edward Appleton called him "a prince among broadcasters".

Oliver Lodge's reputation has been sullied in the eyes of many of the scientific community by his advocacy of spiritualism. Many eminent nineteenth century scientists were interested in, and indeed, researched into the paranormal – Sir William Crookes, Lord Rayleigh and J. J. Thomson, to name a few. Amongst the non-scientists who were members of the Society for Psychical Research were Alfred Tennyson, William

James, Arthur Balfour, John Ruskin, Lewis Carroll and George Frederick Watts. Lodge had the misfortune to live on into a more rational era which ridiculed or, at best, ignored such work, so he got the reputation of being something of a crank. Nobody called J. J. Thomson a crank for once holding similar views!

A recent study[27] has traced Lodge's work in the paranormal and argued that it arose out of his belief that all subjects would benefit from scientific analysis – the present state of physics might not provide a satisfactory answer but the attempt to rationalise human experience was the true province of the natural philosopher. Lodge was acutely aware of the possibility of being duped but felt that paranormal experience was so widespread in late Victorian times that it might provide a new route to investigate the physical world. His writings on both thought transference and spiritualism are often couched in the language of the new physics – the ether, fourth dimension, field of force, signal strength, transmitter and receiver.

Lodge took the opportunity of his giving the Presidential Address to the British Association meeting in Cardiff in 1891 to advocate a scientific approach to psychic matters in a lecture which also covered the suggestion of a National Physics Laboratory, the term 'fourth dimension' and an early account of his ether drag experiment.

In 1883 a music-hall performer, Irving Bishop, visited Liverpool with a 'mind-reading' act and was a popular success. Some shop-girls from George Henry Lees' department store repeated his experiments and two of them showed remarkable abilities; this harmless pastime reached the management and one of the partners, Malcolm Guthrie, reported their results to both the Society for Psychical Research and to the Liverpool Literary and Philosophical Society.[28] At this time Lodge was not a member of the former society but he was an active participant in the latter. When Guthrie planned a new series of experiments he approached two of the University professors to act as advisers; these were Lodge, the physicist and William Herdman, the biologist. The young shop-girls were paid to go to the University on their Wednesday afternoon off for the tests. Lodge's notes on the sessions show a healthy scepticism. When one girl was trying to guess a picture of a teapot she remarked: "Like a silver duck ... head at one end tail at the other"; Lodge could not resist the tart footnote "this is not uncommon in ducks".

Lodge quickly realised that when the target was a complicated object it was almost impossible to quantify a partial 'success'. His ingenious solution to this problem was to have a small number of simple and specific shapes, which removed any ambiguity about the success of the outcome. So he devised a set of cards with a circle, a triangle and a square which were presented to the 'transmitter' in a random order. The 'receiver', in an adjacent room, had to guess the picture, but, of course, they might have guessed this by chance; putting the tests on a scientific basis required proper statistical analysis. This work was first published in *Nature* on 12 June 1884 and continued for some years – sometimes involving Oliver's mathematical brother Alfred. Professor Rhine of Duke University achieved fame some 50 years later by repeating this work and such cards are now named after him. Lodge read a paper on 'Thought Transference' to the Society for Psychical Research on 30 June 1884. He was still writing on the subject – to *The Times* on 18 December 1924 – forty years later; and he was involved in the first mass telepathy experiment put out by the BBC in February 1927 – despite 25,000 replies from listeners, the results were inconclusive.

Lodge was convinced that certain people could guess consistently higher than by chance and considered that perhaps the transmitter and the adjudicator were subconsciously providing clues using what we would call 'body language'. So he designed his later experiments so that the transmitter and receiver could not see each other. His conviction that some form of thought transference was possible (but still inexplicable by known physics) also coloured his approach to spiritualism: how could we know that the 'message' had not been telepathically picked up by the medium, rather than via communication with the dead? He seems to have anticipated the 'double blind' technique by what he called 'cross-correspondence' in which the same information is extracted from two separated independent mediums at the identical time.

In 1870 when Sir William Crookes announced that he intended to investigate the celebrated medium Daniel Douglas Home, the subject of Browning's poem *The Medium*, he was bitterly attacked by his scientific peers for treating the phenomenon seriously. As a consequence of the outrage felt by Frederic Myers and Henry Sidgwick, at this intellectual bigotry, a loose association was formed in 1873 to investigate spiritualism and the paranormal. Both Myers and Sidgwick had felt obliged to resign their fellowships at Trinity College, Cambridge rather than subscribe to the Thirty Nine Articles of the Church of England. By 1882 this small group of friends had evolved into the Society for Psychical Research. It should be understood that the members did not set out to prove the phenomena but to investigate them with an open mind; indeed several of the most active members remained unbelievers throughout their lives. The Society started its *Journal* in 1884; so Malcolm Guthrie's article about the Liverpool shop girls was one of their earliest publications. It is not absolutely clear why Lodge decided to join in 1884; in his autobiography he says: "I found a series of facts which were unpalatable and mainly neglected by scientific men and felt worthy of attention." These 'facts' had come from his experimental work on thought transference and concerning these he declares specifically: "These experiments in telepathy were the only fact with which I was acquainted in that department", i.e. the work of the Society for Psychical Research.[29] It was typical of Lodge that whenever he joined any society, he quickly took high office: he was President in 1901-3 and President of Honour, with Mrs Henry Sidgwick, in 1932.[30]

Spiritualism as a social phenomenon began to take off in Britain in 1852 after a lecture tour by an American medium Mrs Hayden, and by the time Lodge joined the Society for Psychical Research, the British Association of Progressive Spiritualists was absorbing local regional societies until, by 1896, there was a branch in fifty-eight towns and the name changed to the Spiritualist National Union. The relationship between the Union and the investigating Society was often hostile as much of the work of the Society was in unmasking fraudulent mediums. They were not the only investigating group; the magazine *Scientific American* set up a committee of five researchers, including the escapologist Harry Houdini, and were successful in catching a Mrs Crandon in the act of regurgitating cheese cloth.

The American psychologist, William James (brother of the author Henry James) wrote to the Society for Psychical Research about a woman in Boston, Mrs Piper, who displayed remarkable psychic powers and after some correspondence, she was invited to England in 1889. Lodge met her off the boat in Liverpool and a couple of weeks later was invited to Cambridge to attend a séance with her. He was impressed by Mrs Piper but was aware of the possibility of being duped. He, as an eminent scientist, was in demand as a tester of the claims of several mediums. He remained convinced that there was something deserving of investigation even after he had caught a well-known medium, Eusapia Paladino, cheating. His work in psychic matters took a new direction when his youngest son, Raymond, was killed in the First World War. His precognition of the event and subsequent sittings led to the book *Raymond*, in 1916; the very common loss of a loved one in the War led to the enormous success of the work.

In his will, Lodge set up his final experiment. He deposited a package containing seven envelopes, one inside the other with subsidiary information on each enclosed envelope and a specific message in the innermost. Instructions were left that a group of eminent scientists and mediums were to be assembled and the latter should try to divine the contents of the package as successive layers were unwrapped. For reasons never properly explained, but possibly due to the Second World War, Lodge's detailed instructions were not adhered to. The first two envelopes were opened at the same session on 10 February 1947. Thereafter over a hundred séances were held before the final envelope was opened on 19 May 1954. The panel of experts and the many outside mediums who wrote to the executors claiming contact, all failed to suggest anything remotely like the final message – a short childhood piano exercise.

He was an experimentalist to the end.

CONFIDENTIAL.

THE HEALTH OF MR. RUSKIN.

To ....

Sir,

It has come to my knowledge that Mr. RUSKIN'S illness has left him in a desponding condition with regard to a great part of his life work. He has a feeling that some of it is ill done, and that much of it will be misunderstood, and its real meaning and purpose misapplied or neglected, because of the form in which it is set forth.

Such depressed feelings are very natural after a severe illness, and during a time when customary occupation is forbidden; but they are painful while they last, and it seems to me, that if some general kind of testimony that such feelings are without reason, and that the essence of his work is already recognised by many students throughout the country, who are persuaded that his teachings must more and more come to be accepted and acted upon as time goes on, it might be a great comfort and help to him in this dark time.

No doubt he would most appreciate a statement of the kind with regard to his social doctrines, which, as we know, have been, and to a less extent still are, assailed in many quarters as impracticable, visionary, and absurd. Now, without endorsing every item of his teaching in these matters, and with some difference of opinion on many debatable points, it is still possible for a large number of his students to agree in certain cardinal matters, and to attribute their own appreciation of these truths in great part to Mr. Ruskin's writings.

The most helpful form of memorial I can suggest (short of a great book—which is not a thing to be written on demand) is a plain, careful, unexaggerated summary of the main principles of Mr. Ruskin's teaching, followed by a simple expression of gratitude for their enunciation, signed by all those who honestly feel able to do so. Individual letters might seem more natural; but they suffer under the obvious disadvantage of entailing the labour of a large number of replies. The drawing up of a memorial is, I fully admit, a delicate and difficult matter; but there have been occasions when an old master, as for instance Carlyle, has been cheered and reassured by some spontaneous expression of love, sympathy, and faith, on an anniversary or other natural occasion.

The only occasion to be pleaded here is the illness; but, to many grateful disciples, full of feeling for what they owe him, and eagerly willing to express that feeling if only it could be done without burden and fatigue to the recipient, it may become a source of permanent regret if Mr. Ruskin should remain uncheered by a well-considered and united expression of intelligent appreciation and gratitude, if such an expression be in any way possible.

Whatever is done should be done quietly and at once; and it is obviously desirable to guard against this communication being in any way, through the Press or otherwise, permitted to come to the knowledge of Mr. Ruskin himself.

Fig 15. Appeal for John Ruskin, 1885.

University College Liverpool.
27. October 1885

Dear Sir,

I enclose a form of circular which is intended for friends and sympathisers only, & which should be stringently guarded from being made public property. If it happen that the proposal therein contained strikes you as valueless will you kindly suggest an amendment, or otherwise give me the benefit of your opinion. If, on the other hand, the proposal appeals to you strongly, will you set down, in brief, the parts of Mr. Ruskin's teaching, in any or every branch, which seem to you to be of greatest & most permanent value. It is necessary to adhere to principles, as distinct from doctrines, so as to avoid every appearance of a "Ruskin creed" – the production of which would be distasteful & in many ways injurious. Should you bethink yourself of any person likely to give efficient aid, would you kindly communicate with him also with a view to getting a similar statement from him also. After obtaining several such statements from prominent persons it is proposed to compare them, &, if they be found largely to agree, to embody them in a document, which might then be sent round for signature. If however they resist being thus harmonised it may be well to use them as independent documents.

When this has been accomplished I further wish to ask if you would act as a centre to bring the matter before the notice of any person whose opinion is worth having, & ask him for his signature. For this purpose, if you consent, I can supply you with a few copies of the enclosed circular, which you will use or distribute sparingly according to your judgment. The whole affair should be conducted with as little delay as possible, so I trust I may hear from you very soon. I must ask you to believe that the only prominence I myself desire in the matter is that of being willing to take all necessary trouble, & to aid in bringing the scattered opinions of others to a focus. No steps towards approaching Mr. Ruskin himself will be taken without further communication with you; & your advice at any stage of the proceedings will be very welcome.

Yours faithfully
Oliver Lodge

Fig 16. Lodge's covering letter for the Ruskin appeal.

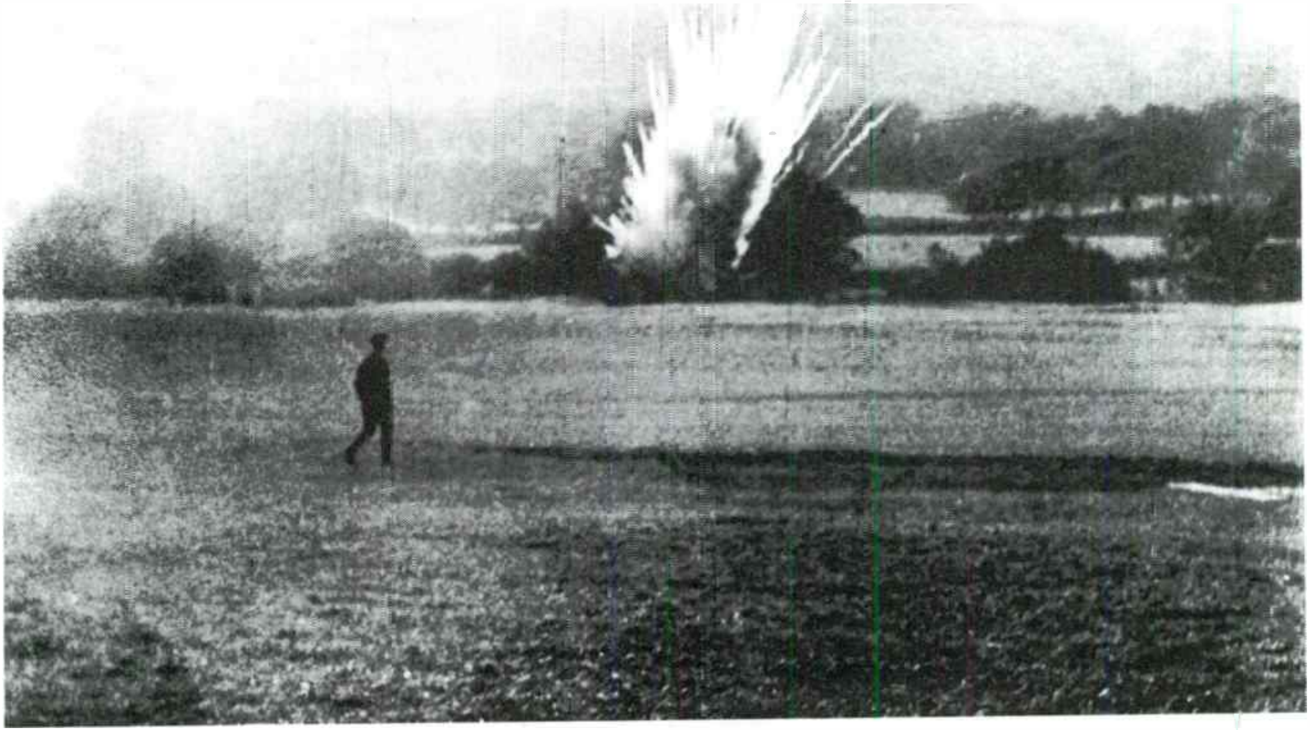


Fig 17. Explosion detonated by radio at Beaumaris in 1907.

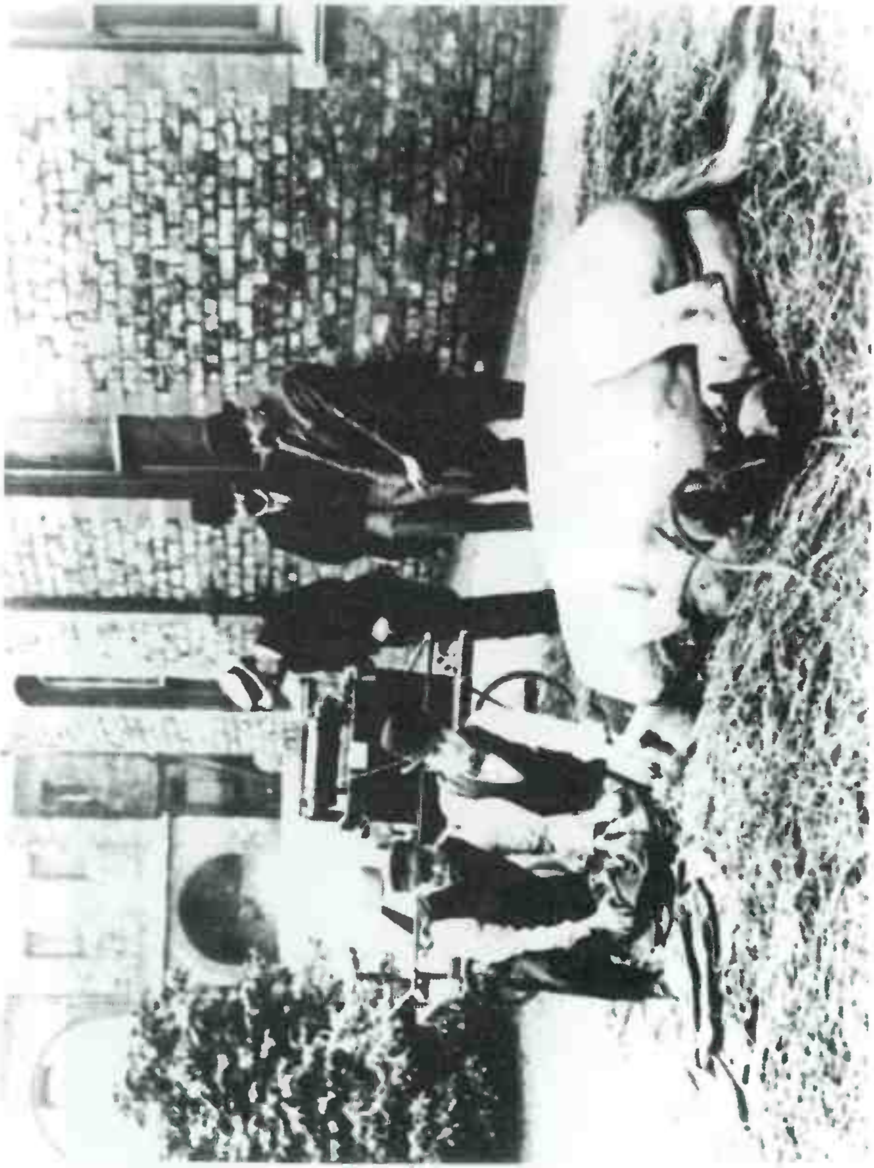


Fig 18. Alfresco X-ray of horse, 1898.

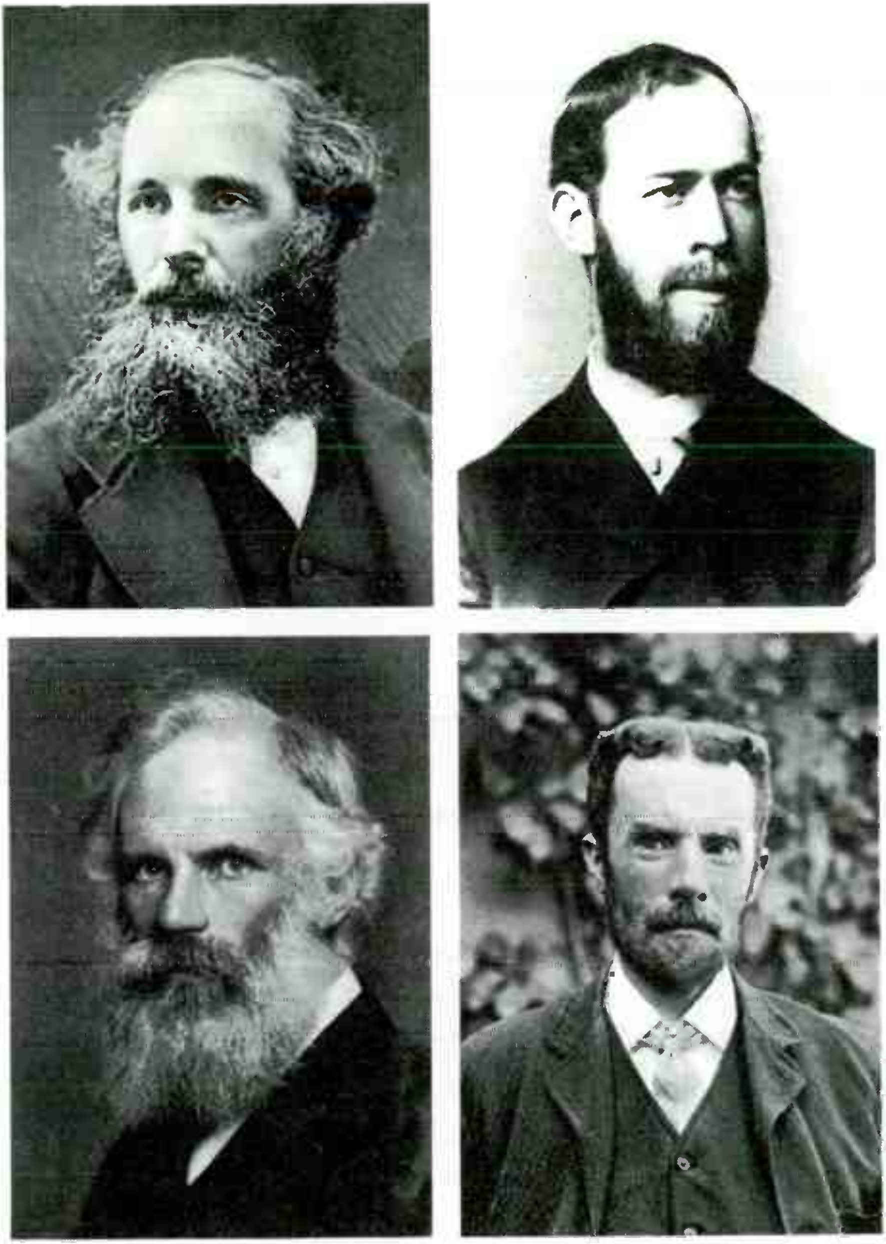
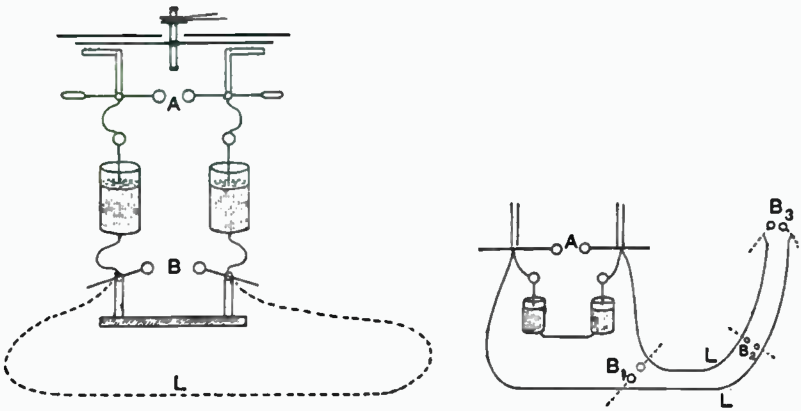
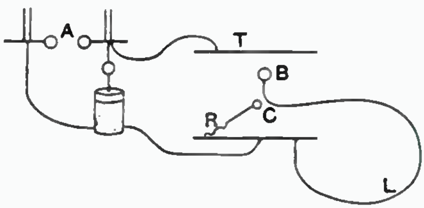


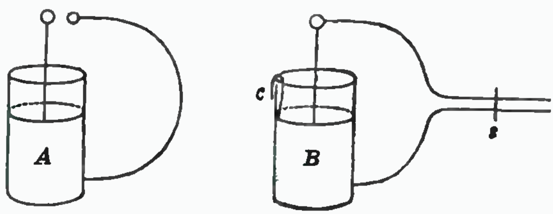
Fig 19. James Clerk Maxwell; Heinrich Hertz; George Francis FitzGerald; Oliver Heaviside.



(a) alternative path (b) recoil kick

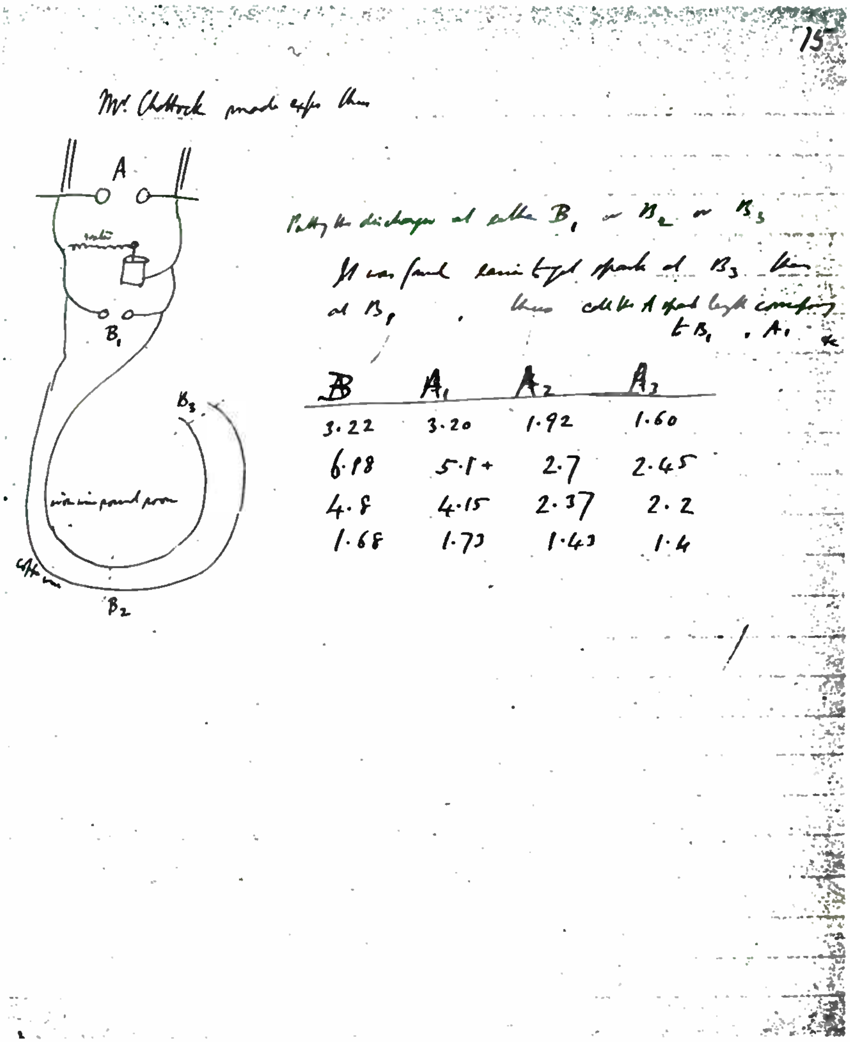


(c) side flash



(d) syntonic Leyden jars

Fig 20. Lodge's early experiments with Leyden jars.



75

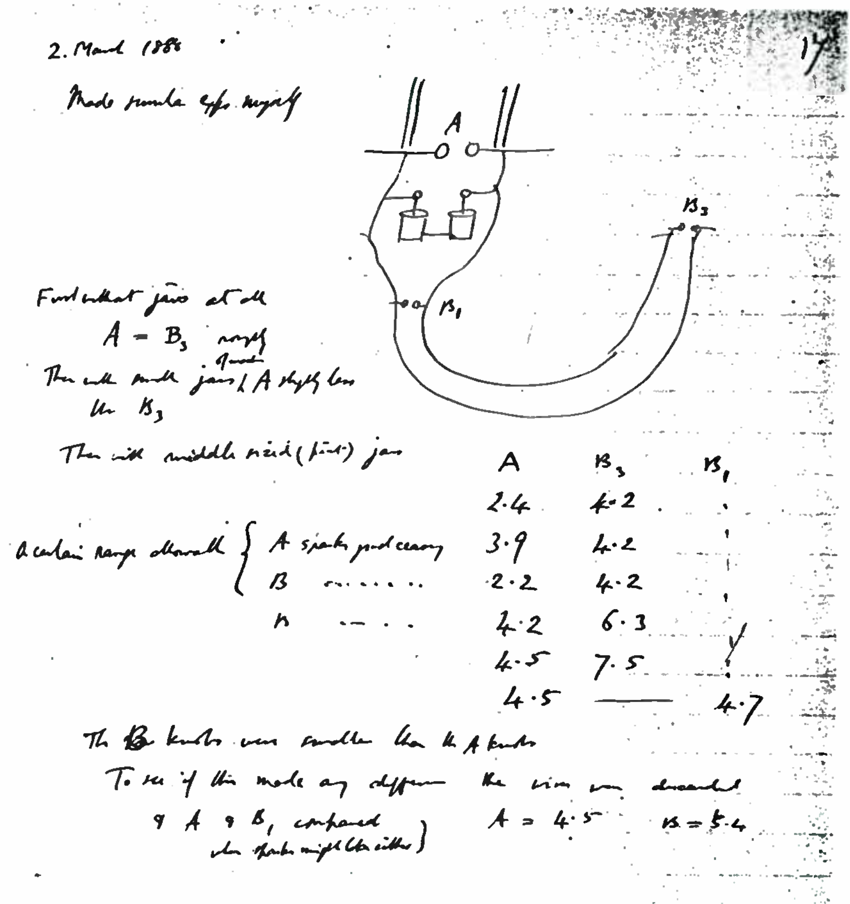
Mr. Chattock made expts thus

Putting the discharge at either B_1 or B_2 or B_3

It was found same length spark at B_3 then at B_1, thus call the A spark length corresponding to B_1, A_1 &c

B	A_1	A_2	A_3
3.22	3.20	1.92	1.60
6.18	5.1+	2.7	2.45
4.8	4.15	2.37	2.2
1.68	1.73	1.43	1.4

Fig 21. Lodge's notebook, 1 March 1888.



A	B3	B1
2.4	4.2	
3.9	4.2	
2.2	4.2	
4.2	6.3	
4.5	7.5	
4.5	—	4.7

Fig 22. Lodge's notebook, 2 March 1888.

Chapter Four
RADIOWAVES

by Peter Rowlands

Technologies tend to develop rather than spring up overnight in the mind of a single inventor. Popular culture, however, demands one name as the inventor of a technology, as if such a complex thing, say, as 'the computer', had a single origin, and as if every single subsequent development could be said to 'arise' in some way from the same simple beginnings, the 'inventor', as it were, having a kind of historical patent right on all subsequent developments.

In the case of radio telegraphy, the name assigned by popular mythology is not that of Oliver Lodge, but of Guglielmo Marconi, and the year is not 1894, but 1896. This is, of course, a cultural artifact. Marconi's contributions are well-known and not in dispute, but they are subsequent to those of Lodge, and to a certain extent dependent on them. The claim that Oliver Lodge is the most significant *early* name in the history of radio technology can be made for the following reasons:

(1) He believed that electromagnetic waves could be generated. He was an early supporter of Maxwell's theory and made a conscious effort to find the waves, succeeding early in 1888, at the same time as Heinrich Hertz, though not so spectacularly.

(2) He developed the first efficient and practical radiowave detector – the coherer – in several forms.

(3) He built and publicly demonstrated the first complete practical radio apparatus of transmitter and receiver capable of being used in wireless telegraphy and publicised the technology in a major lecture transmitted throughout the entire world.

(4) He first publicly demonstrated signalling of information by Morse code.

(5) He developed the idea of tuning on the basis of his own scientific experiments and emphasized its importance.

(6) With his partner, Alexander Muirhead, he built and sold radio sets of a high standard for a number of years.

The central point in these various developments was the year 1894 when Lodge gave four public lectures which effectively launched a world-wide effort to develop radio technologies. There is no doubt that, directly or indirectly, most of the major names in the early history were inspired by Lodge's work. Whoever may be claimed as the 'inventor' of radio, there is no doubt that 1894 must be counted as the year when it actually began. But the invention would have been impossible without a purely scientific discovery made six years before. This was the realisation that energy could be produced by electrical apparatus and transmitted as radiation, or *electromagnetic waves*, into free space. Lodge also contributed in a very significant way to that discovery.

The events leading up to the 1894 demonstrations had begun more than thirty years earlier in work of a highly theoretical nature. What is often now regarded as the greatest theoretical discovery in nineteenth century physics was made between 1861 and 1864 when James Clerk Maxwell, then a professor of physics at King's College, London, developed his theory of the electromagnetic field. In addition to providing a unified system of equations for the explanation of electric and magnetic phenomena, Maxwell's theory also explained light as an electromagnetic wave. In an oft-quoted statement in part 3 of his paper 'On physical lines of force', published in January 1862, Maxwell wrote: "We can scarcely avoid the inference, that *light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena*."[1] He did not at this time, or in any subsequent publication, make an explicit prediction that waves could be generated by the actions of electromagnetic fields. It was Oliver Lodge who first made such a prediction.

Lodge's first encounter with Maxwell and his theory came in 1873 when he called in at the Bradford meeting of the British Association, while he was staying in Leeds on a journey selling potter's materials for his father's business to clients in Scotland and the North of England. The whole meeting was a revelation to the twenty-two year old Lodge, and led to a firm resolution on his part to follow a scientific career; the following January, he gave up business and enrolled as a full-time student at University College, London. At Bradford he heard Maxwell himself give “a memorable discourse” on ‘Molecules’ which, he said, “riveted the attention of the audience”;[2] he also bought a copy of Maxwell’s recently published *Treatise on Electricity and Magnetism*, after hearing it praised. The *Treatise*, however, proved to be a difficult book, and Lodge did not study it intently until he had gained his BSc from London University, and been taken on to the staff at University College. He was finally able to give the work his full attention during a six weeks summer vacation spent in Heidelberg in 1876, following which he devised a teaching model made of strings and pulleys, which achieved a commendation from Maxwell himself.[3]

Maxwell’s *Treatise* proved to be difficult because it was not arranged as a textbook, nor as a systematic exposition of his theory. It was an exploration of various themes opened up by his discovery, written, as it were, in the very act of discovery itself; this undoubtedly contributed to the fact that Maxwell’s theory was not taken up in influential circles until it had been promoted for many years by a small group of exceptionally gifted younger scientists. Besides Lodge, it gained two very notable early converts: Oliver Heaviside, a brilliant but eccentric telegraph engineer who had elected, in effect, to take an extremely early retirement, in 1874, at the age of 24, and George Francis FitzGerald, an up-and-coming mathematical physicist of Trinity College, Dublin. Elected a fellow of Trinity College, at the age of 26, in 1877, FitzGerald made his first visit to the British Association at the Dublin meeting of 1878, and there met Lodge; the two men instantly became friends when they realised that they shared a common interest in Maxwell’s theory, and their partnership was subsequently extremely close, Lodge frequently relying on the theoretical backing supplied by the better-trained and more-established FitzGerald.

Lodge’s interest in the possibility of electromagnetic waves can be traced back to an entry on ‘Electromagnetic Light’, made in his notebook on 3 August 1879, while, at the British Association meeting held that month in Sheffield, he suggested, using an early version of a cog-wheel model of the aether, that “light could be got from oscillations”.[4] In his notebook he suggested sending an alternating current through a helix at “several billion” oscillations per second. “Query whether this could be done with a rotating carbon disk & a spring contact a la microphone.” He even thought of generating waves using a steady battery current applied to a vacuum tube.[5] FitzGerald, however, was not convinced, and gave his opinion, in a paper read to the Royal Dublin Society on 17 November, just twelve days after Maxwell's premature death at the age of 48, that electromagnetic waves would not be produced.[6]

Lodge, nevertheless, continued to develop his ideas, and, between 19 and 22 February 1880, made several relevant entries in his notebooks: "To get emission of light electromagnetically suppose a set of coils were arranged so as to give induced currents of a high order."[7] Here, he calculated that something like a cascade of 120 coils, each doubling the input frequency at its output, would be necessary to produce emission at the frequency of light. Then, he thought: "Perhaps the current would be better to be a discharge from a jar. This itself is oscillatory ... . Connect a thin mica condenser with the last coil it ought to emit light. Or have a jar – charge with a condenser. A jar being discharged does emit light. This must be the very thing ... ."[8] This was an important idea, for it later became the basis of the 'magnetic oscillator' method for generating electromagnetic radiation. The Leyden jar, to which Lodge had referred, was a device discovered in 1746 for storing large quantities of electric charge, being effectively what we would now call a condenser or capacitor. The principle of the magnetic oscillator was that a combination of jar (with the property of capacitance) and coil (with the property of inductance) would produce a resonant frequency of oscillation depending on the constants representing inductance and capacitance. In principle, a condenser or Leyden jar, of capacitance C, discharged in a circuit of inductance L, would generate waves of frequency $1/2\pi\sqrt{(LC)}$, though the radiation would not be visible light, as Lodge had supposed, the visible light which accompanied the Leyden jar discharge being produced by a different mechanism.

This primitive 'magnetic oscillator' was mentioned, with some of Lodge's other ideas, in a letter to FitzGerald of 26 February.[9] FitzGerald's reply has not survived, but we know that it must have been negative. In a set of notes of this period entitled 'Effect of distance and medium on Electromagnetic disturbances', Lodge had considered generating electromagnetic waves between the two coils of an induction balance, but: "If EM disturbances travel with the velocity of light, it is not probable that any effect will be perceived, when the coils were very large and the distance very great." According to Maxwell's theory, the waves would travel in free space with the velocity of light, but their velocity in a material medium would depend on the electric and magnetic constants of the medium, in particular the dielectric constant (k) and the magnetic permeability (μ). He had therefore proposed to test the Maxwellian theory that the velocity of the waves would equal $1/\sqrt{(k\mu)}$ by interposing materials of high dielectric constant and magnetic permeability, and also by putting a prism between the coils to see if the waves could be deflected: "if EM disturbances travel with the vel(ocity) of light in all media (i.e. if $k = \mu$) they ought to be refracted like light". But, in a footnote, dated April, he added: "This is all a misunderstanding", and in another, dated August, he wrote that – "It acts as a proof that ordinary EM disturbance is not of a wave nature."[10]

But it was FitzGerald, and not Lodge, who was mistaken. In Maxwell's theory, it was the introduction of a new mathematical term – the famous displacement current – into one of the basic laws of electromagnetic theory, the Ampère force equation, which had been responsible for producing the wave solutions which predicted the dispersal of energy into space. But the introduction of the displacement current also meant that the theory was different, in principle, from the instantaneous action-at-a-distance theories favoured – particularly by physicists, like Hermann von Helmholtz, on the Continent – in which there would be distant interactions caused by inductive effects between overlapping magnetic fields but no free radiation into space. FitzGerald failed to recognise, in effect, the difference between the cases for static charges and steady currents, in which the results of Maxwell's theory agreed with those from the action-at-a-distance model, and the case for changing currents where the results of the theories differed. Lodge, however, deferred to his friend's better judgment, though at the Swansea meeting of the BA in August, FitzGerald was persuaded to change the title of his paper 'On the Impossibility of Originating Wave Disturbances in the Ether by Electromagnetic Forces' to 'On the Possibility ...'.[11]

Influenced by FitzGerald, Lodge had given up his search for the electromagnetic waves by the time of his appointment as Professor of Physics at University College, Liverpool in 1881, and his new duties gave him little time for such activities for a number of years afterwards. Immediately after his appointment, while his new Department was being created out of the old lunatic asylum on Brownlow Hill, Lodge set out on a summer tour of the major Continental laboratories. This tour was significant in at least two respects. On his tour of the laboratory at Berlin, he was briefly introduced to Helmholtz, but quickly passed on to Heinrich Hertz, who was then Helmholtz's demonstrator, and who subsequently became his firm friend. Then, at Chemnitz, in Saxony, he bought a fine set of Leyden jars, which he was to use in an important series of experiments. These jars, as he recalled, were "exceptionally well made, with no chains, wooden lids, and other gimcrack arrangements, such as were usual in this country".[12]

Ironically, by 1882, FitzGerald had realised that the existence of mutual inductance effects between the currents in a non-conducting medium meant that the Maxwellian and action-at-a-distance theories were *not* equivalent, and so free radiation would occur after all as a result of electric currents. "It seems ... highly probable," he wrote, "that the energy of varying currents is in part radiated into space and so lost to us." But it was more the discovery of a new solution by Lord Rayleigh to the set of same differential equations than any residual influence from Lodge which led to this dramatic about face; Rayleigh's solution, derived for acoustic waves in his *Theory of Sound* (1877), produced a set of progressive waves, radiating energy into the medium, rather than the standing-wave solution originally proposed by FitzGerald for electric oscillations in a conductor, for which no such radiation would occur. Taking "Lord Rayleigh's form of solution would lead to the conclusion that a simply periodic current would originate wave disturbances such as light, and not the stationary waves that my solution leads to," he wrote.[13] By 5 May 1882, at any rate, FitzGerald was proposing before the Royal Dublin Society that: "It might ... be possible to obtain sufficiently rapidly alternating currents by discharging condensers through circuits of small resistance." This was similar to Lodge's proposal of 1880, and, FitzGerald told his audience, "Dr. Oliver Lodge has already tried to originate light by induced currents of a high order"; but FitzGerald had made a distinct advance also in realising that the waves obtained would not be visible light, as Lodge had supposed, but a much longer-wavelength invisible kind.[14]

At the British Association meeting at Southport in the following year, he gave a paper on 'The Energy lost by Radiation from Alternating Currents', which showed that shorter (but still invisible) waves would be more effective than longer ones, because the radiation intensity would be proportional to the fourth power of the frequency. He also spoke of 'A Method of Producing Electromagnetic Disturbances of Comparatively Short Wave-Lengths', proposing the exact method by which such waves were later to be generated: "This is by utilising the alternating currents produced when an accumulator [that is, a capacitor or Leyden jar] is discharged through a small resistance. It would be possible to produce waves of as little as ten metres wave-length, or even less."[15] Though short in comparative terms, such wavelengths would still have been more than a million times longer than those of light.

FitzGerald's conversion came too late to persuade Lodge to return to his attempts at obtaining electromagnetic waves. In any case, even if the method of generating the waves had been found, it was by no means obvious how they should be detected, since they would not now be visible. Neither Lodge nor FitzGerald knew that, almost at the very moment when Lodge was making his first speculations, the waves had been both produced and detected, but the fact had gone unrecognised.

In the autumn of 1879 the well-known London-based engineer David Hughes found that a "semi-metallic" microphone which he had invented, and attached to a Bell telephone (then a comparatively recent technological innovation), gave a response every time he interrupted the current in a nearby coil, regardless of whether or not the two were actually connected; he tracked down the reception to the imperfect contact on which his microphone was based, and obtained the same effect from sparks produced by electrostatic means. He tested the reception between rooms 60 feet apart, and then outside his residence in Great Portland Street, where he found the signals were audible over a range of 500 yards.[16] He also tried other methods of transmission, including the one now known as the Hertz antenna. He invited Fellows of the Royal Society and other prominent scientists to witness his demonstrations; among those who took particular interest was William Crookes, while another who was present was the Assistant Engineer-in-Chief to the General Post Office, William Preece.

Hughes recognised that his principle was new and that the effects were not due to induction but he never realised that they were produced by electromagnetic waves; nor did he recognise the effects of wave reflection and interference when he reported that "opposite certain houses, I could hear better, whilst at others the signals could hardly be perceived". Hughes apparently thought the effects were produced by conduction through the air.[17] Later publications of his work, which followed the discovery of electromagnetic waves, obscured this fact. On 20 February 1880 a more formal delegation of Royal Society fellows, comprising Sir George Stokes, the President William Spottiswoode, and the famous biologist Thomas Huxley, stayed with him for two and a quarter hours, observing the phenomena. At the end of this time, however, Stokes declared that the effect was nothing more remarkable than induction; and, although Hughes was advised to publish, he was too discouraged, in fact, to do so.[18]

Hughes had been unlucky in demonstrating his work at a time when the people most likely to appreciate it were unavailable. Maxwell, for example, might have recognised it as a confirmation of his theory, but he had died in the previous November, about a month before the first demonstration. Lodge, again, might have recognised the waves, but he was at this moment expecting to produce visible, rather than long-wave, effects, and, though based in London, was not yet a Fellow of the Royal Society. The work, however, was never completely submerged, for Hughes was soon afterwards made a Fellow and awarded a Royal Medal on the basis of his earlier work on telegraphs and microphones; and the experiments long remained a talking point among some of his new colleagues.

The Hughes demonstration was, in fact, really the most elaborate in a long series of unrecognised observations of electromagnetic waves. Thus, in Philadelphia in 1871, the 18-year-old Elihu Thomson found sparks from a Rühmkorff induction coil produced sparking all round a series of Leyden jars, and the sparks could be drawn with a knife to a metal table top and could even light a gas burner. When Thomas Edison, in 1875, thought he had discovered a new non-electric "etheric force" when he got sparks from metallic objects placed near a magnetic vibrator relay, Thomson repeated his own earlier experiments to show that the force was, in fact, electric, while the almost equally young Silvanus Thompson, in London, detected the sparks with a luminous discharge tube, and used a rotating mirror to show that the discharge was oscillatory. He attributed the effects to electrostatic induction.[19] A few years after Hughes, on 23 March 1882, the American inventor Amos

Dolbear exhibited a "New Telephonic System" to the Society of Telegraph Engineers in London, in which the transmitter and receiver were connected at one end to the ground and at the other end to a free wire; improved results were obtained when the free wires were elevated, when the receiver was connected to an insulated tin roof, and when one terminal of the induction coil in the transmitter was grounded on the gas or water pipes. Though it is probable that the device operated on electromagnetic waves, Dolbear himself believed that the transmission was through earth conduction.[20]

The oscillatory nature of certain electric discharges, referred to by Lodge in his 1880 notebook, had, in fact, long been known. Joseph Priestley had established the oscillatory character of the Leyden jar discharge when he investigated the phenomenon of 'side-flash' in 1770, while Luigi Galvani, in his famous experiments on frogs' legs found that convulsions could occur at some distance from the electrostatic generator and that a luminous discharge alternately arose or vanished as the spark was drawn or extinguished.[21] There were numerous early suggestions, by Faraday and others, that electricity might be transferred by a wave motion analagous to light;[22] and it was by no means unknown for waves of electricity to be associated with phenomena like lightning. Thus, when the amateur 'electrician', William Weekes of Sandwich, published a report in 1841 in *Annals of Electricity* on his experiments on lightning, in which "almost identically with the appearance of each flash, streams of brilliant fire, having most extraordinary intensity, rushed through the apparatus with a loud hissing sound", the editor, William Sturgeon, added the comment: "These grand displays of the electric matter from the apparatus, were obviously the effects of *electrical waves*, occasioned by the distant flashes of lightning."[23]

Oscillatory discharges were also recognised by William Wollaston in the electrolysis of water (a static discharge producing a mixture of hydrogen and oxygen at each electrode), by Felix Savary who observed the magnetisation of iron needles in alternate layers, and by Joseph Henry, who in 1842 observed magnetisation by a spark at a distance of 30 feet, and assumed "the diffusion of motion" to be "comparable with that of a spark from a flint and steel in the case of light".[24] Since that time, the theory of such oscillatory discharges and of related problems of oscillations in electric circuits due to alternating currents had been extensively discussed by physicists like Helmholtz, Kirchhoff, William Thomson, Feddersen and Schiller, while Wilhelm von Bezold in 1870, had carried out experiments in which he produced standing waves in wires by interference between incident and reflected alternating current oscillations, and determined the presence of nodal points by observing changes in the current polarity.[25] But the explanations of such effects could apparently be contained within the action-at-a-distance models currently employed, and did not require Maxwellian radiation into space.

One physicist who began working with such a model was Lodge's old acquaintance, Heinrich Hertz. Hertz, who had become Professor of Physics at the Technical School of Karlsruhe during Easter 1885, had heard nothing of FitzGerald's suggestion for generating electromagnetic waves, and, like most German physicists of the time, had a very imperfect knowledge of Maxwell's theory. He knew, however, that Maxwell's theory, by introducing the displacement current, had made dielectric polarisation equivalent to a conduction current in producing electromagnetic effects, and, acting on Helmholtz's suggestion, he resolved to put this to the test. In November 1886, he realised that a set of induction coils he had been using for lecture demonstrations would be ideal for tackling the problem. Intending to investigate the dielectric properties of paraffin and pitch, he set up an apparatus consisting of an induction coil as source, with a spark gap formed from an unclosed rectangular loop of copper wire as the detector. When the loop was connected by a wire to a point in a circuit through which a spark had been discharged by the induction coil, sparks passed in the spark gap of the detector. In his earliest work he experimented on oscillatory discharges, in a similar manner to von Bezold, though without knowledge of this earlier work, but he soon made the important discovery now described as the photoelectric effect, in which spark production was enhanced by the presence of ultraviolet radiation. It was only after lengthy experiments on this phenomenon, which he reported to the Berlin Academy on 9 June 1887, that he was able to return to the problem of Maxwell's theory. He subsequently showed, to his own satisfaction, that the displacement current could produce electromagnetic effects in dielectric media; the next stage was to extend the experiment to the aether itself.[26]

At almost exactly the same time, a request from the Society of Arts led Oliver Lodge to return to the same problem of testing the validity of Maxwell's theory. Lodge, newly elected FRS, had been chosen to give a series of lectures on lightning conductors in commemoration of the South African benefactor, Robert Mann. He immediately realised that the discharges of a Leyden jar would be an excellent way to create spectacular demonstrations of artificial lightning. Lodge was convinced that the lightning discharge was oscillatory, like that of the Leyden jar, and decreased in amplitude at every reversal of polarity. This he knew would have controversial consequences, for while conventional lightning conductors were designed to follow the path of least resistance, an oscillatory discharge (of frequency f) would rather follow the path of least *reactance* ($2\pi fL$), as it was called, provided by an object with low self-inductance (L), making the conventional lightning conductor useless.

Working with his demonstrator, the "brilliant but self-effacing" Arthur P. Chattock,[27] and his assistant, Edward E. Robinson, Lodge set up preliminary experiments, in February 1888 in the Physics Lecture Theatre at University College. Four or five copper and iron wires of various types and thickness, and each about 95 feet long, were stretched around the theatre and "supported on four vertical posts" positioned well away from the walls. Working from FitzGerald's suggestion of 1883, electrical oscillations were generated by the discharge of a specially made large glass condenser, which had been previously charged by a Voss or Wimshurst electrostatic machine. Lodge was particularly interested in testing whether oscillatory discharges would choose the path of least resistance or that of least inductance; so, in the first experiments, the sparks generated by friction at the terminals of the electrostatic machine were allowed to take one of two 'alternative paths': either through a loop of wire with small resistance, or through a spark gap with high resistance, but low inductance.

As he had expected, powerful discharges were produced in the air gap, even when the resistance of the alternative path round the wire was as low as 0.025 ohm, but, somewhat unexpectedly, the sparks in the gap were noticeably stronger than those produced at the output terminals of the Voss; this, however, could be explained in terms of the oscillatory nature of the discharge. When he tried substituting a "common Leyden jar" for the large glass condenser, he noticed that "the jar frequently overflowed by sparking over its lip; he recognised this as "evidence of the momentum of a reflected pulse". This observation led to a series of experiments on 'overflow', in which a "special overflow or short-circuiting path was ... provided". In such experiments, as Lodge realised, it was important "to have joints better made" than was "usual for high-tension electricity", for as he noted, obviously from experience: "Fizzing or sparkling inside jars is abominable."[28]

The experimenters had found that the discharge of a Leyden jar was oscillatory, as expected, "but Chattock insisted, in accordance with FitzGerald's suggestion of 1883, that these oscillations ought to emit waves", like those produced by a tuning-fork in air, and Lodge recalled analagous experiments exhibited by Lord Rayleigh at the Royal Institution on 20 January on the interference of sound waves.[29] Preliminary evidence for waves had been found in the experiments on overflow, but a much more dramatic result was obtained on 1 March when Chattock, in Lodge's absence, cut the wires at a long distance from the two spark gaps. Then "a singularly long spark or strong brush discharge attempted to jump the space there whenever the machine spark occurred." This observation, of reflection at the free ends of wires, became known as the experiment of "the recoil kick"; Chattock had no doubt that he had found clear evidence of the effect of stationary waves in the wires, and he would have been "prepared to look for evidence of nodes and loops if the wires had been long enough".[30] Lodge recognised that the waves were being sent into the space surrounding the wires, and he soon discovered strong theoretical backing in the papers that Oliver Heaviside had been publishing in *The Electrician* since 1885, but which had attracted little notice from other physicists.[31]

Heaviside, working on his own and without any encouragement from the scientific establishment, had been reformulating Maxwell's theory in a much-simplified and more usable form, and had already discovered the 'skin effect', in which currents were predicted to be conveyed only by the 'skin' or outer edges of a conductor; he had also used Maxwell's theory to stress the value of loading telegraph cables with inductance coils to reduce the distortion of signals produced by the cables' capacitance. During the same period, another early follower of Maxwell, John Henry Poynting, Professor of Physics at Mason College, Birmingham, discovered the equation for the flow of energy in an electromagnetic field, and showed that electric energy "was not carried along [a] conductor by the current" but, rather, in the surrounding medium. Lodge had been particularly struck by Poynting's paper on its publication in 1884, and developed a qualitative analysis of his own in which each individual element of energy assumed an 'identity' which could never be altered by any set of transformations; in effect, the principle of conservation of energy became a principle of *local* conservation, in which energy must be transferred through the aether and not destroyed at one place to be created in another. This was an extremely prescient suggestion, for local conservation principles of this kind are fundamental to modern gauge theories, but the immediate consequence was that it required an explicit denial of the possibility of action-at-a-distance.[32]

On the day after Chattock's preliminary experiment, Lodge used gallon jars, insulated from earth, to produce very long recoil sparks. Now, "the wires glowed at every" spark from the machine "along a considerable portion of their length, looking thick and fuzzy with momentary luminosity." In his notebook, he calculated a wavelength and used it to determine the self-inductance of the circuit: "The capacity of the gallon jars is about 1800 centimetres (Electrostatic units) hence if the wavelength is twice the length of the wire round the room – viz. 2 × 2825 centimetres one can calculate the self inductance of the jars and A knob circuit", the A knobs being the terminals of the Voss machine.[33] Nearly a decade after he had first predicted the waves, Lodge had found almost by accident, and during experiments carried out in hurried preparation for lectures to be given a couple of weeks later, that "simply by attaching long wires to a discharging Leyden jar circuit," they "had become without trouble conspicuous. One had only to lengthen the wires enough, and to look at them in the dark, to see by the brushes the nodes caused by the interference of the direct and reflected pulses surging to and fro in the wires; to see in fact the waves themselves, and to measure their length in a manner precisely analagous to the well-known experiment of Melde" on strings attached to vibrating tuning forks.[34]

"The discharge, which at the near end might be half an inch long, could, when a certain tuned length was employed, give a spark at the far end about two inches long, or something in that ratio. But the wire had to be adjusted so that the reverberations of the wire could be in tune with the main oscillations of the jar, on the principle of resonance." This was the beginning of a whole "series of experiments on electric waves travelling along wires." For example: "A jar was held in the hand near either glowing terminal, for the wires to spark into. They kept on doing so, but the jar was not charged, showing that they sparked in and out again." This was the phenomenon of 'side flash', investigated more than a hundred years earlier by Priestley under the name "lateral explosion".[35] Carrying out a systematic and planned investigation, Lodge found that "connecting the machine side of the jar to earth" increased the strength of the sparks at the discharge interval near to the jar; with the jar set aside, sparks still occurred there whenever there was no spark at the terminals of the machine. This led to a new series of experiments which he described as "the surging circuit".[36]

The Mann lectures were given on 10 and 17 March 1888 and Lodge made mention there of these discoveries, with the specific statement that "electric waves could be thus detected and measured".[37] They were published in the *Journal of the Society of Arts* in June. In the second of the lectures, Lodge made specific reference to Heaviside's recent derivation from Maxwell's theory of the fact that alternating current oscillations were confined to the *surfaces* of conductors. This was the skin effect, which had been discovered experimentally, independently of Heaviside's theoretical prediction, by David Hughes in January 1886, and it was the first serious notice of Heaviside's work made by any fellow-scientist. Though it was not entirely complimentary, Heaviside regarded it as a great vindication of his efforts: "what a singular insight into the intricacies of the subject, and what a masterly grasp of a most difficult theory, are to be found among the eccentric, and in some respects repellant, writings of Mr. Oliver Heaviside", wrote Lodge. In the same lecture, after comparing the experimental arrangement for the 'recoil kick' to a vibrating string or "resonant tube excited by a tuning fork or reed", Lodge quoted a wavelength of 190 or 200 feet and used it to calculate a value of 5 "metres" for the self-inductance of the circuit which he thought must be close enough to its true value to give the correct velocity of light. He also described his direct observation of the recoiling pulse in the form of a "vivid brush light" seen at the ends of the wires in the dark.[38]

On 11 May he showed a further set of experiments to the Physical Society at South Kensington. According to the account later published in

Lodge's autobiography: "A long wire about one-eighth or one-sixteenth of an inch in diameter was stretched around the theatre at South Kensington, several times round. On now sending a series of oscillating pulses along that wire, a glow was seen on the wire in the dark at the central segments of each pulse, while it was dark at the nodes, exactly in accordance with Melde's experiments of a string attached to a vibrating tuning-fork. It might vibrate as a whole, and then the recoil kick made the fact manifest in the electrical case; but, if the oscillations were made two or three times more rapid, it would divide itself into two or three segments, in accordance with the harmonics of the fundamental note, giving first the octave, then the twelfth above the octave, and so on, as well understood in acoustics. The point of the demonstration was not another demonstration of the oscillations, but a proof that true waves ran along the wires, being thereby guided and prevented from spreading out into space, and by reflexion were converted into stationary waves which showed themselves by nodes and loops."[39] The waves, as he well knew, were *in space*, not in the wires.

From the acoustical analogy, it was clear that, when the lengths of the wires up to the discharger position were exactly half a wavelength (or some multiple of this), the spark circuit and the wires "would vibrate in unison like a string or column of air resounding to a reed". Assuming Maxwell's theory to be correct, the velocity of the waves generated along the wires, determined from the product of wavelength and frequency, would be identical to c, the velocity of light. Lodge's experiments, therefore, set out to compare the calculated values of half-wavelength, determined by the ratio c/2f, with the resonant lengths estimated visually from the strength of spark produced; and with the nodal points caused by the interference of direct and reflected pulses easily observable between the glowing brush discharges visible in a darkened room.[40]

Fully aware of the importance of these experiments, Lodge followed up his lectures with more accurate versions of the 'recoil kick', for eventual presentation to the Royal Society. In May, he had a circuit "carefully prepared" to make "real" measurements of wavelength, using the corona or visual glow observable in the dark at the peak voltage intensities, as opposed to the earlier "estimates", based on assumptions about the strength of the sparks produced, his analysis relying on the principle, derived from Maxwell's theory, that the velocity of the waves was equal to $1/\sqrt{(k\mu)}$, with k the dielectric constant and μ the magnetic permeability. In his notebook, on 12 May, for instance, he calculated a wavelength of 33 metres; on 14 May, 70 and 71 metres, and then 44 metres with altered capacity; and on 28 May, 27, $31\frac{1}{2}$ and 18 metres.[41]

The results obtained by Lodge in May and June, and later presented to the Royal Society, show that calculated and measured values of wavelength were found to be in reasonable agreement for either the fundamental frequency or for one of the harmonics. In principle, therefore, Lodge had found that the waves travelled at the speed of light; and, by the time that the second of the two Mann lectures appeared in the Society of Arts' *Journal* on 22 June, he was able to add a quite explicit statement to the account of the 'recoil kick' experiment: "Since the delivery of the lecture, a great number of quantitative observations on these lines has been made. *Evidence of electro-magnetic waves* 30 yards long has been attained. I expect to get them still shorter."[42] This was the first explicit and unambiguous statement that electromagnetic waves had been discovered to appear in the scientific literature.

While Lodge was occupied with the recoil kick, Hertz began for the first time to realise the importance to Maxwell's theory of the finite speed of propagation for electric effects. By early 1888 he had begun to detect the induction effects of electrical oscillations on neighbouring closed circuits over a distance of 12 metres. His paper 'On the Finite Velocity of Propagation of Electromagnetic Action', presented on 2 February 1888, reported the interference of electric oscillations on a conducting wire with the direct electric 'action' or 'force' propagated through the air, but he did not yet refer to wave-radiation – his oscillations were still assumed to be "in" the wires – and he also obtained different speeds for electric action in air and in the wires, suggesting different velocities, in turn, for electrostatic and electromagnetic forces, when the analyses of Heaviside and Poynting, based on Maxwell's theory, had suggested that the speeds should have been identical. Hertz's surprisingly low value of 200 000 km per second for the velocity of electric waves in wires was apparently the result of an erroneous value for the capacity of his oscillator.[43]

In the course of these experiments, Hertz noticed that the inductive action seemed to act as if it were being reflected from the walls of his laboratory, faint sparks being induced in secondary circuits which were not in the direct path of induction from the primary. Though he was familiar with Maxwell's theory, in the somewhat distorted and limited form in which it had been presented to the German physics community by Helmholtz and others, the idea of such a reflection seemed impossible to him, because it contradicted his own conceptions of the transmission of electric force. However, in experiments completed in March 1888, Hertz proved unambiguously that it was a genuine effect when he managed to set up standing waves of 9 metre wavelength by reflection in air.[44] Hertz's experiments showed electric action had a finite velocity in air, of the same order as that of light, but it was only as a result of later, and more accurate, experiments that it was established that the two speeds were actually identical.

On 7 July, before writing up a detailed account of his researches on the Leyden jar discharge, Lodge sent a paper on 'Lightning Conductors' to the *Philosophical Magazine*. In the final section, however, he "spoke of electric waves, calculated their length along wires, and emphasized the importance of the discovery from the point of view of the verification of Clerk Maxwell's theory of the nature of light", while giving a reasonably extensive account of the theoretical background. "It is interesting to see how short it is practically possible to make waves of this kind", wrote Lodge. "A coated pane can be constructed of, say, two centimetres electrostatic capacity, and, by letting it overflow its edge, a discharge circuit may be provided of only a few centimetres electromagnetic inductance. Under these circumstances the radiated waves will be only some twenty or thirty centimetres long, corresponding to a thousand million alternations per second ... .

"No doubt much shorter waves may still be obtained by discarding the use of any so-called condenser, and by causing the charge in a sphere or cylinder to oscillate to and fro between its ends, as might be done by a succession of sparks. ... By setting up electric oscillations in a body as small as a molecule, no doubt they would be rapid enough to give ordinary light-waves; but the probability is that this is precisely what light-waves are." He also thought that electromagnetic waves might be observable in free space away from wires.[45]

Hertz had by now completed the analysis of the experiments carried out in March, and, in the same month, he published a paper indicating that his results seemed to favour Maxwell's theory. Quoting some famous optical analogies, he remarked that it was a "fascinating idea that the processes in air which we have been investigating represent to us on a million-fold larger scale the same processes which go on in the neighbourhood of a Fresnel mirror or between the glass plates used for exhibiting Newton's rings." But he also referred to the problem represented by the different velocities for the waves measured in air and in wires; and the full implications of the experiments only gradually became apparent as Hertz replaced the theoretical framework of Helmholtz, in which the velocities of electrostatic and electromagnetic forces were different, with a new theory, based on Maxwell's, in which they were identical.[46]

Hertz's article came to Lodge's attention towards the end of July, when he was on the point of leaving Liverpool for a holiday on the Continent, of which the intellectual highlight was a discussion of Hegelian philosophy with his friend and fellow-professor, Andrew Bradley. At Cortina in the Tyrol, he appended a note, dated 24 July, to his as yet unpublished *Philosophical Magazine* paper saying that the whole theory of electric waves seemed to be "working itself out splendidly".[47] He left the major announcement of his results for the British Association meeting at Bath in September.

Entries in Lodge's notebooks show that he resumed his experiments in preparation for this meeting after his return from the Continent. On 31 August 1888, for example, he – "Found that the light of one spark caused the spark of another circuit." Three days later he: "Tried this arrangement of gallon jars 2 in series for one observation of the recoil kick".[48] But the meeting didn't quite work out as he had planned. In the absence of Arthur Schuster through illness, FitzGerald had been asked to take over the presidency of Section A, and, having become acquainted with Hertz's work even before Lodge, gave, on Thursday, 6 September, a rousing speech centring on an enthusiastic account of Hertz's discoveries, with a passing reference to the supporting work of Lodge, and ending with the famous statement that, as a result of these researches, man had "snatched the thunderbolt from Jove himself, and enslaved the all-pervading ether".[49] He had certainly stolen Lodge's thunder. The latter found that his confirmation of Maxwell's theory had been done even more strikingly by Hertz using waves in free space, whereas his own experiments had been confined to waves guided by wires.

Lodge knew full well, from his study of the work of Heaviside, that, from the point of view of confirming Maxwell's theory, there was no essential difference between waves in free space and waves along wires – both representing radiation into space – but FitzGerald, as President, emphasized the discovery of their transmission through free space because it provided, for him, clearer evidence that electric waves travelled in the aether, the main object of his interest. According to Lodge, FitzGerald's "brilliant Presidential address ... called the world's attention to" Hertz's results "in an unmistakeable manner", for "FitzGerald recognised more vividly than Hertz himself the full import of his experiments".[50] At any rate, Lodge's own address on the following day must have seemed something of an anticlimax. Here he hastened "to acknowledge the superiority of Hertz's method" but considered his own results as of interest "in confirming the view taught us by Poynting and others concerning the mode of propagation of energy through the ether, and the theory of Kirchhoff and Heaviside concerning the rate of transmission of signals by a telegraph wire", and stated how he had described them "quite hastily and briefly in the midst of other matter, in a lecture to the Society of Arts last March on lightning conductors".[51]

At the Bath meeting, apart from giving papers on the 'Measurement of Electromagnetic Wave-lengths' and on the 'Impedance to Conductors of Leyden Jar Discharges', Lodge was involved in a major side-show, to which the attention of a large number of the spectators at the meeting was soon diverted. On the same day as FitzGerald made his stunning announcement of Hertz's discoveries, the Post Office engineer William Preece, in his Presidential address to Section G (Engineering), challenged Lodge's assumption that lightning discharges were oscillatory. He was, in fact, right; lightning is not oscillatory, and it is by no means the same sort of thing as a Leyden jar discharge writ large. However, Lodge's overall argument was still valid in principle; for lightning, as an *intermittent* direct current, has a finite frequency and so is still liable to follow the path of least reactance, provided by any object acting as a capacitor or inductor, rather than that of least resistance, provided by a thick metallic lightning conductor. Now, Preece, who considered himself a 'Practical Man', had no time for theoretical concepts such as self-inductance and reactance, and had had a bitter battle with Heaviside on that very subject; Heaviside, in turn, had no time for Preece, describing him in print as "the eminent scienticulist" and referring to his work on the inductance of copper wire as "really dreadful stuff, rank quackery".[52] In the course of this conflict, Heaviside had found himself up against a ruthless and powerful adversary who prevented him publishing his papers in influential journals and who even went so far as to remove the editor of *The Electrician* who had published most of Heaviside's earlier work. On Tuesday, 11 September, then, the scene was set for a spectacular debate on the nature of lightning conductors between the 'Theoretical Men' of Section A, represented by Lodge, and the 'Practical Men' of Section G, represented by Preece. According to the most impartial accounts, Lodge won the debate, but Preece's supporters claimed victory for their man. Though it provided immense entertainment for the British Association 'amateurs', who regularly applauded the telling points made by each speaker, Preece took a dim view of having his authority challenged in public, and resolved to take his revenge when an opportunity offered.[53]

FitzGerald's announcement has led to a tradition in which Lodge's experiments on waves on wires have been considered as all but superfluous to the main development of physical science. This view is in error for many reasons. In the first place, Lodge had been the first to propose the waves' existence as a consequence of Maxwell's theory, he had found them by his own experiments and he had understood what he found. By contrast, electromagnetic waves were not on Hertz's original agenda, at least in the form of free radiation; his early experiments had not set out to find the waves, for his understanding of Maxwell's theory was then very limited; it was only gradually that he realised that his experiments pointed to the existence of free radiation in space, and not the effects of induction. Even then, his knowledge of the theory was imperfect, for he postulated different speeds for the radiation in free space and along wires. Furthermore, the acceptance and development of Hertz's work depended on the reception it received at the British Association meeting in 1888, and that acceptance was largely made possible by prior knowledge of the independent work of Lodge. The discovery of electromagnetic waves was really a cooperative affair involving Lodge, FitzGerald and Heaviside, as well as Hertz. If, as Lodge proclaimed, FitzGerald, undoubtedly, "recognised more vividly than Hertz the full import of his experiments", he recognised it partly because of his long association with, and intimate knowledge of, the work of Lodge. FitzGerald himself had declared at Bath that: "The year 1888 will be ever memorable as the year in which this great question [the transmission of electromagnetic force through an intervening aethereal medium and not by direct action-at-a-distance] has been experimentally decided by Hertz in Germany, and, I hope, by others in England."[54] The full clarification of Hertz's ideas, in fact, required lengthy correspondence with the three British Maxwellians, and he readily acknowledged their contributions.[55]

In principle, as Heaviside proclaimed, the results of Lodge were "equally conclusive to those of Hertz" in demonstrating Maxwell's theory, and "in one respect, perhaps, more so, because their theory is simpler, and can be more closely followed".[56] They were also free from Hertz's incorrect conclusions concerning the velocity, and it is interesting that the experiments of Ernst Lecher and others which finally cleared up this discrepancy were almost identical, in conception, to those of Lodge.[57] Again, in terms of publication, Lodge's results were at least as early as the crucial ones of Hertz, the basic results being announced in March and published in June. Finally, there was the technological significance; although Hertz's experiments eventually led to radio communications, Lodge's led on to the equally important development of waveguide technology. According to Allan Ferguson, Lodge's experiments "foreshadowed the ultra short-wave advances of a later generation".[58]

From the practical point of view, of course, as Lodge recognised immediately, Hertz's methods were immeasurably superior, and he accordingly adopted them in his own research. The discovery of waves in free space he recognised as a great breakthrough, beyond the limits of his own arrangements. He also found it convenient to renew his friendship with Hertz after a gap of seven years. A brief request for reprints, made on 25 September, was followed by a return request from Hertz, with a statement from the latter that he had "read with interest" that Lodge was "engaged in the same direction".[59] Lodge later described Hertz's work in *The Electrician* as "one of the most marvellous combinations of mathematical and experimental power that we have seen in recent times", and made many other professions of his admiration for his fellow-physicist.[60] "Never," he wrote in 1923, "was there the smallest iota of jealousy between us, or anything but cordial and frank appreciation."[61] Yet, despite his certainly genuine regard for Hertz, which was greatly helped by the latter's characteristic generosity in taking note of the work of others, there was always some feeling in Lodge's mind that he was entitled to a share in the credit for the discovery, and that somehow his loss of this share of credit was due in some way to the manner in which FitzGerald had made his announcement. Lodge admired his friend for his indifference to matters of personal priority and credit, but he sometimes found it difficult to live up to the same standard.

The reception of his results at the British Association proved a great encouragement to Hertz, who had received little attention to that date in Germany. He felt able to pursue his investigations to provide a conclusive proof that the electromagnetic waves produced by his oscillators were of the same kind as light and possessed the same properties. By 13 December 1888 he had produced a paper 'On Electric Radiation' which not only demonstrated the existence of "rays of electric force", but also showed that they obeyed the laws of diffraction, rectilinear propagation, reflection, refraction and polarization. Almost immediately afterwards, he completed and published some experiments on the propagation of electric waves on wires of the same kind as had been previously performed by Lodge, referring in this work to the earlier publications he had now received through the post from the Liverpool professor.[62] Lodge, on the other hand, concentrated on giving a series of lectures which set "all London agog".[63] Writing to Hertz, early in 1889, Lodge revealed that he had begun a repetition of the latter's experiments, while Hertz, in reply, expressed a wish that they would both take part in "exploring" the new developments.[64] During this period, however, Hertz left Karlsruhe to become Professor of Physics at the University of Bonn. His experimental opportunities there were more limited, and he concentrated largely on theoretical studies; he had, in additon, developed eye problems from working with electric sparks and felt it necessary to reduce his exposure to this hazard. The experimental development of Hertzian radiation was mostly pursued by others, and, to a large extent, Lodge took the lead.

A Royal Institution lecture by Lodge, on 8 March, was preceded by a demonstration of what he described as 'syntonic' or resonant Leyden jars, a development of his earlier experiments on the 'recoil kick' and 'overflow'. On 2 March 1889, he noted: "Having the other day observed that a certain length say 2 feet of gutta perche wire 'resounded' to the spark between the 2 spheres and knobs excited by the Voss ... I today tried the resounding Leyden jar exp(eriment) thought of before. Two ...(?) Leyden jars very small made similarly were put in the focus of parabolic reflectors. But no resonance of course because the air gap in the receiver stopped all preliminary swinging But then tried an air condenser with plates connected varying capacity till sparks between plates. Easily done. Increase length of wire, had to decrease capacity. Distinct max(imum) resonance with a certain capacity. Decrease length of wire had to increase capacity. All quite right."[65] The demonstration arranged two Leyden jars facing each other, with one connected by a single loop of wire to a spark gap which could be activated when the jar was charged up by a Voss, and the other to two wires joined up by an air condenser, to vary the capacitance of the circuit, or, by a sliding contact, to vary its self-inductance, and make the resonant frequencies identical; when adjusted for resonance, each discharge of the first jar resulted in an overflow of the second. (The modification of using a condenser of variable capacity, rather than the more usual variable self-induction, was attributed by Lodge to the inventive Robinson.)

Great crowds were apparently attracted to the lecture on 8 March, and the audience certainly had some highly theatrical moments to entertain them. When Lodge demonstrated the resonant Leyden jar: "The walls of the lecture-theatre, which were metallically coated, flashed and sparkled, in sympathy with the waves which were being emitted by the oscillations on the lecture-table ... . This was a novel result, surprising to myself also, and I hailed it as an illustration or demonstration of the Hertz waves", the sparking clearly showing the propagation of waves freely in all directions through space.[66] Lodge also used a rotating mirror to illustrate the oscillations of a Leyden jar spark, and he showed how this apparatus could demonstrate the Faraday effect, or the rotation of the plane of polarization of electromagnetic waves in a magnetic field.[67] Two days after this lecture, while he was still in London, Lodge called on the reclusive Heaviside at his lodgings in Kentish Town; it was the only ever recorded meeting of these two great scientific allies. Just a month before, on 8 February, FitzGerald had paid a visit and discussed with Heaviside the ideas which led to the proposal of the FitzGerald contraction in explanation of the Michelson-Morley experiment.

With a second major lecture to give to the Institution of Electrical Engineers at Great George Street on 25 April, Lodge continued experimenting on Hertzian waves through March and into April. During March he "made a gigantic Hertz oscillator". Then he decided to – "Bring t... of lightning conductor in sparking distance from gas or water pipes, and then look for surgings or spittings from them." On 1 or 2 April, he wrote that: "With the Hertz plates connected to induction coils spark can be got from ...(?) gas and water pipes in the building." Also the new demonstrator, who had replaced Chattock, James "Howard noticed telephone ...(?) on water pipe ...(?) large Hertz oscillator was working. The telephone connected by one(?) wire is a sensitive detector."[68] This was the "first [conscious] detection of waves by telephone", though Hughes and Dolbear had done it unknowingly before. It was referred to in the April lecture, and later formed a significant item in Lodge's patent claims. Lodge and his assistants also tried "to make a Hertz detector of a brass tube with a telephone wire inside it"; with the result: "too quick for telephone but perhaps vacuum tube".[69]

At Great George Street, Lodge used the elaborate gilt-key pattern on the walls to dramatic effect when he obtained the same flashing and sparking as at the Royal Institution. He had an even more spectacular opportunity for self-dramatisation, when, in the middle of the lecture, the caretaker of the building came up white-faced, saying that there was sparking between the gas and water pipes in the basement. The lecturer, of course, remained unperturbed because this was exactly what he had observed at Liverpool a month before, and he invited Sir William Thomson and other members of the audience to go down to see it.[70]

Apart from being a great personal bonus for Lodge, the presence of Thomson (later, Lord Kelvin) at the lecture was a highly significant fact in itself, for, though previously opposed to the Maxwell theory on account of its essentially abstract nature, Thomson was now prepared, for a few years, to give it qualified support, and, consequently, to make it scientifically respectable. This temporary conversion followed on from a discovery he made at the Manchester meeting of the BA in 1887 that a vortex sponge model of the aether proposed by FitzGerald on the basis of an earlier model of Thomson's could generate electromagnetic waves in exactly the same way as Maxwell's theory. Realising the tremendous importance of obtaining even the slightest degree of support from Thomson, FitzGerald had been suitably excessive in describing this as "the greatest step towards comprehension of the universe which had been made since the time of Newton"![71]

Lodge and Howard took time during the Easter vacation to extend the findings of Hertz on the optical properties of radio waves, by demonstrating the refraction and focussing of radio waves using large lenses made of pitch. The joint paper with Howard was read to the London Physical Society on 11 May.[72] Here, Lodge also corrected Hertz's analysis of the value of radiation intensity when he calculated the radiating-power of a small Hertz oscillator at 100 hp. This, he observed, would be expended principally in one swing, thus explaining the tendency of the Hertz oscillator to produce sparks lasting only about 100 microseconds. This proved to be a particularly important insight. In connection with his syntonic Leyden jars, Lodge realised that a highly damped discharge from one jar, expending its energy in a few cycles, would easily produce a response in the other, regardless of the values set for inductance or capacitance, but, for a pair of linked circuits in which the first was a low power "persistent vibrator", continuing to oscillate for something like 30 or 40 cycles, the values of inductance and capacitance set for the second circuit were critical for a resonant response. Hertz took an interest in the experiments on lenses; he also conceded, in a letter of 21 July 1889, that his earlier view of a different rate of propagation for waves in air and along wires was probably the result of an error in his measurements.[73] This was later tracked down to the distorting influence of an iron stove placed near the wire in his laboratory.[74]

An incidental result of the 1889 series of experiments was "a curious effect, afterwards known as the coherer principle, whereby a couple of little knobs in ordinary light contact, not sufficient to transmit a current, become cohered or united at their junction whenever even a minute spark passed, and thus enabled the passage of a current from a weak E.M.F. through a galvanometer, until they were broken asunder again, which a tap sufficed to do." The significance of this only became apparent later, but it led in the early stages to an improved version of the resonance jar experiment in which a knob 'coherer' was connected across the secondary Leyden jar together with an electric bell. Discharging the first jar to a tuned second jar then caused the knobs to cohere, thus ringing the bell.[75]

After spending the summer in J. J. Thomson's laboratory at Cambridge, where he measured the velocity of electric sparks from the discharge of a condenser, using a rotating cylinder and high speed photography, having previously showed that an electrostatic field could be generated from a varying magnetic one, Lodge returned to his studies of Hertzian waves in the following winter, and made some important innovations. A resonance jar experiment, with the two jars constituting, in effect, "a Hertz oscillator and receiver", was described in *Nature* on 20 February 1890, and ultimately became the "foundation of tuning and wave measurement", though it followed on from an experiment "on the overflow of one Leyden jar by the impulses accumulated from a similar jar discharging in its neighbourhood" which had been exhibited "in its early stages" at the Royal Institution a year before.[76] Though the direct outcome of an investigation of electromagnetic waves on wires, the principle could be transferred to Hertzian waves in free space once a means of controlling the frequency could be established; in its discovery of effects particular to controlled frequencies of operation, Lodge's work on guided waves contributed also to subsequent radio technology, and led him to results which were greatly in advance of all his competitors.

A letter sent by Lodge to *Nature* on 11 March described an improved oscillator which, unlike the original Hertzian transmitter, could generate waves of a constant frequency. Metal spheres introduced between the secondary terminals created a series of spark gaps, the frequency of the waves produced being determined by the size of the metal spheres. His letter commented on the production of waves "only 17 centimetres ... long" which he supposed were "about the shortest yet dealt with" and explained how a "receiver not very unlike the rod-and-cone structure of the retina" could be made, using an array of metal cylinders.[77] Lodge took great interest in the possible analogy between the reception of radiowaves by Hertzian detectors and that of light by the eye and it was partly his desire to understand the physiological process which subsequently encouraged him to develop an improved radio detector.

Lodge continued to lecture on Hertzian radiation during 1890 and the early part of 1891; on one occasion, apparently after lecturing to the Philosophical Society of Glasgow on 16 April 1890, he returned home unexpectedly early to find the hotels full and his house deserted, and had to spend the night on a bench in Sefton Park.[78] FitzGerald, also, took to lecturing enthusiastically on the new radiation, and, at the Royal Institution, in January 1890, used a sensitive galvanometer for the first time as a radiowave detector.[79]

At the end of the year, Lodge and FitzGerald entertained Hertz at the Langham Hotel when the latter visited London to receive the Royal Society's Rumford Medal on 2 December. Perhaps it was being present at this award which spurred Lodge on to write up the first full account of his experiments with Leyden Jars and read it before the Royal Society on 2 May 1891, with the apologetic statement that they "ought to have been written out for publication long ago". Referring in the opening paragraph to the importance of the experiments as observations of electromagnetic waves and to their success in measuring the speed of electrical impulses along wires, he made a point of incorporating a section of 'Historical Observations' which made it clear that he knew from the beginning that the waves actually travelled in air, that he had made his observations known to the Society of Arts as early as March 1888, and that he was on the point of proceeding to discover the waves in free space as well. "The achievement of Hertz is well known," he said, "and it is only the customary interest attaching to circumstances connected with what will probably be regarded as an epoch in electrical science that constitutes my excuse for making the above statement." The "excuse" that he almost certainly felt justified in making was the feeling that, if there had been an epoch-making discovery, then, without taking anything away from the achievement of Hertz, he was entitled to a share of the credit. In addition, he had not been privileged with the "comparative freedom from students" enjoyed by Hertz, and had actually been alone in demonstrating the identity of the speeds of waves along wires and in free space. This point of view he maintained in all his subsequent publications.[80] He was making the strongest possible statement of priority, or at least equality, compatible with maintaining his position as a Victorian scientific gentleman. He seemed also, with this publication, to be preparing to close the account of his ten-year campaign aimed at finding a proof of Maxwell's theory while the possibilities of other areas of research opened up before him.

In the early years after the discovery of electromagnetic waves, researchers, including Lodge, regarded them chiefly in terms of their confirmation of Maxwell's theory. Early experimenters on Hertzian waves concentrated especially on demonstrating their quasi-optical properties. Technological exploitation was not an immediate priority. At the British Association meeting in 1888, Lodge had prophesied that "the now recognised fact that light is an electric oscillation must have before long a profound practical import",[81] but Hertz himself was a pure scientist, and made no suggestion for technological developments in any of his writings. Doubtless, some like William Crookes, who had observed both Hughes' and Lodge's experiments, were thinking in the direction of new methods of wireless telegraphy, again using the optical analogy, and the editor of the Russian journal *Elektrichvesto* added a footnote to a paper by O. D. Khvolson suggesting "wireless telegraphy similar to optical", as a possible application.[82] The idea of telegraphy or telephony was certainly in the minds of inventors like Hughes and Dolbear who had stumbled on electromagnetic wave phenomena without realising what they had discovered, but neither man came forward after the waves had been finally identified, though Hughes corresponded with Heaviside in 1889 on the nature of the skin effect, and expressed his appreciation of the experiments of Hertz.[83]

To the engineer of 1890, "wireless telegraphy" meant the systems of Morse, Loomis or Edison, depending on water or earth conduction, or alternatively on inductive effects. Such methods were advocated by Preece at the Post Office, and he was personally responsible for several ingenious applications, beginning with the seawater conduction used in 1882 when the telegraph cable across the Solent was broken, and progressing to the inductive system which in the early 1890s linked Lavernock Point near Cardiff with the island of Flatholm in the Bristol Channel. When practical methods were suggested for linking wireless telegraphy with Hertzian radiation they depended heavily on the results which Lodge had announced in his lectures and papers of 1889 and 1890.

Chapter Five
'THE MAN OF BRASS'

by David Sealey

In the same year as his work on the 'recoil kick' (1888) Lodge had been asked to give a series of talks by the Society of Arts, the Mann lectures, on the nature of lightning. In an article in *The Electrician* he described how the experimental set up used in his search for the ether waves grew out of his preparation for these lectures: "it was whilst I happened to be experimenting on lightning and somewhat to my surprise as an outcome of these experiments, I hit on an arrangement that gave me evidence of the very waves I had been thinking so much about."[1]

During the course of this work, besides hitting upon the 'coherer principle', Lodge developed a theory as to the oscillatory nature of lightning. This theory implied that a lightning discharge could take the path of least reactance rather than least resistance and would explain the failure of much of the protection afforded to buildings and telegraphic equipment of the time. It was, perhaps, a theory which was to prove personally expensive to him at a later date for the ideas with which it dealt, self inductance and the skin effect, brought him into conflict with William Henry Preece, electrician and, by 1888, Engineer-in-Chief to the Post Office. Lodge's ideas implied that a thin piece of iron, under certain circumstances, could prove to be a better lightning conductor than a thick piece of copper. "It is remarkable [said Lodge] how many most unlikely circumstances have to be taken into account in order to secure safety from lightning, circumstances which, if they had been mooted, twenty or even five years ago, would have excited contempt in the minds of older electricians."[2]

But it was not contempt that his counter-intuitive ideas brought him so much as open conflict with these self same "older electricians", the most important of whom was Preece, a chief member of the lightning rod conference of 1878-1881 and arbiter of all that was good in lightning rod design. Preece was a self-styled practical man, familiar with direct current and Ohm's law, but reticent to acknowledge their limitations. He was, in addition, seriously deficient in mathematics and scientific methodology and openly contemptuous of theoreticians. In an address to the Institution of Electrical Engineers in 1893 he expounded his views on the subject: "The advance of our knowledge in this branch of electrical development has been very much retarded by the phantasies of visionary mathematicians who monopolise the columns of our technical literature and fill the minds of the student with false conclusions. I have no sympathy with the pure mathematician who scorns the practical man, scoffs at his experience, directs the universe from his couch and invents laws to suit his fads."[3]

Much of this abuse was directed at his arch tormentor, Oliver Heaviside, the brilliant "visionary mathematician" whose theories on electrical phenomena, such as self induction and the 'skin effect', were hopelessly beyond Preece. To Heaviside he was known as the nameless one, the man of brass, the bouncer, Taffy, Mr Priggs, the unscientific speculator and the eminent scienticulist. (Being described as eminent raised Preece from the ranks of the mere ordinary scienticulists where Heaviside was prone to apply his 'scienticulometer' as a measure of a man's scientific eptitude.)[4]

Confrontation between Preece's fellow men of experience and the theoreticians had become inevitable as theoretically applicable advances by men such as Heaviside had threatened to leave the practical men behind and it was the storm brewed up by Lodge's work on lightning, directly challenging, as it did, the findings of the lightning rod conference that forced both sides into a bitter and public quarrel at the 1888 BA meeting at Bath.

On the 12th September 1888 *The Times* reflected on the previous day's "Battle of the Lightning Conductors" in which the mathematicians were "arrayed against the electricians" and which had led "to a great meeting of the mechanical and mathematics sections in which rival theories were championed by Mr Preece and Professor Lodge".[5]

All the reports, with the exception of the hopelessly neutered official one,[5] give an impression of the drama and passion of the afternoon's events; the repartee of the principal exponents frequently being punctuated by cheers, applause and laughter, as each side scored points at the other's expense. Fundamental to the conflict was the relationship between Preece and Lodge which was as much a conflict of personalities as scientific ideology and which was to become important in respect of later events connected with the invention of radio.

The mood of the afternoon's proceedings is captured perfectly by the first prickly exchange between Preece and Lodge which for convenience I have written as statement and response but which in reality occurred as a long address from Preece with a somewhat shorter reply to the issues raised, by Lodge.[6]

Preece began by declaring that he "had under his supervision 500,000 lightning conductors ... and about 30,000 or 40,000 lightning protectors. If 500,000 lightning conductors and about 40,000 lightning protectors were not sufficient to give a man a little experience, what could give a man that experience? (applause)."

Later, Lodge, in rising to reply, gave his, often misquoted, rejoinder: "far from having half a million lightning conductors under his supervision he had not even one. He had not a lightning conductor in his house, nor was there at present one to the college at Liverpool with which he was associated. He had asked for one to be put up; but lightning conductors at present seemed to be so expensive [because of the use of copper rather than iron!] that the answer he usually got was that it was cheaper to insure. (laughter)"

Preece continued in a vein that must have made many of the theoreticians inwardly chuckle: "He [Preece] made mathematics his slave and he did not allow mathematics to make him its slave (applause) ... engineers had no great respect for mere mathematical development unless it was proved by absolutely true experiments. (applause)"

Lord Rayleigh later at the same meeting observed that "during Mr Preece's address one felt that 'mathematician' was becoming almost a term of abuse",[8] while Lodge simply noted that: "Mr Preece had poked some fun at mathematicians but as he could hardly pretend to be a mathematician in that room he would not say anything in reply to it – in fact it was quite unnecessary."

Preece than considered the "bugaboo" of self induction: "As practical men in the telegraph world they had been familiar with self induction for the past twenty years – they knew it, they called it electromagnetic inertia ... Professor Lodge had made a discovery – he did not know what it was – but that Professor Lodge in being possessed by his mania, he would call it, for self induction – he had self induction before his eyes and nothing else, had neglected to study Professor Poynting's paper to the advantage that one would expect."

Of all people to be directed to by Preece, Lodge must have been shocked by his advocacy of Poynting, the work of whom would have been utterly incomprehensible to Preece. (As Nahin says, in his biography of Heaviside, Preece could not have got past the first equation.) Lodge's reply to his statement about self–induction is almost contemptuous and, as such, does not even appear in the official report.

"The term electromagnetic inertia seemed to imply that they [the 'practical men'] knew more than they did, so he preferred self induction till they attained to knowledge."

The most astonishing section of the debate involves Preece's assertion that "Professor Lodge was selected to deliver lectures at the Society of Arts to crack up or eulogise the reports of the conference. (applause) but they had produced, he was sorry to say, a veritable Balaam, who rode upon the British Ass, and instead of going there to bless, he ended by cursing the work of the conference (renewed laughter)."

Preece had unwittingly set himself up for the kill and Lodge responded. "They did not ask him to bless the report they asked him to give a lecture on lightning conductors, so that there had been no breach of contract. There were three parties in the little drama to which Mr Preece referred – Balak, Balaam and the Ass (laughter). Balak was the gentleman who asked the prophet to come and give a lecture; Balak was therefore the Society of Arts ... Balaam was the prophet, who went and said what he ought to have said. He did not know who the third party was, unless – (great laughter) – unless he was the party who spoke against the prophet." In other words, and in the politest possible Victorian phraseology, Preece was an ass, perhaps Heaviside's original Br(itish) Ass!

And so it continued with neither side able to convert the other to its point of view; in the end it was a debate that decided nothing, neither the best method of lightning protection nor which was better, theory or experience. Lodge admitted that, whatever the limitations of the protection, some was significantly better than none, while Preece stated that "the points between Prof. Lodge and himself had been reduced to a very small compass indeed".

In conclusion the President, FitzGerald, remarked that while there "was no doubt that, though there might be room for improvement in the conductors, they [the Practical Men] had on the whole been right".

Despite the somewhat neutral nature of the conclusion there was still the thorny question of who, personally, had got the upper hand. *The Times* observed that: "At present it is generally admitted that Professor Lodge held the best of it in the practical as well as in the scientific aspects of the discussion."[9]

Preece did not agree and his own trade journal *The Electrical Plant* showed a cartoon of the gladiator of experience (Preece), holding a lightning rod, crushing the foe of theory (Lodge) underfoot. There was no sense of this, however, in the following letter in which Preece showed his political guile: "My Dear Lodge, I was very sorry to read in the Electrician this morning your note in reply to Snell's anonymous 'valued correspondent.' I have always made it a rule never to take notice of anonymous writers, and I have benefited from it in the long term. I wish you would think about this and do the same. I am much amused by the absurd and ludicrous line that this controversy – Practice v. Theory – has taken. I repudiate all all [*sic*] responsibility for originating it because you are the principal culprit."

After giving instances of problems where he believed the practical men had formulated solutions before theoreticians had jumped on the bandwagon (including Kelvin's submarine cabling theories) he concluded thus: "... Edison and Hopkinson worked entirely on their own lines and have produced the dynamo of the present day without any help from your so called 'theories'. Lastly the new views of electricity that you are now propounding, and that are being so admirably developed by Hertz, are simply those which I have been preaching and teaching for the past twenty years; and it seems to me that the teaching of Hertz is absolutely the reverse of your own views as propounded by yourself in your early papers in '*Nature*'. I don't want to have controversy with you or anybody else in the newspapers. When you read your paper, as I hope you will, at the Telegraph Engineers we can renew the contest that we waged so admirably at Bath; but I am not going to be drawn into print and my sole object in writing to you today is to try and restrain you from the same practice."[10]

Yet again Preece displayed his ignorance. To argue that the development of the Edison-Hopkinson (or Manchester) dynamo was the result of the cooperation of two practical men and owed nothing to theory is quite untrue. Edison was a practical man but John Hopkinson was a theoretician – a Cambridge Wrangler – whose understanding of the theory of the magnetic circuit helped him to drastically improve the "Manchester" dynamo's efficiency.

Nevertheless, the practical men remained unconvinced by Lodge's arguments. He had, after all, made an enormous jump in assuming that a discharge across a spark gap is identical in nature to lightning; a lightning strike actually consists of a series of intermittent discharges rather than Lodge's electrical oscillations (although the two mechanisms would produce similar effects in the lightning conductor). With nothing having been radically altered, Preece seemed to be happy, for a while, with the status quo. In 1889 he wrote to Lodge: "You and your friends believe one thing – W.H.P. and the old boys believe another, and no one seems inclined to be convinced against his will."[11]

However, the matter continued to fester and one can sense the relationship worsening, despite the fact that to all intents and purposes Preece's views still held sway. In 1893, for example, Lodge felt compelled to write to *Nature* in response to remarks made by Preece. "In the recent Presidential Address to the Institution of Electrical Engineers by Mr. Preece I find the following reference to myself.

"'Prof. Oliver Lodge has ... endeavoured to modify our views as to the behaviour of lightning discharges, and as to the form of protectors, but without much success. His views have not received general acceptance, for they are contrary to fact and to experience.'

"I was quite prepared to laugh at this with the rest but I find the general and semi-scientific public are apt to take Mr. Preece's little jokes, of which there are many towards the end of this address, as serious and authoritative statements of scientific fact. And it has been represented to me that unless I take some notice of the above, it may be assumed that I wish silently to withdraw from an untenable position without acknowledging having made a mistake. ... My reply is that so far was I from that attitude, that I did not suppose that the statement was either meant or would be taken seriously."

After reiterating his views on lightning Lodge continued: "If Mr. Preece only means that these views regarding lightning and its dangers are not yet practically accepted by the Great British Telegraphic Department, that is, I admit perfectly true."[12]

In September 1896, this controversy was to lead to dramatic developments at a BA meeting held in Lodge's own Department in Liverpool. Nine months before the meeting, Lodge had written to Preece, apparently complaining that his position as nominated head of the Electrotechnical Division had been usurped in his own back yard. Preece's reply was suitably conciliatory.[13] "My dear Lodge," he wrote, "To put the applied Electricity Department under Hele-Shaw seems to me ridiculous. My experience of him in connection with BA Committees is very unfavourable & I regard him as rather a sassy gentleman. Besides he knows nothing of Electricity as far as I know.

"To take it away from you would be worse than transferring the play of Hamlet to King Lear and leaving poor Hamlet in Elsinore. You have made the subject your own and have the happy gift of enthusing the young (and sometimes the old) and certainly you have made a school of your own.

"Sincerely yours, W. H. Preece." In characteristically Machiavellian style, he added as postscript: "You can show this to the Principal." The Principal of University College, G. H. Rendall, had been one of the leading architects in gaining the nomination for Liverpool, and was clearly influential with the BA organising committee. Lodge must have considered Preece's letter as strong support for his position, and as evidence for the overall good relations that the two men had maintained for the past seven years, despite their differences of opinion on technical matters.

Back in 1888, he still regarded the lightning rod controversy as a friendly affair, in fact something of an entertaining diversion. On 23 September in reply to a blistering attack on "the man of brass" by Heaviside, he had written: "Unfortunately I am engaged in a friendly controversy with Preece at the present time. He pulls my exp[eriment]s and explanations of them about, but it is absurd to resent it. As a matter of fact I don't resent it in the least. ... That Preece is something of an ignoramus is perfectly well known, but that he is not a good sort of fellow is by no means generally known. ... I have heard Ayrton foaming out at Preece's scientific pretensions, but always thought it foolish of him to get excited about nothing. So long as a man behaves as a gentleman his scientific knowledge or ignorance is of absolutely no moment."[14] In eight years time Lodge was to find out how much of a gentleman Preece actually was.

Fig 23. The British Ass.

Fig 24. *The Electrical Plant's* view of the Lodge-Preece controversy 1888.

Fig 25. Oliver Lodge in 1894.

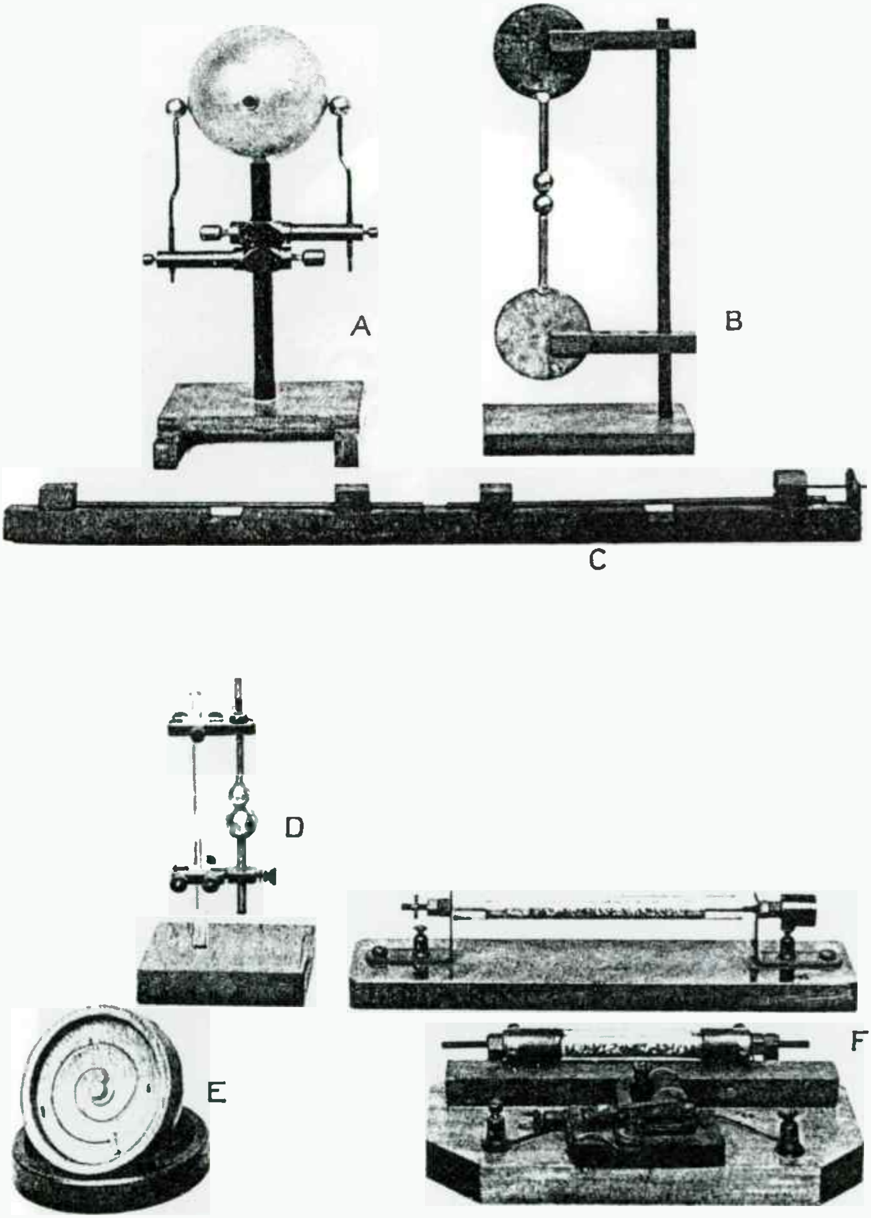
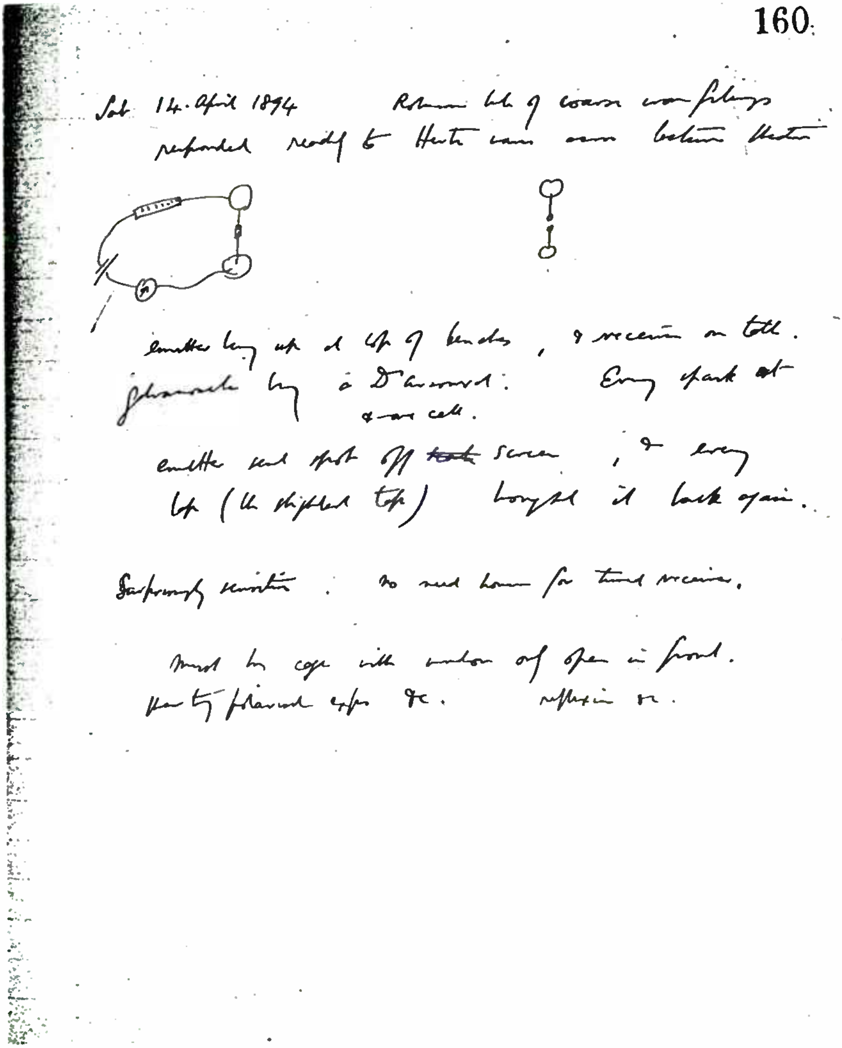


Fig 26. Apparatus used by Lodge in his demonstration in 1894.



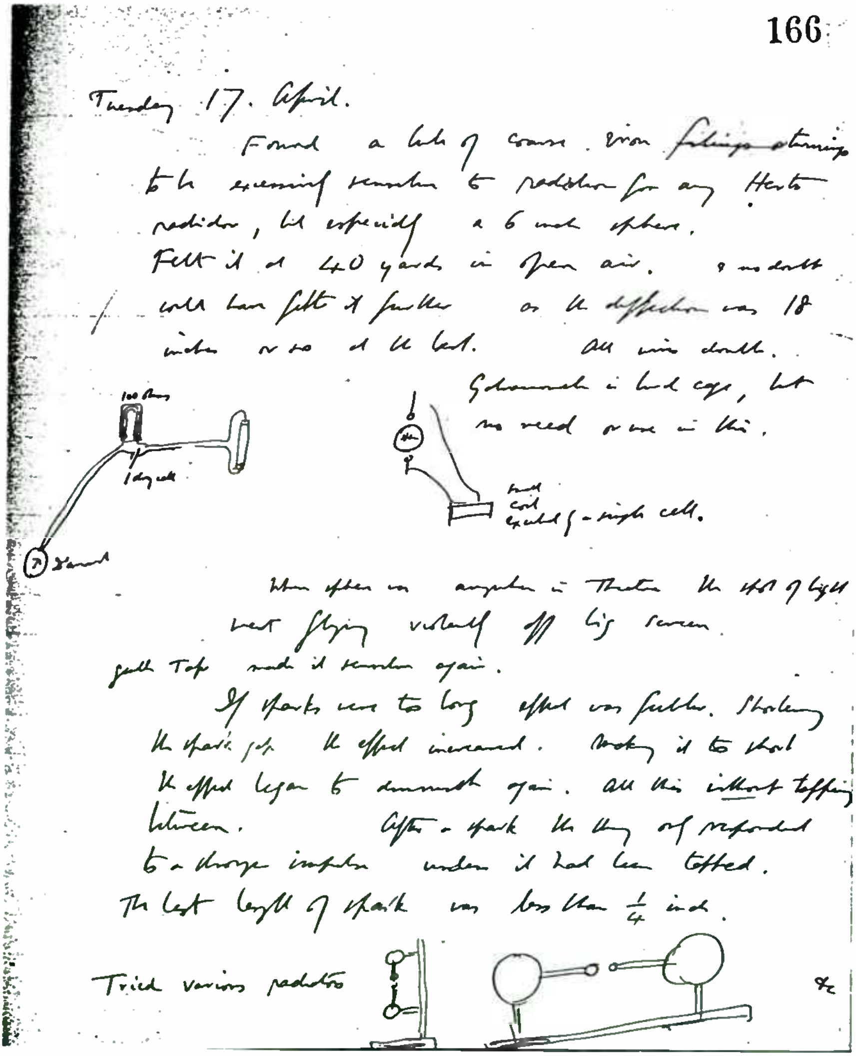
Sat. 14 April 1894   Rotating tube of coarse iron filings responded readily to Hertz waves even between Hertz

emitter being up at top of stairs, & receiver on table. galvanometer being a D'Arsonval. & one cell. Every spark at emitter sent spot off ~~scale~~ scale, & every tap (the slightest tap) brought it back again.

Surprisingly sensitive. No need known for tuned receiver.

Must try cage with window of open in front. Partly polarised expts &c. reflexion &c.

Fig 27. Lodge's notebook, 14 April 1894.



166

Tuesday 17. April.

Found a tube of coarse iron filings ~~borings~~ to be exceedingly sensitive to radiation for any Hertz radiator, but especially a 6 inch sphere.
Felt it at 40 yards in open air. & no doubt could have felt it further as the deflection was 18 inches or so at the last. All wire double.

Galvanometer in lead case, but no need of one in this.

100 ohms

1 daniell

Daniell

bell coil excited by a single cell.

When sphere was anywhere in Theatre the spot of light went flying violently off big screen.
gentle Tap made it sensitive again.

If sparks were too long effect was feebler. Shortening the spark gap the effect increased. Making it too short the effect began to diminish again. All this without tapping between. After a spark the thing only responded to a stronger impulse unless it had been tapped.
The best length of spark was less than $\frac{1}{4}$ inch.

Tried various radiators &c

Fig 28. Lodge's notebook, 17 April 1894.

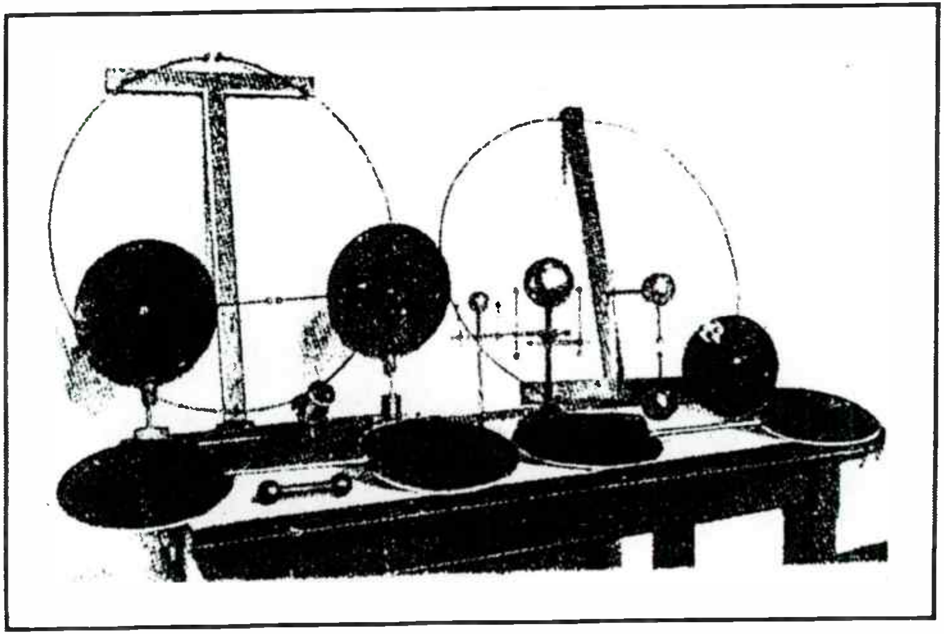


Fig 29. Transmitters used by Lodge at Oxford in 1894.

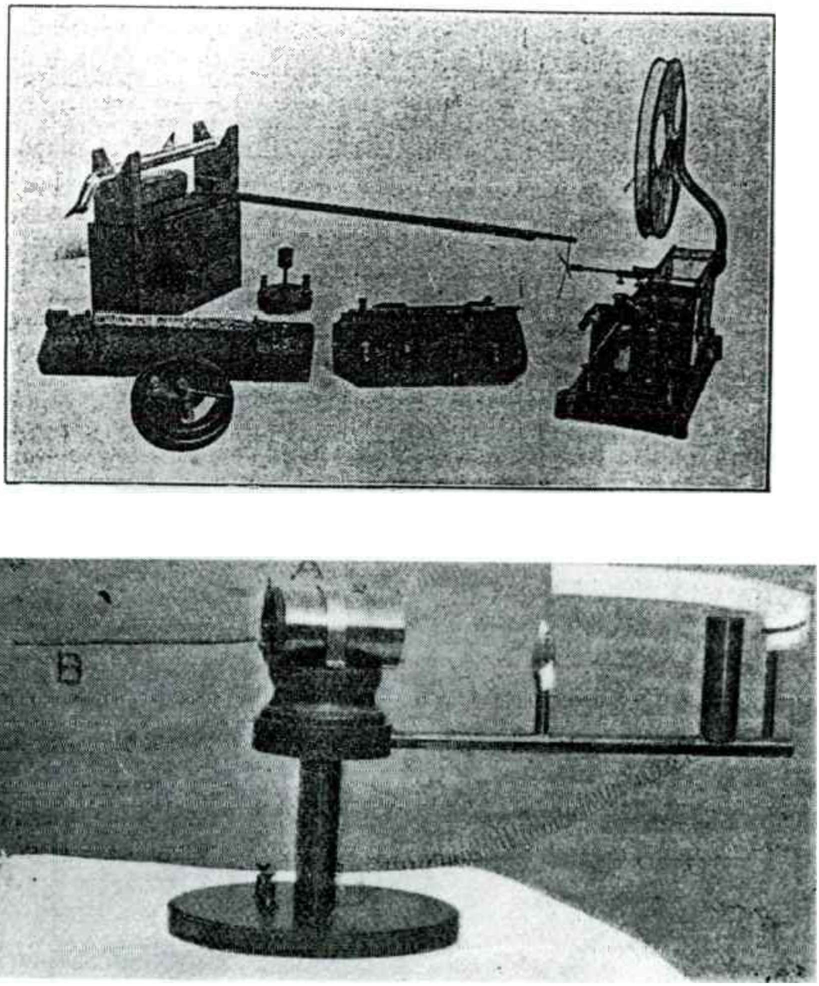


Fig 30. Receivers used by Lodge at Oxford in 1894.

Chapter Six
RADIO BEGINS IN 1894

by Peter Rowlands

The discoveries of Hertz and Lodge generated immediate interest in many places, particularly from those who had attended or read the text of Lodge's popular lectures, which had been reproduced, among other places, in the widely-read trade journal, *The Electrician*. At an early date, for instance, Alesandr Popov, an instructor in the Russian Imperial Navy's torpedo school at Kronstadt, reconstructed a version of Hertz's apparatus for use in his lectures, and in 1890 he gave a more formal presentation in St. Petersburg to a group of naval officers on the properties of electrical waves. The contents of this lecture, which included "Conditions for resonant discharge – electrical resonance phenomenon" and "Wire transmission of electrical oscillations", suggested considerable familiarity with the most recent work of Lodge.[1]

In the following year, Alexander Trotter, the editor of *The Electrician*, and a former lighting consultant to the Royal Navy, proposed that "flash signals" of invisible electromagnetic waves could be used to communicate "between lightships and the shore".[2] Trotter's suggestion had an immediate impact on at least two important people: the naval Lieutenant, Henry Jackson, and the brilliant all-rounder, William Crookes. Jackson, who, like Popov, was on the staff of a torpedo school, originated the idea that Hertzian waves could be used for signalling between ships, a pressing need at that time within the Royal Navy, although security requirements prevented him from publishing it.[3] Crookes, however, the retiring President of the Institution of Electrical Engineers, who had been present at Lodge's Royal Institution lecture of March 1889, and who had even witnessed some of David Hughes's demonstrations ten years previously, followed up, in the *Fortnightly Review* for February 1892, with a specific set of proposals for creating such a system of wireless telegraphy.[4] It would need, he said, a "simpler and more certain means of generating electric waves" of all wavelengths from a few feet to thousands of miles, "more delicate receivers" (to ensure privacy of communication) responding only "to wavelengths between certain defined limits", and "a means of darting the sheaf of rays in any desired direction"; the "flash signals" required by Trotter were precisely identified by Crookes as "messages in the Morse code". For Crookes, this was no idle dream, for "all the requisites needed to bring it within the grasp of daily life" were "well within the possibilities of discovery". He had himself, he said, participated in short-distance transmission of messages (apparently a reference to the experiments of David Hughes), while the recent work of Lodge on syntony had already led to the partial realisation of "a receiver sensitive to one set of wavelengths and silent to others". Though it was not published in a technical journal, Crookes's article, like his other famous contributions to social prophecy, gained a very wide readership.

In the autumn of that year, Nikola Tesla went on a lecture tour of Europe and met both Crookes and Lodge, with whom he shared psychic, as well as technical, interests. It is more than likely that he discussed with them the problem of long-distance communication by electromagnetic waves. Wireless telegraphy, as advocated by Crookes, might seem to be limited in range by the curvature of the Earth, signals beyond a certain range shooting off directly into space. Lodge's friend, FitzGerald, however, had proposed that waves of about 17 000 km and frequency 0.06 Hz, might be long enough for the Earth to be no obstacle to them, and might be generated in the Earth itself. Tesla, accordingly, suggested a method of wireless telegraphy at very low frequencies, using an alternating current generator to disturb the electrostatic field of the Earth; the receiver, "a properly adjusted self-induction and capacity device ... set in action by resonance", could have come straight from the work of Lodge. The extended version of Tesla's proposals, published in the *Journal of the Franklin Institute* in 1893, suggested the use of "a grounded wire reaching up to some height", in which the current "could be increased by connecting the free end to a body of some size" (a scheme used previously in the inductive system of Tesla's former employer, Thomas Edison), and indicated that the "experiment would probably best succeed on a ship at sea". Before he could transmit "intelligible signals", however, Tesla needed to set about finding the

Earth-generated electromagnetic waves of frequency 0.06 Hz which FitzGerald had predicted and which Lodge had already searched for without success.[5]

During this period, Lodge himself was concentrating his research effort in another direction, a massive and expensive project investigating the possibility that massive objects in rapid rotation could produce a dragging effect on the aether around them, so affecting the velocity of light. The thing that revived his interest in electromagnetic waves was the possibility of a new method of detection. In November 1890, Professor Edouard Branly of the Catholic University in Paris had announced the results of a series of researches on the conducting properties of metal filings in glass tubes.[6] Using the sparks produced by electrostatic generators and induction coils, at a distance of more than 20 metres, Branly found that the resistance of the tubes was dramatically lowered, but recovered its original value on shaking. Reports of Branly's results appeared in *The Electrician* in June and August 1891, and the experiments were demonstrated by Dr Dawson Turner at the British Association meeting at Edinburgh in August 1892, a meeting at which Lodge was present. On this occasion, the engineer George Forbes suggested the use of Branly's tube as a Hertzian wave detector.[7] Even then, the possible connection with radio telegraphy was yet to be made; there was, as yet, no general interest in this subject, though William Preece was reported in *The Times* on 22 November as saying that the inductive method of telegraphy which had been used for ten years by the Post Office was transmitted by means of Hertzian waves.[8]

At what stage Lodge became actively interested is not yet known for certain, but it may have been connected with a collaborative investigation made with the physiologist, Francis Gotch on the supposed switching mechanism operating the rods and cones of the eye, extending from ideas proposed by Lodge as early as 1890; Branly, who had discovered his effect by accident while investigating the functions of the nervous system, had similarly speculated on a possible analogy between the switching mechanism and the action of neurones in the brain. On 21 November, Lodge's assistant, Robinson, showed to the Liverpool Physical Society a Voss machine in operation and a key for electrical experiments which could be used "either as a reverser or a double Morse key", while on 19 December Lodge himself showed "a large Hertz vibrator giving electric waves of about 30 metres length" and "exhibited the resonant vibrations set up in various conductors in the room, such as gas-pipes and hot-water pipes". He even went so far that month as to insert his Royal Society paper on 'Experiments on the Discharge of Leyden Jars' into the Liverpool Society's *Proceedings*, in what looks like a clear claim for priority in the original discovery of electromagnetic waves.[9] But Lodge was, as yet, preoccupied with his work on aether drag, and, even if he had then decided to revive his interest in radiowaves, he would still have had little time to pursue it.

Branly filings tubes were again demonstrated about a year later at the Physical Society of London by W. B. Croft, and gained the attention of Professor G. M. Minchin of the Royal Engineering College, a friend of Lodge. It was in a response, dated 24 November 1893, to a circulated preprint of a paper by Minchin that Lodge gave his first public discussion of the principle involved in "the Sudden Acquisition of Conducting-Power by a Series of Discrete Metal Particles". In attempting to explain the phenomenon, he recalled his own experiments of 1889 on the cohering brass knobs, which had responded to even minute sparks, and allowed the passage of an electric current until separated by a tap from the hand.[10]

Trying out a Branly filings tube for himself, Lodge found it more sensitive to electromagnetic radiation than the simple brass knob "coherer" of 1889. According to Lodge, electromagnetic radiation caused the metal filings in the tube to stick together, but to be used as a practical detector, it was clear that the device would require a mechanical vibrating or automatic tapping mechanism to continually separate out the filings between signals and restore their conducting powers. Almost immediately afterwards, however, Lodge and FitzGerald devised an even more sensitive detector, which, when used in conjunction with a telephone, could be restored without any mechanical tapping. In this new kind of single point "coherer", a fine iron wire spring, fixed on to an adjustable spindle, made light contact with an aluminium plate.

Though both the single point and filings tube devices were later known generically as "coherers", they were, in fact, somewhat different instruments. In principle, perhaps, the single point coherer was a rectifier, while the filings tube was a switch; the former could pick up audio frequency "communications from ordinary telegraph lines", but the latter was better adapted to receiving Morse-type telegraph signals. Again, though the single point coherer was more sensitive, the Branly tube was more robust and responded better when subjected to rougher treatment.[11] Though Lodge claimed that a whole series of "quasi-optical" experiments was shown with such a device "to students and the Liverpool Physical Society", there is no record of such demonstrations in the Society's minutes; but he certainly provided signals across the quadrangles at University College, and at home in Sefton Park, his receiver being so sensitive "that even the smallest spark, as from a gas-lighter, gave very appreciable results on an electroscope". In the centre of Liverpool, he went around with telephone receivers in his ears, listening to the radio signals from transmitters stationed at University College.[12] In the meantime, on 1 January 1894, Hertz died, aged only 36, and Lodge was asked to give a memorial lecture. His notebooks for March and April show frenetic activity, as he made last-minute preparations for the lecture on Hertz.[13] On 31 March, he was using a Hertzian detector. On April 4 (following collaborative work he was engaged on with Gotch) he – "Found that nerve and muscle (frog) preparation was not sensitive to Hertz or other quick oscillations though violently sensitive to feeble electrostatic jerks or to low voltage." On Saturday, April 14: "Robinson tube of coarse iron filings responded readily to Hertz waves across lecture theatre. ... Surprisingly sensitive. No need however for tuned receiver." Then, on Tuesday, 17 April he – "Found a tube of coarse iron turnings to be excessively sensitive to radiation from any Hertz radiator, but especially a 6 inch sphere. Felt it at 40 yards in open air, and no doubt would have felt it further as the deflection was 18 inches or so at the least." After further work with tubes of iron filings (18 and 20 April, and 19 May), a "Sender in Zoology Theatre affected coherer in Physics Theatre perceptibly (?) but not violently" on 25 May.

The death of Hertz seems also to have helped renew interest in electromagnetic waves in other places. Augusto Righi, Professor of Physics at Bologna, wrote an obituary for *Il Nuovo Cimento* in April 1894. This was followed by a paper describing experiments which illustrated Hertz's discoveries.[14] Righi's four-ball spark-gap transmitter was clearly based on Lodge's of 1890, although Lodge himself was not named, but his receiver, at this stage, was a Geissler tube, not a coherer. Quite independently, it seems, the young Ernest Rutherford in

Canterbury, New Zealand was using a totally different principle for radiowave detection, based on the demagnetisation produced by electromagnetic radiation in a bundle of steel needles, although he had no means, as yet, of rapid remagnetisation. He may have been working with the discharges from a Leyden jar as early as 12 March 1894 (the year is uncertain); he certainly spoke to the Canterbury Science Society on 'Electrical Waves and Oscillations' on 12 May. Rutherford was well aware of the earlier contributions of Hertz and Lodge, for, in addition to using a version of a Hertzian dumb-bell oscillator in his earliest researches, he had the temerity to criticise the views of both men on the magnetisation of iron in his first published paper.[15]

Lodge's lecture on 'The Work of Hertz' was given at the Royal Institution on 1 June, with the technical assistance of Edward Robinson. Here he gave the first public demonstration of the working of his 'coherer', and showed "a compact 'pocket' Hertz receiver, complete", which had been made by his other assistant, Benjamin Davies, to his specifications, and "was very sensitive to the short waves emitted from a six-inch sphere if the knobs and surface were well polished". Great stress was placed in the lecture on the importance of 'syntony' or resonance tuning for radio detection. Lodge explained that in some receivers vibrations might persist for a long time whereas in others they would be rapidly damped. Persistence could only occur in receivers, such as syntonic Leyden jars arranged in a closed circuit, which responded to oscillations at some natural frequency of vibration; but the signal here, though persistent, would be comparatively feeble. Powerful radiators, on the other hand, such as Hertzian transmitters, although able to excite sparks in conductors not in tune with them, produced vibrations which were rapidly damped. The ideal combination, of significant energy of radiation and persistent electrical oscillation, at present existed only in the Sun and stars, and electric arcs and furnaces. Syntonic detection would enable the experimenter to receive radio transmissions over a distance of half a mile. Lodge implied that he had conducted such tests, though not necessarily directly over the half-mile distance, and he later implied that the half-mile limit referred only to the relatively "primitive" experiments using sparks generated from a sphere 6 inches in diameter and producing 9 inch waves.[16]

Like other experimenters on Hertzian waves, Lodge set out particularly to demonstrate their optical-like properties, such as reflection, refraction, diffraction, interference and polarisation. Here, he used a 2-inch hollow cylinder and 6-inch sphere as sources and a coherer and Kelvin spot galvanometer as receivers, the spot galvanometer having already used been as a Hertzian receiver by FitzGerald in the same lecture theatre as early as 1890. Linking this with his work on the mechanism of vision, he expanded on his theory of 1890 that some part of the eye was an electrical organ, which controlled the action of the rods and cones. He also stated that he intended to try detecting radio waves from extra-terrestial sources, in particular, the Sun, "filtering out the ordinary well-known waves by a blackboard, or other sufficiently opaque substance".

The clear opportunity for telegraphy could be found in Lodge's statement that, "by mounting an electric bell or other vibrator on the same board as a tube of filings, it is possible to arrange that a feeble electric stimulus shall produce a feeble steady effect, a stronger stimulus a stronger effect, and so on".[17] The possibility was not lost on Alexander Muirhead, a leading manufacturer of telegraphic apparatus. Muirhead, we are told, after a sleepless night, "went to Lodge with the suggestion that messages could be sent by the use of waves".[18] Lord Rayleigh was also greatly impressed by the idea, and, about this time (possibly after this lecture, but equally possibly after a later one at which he was certainly present), said to Lodge: "Well, now you can go ahead; there is your life work!"[19]

Twelve days later, at the annual Ladies' Conversazione at the Royal Society, on Wednesday, 13 June, Lodge once again displayed his compact and sensitive detector, this time with the explicit purpose of demonstrating radio telegraphy, or the sending of messages across space using electromagnetic waves. Though he had already signalled in this way over distances of at least 40 yards in Liverpool using headphones, he now replaced the headphones, for the purposes of public demonstration, with a sensitive mirror galvanometer lent by Muirhead.[20]

For scientists of Lodge's generation, however, the British Association was always the big public event of the year, and it was at the British Association meeting at Oxford on 14 August that Lodge gave the most spectacular demonstration of this work to date. On that day, there was a joint meeting between physicists and physiologists on the mechanism of vision, and Lodge intended to show that the process of converting electrical energy into an impulse in his receiver was similar, in principle, to the process of converting light into an impulse in the brain. In doing so, after presenting the ususal quasi-optical effects associated with electromagnetic waves, in a paper 'On Experiments Illustrating Clerk Maxwell's Theory of Light', he provided the world's first public demonstration of radio signalling in Morse code using the waves.[21] A transmitter, consisting of a Hertz vibrator activated by an induction coil, was set up in the Clarendon Laboratory, and when triggered by a Morse key operated by Robinson, sent signals to the receiver, consisting of an iron-filings coherer, connected to a sensitive spot galvanometer stationed in the Oxford Museum, where Lodge was lecturing, 180 feet and two stone walls away. The receiver was also connected to a siphon recorder or "Morse inker", which could record the signals on paper tape, but Lodge preferred to use the galvanometer for most of the demonstration.

Though some of the equipment, including the spot galvanometer (which was of a type specifically designed for submarine cable telegraphy) had been supplied by Muirhead, the key was probably the one that Robinson had demonstrated to Liverpool Society in November 1892. Long and short deflections were produced which depended on the length of time that Robinson held down the key, and Lodge used this to demonstrate the transmission of letters using the dots and dashes of Morse code. Apparently, though individual letters were transmitted, there was no simple eye-catching message, such as was used by later pioneers. Having found that such dots and dashes could be received with ease from the other side of the College quadrangle, a distance of sixty yards, Lodge estimated again that the transmissions could be made over a distance of half a mile.

Lodge did not use the opportunity to proclaim his demonstration as the beginning of a new method of wireless telegraphy, probably because he had no idea that it would really be important in this respect; but the possibilities must have been obvious to some of the others who were present, besides Rayleigh and Muirhead, and the recording apparatus was quite specifically telegraphic. Only the day before, Preece had once again made the claim, with the appropriate reference to ships and lighthouses, and Morse code, that the Post Office system of 'Signalling across space without wires' was transmitted via Hertzian waves, and this had appeared in *The Times* on the very morning of the lecture;[22] the audience, also, included such significant figures in radio history as Alexander Trotter, J. A. Fleming and Silvanus Thompson. Lodge's demonstration, we are told, "excited great interest" and the large lecture theatre of the Oxford Museum was "crowded to overflowing".[23] A leading engineer, A. A. Campbell Swinton, was so impressed that, immediately after the lecture, he set about recreating the experiments in his office "sending signals, ringing a bell and so on through several walls, with a large Tesla high-frequency coil used as a transmitter, and as a receiver a coherer consisting of a heap of tintacks".[24] The paper by Lodge on 'An Electrical Theory of Vision', which followed on immediately after the demonstration, "was received with hearty and prolonged applause", and its suggestion that rods and cones acted like coherer circuits led to an extensive discussion among the physicists and physiologists present, perhaps at the expense of diverting some of the attention away from the preceding telegraphic experiments.[25]

Like many BA talks it was reported on only incidentally; Lodge considered his lectures of 1894 to be essentially variations on the same theme, which had been extensively covered in the Royal Institution talk on 1 June. Lodge also subsequently realised that he had lacked the technological vision of men like William Crookes. As he conceded later, if the "Editor of *The Electrician* (who at that time was exceptionally competent)" had not been present, it would not have received serious notice in the scientific literature. This was a slight exaggeration for an account of the proceedings also appeared in *Nature*, which stated that "the audience, which filled every part of the large museum lecture-room, repeatedly showed its appreciation of Prof Lodge's beautiful experiments".[26] The man who did report it for *The Electrician*, Alexander Trotter, was the editor who had suggested the possible value of such a technology three years before.

But, though he was now aware that his scientific experiments might have some worthwhile technological consequences, Lodge did not follow Rayleigh's advice or the pleadings of Muirhead. Almost immediately after the British Association meeting he went for a prolonged stay in the South of France where he was involved in a series of lengthy experiments on testing the powers of a famous medium, later exposed as a charlatan, and there were other matters to occupy his mind when he returned. But *The Work of Hertz*, was published as a book in September 1894 as well as in several journals, and immediately made its way around the world.

The most significant of its early readers was probably Righi, who began at this time to replace his Geissler tube receivers with coherers. This was significant, not because of Righi's own work, but because his near neighbour at the Villa Grifone was the twenty-year-old Marconi. While on holiday at Biellese in the Italian Alps, during the summer, Marconi had read Righi's Italian-language articles in *Il Nuovo Cimento*, and, according to his own account, conceived of a system of wireless telegraphy; but he made no experiments before he returned home in the autumn, and consulted with Righi himself; he may even have attended a few of the Professor's lectures in Bologna. Righi had by then read the report of Lodge's Royal Institution lecture in *Nature*, and Lodge's influence is clear in Marconi's early work. Though the latter may not have heard directly of Lodge, his transmitter was certainly based on Righi's (and hence, ultimately, on Lodge's of 1890) and his receiver was constructed on the basis of what he could learn from Righi about the Branly-Lodge coherer.

Marconi, whose mother was Irish (a member of the Jameson family of whiskey distillers) and who was well-versed in the English language, was very probably also influenced by Tesla, whose work may well have been available in the Bologna University library to which Marconi now had access. The use of longer wavelengths, transmission through earth or water, capacitative tuning between transmitter and receiver, and raised conducting metal plates with earth connections at both transmitter and receiver, with which he now modified his apparatus, are characteristic of Tesla's proposals of 1893.[27] It is interesting that the technically ill-educated Marconi should have considered it possible to overtake the university-trained and world-famous scientist, who already had at least two years start. Here he had a significant stroke of luck; though Marconi did not know it, a major potential rival was removed when Tesla's New York laboratory caught fire on 13 March 1895.

Marconi's lack of technical training was certainly a problem. It seems that, an early stage in his researches, Marconi made contact through his Irish connections with Frederick Trouton, G. F. FitzGerald's protégé in Dublin, asking for advice through a mutual friend. Trouton apparently suggested that he should go to the City and Guilds Institute in London to learn the relevant theory, and that he should go direct with his invention "to the Post Office as no patents were valid against them".[28]

Even earlier than Righi, there had been a positive response to Lodge from the American engineer Elihu Thomson, who had been one of the early inadvertent discoverers of radiowaves. In July 1894, only a month after Lodge's initial demonstrations, Thomson wrote in *The Electrician* that bad contacts had given him problems while electroplating during a thunderstorm because the plating bath had behaved like a coherer; this "suggested the use of Dr Lodge's ingenious instrument in the study of the waves which are propagated during thunderstorms".[29] The experiment was tried out by Popov in the spring of 1895, and reported on the following May. Popov's lightning conductor used a wire attached to a mast at one end and a coherer at the other, the other end of the coherer being earthed through the water supply pipes. In describing this system in January 1896, Popov specifically acknowledged the origin of his coherer and electric bell combination in Lodge's work, though he had made significant improvements in the method of de-coherence.[30]

Yet another line was followed up by Jagadis Chunder Bose, Professor of Physics at Calcutta University. Bose had already published a study on the optical aspects of radiowaves in the *Proceedings of the Royal Society* when, in December 1895, he contributed three short articles to *The Electrician* describing a system of spark-gap transmitter and receiver, and citing Lodge as source. His receiver was an elaborate variation on the Lodge-FitzGerald spring-mounted point-contact device. Bose's work on the coherer was commended in an anonymous editorial in same issue of the journal, which once again brought up the subject of electromagnetic wave signalling between lighthouse and ship; "the substantial and workmanlike form of 'coherer' designed by Bose", according to the author, would be ideal for the kind of robust receiver required for shipboard use.[31]

As soon as he read this issue, Henry Jackson, now commander of the torpedo training ship, HMS *Defiance*, at Devonport, realised that the coherer principle gave him the opportunity he had been seeking since 1891 "to obtain signals by Hertzian waves from a distant vessel", and he immediately began to experiment.[32] Jackson started with a point-contact coherer, and an induction coil transmitter, along the lines of Bose's apparatus; a few months later, he was also using glass or pitch lenses to concentrate the radiation from the transmitter, again building on a line of work that Lodge had begun.

The idea of using radio telegraphy in connection with shipping was becoming fairly standard among workers in the field. Rutherford, now a research student at Cambridge, who had just demonstrated signalling over a half a mile to the Cavendish Physical Society, wrote home to New Zealand in January 1896: "I have every reason to hope that I may be able to signal miles without connections before I have finished. The reason I am so keen on the subject is practical importance. If I could get an appreciable effect at ten miles, I would probably be able to make a considerable amount of money out of it, for it would be one of great service to connect lighthouses and lightships to the shore so that signals could be sent at any time." Though he did not mention shipping, Popov, in the same month, expressed the hope that his lightning conductor apparatus would "be applied for signalling on great distances by electric vibrations as soon as there will be invented a more powerful generator of such vibrations".[33]

It was while such events were taking place that Marconi came to England in February 1896 after his application to the Ministry of Posts and Telegraphs in Rome had met with a brusque refusal. Marconi had relatives in England, and his cousin, Henry Jameson-Davis was an engineer with a successful practice in London. Accompanied by his mother, the young inventor was well-received. If Marconi knew nothing of Lodge before he came to England, then he would certainly have had the opportunity to do so when Jameson-Davis invited Campbell Swinton and others to see demonstrations of Marconi's apparatus in his lodgings in Bayswater. Swinton is supposed to have asked Marconi how his system differed from that of Lodge which had made such a vivid impression on him less than two years before. Marconi apparently replied that it was much the same but used a more sensitive form of coherer.[34]

With the problem of communication between ships and shore then prominent, it was natural that the proposed invention should be referred to the Engineer-in-Chief of the Post Office. Swinton, accordingly, wrote a letter of recommendation to Preece on March 30: "I am taking the liberty of sending to you with this note a young Italian of the name of

Marconi who has come over to this country with the idea of getting taken up a new system of telegraphy without wires, at which he has been working. It appears to be based upon the use of Hertzian waves, and Oliver Lodge's coherer, but from what he tells me he appears to have got considerably beyond what I believe other people have done in this line."[35]

Marconi, however, always remained sensitive to any insinuation that his receiver was nothing more than a development of an existing apparatus. Thus, Trouton, on a visit from Dublin, was impressed by receiving messages in Morse code at a distance of hundred yards, but when Marconi opened the sealed box and Trouton observed that it contained merely a Lodge coherer, Marconi angrily shut it again, exclaiming, "You would steal my invention".[36] In fact, despite the stories of experiments on 500 substances in the effort to improve this device, it is extremely doubtful whether, at this stage, Marconi's coherer represented any sort of 'development' on previous work.

While Marconi was desperate to gain commercial sponsors for his invention, others were not so interested. On 24 March, Popov used his system to transmit the message "Heinrich Hertz" in Morse characters to a meeting of the Russian Physical-Chemical Society, but, in almost exact repetition of Lodge's behaviour in 1894, he promptly left off these researches with the satisfaction of having proved that it could be done.[37] Popov, like Lodge, was a scientist, rather than engineer, and he was far more interested in fundamental physics than in any technological application.

Rutherford, again, gave the first public demonstration of his magnetic detector in England at a Science Conversazione at the Cavendish in March 1896, and received confirmation that the Royal Society had accepted his paper on 'A Magnetic Detector of Electrical Waves' soon afterwards. But, with rather more scientifically exciting fields opened up by the discovery of X-rays and radioactivity, Rutherford had given up his main interest in radio work by April, and he turned down an offer to demonstrate the device at the Royal Institution in June. When the Cavendish's research director, J. J. Thomson, asked for advice from Lord Kelvin on the possibility of making Rutherford's invention commercially successful, he was informed that £ 100 000 should be taken as the limit to capital expenditure.[38] Such a sum, needless to say, was well outside the Laboratory's budget, even as a "limit"! But, in any case, Rutherford's system was still unsuitable for Morse-code telegraphy, as he had, as yet, devised no means of automatic remagnetisation.

Marconi and Jackson alone pursued practical application. On 20 May Marconi wrote to the War Office suggesting that his invention could be used for guiding "a self propelled boat or torpedo from the shore or from a vessel", and Major C. Penrose, the Assistant Inspector of Submarine Defences, was given the task of evaluating the system.[39] Jameson-Davis realised the importance of protecting his cousin's rights to the invention and a patent was filed on 2 June.[40]

Preece was, in fact, distinctly unimpressed by the demonstration to the Post Office which took place that month. The 'coherer', as Preece's assistant later recalled, was a crude "home made" device, consisting of "a rather large-sized tubular bottle from which extruded two rods terminating inside the bottle on two bright discs very close together and between which could be seen some bright filings or metal particles". It was an altogether more clumsy arrangement than the compact device which was described in the subsequent patent specification; and it came without any automatic means of decohering. The coherer merely operated a bell which continued to ring until the glass tube received "a few sharp taps".[41] The rest of the week was given over to experimenting on a rather ad hoc basis, which included the introduction of an automatic decoherer, after which "The Chief arranged for Marconi's apparatus to be greatly improved in the Mechanics' shop for demonstration to the Admiralty."[42] Unlike Preece, Penrose, representing The War Office, was impressed and arranged a meeting of the Torpedo Committee for 31 August, at which Captain Jackson would be among those requested to be present.

At Preece's request, Marconi set up a more formal demonstration on 27 July for a group of senior officials from the Post Office, in which signals were transmitted between the roof of the GPO West building in St. Martin's-le-Grand and the GPO South building in Queen Victoria Street, about 300 yards away. This time there was a significant improvement. "The Chief's" mechanics created a pair of parabolic reflectors to focus the radiation generated by the spark gap oscillator and detected by the coherer and Morse inker combination acting as receiver;

a bell was connected in parallel with the inker to act as decoherer. The coherer itself probably now took the form of the device described in the patent specification, of a glass tube containing nickel and silver filings about 38 mm long and 3 mm in diameter.[43] On this occasion, Marconi met George Kemp, a former instructor in the Royal Navy torpedo schools, who became thereafter a highly significant member of his team.

Jackson's experiments continued independently into the summer, and on August 20 resulted in the first radio transmission of Morse code messages on shipboard, across the cabin of HMS *Defiance*; by the end of the month the range had been extended to cover the entire length of the ship. By this time Jackson had replaced his point-contact device with a tin- and iron-filled filings tube, decohering with an "electric trembling bell", as Lodge had done in 1894; and had exchanged his pitch lenses for "long stiff copper wires" (acting as aerials) connected "to the terminals of the coherer".[44] Eleven days after his first success, Jackson met Marconi at the War Office conference; a letter of 21 August had directed him to attend, at the apparently considerable cost of a day's partridge shooting. Marconi was less than ecstatic to find out that Jackson had been experimenting on similar lines, but was greatly relieved when he learned that the latter had no intention of patenting it and that Jackson's apparatus was "less advanced in the details" than his own. The two men decided on cooperation rather than competition.[45]

Trials of the Marconi system were arranged on Salisbury Plain beginning on 2 September; Jackson attended as Admiralty representative. A range of $1\frac{3}{4}$ miles was achieved using a spark-gap and coherer, with the radiation again focused by parabolic reflectors. It was during this series of experiments that it was realised that the Hertzian oscillator could be replaced by a simple spark gap and aerial wires raised to heights of 100-150 feet above the ground. Preece later claimed that Marconi had not understood "the proper use and function of vertical wires" before the "Post Office made them for him", but the principle had been used in one form or another by several of the early radio pioneers, and even predated radio telegraphy itself.[46]

By 20 September Preece had decided against the Marconi system, believing the Post Office's induction method to be "cheaper and more practical".[47] On the following day, Rutherford described his 'Magnetic Detector of Electric Waves' to a meeting of Section A of the British

Association, held in Oliver Lodge's department in Liverpool. And Rutherford's was not the only radio apparatus seen by the audience, for Lodge had known since August 13 that Rutherford was to demonstrate his new detector, and had time to make sure that he had his own apparatus ready for display. Hertzian waves were clearly a popular theme at the meeting, for Rutherford's presentation was followed by a lecture by Bose 'On a Complete Apparatus for the Study of the Properties of Electric Waves', featuring his modified version of the point-contact spring coherer.[48]

Discussion of Bose's paper was adjourned until the next day, 22 September, and it was led by a demonstration by Lodge of his radio apparatus of 1894 in full working order. It was after this discussion that Preece made the rather startling announcement that an unknown young Italian had demonstrated, on Salisbury Plain, a few weeks before, a "quite new" system of wireless telegraphy.[49] *The Times* report stated that it was a Hertzian method, but Preece contrived to give the impression that it was something entirely different, and *The Electrician*, on 25 September, asked Preece to reveal details of the new system.[50] Correspondence between Lodge and his friends, FitzGerald and Heaviside, shows their consternation that a Government agency had taken up with an "Italian adventurer", while Lodge's immediate reaction at the meeting was to arrange for a demonstration of his apparatus transmitting Morse signals to come immediately after a paper given by Preece on the following day, and to introduce it with some pointed remarks about Government resources being made available to foreigners but not to workers in Britain.[51]

Despite their private grievances, Lodge and his supporters, upholders of the gentlemanly code in scientific matters, made no public complaint about Marconi. (Bose, who was beginning to have ideas above his station, was quietly dealt with behind the scenes.) The public affirmation of Marconi went by default. For all his other failings, Preece was an outstanding public speaker, and, on 12 December, he lectured in the Toynbee Hall in East London. The theatricality of the occasion was emphasized by a stage-managed demonstration in which the lecturer pressed a telegraph key connected to a transmitter hidden in a black box setting off a bell in another black box carried by Marconi among the audience. Using considerable exaggeration, Preece stated that "the Post

Office had decided to spare no expense in experimenting with the apparatus"; he also claimed that Marconi telegraphy used electrostatic, rather than electromagnetic, effects.[52]

Whatever the merit of his claims for Marconi, Preece's announcement and subsequent lectures had the effect of spurring on the rather desultory efforts of scientists like Popov and Tesla, who now began to resume work on radio signalling in earnest. Tesla was slow in perfecting his system, but, by the spring of 1897, Popov, who had been greatly startled by the news of Marconi's work, was carrying out trials on Russian Navy ships in the harbour at Kronstadt. Another effect was the realisation by the other great powers, such as France and Germany, that this venture might be of considerable commercial (and military) significance. By early 1897, for example, Eugene Ducretet, a scientific instrument manufacturer from Paris, was writing to Popov to find out if he could circumvent Marconi's patents,[53] while the German Emperor's scientific adviser, Adolf Slaby, was taking steps to find out what he could about the Marconi system.

The system itself remained shrouded in secrecy for several months; to the editor of *The Engineer* on 12 March it was still a new system, apparently not Hertzian.[54] Meanwhile, between 15 and 25 March 1897, Marconi's team were once again working on Salisbury Plain. Jackson advised Marconi that raised plates on aerial wires were unnecessary and that only the length of the wire was significant. Lengthening the wires, in fact, greatly extended the range of transmission to $4\frac{1}{2}$ miles. When Jackson visited the site on 24 March, Marconi was using wires raised to "60 or 120 feet by flying kites or balloons", and earthing "one pole of both transmitter and receiver"; Jackson subsequently installed aerials on the masts of HMS *Defiance*.[55]

At this time, Lodge was making only relatively mild protests about Marconi, and seemed content to let the latter pursue the commercial possibilities. On 16 March he wrote to Silvanus Thompson (who was well in with Preece): "But at Oxford I had a coherer on a board with an E. bell & also with a clockwork arrangement (which does better) to shake it back. ... Also I have shown it working a relay. However I hope that Marconi is improving things all round & going to bring in commercially. There will be many improvements wanted in detail before that can be done." But he remained curious about the nature of the latter's system. On 12 April Thompson wrote to him: "I have heard nothing more of Marconi. Preece is to lecture (on him I presume) at R. Inst. ... I shall try to get a sight of Marconi's apparatus before then." Lodge replied on 14 April: "Marconi is nothing but coherer & relay I am first going to publish or patent a plan of precise tuning between send & receiver." (The words "or patent" are an insert showing that Lodge had not yet made up his mind to patent.)[56]

Between 10 and 30 May, Marconi's apparatus was tested alongside Preece's inductive systems across the water from Lavernock on the mainland to the island of Flatholm in the Bristol Channel. On Tuesday, 18 May, after initial failures, signalling was achieved over 8.7 miles. The improvement was largely due to extending the aerial wires, as suggested by Jackson; and the same principle was demonstrated simultaneously by Jackson himself on HMS *Defiance*. Marconi was now convinced that the oscillations were not transmitted via earth as he had previously thought. To Marconi's chagrin, Slaby, was invited to be present. No doubt flattered by letters of commendation bearing the name of the German Emperor, Preece thought it more important to please this foreign ruler than to protect the secrets of a system he thought of no particular technological consequence, and so became party to a blatant example of industrial espionage. Kemp was even ordered by Preece to provide the German with a spare set which Slaby reconstructed on his return home! And Slaby wasn't the only spy at Lavernock. Between 16 May and 4 June, Dr Rhys Jones, a cousin of Benjamin Davies's mother, and a former fellow-student of Lodge's at University College, London, who lived in Cardiff, started reporting on the activities at the coastal station in letters (in Welsh) to his cousin.[57]

By this time, Lodge had decided to patent those aspects of his system which he was certain Marconi had not duplicated. His major patent, 'Improvements in syntonised telegraphy without line wires', was filed on 10 May 1897 while Marconi's was as yet unpublished and while the technical details of Marconi's system were still unknown. The patent presented, in effect, a "complete system of telegraphy by Hertzian waves", with the emphasis on selective tuning as accomplished by self-induction, the prototype being developed with the assistance of Muirhead. In this system, a large amount of power radiated from a narrow range of frequencies was transmitted to a receiver, specially tuned to it. By increasing the self-inductance of the tuning circuit, and coupling it to the aerial, Lodge effectively imposed mechanical inertia on the oscillations. While this reduced the radiation intensity and power consumption, it prolonged the oscillations for a sufficient length of time to allow reception on the selectively tuned receiver. Pairs of cone-shaped sheet-metal 'capacity areas' which terminated in adjustable inductive tuning coils formed the aerials at both transmitter and receiver. The patent also considered the possibility of a grounded aerial and coupling at the receiver by a high-frequency transformer, while a later patent from the same year introduced an extra capacitor to make the *detector circuit* resonant, in addition to the aerials.[58]

The experiments at Lavernock had finally established that the Marconi method did not involve a new form of radiation. On Monday, 31 May, the day after the party returned to London, Preece wrote to Lodge: "I wish you had called here on Friday. I could have shown you everything – even Marconi – who never fails to acknowledge what he owes to you but he never saw your paper on the Work of Hertz until he came here. He learnt what he knows from Righi." On the following day, Lodge wrote to Thompson: "Best thanks for kindly information re Marconi. We had the automatic tapping back in '94 at Oxford. ... I wonder if Preece believes in 'Marconi Waves'!"[59]

But events stimulated by Preece's Friday evening lecture at the Royal Institution two days later finally roused Lodge to a public protest. The lecture, which attracted a very large audience, was reported on in *The Electrician*, and gained a wide coverage in the press and other scientific journals; Thompson contributed by supplying a mechanical model which simulated electric oscillations.[60] Preece here was slightly on the defensive. If it had been said that Marconi had done nothing new, that he had not used a new type of ray, that he had used an old type of transmitter, and a mere modification of Branly's coherer, then he had still produced "a new system of telegraphy that will reach places hitherto inaccessible". Although an editorial in *The Electrician*, proclaimed that Marconi's methods were the same as Lodge's, just achieving a greater range by extending the wavelength from 8 inches to 48,[61] Preece's lecture to the Royal Institution, and another to the Royal Society a fortnight later, the day after Lodge and Muirhead first publicly demonstrated their new tuned radio system at a Royal Society soirée, somehow contrived to give the impression among members of the public that some altogether new scientific discovery was involved.

Lodge felt obliged to write to *The Times* and urged his friend, FitzGerald, to do so as well: "It appears that many persons suppose that the method of signalling across space by means of Hertz waves received by a Branly tube of iron filings is a new discovery made by Signor Marconi, who has recently been engaged in improving some of the details.

"It is well known to physicists, and perhaps the public may be willing to share the information, that I myself showed what was essentially the same plan of signalling in 1894. My apparatus acted very vigorously across the college quadrangle, a distance of 60 yards, and I estimated that there would be some response up to a limit of half a mile … ." Lodge stated that his quarrel was not with Marconi, who was putting every effort into commercial success, but with those writers of popular articles who had written of "'Marconi waves', 'important discoveries', and 'brilliant novelties'". The only 'important discovery' had been that of Hertz in 1888, on which was based the transmitter; while the principle of the receiver depended on "cohesion under electrical influence", which had been observed in different forms by Lord Rayleigh, by Lodge himself and numerous other experimenters.[62]

It is clear from the correspondence of this period that Lodge was greatly disturbed by the whole business, and to a greater extent than he cared publicly to admit. He must have been pleased to receive a letter from Righi, dated 18 June, which referred to Marconi's "so called" invention and called the Lodge coherer a "truly admirable" device. "I shall be very curious," wrote Righi, "to know about his [Marconi's] apparatus, but I suspect it resembles what he rigged up here with my oscillator and your coherer."[63] According to a letter of FitzGerald, there was even a suggestion that Lodge should join up with Marconi to prevent patent disputes. As he wrote on 18 June: "Trouton tells me he wanted you to join the Marconi company. If the Marconi patents are disputed it will be on your work so that they are naturally anxious to get you on their side. I don't suppose you are anxious to be involved in patent right disputes anyway."[64] In another letter, written three days later, FitzGerald described how he and Trouton had been approached by a Dublin stockbroker, named Goodbody, when Marconi was trying to set up the new Company, and that Trouton had been sufficiently impressed with the invention to put money into it, though Goodbody wouldn't tell him how it worked. Trouton, however, was now doubtful about the validity of the patents and wasn't prepared to put up any more money.[65]

It seems clear, though, that FitzGerald, though sympathetic to Lodge, saw no value in prolonging the dispute. In this letter of 21 June, he offered to send letters to any papers that Lodge should ask for. But, he also wrote: "It would be important to keep it from becoming a personal question between you and Marconi ..." The "apportionment of scientific credit," he considered, "is of no value or importance. People like Dewar and Preece think it is and they have their reward." That was the FitzGerald philosophy; it had already cost Lodge dearly once before. According to FitzGerald, Marconi deserved credit for his enterprise; it was Preece who was to blame for the problem. It was "dreadful having an ignorant creature" like Preece where he was.

A letter from Silvanus Thompson on 30 June hints at a more cloak-and-dagger atmosphere behind the scenes. Referring to an article he had written in the *Saturday Review*, Thompson says: "I wanted without unduly offending Preece to put the position of things straight particularly as to the financial aspect. I happen to know that Moulton was called in to advise Marconi on the claims of his final specification of patent, (I did not get this from either Moulton, Preece or Marconi), and he advised him to claim everything. I understand that as the claims are drawn they claim, for telegraphy, not only coherers, oscillators, and such like details, but even Hertz-waves! Naturally I lost no time in saying plainly, there is nothing new except the Hertz-wave, the oscillator and the coherer, and these are not patented nor now patentable."[66]

Lodge was not alone in claiming priority for the invention. Tesla, an almost pathological self-publicist, immediately claimed to have "constructed both a transmitting apparatus and an electrical receiver" in an article which, though anonymous, has all the signs of coming from his own authorship: "Experiments have been made attempting to prove the possibilities, but it has remained for Mr Nikola Tesla to advance a theory, and experimentally prove it, that wireless communication is a possibility and by no means a distant possibility".[67] A patent specification was filed in September, but it was another year before his apparatus was ready for public demonstration.

While the storm broke out in England, Marconi himself was in Italy. On 6 July he gave a rather low-key demonstration in Rome (witnessed, among others, by the Minister of Posts and Telegraphs who had previously rejected him), in which he sent the calculatedly patriotic message "*Viva l'Italia*" between two floors in the offices of the Ministry of Marine, but it was sufficient to have him fêted as a national hero and summoned for an audience with the King of Italy.[68] There followed several weeks of intensive trials of communications between ship and shore at the dockyards of La Spezia. At the same time, his business affairs were put onto a more secure footing when, on 20 July, while he was still absent abroad, The Wireless Telegraph and Signal Company was registered by his cousin, Jameson-Davis, with the promise of massive financial backing from the Jameson family; the formation of the Company effectively ended any serious possibility of cooperation with the Post Office, though Preece's attitude had made this pretty unlikely in any case. Marconi did not return to London till 14 August, when Lodge was on his way to Toronto for the British Association meeting.

When details of the Marconi patent became available, it was evident that his system was not significantly different from that of Lodge. Publishing an abstract of the patent on 17 September, *The Electrician* put forward Lodge's case for priority in the invention, and a note from the editor showed illustrations of Lodge's Oxford apparatus.[69] Numerous claims were immediately made, also, for other anticipations of the Marconi system, particularly in the use of radio aerials, correspondents to *The Electrician* making representations for the early use of this technology on behalf of Edison, Tesla, and even Minchin.[70] FitzGerald even suggested that Lodge might have a claim on the idea himself, writing to his friend on 30 October in a letter marked "Private": "I would like to know whether I am right in saying that you long ago found that connecting transmitter and receiver to a good earth like the gas or water pipes was of great use in increasing the power of the signals. Did you ever publish this? Because this is what Marconi etc are depending on a good deal as I gather from Minchin and the papers. I don't think he understands the real use of it but that does not much matter."[71]

The revelation of Marconi's patent details seems to have come as something of a shock to Lodge and his supporters, as they arrived back from Toronto; Lord Kelvin, for example, wrote on 10 November: "P.S.

I have today seen the 'Electrician' of Sep 17 with Marconi's patent!!!!".[72] Even earlier, on 13 September, Minchin had written to him: "λ [apparently, Lodge's son, Oliver] says that you did not like Toronto. Has Tesla telegraphed 20 miles without wires? [Tesla's first major public demonstration was still a year away.] Marconi gets absurd credit for having taken Righi's transmitter & Branly's tube."[73] On 28 October Lodge wrote to Benjamin Davies, saying that he was thinking of moving to London to pursue the commercial application of radio. Minchin offered his services, writing to Lodge on 1 November: "Λ, I had not seen any letters of yours against Marconi's claims; but I have not been reading the papers. I understood that you opposed his claims to the use of the electromagnetic tapper. How could he possibly get £ 15000 and shares in the City before people can have known what his patent is worth?

"If you think that anything that I have can be combined in any way with your arrangements so as to solve the problem of wireless telegraphy, I shall be happy to join.

"A fortnight ago I took out Provisional Protection for a Receiver which I believe to be extremely sensitive; but I have not used it with the proper transmitting apparatus, so that I am not able to judge its merits against the Branly tube. It answers a little gas-lighting electric machine at a distance of about 50 feet. On the other side is a picture of the apparatus which I sent to FitzGerald three days ago. Keep it secret for the present. ..."

Marconi's patent, of course, threatened to prevent the use by others of apparatus which would be necessary for producing long-range transmission. There was considerable anxiety from both FitzGerald and Minchin about the vertical wire aerials, whose principle, they were convinced, Marconi did not understand. As Minchin asked Lodge: "And is it not possible to dispense with long vertl. wires and kites? I have written to FitzGerald about this. What we want is a long wave. FitzGerald says that the wave from the Hertz balls is not the active one, but the much longer one wh. travels up & down the kite.

"Does Marconi want to prevent us from earthing our poles? I gather he does!! Can the long wave be produced without kites?? I would say that it can."[74] The opposition, however, turned out to be successful. According to Preece, "Marconi applied for a vertical wire to be included in the original patent but was successfully opposed by Lodge and Muirhead."[75]

Using the method of "electrical oscillations" with "rather "primitive apparatus", signals were apparently transmitted by Lodge between University College's new Victoria Building on Brownlow Hill, and the tower of Lewis's, a store owned by Lodge's friend, Louis Cohen, in Ranelagh Street, half a mile distant.[76] Remarkably, however, Lodge put his main hopes on a system of 'Magnetic Telegraphy', using vibrating coils to transmit and receive currents through the Earth. This was similar, in principle, to the inductive 'wireless telegraphy' which had been pioneered by Preece at the Post Office, but employed the additional features of a syntonic system and the coherer as detector. Using the magnetic method, Lodge had been able to signal with relative ease over a much longer distance. It must have seemed at the time more promising than Hertzian waves, and it also had the advantage of using audio signals; it was telephony, rather than telegraphy. Robinson and Davies were set to work on the alternative methods.

By now there was commercial competition developing among Britain's major trading rivals. On 1 November Slaby lectured in Berlin and demonstrated transmission over 21 km, taking care to avoid using Marconi's patented devices, while, on 19 November, Ducretet exhibited his system in Paris, pointedly leaving out both Lodge and Marconi from the acknowledgements.[77] Ducretet's was already a commercial enterprise, while, within a year, Slaby would be founding his own company, which eventually merged with a company founded by Karl Ferdinand Braun to become Telefunken, Marconi's main commercial rival. On 15 December, Thompson wrote to Lodge, sending a copy of Slaby's account: "You will see that he is quite ignorant of your Oxford work, Tesla's work, of Rutherford's $1\frac{1}{4}$ miles, and generally gives too much away to Marconi. He used absolutely nothing that Marconi has any claim to have invented."[78] In November, also, Marconi himself came nearer to commercial exploitation of the lucrative shipping market he sought when he set up a permanent station on Isle of Wight and in the following month arranged trials between a transmitter at the Needles Hotel and a receiver on a steam tug in Alum Bay; messages could be sent over this distance at about 12 words per minute. In February 1898 he set up a second station at the Madeira Hotel, Bournemouth, though this was fairly soon dismantled and moved to the Haven Hotel, Poole.

Lodge showed his annoyance with the Marconi faction and its popular support in articles published in November In a letter to the editor of *Philosophical Magazine*, he wrote that it was absurd to suppose that "electric waves of considerable length" could "penetrate a complete metallic enclosure and affect a coherer inside. ... The statement that they do is a purely misleading one, likely to cause eminent continental physicists to surmise that there may after all be some discovery involved in those sensational newspaper accounts which have not scrupled to use the absurd phrase 'Marconi Waves' and to speak of them as if they were novelties unknown to science."[79] And, on 12 November, he spoke in *The Electrician* of how: "One of the students in Prof. A. Righi's class at Bologna, being gifted, doubtless, with a sense of humour as well as with considerable energy and some spare time, proceeded to put a coherer into a sealed box and bring it to England as a new and secret plan adapted to electric signalling at a distance without wires."[80] A US patent application on the tuned system, which he filed on 1 February 1898 and which was issued on 21 August, later proved highly significant.[81]

In the early months of 1898, Lodge gave a series of public lectures on signalling without wires to such organisations as the Physical Societies of London and Liverpool, the Liverpool Literary and Philosophical Society and the Liverpool Engineering Society. On 21 January, at the London Physical Society, he exhibited a large apparatus made by Muirhead for syntonised electrical signalling to an audience including Rutherford and Campbell Swinton. Lodge's statement, in this lecture, that "No one wants to pay for shouting to the world" shows how far his – and Marconi's – conception of wireless telegraphy was from the modern idea of radio broadcasting. Minchin, who had invited guests to dinner that evening, had to leave before the end, and wrote to Lodge saying that he had missed what he "particularly wanted to hear – viz., the arrangement of capacity & inductance at the Receiver"; his diagram suggests that Lodge was already using the flat triangular plates, which later became such a characteristic feature of the commercial Lodge-Muirhead system, presumably replacing the horn-shaped antennae of 1897.[82] At Liverpool three days later Lodge described his successes in signalling, using electrical oscillations, between the Victoria Tower and Lewis's and, using syntonic magnetic induction methods, between

University College and his house at Grove Park.[83]

On 4 March, presumably hearing that Marconi had now effectively broken with the Post Office, Lodge wrote to Preece, describing how he had been successful with a method of magnetic telegraphy, which did use "an oscillating condenser-discharge", "but with no propagation of waves worth noticing", over the two mile distance from University College to Grove Park, and that he now "had all the calculations ready to plan a circuit for any distance". Preece, replying on 7 March, was glad that Lodge had dropped the "coherer mania"; he had himself done so long before. Lodge had not, in fact, done so, for his new method also used coherers, and he was still investigating the Hertzian method, though on a smaller scale.[84] On May 11, he actually exhibited the two methods of wireless telegraphy side by side, once again in the unlikely setting of the Royal Society's annual Ladies' Conversazione.[85] With somewhat unconscious irony, Preece had explained why he had abandoned his support of Marconi in a letter of 10 March: "I don't think there is any use in trying to work with people that are not willing to be open themselves."[86]

By this time, Robinson was working at Muirhead's electrical laboratory at Elmers End, near Beckenham in Kent. A letter from Minchin, written on a Tuesday soon after 20 April, gives some idea of the atmosphere which had developed following the announcement of the Marconi patent. Minchin, it seems, could not even be sure of the reliability of Muirhead. "Λ, I propose to take the Receiver to Elmer's End on Thursday morning, if you approve. But is it safe? I took out a provisional protection on October 18. Does this make it safe to show the Receiver to Dr. Muirhead? Send me a telegram tomorrow saying yes or no to this question. ... I find that Earth-connection is not necessary; it can be used, and is just as good as a second capacity at each end, but no better. How does this affect Marconi?? ... I'll think about Soirée. I don't like to show things until all is ready to be launched. ... Would Muirhead be good to launch the affair commercially? Can you contest Marconi's emitter? If you can supply the proper arrangements of plates so as to bowl out Marconi, our efforts should be quite successful." At the end of this letter is a note saying: "I hope that Robinson has not explained Receiver to Muirhead."[87]

There was as yet no fully commercial market for radio telegraphy, though the Wireless Telegraph and Signal Company had secured a few minor contracts. In May, Marconi set up an experimental installation between Ballycastle on the north east coast of Ireland and Rathlin Island, for Lloyd's of London, the first radio communication between a lighthouse and the mainland; the trials, which lasted till August, were plagued by a series of unfortunate incidents, and no firm order resulted. But, during the summer months of 1898, Marconi made the most of several gift-wrapped opportunities for maximum publicity. In June, the great Lord Kelvin called at Alum Bay, sending radiotelegrams to Preece and Stokes, which he insisted on paying for; at a shilling each, they became the first commercial radiotelegrams in history. But Kelvin proved more difficult to acquire as a scientific adviser; his terms, requiring that the Company should not attempt to raise any more capital from public share issues, naturally proved quite unacceptable.[88] Another massive publicity scoop for Marconi came in July, when the Company was hired by the *Dublin Daily Express* to transmit coverage by its correspondent of the regatta of the Royal St George Club at Kingstown, near Dublin, with FitzGerald among the passengers on the reporters' launch. Soon afterwards, Marconi and his staff were ideally placed on the Isle of Wight to supply Queen Victoria at Osborne House with radio contact to her son, the Prince of Wales, on the Royal Yacht in Cowes Bay.

Lodge wrote again to Preece in August, stressing how he had been inspired by accounts of Preece's experiments and "partial success" with induction telegraphy. This time there was a more positive response, for Preece invited him to inspect the installations at Lavernock when he came to Bristol for the British Association meeting in September.[89] At this meeting, apparently, when Fleming spoke on Marconi's work, Lodge refused to second the vote of thanks, and "had the impertinence to doubt the results of the Marconi system".[90] Lodge reported to Preece on the Lavernock installations on 18 September. According to his account, Preece's system worked off earth-conduction, rather than induction, though he did not consider this a disadvantage in practical terms. His own magnifier, he believed, would eliminate the need for holding telephone receivers to the ear, as in Preece's system.[91] Preece, replying four days later, showed his general lack of confidence in the whole Marconi enterprise, when he advised Lodge: "If you can get any money out of Marconi's people do it soon. Their big ideas are bubbles."[92]

When Lodge was awarded the Rumford Medal from the Royal Society on 30 November, it was generally seen as a kind of compensation for the massive degree of public attention which had been paid to the work of his rival, especially as the earlier winners included such great names as Faraday, Maxwell, Röntgen and Hertz. Even then, however, the presentation speech by the President, Lord Lister, contained a misconception about his early work which Lodge felt obliged to correct in his autobiography, but which is still current in the literature.[93]

Lodge's paper on 'Improvements in Magnetic Space Telegraphy', read to the Institution of Electrical Engineers eight days later, concentrated mostly on the magnetic method, though it did discuss the collaboration with Muirhead on the method of "electrical oscillations". Preece was in the audience, and Lodge made the point that "the public" owed "its interest" in Hertzian wave telegraphy to him, though he was unable to resist the irony of stressing that it was "owing to Mr. Preece's great influence and power of lecturing" that this "most recent method" of wireless telegraphy had "become the best known of all; and, indeed, Italy" had been "generally credited with the whole discovery". Though Preece no doubt recognised the barbed nature of the tribute, he was full of praise for the speaker. "Professor Lodge", he said, had given an "admirable discourse" and he would be interviewing him the next day to arrange trials with the Post Office.[94]

At a discussion session on 12 January 1899, regrets were expressed that Lodge appeared to have "discarded Hertzian wave telegraphy". But Lodge denied this, saying that the subject would be better discussed later in the year when Marconi was due to present a paper to the Institution. He was, he said, "continually making experiments" with the Hertzian system, "though not on a large scale. Mr. Marconi had much better facilities than he had, and was evidently doing very good work."[95]

Marconi's lecture, in March, created "phenomenal" interest; many were turned away at the door, and the lecture had to be repeated a week later with even greater numbers still unable to gain admission. While the contribution of Marconi's assistants "in the practical application of wireless telegraphy" was generously acknowledged, together with the fact that he had used Righi's oscillator as transmitter, the invention of the coherer was ascribed to one "Professor Calzecchi Onesti, of Fermo, ...

improved by Branly, and modified by Professor Lodge and others."[96]

The urgency with which Lodge and Davies pursued magnetic telegraphy increased as Marconi's successes mounted. On 17 March the Marconi system first showed its value in a marine emergency when the steamship *Elbe* ran aground on the Goodwin Sands, and the radio apparatus on the lightship, installed in December, was used to call out the Ramsgate lifeboat. Ten days later, with the by-now usual massive publicity and representations from the respective Governments, came the first cross-Channel signalling, from the Chalet d'Artois at Wimereux, near Boulogne, to the South Foreland lighthouse in Kent. In a clever stroke of policy, Branly received a personal message of commendation as the 'inventor' of the coherer, thereby undercutting Lodge's claim to the invention of the device based on the scientific principle which Branly had investigated. Fleming, who observed some of the transmissions, made the suggestion that an even greater degree of publicity could be expected if the demonstration could be repeated at the British Association in September. The experiment, which had been planned over a period of many months, was a great success, and led to a contract for trials with the French Navy, as a result of which the Admiralty quickly arranged for wireless telegraphy experiments on the forthcoming Royal Navy manoeuvres; Jackson was recalled from his posting in Paris so that he could take part.

From early in 1899, both of Lodge's assistants were working at Elmers End. While Davies carried on with the magnetic system, Robinson was working simultaneously on the Hertzian method and attempting to set up "two Marconi pole stations". Lodge suggested the use of flat triangular plate-like 'capacity areas' for the aerials, similar to the ones which had featured in the correspondence with Minchin early in 1898. As Lodge wrote to Davies on 15 May 1899: "I suppose that in the Elmers End Hertz experiment there is a large capacity at the top of the pole and not a mere wire? This plate may preferably be horizontal like a lid or roof as in one of my patents. Remind Dr. Muirhead of my insulated roof sometime ... ."[97] Rhys Jones continued to keep the partners informed on Marconi's progress.

It was at about this time that Hughes's results were resurrected after twenty years' neglect. They had never been wholly forgotten. Many Fellows of the Royal Society had seen the experiments and Hughes himself had been elected a Fellow shortly after the affair had ended. By 1899 wireless telegraphy was already considered old enough to merit a history, and the historian, John Joseph Fahie, on hearing of Hughes's work, asked the now 68-year-old inventor for information. Hughes at first declined to claim priority, but he subsequently sent details to Fahie and the correspondence was published in *The Electrician* on 5 May. The published accounts, however, were written on the basis of explanations generally available in 1899 and Hughes's transmission by air conduction became transmission by electromagnetic waves.[98] (Lodge had complained about the same process occurring with the early work of Hertz.)[99] It was also seen that Hughes had had a loose contact in his microphone and hence had effectively used 'coherer' action. The argument could be, and was, used by people who wanted to deny credit for the invention to Lodge, though predecessors of the 'coherer' effect are legion and are still being discovered.[100] Interestingly enough, though Hughes had no idea that he was observing electromagnetic waves, he did, in fact, have some connection with the origin of radio, for Crookes had seen his experiments and been partly influenced by them – after also seeing those of Lodge; Tesla, in turn, had been influenced by Crookes on his visit to England; while Marconi undoubtedly borrowed from the published work of Tesla.

During 1899, Lodge became seriously ill with typhoid fever, and had to direct the work of his assistants from a considerable distance. He was, however, well enough to attend the British Association meeting at Dover in September, in time to witness another spectacular feat by his rival. Acting on Fleming's suggestion, Marconi, whose apparatus had been used to transmit messages over distances as great as 150 km at the Royal Navy manoeuvres in July, duly set up his apparatus in the Town Hall to establish a radio link, via the Wimereux station, with members of the corresponding French Association in Boulogne. Then, on 21 September, he arrived in New York, to a tumultuous reception, to report on the America's Cup race for the *New York Herald*, and to conduct subsequent trials on US Navy ships. The visit, however, was marred by a threatened lawsuit from the American Wireless Telegraph and Telephone Company, who claimed a monopoly on "wireless telegraphy" on the basis of Dolbear's patent of 1885, and, more seriously, by the fact that his tuning methods were inadequate to prevent interference between signals under the conditions that the US Navy had specified. He was unwilling, he claimed, to use the instrument he had devised to correct this problem because it was as yet unprotected by patent. He left America, at any rate, on 9 November, leaving behind the impression that his system had added nothing to American "knowledge of wireless telegraphy".[101]

Marconi's major problem was that, though he had managed a series of spectacular demonstrations to potential customers, and had exported his radio sets across the world, he had still to win the kind of lucrative order that would ensure the financial success of his Company. With Britain now fighting a war in South Africa, the provision of radio apparatus to the Royal Navy had become an urgent requirement; but, in December, the Admiralty, though thanking Marconi for the use of his equipment during the July naval manoeuvres, wrote to him suggesting that they might use the authority they possessed under an Act of 1883 to manufacture their own equipment. At the same time, the Post Office commisioned Lodge and Thompson to write secret reports on the validity of Marconi's patents.

Marconi's experiments had shown that long-distance signalling was impossible without the tuning method which Lodge had patented in 1897, and he was particularly anxious to silence his American critics by sending radio signals across the Atlantic. As Lodge had always recognised, tuning had to be incorporated into an effective radio system, particularly to prevent interference between different users at long distance; so in March 1900, Marconi took out a patent (7777), which blatantly infringed Lodge's of 1897. That Lodge, himself, was still strongly committed to the magnetic induction method is apparent from his advocacy of the system for maintaining contacts with the besieged population at Ladysmith, and from his paper on 'Further Progress on Space Telegraphy', which was read to the Liverpool Engineering Society on 28 March 1900, where the two options were again contrasted.[102]

Analysing Marconi's method of Hertzian telegraphy, Lodge said that it required the creation of vertical oscillations in a spark gap between an electric aerial and Earth. Lodge had used the same principle in his own early work on discharges to gas and water pipes (as demonstrated in his lecture at Great George Street in April 1889) and he had later extended the idea by using a lead roof as the 'aerial'. The advantage of the method, as Marconi had found out, was that the longer wavelength radiations which it generated allowed transmission over greater distances, but, in its simplest form, the method depended heavily on the quality of the ground. Lodge had claimed in his paper of 1898 that earth-conduction, the method he was now proposing to employ with his 'magnifying telephone', played a considerable part in such signalling.[103] But, as he wrote later, in a joint paper with Muirhead, he disliked the Marconi method because using the Earth as one terminal of a spark gap tended to damp out the vibrations and lead to imperfect tuning.[104]

In the early months of 1900, the Royal Navy set out to manufacture their own radio sets, under the supervision of Captain Jackson, but the performance was disappointing; and, after protracted negotiations between the Admiralty and the recently renamed Marconi's Wireless Telegraph Company, it was agreed in July that 32 sets would be supplied at a total cost of about £ 6000, with a further £ 3200 during each of the next ten years. This was the financial breakthrough the Company needed, and, in the same month, they acquired Fleming as a scientific consultant. Part of the deal with the Admiralty involved training the wireless operators, and this led to a change in Company policy; radio sets were now to be leased, rather than sold, together with the personnel to operate them.

Lodge and Thompson's reports, which were completed after the contract was signed, claimed that Marconi had no legal or moral right to his patents. Lodge pointed to his demonstrations at the Royal Institution and the British Association in 1894, and highlighted features which he believed Marconi to have been taken direct from his writings. He claimed, in effect, that he had demonstrated the technique of signalling, though he had been unaware that there would be any demand for Hertzian telegraphy.[105]

From the Post Office, the reports were sent to the Admiralty, where, fortunately for Marconi, they were passed on to Jackson for comment. Writing to Vice-Admiral Sir John Fisher on 28 November, Jackson admitted prior publication of "most of the various instruments and methods described in the Marconi Patents", and added that "a case contested solely on these grounds would probably invalidate many of the claims". But he argued for Marconi's independence, and for his development of practical instruments out of "lecture room forms", often abandoned as useless by their original creators. He even implied that

"Professor Hughes was the original discoverer of the system", claimed by Lodge, a tactic also used by Marconi, who, in a lecture to the Royal Institution in February, just after Hughes had died, gave fulsome praise to "the eminent electrician" who had been "on the verge of a great discovery". But Jackson was being economical with the truth when he said, with regard to his own work, that "at the time I first commenced my experiments in 1895, I had not heard of [Lodge's] experiments, and I had not read any of his works, nor any of those mentioned by him". There is no doubt that he had derived his initial ideas from Bose, who made no secret of his indebtedness to Lodge; and he could hardly have read copies of *The Electrician* without finding the name of Lodge plastered across virtually every page. Jackson, at any rate, advised the Government not to challenge the Marconi patents, and no legal action was taken.[106]

Preece (now retired from the Post Office) was also asked to comment. He had no doubt that it was Marconi who had first demonstrated the use of Hertzian electromagnetic waves in telegraphy. Lodge had never considered such a use till Preece himself had reported on the results of the experiments at Salisbury Plain to the Liverpool meeting of the British Association. Though Lodge was a little more generous than Thompson in his assessment of the Marconi system, both had spent too much time on unimportant details. The Marconi Company should be allowed to indulge in "their imaginary strength" while the Post Office got on with the real business of inductive telegraphy, using either an electrostatic or an electromagnetic system.[107]

Lodge still had great hopes for his alternative system, and from October 1900 to January 1901, while Lodge was establishing himself in his new position at Birmingham, Davies was involved in setting up trials with the Post Office at the Ballycastle site. But the new Chief Post Office engineer, John Gavey, was less sanguine about the project than his predecessor had been, and the trials were finally abandoned in November. Gavey recommended that it would be too expensive for further lines to be laid, though the existing apparatus could be left in working order "so as to make the best of things".[108] Lodge evidently considered this failure a major disaster, for he made no mention of it in his autobiography, and appears to have destroyed his half of the correspondence with his assistant. (It was not the only disaster that year, for Lodge's two closest friends, Myers and FitzGerald, had died within a few weeks of each other during the previous winter.) The magnetic telegraphy had had at least one positive result, however, in the invention of the moving coil loudspeaker, first described in the 1898 paper,[109] while a system of a similar kind was found useful in France, in the First World War, for eavesdropping on telephone calls made from the German trenches.[110]

There was, apparently, to be no alternative to the less-favoured Hertzian system, which Robinson had been setting up between Ilfracombe and Swansea since at least as early as March – Mr. Gavey, Lodge reported, "evidently thinks the other plan is better";[111] and it may have been a response to the likely failure of the 'magnetic telephone' that led to the Lodge-Muirhead Syndicate finally being formally incorporated as a limited liability company in 1901.

The Syndicate set about building radio sets using a new detector, a 'wheel coherer', which required no tapping back after use, and which recorded remarkably clear messages onto tape when used in conjunction with a siphon recorder; but by the time that this device was patented in 1902, and the system tested across the Irish sea and on board the S.S. *Vedamore*,[112] Marconi had already received signals sent across the Atlantic by the giant transmitter installed by Fleming at Poldhu in Cornwall. Unable to break into the lucrative marine communications market, where the Marconi Company had a virtual stranglehold, and the marine insurance business, where a Marconi monopoly was ensured by an agreement made with Lloyd's on 26 September 1901, the Syndicate concentrated on supplying high quality apparatus to customers' specialised requirements. Typical Lodge-Muirhead sets incorporated such features as grounded antennae, and variable capacitance and inductance circuits for tuning, and offered high selectivity at low power over comparatively short distances, usually overland. When able to compete on even terms, the Syndicate did win some major orders, in particular one of 1904 from the Indian Government for communication with the Andaman Islands, which was gained in open competition with the Marconi Company.

Arguments about the invention of radio were pursued in newspapers and periodicals for some years after the turn of the century, with Silvanus Thompson, notably, writing in support of Lodge. In a letter to

The Times of 27 October 1906, Lodge spoke of the "admirable way" in which "Marconi had worked up his invention", but said that this did not entitle the Marconi Company to a monopoly on the technology (they were not in fact, even at that time, the world's majority suppliers);[113] and this remained his official position, whatever he may have thought in private. Presumably, he considered it somewhat less admirable that the Marconi Company at about this time had warned the War Office against buying Lodge-Muirhead equipment "on the ground that it infringed Marconi's tuning patent of 1900"![114]

We have no public reaction from Lodge to the award of the Nobel Prize in Physics to Marconi and Telefunken's Karl Ferdinand Braun, at the height of their intense commercial rivalry in 1909, nor to the award of the Albert Medal of the Royal Society of Arts to the same pair in the same year. Some amends were made ten years later when Lodge himself was presented with the Albert Medal, perhaps through the influence of Trueman Wood, who, as Secretary of the Society long before, had sent out the original request for the Mann lectures on lightning and lightning conductors.[115] But, if Lodge ever read the text of Marconi's Nobel Lecture, he would have been only too well aware of how much commercial concerns had distorted the early history of wireless telegraphy – an inevitable result of the decision to award such a prize in the middle of a major commercial war. Lodge was mentioned only once – in a footnote to a statement that "many physicists" had failed to understand the "practical value" of the innovation of using earthed wires as aerials. On the other hand, "syntony" was mentioned everywhere, as though it were an obvious development of radio technology, and not the characteristic innovation of Lodge – Lodge's theoretical analysis of the difference between powerful, but damped, oscillators and persistent syntonic ones, in an almost exact paraphrase of his own words, was introduced with the phrase "As is now well known". The "sensitive telegraph relay actuating another circuit, which worked a tapper or trembler and a recording instrument" became "Another, now well-known, arrangement which I adopted". The early part of the lecture provided the basis for the official history of Marconi's invention, but in a form which was clearly at variance with the facts.[116]

Marconi and his supporters, of course, strongly emphasized the practicality of his inventions compared to the academic nature of the work of Lodge and his kind – this was particularly true of Fleming, who had proposed Marconi for the Nobel Prize in 1901 even before the transatlantic transmission had been accomplished. But they neglected to point out the essential contribution to practical success made by Lodge's concept of the syntonic circuit, or went out of their way to deny him credit when they found themselves obliged to use it. The origin of this way of thinking had been partly due to the endless debates on 'Practice vs. Theory', centring round Preece, which had been going on at British Association meetings since 1888, and which, every now and again, reared up into a full-scale set-to. One such occurred on 5 September 1910, at Sheffield, when G. H. Bryan, FRS, was given the responsibility for initiating a BA discussion about the mechanics of aircraft flight; the discussion clearly got hopelessly out of hand.

Lodge showed his exasperation with the proceedings in a letter of 7 October to his former pupil, Arthur Porter, now at University College, London. "My dear Porter," he wrote, "To go back to rather ancient history – I do not know who was responsible for selecting Bryan to open a joint Discussion between A and G at Sheffield, but it should be handed down as a tradition of the section that he is utterly incompetent for such a part. In so far as the Discussion had any practical outcome, its result was merely to open a closed breach between the Theoretical and Practical camps.

"I did not hear the whole of his paper, but what I did hear seemed to be flippant irrelevant nonsense, and he himself not far removed from a lunatic for all practical purposes."[117] Lodge's words suggest that, with a serious test of his system against a commercial rival about to reach its climax in a legal battle, his patience with the kind of thinking which had been responsible for the whole débâcle initiated by the original conflict with Preece had finally run out.

A significant point at issue was the validity of the Marconi system of tuning. Legal judgment was effectively made on the Marconi system in 1911, when Mr Justice Parker made the unusual step of extending the 1897 patent of Lodge for a further seven years. Lodge now threatened legal action against the Marconi Company, and put together a 'fighting fund' of £ 10 000, but he eventually agreed to a settlement, arranged through the mediation of Preece, which was signed on 21 October. (It had certainly been an extraordinary turn of fate that conspired to make

Preece the 'honest broker' in this transaction!) Under the terms of this settlement, Lodge's patent rights were bought out for an undisclosed sum, apparently in excess of £20 000, and the Lodge-Muirhead Syndicate was required to cease all activities; Lodge was made a consultant to the Marconi Company, but was, according to his own acount, never consulted. Though Lodge considered the settlement to be a bad bargain, he decided that it was better than litigation, and wrote to Preece that he was "glad to be on friendly terms with the people who have been so enterprising and spirited and successful in world wide practical development".[118] The Marconi Company used its influence to keep news of these transactions outside the national newspapers, but ownership of both tuning patents gave them the opportunity to exercise a virtual monopoly on the radio industry in America and to strike a deal with Telefunken on favourable terms (Telefunken being prepared to accept the validity of Lodge's patent claims, but not those of Marconi). The "Italian adventurer" had become a British commercial hero.

After the Marconi Company buyout, Lodge's interests moved to other things, but his enthusiasm for radio revived in the 1920s when he became well-known as an early broadcaster on the BBC, and contributed extensively to a number of wireless periodicals. Lodge's enthusiasm for radio during this period is vividly recalled by W. H. Eccles: "In the nineteen twenties, when he had a flat in Westminster, I sometimes heard a gentle tap on my front door about midnight and on opening saw the imposing figure of Sir Oliver in a tremendous ulster and cloth cap. 'I was on the way home,' he would say, 'and saw your hall light burning.' Then for an hour or two we would discuss superheterodynes, regenerative reception, or the clipping of sidebands."[119]

In 1925, a year in which he served as President of the Radio Society of Great Britain, Lodge produced a book of *Talks about Wireless*, based on his broadcasts, in which, apart from advocating cryogenic methods to reduce noise levels in receivers, he referred several times to the early history of radio, in particular to the events at the Oxford meeting of the British Association in 1894.[120] He was particularly pleased when the Prince of Wales spoke of these in his Presidential Address to the later Oxford meeting of 1926.[121] He would, no doubt, have felt finally vindicated when the US Supreme Court, on 21 June 1943, three years after his death, declared that the US version of his tuning patent of 1897, filed in February 1898, was the only valid one held by the Marconi Company, Marconi's four-circuit tuning patent of 1900 being among those declared invalid.[122]

The story of the development of radio is a complex one involving the contributions of many people; of the early pioneers, Lodge and Marconi were important above all others.[123] But the two men were contrasting types, and their contributions were different in character. Lodge was a scientist, interested in commercial exploitation of his work but not interested in doing it himself. He notably left the commercial exploitation of his other technological discoveries to be pursued by his sons. Left to Lodge, no radio industry would ever have developed. Even when he was offered the backing of Muirhead, he made no use of the opportunity; he wasn't really interested in a full-scale business struggle. He didn't even believe wholeheartedly in the Hertzian method, and lost time by pursuing the less satisfactory magnetic system. Similar comments, no doubt, could be made of Popov, and of Tesla, the 'scientist' who refused to share the Nobel Prize with the 'inventor', Edison. Of the other early pioneers, Rutherford and Bose were clearly scientists along the lines of Popov and Lodge, while Jackson's efforts were limited by the demands of his naval career.

Marconi, by contrast, was the inventor-entrepreneur, determined, single-minded, obsessive, and slightly unscrupulous, always prepared to use ideas from any source to make his invention work. Above all, he was guaranteed the financial backing from his wealthy family and supporters. Successful inventions always need such characters, however dubiously they go about their business. Of all the early radio pioneers, only Marconi had the vision, the financial backing, the determination and the commercial cunning to make it a world-wide success. The world cannot be expected to wait for the time when people like Lodge or Popov or Tesla should be ready to exploit their inventions. Marconi's, undoubtedly, was a big contribution; others may have toyed with the idea of commercial exploitation but none was so determined to do it.

Early on, when his technical knowledge was still very limited, Marconi, quite naturally, relied on the technological insights of other people. Later on, he made some significant technological innovations himself, but everything in Marconi's original system was borrowed from previous work by Lodge or Tesla; and, even after he had greatly extended the range of reception using high wire aerials, he would not have been able to transmit useful messages across such long distances without direct use of Lodge's work on tuning. Lodge expected Marconi to acknowledge his contribution. He never claimed to have had Marconi's vision of a world-wide radio network, but he did claim, with justification, that the basis of Marconi's development lay in his prior invention.

In order to protect his patent rights and financial investment, Marconi had to deny Lodge his contribution and create the myth of independent invention which has persisted to this day. Lodge's work then had to be presented as one of those precursory efforts that might have led to something but didn't, rather than as the *source* of most of that which followed, which it undoubtedly was; none of the early pioneers could have done their work without first knowing, directly or indirectly, about that of Lodge. Whatever modifications were subsequently made, Lodge had shown that the technology was possible and his work became the direct model for all later developments. With or without acknowledgement, his successors used his transmitters, his receivers and his methods of tuning.

Marconi never publicly admitted his indebtedness to Lodge and contrived, in particular, to suggest that the coherer was a device already invented, which Lodge and several other people had independently exploited.[124] But not one of the users of the 'coherer' was an independent inventor; nor was the coherer a device waiting to be invented. Radio need not even have used it; it could, for example, have been developed on the basis of Rutherford's less sensitive, but more reliable, magnetic detector, an improved version of which replaced the coherer in Marconi's apparatus from 1902. The fact that it used the coherer was because Lodge had used it, and had been successful in using it.

Four years lay between Branly's investigation of the conductivity of tubes of metal filings and Lodge's exploitation of it in a radiowave detector with automatic decoherer. Lodge's success led others to borrow the technique directly from his writings. Everyone who developed a system of radio in the 1890s relied on the technological breakthrough which Lodge had exhibited in his lectures of 1894. In this sense, it doesn't really matter whether or not Lodge transmitted Morse messages at Oxford in August; the fact is that the Royal Institution lecture of 1

June contained all the technology that was required for radio telegraphy, and this fact was immediately recognised by several people. While Marconi brought the enterprise of radio telegraphy to a successful conclusion, Lodge's work was its beginning, and essential to its subsequent development.

Chapter Seven
OLIVER LODGE AND THE COHERER

by Peter Andrews

In 1864 James Clark Maxwell published 'A Dynamical Theory of the Electromagnetic Field' from which it could be predicted that electromagnetic waves would be radiated from oscillating fields. To confirm this experimentally would clearly provide confirmation of Maxwell's central prediction that light was an electromagnetic wave of high frequency. In 1870 von Bezold showed that electric waves on wire have a definite velocity and that standing waves were formed. With a better understanding of the theory, this might have demonstrated the correctness of many of Maxwell's predictions but further confirmation would still have been needed to extend the observations to radiation into space. Oliver Lodge was one of those who set out to provide this support and he started with studies of waves on wires. At the same time Heinrich Hertz was performing a series of experiments which have become famous for confirming in almost every respect the predictions of Maxwell's theory. Following the publication of Hertz's results in 1888 many scientists set out to reproduce these experiments.

The earliest detectors used for research on the 'Hertzian Waves' were wire loops, approximately resonant with the source, which was a powerful electric spark jumping a gap between two metal plates extended on conducting arms. The presence of waves was shown by sparks jumping across narrow gaps in the receiver loop. For a spark to occur at all required a voltage of at least 300 Volts and at this low level the gap was so small and the spark so weak as to be barely visible. Various tricks were used to make the passing of a spark easier to observe and Oliver Lodge was using one of these arrangements, which had been devised by Ludwig Boltzmann, when he discovered a phenomenon that was to be the key to the early developments in wireless telegraphy. In the Boltzmann arrangement, the detector circuit was modified to include a charged electroscope and when the spark bridged the gap it allowed the electroscope to discharge. Lodge was experimenting with various modifications to this arrangement when he realised that it still worked when the brass spheres of the spark gap were actually in physical contact.[1] He coined the name "coherer" for the device because he believed that the passage of the oscillating current made the spheres cohere together allowing a direct current to flow. The name, with its implied mode of action, was probably suggested to him by the fact that the current continued flowing after any high frequency oscillations had died away and could only be stopped by tapping the coherer back.

Lodge had already observed 'coherer' action in circuits during 1889 when he was experimenting on the mode of action of lightning conductors and lightning guards.[2] He had noticed that when the plates of a lightning guard were actually in contact and a surge due to a spark occurred in the circuit, the previously non-conducting contact became conducting. His account of these experiments suggests that there may also have been some rectification taking place at the contact. The series of experiments on lightning guards was particularly fruitful for Lodge as it also led to his famous 'syntonic jars' experiment by which electromagnetic coupling between two resonant circuits was demonstrated for the first time. In these experiments he used the simple lightning guard coherer as a sensitive detector in the receiving circuit. At this early stage he seems also to have been using a bell to vibrate the contact and restore it to its non-conducting state. This became a normal feature of coherer circuits after 1894.

David Hughes had found in 1879 that a bad electrical contact in a bridge circuit could detect electrical oscillations from a spark at a considerable distance. From this he developed a detector consisting of an iron needle resting on a carbon block. He was persuaded by Sir George Stokes and others that he was not detecting radiation from the spark. He abandoned his experiments on radiation and worked instead on a carbon microphone which had originated from the same work on bad contacts. In 1890 Edouard Branly in the Catholic Institute in Paris was experimenting on the effects of Hertzian waves when he discovered that a burnished layer of red, oxidised copper spread on a sheet of glass became permanently conducting when a spark occurred close to it.[3] He went on to investigate many similar arrangements and eventually produced a simple device consisting of a tube of metal filings between two metal plugs which became the usual form for the coherer. The meetings of the French Academy of Science were reported in *Nature* in a brief form and the work of Branly would have been available to readers of *Nature*.[4] At the British Association meeting in Edinburgh in 1892 Dr Dawson Turner did 'Experiments on the resistance of metallic powders' which essentially duplicated the work of Branly.[5] The report in *Nature* begins by commenting: "It is well known that metallic powders have very great electrical resistance."

In October 1893 W. B. Croft, who appears to have been setting up a science course at Winchester School, gave a number of lecture demonstrations at a meeting of the Physical Society.[6] Among them was 'Electric radiation in copper filings' at which he showed a Branly tube type device. Lodge and Minchin were present and showed great interest. Minchin drew attention to the similarity of the behaviour of the tubes of filings to that of his impulsion cells. These were photosensitive selenium cells which probably had faulty contacts and became sensitive to light only when a spark occurred nearby. He had first experimented with these in 1889-90. In reply to a question Minchin stated that the change in resistance was due to electromagnetic vibrations and not to light emitted by the spark.[7] This seems to be the first occasion on which Lodge became fully aware of the work of Branly and the potential of the tube of filings for experimental work on electromagnetic waves. Lodge, Minchin and other members of the Physical Society started experimenting with tubes of filings and mixtures of filings in insulators later in 1893.[8]

Soon after the 1893 meeting Oliver Lodge with FitzGerald produced a more convenient version of his spark gap coherer in which a spring of iron wire touched lightly on the surface of a piece of aluminium.[9] He reserved the name "coherer" for this device and used it for detecting Hertzian waves. Lodge also began using what he called "the iron borings tube" in parallel with his "coherer" for his experiments on electromagnetic waves. He recognised that the action of the two devices was similar but still reserved the name coherer for his own spring coherer when, on June 4th 1894, he lectured 'On the work of Hertz' at the Royal Institution.[10] After that time the term coherer was used in the English speaking world for all devices that appeared to operate in a similar way. As Lodge explained in a lecture to the Physical Society in January 1898: "The name has been extended by others to the filings tube of M. Branly ... ."[11] The fact that this name became universally used for these early detectors gives some support to Lodge's claim that the 1894 lecture had an influence on those who followed him, although Jackson and Marconi both later denied having any knowledge of it. The lecture certainly established the coherer as a sensitive detector of electromagnetic waves and not merely a puzzling laboratory curiosity.

One of the things emphasised by Lodge in 1894 was the great increase in sensitivity of the coherer compared to a spark gap detector and consequently the huge increase in the range over which Hertzian waves from the usual induction coil and spark gap arrangement could be detected. Marconi began experimenting with apparatus very similar to that used by Lodge in 1895 but later claimed that he did this quite independently and in ignorance of Lodge's lecture. This is a little surprising but he also attempted to minimise his debt to Righi, a neighbour and early experimenter on Hertzian waves, who knew the details of Lodge's lecture. The extent to which Lodge influenced other experimenters is difficult to determine because, on his own admission, the Branly devices were already exciting considerable interest before his lecture in 1894 although it was undoubtedly Lodge who demonstrated its value as a detector of electromagnetic waves. The coherer became the standard detector used for wireless telegraphy in the pioneering period from 1896 until 1902 when the magnetic detector was introduced.

In 1894 Oliver Lodge quite reasonably surmised that the operation of the coherer depended on the electrical breakdown and subsequent changes in the oxide layer which is always formed on the surface of a metal exposed to air. His picture of how this happened was framed in terms of molecules but there was no proper atomic theory at that time and certainly no modern band theory of solids with which he could develop the idea.[12] A few years later, in 1899, he was less certain.[13] A confusing variety of effects had been observed when high frequency currents were passed through mixtures of particles and liquids and it was easy to imagine that all of them had similar causes although this was probably untrue. It was widely believed that there was something mysterious about the way the coherer worked but it should be remembered that experimenters had no way of measuring the peak voltages induced in circuits by the extremely short wave trains from spark transmitters. Even with today's equipment it presents problems. This led to many quite unjustified claims. It is easier for us with access to the knowledge accumulated in the century since 1894 to understand their operation.

My tests suggest that the iron/aluminium spring coherer breaks down electrically at a voltage around 2 V, and filings coherers at similar voltages if carefully made. The process is extremely fast and there is no reason to believe that the breakdown is different for high or low frequencies. Once a current flows there is movement of ions in the insulator that reduces the dielectric strength and effectively results in a permanently conducting path. When this has happened the only way to restore the coherer to the insulating condition is to mechanically shift the point contact to a fresh position on the aluminium surface. The metals used in filing coherers all have oxides which are easier to ionise than aluminium oxide and the operation is due to the current finding a path through many point contacts between the filings that are accidentally in series and parallel but the principle is the same. The areas in which conduction take place are likely to be very small and since the oxide layers vary across the surface the sensitivity of the coherer is rather unpredictable. Using fine filings, which became the rule after 1897, would provide many alternative possible conducting paths through the mass and this may have helped give a more constant sensitivity.

Coherers had many disadvantages. They were erratic, relatively insensitive and only had two states: insulating or conducting. In spite of this they were the key components that allowed the laboratory apparatus of 1894 to become the wireless telegraphy receiver of 1900. For this role they had several advantages over the spark gaps that preceded them and the crystal detectors that might well have been used instead. Their great advantage was that they were hundreds of times more sensitive than spark gaps, but they were also indestructible and could be operated close to the high voltage sparks that were used for generating radio frequency waves at that time without being damaged. The Fleming diode which came into use after 1904 must have had similar advantages over crystal detectors. Coherers had another more subtle advantage as a bridge between the laboratory scientists who were studying electromagnetic waves as analogues of light and the engineers who wanted long range communications. Their operation was extremely fast so they responded to the peak voltage induced in the receiving circuit by the short train of waves produced by a spark transmitter. Such transmitters could produce enormous peak powers for nanoseconds although their average power output was small. Oliver Lodge was fully aware that the wave train from his radiators was extremely short: "In consequence of its radiation of energy, its vibrations are rapidly damped, and it only gives some three or four good strong swings."

Another result of their rapid response was that coherers were useful at the very high frequencies used in the initial wireless telegraphy experiments while few of the later detectors would have been. Oliver Lodge used waves with wavelengths of from 3 to 9 inches and frequencies in the GHz range which have recently found widespread use for satellite broadcasting. Marconi used a wavelength of 1 metre in his early experiments but later, when he started to raise his aerials to increasing heights to gain improved range, he was simultaneously reducing the radiated frequency. After 1901 very long wavelengths became increasingly used because they were found to give increased range. This was explained in 1902 by Kennelly and Heaviside as being due to a conducting layer of ions in the upper atmosphere which guided the waves and kept them close to the surface of the earth. By 1902 frequencies had come into use that were lower than any used today for all but very specialised applications. This simplified the development of the next generation of detectors which depended on demagnetising iron and allowed the development of high frequency alternators that were the first sources of truly continuous waves.

Some students and I have carried out experiments on the operation of coherers. The Lodge spring coherer is a convenient system to study because oxide layers on aluminium are probably the best understood system of their kind. The oxide layer grows on clean aluminium in air within seconds to an equilibrium thickness of a little over 20 Å. The high speed of response of the coherer is a result of the thinness of the oxide layer because even a slow propagation rate for the breakdown would still result in times of nanoseconds or less. In my experiments the aluminium oxide film breaks down at potentials of about 2 V which implies a dielectric strength of about 10^9 V/m. This is very high but the oxide layers on aluminium are some of the most perfect dielectrics known. 2

Volts is less than the 7 eV band gap of aluminium oxide, but it is unnecessary to excite electrons across the band gap to cause breakdown.[14] It is sufficient merely to ionise the impurity or other defect states that are always present. Coherers have a wide spread in breakdown voltage that can only be expected from a random surface and they usually continue to conduct after breakdown even when the direct current is removed. This is probably due to movements of ions during breakdown as most of the oxides will conduct ionically as well as electronically.[15] Any increase in the density of impurity states would reduce the dielectric strength in the region of the original conducting path.

The processes involved in electrical breakdown in real oxide films are complicated and still not well understood. In the filings tube type of coherer many oxide layers are in series with the circuit and the dielectric strength of each one must be very much lower than that of aluminium oxide which is quite unsuitable for use as filings.[16] However, the overall response is not very different. The sensitivity can be adjusted by controlling the number of oxide layers that are effectively in series with the input circuit. This is simply done by adjusting the length of the path through the filings and the diameter of the metal particles. Within limits it appears that you can achieve a similar sensitivity with many of the metals that were used in filings coherers such as nickel, brass and copper. The sensitivity of the galvanometers, telephone receivers or relays used in the indicator circuit were probably just as important in deciding what was a suitable coherer filling than the question of sensitivity. When a galvanometer or telephone receiver was used the coherer could be adjusted to operate at a low voltage because only a low voltage would be required in the local circuit. 'Tapping back' would have to be done by hand or by vibrating the coherer continuously. As noted above, an electric bell was often used to 'restore' the coherer but the spark at the bell contact could cause the coherer to conduct. Lodge made a clockwork 'tapper back' to keep the coherer sensitive while a train of pulses was received, and allow unattended operation, but it appears that he used his iron borings tubes without this aid in many experiments. I am unclear whether the bell shown as a part of many coherer systems was ever run continuously. It appears to have been usual to activate the bell only after the coherer became conducting. This intermittent operation required a sensitive relay in the coherer circuit and its characteristics would have set a lower limit on the voltage that could be used across the coherer and hence the sensitivity. Unfortunately I have no information on the relays available to Lodge and Marconi.

Why then did Lodge prefer the iron borings tube for his experiments and why did iron recur as a coherer metal from then until coherers finally vanished from the wireless telegraphy? In 1894 Lodge explained that the iron borings tubes "were more metrical". In 1898 he still preferred iron filings in the best possible vacuum; "brass too is very good but less easy to manage".[17] In his experiments Lodge was using the coherer to measure the radiation from various arrangements of resonators and he was attempting to demonstrate optical analogues. He connected his filings tube containing coarse iron turnings in series with a battery and galvanometer with which he could measure the current after breakdown. He states that the arrangement was most satisfactory when a small current was flowing initially. The oxide layer on the surface of iron is complicated and in my experiments I found the iron filing coherers showed a distinct non-linearity of conduction at low currents and voltages after an initial breakdown. With a carefully adjusted bias current such a detector would be acting as a simple rectifier. However, Lodge gives no hint that he was operating in this mode. Rather, he suggests that the current that flowed after breakdown was proportional to the intensity of the initial high frequency pulse but in 1894 accepted that his evidence for claiming this was not strong. In 1898 he provided experimental evidence to support the claim and emphasized that he believed that the final resistance was proportional to the received stimulus for all coherers.[18] In a footnote to the account of the Royal Institution lecture, dated July 1894, Lodge wrote: "Mr. Robinson has now made me a hydrogen vacuum tube of brass filings which beats the coherer (the spring coherer) for sensitiveness." This suggests to me that it was only during 1894 that Lodge attached more importance to achieving high sensitivity. For his experiments the primary requirement had been a device which gave a quantitative measure of the Hertzian waves. It is clear from the accounts of his experiments that his radiators gave more intensity than he could easily handle and he was forced to make electric screening boxes to control how the radiation entered his detectors.

Iron coherers continued to be used even after Marconi convinced the world that his nickel and silver combination with a touch of mercury achieved the highest sensitivity. H. Rupp of Stuttgart was using them in 1898 with a system for restoring them continuously by rotating the coherer tube.[19] A device used around 1900 was "the Italian Navy coherer" which contained mercury between iron plugs. The odd name arose because its invention was disputed between two Italian naval officers, P. Castelli and L. Solari. It was referred to as a "self restoring coherer" and was used in a circuit with an adjustable voltage source and headphones. It conducted continuously and was very noisy, which made it unpopular, but it seems to have had real advantages over the more conventional coherers. Marconi took this type of coherer with him to Newfoundland in 1901 along with others and used it in his famous test of transmission across the Atlantic. From all the descriptions of its operation it appears that it operated as a crude rectifier rather than relying on dielectric breakdown.

Alexander Muirhead was present at Lodge's 1894 lecture and was inspired to repeat many of the experiments. Lodge and Muirhead later joined forces to produce a commercial wireless telegraphy system. It was difficult to obtain contracts in competition with the Marconi Company but in 1904 the Lodge-Muirhead system achieved a notable success by establishing reliable wireless communication between the Andaman islands and the mainland of Burma, a distance of over 300 miles. This was done with less than one horse-power driving the transmitter. The detector used was a novel coherer consisting of a sharp edged steel disc touching a globule of mercury and insulated from it by a thin film of oil which was constantly refreshed by rotating the disc to draw in oil from a pool floating on the mercury surface. The passage of a signal caused the oil film to break down and a current flowed between the disc and the mercury then through a relay in the usual way. Both the aerial and detector circuits were tuned. This form of coherer was self-restoring and had a more constant high sensitivity than the metal oxide coherers but, in spite of its advantages, it was too late to have a major impact. A variety of new detectors were already supplanting coherers in wireless telegraphy systems.

Oliver Lodge certainly invented the name coherer and was probably the first to demonstrate the usefulness of coherers as detectors of radio waves. He was undoubtedly a co-inventor of the device although the form first made by Branly was the one that was widely used from 1896 to 1902. However, there is no suggestion that the Branly tubes were recognised as detectors of electromagnetic waves earlier than 1893. After the demonstration by Croft, Minchin, Lodge and many others who were present must have recognised this. How much influence Lodge had on subsequent work is hard to determine because so many of the pioneers were later employed by the Marconi Company and Marconi denied all knowledge of Lodge's work. One must assume he wished to protect his patents. The two lectures given by Lodge in 1894 to the Royal Institution and the British Association[20] received wide publicity and writers in the period to 1910 always gave Lodge full credit for his work on the coherer and on syntony. Typical is an American (C. G. Ashley) writing in 1911: "Mention must be made of the great debt which radiotelegraphy owes to Sir Oliver Lodge for his many valuable contributions both to theory and practise. He has been in the forefront of every advance made in the science of radiotelegraphy, and might in all truth be called its patron saint. To him is due our knowledge of syntony which forms a vital part of all modern systems. He was the first man to employ the Branly coherer as a detector of Hertzian waves, and while engaged in demonstrating the discoveries of Hertz was sending signals over distances measurable in hundreds of feet ... ."[21] Lodge himself always believed that his influence on the pioneers of wireless telegraphy was considerable and stated this firmly in the Sylvanus Thompson Memorial lecture which he gave on 1st February 1923. H. M. Dowsett, writing that year, reports: "He spoke of his own lecture on 'The Work of Hertz', in which the receiving of signals by coherer was demonstrated and rightly claimed that his lecture stimulated Captain Jackson, Admiral Popov, Professor Righi, and others at that date, to their experimental success."[22] Dowsett must be regarded as a reliable witness. Along with Franklin, Round, Gray and Vyvyan he was an early recruit to the Marconi Company and was still working on the technical side of the company in 1920. The coherer was essential for Marconi's pioneering work on wireless telegraphy and, although it was replaced by better detectors within ten years, none of these would have been developed if the coherer had not been invented first.

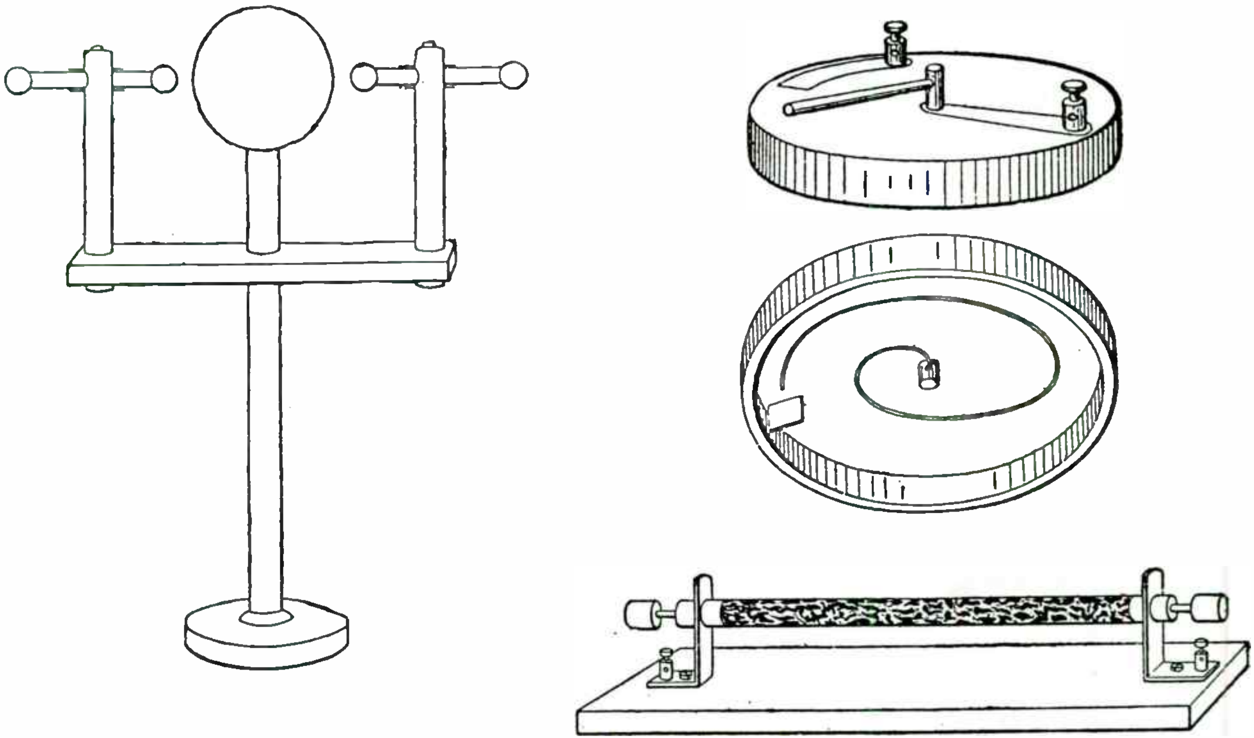


Fig 31. The Lodge spherical transmitter, borings tube, and spiral wire coherer.

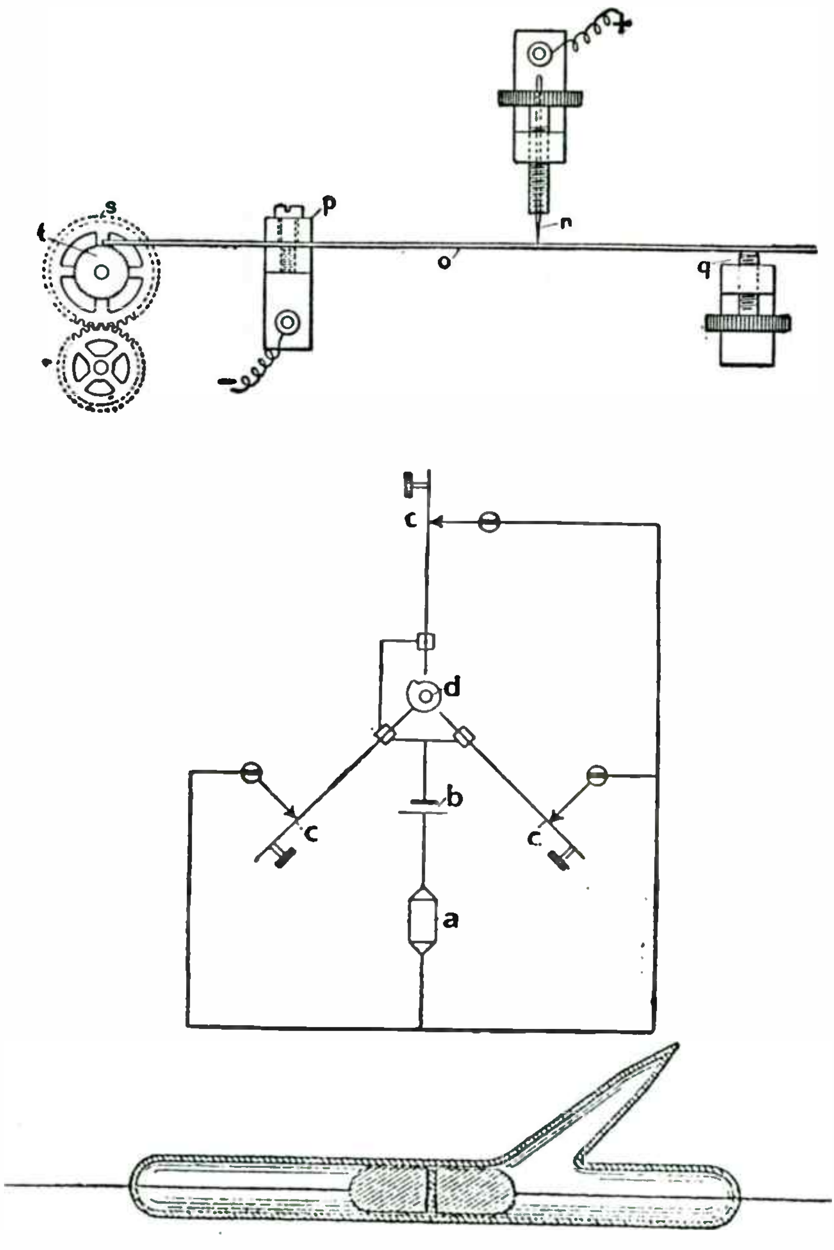


Fig 32. Lodge's single point spring coherer with clockwork decoherer and the Marconi coherer.

Chapter Eight
WAVES FROM THE SUN

by Peter Rowlands

In his historically-important lecture to the Royal Institution on 1 June 1894, Lodge commented incidentally on the possibility of detecting radio waves from extra-terrestial sources, in particular, the Sun: "I hope to try for long wave radiation from the Sun, filtering out the ordinary well-known waves by a blackboard, or other sufficiently opaque substance." The experiment was carried out on several separate occasions during the same month, with negative results in each case.[1]

On 12 June, Lodge set up a reflecting galvanometer, designed to receive centrimetric wavelengths, as receiver, in an iron shed that served as an electrotechnics laboratory in his Department at University College. The notebook entry is still preserved: "Tried sunshine today on coherer in hole in dark room. Reflected in through observation (?) window by tin plate outside. Spot of light did not keep still but couldn't swear to proper sun effect

"Tried next filings tube. Spot steadier, on admitting sunlight the spot crawled slowly but distinctly up and did not return. Effect repeated every time copper screen was removed. Probable heat effect. Interposed extra screen of paper. Now effect was less.

"Evidently no strong constant sun effect, but it may be intermittent or it may be weak."[2]

Further attempts were recorded on 24 June: "Tried many exp(eriment)s meanwhile and now a brass filing tube was tried. It got tired and after a few days was quite insensitive. Clean filings were fearfully (?) sensitive but very difficult to work. Conducted too well. Old filings too lazy (?).

"Put them in eye-liquor and they were killed. Benzoin did not kill them."

Lodge also used two separate coherer-receivers, presumably to establish syntony if radio signals were received: "Tried 2 separate tube circuits in sunshine to see if they kept time. Session of (?) operation on lead roof. no connexion with roof. Exp(eriment) not distinct as to result."[3]

It is possible that Lodge's apparatus may not have been sensitive enough to achieve a positive result, but the main problem was the high level of disturbance for an unprotected apparatus in the middle of a city. As he wrote later: "I did not succeed in this for a sensitive coherer in an outside shed unprotected by the thick walls of a substantial building cannot be quiet for long. I found its spot of light liable to frequent weak and occasionally violent excursions, and I could not trace any of these to the influence of the Sun. There were evidently too many terrestial sources of disturbance in a city like Liverpool to make the experiment feasible. I don't know that it might not possibly be successful in some isolated country place, but clearly the arrangement must be highly sensitive in order to succeed."[4]

Though unsuccessful, this was the first experiment in radio astronomy that we know to have actually been carried out. An experiment to detect long-wavelength radiation from the Sun had been planned a few years earlier by Thomas Edison and the electrical engineer, Arthur Kennelly, and outlined in a letter from Kennelly to Professor Holden, Principal of Lick Observatory in California, dated 2 November 1890. It is by no means clear that the experiment was aimed at detecting Hertzian radiation – Kennelly's letter suggests otherwise: "I may mention that Mr Edison, who does not confine himself to any single line of thought or action, has lately decided on mining a mass of iron ore in New Jersey, that is mined commercially, to account in the direction of research in Solar physics. ... Along with the electromagnetic disturbances we receive from the sun which, of course, you know we recognise as light and heat (I must apologize for stating facts you are so conversant with), it is not unreasonable to suppose that there will be disturbances of much greater wavelength. If so, we might translate them into sound. Mr Edison's plan is to erect on poles round the bulk of the ore, a cable of seven carefully insulated wires, whose final terminals will be brought to a telephone or other apparatus. It is then possible that violent disturbances in the sun's atmosphere might so disturb either the normal electromagnetic flow of energy we receive, or the normal distribution of magnetic force on this planet, as to bring about an appreciably great change in the flow of magnetic induction embraced by the cable loop, enhanced and magnified as this should be by the magnetic condensation and conductivity of the ore body, which must comprise millions of tons."[5] Such an experiment, needless to say, would have had no realistic chance of success, and we have no evidence to suggest that it was actually carried out, though the poles had arrived by 21 November.

Today, the idea of extending optical astronomy to cover the whole electromagnetic spectrum is perfectly obvious, but the existence of such a spectrum only became apparent with the discovery of radio waves in 1888, and the subsequent establishment of Maxwell's electromagnetic theory through the efforts of 'Maxwellians', like FitzGerald, Lodge and Heaviside. Lodge, however, realised the opportunities right away. After Captain Abney had extended the techniques of photography far into the infrared, for example, Lodge suggested to the inaugural meeting of the Liverpool Physical Society on 16 December 1889 that "Celestial photography, with plates sensitive to obscure rays, might reveal a number of invisible semi-cool worlds".[6] Again, almost as soon as X-rays were discovered, and claimed by some to be an extension of the spectrum beyond the ultraviolet, Lodge was asking readers of the *Liverpool Daily Post* if the Sun emits X-rays, for Alpine tourists had reported that their photographic plates were being fogged.[7]

Lodge's solar radiation experiment might have been undertaken in a spirit of general scientific curiosity, but it is also possible that it was part of a larger research programme whose agenda had been set by his friend, FitzGerald. In the ninth edition of *Encyclopaedia Britannica* (1882), Balfour Stewart, Professor of Physics at Owens College, Manchester, had suggested that a conducting layer in the upper atmosphere might explain correlations between fluctuations in the Earth's magnetic field and the sunspot cycle.[8] By 1892, FitzGerald had developed a "theory of the travel of electric waves round the globe", assuming such an upper conducting layer, which he first presented publicly at the British Association meeting in 1893.[9] In principle, according to FitzGerald, the "period of a simple sphere of the size of the earth, supposed charged with opposite charges of electricity at its ends, would be about 1/17 of a second, but the hypothesis that the earth is a conducting body surrounded by a non-conductor is not in accordance with fact." Rather: "The fact that the upper regions of the atmosphere conduct makes it possible that there is a period of vibration due to the vibrations similar to those on a sphere surrounded by a concentric spherical shell."[10]

The period of oscillation of these Earth-generated waves would, therefore, depend on the height of the conducting layer. At 60 miles, or 100 kilometres, which he considered "much higher than is probable", it would be of order 0.1 second; as usual, he put it to his friend, Lodge, that he should try the experiment. Lodge tried to detect waves at 1/17 second, but without success. FitzGerald expected to find that alternating currents in the upper atmosphere, travelling north and south round the Earth, would give rise to alternating magnetic fields travelling east and west. Lodge, therefore, hung up a compass needle in his laboratory and spent hours watching it to look for magnetic disturbances. His assistant, Edward Robinson attempted to find a "difference in the permeability of iron" for North and South magnetic poles, due to the action of the Earth's magnetic field.[11]

From the point of view of electromagnetic wave transmission, a period of 1/17 seconds would correspond to a wavelength of 17 000 kilometres, large enough for the Earth to be no obstacle to its progress. These ideas of FitzGerald's were discussed with Tesla when the latter came to England on his tour of Europe in the autumn of that year, and led to Tesla's proposal for a system of wireless telegraphy using "rapid variations" of the Earth's electrostatic field. To facilitate the introduction of this system, Tesla resolved, on his return to the United States, to conduct a research programme to generate standing waves in the Earth's electrostatic field and to determine their period.[12]

In November 1892, FitzGerald visited Liverpool as external examiner for University College; he may well then have discussed a new idea he had had concerning magnetic storms. It was mentioned in a letter to Lodge of 14 November, in connection with comets' tails. Then, at the Liverpool Physical Society, on 21 November: "Prof. Lodge called attention to the fact noticed by a French astronomer, that a period of some hours elapses between the occurrence of a sun-spot and the magnetic storm consequent upon it. If the magnetic disturbance were directly due to the spot the effect would reach the earth with the velocity of light and so the spot and its magnetic storm would be simultaneous.

Prof. FitzGerald explains the storm by supposing a cloud of electrified particles to be projected from the sun at the time the spot occurs. These passing near the earth would create a magnetic storm."[13] Here was an adumbration of the later discoveries of the solar wind and cosmic rays (the cause, incidentally, of the fogged plates which Lodge had attributed to the action of X-rays).

The idea first reached print in a review of Heaviside's *Electrical Papers*, published in *The Electrician* in August 1893; magnetic storms were there suggested as being due to "a projection of electrical ions in some of the outlying streamers of the corona".[14] FitzGerald later recalled that he had supposed magnetic storms to be "due to something of the same kind as cathode rays" produced in vacuum tubes (or what we would now call electrons) and he "made a calculation as to the density of electrification". Other writings of his suggest that this explanation could be linked in with the phenomenon of the aurora, already known to be connected with magnetic storms; a contemporary manuscript applies the "striae of vacuum tubes" to "aurorae".[15]

When FitzGerald gave his report 'On the Period of Vibration of Electrical Disturbances upon the Earth' to the British Association meeting at Nottingham in September 1893, he connected the alternating currents in the upper atmosphere with the aurora and magnetic storms, and it seemed reasonable to discuss the possibility that such a conducting layer might also surround the Sun. FitzGerald considered that a conducting layer round the Sun would produce oscillations which would not give rise to radiation, but that it should be possible to detect the alternating magnetic fields produced by the alternating currents in the upper atmosphere of the Earth. "Dr. Lodge" he said, "has already looked for evidence of such magnetic forces."[16]

Lodge immediately gave his opinion that the detection and observation of the magnetic disturbances sought by FitzGerald could be done only in a National Physical Laboratory, an institution whose formation he had been advocating on a regular basis at meetings of the British Association. He considered that: "If the Sun were a conducting layer surrounded by a non-conductor, the period of an electrical oscillation upon it would be $6\frac{1}{2}$ seconds. He had hung up a needle in his laboratory and watched it for hours, but the only disturbances he observed were due to trains and traffic. He pointed out that electric vibrations of a molecule, calculated from its size, were more rapid than those required to produce light." In contrast to FitzGerald, he thought that there might well be a conducting layer surrounding the Sun, but questioned the latter's assumption that this would necessarily prevent radiation.[17] It was presumably following this, when he had created a superior radio wave detector, that Lodge decided to looked more directly for electromagnetic waves from the Sun.

A few other independent attempts were made by various workers near the end of the century to detect the Sun's radio emission, which were, for a variety reasons, once again unsuccessful. Wilsing and Scheiner tried at Potsdam in 1896 during a sunspot minimum; while Nordman in 1901, who referred to Wilsing and Scheiner's attempt, used a long aerial placed high up in the French Alps, giving up after a day when persistence would probably have led to a successful result.[18] No further experiments seem to have been made before the 1930s.

Meanwhile, Tesla's attempt to generate standing waves in the Earth's electrostatic field, which was delayed by the fire in his laboratory in March 1895, and then by his need to develop a practical radio system to rival that of Marconi, finally got under way at Colorado Springs in May 1899. Subsequently, he claimed that he had generated such waves and had determined their period at one-sixth of a second, corresponding, on FitzGerald's theory, with a conducting layer at 100 kilometres.[19] The theory certainly suggested a way in which long-distance radio transmission could be achieved despite the curvature of the Earth, possibly using a diffraction effect. On 7 May 1899, for instance, FitzGerald asked Heaviside: "Have you worked at the propagation of waves around a sphere? A case of this is troubling speculators as to the possibility of telegraphing by electromagnetic free waves to America. It is evidently a question of diffraction and I think must be soluble." In another letter, of 20 May, FitzGerald said he thought "it should be workable".[20]

Such speculation became unnecessary when Marconi finally succeeded in transmitting radio signals across the Atlantic. His previous experiments in long-distance radio had suggested to him that radio signals would follow the curvature of the Earth and not go off in a straight line directly into space. During September 1901 a very powerful transmitter, designed by Fleming, forming a ring 200 feet in diameter and with masts 200 feet high, was set up on the Atlantic coast at Poldhu in Cornwall. Though this structure was blown down in a gale on 15 September, another was erected. After abandoning a plan to use a massive receiving station at Cape Cod, Marconi and his assistants, Kemp and Paget, arrived at St. John's, Newfoundland, on 6 December, where they set up a very primitive apparatus consisting of a mercury detector and telephone receiver connected to an aerial wire attached to a kite. Six days later, in appalling weather conditions, Marconi received three times through his earphone the prearranged signal of three dots representing the letter S in Morse code. "Sigs. at 12.30, 1.10 and 2.20", he wrote in his diary. But the signals were too weak to trigger the coherer and Morse printer, also attached to the detector, and produce a permanent record.[21]

The feat of transatlantic signalling was acclaimed in the *New York Times* as "the most wonderful scientific development in modern times",[22] but Marconi was threatened with legal action by the Anglo-American Telegraph Company, which claimed to have a local monopoly, and quickly left Newfoundland. Doubts were expressed in certain quarters, not unreasonably in view of the relatively primitive nature of the receiving equipment and the lack of detail about such things as the transmitter frequency. Lodge, writing to *The Times*, was cautiously sceptical, but was careful to avoid appearing unsympathetic to Marconi.[23] A few months later, Marconi removed all possible doubt by using automatic recording equipment to receive signals transmitted from Poldhu on board the S.S. *Philadelphia*, 2000 miles out into the Atlantic.

The tests revealed, incidentally, the puzzling fact that the range of the signals was much greater at night than during the day, 1653 miles (or 2650 km) as opposed to 700 miles (or 1120 km).[24] The explanation was supplied by both Kennelly and Heaviside, who suggested that the waves were transmitted via reflection off a conducting layer of ions in the upper atmosphere, which were produced by solar radiation, and hence would have different effects during different parts of the day. Kennelly estimated the height of the layer as 50 miles. He assumed at first that the air there was conducting because it was at low pressure; it was only later that it was realised that the air must be ionised.[25]

Heaviside, who, characteristically, had a paper on this conducting layer (or "ionosphere", as it later came to be known) turned down by the editor of *The Electrician*, compared its action to that of the waveguides he had explained in 1885-1887. As he wrote in the third volume of his *Electromagnetic Theory*: "There is something similar in 'wireless telegraphy'. Sea water, though transparent to light, has quite enough conductivity to make it behave as a conductor of the Hertzian waves, and the same is true in a most imperfect manner in the earth. Hence the waves accommodate themselves to the sea in the same way as waves follow wires. The irregularities make confusion, no doubt, but the main waves are pulled round by the curvature of the earth and do not jump off. There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other."[26]

Because it could not be observed directly, the existence of the conducting layer remained controversial for some time, and W. H. Eccles' pioneering quantitative theory, presented to the Royal Society in August 1912, was far from meeting universal acceptance.[27] Alternative explanations were considered equally possible. A few months after witnessing a strong debate on the issue at the British Association meeting of 1913, Lodge urged that "waves should be sent up to find out whether they are reflected or transmitted or refracted or totally reflected".[28] This experiment was, in fact, carried out shortly after Joseph Larmor, building on Eccles' work, had given the first complete mathematical theory of the phenomenon.[29] In December 1924, Edward Appleton and Miles Barnett, sent out signals, at varying frequencies, from the BBC transmitter at Bournemouth, to produce interference between the transmitted waves and waves which had been reflected from a height which they estimated to be 60 miles or 96 kilometres.[30]

The discovery of the ionosphere did not lead immediately to a development of radio astronomy, though the radar technique effectively employed by Appleton and Barnett contributed greatly to the subject from the time of the Second World War. The superior receivers made after 1900 would have made detection of solar radiation, in particular, much more possible; but no one, least of all Lodge himself, sought to revive the subject. Marconi, curiously, came nearer to success. During the First World War, British radio engineers had complained about unexplained static disturbances interfering with the signals on their new short-wave receivers. Marconi, in 1916, guessed that it might be of solar or cosmic origin,[31] but, though the same idea subsequently occurred to others, it was generally regarded as an inconvenience rather than an opportunity.

The first successful detection of radio emission from a cosmic source was made in 1932 by Karl Jansky, a radio engineer at the Bell Telephone Laboratories, who had been set to investigate the static which interfered with radio communications on the transatlantic radio-telephone servicer. Jansky set up a receiver with a steerable antenna, working at 14.6 m (or 20.5 MHz), at a site in Holmdel, New Jersey. After eliminating the effects of local and distant thunderstorms, he was left with a background hiss which he identified as coming from the centre of the Galaxy.[32] Though Jansky did not long pursue this discovery, another engineer, Grote Reber, from Wheaton, Illinois, built a more modern style of parabolic dish antenna, 30 feet in diameter, and produced the first radio maps of the sky.[33] At the same time, British radio amateurs were, once again, observing a high level of noise affecting their radio transmissions which D. W. Heightman attributed to an increase in solar activity.[34]

A direct radio emission from the Sun was first detected during the Second World War by J. S. Hey of the Army Operational Research Group. On 27 and 28 February 1942, while investigating what was believed to be jamming of British anti-aircraft radar by the Germans, he found that it came from the direction of the Sun, and identified it with the emissions from an exceptionally active sunspot which had been noted at Greenwich. Jansky had failed to detect the solar radiation because he was observing at a sunspot minimum. Sir Edward Appleton was the first to announce the discovery after the war and to link it with the observations of increased radio noise made by the amateurs during the 1930s. In making his original deduction, Hey compared the emission of metre wave radiation from the Sun, via corpuscular streams of ions and electrons in high magnetic fields, with the similar processes that he had observed at centimetre wavelengths in the cavity magnetron valves used in airborne radar.[35] In a sense the FitzGerald-Lodge programme for investigating the Sun's emissions using radio waves, which had stemmed from the emission of a stream of electrified particles from an active sunspot observed fifty years earlier, had finally been achieved.

If Lodge attempted no more experiments in radioastronomy after 1894, he did make several indirect contributions, in that he produced several theoretical ideas whose subsequent experimental realisation depended on the work of radioastronomers. In November 1919, after the announcement of the results of the famous eclipse expedition to Sobral in Brazil, and Principe Island off the coast of Spanish Guinea, which first announced the bending of light from the stars in the gravitational field of the Sun, as predicted by Einstein, Lodge suggested the idea of gravitational lensing, with "the simple idea of refractivity, through a diminution of the velocity of light by a gravitational effect ... as expressive of a refractive index".[36] In a letter to *Nature*, dated 30 November, he said that the solar gravitational field could not, strictly, be called a *lens*, for it had no focal length, but if the Sun were backed by a nebula or any luminous area, the light grazing its rim all round would be brought to a focus at a position 17 times the distance of Neptune, while light from a circle of larger radius would focus still further off in proportion to the area of the circle; from any uniformly luminous area there would be a focal *line* of constant brightness.[37]

In a 'Discussion on the Theory of Relativity', held at the Royal Astronomical Society' on 2 December, Lodge also used the planet Jupiter as an example of a gravitational lens, two stars either side of the planet being shifted relative to each other by 1/60 th of a second. In the following year, Eddington considered the case of a dim star forming multiple images of a brighter but more distant one along the same line of sight.[38] The idea was taken up later by others, including Einstein himself, and became a standard topic of discussion in the theory of relativity. The explicit formula $(1 + 2V/c^2)$ now used for calculating the refractive index due to a gravitational potential V was first given by Lodge in 1921.[39] The first gravitational lens was identified sixty years after Lodge's suggestion, when the radioastronomers, Denis Walsh, Robert F. Carswell and Ray J. Weymann explained a double quasar found in a survey taken at Jodrell Bank as consisting of two images of a single quasar refracted from the two sides of a dim, but less distant, galaxy obstructing the direct line of sight.[40]

The discussion of gravitational lenses and gravitational refraction also led to a revival of the black hole concept which had been first postulated in the eighteenth century on the basis of Newtonian theory by

John Michell and Pierre Simon Laplace. In February 1920, writing in the *Philosophical Magazine*, Professor Anderson of University College, Galway, extended the concept of refraction to the case of complete gravitational collapse: "if the mass of the sun were concentrated in a sphere of diameter 1.47 kilometres, the index of refraction near it would become infinitely great, and we should have a very powerful condensing lens, too powerful indeed, for the light emitted by the sun itself would have no velocity at its surface. Thus if, in accordance with the suggestion of Helmholtz, the body of the sun should go on contracting, there will come a time when it will be shrouded in darkness, not because it has no light to emit, but because its gravitational field will become impermeable to light."[41]

About a year later, speaking to a Students' Mathematics and Physics Society at the University of Birmingham, Lodge made some quite remarkable suggestions. A "sufficiently massive and concentrated body would be able to retain light and prevent its escaping", but the "body" need not be a single star; "it might be a stellar system of exceedingly porous character". "For a body of density 10^{12}, – which must be the maximum possible density, as its particles would then be all jammed together, – the radius need only be 400 kilometres. This is the size of the most consolidated body. For anything smaller than that the effect would be impossible."[42] This was the first suggestion of what might be called a collapsed matter star. For the modern-day astrophysicist Werner Israel, "Lodge's casual acceptance of the possibility of attaining nuclear density is truly noteworthy".[43] After the neutron was discovered in 1932, it was realised that such a star could exist if composed only of neutrons. In August 1967, the first neutron star was discovered in the form of a pulsar, by the radioastronomers Jocelyn Bell and Antony Hewish at the Mullard Radio Observatory at Cambridge.[44]

In his talk Lodge continued: "If a mass like that of the sun (2.2×10^{33} grammes) could be concentrated into a globe about 3 kilometres in radius, such a globe would have the properties above referred to; but concentration to that extent is beyond the range of rational attention … ." However, a "stellar system – say a super spiral nebula – of aggregate mass equal to 10^{15} suns", in a "group radius of 300 parsecs" – would not be "utterly impossible".[45] According to Israel, again, Lodge had presented "an essentially correct physical picture of the full range of black holes that are of astrophysical interest today".[46] In a slightly later work, *Evolution and Creation* (1926), Lodge wrote that: "doubtless there are many objects which we do not see, because they have ceased to radiate, and grown too dark to affect our eyes – these representing a still later stage" in stellar evolution than white dwarf stars of the same kind as Sirius B.[47] Black holes are largely the province of X-ray astronomy, the best candidate to date being the X-ray source Cygnus X-1, first identified by the Uhuru satellite in 1971, but now linked also with radio and optical sources.[48] Much speculation exists, however, on the existence of black holes at the centres of such characteristic radio objects as quasars, the modern successors to Lodge's "super spiral" nebulae. Lodge's theoretical speculations are still providing research topics for today's radioastronomers.

Chapter Nine
THE SIGNIFICANCE OF THE AETHER

by Peter Rowlands

Lodge saw his major contribution to physics in terms of the theory of the aether. This theory was important to his work on radio because it was the basis on which he predicted the production of electromagnetic waves and eventually discovered them, but it was also central to many of his other interests, such as the theory of matter and astronomy. Now, it is still common parlance to say that radio messages are transmitted "through the aether", as Lodge directly believed, but the aether is a poorly understood concept in historical terms and its richness as a source of inspiration and physical explanation to physicists of Lodge's generation has not been properly appreciated. Because of its use of the term "aether", rather than "vacuum", and its largely qualitative nature, Lodge's contribution to this area of physics has been neglected, though several powerful anticipations of subsequent astronomical developments have been noted with some degree of surprise by recent commentators. But, if Lodge's physical insight was sufficiently powerful to discover what such outstanding mathematical theorists as FitzGerald, and even Maxwell himself, had failed to grasp – namely the production of electromagnetic waves from electrical oscillations – then it is more than likely that he also led the way in other physical developments, and did so because of his almost unique grasp of the physical meaning of the concept of aether.

Wave theories before Maxwell's, such as Fresnel's theory of light, had always assumed the presence of a medium of some kind through which the energy of the waves was transmitted. The existence of such transfer through a medium (however abstract and nonphysical), rather than by action-at-a-distance through empty space, was precisely the point at which the Maxwellian electromagnetic theory differed from the alternatives explored by physicists like Helmholtz and, at first, Hertz.

Maxwell's explanation of light as electromagnetic waves depended on his introduction of the displacement current, a current which would still exist even between the static charges on a parallel plate capacitor when no ordinary current could be detected. This concept seemed to indicate the presence of an energy source within space itself, and Poynting's theorem and Heaviside and Lodge's work on waves on wires indicated the transfer of energy through the space *surrounding* a conductor rather than through the medium of the conducting material. FitzGerald's strong response to Hertz's work in 1888, with its discovery of radiation travelling quite independently of the conductors from which it was produced, was partly due to its apparently clear-cut vindication of the fundamental validity of the underlying aether model.

Lodge had from the beginning an idea of an aether in which wave motion was generated from a kind of shearing into positive and negative components, "geared up like cogwheels rotating in opposite directions"; "a disturbance would spread laterally when any part of it was twisted (magnetism); and hence ... light could be got from oscillations".[1] A lecture of December 1882 on 'The ether and its functions' characterised the aether as: "One continuous substance, filling all of space: which can vibrate as light; which can be sheared into positive and negative electricity; which in whirls constitutes matter; and which transmits by its continuity, and not by impact, every action and reaction of which matter is capable."[2] Lodge also pointed out that the emission of light from an atom was due to oscillations within only a small part of the atom.

According to Lodge's reasoning, the two arbitrary constants in Maxwell's theory, μ and $1/k$, representing, respectively, the 'permeability of free space' and the inverse of its 'dielectric constant', were in fact a measure of the density and rigidity of the aether; and, in a wave theory, the rigidity of the medium determined the energy density of radiation. This was the reason why the ratio of rigidity and density equalled the square of the 'velocity of light': "Once given the density of the ether, its rigidity follows at once, because the ratio of the rigidity to the density is the square of the velocity of travelling wave propagation; viz. in the case of ether 9×10^{20}." Of course, since only the *relative* values of these constants was then known, it was usual to fix μ and k with specific values (like $k = 1$) to provide a convenient relation between measurements made in different units, but, while recognising its convenience, Lodge always opposed this because he believed that it would be possible one day to determine their absolute values.

Though he developed a mechanical model to illustrate it (described in elaborate detail in *Modern Views of Electricity* in 1889),[3] Lodge's aether was remarkably abstract for its time, and became more so in subsequent years, in line with the nonphysical ideas with which it also tended to be linked. This abstract nature made it a precursor of the modern idea of the quantum mechanical vacuum, in which the displacement current results from a continual polarisation of space into pairs of oppositely charged virtual particles. "In free space the structure only quivers with incipient separation," wrote Lodge, as early as 1882.[4]

An attempt to detect the aether had been made by Michelson and Morley in 1887, who had used an interferometer placed at different orientations with respect to the Earth to detect changes in the velocity of light produced by the Earth's motion with respect to the universal medium. When they failed, to their surprise, to detect any such 'aether drift', FitzGerald, on the basis of results obtained by Heaviside from Maxwell's electromagnetic theory, suggested that it was a contraction of the arms of the interferometer in the direction of motion which had prevented detection of the effect. This idea, produced in March or April 1889 in Lodge's study at Waverley Road, was published, rather obscurely, by FitzGerald later in the same year, but was more widely publicised by Lodge; it later became a fundamental component of the special theory of relativity.[5] Lodge subsequently carried out a lengthy and difficult experiment to see whether moving matter, in the form of two rotating discs spun by a Manchester dynamo, could 'drag' the aether within its vicinity and so change the velocity of light in a different way. Again, a negative result was recorded, even with magnetic and electric fields applied; but this time the result was largely what was expected, and indicated that no experiment was likely to detect a change in the velocity of light due to the motion of source or observer. Though a real change in velocity might actually occur, other effects would conspire to prevent its detection.

Lodge's experiment may have been 'aethereal' in conception, but, in experimental terms, hi-tech was required, particularly in the use of dynamos, a technology which Lodge had investigated in a long series of contributions to *The Electrician* during the early 1880s;[6] it was also very expensive and rather dangerous, and has never been repeated by any subsequent investigator. Preliminary results were presented in 1891 and 1892; and major papers in 1893 and 1897.[7] The associated theoretical work was the first to relate the electromagnetic aether to the absolute standard of rest required by the Newtonian theory of dynamics.[8] In a different experiment, not using the discs, Lodge looked for a new force between current elements predicted by his friend, Joseph Larmor, again without success.[9]

With the subsequent development of the electron theory, mainly through the work of Larmor and Lorentz, the shearing of Lodge's aether into positive and negative electrical components became associated with the production of pairs of positive and negative electrons with opposing rotational strains, the ancestor of today's virtual positron-electron pairs with opposite spins. In 1897, Lodge was the first to calculate the approximate size of an electron (equivalent to the classical radius) and he followed this with more accurate versions on subsequent occasions.[10]

As new discoveries were made in rapid succession during the 1890s – X-rays, radioactivity, the electron as a component of matter, the Zeeman effect – Lodge was nearly always in the forefront of analysis and development, making the most of the good ideas and distinguishing them from the kind of pretentious nonsense which he detected in Singer and Berens' description of *Some Unrecognized Laws of Nature*. "Thus at length the lofty position appropriate to superior knowledge is fully assumed," he wrote in a review of December 1897, "and from pitying and apologising for Newton, rebuking and correcting Thomson and Tait for their fundamental errors, the authors proceed to laugh at an estimate by von Helmholtz. Behold a greater than these men has arisen; another still larger volume in manuscript is threatened; and the next philosopher of the twentieth century is to be Ignatius Singer!"[11]

Lodge was undoubtedly one of the most brilliant synthesizers of his generation, and it was partly through his efforts, and those of his friend FitzGerald, that the mathematical electron concept of Lorentz and Larmor became inextricably fused with the physical corpuscle announced as a universal component of matter by J. J. Thomson at a Royal Institution lecture of 30 April 1897.[12] It was, in fact, pursuit of this discovery, which FitzGerald had thought "might eclipse most of the other great discoveries of the twentieth century",[13] which seems to have taken Lodge's main attention away from the pursuit of radio technology. At the Dover meeting of the British Association in 1899, for example, while Marconi was demonstrating the ability of his system to signal across the Channel to members of the French Association at Boulogne, Lodge showed rather more interest in the new results which Thomson had found in support of his hypothesis. According to his own account, the first quarter of an hour of Lodge's scheduled talk on 'The Seat of the E.M.F. in a Voltaic Pile' was taken up with the speaker enthusing about "Thomson's brilliant discovery".[14]

Beginning in March 1900, Lodge started a major series of lectures, synthesizing contemporary views on the electron as they developed, and adding many speculations and interpretations of his own, some of which were highly original and frequently in advance of later developments.[15] In December 1900, for example, he elaborated on the FitzGerald-Arrhenius theory of electrons streaming from the Sun causing aurorae and magnetic storms.[16] (He used the analogy of a "wind" in a paper of 1909.)[17] Besides extending this, in a lecture given two years later to the IEE, Lodge stated that the atom was mostly empty space. He saw an atom as composed of positive electrons grouped at the centre with negative electrons in orbit around them, as with the planets in the solar system, but with the relative distances between positive and negative electrons more spaced out than in the equivalent spacing of Sun and Earth. It was not clear, however, why no radiation was produced by the orbiting electrons, as would be expected on conventional electromagnetic theory.[18]

In February 1903 Lodge gave successive lectures, at Bedford College, London and University College, Liverpool, in which he implied that radioactivity was the source of the Sun's energy; and proposed an infinitely hierarchical theory of matter based on a parallel infinite series of aethers proposed in Tait and Stewart's popular pseudo-religious *Unseen Universe* of 1875.[19] In June, he spelled out the consequences that the classical theory of radiation posed for the stability of electron orbits; and speculated that the whole of matter might be in a transient state.[20] This led him to give unequivocal support to Rutherford's theory of radioactive decay at the British Association meeting at Southport in September. Lodge's ideas apparently influenced Rutherford into perceiving radioactive decay as a slow but inevitable process within matter.[21] A book on *Electrons*, expanded in 1906 from the 1902 lecture, calculated the classical equivalent of the Bohr radius for the ground state of hydrogen at 10^{-8} cm, and attributed novae to radioactive processes.[22]

Lodge saw the aether as a vast store of energy, vaster even than that in the atom, and of possible use at some future date; he calculated its energy density, in March 1907, at 10^{33} ergs per cc, with equivalent mass density 10^{12} g per cc, and related it to a scale of length, which is now considered fundamental as the Planck length or Grand Unification length (10^{-30} or 10^{-33} cm). This energy density is effectively that of an aether made up of positive and negative electron pairs; and thus the discovery of the electron effectively enabled Lodge to fix, for the first time, the 'absolute' or 'true' values of the Maxwellian constants k and μ.[23] (In the much later Roscoe lecture of November 1927, he saw the aether as "the seat of an immensity of energy such as humanity has never yet realised or imagined", and, in his book on *Atoms and Rays*, published in 1924, speculated on it being used for rocket propulsion.)[24] At the BA at Leicester in August, he saw aether as a continuous substance of immense density "every part of" which was "squirming with the velocity of light" and generating travelling waves on gyrostatic principles; it was hardly a coincidence that, at about this time, he had himself portrayed holding a gyroscope on the Victoria Monument in Liverpool.[25] A lecture on 'The æther of space', given at the Royal Institution in the following February, speculated on the significance of the "scattered condition of gravitative matter" looking the same as if it had been produced by the stresses caused by the whole universe being "concentrated into one body".[26] The Hurter Memorial Lecture on 12 March suggested coalescence of the materials of nebulae into heavier elements in the formation of stars as a reverse process to radioactive disintegration.[27]

All these ideas were informed by Lodge's fundamental belief that matter was, in some way, a localised high-density state of the aether. In effect, it anticipated the virtual particle concept, and the polarisation of the vacuum, radiation being an "evanescent kind of matter – a sort of attempt by an accelerated electron to reproduce itself".[28] The production of matter from aether, he thought, might be the converse process to the production of electromagnetic radiation by the acceleration of electrons.[29] Lodge discussed the pairing of positive and negative electrons on many occasions and, in 1922, suggested that the proton, which he had helped to name two years earlier, might be composite.[30] He was still discussing the positive electron in October 1929, at just about the time when it began its slow emergence, in the modern form, from the electron theory of Dirac.[31]

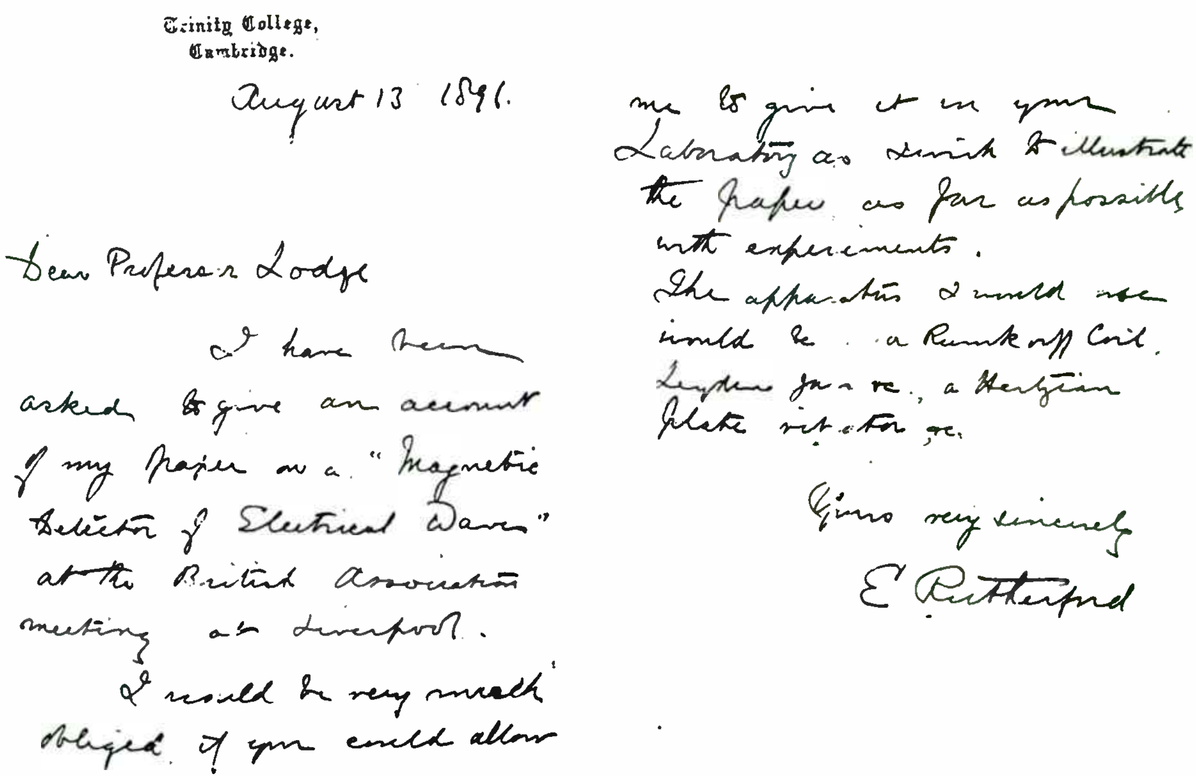
Some slightly more formal ideas, reminiscent of the modern development of multivariate algebra, are particularly interesting in the context of the peculiar nature of electron spin and the appearance of imaginary numbers in quantum mechanics. In August 1921 Lodge proposed (on the basis of Larmor's use of least action principles) that the product of the imaginary number *i* and angular momentum was suggestive of a constitutional gyrostatic aether structure.[32] A late paper, written in 1933 with his brother Alfred, suggested that rotation in the aether could be considered as rotation through an imaginary angle;[33] while a contribution to the Liverpool BA meeting of 1923 considered the rotation of matter as relative while the rotation of aether remained absolute.[34]

Lodge and Larmor were well aware of the parallels between their theories and the new ideas resulting from quantum mechanics; according to a letter by Lodge of 8 March 1930, Larmor had detected "Maxwell in Dirac".[35] From the late 1920s, in effect, they were – like such significant quantum pioneers as Schrödinger, de Broglie, Nernst and Dirac – equating their version of the classical aether with the vacuum of quantum mechanics; and with some justification, for, in a filled vacuum, of apparently infinite energy density, seething with a mass of virtual positron-electron pairs continually coming in and going out of existence, the zero point energy of quantum mechanics at last makes sense of the classical aethereal displacement current. Lodge was certainly quick to appreciate the new physics; by April 1928 he was already recommending the work of Heisenberg, Schrödinger and Dirac.[36] Four years earlier, he had produced an outstanding popular work on the Bohr theory of the atom.[37]

In various lectures, also, beginning with one given in Liverpool on 31 October 1921, Lodge promoted the idea that Einstein's general theory of relativity was an aether theory, a view with which Einstein apparently agreed, especially in their discussions at Oxford in June 1933.[38] Lodge used his aethereal interpretation of Einstein's results in his prediction of gravitational lenses and collapsed matter stars, and in his pioneering discussion of black holes and the Schwarzschild singularity. He referred to this work in the article on 'Ether' which he characteristically included in his edition of *Harmsworth's Radio Encyclopedia*, and which, even more characteristically, lined up both Newton and Einstein in its support![39]

In his later work, Lodge particularly stressed the abstract nature of the aether theory, as, for example, in April 1929: "Objections to the ether are really objections to the nineteenth century conception based in terms of mechanical models. No such ether exists ...";[40] and again in November 1930: "I have abandoned the old material ether of Lord Kelvin in favour of some hydrodynamic or other perfect mechanism at present unknown."[41] But, almost from the beginning, his aether was basically an abstract concept, not to be equated with ordinary matter. There was "no other body", for example, which could be described as absolutely continuous, "and hence the properties of ether must be somewhat different from those of ordinary matter".[42] Lodge's attempts in later years, however, to equate the physical aether with a spiritual one, caused the word, though not the idea, to become discredited.

The final summary of Lodge's aether theory appeared in *My Philosophy*, published in June 1933, the month in which he met Einstein.[43] At the end of the following year, he expressed his strong commitment to the aether in the film made for the Institution of Electrical Engineers, which invoked the names of Jeans, Eddington and Dirac, as justification for the concept, at the same time as stating its relevance to the technology of radio which he had done so much to develop.[44]



Trinity College,
Cambridge.

August 13 1896.

Dear Professor Lodge

I have been asked to give an account of my paper on a "Magnetic Detector of Electrical Waves" at the British Association meeting at Liverpool.

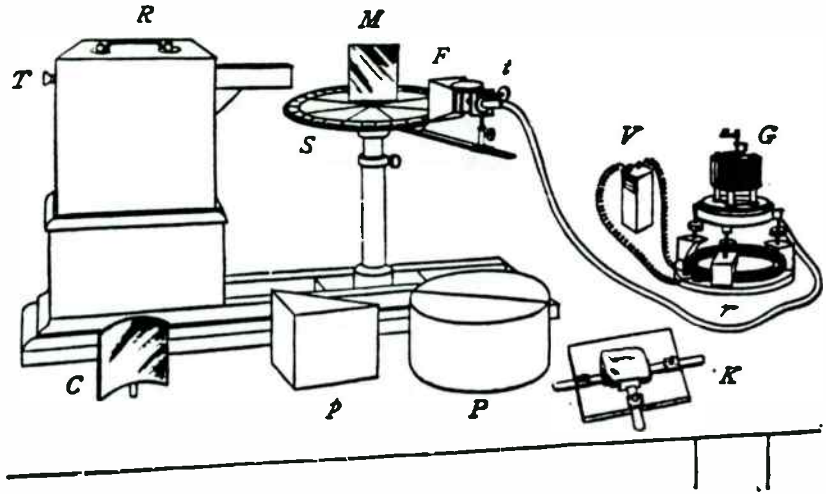
I would be very much obliged if you could allow me to give it in your Laboratory as I wish to illustrate the paper as far as possible with experiments.

The apparatus I would use would be a Ruhmkorff Coil, Leyden jars &c., a Hertzian plate vibrator &c.

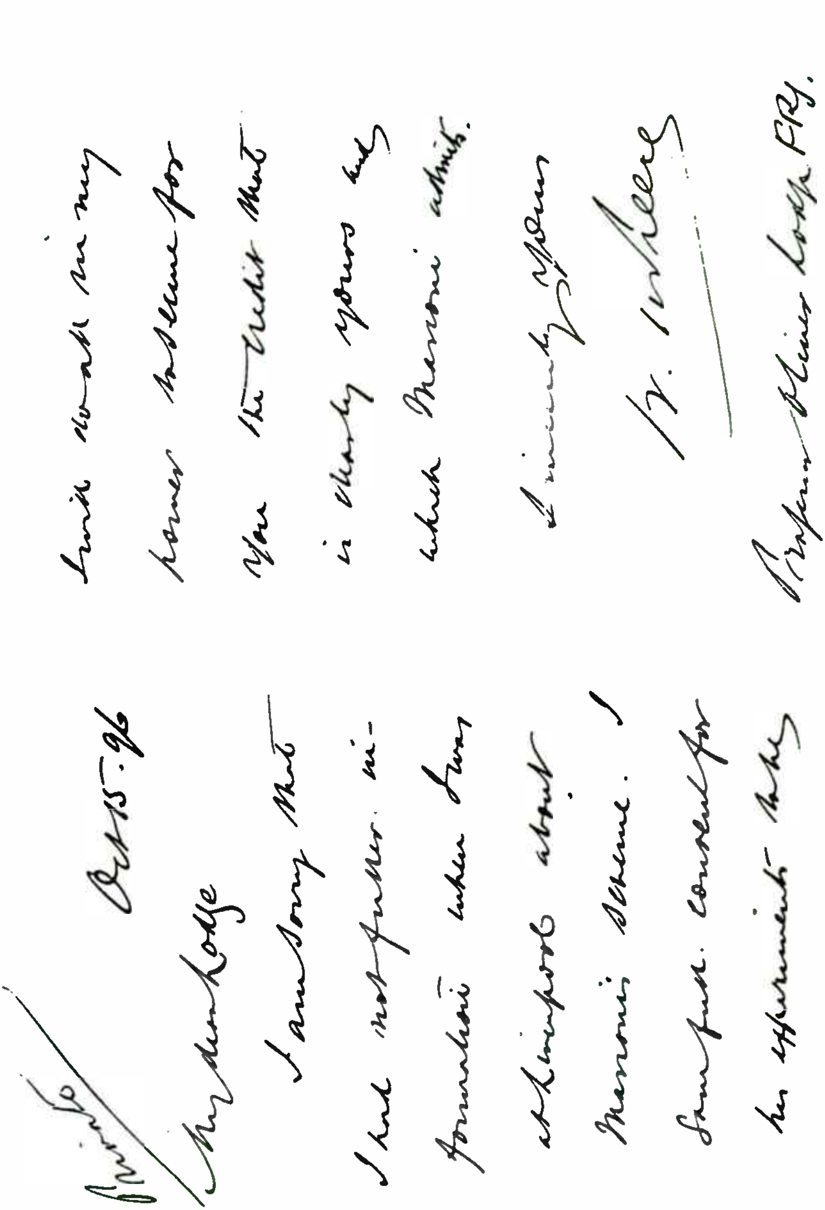
Yours very sincerely
E Rutherford

Fig 33. Rutherford to Lodge, 13 August 1896.

Fig 34. Apparatus demonstrated by Bose at Liverpool in 1896.



R, the Radiator. *T*, the Tapping Key. *S*, the Spectrometer-Circle. *M*, the Plane Mirror. *C*, the Cylindrical Mirror. *p*, Totally Reflecting Prism. *P*, the Semi-Cylinders. *K*, the Crystal-Holder. *F*, the Collecting Funnel attached to the Spiral Spring Receiver. *t*, the Tangent Screw, by which the Receiver is rotated. *V*, Voltaic Cell. *r*, the Circular Rheostat. *G*, the Galvanometer.



Private

Oct 15. 96

My dear Lodge

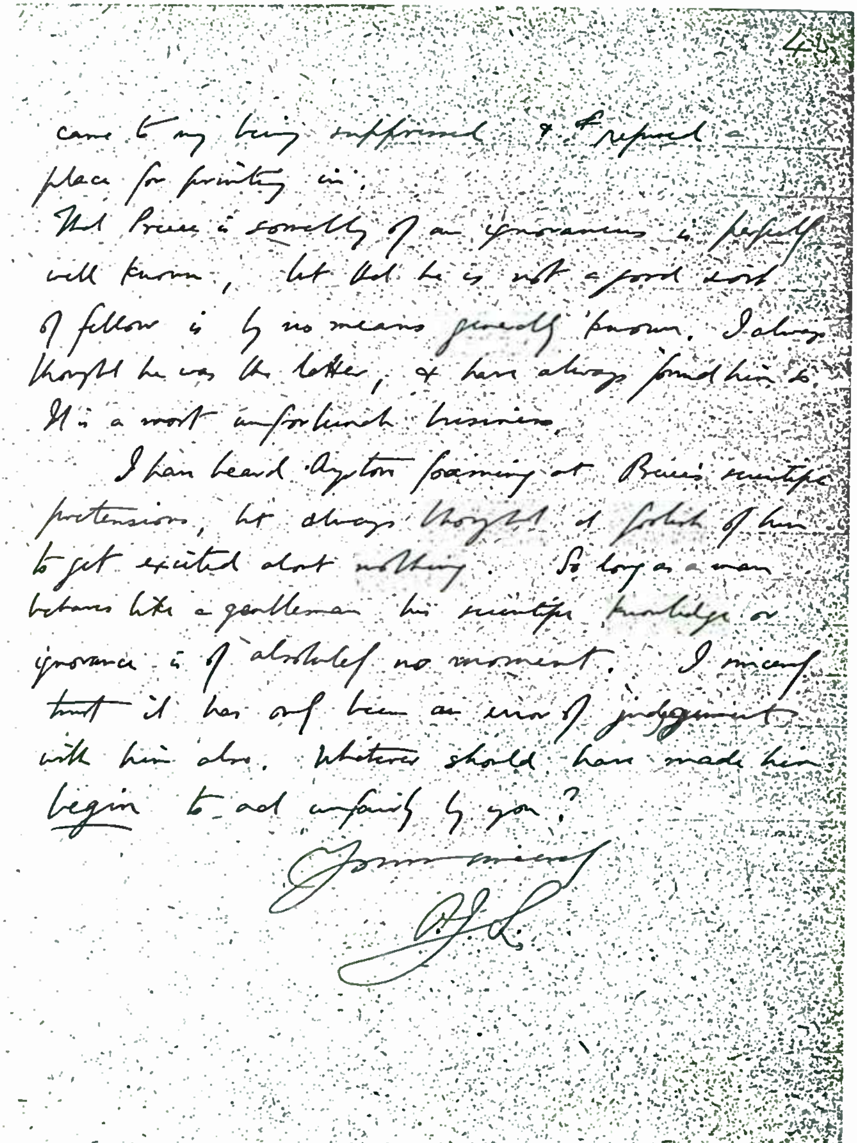
I am sorry that I had not fuller information when I was at Liverpool about Marconi's scheme. I gave full consent for his experiments to be & will do all in my power to secure for you the credit that is clearly yours and which Marconi admits.

Sincerely yours

W. H. Preece

Professor Oliver Lodge FRS.

Fig 35. Preece to Lodge, 15 October 1896.


48

came to my being suppressed & prepared a place for printing in.

That Preece is something of an ignoramus is perfectly well known, but that he is not a good sort of fellow is by no means generally known. I always thought he was the latter, & have always found him so. It is a most unfortunate business.

I have heard Ayrton foaming at Preece's scientific pretensions, but always thought it foolish of him to get excited about nothing. So long as a man behaves like a gentleman his scientific knowledge or ignorance is of absolutely no moment. I sincerely trust it has only been an error of judgment with him also. Whatever should have made him begin to act unfairly by you?

Yours sincerely

O.J.L.

Fig 36. Lodge's earlier opinion of Preece, from a letter of 23 September 1888 to Heaviside.

Chapter Ten
'MARCONI WAVES'

by David Sealey

"... the inventing of ... things is drudgery for the lowest slaves; philosophy lies deeper. It is not her office to teach men how to use their hands. The object of her lessons is to form the soul." (Lucius Annaeus Seneca)

In 1894 Lodge made the first public demonstration of wireless telegraphy; of this scientific and historical fact there can be no doubt. Two years later, William Henry Preece announced a "new plan" for wireless telegraphy by one Guglielmo Marconi which differed only in relatively small details from Lodge's 'old plan'. Why, then, is Marconi considered to be the 'inventor of radio' in virtually every popular text book and museum display on the topic? The answer, we will find, lies in the Victorian code of conduct for 'gentlemen' that Lodge and the majority of his contemporaries strictly adhered to while others exploited the opportunities that the code granted them; the development of radio, in fact, is as much a story of personalities, as it is of technology.

The story of the year after Preece's announcement is given in detail in a letter to Lodge from his close friend, G. F. FitzGerald. It is a letter that introduces some of the major personalities in the story and relates how Marconi exploited his opportunities during the course of 1897. One section of the epistle begins with a response to a grievance Lodge had developed with FitzGerald's assistant, Frederick Trouton, who had recently invested in Marconi's Company and had given the young man advice at an even earlier period.

"As for Trouton & Marconi," FitzGerald wrote, "I don't think he [Trouton] could have done anything else than he did. Some years ago, I think about four, a friend of Trouton's told him of a young Italian friend of his, whose mother was Irish, and who was working at Hertzian radiation and he asked Trouton's advice as to what he should do. Trouton told him that he ought to learn the theory of what he was at and if he came to England advised his going, as well as he recollects, to the City & Guilds Institute. The youth was about 16 at the time. He further said that if he wanted to use his methods of telegraphy he should go direct to the Post Office as no patents were valid against them. This was Trouton's advice. He did not know how Marconi worked and when asked his advice by a mutual friend gave the advice he thought wisest for Marconi: and I do not see how he could have been justified in doing anything else. Marconi took part of his advice in that he went to Bologna to Righi and worked with him for some time and then he seems to have taken the other half of his advice and attacked the Post Office with a secret box and introductions from Lord Coleridge (Trouton thinks)."

FitzGerald seems to have thought it necessary to justify the financial involvement of his assistant: "When the [Marconi] company was being started a Dublin stockholder that we know very well, Goodbody, became in some way mixed up with it and consulted Trouton and myself about it, but at the time the patents were not issued, they would not tell how the secret box worked (even afterwards when taxed with it M. denied that it was a coherer) and all I could advise was to be sure it could stand moderate ill usage without being disorganised. It stood this and Trouton was sufficiently impressed with its value to venture some money in the concern. Since finding out how the thing is really worked he has become much more doubtful as to the validity of the patents and has refused to put any more money into it. It is all a question of patent rights and may depend on such a question as that mercury is important to make it work with certainty and that a hammer worked by the relay itself is important and so forth. If these things are of value and patentable the patents may be of considerable importance. Branly's tube Righi's emitter are all certainly unpatentable, but so many things go to make up a workable invention that Marconi's patents may be valuable. You can hardly expect people like Trouton, with lots of money to spare, not to try and invest it in new inventions even though the patentee or his friends, claim a lot more credit for him than he deserves."

The letter continues with words which had considerable influence on Lodge, for it is paraphrased in much of his writings on Marconi over the next thirty five years as FitzGerald, not for the first or last time identified the root of the problem; the man of brass himself, William Henry Preece. "This young chap himself, I understand he is only 20, deserves a great deal of credit for his persistency, enthusiasm, and pluck and must be really a very clever young fellow and it would be very hard to expect him to be judicial in his views as to everybody's credit in the matter. Preece is, I think, distinctly and intentionally scoffing at scientific men and deserves severe rebuke. If I had some easy way of getting at Labouchere [a well-known journalist and politician] I would like to get him to move a reduction of the Post Office vote on account of the supineness of the Post–Office in the matter, in their neglect of the scientific publication, and in their accepting a secret box for the expenditure of money on. The worst of it is that it would be impossible to get Labby half as well coached in the attack as Preece would coach the repliers and Lord Kelvin & Rayleigh are useless in the house of Lords as they are far too 'gentlemanly' to raise ructions and deliberately fight with Preece in public. It is dreadful having an ignorant creature like that where he is. I believe his own induction experiments across estuaries and to lightships could have been made quite successful in competent hands, but what are you to expect of a person who tries to increase self induction and decrease capacity by increasing capacity and decreasing self induction [this is a reference to a paper he gave at the BA in 1896, of which more later]. He is the person to blame in all this. Marconi has not been very open, but he is hardly to blame if his head is a bit swelled under the circumstances, and no Italian or other foreigner was ever really fair in their judgements so that it is quite unreasonable to expect them to be so.

"But at present the Post Office and Marconi's company are more or less in opposition: for the Post Office don't want to pay too much and the company want to prove that the patents are worth no end of a lot. I have not seen the patents and don't know what they rely on but as far as I can judge from what I am told it is only details that are patentable and their value is not proved."

Regardless of Marconi's actions in taking out patents, many of Lodge's contemporaries, in fact, recognised that his work of 1894 was of paramount importance in the development of wireless. Augusto Righi, for example, guardedly acknowledges his debt to Lodge in a letter dated 18th June 1897[2] whilst Jagadis Chunder Bose, Professor of Physical

Science at Presidency College, Calcutta, on his departure from England, five months after the successful delivery of his paper 'On a Complete Apparatus for the Study of the Properties of Electric Waves' to the 1896 meeting of the British Association for the Advancement of Science, wrote in a letter to Lodge: "Please accept my best thanks for the kindness we received at Liverpool, and also for the interest in my present work, which I owe to you."[3]

The work that had inspired Righi and Bose, among others, had culminated with a memorial lecture on 'The Work of Hertz', given in June 1894, in which Lodge used an improved coherer (as receiver) and spark gap transmitter to show the optical properties of Hertzian waves. Later in the same month he displayed a compact "pocket" apparatus at a Ladies' Conversazione at the Royal Society similar to (or even the same as) that shown in the third edition of *Signalling across space without wires* (an extended version of *The Work of Hertz*).[4] Using headphones to detect the signal he claimed transmission distances of up to half a mile in Liverpool. In August of that year Lodge, in the course of his delivery of "some brilliant experiments and two remarkable papers"[5] – 'On Experiments Illustrating Clerk Maxwell's Theory of Light' and 'On an Electrical Theory of Vision' – gave his celebrated wireless demonstrations at the Oxford meeting of the BA when he "demonstrated the possibility of actual signalling".[6] In the course of his demonstration signals were transmitted from the Clarendon laboratory 180 feet through two stone walls to the Oxford Museum lecture theatre where they were received and recorded on a siphon recorder, the coherer signal could also be displayed to the audience via a mirror galvanometer.

There can be no doubt that Lodge never realised the commercial and scientific possibilities of what he had done, despite Lord Rayleigh's prediction that "If you follow that up, there is a life-work in it."[7] However, if he did not recognise what he had done there were others who did. Alexander Muirhead, according to his wife, spent a restless night following the Oxford lectures and "the next day he went to Lodge with the suggestion that messages could be sent by the use of these waves",[8] until the arrival of Marconi, however, nobody seemed capable of convincing Lodge of the importance of developing this work. Muirhead also lent Lodge various items of telegraphy equipment for his demonstrations at Oxford, the mirror galvanometer (used in Atlantic cabling), the siphon recorder and, "in all probability",[9] the Morse key. It is interesting to note that Aitken cannot be more definite about Muirhead's loan of the Morse key. In the light of the fact that Lodge had already had a key built by his assistant, Robinson, and shown to the Liverpool Physical Society, in November 1892,[10] there seems no reason to suppose that he wouldn't have used his own key at Oxford. This together with the fact that Lodge demonstrated "a large Hertz vibrator giving electric waves of about 30 metres length"[11] to the same Society the following month rather suggests that his interest in electric waves was still strong even at the height of his work with the great ether whirling machine. Muirhead's actions, however, forged a union of telegraphy and science that had been absent from Lodge's previous lectures and hence is said by Lodge to "have conceived the telegraphic applications which ultimately led to the foundation of the Lodge-Muirhead syndicate now bought out by the Marconi Co".[12] At the Oxford meeting, Lodge appears to have been almost an unwitting pioneer but a pioneer nevertheless.

In the two years following Lodge's demonstrations many were to become intrigued with the possibility of wireless telecommunication, possibly inspired by the many obituaries of Hertz. Certainly many were directly influenced by the work of Lodge. (Ernest Rutherford appears to be the only person working in the field who wasn't.) Much unpublicised practical development took place during this period in the two years following the 1894 BA meeting. Receivers, for example, had been developed from the spark gaps employed by Hertz by Lodge's original conception of the " coherer principle, whereby a couple of little knobs in light contact, not sufficient to transmit a current, became cohered or united at their point of contact whenever even a minute spark passed [and emitted electromagnetic radiation], and thus enabled the passage of a current from a weak E.M.F. through a galvanometer."[13]

Branly, despite not conceiving the idea as one applicable to wireless reception, had taken the idea further when he invented a more sensitive device, a tube containing metal filings which stuck together on reception of electric waves, thereby increasing the detector's conductivity and affording a means by which they could be detected.

So it was, then, that on 21 September 1896 Lodge sat in a meeting of section A of the Liverpool meeting of the British Association listening to the paper by Rutherford 'On a Magnetic Detector of Electric Waves'. On 13 August Rutherford had written to Lodge listing the requirements for the demonstration[14] of a detector that *Nature* described thus: "the detector consists of a group of fine steel wires about 1 cm long, insulated from each other by shellac. These are first magnetised, and then inserted in a coil of many turns of wire provided with a suspended magnet and mirror. The passage of Hertzian waves alters the magnetism of the group of magnets and shifts the position of the spot of light. For long waves the detector has been found to be very sensitive and has been found to respond to waves produced half a mile away (with houses in-between); but for short waves a coherer is more sensitive."[15]

During Rutherford's discourse, according to A. S. Eve, his equipment which, at the time, was claimed to hold the world record for wireless transmission, failed. Eve records that Rutherford simply turned to his distinguished audience and "coolly" announced: "Something has gone wrong! If you would all like to go for a stroll and a smoke for five minutes it will be working on your return." Of course, when the scientists returned all was well, and an 'eminent physicist' was recorded as saying: "That man will go a long way."[16]

Later the same day Bose read his paper 'On a Complete Apparatus for the Study of the Properties of Electric Waves using equipment that Lodge described in his 'History of the coherer' as being "well designed in detail and exceedingly compact", despite his form of coherer (Lodge's own design!) being "not particularly convenient"[17] – Lodge went back to using the Branly tube. (Bose created quite an impression at the meeting. At one of the garden parties that were such a tradition of the British Association proceedings, *The Liverpool Courier* reported that: "We were all interested in Professor Chunder Bose of Bombay, whose remarkable address on the measurement of electrical waves has been one of the great sensations of the congress. He is a slight dark man with brilliant eyes and an eager manner."[18])

The next day there was an adjourned discussion on Bose's paper, introduced by Lodge's demonstration of the compact "pocket" system he had used to study electric waves, the same system he had demonstrated so successfully two years earlier. Despite the description of compactness, he "characterised his apparatus as being rather unmanageable as compared with that of Prof Bose".[19]

It was following these proceedings that William Henry Preece, chief engineer at the Post Office, announced, with impeccable timing, that "a young Italian, Signor Marconi" had, with Preece's assistance and the not inconsiderable resources of the Post Office, "succeeded in producing electric waves and reflecting them from one parabolic mirror to another, one and a quarter miles distant. At the latter place they fell on a receiving apparatus and actuated a relay and produced Morse signals."[20]

The singular importance of the BA as an open and public forum for scientific issues cannot be overemphasised and it is no coincidence that Preece chose this particular moment, at that particular place, to make this announcement, to this particular scientific body. He knew full well that it would maximise the public and scientific attention given to 'Signor Marconi' and, at the very least, greatly irritate an old adversary of his, Oliver Lodge. In consequence this moment is probably one of the most significant in the history of the British Association and, it is because of it, that the name of Marconi has, in the popular imagination, become synonymous with the invention of radio.[21]

To Lodge and "the likes of FitzGerald [and] Kelvin" Preece's words were "stale news",[22] whilst Oliver Heaviside, the "Sage of Devon",[23] and the thorn in Preece's side, wrote to Lodge thus: "What about the latest proposal of W.H.P., last BA meeting? Wasn't it preposterous, after all that has been done."[24] Having failed to win acclaim as the discoverer of the long sought after ether waves Lodge must now have realised that his work on wireless transmission was in danger of being usurped by the young Italian and his 'secret box'.

Lodge, however, was never one to miss a chance to show what he had accomplished himself. Having already reminded the audience of his priority, by demonstrating his own equipment before the Bose discussion, the next day found him, together with the more eminent and knowledgeable members of the section, amongst the small group who had gathered to hear Preece's paper on improvements on submarine cabling in the electrotechnics division, the section having been divided due to pressures of time.

"At the close of the sitting PROFESSOR OLIVER LODGE referred to the statement of Mr. Preece on the previous day that an Italian (Signor Marconi) had transmitted Morse signals by means of Hertzian waves. He invited members of the section to witness in his laboratory an experiment in which, at an hours notice, his assistant had arranged apparatus to do an exactly similar thing.[25] He regretted that all the resources of the government should be open to foreigners while so little encouragement should be given to workers in our own country."[26]

This was a particularly salient point since Marconi had come to England because his own government would not support his work. Lodge was not the only one irritated by the events and circumstances. To overlook previous accomplishments was one thing but to do it in favour of what FitzGerald perceived as the wrong type of foreigner was almost too much to bear. In a letter to Heaviside later the same month he wrote: "Preece surprised us all by saying he had taken up an Italian adventurer who had done no more than Lodge and others in observing Hertzian waves at a distance. Many of us were very indignant at the overlooking of British work for an Italian manufacturer. Science 'made in Germany' we are used to but 'made in Italy' by an unknown firm was too bad."[27]

In reply Heaviside directly apportioned blame: "Marconi is the adventurer you refer to, I suppose. I know nothing about him and he may be a very good fellow trying to earn an honest living. The worst I know of him is his assn with P. [Preece] I should put the adventurer cap on his head, no other."[28] Historically however, as regards priority over the invention of radio, the damage had been done. Many years later, Eve in his biography of Rutherford had been so taken in by the hype over Marconi's "discovery" that he put the words of Preece into the mouth of Marconi; not only had he invented radio but he was actually present at the historic section meeting to announce it![29]

A brief consideration of Preece's submarine cabling paper may now be appropriate, in order to show the esteem in which the man was held. Though a brilliant popular lecturer, Preece seems to have been out of his depth when giving lectures to audiences which comprised the likes of Kelvin and it is hard to escape the conclusion that when, in the ensuing discussion, Kelvin pointed out the impracticality of Preece's cable over long distances due to excessive capacity and S. P. Thompson remarked on the fact that Preece had not considered the effects of earth currents (the cable was a send and return unearthed cable), they were politely holding back from a full blooded attack because Preece was simply not capable of defending himself against a scientific argument. As further proof of this, Preece believed his cable to have the benefit of decreased capacitance and increased inductance. (The idea that he could consider the idea of increased inductance in a cable as being beneficial is, in itself, remarkable.) In fact the design, as attested to by Kelvin's comments, has precisely the opposite effect.[30]

It is pretty certain that Preece would have been stung by criticism from Kelvin against which his only defence was to suggest that his ludicrous K-R law (an extremely weak empirical adaptation of Kelvin's original submarine cabling theories)[31] would be "modified in telegraphy by dielectric hysteresis which relieved to some extent the retardation".[32] Privately Kelvin and FitzGerald were more damning. Kelvin wrote to Preece: "If this week's *Electrician* does not contain your paper I think it might be preferable to defer the publication. I write in haste to save time in case of your thinking of deferring or stopping altogether publication. I think you should not go on with the half moon cable I feel pretty sure it cannot give valuable results for practical use."[33]

At the same time, FitzGerald wrote in a similar vein to Heaviside: "This [Preece's Marconi announcement] was capped on the last day by that extraordinary paper ... It is awful to contemplate that the head of our telegraph department should make such extraordinary statements as that the capacity of a pair of concentric cylinders is independent of the difference in their radii [it actually varies inversely with the logarithm of their ratio] and should spend public money in trying to verify it by experiment. Why it makes us the laughing stock of all European science ... Lord Kelvin came in at the end and contented himself with a mild dissent."[34]

By comparison, Heaviside's reaction was almost complimentary, for he found the paper "not as bad as some of his former ones. Perhaps you [FitzGerald] never made acquaintance with them. This is the same usual studious comical ignoration of everything in the way of the cable theory going beyond W. Thomson, but at the same time he tries to make use of my results [on self induction]; only he does it all wrong."[35]

So Preece was an indifferent scientist but he was not without media influence. By October 1897 priority considerations over the invention of radio were being mooted in the popular press and it is clear who was behind it all. Heaviside wrote to Lodge: "I suppose you are back from America. I saw two funny things in the Daily News while you were away. One was an article on the new telegraphy containing a striking comparison (of obvious origin [i.e. Preece]) between the learned Professor [i.e. Lodge], with every advantage on his side, who tried and failed; and the poor foreigner [i.e. Marconi] with everything against him, who succeeded. And the Professor was angry. The other was more amusing still, being a speech by I forget who, buttering up Mr P. He [Preece] ... had been working at this question of telegraphy without wires for a great many years, and now, no sooner does Sr Marconi come forward with a better way, than [?] Mr P. drops his own claims and takes up Marconi. Was there ever, in the annals of electrical science, another example of such unparalleled generosity. How Mr Priggs must have laughed afterwards!"[36]

Above all else, however, Preece was a politician and six months later, after a mutual cooling of relations with Marconi, a reconciliation between Preece and Lodge was on the cards. As Marconi and Mr Priggs parted company, Preece returned to the inductive signalling which he had always considered the superior method of wireless telegraphy. He wrote to Lodge: "I am glad that you have dropped the coherer mania. I did so 6 months ago [when he was 'dumped' by Marconi] and all the rubbish that you have seen in the Times is the booming of a financial crowd with which I have nothing whatever to do. I shall be only too glad to give you every possible facility to test your new plan. I have not been idle. I have never ceased experimenting on my own plan. It is now quite practical and we have put up a permanent installation not to test it but to work it. I have been experimenting between England and Ireland but have been beaten by what no science nor mathematics nor the wildest imagination could have anticipated ... Your contribution and I think your science are shaky."[37]

FitzGerald wrote of this communication: "That letter of Preece is most extraordinary. Is he a little m--? What powers has he left at the G.P.O.? I thought that he had severed his connection therewith about a year ago"[38] and Lodge, possibly spurred on by FitzGerald, protested about some point in Preece's 'plan', for he received the following letter from Preece: "My Dear Lodge, It is fortunate for the peace of this world that there are points on which people agree to disagree I have not published in any technical paper my recent work in developing [?] the electromagnetic plan but I have published it in a legal sense so far as to present observations [?] from patents."[39]

There are numerous instances of this type of writing from Preece, particularly from the time of the 'great electrical debate' of the late 1880s. Preece may have had his hand on the pulse of politics, but, to use Heaviside's words, though he may have been "King of his [GPO] castle", he was really little more than a "scientific pretender. That is [added Heaviside] he has gone in for the scientific business to advance himself in the world."[40]

In the years preceding Preece's announcement, of course, many had contributed and developed ideas and apparatus towards the development of radio, none of which was patented (the public display of apparatus meant that, according to British law it couldn't be patented anyway), and therefore ownership of the technology of radio, such as it was, was common. When Kelvin wrote in a post script to a letter to Lodge "I have today seen the *'Electrician'* of Sept. 17 with Marconi's patent!!!!"[41] his astonishment is probably due to the fact that anybody could dare to patent common property rather than an act of contrition to Lodge. Kelvin, it seems to me (and certainly to himself), judged everything impersonally on its scientific merits.[42]

Claimants for priority over Marconi were legion; men such as Rutherford (who at the time claimed the world record for transmission), Bose, Henry Jackson, Alexandr Popov and Augusto Righi had done their work subsequent to Lodge but previous to, or at least at the same time as, Marconi. Inventions, however, are rarely perceived as corporate, and public sentiment seems to require an individual. Why that individual should be Marconi rather than Lodge, given the seemingly incontrovertible evidence of his 1894 work, is I feel an important historical question.

It is almost impossible to imagine that Marconi could have become successful without Preece and his strident publicity. (This contention remains true whether or not one accepts Pocock's assertion, based on the GPO records, that Preece privately thought Marconi's scheme to be of little value.)[43] Preece's manipulation of the media is apparent in a letter from Heaviside to Lodge written eight months after the first announcement in which it is clear how quickly Preece had made Lodge's work subordinate to that of Marconi: "I have been much amused to see in the daily papers that a rival to Marconi's apparatus which the man of brass and bouncer, otherwise 'the leading scientific representative', says is the most important invention of the century, (or something of that sort) has come forward, namely O. J. L.'s arrangement. It is a pity that a scientific man should have to appear (in the daily papers) to come forward as a rival. This Marconi-Preece affair is only another illustration of the mischief worked by having a man of that kidney in power. But I think the scientific men have been to blame for letting it appear (to the daily papers) that Mr Priggs was such a great scientific man."[44]

By allying his cause to that of Preece, Marconi managed to keep outside the mainstream of British science, whereas the scientific establishment could control Rutherford and Bose since they sought to work within the technical confines of British science. Immediately after the BA meeting it was Bose who appeared the immediate threat to Lodge. In a series of letters involving Kelvin it is apparent that Lodge is concerned over the amount of press that Bose is getting in promoting his cause. Bose's BA paper was published in the *Philosophical Magazine* and it is clear from the Kelvin-Lodge correspondence that the editorial preface was written by Lodge. It stated that: "The general design of the apparatus, both in respect to generator and receiver, was given originally by Prof. Lodge, and described in his book 'The work of Hertz and some of his successors'." Lodge also appended a note to the text and, in it, he wrote that the word 'here' (referring to where the work of Hertz was developed) "meant not only England, but Professor Lodge's laboratory especially where the paper was read, and where, *as is well known* [my emphasis], some of the most important investigations on electric radiation have been carried out."[45]

This was written in response to the following communication from Kelvin: "I think we must put in an editorial note in large print at the top of Bose's article in the Phil Mag, making it clear that it is merely a description of a carefully designed apparatus for using your methods of investigation of electrical waves: that there is no discovery in it, and that the novelty only consists in some good design in respect to details of your apparatus and the particular experimental applications described in the paper. Will you be inclined to write a proper notice of this kind which I shall adopt with editorial responsibility? ... Since I last wrote to you I have seen two or three somewhat flagrant proofs of self advertisement on the part of Bose, for which I have hitherto been unwilling to hold him responsible. I am horrified today by 'An Electric Eye' in the double Christmas number of *Pearson's Magazine* for which I should think Bose himself is wholly responsible ... The popular magazines and newspapers will be full of the 'marvellous discovery of an Eastern Professor'; but the publication of what it is, with a proper editorial in the Phil. Mag. will help to keep matters right in the scientific world.

"I am sorry to trouble you but I think if you will kindly undertake this it will, I believe, be really useful; otherwise I think I should withdraw the paper from ... the Phil. magazine."[46]

Marconi's only interest, however, was in the practical development of radio and for this he needed the engineering resources of the GPO (many of his improvements of the next few years were due as much to the work of Preece's assistants, H. R. Kempe for example, as to Marconi) and the advertising skills of Preece. Part of Marconi's immediate success was due to Preece's manipulation of the popular press. Over the next twelve months he gave numerous, widely reported, lectures on the subject to packed audiences. In the course of these practical demonstrations of radio it proved extremely difficult to find out what advances Marconi had actually made because of the enclosure of Marconi's equipment. Little changed in the months following the meeting from the time when *The Electrician* noted that: "Further technical information is unobtainable, just now but, having divulged so much, and artistically whetted our curiosity, we trust Mr. PREECE will be merciful, and before long give the electrical world something more substantial. Many of us would like to know the nature of the receiving and transmitting apparatus."[47]

But Preece was not "merciful". Only those on the inside were allowed to see the apparatus, and when Captain Henry Jackson, R. N. met Marconi at a trial on Salisbury Plain, three weeks before Preece's announcement, he seems to have somewhat ruffled Marconi's feathers by a comparison of their respective systems. In a letter to Gavey a year later Jackson wrote that he had been working on "evidently the same thing which rather upset him [Marconi], till I told him that I had no idea of patenting it ... he could do no more than mine did except as regards distance, but he was using an 8" coil, I only a 2"."[48] Jackson wrote that "I can positively assert that I got Morse signals with my apparatus before I saw Marconi or knew what the system was."[49]

The British were not the only ones to cast doubts on the originality of Marconi's work. Lodge considered the following letter from Righi important enough to pass on to Kelvin: "I have just received your book 'The work of Hertz', of which I had some knowledge since its publication in *Nature* and I thank you for it. Your coherer is truly an admirable apparatus for its sensitivity and its simplicity and you have been able to do a great deal with it. Perhaps you have seen an interview with me, published in a Bologna journal, *a propos* of the so called invention of Mr Marconi. I know the young man, who is very intelligent, although but little instructed in Physics. I have advised him to pursue a regular University course. I shall be very curious to know about his apparatus, but I suspect it much resembles what he rigged up here with my oscillator [itself an adaptation of Lodge's transmitter of 1890] and your coherer."[50] The letter, while undermining Marconi's claim to have studied Physics under Rosa at the Livorno Lyceum,[51] does, at least, support his own assertion that he was not actually Righi's student. Kelvin replied, with some apparent pleasure: "I am much obliged to you for the extract from Righi's letter. I have sent it to Preece merely saying 'I think it will interest you'."[52]

Over the next few months attempts were made to discover the nature of Marconi's equipment, the reason for its secrecy clearly being its lack of innovation, a fact (as can be seen from Jackson's words above) that he was always sensitive about. Consider this extract from a letter of S. P. Thompson to Lodge: "I have heard nothing more of Marconi. Preece is to lecture (on him I presume) at R. Inst. June 4. I shall try to get a sight of Marconi's app before then."[53] In reply Lodge stated that he had already been in touch with Preece as he wrote: "I shall send you copies of my RI lecture ['The work of Hertz'] with great pleasure. I have sent one to Preece, in order to remind him before his lecture ... I wonder if Preece believes in 'Marconi Waves!'"[54]

At this lecture came the following words: "It has been said that Mr Marconi has done nothing new. He has not developed any new rays; his transmitter is comparatively old; his receiver is based on Branly's coherer. Columbus did not invent the egg, but he showed how to make one stand on its end."[55]

When he said these words Preece may have appeared to admit

Marconi's lack of innovation but there was clearly something more devious occurring. Witness the following words of Thompson to Lodge. "After my lecture a man came up to me. Said he had heard a lecture on Marconi by a lecturer who had Marconi's own apparatus to show, who told them that M. did not use electromagnetic or Hertz waves: for e/m waves spread like sound in all directions ... while the Marconi waves went straight to the place to which they were directed – even through mountains."[56]

The 'official' version of this lecture, printed as an abstract by Preece in *Nature*, uses somewhat different language to this particular witness's report. In addition to going out of his way to describe Marconi's transmitter as being based on *Righi's*, Preece went further when, in a detailed description of coherer action in *Marconi's* receiver, he was at pains to point out all the precursive stages of its development; so that by the time he wrote: "Prof Oliver Lodge, who has done more than anybody else *in England* [my emphasis] to illustrate and improve the work of Hertz and his followers, has given the name of 'coherer' to this form of apparatus", it was apparent that Lodge was no more than a 'term–coiner' for the technology. He was thus able to introduce the vital element of *Marconi's* decoherence without undue reference to its actual origin. Nowhere in the abstract, of course, do the words "Marconi waves" appear (though "Hertzian waves" do). The most likely site for this phrase in the original lecture is in the conclusion to the talk when Preece said: "It is curious that hills and apparent obstructions fail to obstruct. The reason is probably that the lines of force escape these hills. [Could this be because of Marconi's mysterious waves?] Weather seems to have no influence; rain, fogs, snow and wind, avail nothing.

"There are some apparent anomalies that have developed themselves during the experiments. Mr. Marconi finds that his relay acts even when it is placed in a perfectly closed metallic box. This is the fact that has given rise to the rumour that he can blow up an ironclad ship. This might be true if he could plant his properly tuned receiver in the magazine of an enemy's ship. Many other funny things could be done if this were possible. I remember in my childhood that Captain Warner blew up a ship at a great distance off Brighton. How this was done was never known, for his secret died shortly afterwards with him. It certainly was not by means of a Marconi relay."[57]

It was this last section which forced Lodge to protest to the editor of *Nature* (Richard Gregory) attacking Preece's belief that it would be possible to communicate with a coherer which was placed in a sealed metallic box. What happened to that letter is revealed in a note to Kelvin. "Recently I inquired about the fate of this note, & have received the preposterous reply copied on back of this [see note]. Nature evidently intends to burke the subject. This being so I have sent it to the Phil. Mag. It is not a satisfactory position for Nature to assume, & hence I inform you & Lord Rayleigh merely as information." The following letter did indeed later appear in *Philosophical Magazine*:

"Among other misstatements in this country I observe one to the effect that electric waves of moderate length can penetrate a complete metallic enclosure and affect a coherer inside.

"As shown by me in 1894 [*The Work of Hertz and his Successors*] they can readily get in by insulated wires, or by chinks or other interruptions of metallic conductivity, but into a cavity really bounded by a conducting wall of fair thickness they do not go.

"The statement that they do is a purely misleading one, likely cause eminent continental physicists to surmise that there may after all be some discovery involved in these sensational newspaper accounts which have not scrupled to use the absurd phrase 'Marconi Waves' and to speak of them as if they were novelties unknown to science."[58]

The rejection of the original letter by *Nature* caused Lodge to question privately the magazine's neutrality on the issue, and write in protest to his friends FitzGerald and G. M. Minchin, as well as to Kelvin and Rayleigh.[59] FitzGerald replied: "I am surprised to hear about 'Nature' I suppose they excuse themselves on the plea of not wanting to go into any business squabbles"; while Minchin agreed that there was something fishy going on: "You are quite right about Nature. The Editor returned a letter to me giving a most preposterous reason for non publication." Rayleigh too appeared sympathetic: "I can't imagine why Nature s[houl]d think the last bit of your letter to be of self [?] special interest." The ever-neutral Kelvin replied, however: "To the editor of Nature your scientific allegation might have seemed insufficiently proved considering the experiment shown by Preece at the Royal Institution last June in which coherer, battery and bell were placed inside a metal box, the lid of which was caulked with mercury. The audience certainly heard a sound. (Do you think there can have been any flaw in the enclosure?) But," he added, in support of Lodge, "to say that the proper place for publishing it was not Nature but a technical journal is too monstrously absurd."[59]

On such events as Preece's 1897 Royal Institution lecture was born the idea of Marconi waves, a concept made easier for Preece to push by the plethora of rays, both real and imaginary presented to the public in 1896, but since it is inconceivable, even for Preece, to have believed that Marconi had come up with a new form of radiation, it is not unreasonable to assume that he had identified the lack of knowledge of his audience and worked on it, setting a more acceptable version in print for his scientific audience.

As to why Lodge is not perceived as the inventor of radio, Aitken has made out a case for a lack of intent on Lodge's behalf,[60] the fact that he may not have suggested in public that his equipment could be used for signalling, a prime piece of evidence for this being the hint of pleading when he wrote some thirty seven years after his Oxford demonstrations: "... it was easy to demonstrate the signalling of some letters of the alphabet, so that they could be read by any telegraphist in the audience – some of whom even now may remember that they did so."[61]

The fact that in three of his four demonstrations of 1894 the theme of his lectures was not wireless telegraphy, but the relationship between light and radio waves in two cases and a demonstration of his own theories regarding the nature of the eyes response to stimuli in the third is also given as a matter of some import. Perhaps, Aitken argues, all we have is a simple case of an old man's forgetfulness as regards the true nature of his work.

It may be possible to accept the fallacious idea that the incidental and, I should stress, familiar, employment of a device not in use elsewhere (an inventor using his invention?) does not give the user a major claim in priority, but this still leaves the *conversazione* where Lodge did little else but demonstrate wireless telegraphy.[62] The details of this event must lead one to the conclusion that the first public demonstration of wireless telegraphy was given by Lodge, and that, in Aitken's own words, radio was "born not on the rolling hills of the Marconi estate near Bologna, nor on the barren heath of Salisbury Plain where Preece carried out his Post Office tests ... but rather amid the tea cups and genteel chatter of a ladies *conversazione* on a June evening in London. ... [The gain in accuracy] is certainly bought at the expense of historical drama."[63]

Lodge was, of course, an eminent and busy scientist with a heavy teaching load and a multitude of interests whilst Marconi was single minded, "not the inventor but the skilled exploiter of telegraphy without wires",[64] and not really a scientist, despite his eventual eminence as a Nobel Laureate. He had a single objective, the development of wireless communication. As an example of the difference in approaches, the following quote from Lodge's *Past Years* is informative: "His [Marconi's] novelty was that he employed a high aerial and an earth connexion as the effective radiator. In the achievement of actual telegraphy the earth connexion was an assistance; but in my experiments on the demonstration of the waves, I had avoided the earth connexion as giving an unfair advantage from the point of view of theory."[65]

This rather implies that Lodge never used the aerial, as opposed to the Hertzian dipole arrangement, since this would not then be true space transmission, in other words it would be cheating. It is however quite evident from the correspondence between Lodge and the likes of FitzGerald, Heaviside and Minchin that he was well aware of the advantages to be gained from the use of aerials (or "airials" as Heaviside would have called them).

Inspired, one way or the other, by Righi, who was, in turn, inspired by Lodge, Marconi worked, "with great spirit and enthusiasm and persevering energy, and assisted by government officials, [he] overcame many practical difficulties and really began to establish on a practical commercial basis his system of Wireless Telegraphy by Hertzian waves."[66]

Clearly it was Preece who was the object of most of Lodge's public anger, rather than Marconi. Lodge's gentlemanly approach to the issue must have been heavily influenced by FitzGerald, whose letters to Lodge in June 1897, at the inception of the debate concerning the invention of wireless, clearly show his character and personal philosophy. On 27 June, for instance, he wrote: "I am returning Schuster's & 'The Times' letters.

"The starting of the hammer by the coherer is good and I dare say patentable. In fact any invention of this kind has so many subsidiary inventions necessary to make it work in ordinary practice that the person who makes it work in ordinary practice requires just as much protection from infringement as the inventor of the original principle that is worked out in practice.

"I am afraid that nothing can compensate for the want of 'business' capacity in human affairs as far as 'getting on' in worldly matters is concerned. My classical friends here amuse themselves jeering at me for not inventing something like pneumatic tyres to which I can only retort that they should try and write Popular novels that would bring them in considerable fortunes."[67]

A few days earlier, he had written: "I am returning you the copy of your letter [for *The Times*] that you sent me. If you are writing to other papers and would like it I will send a similar letter to the one I wrote for any paper you like.

"It would be important to keep it from becoming a personal question between you and Marconi. The public don't care about that and will only say 'This is a personal squabble: let them settle it amongst themselves'. The points to make are that (1) The Post Office is absurdly ignorant, as usual. (2) They are entirely neglectful of scientific discoveries but paid attention to a secret box, when introduced under the auspices of a nobleman. (3) The Government will never pay attention to scientific discoveries unless the public appreciate that they are of importance and that consequently it is important that the true discoverer should be appreciated at least as much as the person who works out the details." FitzGerald concluded the letter with the following words which clearly struck a chord with Lodge for he paraphrased them thirty six years later in his autobiography (they are words with which I shall conclude this chapter).

"The question as to scientific credit is quite a different matter and though it is of public importance that the public should appreciate that scientific discoveries are of importance their apportionment of scientific credit is of no value or importance. People like Dewar and Preece think it is and they have their reward."[68]

If one accepts the idea that the leading light in this little drama was Preece, one is then forced to ask why he chose to back Marconi, rather than Lodge. Marconi was a foreigner armed only with a letter of introduction from Campbell Swinton which emphasized the lack of innovation on the young man's part and talked of his employment of Righi's transmitter and *Lodge's* detector.

There are, in fact, only three possible interpretations of Preece's actions:

(1) He was ignorant of Lodge's work (hardly likely, although that was always Lodge's public version of the tale: "Preece knew nothing of the experiments that had been shown two years before in this country [1894]: he was doubtless fully occupied with his official duties.")[69]

(2) He knew of Lodge's work but believed he would have more control over the project with an outsider.

(3) He knew of Lodge's work but chose to ignore it for personal reasons.

As to the first point, three years after winning a suit against the Marconi Company which extended Lodge's syntonic tuning patent of 1897 and in which, perversely enough, Preece acted as honest broker, Lodge quietly (i.e. in a letter) protested that "Marconi came over with the same thing in a secret box, with aristocratic introductions to Preece of the Government telegraphs, and was taken up and assisted by him – who was far more ignorant than he ought to have been of what already had been done."[70]

However, as has already been implied, I would dismiss the ignorance interpretation. If on hearing of Marconi's equipment Preece truly considered it something quite new, as Lodge claimed, one is really moved to ask, why? In his obituary of Preece, S. P. Thompson, a personal friend of Lodge's, found his ignorance a little peculiar and wrote: "Strange to say, he entirely missed the significance of the wireless signalling by Hertzian waves that was shown by Oliver Lodge at the British Association meeting at Oxford in 1894; and yet when Signor Marconi arrived upon the scene in 1896, using the same method and the same devices of oscillators, spark gaps, coherers and tappers, Sir William Preece received him with open arms, and put the resources of the Post Office at his disposal, with results known to all the world."[71]

These are pretty strong words for an obituary, particularly by a man born into a society where 'never speak ill of the dead' was a golden rule. Furthermore, as has already been alluded to, Preece had employed Heaviside's brother, Arthur, in an investigation directed towards outlining the parameters of the problems involved with using inductive telegraphy as a means of wireless communication. He had, therefore, illustrated his intent and vision in communication through free space. In addition Preece was present at the 1894 meeting where, on the day before Lodge's demonstration, he gave a lecture on ... "signalling through space" – "The novice who had read the title must have wondered if it was possible to signal anywhere else"[72] – and it is inconceivable that Preece never heard of Lodge's demonstration, particularly since the lecture theatre was reported as being full to overflowing. It may be important to note, however, that *The Electrician* never made the link between Lodge's presentation and Preece's signalling through space. Indeed it ridiculed Preece's ideas of communication with Mars using his system: "even assuming the possibility there would be far less chance of being understood than if they were to signal the polar bear at the zoo".[73]

A further point is that Lodge's signalling equipment was on public exhibition at the Liverpool meeting. Preece would truly have to have spent his life in 'splendid isolation' not to have heard of Lodge's work before he made his announcement. Finally, and most damningly, there is in existence a letter which, as far as I am aware, has never been quoted, the contents of which are as follows: "My Dear Lodge, I am sorry that I had not further information when I was at Liverpool about Marconi's scheme. I gave full consent for his experiments to be tried as I should do for anyone else. We are always trying new things and only get kicks for our pains.

"I am fully aware of all your work and all your labour in this field and I think that you should know what has been done. I send you this confidential report which pray return when read. I shall be very glad to know your views on the matter and I will do all in my power to secure for you the credit that is clearly yours and which Marconi admits."[74]

It is a further reflection on the characters of the two men to note that whilst Lodge kept the commitment to confidentiality forced upon him by Preece, the favour, giving Lodge public credit, was not returned.

If Preece can be excused of the charge of ignorance of Lodge's work, then I would suggest the second and third factors I mentioned as being the key to Preece's motivation. Oliver Heaviside probably got it right when he wrote: "Mr Priggs would have been just as willing (or more so) to <u>blow</u> your trumpet, if you had gone the right way to work; butter him up & support him in his fictions to the general public, and so forth."[75]

While there can be little doubt that he saw, in Marconi's work, the opportunity for personal advancement, there is also the significant possibility that Preece was motivated by a desire for some sort of personal redress, for revenge (the fact that Preece seems to have not rated Marconi's system very highly,[76] at least in private, adds credence to the revenge angle). The ill feeling that existed between the two men, and which must have spurred on Preece in his support of Marconi, can be directly traced to the incidents that occurred at the 1888 meeting of the BA and, in particular, the "battle of the lightning conductors".

Marconi filed his first patent application on June 2nd 1896 and Preece would have been well aware of the significance of this act. In an address to the BA in 1887, he had said: "A patent certainly has one great use it fixes a date and it defines an invention."[77] In a letter, written in December 1896, he showed the insincerity of his promise to Lodge to 'give credit that was clearly his' when he wrote of Marconi's patent: "His patent is a very strong one but its validity is sure to be contested. Professor Lodge claims priority of invention. I have, however, carefully examined Professor Lodge's claims ... and I find them baseless."[78]

The Electrician, however, prominent in the media circus that pushed Marconi into the international limelight, was not so reticent as regards Lodge's role. In 1897 it published an abstract of the specification of Marconi's patent that had been granted that year and felt compelled to append a note from the editor: "In connexion with the patent of Signor Marconi ... we are able to present our readers with two illustrations taken from photographs of some Hertzian- wave apparatus shown by Dr. Lodge at the Oxford meeting of the British Association in 1894. From these it will be seen that Dr. Lodge publicly exhibited:–

1. Oscillators with very large copper plates.
2. Receivers of the coherer type with wings and wires attached to them.
3. Coherers in sealed tubes.
4. A trembling bell attachment to receivers of the coherer type to assist them in decohering after the impingement of the electric oscillations.
5. Morse instrument to shake the filings.

"In fact Dr. Lodge published enough three years ago to enable the most simple minded 'practician' to compound a system of practical telegraphy without deviating a single hair's-breath from Lodgeian methods. Both at Oxford and at the Royal Institution, Dr. Lodge described and exhibited publicly in operation a combination of sending and receiving apparatus constituting a system of telegraphy substantially the same as that claimed in the patent we have referred to."

Lodge was clearly asked for a note to be appended to this article: "It is reputed to be easy enough for a clever lawyer to drive a coach and four through an act of Parliament. If this patent be upheld in the courts of law it will be seen that it is equally easy for an eminent patent-counsel to compile a valid patent from the publicly described and exhibited products of another man's brain. No longer is it necessary to devise even so much as 'a novel combination of instrumentalities', and the saying ex nihilo nihil fit [nothing from nothing] evidently was not intended to fit English patents at the end of the nineteenth century.'"[79]

Preece entitled his Friday evening lecture at the Royal Institution 'Signalling through space without wires.' Hiding Marconi's apparatus in black painted boxes to heighten the mystery, he delighted the packed lecture theatre by his magical transmission of messages across free space, their reception being announced to the multitude by the ringing of a bell. In his flair for the dramatic and his ability as a public lecturer, at least, he was the equal (though also the plagiariser) of Lodge. It is, however, hardly a coincidence that when Lodge's book on Hertz was reissued in 1898, in the glare of publicity surrounding Marconi's growing fame, it was retitled ... *Signalling through space without wires*.

Whilst his primary anger was always directed at Preece and he always recognised the enthusiasm which had pushed Marconi on, it is in the years immediately following Preece's announcement that Lodge is at his best at refuting his opponents, Marconi included. Take for example the following quotation from the closing section of his 'History of the Coherer Principle': "in the Autumn of last year there came a development. One of the students in Prof. A. Righi's class at Bologna, having heard the Professor lecture on the production and transmission of Hertz waves across space, and their detection by the cohesion which they caused in a group of metallic filings, and being gifted, doubtless, with a sense of humour as well as considerable energy and some spare time, proceeded to put a coherer in a sealed box and to bring it to England as a new and secret plan adapted to electric signalling at a distance without wires. Being influentially introduced to the chief engineer of the Government Telegraphs who, presumably, was too busy to remember what had recently been done in the Hertz-wave direction, the box was announced as containing "a new plan" which had been "brought to England". Lectures were given on it at both the Royal Institution and Royal Society, the House of Commons voted £ 600 for special experiments, and trials were made by the experienced official staff with their usual skill. Mr. Marconi is to be congratulated on the result of his enterprise; the newspaper press of this and other countries have taken this matter up, popular magazine articles have been written about it, and so now at length the British public has heard, apparently for the first time, that there are such things as electric waves, which can travel across space and through apparent obstacles to a considerable distance, and can there be detected in a startling fashion. Thus the public has been educated by a secret box more than it could have been by many volumes of Philosophical Transactions and Physical Society Proceedings."[80]

Lodge would certainly have regretted missing out on the credit for a discovery which would have elevated him to a position of international fame, a fact that he explained to himself by his tendency to drift "without ambition". But, three years after his death, the US Supreme Court declared that the only valid patent held by the Marconi Company was Lodge's syntonic tuning patent of 1898, acquired when they bought out the Lodge-Muirhead syndicate in 1911. Lodge is normally described as *a* pioneer of wireless telegraphy, I would describe him as *the* pioneer, certainly on the technological side. As an illustration, even when Marconi patented the corporate ideas of wireless telegraphy, Lodge realised that a practical system required tuning, an idea that can be traced back to his syntonic Leyden jar experiment of 1889. It may be of interest, at this point, to wonder how Marconi got in on the tuning game. A clue may be gained from the following letter, written by S. P. Thompson: "I need not enlarge ... on the means (entirely creditable to both parties, of course) by which Sir Oliver Lodge's unpublished investigations in this direction [syntonic tuning] became known to Signor Marconi. Suffice it to say that in March 1899, Signor Marconi was able to announce that he also was working at experiments on syntonic systems."[81] To anyone who is familiar with the biting sarcasm of

Thompson's writings on this kind of theme, it is clear that the above quote is hinting at something underhand on the part of Marconi.

Doubtless the failure of Lodge to be, in the public perception, the inventor of radio is due to his personality and circumstance but if the problem is approached from the point of view that conception and understanding – which, as evidenced by the ease with which Lodge stole his march as regards tuning, was clearly lacking in Marconi – are the most important factors in scientific or technological advancement, then one can understand the feeling aroused in the early years of the twentieth century.

During the first six years of this period one can find enormous debate in the popular literature over the invention of radio, and it would be my contention, that the lines of demarcation, as regards what one believed as regards the invention of radio are similar to those described in the battle of the lightning conductors. A scientific/technological phenomenon was brought into the public domain which meant that *the practical men* (the money people) were drawn to Marconi while the theoreticians who, broadly speaking, were the men who had actually witnessed the development of the topic first hand, had been a little shocked by the actions of the "Italian adventurer" – none more so than S. P. Thompson who stoutly supported Lodge as 'the inventor of wireless telegraphy' in an acrimonious debate with Marconi that littered the pages of the *Saturday Review* in 1902. Whatever Thompson's motives, he was aroused by the complaints of Marconi. In the wake of his transatlantic accomplishments, Marconi was annoyed by the use of his system by Adolf Slaby and Count Arco. Thompson pointed out that all wireless telegraphy systems utilised "Lodgeian methods" and concluded: "Signor Marconi may whine as he pleases about other men snatching the rewards from a scientific investigator; that is precisely what he himself has been trying to do for these last four or five years, his victim being the Englishman who was first in the field, and who, if he but knew it, is to-day the master of the situation."[82]

Perhaps Thompson, in making Lodge 'the master', underestimated the power of commercial concerns. Maybe Lodge, one of the originators of 'big science' according to Hunt, was also one the first victims of twentieth century big technology. Whatever we may choose to believe, when Marconi replied[83] to Thompson's assertions, the substance of the response was of the "sue me and we'll see who wins" variety. As has already been shown, when Lodge did go to court ... he won! But, probably the most important letter was Thompson's second: "From the warmth of the expressions of Signor Marconi in his letter to you ... it is evident that I am serving the humble office of lightning-conductor to avert some of the wrath which would otherwise have fallen upon the offending head of Professor Slaby, Signor Marconi's rival."[84]

Thompson then proceeded to refute all the points in Marconi's letter, for example: "I read on and find that it is "blank ignorance" to represent "my [Marconi's] system as being dependant on the 'coherer principle'"; and he [Marconi] adds: "I desire to state categorically" (to the confusion of myself [Thompson] as a totally inaccurate person), that "I [Marconi] have proved my system of wireless telegraphy to be thoroughly workable in complete independence of the use of any receiving instrument designed on the 'coherer principle'". I [Thompson] rub my eyes to make sure I am not dreaming. "My system" not dependant on the "coherer" principle! Categorical statements wont put back the clock nor cancel half a line of the great "basic patent. Let us see what Signor Marconi has described as his "system"."[85]

Thompson then proceeded, line by line, to show the lineal descent of Marconi's system from Lodge's and, although Marconi replied, no response to these accusations was ever given: "The world now knows that Signor Marconi, challenged with these references to original sources, evades the issue and lapses into abuse."[86]

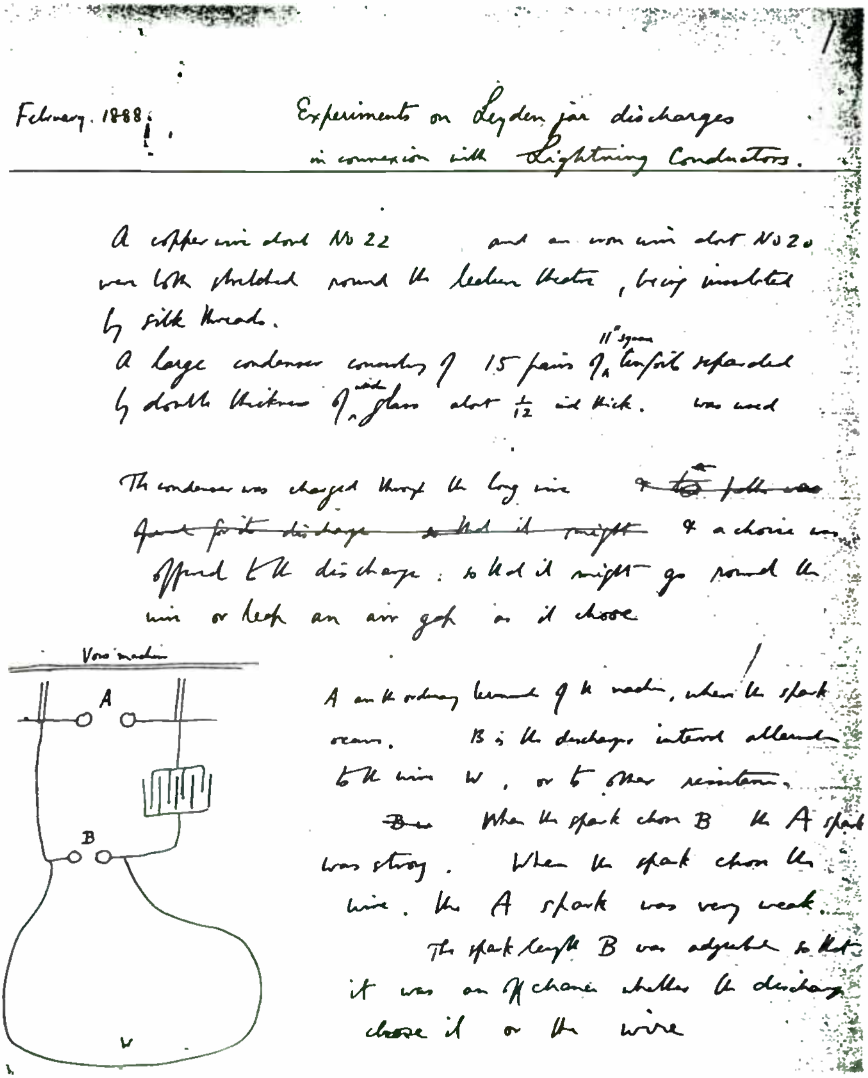
And so the debate petered out, with Marconi not even bothering to conclude the correspondence personally. The matter flared up again in *The Times* four years later. The occasion was the Berlin conference on wireless telegraphy at which time a British Member of Parliament, Henniker Heaton, prompted (or so claimed Thompson) by the Marconi Company, renewed the attacks on Slaby.[87] He described Slaby's work as "piracy" and the event brought the practical and scientific camps out in force; Thompson renewed his support for Lodge, Preece renewed his support for inductive telegraphy, Kelvin renewed his neutrality, employees of the Marconi Company renewed their attacks on Thompson,[88] but, most important of all, A. A. Campbell Swinton renewed the idea that he had introduced Marconi to Preece on the understanding that he had done nothing new.

"Mr Marconi came to me early in 1896, and described his system and what he was able to do with it. I at that time formed the opinion that he had then in no material way advanced upon what had already been performed and published by Sir Oliver Lodge, with whose system I was acquainted and whose experiments in transmitting signals by means of Hertz waves I had previously repeated for my own satisfaction. ... it is, humanly speaking, certain that had it not been for the labours of Lodge, Branly, and others Mr Marconi would never have made his improvements in wireless telegraphy, at any rate on the Hertz wave principle, at all for the very sufficient reason that there would have been no such telegraphy for him to improve upon. *May I say, in conclusion, that I have no pecuniary or other interests in the question whatever* [my emphasis]."[89]

Marconi cleverly outmanoeuvred any attempts by Preece and the GPO to gain any form of control over his equipment and, as soon as it became advantageous to Marconi he abandoned him, incidentally, causing an apparent reconciliation with Lodge. The ruins of Preece's ambitions clearly showed when he wrote, perhaps a little bitterly, in 1900, "The sensation created in 1897 [and stirred up by Preece] by Mr Marconi's application of Hertzian waves distracted attention from the more practical and older method [the inductive telegraphy method of Preece]".[90] The impression given is that the events initiated by Preece in 1896 had swiftly got beyond his control.

For the greater part of the debate Lodge kept a considered stance (although he was clearly upset in the private correspondence immediately following the 1896 meeting) and always credited Marconi with the vision that he lacked. I have little doubt to what he was referring when he gave his views on the meaning of priority late in his life: "There is one kind of controversy which is not really edifying – namely, one which deals with questions of priority ... To the race in general this matters next to nothing. To the individual it does matter, but not exaggerately. There have been cases when it has been difficult to apportion credit; and it is only human to be regretful if credit is given in what seems to us a wrong direction ... Priority considerations are ... the business of scientific historians; contemporaries often make slips not having all the details complete."[91]

Perhaps he was hoping that somebody would one day set the record straight, but as one witness, albeit from the biological section, to the events of 1896, Francis Darwin, put it on a different topic: "in science, credit goes to the man who convinces the world, not to the man to whom the idea first occurs".[92] As Lodge may have reflected, was it Marconi or Preece who convinced the world?



February. 1888.

Experiments on Leyden jar discharges in connexion with Lightning Conductors.

A copper wire about No 22 and an iron wire about No 20 were both stretched round the lecture theatre, being insulated by silk threads.

A large condenser consisting of 15 panes of 11" square tinfoil separated by double thickness of window glass about $\frac{1}{12}$ inch thick. was used

The condenser was charged through the long wire ~~& the path was offered for its discharge so that it might~~ & a choice was offered to the discharge: so that it might go round the wire or leap an air gap as it chose

A are the ordinary terminals of the machine, where the spark occurs. B is the discharger interval alternative to the wire W, or to other resistance.

~~Bu~~ When the spark chose B the A spark was strong. When the spark chose the wire. the A spark was very weak.

The spark length B was adjusted so that it was an even chance whether the discharge chose it or the wire

Fig 37. Page from Lodge's notebook showing 'alternative path'.

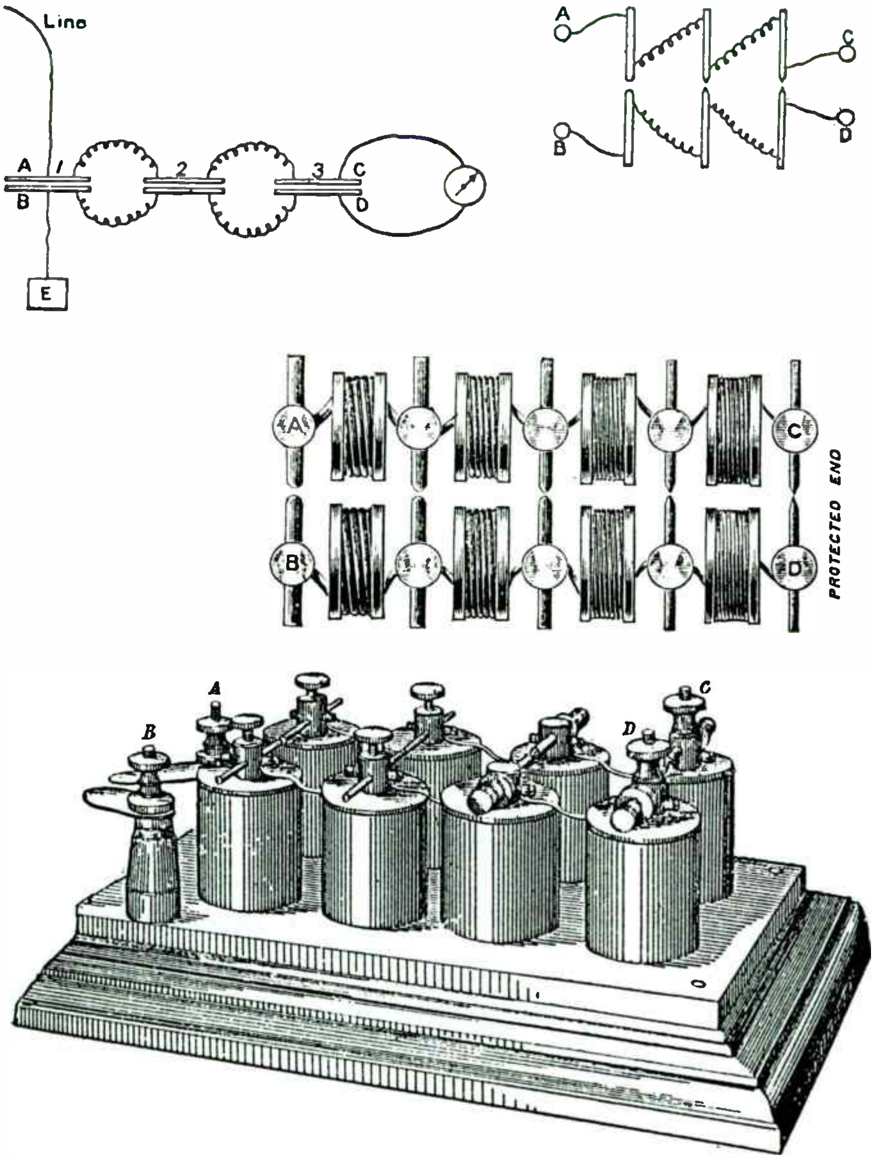


Fig 38. Diagrams of lightning guards for telegraphic instruments; Muirhead guard.

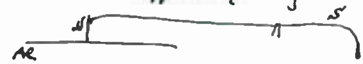
Fig 39. Double and single ended types of lightning guard manufactured by Muirhead and Co.; a lightning guard for mains circuit.

1. May. 94.

Δ Λ

I tried whether a needle point pressing on a plate would do. I first tried iron but they stuck magnetically (which may be a bother with your filings) and then tried zinc but the coat of oxide (?) was so thick it seemed very uncertain so I tried aluminium plate and it seemed very delicate, responding to invisible spark 7 or 8 meters off. The whole thing was however dreadfully sensitive to sound, for clapping your hands reduced the deflection which spark of course increased it. This was probably due to my use of a pretty big aluminium plate but it suggests a possible form of sound receiver in a resonance box, though probably not better than carbon contacts; I have not tried whether the latter would keep to their final resistance the way metallic ones do. My single point was quantitative like your tubes. I had it too jiggly so that vibrations in the room affected it but that does not seem essential.

I had an Al. plate Al with a needle N supported by a long thin



steel wire on which I put a rider so as to vary the intensity of contact.

I found that the needle evidently scratched the Al. and by a little pretty strong tap would make good contact and then by a series of gentle taps you could get the spot to stand anywhere you liked less than the max. A spark then caused an increased deflection depending on its intensity or. Of course single contact may not be more convenient than multiple ones but one would expect that their properties would be more easily studied and controlled. A nice little thing could be made with a quite small spring and a fine adjusting screw that would not take up more room than the size of a threepenny bit and it with a cell and galvanometer might all fit in your waistcoat pocket.

I had a fine passage and got home all well and found them all so. I am a bit sleepy today all the same. I am afraid the theory of these waves going round the ends of conductors is rather complicated. I was since thinking that two or three ionic units of al. would suffice to increase the contacts when there was an oxide coat though it is hard to see why, when there is passage already there new passages should be formed: maybe due to superficial tendency of rapid waves.

φ.

Fig 40. Origin of the spiral wire coherer? FitzGerald to Lodge, 1 May 1894.

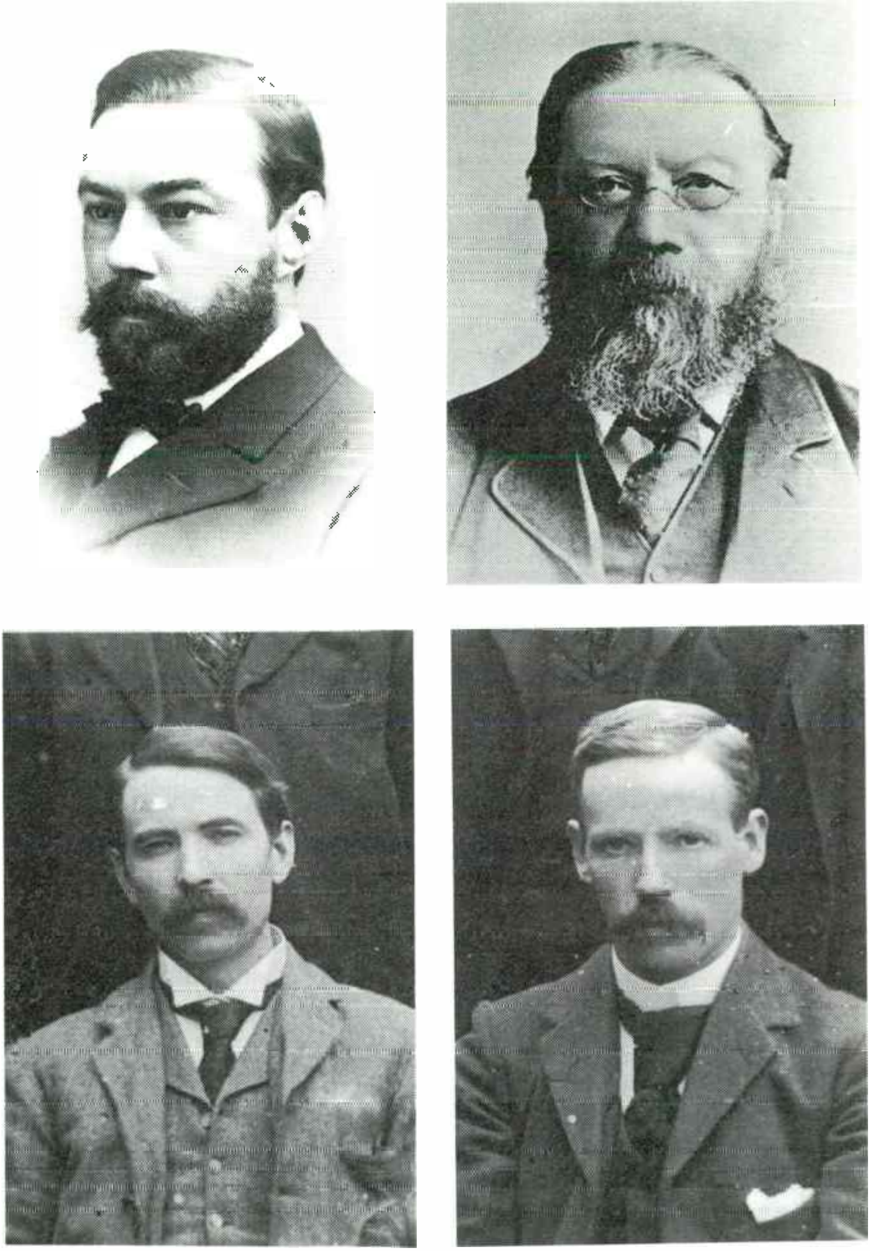
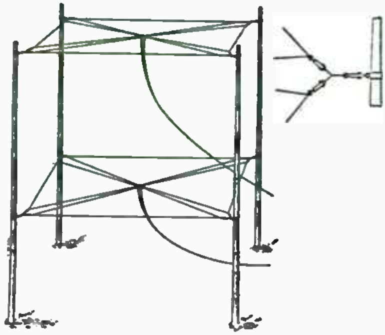
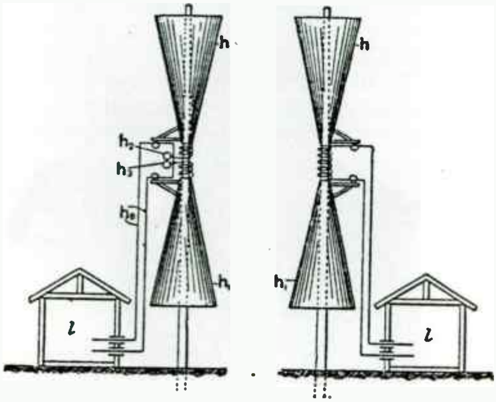


Fig 41. Alexander Muirhead; William Preece; Benjamin Davies; Edward Robinson





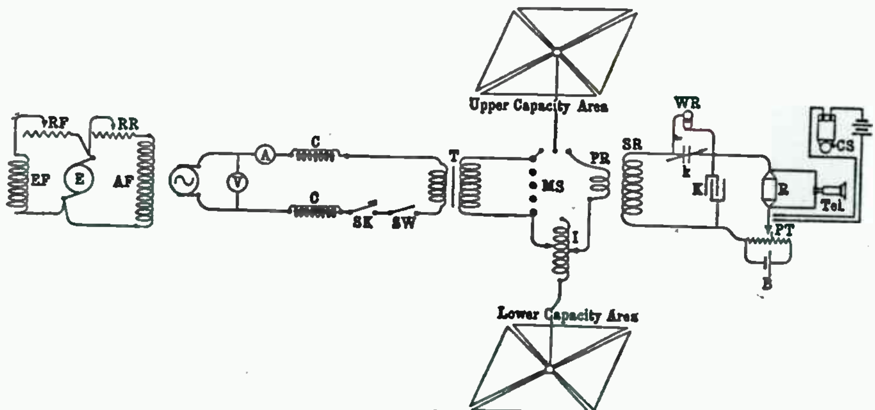


Diagram of the Connections of a Complete Installation.

I. Sending and Primary Receiving Inductance.
MS. Subdivided Spark Gaps.
T. Sending Transformer.
SW. Safety Switch.
SK. Sending Key.
CC. Inductance Coils (adjustable).
A. Ammeter.
V. Voltmeter.
∿. Alternator (Armature).
AF. Alternator (Field Winding).
RR. Regulating Resistance for Alternator Field Winding.
E. Exciter Armature.
RF. Regulating Resistance for Exciter Field.
EF. Exciter Field Winding.
PR. Primary of Receiving Transformer.
SR. Secondary.
k. Adjustable (overflow) Air Condenser.
WR. Coherer (Wheel type).
K. Receiving Condenser.
R. Recorder.
Tel. Telephone Receiver.
PT. Potentiometer.
B. Battery (Receiving).
CS. Call-up Set.

Fig 42. Conical capacity areas (1897); Lodge-Muirhead Maltese cross aerial; complete circuit of transmitter and receiver.

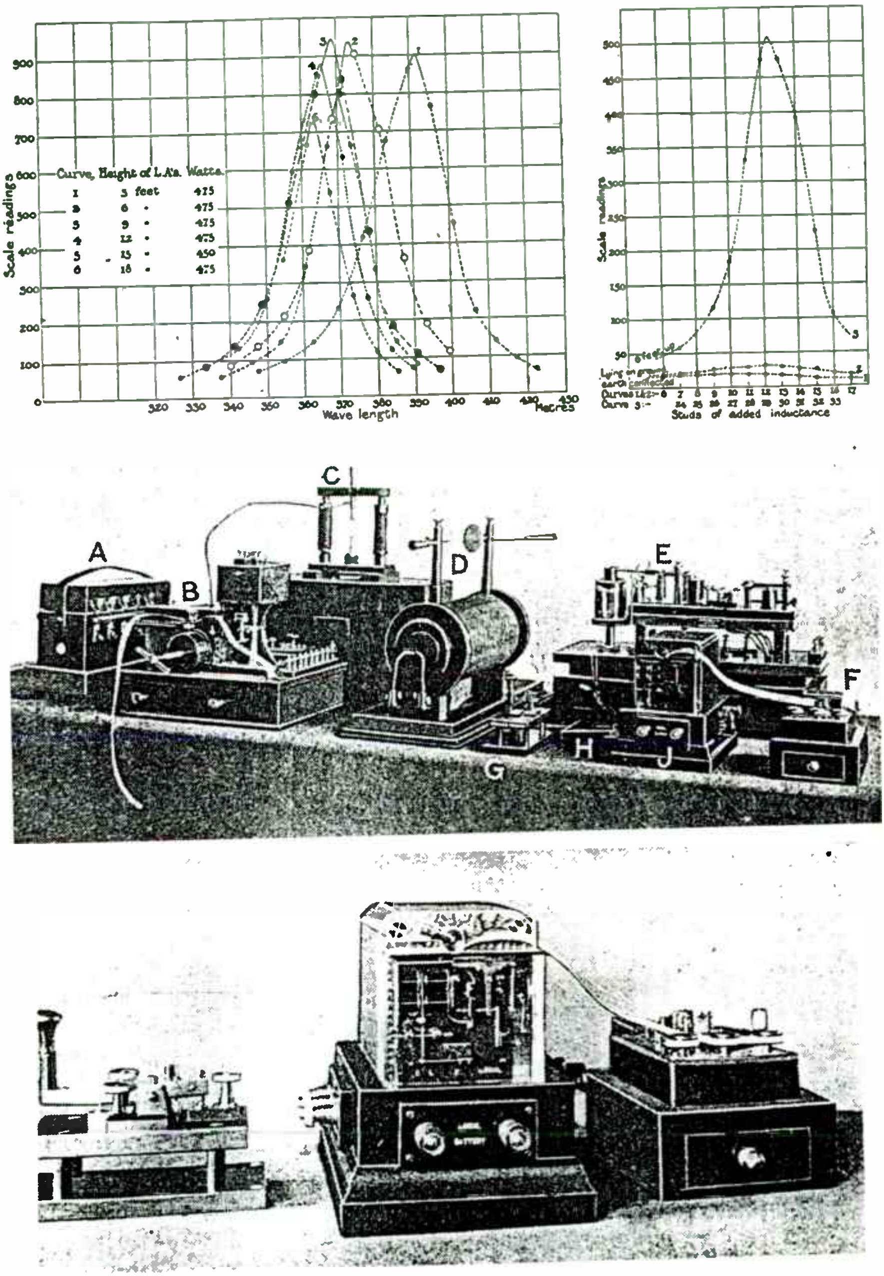


Fig 43. Effect of aerial height and earth connection on tuning and items of Lodge-Muirhead radio equipment.

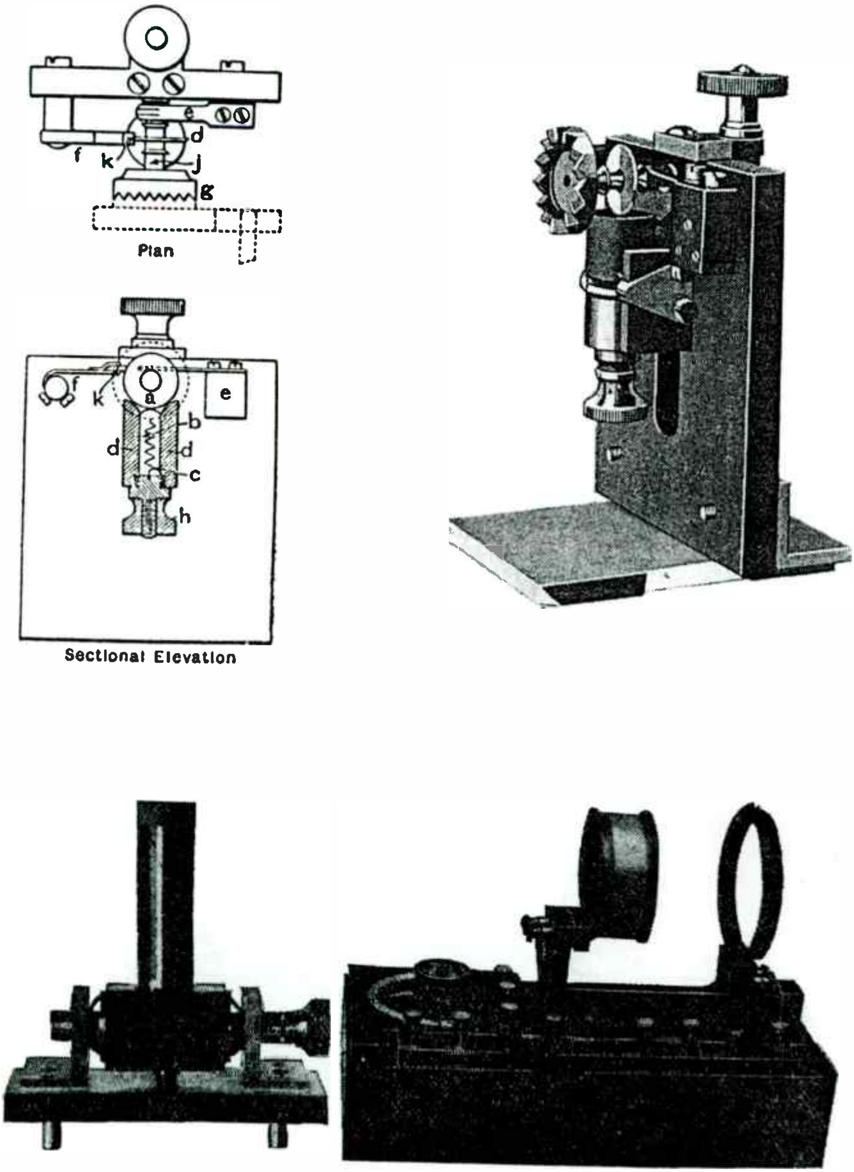


Fig 44. Wheel coherer; single point coherer in oil; Lodge-Muirhead receiver with variable magnetic coupling.

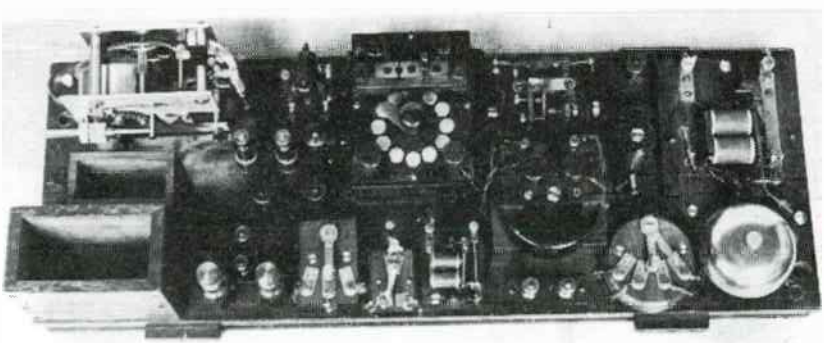


Fig 45. Lodge electrolytic detector (1910); Lodge-Muirhead experimental equipment.

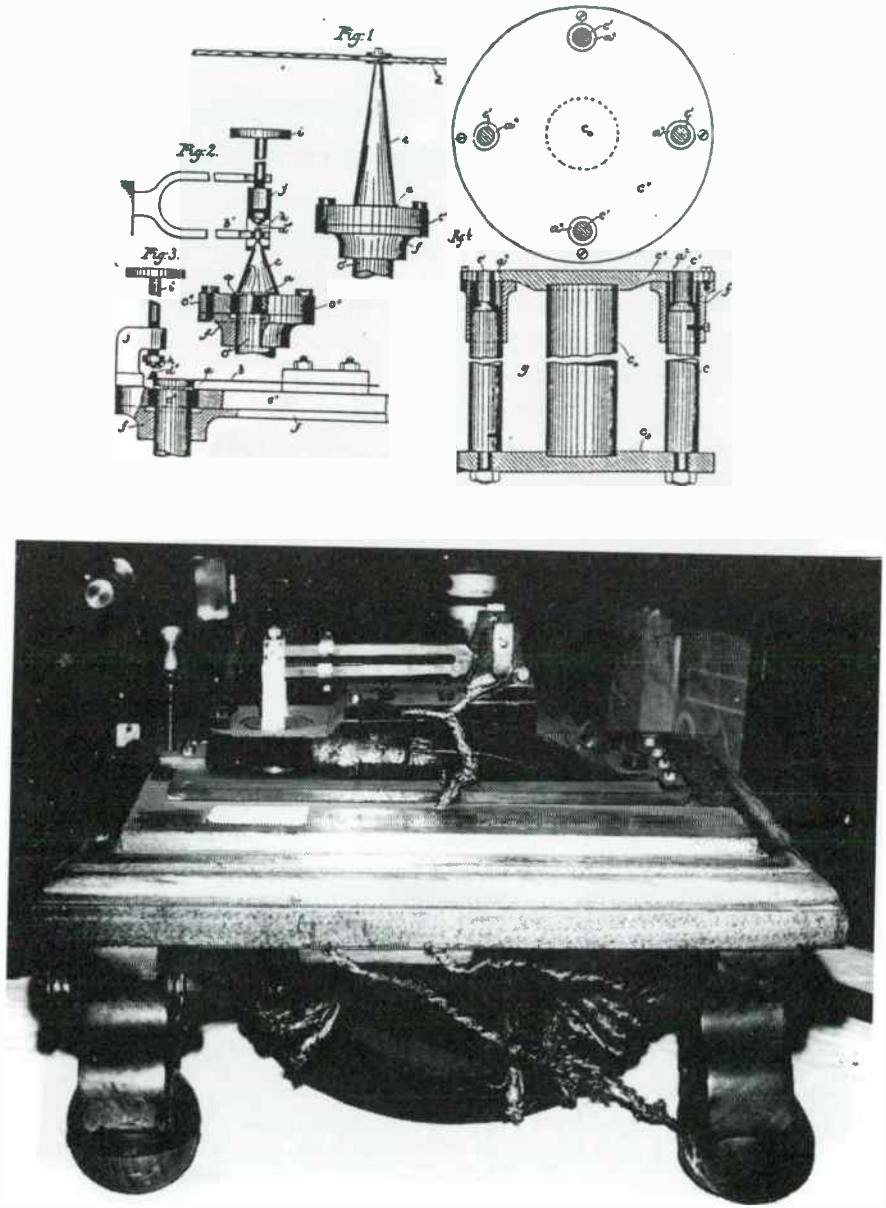


Fig 46. Moving coil loudspeaker patent diagram; 'magnifying telephone' (tuning fork version).

Chapter Eleven
THE TECHNOLOGICAL HERITAGE OF OLIVER LODGE

by J. Patrick Wilson

"In surveying the literature ... one cannot but be struck with the immense number of workers who have contributed to the invention, and the number of details that have been independently reinvented by different individuals. The literature ... affords, indeed, a striking proof of the fact that inventions grow rather than are made. The invention is essentially the product of the age in which it appears, a necessary consequence of the inventions and discoveries that preceded it. The scientific method of investigating historical events has shown us how false, how childish, is the "great man" theory of history, which was taught – and alas! is taught still – to us at school. But if the great man theory of history is fallacious, so is also the great man theory of inventions. There were steam engines before Watt, locomotives before Stephenson, telegraphs before Wheatstone, telephones before Bell, gas engines before Otto. It may be that occasionally an inventor strikes upon a valuable or useful improvement; it is exceedingly rare for an absolutely original invention to be sufficiently perfect to be of immediate use."

So wrote Silvanus P. Thompson, a contemporary of Lodge's, in referring in 1887 to the mercurial air pump.[1] Lodge would no doubt have echoed this sentiment because, although his name is not strongly associated with any particular invention, he did in fact have a hand in many applications of science to the benefit of man. In this he was careful to acknowledge the contributions of others and rather scornful of those who did not do likewise. Much of Lodge's consulting work was of a rather mundane nature such as improvements to lead-acid batteries, but this chapter will concentrate on the higher profile activities in which he had longer term involvement, and two of which continue to this day.

11.1 Lightning Protection

Lodge's work on protection from lightning damage concerns two topics: firstly, the protection of buildings by the proper design of lightning conductors; and, secondly, the protection of telegraphy equipment which by its nature is particularly susceptible to damage and malfunction. To put the topic in perspective we will consider present knowledge and practice first and then consider the views he was proposing and how they compared and contrasted with those of his predecessors and contemporaries.

Present knowledge[2] comes from electronic and other instrumentation which had not been developed at that time. In fine weather, clouds are normally positive with respect to earth, giving a positive field of about 100 V/m. With a thunder cloud this is reversed to give a field of about –20 kV/m, and at a typical height of 2.5 km for the lower negative charge, this represents a potential of 50 MV. Discharge starts with a downward leader of several hundred amps advancing in 20 m steps at a speed of $1\text{-}2 \times 10^5$ m/s followed by a return stroke averaging 25 kA at 10^8 m/s. This is frequently followed by one or more dart leaders and their return strokes at 3-100 ms intervals. In each return stroke the rate of current increase, di/dt, increases to a maximum at the time of peak current, being about 30 kA/µs for the first stroke and 80 kA/µs for subsequent ones. Current then drops more or less exponentially with time constants of about 100 ms for the first and 20 ms for subsequent returns. These negative discharges account for about 95 % of strokes with rather more severe positive discharges accounting for the remainder. When a lightning conductor is hit, its top will reach a potential $V = Ri + L di/dt$, where R is the earth resistance and L the inductance of the conductor. For a 10 m high conductor and 10 Ω earth resistance this would typically give 1 MV for the first term and 0.8 MV for the second. This immediately accounts for the anomaly of lightning protection – that the so-called protected zone is a very dangerous place to be – firstly, because any earthed structure in the vicinity, such as a water tank, is likely to receive a side-flash and secondly, because there is likely to be a very high potential gradient in the ground nearby. Current practice recommends strapping such structures to the conductor, top and bottom, and spreading the earth connection over a considerable area underground to reduce the gradient. A cross-section area of 25 mm^2 is now considered sufficient to avoid fusion for copper or iron conductors. The ability of spikes at the top to provide a silent brush discharge is now recognised as infinitesimal. Lightning, even now remains perverse and will occasionally defy the most elaborate precautions.

The Lightning Rod Conference of 1882 forms the background for Lodge's interest. This contained a vast amount of information on the behaviour of lightning, with much useful guidance, but also with much contradictory advice so that the net effect was a topic ripe for logical thought and scientific investigation. For the older style engineer a lightning rod of perhaps 3 mΩ would provide an almost perfect bypass so that, even at 100 kA, only 300 V would be dropped across it. However at this time the implications of Clark Maxwell's theories were being worked out in detail by theorists such as Heaviside and attracting much interest by scientists such as Lodge and FitzGerald. When Lodge was invited to give two lectures in honour of the late Dr Robert Mann, who had been an enthusiastic advocate of lightning rods in South Africa, he jumped at the opportunity it gave him to exploit his electrical knowledge and to do further experiments to clear up the many misconceptions on the subject. Many of these experiments in turn provided insights which were later to prove valuable in wireless telegraphy and motor ignition.

What Lodge immediately saw was flawed was the idea that simple Ohm's law could be applied to transient signals like lightning.[3] He recognised from his electrical experiments that sparks could occur between points which were connected together and therefore should have been at the same potential. He set about investigating this further and proving that it was due to the effects of self-inductance.

For these experiments he used a Voss electrostatic machine and a modification of his A and B-spark principle, which can be described as follows. In the conventional electrostatic machine there are two Leyden jars whose outer coatings are normally connected together and not specially isolated from the ground. It is the inner coatings that are well insulated, and upon which the high negative and positive potentials are built up, and between which sparks normally pass. If one wishes to generate a spark in a piece of equipment it is natural to think of connecting it between these two points. When, however, there is the slightest electrical leakage in the equipment concerned it will prevent a charge ever building up. What Lodge had observed was that if the external device is connected between the two outer coatings of the Leyden jars, leakage would conduct rather than short-circuit the charging process and when the A-spark between the inner coatings occurred as normal it caused a secondary B-spark to occur between the electrodes placed between the outer coatings. This discharge, or impulsive rush as he frequently described it, occurred between points which were until that time at the same potential. This B-spark forms the basis of many of Lodge's experiments and inventions.

In the lightning experiments he introduced an alternative path for the B-spark (Fig. 37) so that the discharge could either flash between the knobs provided for the B-spark or pass silently through the alternative path. By adjusting the separation between the knobs so that either outcome was equally likely he had a measure of the facility for discharge of the alternative path. In this he was able to show that even a comparatively small loop of thick copper wire was as big a barrier to discharge as the spark gap. This effect he attributed to be due to a combination of inductance and the skin effect. These effects both become more prominent as the frequency increases, or, for transient signals, as the rate of change increases. His experiments led him to believe that lightning discharges in conductors could be oscillatory even though the primary source of potential is dc, in the same way that a Leyden jar could discharge in an oscillatory manner. He also demonstrated that the order in which points, knobs and resistive structures were struck was quite different according to whether the discharge was A or B type. He stated that up until now only the former case had been considered, but that flashes between clouds could lead to a B flash to earth.

In these experiments he also noted the effect that he termed the recoil kick (Fig. 20). In this, when long lengths of parallel wires were connected to the equipment, spark gaps at certain positions along the wire could give sparks several times longer than the A spark. This he attributed to the effects of standing waves and used the analogy of water sloshing about in a bath.

From these experiments he made a series of recommendations for the design and installation of lightning conductors. He was particularly at pains to point out that the statement of the Lightning Rod Conference that "there is no authentic case on record where a properly constructed conductor failed to do its duty" was not "most decisive" as William Preece had claimed but "decided" in the sense that any rod that failed was deemed retrospectively to have been defective. Resistance was not itself important because it was negligible compared to reactance, which could amount to several thousand ohms. Although different cross-section shapes, as recommended by various authorities, would differ slightly in their inductive properties the effect was too small to be of importance. Furthermore even when conductors had been so thin that they had fused there was evidence that for that occasion they had provided protection. Galvanised iron was just as good as copper and considerably cheaper. He recommended several well separated conductors of No. 5 BWG rather than one thick one. If possible a ton of coke should be buried at each earth point to improve conduction to earth. He did however think that like Leyden jars discharges, lightning was frequently oscillatory and that there might be some advantage in having sufficient resistance to damp the oscillation. He was somewhat equivocal with respect to points at the top of a conductor, stating in some places that these were of no real value and elsewhere that they should be sharp and numerous.

His Mann lectures received wide publicity and resulted in the famous debate with Preece at the BA meeting in Bath in September 1888 (Fig. 24). It is widely thought that this incident was the root of Preece's treatment of Lodge over the invention of radio.

In addition to the protection of buildings, Lodge was also interested in the protection of telegraphic equipment which by its nature and usage was particularly vulnerable to physical damage, injury to personnel and corruption of messages. Lodge showed that if a heavy duty discharger had a tangle of fine insulated wire draped across its prongs there would be fine sparks between the turns as a Leyden jar was discharged. Thus inductance again was allowing a large transient voltage to occur, indicating the possibility of damage to the insulation of a galvanometer or syphon recorder receiving a side flash from a lightning stroke. He therefore went to considerable lengths to devise a system of filtering out such influences. By arranging a substantial spark gap between the input terminals, A and B (Fig. 38), followed by heavily insulated inductors, followed by a finer spark gap, further inductors of more turns, and so on, it was possible to reduce the effects to any desired extent at the instrument terminals, C and D. He was able to show that this was considerably more effective than other protectors such as the Saunders' guard and, through his friendship with Alexander Muirhead, they were manufactured by the Muirhead Co. A single-sided form was also produced, as also were designs for the protection of mains power circuits. The latter included long fuses to extinguish arcing across the supply initiated by the strike (Fig. 39). These devices were beautifully made and probably comparable in cost to the instruments they were designed to protect.

11.2 Wireless Telegraphy

Lodge's work on radio can be considered in three phases: the pioneering stage before Marconi; then, the attempts to gain a commercial foothold with the Lodge-Muirhead Syndicate; and, finally, the period when he was a popular writer on the topic, a frequent broadcaster and an influence on broadcasting policy by contacts with BBC and government personnel.

The first stage can be traced back to the BA meeting in Bradford in 1873 where he heard Maxwell speak and heard of his recently published *Treatise on Electricity and Magnetism*.[4] This set the theoretical basis for electromagnetic radiation and was a great inspiration to him. He had a number of discussions with his friend, the Dublin physicist G. F. FitzGerald, on the feasibility of generating electromagnetic radiation and it was he who suggested in 1883, after earlier doubts, that the discharge of a Leyden jar should emit such waves. In 1888 Lodge had demonstrated their existence along wires as part his concurrent work on lightning discharges which he thought were oscillatory. Unfortunately for Lodge it was at this same time that Hertz in Germany announced his discovery of electromagnetic radiation in free space. Lodge immediately recognised the superior nature of Hertz's demonstration, and the very thorough series of experiments supporting it, and gave it his wholehearted endorsement. In view of the lack of interest in Germany and the better understanding of the theoretical implications of Hertz's experiments in England by Lodge, FitzGerald and Heaviside, this undoubtedly contributed to its rapid international acceptance.

In 1889 and 1890 Lodge demonstrated his syntonic jars experiment (Fig. 20).[5] In this, a radiator and receiver, consisting of loops of wire about 1 yard in diameter and separated by about 2 yards, were each connected to a Leyden jar, and could be tuned to the same frequency by a slide wire. Only when thus adjusted to resonance would an overflow spark jump a small gap nearly bridging the receiving jar. At this range the coupling would be magnetic but Lodge stated that if the conducting surfaces of the Leyden jar were opened out it would become a Hertz radiator.[6] However, he also emphasised that once it became an efficient radiator damping would be increased and syntony would be destroyed. At this stage, however, neither Hertz nor Lodge conceived of Hertzian waves having practical use for telegraphy and it was left to Crookes to suggest this in 1892 although even then it was not taken up. In 1894 Hertz died and on 1st June Lodge gave a memorial lecture at the Royal Institution in which he summarised the work of Hertz and added many results from his own experiments. Hertz had been limited in detector sensitivity by the requirement for a visible spark and it was not until the development of the coherer that a sensitive detector became available.

Although David Hughes was the first to give a reasonably comprehensive demonstration of radio transmission to members of the Royal Society in 1879 using a carbon contact coherer, the experiment was not accepted for what it was by those present and it remained virtually unknown until Fahie publicised it in 1899.[7] During experiments on lightning protection of telegraph equipment with Muirhead in 1889, Lodge had noticed that when too small, the air gap would fuse across, forming a short circuit and cohesion between the balls. It was from this effect that the name coherer originated. Branly was the first to devise the filings coherer as a detector of sparks although a similar arrangement using carbon had been patented by C. and S. A. Varley in 1866 for lightning protection. It was later greatly improved by Marconi.[8]

For his 1894 lecture, Lodge demonstrated several types of coherer as well as transmitters (Figs. 31, 29), and made the observation that the single point aluminium/iron wire version was the most sensitive but that multiple contact filings or borings types were more reliable. It appears from a letter from FitzGerald of 1 May 1894 (Fig. 40) that the spiral wire coherer must have been developed very soon before the Royal

Institution lecture, Lodge following the suggestions made in this letter with improvements to the geometry to reduce the sensitivity to sound that had troubled FitzGerald. It has been claimed that this coherer might have acted as a point contact rectifier. Experiments by the present author do not support this view. When substituted for a detector in a crystal set it could only be made to act as a very poor detector by the addition of a dc bias and a degree of critical adjustment quite unnecessary for its use as a coherer. The ball radiator (Fig. 31), given as 5" diameter (7" waves) in *Signalling Through Space* and 6" diameter (9" waves) in *Nature*, was detected by this coherer at a distance of 40 yards in the Royal Institution lecture. (The present author believes that the wavelength of the fundamental would be twice the value given (i.e. the circumference) representing a frequency of about 700 MHz.)

This lecture was observed by Alexander Muirhead (Fig. 41) who lent Lodge some of his telegraphy equipment for the repeat performances at a Royal Society Ladies Evening in June and at the BA meeting at Oxford in August. It was the latter which is now regarded as the first public demonstration of wireless telegraphy, although this had been disputed initially. It was, however, done only in the context of illustrating the similar nature of radio waves and light and not with the suggestion that such a system would be technically and commercially exploitable. Lodge's lack of foresight here was based on the premise that, to compete with telegraphy, privacy would be essential. Marconi was of course to exploit its maritime use where privacy was far from necessary, but it was not for another quarter of a century that broadcasting would come into being. Nevertheless Lodge did continue experimenting with the assistance of Davies and Robinson and the collaboration of Muirhead.[9] In view of the publicity that these lectures received Lodge was justifiably piqued when, in 1896, William Preece introduced Marconi's invention as something "entirely new". Was this revenge or ignorance? Neither view seems entirely satisfactory. Although Preece and Lodge, ten years his junior, had had an acrimonious public discussion at a BA meeting over lightning conductors in 1888, the greater credit for the invention of radio was in any case due to Hertz rather than Lodge. As it is impossible to believe that the Chief Engineer of the Post Office could have been unaware of all the work on aetheric transmission that was going on around the world at this time, one has to assume that his economy with the truth had more to do with maximising his impact in the popular press and securing support and monopoly for the Post Office from the government.

Marconi's successes and obvious faith in the potential of radio seems to have spurred Lodge to renewed activity as he patented tuning in 1897[10] and collaborated with Muirhead on further experiments and patent applications.[11] By the end of 1897, when Lodge, and Lodge and Muirhead, had 5 British patents for wireless telegraphy, Marconi had just 2. For commercial reasons much of their activity now took place in greater secrecy with Lodge's scientific assistants (Fig. 41), Benjamin Davies concentrating on an inductive system (as Preece had earlier favoured!) and Edward Robinson concentrating on electromagnetic radiation with Alexander Muirhead. Some of these transmissions took place between the Victoria tower and the tower of Lewis's shop in Liverpool and others between the University and Lodge's house in Grove Park, the latter a distance of about 1.5 miles.

By 1901 progress was sufficient for the Lodge-Muirhead Syndicate to be formed. The system devised was very much based on the principle of syntony or sharp resonance to achieve distance rather than brute power. Technically the Lodge-Muirhead system was highly competitive and was adopted by the Indian Government for communication between Burma and the Andaman Islands, a distance of about 300 miles. In addition to their own experimental stations at Downe and the factory at Elmer's End, Kent, the only other installations known[12] were for the Midland Railway's steamers between Heysham and the Isle of Man, the Eastern Extension Telegraph Company's cable ships *Patrol* and *Restorer*, later supplemented by shore stations in Singapore and Hong Kong, a government link between Trinidad and Tobago, and, in Lagos, for the African Direct Telegraph Co. It also appears to have been supplied to Col. Younghusband's expedition to Tibet in 1904.[13]

The system was very much based on the patents of 1897, particularly 11,575, which was effectively the master patent for tuning. This described a number of possible systems and introduced several important principles. It stated that both the transmitter and the receiver should be sharply tuned and that this should be achieved by having large capacity areas of low resistance tuned by inductors inserted between them (Fig. 42). The inductances could be varied to alter the tuning frequency. The third feature was that the degree and type of coupling between the aerials and the rest of the circuit should be such as not to damp the resonant properties of the aerial circuits unduly. Conversely to modern thinking, the aerial circuit was to be the highly tuned one. Lodge also introduced the use of a high frequency transformer (or jigger) to this end in the receiver but not the transmitter. He was insistent that for syntony a dipole structure should be used and that connection to the earth introduced unacceptable damping. He did, however, include the use of an earth in his patent and recognised its advantages at sea. By 1903, the system contained a high frequency transformer in the transmitter as had been included by Marconi in his 1900, 7777 patent.[14] It also used variable coupling for the receiver transformer, and by 1908/9 (Fig. 42) it effectively contained a second stage of tuning in the receiver by the inclusion of a variable capacitor across the coherer and in series with a larger capacitor shunting the (syphon) recorder. A further means of securing low radio frequency resistance was the use of cables made up of many strands of silk-covered No. 40 wire to minimise the skin effect.

The 1903 and 1908/9 descriptions also show that the conical capacity areas had been changed to a Maltese cross design in which the adjacent triangular loops were connected only at the centre (Fig. 42). The 1908/9 paper gives extensive measurements of the tuning properties of the system and how these were compromised by earth connection or even by proximity to the earth (Fig. 43).[15] The best Q-factors corresponding to the curves shown were just over 20, i.e., –3 dB for a detuning of 2.5 % and not quite the claimed "one-half per cent. ...... sufficient to throw the tune completely of the top of the curve". They were also insistent that a rotating mirror had shown their spark to be a practically continuous oscillation and that their signals were free of harmonics – not claims that went unchallenged!

One of the outstanding features of the Lodge-Muirhead system was the mercury-wheel coherer (Fig.44),[16] devised chiefly by Robinson, which, although probably the best coherer invented, was by this time in competition with the Marconi magnetic detector. The wheel coherer was self-decohering by having a rotating steel wheel just touching the surface of a blob of mercury covered by a thin layer of oil. This was in series with a potential of about 0.2 V and a low impedance recording device. Normally the oil layer provided insulation which was broken down by the rf signal and restored by the rotation of the wheel. The 1908/9 paper also mentions use of a single point coherer in oil (Fig. 44) and an electrolytic detector (Fig. 45).[17]

The Lodge-Muirhead system continued until 1911 when the patent wrangle on tuning between Lodge and Marconi was finally resolved in Lodge's favour. At this stage he sold it to Marconi and agreed to be a consultant to the Marconi Company (although he was never actually consulted!), and to discontinue his own commercial activity in radio. Ironically it was Preece who got the two sides together to resolve this issue. It was probably Marconi's more single-minded determination and early monopoly of marine telegraphy which ensured his ultimate success rather than any inherent technical advantages.

In 1900 the Post Office secretly commissioned Silvanus Thompson and Lodge to investigate the possibility of invalidating or circumventing the Marconi patents.[18] Neither felt that this would be too difficult, but Captain Henry Jackson of the Admiralty, himself a radio pioneer and friend of Marconi, felt that this would be unwise as the Post Office might well wish to use Marconi equipment later on. Lodge was for a time a regular correspondent with the Prime Minister and his scientific standing meant that he was informally consulted from time to time on broadcasting policy and related matters. He became a regular broadcaster and consultant to *Harmsworth's Wireless Encyclopaedia* and *Popular Wireless* and a frequent contributor himself – not perhaps activities quite expected of a 'great scientist'! His final fling in this direction was the "N" circuit,[19] probably a device to boost circulation rather than produce any worthwhile improvement in radio reception. This took various forms of high-Q circuit loosely coupled to the rest of the receiver, sometimes involving a degree of positive feedback. It looked mysterious because it was coupled by strays rather than components shown on the circuit diagram but did in a sense hark back to his syntonic jars.

Another invention which nowadays would be associated with radio but was not at the time connected with wireless telegraphy was Lodge's patent for the moving coil loudspeaker. He was quite interested in sound and in about 1908-9 appeared to be supervising a Miss Green on research work on the harmonograph and phonograph. His 1898 patent is chiefly concerned with a system of magnifying an incoming signal using a moving coil driver system with either a permanent- or electro-magnet to provide the strong radial magnetic field in which the coil is suspended (Fig. 46).[20] This coil is attached by, say, a light aluminium cone to a carbon granule or single point microphone. Eddy current damping is considered a merit. Alternatively, the cone can be connected to a diaphragm or sounding board for the direct radiation of sound. Such a system can be cascaded with several moving coil drivers each exciting a carbon microphone, the latter with its battery providing the amplification. The system can be used either for speech by using a light spring for the support of the contact or diaphragm or as a resonant system using a tuning fork (Fig. 46). He also indicated that the sounding board could be the ceiling or wall of a public hall! The idea of using a moving coil as driver for a relay was originally suggested by E. W. Siemens in 1874 and as a loudspeaker in 1877.[21] The carbon microphone amplifier, using a moving iron driver, was used with some success as a telephone repeater by Shreeve in the USA about 1904, and later by S. G. Brown in the UK, and also as a crystal set amplifier. Unfortunately the moving coil loudspeaker had to await the advent of efficient electronic amplifiers and its further development by Rice and Kellogg[22] in 1925 before it become the almost universal transducer it is today.

11.3 Motor Ignition

Although this turned out to be one of the more commercially successful of the Lodge enterprises, it was pursued through his second and third sons, Brodie and Alec, and also for a time his youngest son, Raymond, and second daughter, Honor. It was in fact the spark plug which eventually made the money in this venture and this was not part of their father's original contribution.

The igniter upon which the company was formed was a joint patent of Sir Oliver and Alec in 1903 and arose out of some of Lodge's earlier observations on the generation of sparks.[23] The B-spark not only appeared fatter and brighter than the A-spark but it could be made to occur under water, with a carbon deposit across it, or when short-circuited by a short loop of wire, forming an inductor. Clearly the B-spark was the one which appeared to have the better properties for motor car ignition. At this time the "trembler" was the standard device for ignition. This was simply a portable Ruhmkorff or induction coil, i.e. a transformer with a large turns ratio and a hammer break in the primary winding causing a large repetitive back emf. This was normally used with a distributor to cause the almost continuous spark to be fed to the right plug at the right time. A resistive load across the secondary produced by damp on the plug or carbon across the gap would readily inhibit the spark. The Lodge B-spark Igniter is a modification of the trembler to include capacitors charged by the secondary and an adjustable A-spark occurring within the hygienic confines of the device (Fig. 47). This system proved very effective as the Lodge Bros. were keen to demonstrate.[24] A spark plug would continue sparking even when totally submerged in a glass of tap water!

Armed with this device Brodie, who had graduated in commerce followed by 5 years working in a Liverpool shipping company, and Alec, who had graduated in engineering and was working for the Lanchester Car Co., decided to set up in business together. At first they worked from the family home, Mariemont, in Edgbaston, but in 1904 Lodge Brothers was formed with a one-room office at 14 New Street, Birmingham. Soon a second room was added and by 1907 they had new workshops and offices in Wrentham Street, Birmingham. As their 1912 catalogue mentions works at Birmingham and Elmers End, Kent,[25] it would appear not improbable that the first igniters at least were manufactured by the Muirhead Co. to the Lodge design. They soon diversified and started selling other electrical equipment for cars including lighting systems, spark plugs, distributors, leads, dynamos, etc. In 1907 they also decided to take a stand at the second Motor Show at Olympia where they shouted themselves hoarse. For the next show Alec was inspired to devise an enormous working model sparking plug which, after it had caused a sensation, was banned following complaints from less imaginative competitors. He then set up an array of real sparking plugs so that the sparks spelled out LODGE. This in turn was banned so he did the same thing with electric light bulbs. After that the company never looked back!

Although the igniter was on sale to the motorist in several models until at least 1912, it appears not to have been supplied as original equipment by any motor manufacturer. Thus the trembler was in practice overtaken by the magneto which had been introduced by Bosch at about the same time. In 1916 the gapped distributor was brought out by BTH and this, which is used to this day, has some of the inherent properties of the A and B spark system.

In 1909 H. G. Longford of the Sphinx Sparking Plug Co. suggested that they manufactured plugs to Alec's design. These used porcelain insulators made by French peasants and copper and asbestos seals. These proved so successful that by 1912 Lodge Bros. were claiming the largest sales of any British-made plug. It now became clear that it would be advantageous to produce them themselves. To this end they amalgamated in 1913 with the Mascot Co., which Bernard Hopps had started in 1908 when he left BTH to start his own plug manufacturing company based on a very effective fused glass seal. In 1910 the Mascot Co. was situated in Albert Street, Rugby, and when Hopps and his brother Alfred joined with the Lodge Bros. to form the Lodge Sparking Plug Co Ltd., this became the main factory whilst their offices remained the former Lodge offices at Wrentham Street. As before, Alec Lodge and Bernard Hopps were concerned with the engineering side and Brodie Lodge with the business side, and Alfred Hopps, an accountant, was Chairman.

In 1916 they were able to build a new factory and offices in St. Peter's Road, Rugby, where some of the successors to the company remain to this day. Needless to say, the company had an important role to play in the First World War in the supply of plugs for military vehicles and aircraft. For the latter they developed the mica-insulated "pepper box" plug. For the rapidly increasing engine temperatures they introduced copper sheathing to disperse the heat. After the war they increased their capital and shortened their name to Lodge Plugs Ltd. and returned to the motor car. Steatite insulation was tried but this was not successful without a mica wrapped core which was added for the C3 plug, used by Sir Charles Kingsford in his, 1929, record non-stop flight from England to Australia in *Southern Cross*. Further developments resulted in the A30 and the KR3 series used by the British team in the Schneider Trophy Race in 1931. The success of this proved a great boost to Lodge Plugs and to Britain and the winning Vickers Supermarine became the forerunner of the Spitfire.

In the 1930's motoring magazines and buses bore large advertisements for LODGE. In 1936 the company introduced Sintox (sintered aluminium oxide) for the plug insulators and had the inspiration to add a pink colouring to distinguish it from other materials and from other manufacturers' products. Sintox has the fourfold advantages of very high insulation resistance, high mechanical strength, high thermal conductivity and resistance to damage by sandblasting. Fortunately Alec was able to see the benefit of this in the new world speed records of 345 and 357 mph set by George Eyston in *Thunderbolt* on the Bonneville Salt Flats before the former's death in 1938. Sintox and another innovation, the use of "S" Alloy (thoriated platinum) electrodes, which greatly increased the working life of plugs in aircraft, played an important role in the Second World War. Used by both the RAF and the American Air Force, these plugs were later praised by President Roosevelt in an address to Congress in 1944. "Before and during the Battle of Britain, when the RAF had to work its out-numbered planes around the clock and the Spitfire and Hurricane engines got punishing treatment, the British developed a new type airplane spark plug. It has a life from four to five times longer than the standard aeroplane spark plug. Although the plug was hand tailored, the British worked out production techniques for increasing their limited output during the next two years. After the United States Eighth Air Force began operations from Britain in the summer of 1942 the British undertook to double their production so that they could provide all our Eighth Air Force Fortresses with these plugs. Since early in 1943 virtually every United States Flying Fortress has taken off from British bases with these plugs in each of its four engines. It would be impossible to estimate how many thousand United States bomber crews may since then have owed their lives to these spark plugs, but the performance record of the plugs speaks for itself."

The development of jet engines demanded a reliable jet-igniter rather than spark plugs. Again Lodge were able to provide an answer, based on the original B-spark igniter, which became universal in Rolls-Royce and De Haviland engines. Another wartime device which proved to have enormous value afterwards was the invention by Dr C. J. Smithells of the Thermo-Couple Plug. This enabled cylinder temperatures to be monitored continuously and engine and carburettor design to be improved.

In the 1940's and 1950's the company developed plugs for motor car and motor cycle racing and notched up a tremendous number of successes as well as gaining enormous publicity for their use in more mundane vehicles. It was common to hear reports that races had been won using Lodge plugs.

In the company files there is a letter from Alec to his father requesting support on a scientific point in an attempt to circumvent the infringement of a KLG patent for electrical screening. In 1947 there was a further touch of family solidarity when they installed a Lodge-Cottrell filter (Fig. 49) which is still in use in St. Peter's Road.

In 1949 Brodie (Fig. 50) retired after 45 years in the saddle and the company went public. The company had clearly prospered with the Lodge brothers as Alec owned the Island, Newquay (Fig. 50), which became a frequent destination for Lodge family get-togethers, as well as a house in Leamington Spa, while Brodie owned Floore House, a large mansion between Daventry and Northampton.

In 1961 Lodge Plugs Ltd. was purchased by Smiths Industries who had acquired KLG Plugs in 1927. Smiths continued to market automobile plugs under the Lodge and KLG names until about 1982 and then licensed manufacture by SPICA in Italy under the name "Golden Lodge". Plug manufacturing equipment is, however, still marketed by SIMAC and aviation and specialised plugs and industrial and jet engine ignition equipment by Lodge Ignition, both in Leicester Rd., Rugby.[26] The industrial ignition equipment is again based on the B-spark principle, with the A-spark occurring in a sealed unit and the B-spark across a semiconducting surface supported on a ceramic substrate situated at the position where ignition is required. The factory in St. Peter's Road continues to supply Sintox products for a variety of applications including electrical insulation and armour, still using the distinctive pink colour. These were marketed under the name of Lodge Ceramics Ltd. from 1984 until August 1st 1992 when it became the Rugby Division of Morgan Matroc Ltd.

11.4 Electrostatic Precipitation

In 1884 Lodge gave a lecture to the British Association in Montreal on 'Dust' which received wide publicity. In this he demonstrated the effects of heat, as had been noticed by Tyndall, and now more strikingly by means of electric fields, in producing a "dark space" surrounding a heated or charged body. This had been shown by his experiments with

J. W. Clark to be due to the removal of particles of solid or condensed matter from the air.[27] News of this reached Dr Alfred Walker of the Deeside Lead Works who wanted to remove the fumes from the lead smelting process at Bagillt more effectively than by the traditional method involving two miles of flues. With Lodge he devised a system[28] which he rapidly patented.[29] After initial successful small scale experiments using an 18" Voss machine, he built an industrial scale system using two 5 ft Wimshurst machines and a 1 HP steam engine, which ultimately proved unsatisfactory probably owing to a combination of poor insulation and inadequate power from the electrostatic generators. In any case, even today, lead smelting is one of the more difficult tasks for precipitators.

Electrostatic precipitators work by having an array of wires at a high negative potential. These produce a corona discharge which negatively charges any particles present. These are then attracted to the earthed collector plates from whence they are periodically removed by mechanical rapping. There are in fact several applications of precipitation which have been considered and tried at various times. Industrially it can be used to recover valuable raw materials which might otherwise go to waste. It is an effective way of removing solid or condensed but not gaseous pollutants before they reach the atmosphere. It is a possible way to remove fog and smog from the atmosphere for the sake of visibility or health, and it is also a method of causing clouds to precipitate for the sake of agriculture or military purposes. Lodge's early days in the smoky Potteries undoubtedly influenced his enthusiasm for such applications.

Although the first project failed through inadequate technology he, Robinson, and Franklin were experimenting with fog dispersal aerials over the yard at their laboratory in Birmingham in 1903 as well as with various kinds of high voltage rectifier, both for this and the X-ray equipment that they were also working on.[30] In the course of this work Lodge devised the bridge rectifier circuit based on the Cooper-Hewitt mercury arc lamp.[31] The patent includes two rectifier circuits (Fig. 51) the first being a simple half-wave design with Leyden jars in series as reservoir capacitor (interestingly these components could have been rearranged to form a voltage-doubler circuit) and the second, a conventional bridge circuit without a reservoir capacitor (although he indicated that this could be included). This may well be the first description of the bridge rectifier circuit. It is not clear whether this was a novel use for the Cooper-Hewitt lamp because in 1905 Lodge, Muirhead and Robinson patented their own valve rectifier and later, in his autobiography, Lodge claimed to have invented the mercury rectifier. The 1905 patent[32] (see Fig. 51) relied on a partial vacuum with a variety of substances inside and an asymmetrical electrode layout. Although the substances tried included helium, oils and waxes, phosphoric substances and mercury it is not really correct to describe it as a mercury rectifier, as its working pressure and current was far lower than the high power mercury arc rectifier developed later. It was, however, put into immediate use for the agricultural work (see below) and the fog and fume precipitation. Lodge's fourth son Lionel took an active part in these early experiments in his father's laboratory as well as their later commercial exploitation.

By 1913 the fume work had progressed sufficiently that the Lodge Fume Deposit Co. Ltd. was formed with a workshop and offices in Tintern House, Great Charles Street, Birmingham.[33] Lionel, Noel (the fifth son) and W. F. Newman were directors and Cyril Franklin works foreman; Lodge's fourth daughter, Norah, was also on the staff. It was not a good time for this type of venture, just before the First World War, so that in 1919 it was wound up and with further capital it was reformed as the Lodge Fume Co. Ltd. In 1921-22 they reached an agreement with the International Precipitation Corporation of Los Angeles which brought them the Cottrell patents to form Lodge-Cottrell Ltd. In 1922 over half the world's tin ore smelters were using Lodge-Cottrell precipitators. By 1929 systems for de-tarring gas and for boiler flue gases were developed and the company had expanded sufficiently to move into larger premises purchased from F. & H. Matchett Ltd. in George Street Parade. In 1930 they changed from the Lodge valve to the more powerful Cottrell synchronous motor and commutator rectifier. During the Second World War the Company was registered as "Essential Works" and concerned with penicillin manufacture, with titanium tetrachloride used in smoke-screens, and also in the atomic energy field. After the war increased awareness of atmospheric pollution led to greater demands by the electrical power industry, cement manufacture, dust and mist precipitation in sulphuric acid manufacture, and in the iron and steel industry. Lionel died in 1948.

In 1958 Lodge-Cottrell was acquired by Simon-Carves, who had in fact started such negotiations as far back as 1918, but business was continued under the same name. In 1960 the Precipitator Division of Simon Carves was transferred to George Street Parade, and in 1962 Noel died, ending an era. In 1972 it was acquired by Dresser Industries Inc. of Dallas, Texas, and in 1984 became the Lodge-Cottrell Division of Dresser UK Ltd.[34] Their name changed to Lodge Sturtevant Ltd. in 1991 when they combined with Sturtevant Process Ltd., a company which could trace its roots back to W. C. Holmes in 1850 and B. F. Sturtevant in 1870.

11.5 Electricity in Agriculture

Although some of the technology is common with electrostatic precipitation, this was a separate and ultimately less successful venture. The idea for this work came from Professor S. Lemström in Sweden although others had tried it earlier. Lemström in about 1885, attempting to simulate the aurora borealis in his greenhouse, noticed rapid plant growth and wondered whether atmospheric electricity, strong in the far northern regions, was responsible for the otherwise unexpected fast development and good yields of crops in this region. Controlled experiments soon seemed to confirm this hypothesis. It was considered that serrated leaves, pine needles, etc., might be designed by nature to facilitate collection of electric charges which are particularly abundant on fine days. If so there would be particular advantage in supplementing the natural positive current on dull days when this might be small. This led a number of people including Mr J. E. Newman and Mr R. Bomford to attempt larger scale trials.[35] One of the difficulties which had to be overcome in controlled tests was that the charge released by the equipment would tend to drift or be blown by the wind to neighbouring areas. Lodge was consulted about more practicable methods of producing and distributing the high positive potentials required (60-100 kV) than the Wimshurst type machines utilised previously. This was at about the time when Lodge, Muirhead and Robinson had patented their rectifier valve in 1905 and as Lodge was always keen to put electricity to the service of mankind he readily agreed. Several of his staff and his son

Lionel were involved in this and developed a system with a 2 HP Petter oil engine and a 220 V 3 A dc generator situated in a barn of Bevington Hall Farm, Salford Priors, near Evesham. The cable was led 200 yds to a small hut containing a rotary break, a large induction coil and bank of Lodge valves (Fig. 55). The 100 kV potential was led out to a series of wires (No. 11) supported on 16 foot poles with elaborate insulators including oil. The poles were 71 yards apart in rows separated by 102 yards with thin (No. 24) galvanised wires bridging these at 12 yard intervals, and covered about 20 acres. The natural current density of about 10-12 A/m^2 was increased to about 10^{-8} to 10^{-7} A/m^2 in these tests. The system was live for about 8 hours per day on dull days and sometimes during the night.

Several crops were tried but the records were most complete for wheat, which apart from a year of drought, showed yield increases from 20-40 % over six years compared with a control field. Strawberries showed earlier ripening and a 35 % increase, mangolds showed a 25 % increase, cucumbers a 17 % increase Experiments using the Lodge-Newman equipment were also tried by Mr J. E. Newman at a nursery at Bitton near Bristol where cucumbers showed a 17 % increase, 5th year strawberries 36 %, 1st year strawberries 80 %, broad beans a 15 % decrease but were ready 5 days earlier, cabbages were 10 days earlier, celery showed a 2 % increase but tomatoes no difference. Mr G. R. Newman also found a 33 % increase for beet and 50 % for carrots in his own vegetable garden in Gloucester. Experiments were also tried at two places in Scotland and at a place near Leeds.

The success of these experiments led to formation in 1909 of the Agricultural Electric Discharge Company Ltd. apparently by Lodge and Mr George Newman. Equipment was still being marketed in 1914 by Mr J. E. Newman of the Agricultural Electric Discharge Co., 85 Park End Road, Gloucester. It would appear that G. R. Newman was the father and J. E. and W. F. Newman were his sons. In spite of the experimental success for a wide range of produce (but perhaps excluding leguminous crops) it is not clear when or why this technique was discontinued although presumably the war would have been an important factor. The mechanism of electrical growth stimulation appears to be more complicated than simply the fertilising effect of the nitric oxide generated but has not yet been explained in detail.

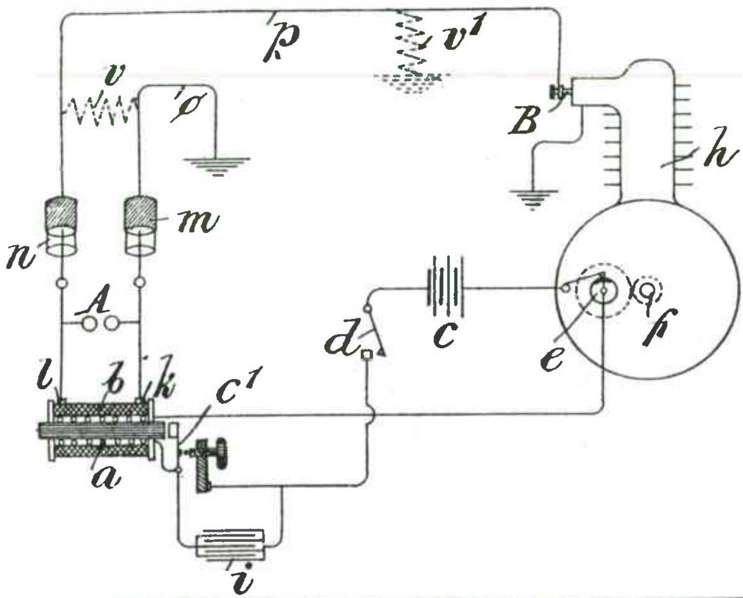


Fig 47. The Lodge igniter for motor cars.

FILE COPY

Sir Oliver Lodge, F.R.S.
Normanton House,
Lake,
Salisbury.

AML/PB

4 January 1932.

Dear Father,

We are at present making caps to fit over sparking plugs in order to prevent the ignition circuit interfering with the wireless receivers. A rival company maintain that they hold a master patent dated 1920 for the application of such caps to sparking plugs. Our attitude is that their patent is invalid, because the screening of the ignition circuit by enclosing it in metal was well-known at the date of their patent. We have evidence of this in that the magneto and ignition cables were screened in this manner during the war.

I believe you published some papers on screening, one experiment I believe you described as "The Copper Hat" and if you could, without trouble, refer me to any publication on this subject made before 1920, it would help us in showing that the subject was well-known.

I do not want you to go to any trouble in making a search because we can probably get information from other sources.

Yours ever,

A M L

Fig 48. Letter from Alec to father, the 'copper hat' refers to the 1894 demonstration.

LODGE-COTTRELL, LIMITED.

1/E

George Street Parade.
Birmingham, 3.

Messrs. Lodge Plugs Limited,
Rugby.

May 10th 1945.

Aluminium Oxide Dust

Dear Sirs,

We are sending you an outline general arrangement of the Electrofilter Plant we should propose, and also a drawing indicating the brickwork requirements.

We have indicated steel hoppers and enclosed these hoppers on three sides, and left an opening on the side next to the new store building for the removal of the dust. The object of the enclosure is to avoid condensation occurring on the inside of the hoppers and caking of the collected dust. This brick enclosure may be sufficient to overcome this possible difficulty, but if it is not then it would be necessary to heat insulate the steel hoppers on the outside with lagging.

Each of the hoppers is fitted with a small hand-operated rotary valve so the dust can be discharged into sacks without any appreciable air leakage. If you prefer it an ordinary dust slide or other alternative can be provided for the discharge of the dust.

We have excluded from the equipment to be supplied by us all building work, brick, concrete, and window frames and doors. We have included for the steel joists which form part of the internal steel equipment and the stairway and platform, all electrical gear, high tension connections and cable.

As regards the supply of the equipment, we expect that we could have all the internal and electrical equipment ready by the time the brickwork was completed, and we could complete the erection of all the equipment we supply in approximately one month.

In lieu of any guarantee of performance we should be prepared to instal this Plant on loan, and maintain it in proper condition for a specified number of years. Our charge for this and servicing the Plant, exclusive of fire insurance, and exclusive of any breakages which might occur outside the normal operation of the Plant, would be £249. (Two hundred and forty nine pounds) per quarter, payable in advance.

We have not been able to prepare our full tender but we send you this provisional information and would like to know whether it meets with your approval.

Yours faithfully,

LODGE-COTTRELL LIMITED

Enclosures. Drgs. Nos. A.624
A.623

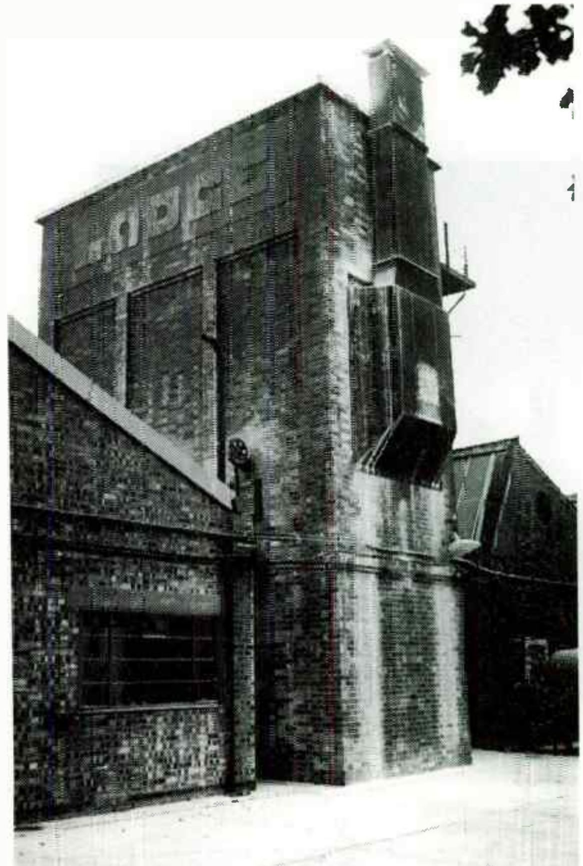


Fig 49. Lodge-Cottrell precipitator at Lodge Plugs Ltd.

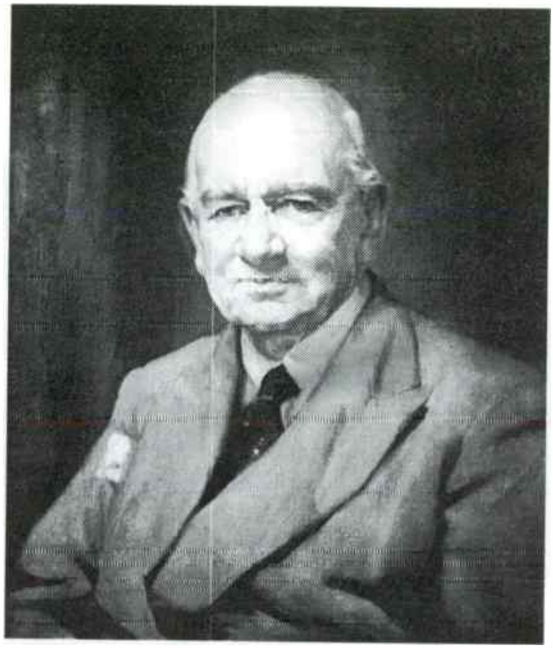


Fig 50. Portrait of Brodie Lodge at Lodge Plugs; Alec's holiday home The Island, Newquay.

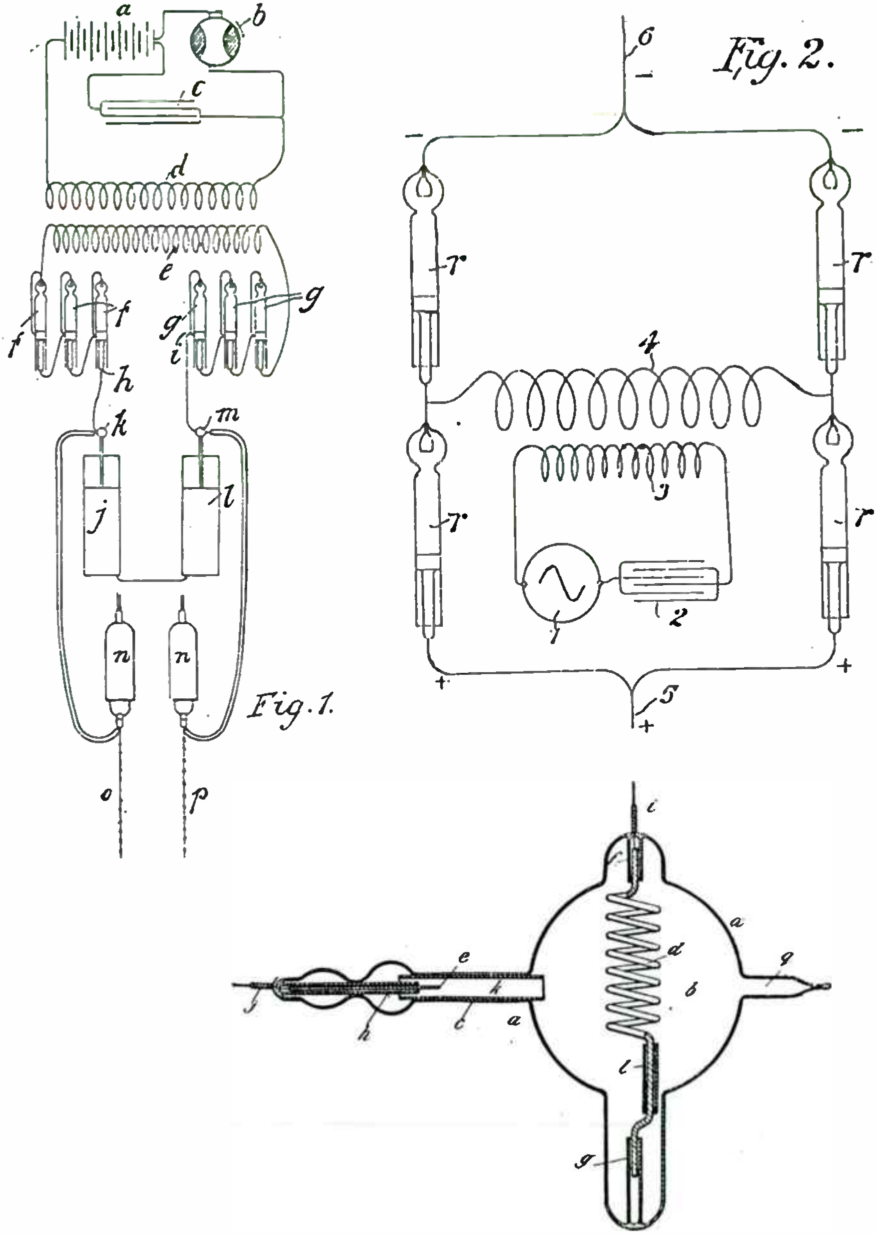
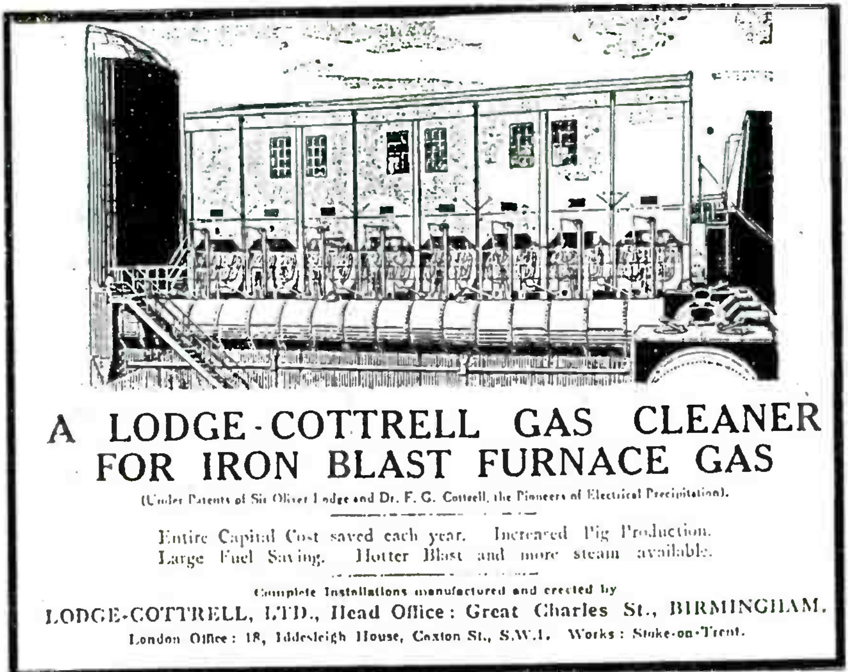


Fig 51. Half-wave rectifier; bridge rectifier using Cooper-Hewitt mercury lamps; Lodge rectifying valve.



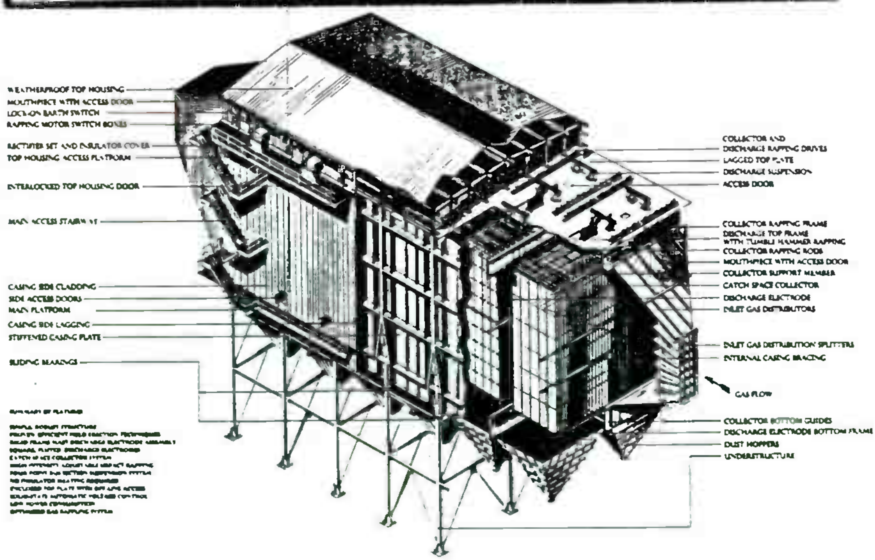


Fig 52. A 1923 advertisment showing the world's first blast furnace precipitator constructed at Skinningrove during WW1; a cut-away diagram of a modern Lodge-Cottrell installation.

6 Jan. 1919.

Dear Sir,

Referring to your letter AIC/7699 of January 3rd, ... the problem of clearing a landing area of fog occupied my attention at an early stage of the War, and I believe that The Lodge Fume Deposit Co. made a proposal to some Department of the Government.

The problem is by no means an easy one, and I am disposed to think that some other than an electrical method would be better.

I am however sending your letter on to The Lodge Fume Deposit Co., Great Charles St Birmingham, in order that they may reply direct.

Yours faithfully,

Oliver Lodge

The Chairman,
Air Inventions Committee,
Air Ministry,
Savoy Chambers, Strand, W.C.2.

Fig 53. Letter from Lodge to Air Ministry in 1919 concerning fog dispersal.

Fig 54. The Wick, Barnt Green, home of Lionel, Noel, Honor and Norah.

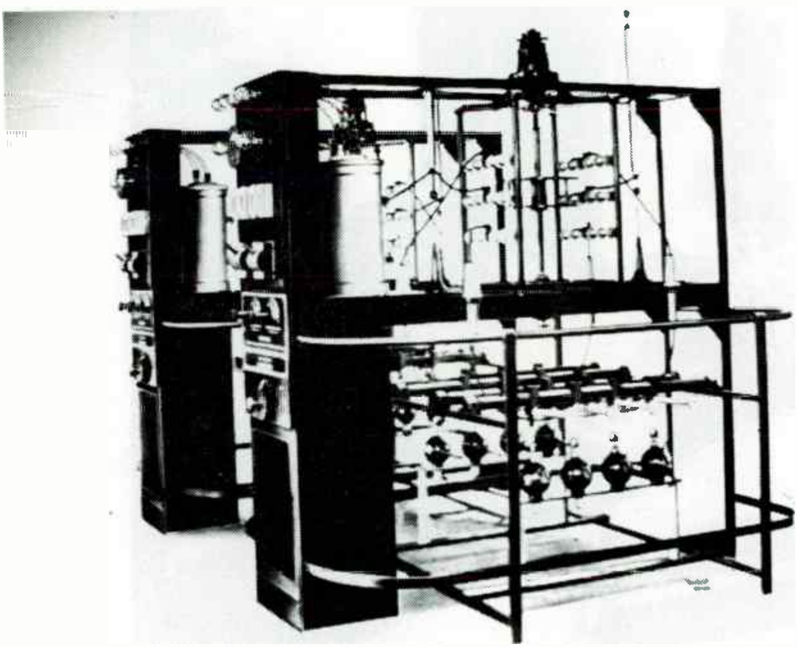


Fig 55. Power supply for agricultural electricity c 1906, using a bank of Lodge rectifier valves.

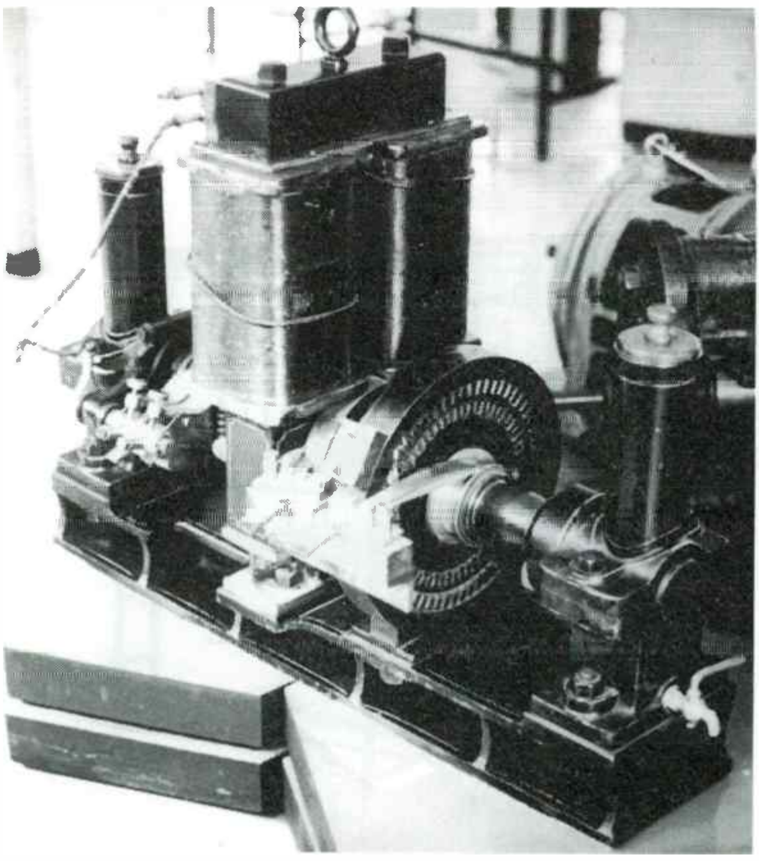


Fig 56. Lodge 3kHz alternator for high voltage generators.

Chapter Twelve
OLIVER LODGE'S ACHIEVEMENT: AN ENGINEER'S VIEW

by Brian Austin

The distinction of transmitting the first radio message must go to Oliver Lodge, Professor of Experimental Physics at University College, Liverpool. He first did this publicly at a meeting of the British Association in Oxford on 14 August 1894. This was some six years after Hertz's famous experiment in Karlsruhe in which he verified the famous prediction from Maxwell's theory that the waves which he detected were the same as light except at a much lower frequency. Hertz provided the first proof of that theory but saw no practical application in what he'd done. That feat in itself was to be of enormous significance and he stands supreme in the annals of physics for that reason. When Lodge performed his demonstration he too made no claims for the eventual usefulness of his technique but it is the first recorded occasion on which intelligence was transmitted by radiowaves sent through space without wires. For a practical application of radio the world had to wait for the arrival in England of Marconi in 1896. It is important to place in context the contributions of each of these pioneers of the science and engineering of radio and to accord to each the recognition that is rightfully their due.

At that demonstration in Oxford, which was at a joint meeting of physicists and physiologists on the subject of vision, Lodge transmitted Morse code letters from his induction coil and-spark gap transmitter in the Clarendon Laboratory to a receiver some 60 metres away in the Oxford Museum. He described it as "a very infantile form of radio telegraphy", a statement reflecting his modesty but an undoubtedly significant one because it established what he had actually done when the induction coil was actuated by a Morse key operated by his assistant E. E. Robinson. The receiver consisted of a coherer, a Lodge invention, which was connected to either a Morse recorder which printed onto tape or a Kelvin marine galvanometer, the deflected light spot of which made viewing by the audience easier. In that audience were Silvanus P. Thompson and J. A. Fleming, both notable scientists in their own right and therefore well able to appreciate what they had just seen.

Why, then, given this seemingly undeniable demonstration of signalling without wires, has the name of Lodge been largely forgotten when the pioneers of radio are discussed? Why are Hertz and Marconi alone remembered, while Lodge, who performed a demonstration "which excited great interest", in a university of renown and in front of a large audience which consisted of many illustrious men of science, has almost been ignored? There are many possible reasons. One may be that Lodge was a polymath in the sense that his scientific work covered a wide area, not just electrical phenomena, with his on-going quest for experimental evidence to confirm the ether probably persisting longest in public memory. Another may be that, like many scientists for whom discovery and not commercial exploitation is the important goal, Lodge made no attempt in 1894 to protect his findings by patent. He did so three years later but by then Marconi had already established himself. With his commercial acumen and the patronage of no less a figure in English electrical engineering circles than William Preece, the Engineer-in-Chief of the Post Office, Marconi was developing a radio system which would present Lodge with formidable competition.

A further possible reason for his lack of recognition is that Lodge was not just an experimentalist; he was also a renowned lecturer, much loved by his students and the lay scientific community, who attended his many presentations at the Liverpool Physical Society. His time therefore was not mostly devoted to research. He also became a well-known populariser of "wireless" as the scientific adviser to the magazine *Popular Wireless* and then, in 1923, consultative editor for *Harmsworth's Wireless Encyclopaedia*. Whereas these roles would have contributed greatly to the enlightenment of the public in all aspects of this new, exciting subject, some of his scientific contemporaries and particularly his critics will have viewed this as a retrograde step which decreased his credibility in their eyes. He has therefore come to be regarded by many as a populariser of science rather than as one who challenged its frontiers.

But there is yet another reason which may be more significant than all the others. Lodge had long had an interest in psychic phenomena and, after 1910, he played an increasingly prominent part in research into the paranormal and published widely in this area. Undoubtedly this foray into a subject which continues to be viewed with the utmost scepticism by most scientists subsequently did his reputation considerable harm and generally tarnished his image. That a previously highly respected member of the inner-circle of science should now espouse such a dubious cause was reason enough for many to discredit him and thereby to diminish his contributions to the development of radio. Whatever the reasons, Sir Oliver Lodge has not, of late, received the recognition due to him for work which laid many of the foundations of modern radio communications and broadcasting.

To examine Lodge's work and to appreciate its significance vis-à-vis that of Hertz and Marconi we need to consider his role in the seemingly unrelated controversy which raged, most acrimoniously at times, about the performance of the lightning conductor. The Post Office had, by 1880, installed hundreds of thousands of lightning conductors throughout England to protect their investment in telegraph lines and equipment. They were not always successful. At the meeting of the British Association in Bath during September 1888, Lodge took issue with Preece's view, that an effective lightning conductor had just to be of adequate height relative to the structure it had to protect and must offer the lowest resistance to the flow of current. This was achieved by the use of appropriate material and by ensuring that the conductor was "properly" grounded. Preece rejected the very idea of inductive reactance, let alone its role in reducing the effectiveness of a lightning conductor. Lodge stressed that the minimisation of this inductive component was crucial to the successful performance of the lightning conductor. In this he was supported by the theoretical work of Oliver Heaviside which was based on Maxwell's equations, and together they constituted a considerable thorn in the side of Preece. This very public clash between two men of considerable reputation was ultimately to cost Lodge dearly in 1896 when Preece threw his full support (and that of the Post Office) behind Marconi when he well knew of the work that Lodge had done in this field. Preece's enthusiastic support caused G. F. FitzGerald, the Irish physicist and brilliantly intuitive speculator on

Maxwell's theory and regular correspondent with Hertz, Lodge and Heaviside, to comment in a letter to the latter that Marconi "had done no more than Lodge and others ... in observing Hertzian waves at a distance". Even Marconi himself claimed to have just an improved form of coherer as his own invention.

Lodge had performed a number of experiments in February 1888 using his Leyden jars to investigate how the lightning conductor functioned. In this process of doing this he discovered, one might say by serendipity, a mechanism which provided real evidence of the electromagnetic waves predicted by Maxwell's theory. He called this the "recoil kick" experiment. Essentially his charged Leyden jar discharged into two parallel circuits, one containing a spark-gap of highly polished copper spheres; the other, the "alternative path", was provided by a single wire, with a resistance of just 0.025 ohms, looped around the laboratory. As he expected a flash occurred across the spark gap, a result which would have amazed Preece since that gap was "shorted out" by the wire! The impulsive nature of the discharge and the inductance of the wire were the cause. Of even more significance, though, was the fact that the intensity of the spark across the gap was actually greater than that at the output of the electrostatic generator used to charge the Leyden jar. Investigation of this phenomenon by Lodge and his assistants showed that it was due to the existence of standing waves along the wire with their characteristic nodes and loops. By decreasing the capacity of the Leyden jar and by varying the length of the wire from about 30 metres, which indicated resonance at 5 MHz, to only a few centimetres he was able to cause the intensity of the spark to increase or decrease. In a darkened room the loops could be clearly seen as a visible glow or brush discharge of varying intensity along the wire. Lodge had discovered electrical resonance. He measured the wavelength of these standing waves and related it to the "capacity of the jar" and the inductance of the circuit. He recorded in his notebook the fact that he had succeeded in generating, detecting and measuring electromagnetic waves which, he said, "disturb the surrounding medium and send out radiations, of the precise nature of light". There is considerable significance in his statement that the waves disturb the surrounding medium because it indicates that he recognised that they were not in the wires but in the space between them: what he called the ether.

Lodge demonstrated these effects at scientific meetings during March and May 1888 and published an account of them in the *Journal of the Royal Society of Arts* in June of that year. His definitive article on 'On the Theory of Lightning Conductors' was submitted to *The London, Edinburgh and Dublin Philosophical Magazine* on 7 July 1888 and was published in Volume 26 of August 1888.

When Hertz commenced his experimental work he was influenced, not by Maxwell's equations, which postulated a finite velocity of propagation, but by Helmholtz's (and Newton's) action-at-a-distance, which implied an infinite value for the speed. The task which he eventually set himself was to determine if the propagation of electromagnetic energy was a wave-like phenomenon possessing a finite velocity. He did this by way of a brilliant experiment in interferometry where he measured the wavelengths of the standing waves by using various radiators and receptors of different sizes and a reflecting metal sheet in his 12-metre-long laboratory. Hertz thus began to accept Maxwell's theory of electromagnetic waves in February 1888 and by March had calculated their velocity of propagation (erroneously, as it transpired). He published his results in *Wiedemann's Annalen* in July 1888, the month in which Lodge's paper on lightning conductors, which emphasized his verification of Maxwell's theory was submitted to the *Philosophical Magazine*.

Lodge and Hertz were working on the same problem at the same time. They had in fact met in 1881 when Lodge visited Karlsruhe in the hope of meeting Helmholtz, which he did, albeit only briefly. In the absence of the great man, it was his demonstrator Hertz who showed him around the laboratories. At the end of July 1888 Lodge read Hertz's paper and, within a couple of months, had resolved to re-establish contact with him. They subsequently corresponded until Hertz's untimely death in 1894. At the meeting of the British Association in Bath that September (1888) Lodge was in the audience to hear FitzGerald, in his role as President of the Mathematical and Physical Sciences Section, call "the world's attention to Hertz's discoveries" while also mentioning Lodge's work in passing. The following day Lodge himself spoke and readily acknowledged "the superiority of Hertz's method ... as evidence of the waves", compared with his own. What is most important, though, is to recognise that, whereas Hertz had produced waves which radiated freely into space, Lodge had used the wires in his "recoil kick" experiment as a transmission line or waveguide which confined the energy to the region between the conductors. Both techniques made use of the interference between an incident and a reflected signal as a means of proving the existence of a wave-like phenomenon. Heaviside, for one, had no doubt that both methods were equally conclusive in confirming Maxwell's theory. He even went further and said that Lodge's method might even be more so because its theory "can be more closely followed".

There was another feature of Lodge's "recoil kick" experiment which was subsequently to play a very significant part in Marconi's work and was to be the centre-piece of a legal confrontation between the two. As noted previously, Lodge recognised that the sensitivity of the spark to the length of the wires was "too suggestive of some acoustic reverberation phenomenon" and so he called the effect syntony, this being "the synchronizing of the vibration period between two things" and he used it in all his subsequent work when describing resonance. When Marconi developed his commercial apparatus he designed it such that it could be "tuned" and so respond selectively to signals of different frequencies, but his patent, filed in 1896 and the first radio patent ever issued, in 1897, contained no reference either to "tuning" or "syntony". In 1897, before the Marconi patent was in the public domain, Lodge filed four patents which referred specifically to his radio telegraphy system. Two dealt with improvements to his coherers while the others were described as 'Improvements to Syntonized Telegraphy' and they must now be seen as crucial contributions to the science of radio engineering, being the first to describe the method of achieving selective communications by radio. In other words a method was described of tuning both the transmitter and the receiver to a selected frequency by the use of a "syntonizing self-inductance coil" in conjunction with the capacitance provided by the antennas or "definite radiators", as Lodge called them. This led ultimately to the formation in 1901 of a syndicate with his colleague Alexander Muirhead in order to further develop and exploit this idea commercially.

Because of these Lodge patents Marconi was legally prevented from using "syntony" or resonance in his radio system, notwithstanding his famous "four sevens" patent of 1900 which has been described as his "master tuning patent". He was forced to acquire the patent rights,-for an undisclosed sum, from the Lodge-Muirhead Syndicate in 1911 in order to be able to enforce his own patent claims against a number of other challengers in succeeding years. Of particular importance, when the priority of Lodge's work is discussed, is the ruling of the United States Supreme Court as late as 1943 that the only valid patent of the three held by the Marconi Company in this area was that acquired from Oliver Lodge in 1911. It is well to be reminded that this landmark legal decision, though long since forgotten in the scientific literature and certainly in the popular view of things, gave priority to Lodge for a crucial element of radio communications.

Before drawing this review of some of Lodge's work to a close, it is important to discuss very briefly some of his other contributions to radio science. His antenna system or "definite radiator" has already been mentioned in passing. It is worth considering in somewhat more detail because the form that he chose is still in common use today as the biconical antenna. Lodge used that configuration because he saw it as providing the distributed capacitance which he wanted rather than the lumped variety in the form of either conducting spheres or plates at the ends of the wire, as used originally by Hertz. His syntonic transmitter and receiver were tuned to resonance by using either series or shunt inductance connected to the antennas' terminals. By definition, therefore, his systems were narrow-band, thus providing the selectivity which he identified as being necessary to obtain communication privacy with a radio system. By contrast today, the biconical antenna is generally used because of its inherently wide bandwidth which is a fundamental feature of its angular dependence. An apparently natural consequence of using inductors in his antenna circuits, but one which required considerable insight when it was first done by Lodge, was the use of transformer-coupling. This technique is now standard practice for the purpose of impedance matching and for the control of the bandwidth of such coupled circuits and was first described by Lodge in his 1897 patent.

There are three other gems within the panoply of Lodge's peripatetic work which must be noted because of the significance of each in subsequent years. The first and arguably the most prescient was his attempt in 1894 to detect emissions from extra-terrestrial sources, most notably the Sun. The experiment failed because his coherer detector of centimetric waves was not sufficiently sensitive. This is recognised, though, as the first attempted experiment in radio astronomy and preceded the first successful one by some 38 years. Whereas he failed in his primary task of receiving noise from the Sun, Lodge certainly received interference from the electrically-powered tram system in the Liverpool area. This, coupled with the fact that he occasionally picked up "communication from ordinary telephone lines", overhearing such oddities as "people ordering potatoes for dinner", was to become the forerunner of electromagnetic compatibility (EMC) much later within the next century and electronic eavesdropping (ECM), first practised in that way in the First World War. Finally, Lodge, being aware of the degrading effect that noise had on the performance of his communication systems, and knowing that such noise was associated with resistance, suggested that conductors might be immersed in liquid hydrogen or helium, "for at these temperatures the resistance of metals almost disappears". Might this not be the first predicted use, at least, of cryogenics in radio technology and ultimately of the science of superconductivity?

Fig 57. Lodge in his laboratory 1923.

Fig 58. Victoria Monument, Liverpool.

Appendix I
The Queen Victoria Monument

by David King

When Queen Victoria died on 22 January 1901, it brought to an end a reign of 64 years; the British Empire was at its zenith and the 'Victorian virtues' of commerce, education and gentlemanly conduct were well established. Many of the Liverpool City dignitaries felt that the Queen's death should be commemorated by a grand memorial and by 11 March – six weeks after she died – an Executive Committee was formed to appeal for public subscriptions for a suitable memorial. By July 1901, the Committee had announced that invitations had been sent to all the principal sculptors to send in suitable designs. Charles J. Allen, sculptor, of Liverpool, was finally selected, with Professor F. M. Simpson, of the Liverpool College, as designer, and Messrs. Willink and Thicknesse as architects. C. J. Allen came to Liverpool in November 1894 from the Royal Academy Schools in London, at the invitation of Professor Simpson, as a Teacher in the newly founded School of Architecture and Applied Arts; he eventually became Vice Principal of the Joint University and City Council School, retiring in 1927. The public subscription raised nearly £ 10 000 and £ 6 000 was granted to the fund by the City Council. A site was chosen which was originally the site of the Castle of Liverpool, and then occupied by St. George's Church in Derby Square; and on the 11th October 1902, the foundation stone of the memorial was laid by Field Marshal Earl Roberts.

The memorial to Queen Victoria is an impressive and magnificent bronze and stonework sculpture. The statue of the Queen is a 14-feet high bronze figure on a 6-feet pedestal all under a stonework canopy. The dome is supported by 16 stone pillars arranged in four groups and on each group of pillars are pedestals supporting bronze groups representing Justice, Charity, Wisdom and Peace. Over the dome is the winged figure of Fame representing victory. The platform by which the pillars are supported has four bays, in the centre of each are a further four groups representing Education, Industry, Commerce and Agriculture. The group representing Education shows the unmistakable features of Sir Oliver Lodge who is seen with a student pondering over a gyroscope. The 'student' has as yet not been identified and may have been a genuine student, or a relation, or even sculpted from memory.

The monument was unveiled on the 27th September 1906 by Princess Louise and at the ceremony she was asked by C. J. Allen to accept a silver statuette, a replica of the figure of Fame which crowns the dome.

In 1911 proposals were put forward to remove the canopy and in the early 1930s, in order to ease traffic congestion – the Square was used as a bus and tram terminus – it was proposed to remove the memorial altogether, but it survived this and the heavy bombing of Liverpool during World War Two. Proposals were again put forward in 1949 and as late as 1963 to remove the canopy and supporting pillars, but, fortunately, the memorial is still in its original form and place.

Appendix II
Chronology of the Life and Works of Oliver Lodge

1851 June 12. Born at family home at The Views, Penkhull, Staffordshire.
1859 Studies at Newport Grammar School (till 1863).
1861 (*circa*) First visit to Liverpool, returning from the Isle of Man.
1863 Studies with uncle at Combs, Suffolk (till 1865).
1865 Works in father's business (till 1874).
1866 Winter. Hears Tyndall lecture at the Royal Institution (1866-67).
1868 First encounters inductance.
1869 Family moves to Chatterly House, Old Hall St, Hanley.
1872 Passes entrance examinations for London University external degree. Studies at Bedford College in the winter of 1872-73.
1873 Visits BA meeting at Bradford. Hears Maxwell lecture and buys his *Treatise on Electricity and Magnetism*.
1874 January. Enrols as full-time student at University College, London.
1875 BSc, University of London. Made demonstrator to Carey Foster at University College.
First presentation to the BA, at Bristol meeting.
1876 Early. Family moves to The Watlands, Port Hill, Wolstanton.
Summer. Reads Maxwell's *Treatise* in Heidelberg.
September. Devises teaching model of Maxwell's theory, presented to BA meeting at Glasgow, and corresponds with Maxwell.
1877 June. DSc, University of London.
August 22. Marries Mary Marshall.
1878 August. Meets G. F. FitzGerald at BA meeting in Dublin.
1879 August. Predicts electromagnetic waves at BA meeting at Sheffield.
Elementary Mechanics; first book.
1880 February. Proposes to generate electromagnetic waves by discharging a Leyden jar.

1881 June. Elected Professor of Physics, University College, Liverpool.
Tours Europe and meets Helmholtz and Hertz.
Takes house at Waverley Road.
December 10. First part of 'On the theory of magneto and dynamo machines', published in *The Electrician* (completed March 1886).

1882 Consultant to the Electrical Power Storage Company, and other firms; works on storage batteries.
December 28. Lectures on 'Ether and its Functions' at the London Institution.

1883 Discovers electrostatic condensation of fog.
Begins experiments on thought transference.

1884 June 12. Letter on thought transference to *Nature*. Presentation to SPR on June 30.
August 9. Alfred Walker patents an electrostatic precipitation system devised with Lodge (11,120).
August 29. Lectures on 'Dust' to the BA at Montreal.
'On the seat of the electromotive forces in the voltaic cell', presented at Montreal.

1885 May 16. Discusses 'identity' (local conservation) of energy.

1886 September. Method for making the migration of ions visible and for measuring their velocities presented to the BA at Birmingham.

1887 June 9. Elected FRS.

1888 February-March. Discovers electromagnetic waves on wires.
March 10 and 17. Mann lectures at RSA on lightning conductors; explicit statements on electromagnetic waves. First to call attention to Heaviside's work.
May 11. Lectures to Physical Society at South Kensington.
June 15 and 22. Mann lectures published in *J. Soc. Arts*.
July 7. Paper on lightning conductors sent to *Philosophical Magazine*. Sets out on Continental tour.
September 11. Debate on lightning conductors at BA meeting in Bath.

1889 March 2. Experiment on syntonic Leyden jars.
March 8. Lectures to Royal Institution in London.
March 10. Meets Oliver Heaviside (for the only time) in London.
March. FitzGerald devises contraction hypothesis in Lodge's study.
April 25. Lectures to IEE in London.

Observes 'coherer' action between metal spheres and devises coherer version of syntonic Leyden jars.
Easter. Experiments with J. L. Howard on concentration of electromagnetic waves using pitch lenses.
May 11. Calculates power output of Hertz oscillator.
June 27. Shows that electrostatic field is produced by the motion of gold leaf in a varying magnetic field.
Summer. Measures velocity of electric sparks using a rotating cylinder and high-speed photography.
September. *Modern Views of Electricity.*
December 16. Inaugural address to Liverpool Physical Society. President till 1893.

1890 February 20. Paper on syntonic Leyden jars.
March 11. Describes improved transmitter generating waves of constant frequency, and discusses a theory of vision.
December 2. Entertains Hertz on his visit to England.

1891 May 2. Paper on 'Experiments on the Discharge of Leyden jars' read to the Royal Society.
July 21. First results on experiment on aether drag.
August. President of BA Section A at Cardiff. Discusses NPL, psychic research, aether drag and the fourth dimension.

1892 March 31. Presents results on aether drag to Royal Society.
Moves to 2, Grove Park.
Searches for effects of upper conducting layer in atmosphere (ionosphere).
October. *Lightning Conductors and Lightning Guards.*
December. *Pioneers of Science.*

1893 February. Experiments on longitudinal magnetisation of the aether. (More accurate experiments in November.)
July 17. Major paper on aether drag received by Royal Society.
May 20. Defines the aether as an absolute frame of reference (MS; first publication, September 1898).
Experiments with Gotch on the effect of high-frequency radiowaves on animal tissues.
November 24. First explanation of coherer action.

1894 February-March. Last experiments on aether drag, including effect of electrification.

Develops two new versions of coherer as radiowave receiver.
Experiments with radio signalling at University College and Grove Park.
June 1. Lectures on 'The Work of Hertz' to the Royal Institution.
June 12. Attempts to detect radio waves from the Sun. (Second attempt on June 24.)
June 13. Demonstrates radio telegraphy at the Royal Society.
August 14. Demonstrates radio signalling in Morse code to the BA at Oxford. Followed by Continental tour.
September. *The Work of Hertz and some of his Successors*.
September. 'Competition v. Co-operation'.

1895 February 22. Lectures to large audience at Liverpool Physical Society on Rayleigh's discovery of argon.
March-May. Searches for the 'Larmor force'.
May 19. Proposes joule as unit of heat.

1896 January 27 and February 3. Lectures on X-rays at Liverpool Physical Society to massive audiences.
February 7. X-rays boy with bullet in hand.
March 24. Speculates on X-rays in *Liverpool Daily Post*.
May 16. Article in *The Lancet*.
September. BA meeting held in Liverpool. Demonstrates his radio apparatus. Preece announces Post Office experiments with Marconi.

1897 January 19. Final paper on aether drag received by Royal Society.
March 12. Calculates approximate size of electron.
May 10. Patents tuning in radio telegraphy (11,575).
May 13. Announces that Zeeman effect involves splitting as well as broadening.
June 16. Lodge-Muirhead tuned system demonstrated at Royal Society.
July 10 and August 11. Two patents on radio, with Muirhead (16,405 and 18,644).
August. Visits Toronto for the BA.
Signals between University College and Lewis's.
Signalling across Space without Wires (second edition of *The Work of Hertz*).
December 8 and 13. Two further patents on radio (29,069, with

Muirhead; and 29,505).

1898 February 1. US version of tuning patent.
April 27. Patents moving coil loudspeaker (9712).
November. Begins work on 'magnetic system' of telegraphy.
November 30. Rumford Medal of Royal Society.
December 8. 'Improvements in Magnetic Space Telegraphy' read to IEE.

1899 President of the Physical Society.
From spring, seriously ill with typhoid fever.

1900 March 5. Lecture on 'Modern Views of Matter' to Liverpool Literary and Philosophical Society.
June. Principal, University of Birmingham.

1901 January 17 / February 22. Death of two closest friends, Myers and FitzGerald.
President of SPR (till 1904).
Moves to Mariemont.
Lodge-Muirhead Syndicate formed.
November. Abandons magnetic system of telegraphy.

1902 June. Created Knight Bachelor in the Coronation Honours.
June 14. Wheel coherer patented (13,521).
Lodge-Muirhead system tested.
Vice-President of the IEE (till 1904).
November 27. Lectures to IEE on electrons; states that atoms are mostly empty space.

1903 January 29. Patents igniter with son Alec (2162).
February. Lectures on the theory of the electron at Bedford College, London and University College, Liverpool; first of a major series contributing to the theory.
June 11. Discusses instability of atom in electron theory.
June 12. Romanes Lecture at Oxford: 'Modern Views of Matter'.
November 9. Patents diode rectifier bridge (24,305).

1904 Lodge Brothers, later Lodge Sparking Plug Company.
Lodge-Muirhead win major contract with Indian Government.
Lectures to the Röntgen Society.
President of the Birmingham and Midland Institute.
President of Teachers' Guild of Great Britain and Ireland.

1905 President of Royal Sanitary Institute.

President of Political Education League.
December 2. Lodge, Muirhead and Robinson patent valve rectifier (25,047 and 25,047A).

1906 Writes *Electrons* (preface July 1906; published January 1907).
September 27. Unveiling of Victoria Monument, Liverpool, with Lodge representing Education.

1907 March. Calculates density of the aether, and relates it to a scale of length now considered fundamental.
Lodge apparatus used for remote-controlled explosion at Beaumaris.
Summer. Hon. DSc. University of Liverpool.
November. *Modern Views of Electricity*, third edition.

1908 February 21. Lectures on 'The æther of space' at the Royal Institution.
March 12. Hurter Memorial Lecture to Society of Chemical Industry.
President of Faraday Society.
Lodge-Newman Company.

1909 January 21. Joint paper with Muirhead on Lodge-Muirhead radio system read to Royal Society.
May. *The Ether of Space*.

1911 October 21. Settlement with Marconi Company; becomes nominal consultant.

1912 October 12. Becquerel Lecture to Chemical Society.

1913 Lodge Fume Deposit Company Ltd; which eventually becomes Lodge-Cottrell.
September. President of the BA at Birmingham. Lectures on 'Continuity'.

1914 July. Travels to Adelaide for the BA. (Returns in October.)

1915 September 14. Youngest son, Raymond, killed in Flanders.

1916 November 2. *Raymond*.

1919 February. Retires as Principal at Birmingham.
Albert Medal of the Royal Society of Arts.
November 30. Proposes idea of gravitational lenses.
December 2. Anticipates Lenz argument on the theory of relativity.

1920 February. Describes radiation as an "evanescent kind of matter";

makes energy density of the aether equivalent to a distance scale of 10^{-30} or 10^{-33} cm.
August. BA at Cardiff; involved in naming of the proton.

1921 February. States gravitational refractive index formula; proposes collapsed matter stars; and explores physics of black holes.
Moves to Normanton House.
October 31. Lectures on 'Relativity' at Liverpool Lit. and Phil.

1922 November 25. 'Speculation concerning the positive electron': composite proton.

1923 June 2. Scientific Adviser to *Wireless Review and Science Weekly*.
July 7. Begins contributing to *Popular Wireless*.
September 14. Speaks at BA meeting in Liverpool.
President of the Röntgen Society.
November. Consulting Editor of *Harmsworth's Wireless Encyclopaedia*.

1924 July. *Atoms and Rays*, last major textbook, containing a popular account of the Bohr theory.

1925 May. *Ether and Reality*.
May 30. Suggests cryogenics to improve signal-to-noise ratios.
President of the Radio Society of Great Britain.
September. *Talks about Wireless*.

1927 November 14. Roscoe Lecture; last given in Liverpool.

1928 March 28. Given Freedom of the City of Stoke-on-Trent.

1929 February 20. Mary Lodge dies.

1930 May. *Beyond Physics*.

1931 September. *Advancing Science*; on the BA, for the Centennial Meeting in London.
November. *Past Years*; autobiography.

1932 President of SPR (second term).
Awarded Faraday Medal of the IEE.

1933 June. *My Philosophy*.
June 13. Meets Einstein at Oxford and discusses aether with him.

1934 December 6. Filmed for the IEE.

1936 Last visit to the BA, at Blackpool.

1938 Abandons writing textbook on *Physics for Everyman*.

1940 August 22. Dies at Normanton House.

1943 June 21. US Supreme Court decides in favour of Lodge patent.

1947 February 10. Posthumous experiment on telepathy.
1951 June 11. BBC celebrates Lodge's centenary.
1954 May 19. Lodge's last experiment.

Notes to Chapter One

Sources and acknowledgements:

1 W. P. Jolly, *Sir Oliver Lodge. A Biography* (Constable, London, 1974)
2 Sir Oliver Lodge, *Raymond* (Methuen, London, 1916)
3 Sir Oliver Lodge, *Past Years. An Autobiography* (Hodder and Stoughton, London, 1931)
4 Peter Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool University Press, 1990)
5 Archives of Birmingham Museum of Science and Industry, Birmingham University, Liverpool University, Lodge Plugs, and Lodge-Cottrell.
6 Personal communications: Professor W. E. Burcham, Dr D. Edwards, Dr N. Godlee, Mr O. R. W. W. Lodge (6th), Mrs Somervail.

Notes to Chapter Two

The sources used in this chapter are:

1 Sir Oliver Lodge, *Past Years. An Autobiography* (Hodder and Stoughton, London, 1931). Please note that my grandfather was a better scientist than genealogist. Where the facts stated on pp 13 and 14 of *Past Years* regarding the Reverend Oliver Lodge and his family differ from those in this chapter or in other printed sources, the latter are to be preferred.
2 W. P. Jolly, *Sir Oliver Lodge. A Biography* (Constable, London, 1974).
3 Margaret Lodge, *Sir Richard Lodge* (William Blackwood and Sons Ltd, 1946). A biography by his daughter.
4 J. P. Wilson, 'The Life and Work of Sir Oliver Lodge', a paper delivered at the IEE 20th History of Electrical Engineering Weekend, July 1992.
5 *Dictionary of National Biography*.
6 Family records.
7 Oral tradition.
8 Personal recollection.

Notes to Chapter Three

1 Lodge, *Past Years* (London, 1931), chapters II and III.
2 *Past Years* (1931), ref. 1, 89
3 *Past Years* (1931), ref. 1, 42
4 Sidney Jones Library, University of Liverpool
5 *Past Years* (1931), ref. 1, 67
6 *Past Years* (1931), ref. 1, 109
7 Sidney Jones Library, University of Liverpool
8 T. Kelly, *For Advancement of Learning* (Liverpool, 1981)
9 Dr J. Rivlin, private communication.
10 *The Times*, 26 June 1917
11 Liverpool Fabian Tract No 3 (1894)

12 Keir Hardie to Lodge, 15 October 1894; Lodge Collection, SPR; quoted W. P. Jolly, *Sir Oliver Lodge* (London, 1974), 100.
13 *Past Years* (1931), ref. 1, 98.
14 Major collections of Lodge letters are at Birmingham (2515); University College, London (2070); and Aberystwyth (965). 26 volumes of lectures and reseach notes are at Liverpool.
15 Arts Theatre, 3 February 1896. Liverpool Physical Society Minute Books, 2, 71, 101, Liverpool University Archives.
16 *Past Years* (1931), ref. 1, 150.
17 D. Sealey, *The 1896 BA Meeting*, MSc Dissertation, University of Liverpool (1993).
18 G. F. Haimes, *Sir Oliver Lodge's Unpublished Physics Book*, MSc Dissertation, University of Liverpool (1992).
19 P. Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool, 1990). D. Edwards, MS 'Lecture on the occasion of the centenary of the Liverpool Physical Society', 6 November 1989; Liverpool University Archives.
20 L. Brock, *George Higgs*, MSc Dissertation, University of Liverpool (1994).
21 D. Edwards, *The Medical Historian*, 2, 31, 1989.
22 *Past Years* (1931), ref. 1, 5.
23 Horne and Maund, *Liverpool Transport 1830-1900*.
24 S. S. Shah, *Early X-rays in Liverpool*, MSc Dissertation, University of Liverpool (1993).
25 Arthur Mee, *The New Harmsworth Self-Educator* (London, 1902), 1491.
David Waring, *Oliver Lodge and Plant Growth* MSc Dissertation, University of Liverpool (1995).
26 *Liverpool Daily Post*, 14 June 1938
27 C. G. Parks, *Oliver Lodge and the Paranormal*, MSc Dissertation, University of Liverpool (1994).
28 *Past Years* (1931), ref. 1, 168
29 He was, for example, President of the Teachers' Guild of Great Britain and Ireland, and of the Birmingham and Midland Institute, in 1904; of the Royal Sanitary Institute, and the Social and Political Education League, in 1905; and of the Faraday Society in 1908, in addition to such better known organisations as the BA, the SPR and the Physical Society!

Notes to Chapter Four

1 *Phil. Mag.* (4), 23, 12-24, 1862, 22,: *Scientific Papers*, 1: 590.
2 O. J. R. Howarth, *The British Association for the Advancement of Science: A Retrospect 1831-1931*, second edition (London, 1931), 53.
3 *Phil. Mag.* (5), 2, 353-74, 524-43, 1876
4 Lodge to Larmor, 1 January 1902. Bruce J. Hunt, *The Maxwellians* (Cornell University Press, Ithaca, New York and London, 1991), 30. *BA Report*, 49, 258, 1879 (title only).
5 Lodge to Larmor, 1 January 1902. Hunt (1991), ref. 4, 32.
6 FitzGerald, *Scientific Writings*, ed. J. Larmor (Dublin, 1902), 90-2.
7 Notebook, 3-13. Special Collections, SJL, University of Liverpool.
8 ibid.

9 Lodge to FitzGerald, 26 February 1880, RDS; quoted Hunt (1991), ref. 4, 32.
10 Notebook, 3-13. Special Collections, SJL, University of Liverpool.
11 *BA Report*, 50, 497, 1880 (title only). A detailed analysis of FitzGerald's error is given in Hunt (1991), ref. 4, 33-6.
12 Lodge, *Past Years* (1931), 153-4
13 *Trans. Roy. Dublin Soc.*, 1, 83, 325-6; *Scientific Writings* (1902), 99-101, 101, 99. Rayleigh, *Theory of Sound* (1877), arts. 276-8. Hunt (1991), ref. 4, 39-43.
14 *Trans. Roy. Dublin Soc.*, 1, 83, 325-6; *Scientific Writings* (1902), 99-101, 100.
15 *BA Report*, 53, 404-5 and 405, 1883; *Scientific Writings* (1902), 128-9 and 129.
16 On Hughes, see C. Süsskind, 'Observations of electromagnetic action before Hertz', *Isis*, 55, 23-42, 1964. J. J. Fahie, *A History of Wireless Telegraphy* (Edinburgh and London, 1899, reprinted Arno Press, New York, 1971), 305-11. *The Electrician*, 43, 40-1, 5 May 1899. *Electrical Review*, 44, 883-5, 947, 1899.
17 *The Electrician*, 43, 40-1, 5 May 1899
18 ibid. That Hughes's manuscripts showed that he thought the transmission was due to air conduction rather than electromagnetic waves was established by A. A. Campbell Swinton, *JIEE*, 60, 442-5, 1922.
19 For Thomson, see E. J. Houston, *J. Franklin Inst.*, 91, 417-9, 1871; *Scientific American Suppl.*, 1, 77-8, 1876; Houston and Thomson, *J. Franklin Inst.*, 101, 270-4, 1876; *Scientific American Suppl.*, 1, 326, 1876. For Edison: *Scientific American*, 33, 385, 401, 1875; 34, 33, 1876. For S. P. Thompson: *Proc. Phys. Soc.*, 2, 102-10, 1876; *Phil. Mag.* (5), 2, 191-8, 1876. Heaviside was another who apparently investigated Edison's "new force", 11 or 12 years before a letter of 14 February 1889 to Hertz. See J. G. O'Hara and W. Pricha, *Hertz and the Maxwellians: A Study and Documentation of the Discovery of Electromagnetic Wave Radiation*, 1873-94 (London, 1987), 58. Süsskind (1964), ref. 16.
20 Dolbear, *J. Soc. Teleg. Engineers*, 11, 130-49, 1882. Süsskind (1964), ref. 16.
21 Priestley, *Phil. Trans.*, 60, 192-210, 1770. Galvani, *De viribus electricitatis in motu musculari commentarius* (Bologna, 1791), 1-4, 37-8.
22 Faraday's 'Thoughts on Ray-Vibrations' (*Phil. Mag.* (3), 28, 345-50, 1846) are a well-known adumbration of electromagnetic wave theory. Wave-type mechanisms were almost natural results of aether theories. One rather interesting suggestion, which precedes by many years the discovery of the Leyden jar, is from a manuscript of Newton: "Do not all bodies abound with a very subtil active [potent] vibrating [elastic] spirit by wch light is emitted reflected & refracted, electric & magnetic attractions & fugations are performed, the small particles of bodies cohaere when contiguous, agitate one another at small distances & regulate almost all their motions amongst themselves as the great bodies of the Universe regulate theirs by the power of gravity?" (Cambridge University Library Add MS 3970, f. 241r and 241v give slightly different versions, which have been printed in J. E. McGuire, *Ambix*, 15, 154-208, 1968, 176; R. S. Westfall, *Never at Rest* (Cambridge, 1980), 793, and *Force in Newton's Physics* (London and New York, 1971), 394; R. W. Home, 'Newton on Electricity and the Aether', in Z. Bechler, *Contemporary Newtonian Research* (1982), 191-213, 198-200.)
23 W. H. Weekes, 'A Report of some Experiments in Atmospheric Electricity', *Annals of Electricity, Magnetism, and Chemistry*, February 1841, 89-96, 91.
24 F. Savary, *Annales de Chimie*, 1827, 5. Henry, *Proc. Am. Phil. Soc.*, 2, 193-6, 1842. For Wollaston, see Sir Edmund Whittaker, *A History of The Theories of Aether and Electricity*, 2 vols. (London, 1951-3), 1: 226.

25 The work of Helmholtz, Thomson and others on oscillatory discharges is discussed in Whittaker (1951-3), ref. 24, 1: 226 ff. W. von Bezold, *Berichte der Bayrischen Akad. d. Wissensch.*, 1870, 113; *Poggendorff's Annalen*, 140, 541, 1870; *Phil. Mag.* (4), 40, 42, 1870; 'Researches on the Electric Discharge', in Heinrich Hertz, *Untersuchungen die Ausbreitung der elektrischen Kraft* (Leipzig, 1892), translated as *Electric Waves*, by D. E. Jones (London, 1893), ch. III, 54-62.
26 Hertz, *Wiedemann's Annalen*, 31, 421, 1887; 'On Very Rapid Electric Oscillations', *Electric Waves* (1893), ch. 2, 29-53. *Sitzungsberichte d. Ber. Akad. d. Wiss.*, 9 June 1887, 487; 'On an Effect of Ultra-violet Light upon the Electric Discharge', *Electric Waves* (1893), ch. 4, 64-79. *Sitzungsberichte d. Ber. Akad. d. Wiss.*, 10 November 1887; *Wiedemann's Annalen*, 34, 273, 1887; 'On Electromagnetic Effects Produced by Electrical Disturbances in Insulators', *Electric Waves* (1893), ch. 6, 95-106.
27 Lodge, *Past Years* (London, 1931), 183
28 Lodge, 'Experiments on the Discharge of Leyden Jars', *Proc. Roy. Soc.*, 50, 2-39, January 1892, 3. Lodge, Notebook 3-15, 1, 5, 23, 5; Special Collections, Sydney Jones Library, University of Liverpool.
29 Rayleigh, *Nature*, 38, 208, 1888
30 Lodge (1892), ref. 25, 5, 23
31 Hunt (1991), ref. 4, 149. Lodge first came across Heaviside's work in the February issue of the *Philosophical Magazine*, and he was the first to draw attention to it in his second Mann lecture. (*The Electrician*, 21, 204-7, 234-6, 273-6, 302-3, 1888, 236.)
32 On Heaviside's discoveries, see Paul J. Nahin, *Oliver Heaviside, Sage in Solitude* (IEEE Press, New York, 1988) and Hunt (1991), ref. 4, passim. Poynting, *Phil. Trans.*, 175, 343-61, 1884, 360. Lodge, 'On the identity of energy ...', *Phil. Mag.* (5), 19, 482-7, June 1885 (dated 16 May).
33 Lodge (1892), ref. 25, 26. Lodge, Notebook 3-15, 22; Special Collections, Sydney Jones Library (SJL), University of Liverpool.
34 Lodge (1892), ref. 25, 27
35 Lodge, *Past Years* (London, 1931), 183. Lodge (1892), ref. 25, 26.
36 Lodge (1892), ref. 25, 5
37 Lodge (1892), ref. 25, 28
38 Lodge, *J. Soc. Arts*, 36, 867-74, 880-93, 15 and 22 June 1888, 883, 889, 890. Heaviside, 'Electromagnetic Induction and its propagation', *The Electrician*, 1885-87; *Electrical Papers*, 2 vols. (London, 1892), 1: 492-560. For Hughes, see D. W. Jordan, 'D. E. Hughes, self-induction, and the skin effect", *Centaurus*, 26, 123-53, 1982.
39 Lodge, *Past Years* (London, 1931), 183-4
40 Lodge, 'On the Theory of Lightning-Conductors', *Phil. Mag.* (5), 21, 217-30, August 1888, 227-8.
41 Lodge (1892), ref. 25, 29-39. Notebook 3-15, 15-21, 143-6; Special Collections, SJL, University of Liverpool.
42 Lodge, *J. Soc. Arts*, 36, 867-74, 880-93, 1888, 890. This publication has been insufficiently noticed in the literature on Lodge, authors tending to refer only to the later publication of the lectures in *The Electrician* or the paper 'On the Theory of Lightning-Conductors', published in August in the *Philosophical Magazine*.
43 Hertz, *Sitzungsber. d. Berl. Akad. d. Wiss.*, 2 February 1888; *Wiedemann's*

Annalen, 34, 551-609, 1888; 'On the Finite Propagation of Electromagnetic Action', *Electric Waves* (1893), ch. VII, 107-23. Heaviside, *The Electrician*, 14, 178, 10 January 1885; *Electrical Papers*, 2 vols. (London, 1892), 1: 439-40. Poynting, *Phil. Trans.*, 176, 277-306, 1885. Poincaré also pointed out in 1890 (*Comptes Rendus*, 111, 322) that the velocity of propagation in air, as calculated by Hertz, should have been $\sqrt{2}$ c, rather than c. Finite velocities for electric sparks and for electric propagation in wires had been found in experiments by Wheatstone in 1834 (*Phil. Trans.*, 1834, 583) and Fizeau and Gounelle in 1850 (*Comptes Rendus*, 30, 437); Hertz referred to the latter in his publications.

44 Hertz, *Wiedemann's Annalen*, 34, 610, 1888; 'On Electromagnetic Waves in Air and their Reflection', *Electric Waves* (1893), ch. VIII, 124-36. The experiments were far from straightforward for Hertz had to estimate his wavelengths from only two nodal positions.

45 Lodge, *Past Years* (London, 1931), 184. Lodge (August 1888), ref. 38, 227-30.

46 Hertz, *Electric Waves* (1893), ch. VIII, 124-36, ref. 40, quoting 136.

47 Lodge (August 1888), ref. 38, 230

48 Notebook 3-15, 149, 179; Special Collections, SJL, University of Liverpool.

49 *BA Report*, 58, 557-62, 1888, 562; *Scientific Writings* (1902), 229-40, 240.

50 Lodge, 'George Francis FitzGerald 1851-1901', *Year-Book of the Royal Society* (London, 1902), 251-9, 253.

51 *BA Report*, 58, 567, 1888

52 Quotations from Nahin (1988), ref. 32, 68; and Heaviside to Lodge, 21 September 1888, cited in Bruce J. Hunt, '"Practice vs. Theory": The British Electrical Debate, 1888-1891', *Isis*, 74, 341-55, 1983, 347.

53 Lodge, *Advancing Science* (London, 1931), 93, 96. Hunt (1983), ref. 48.

54 Lodge (1902), ref. 46, 253-4. FitzGerald, 1888, ref. 49, 1902, 231.

55 See O'Hara and Pricha (1987), ref. 19, ch. 2, 55-84.

56 *The Electrician*, 21, 607-8, 19 October 1888; *Electrical Papers*, 2 vols. (London, 1892), 2: 488-90, 489.

57 Lecher, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien*, 99, part 2a, 340-61, 1890.

58 A. Ferguson, 'Lodge, Sir Oliver Joseph', *DNB 1931-40* (Oxford, 1949), 541-3, 542. If there can be said to be a 'discovery moment' in work of so gradualistic a character as that of Hertz, it is more like March 1888, exactly contemporaneous with the work of Lodge, than the late 1887 quoted loosely by so many authorities. The discovery of importance is not that of 'waves' but of Maxwellian *radiation* in the form of waves.

59 Lodge to Hertz, 25 September; Hertz to Lodge, 28 September; Hertz to Lodge, 14 October 1888; in O'Hara and Pricha (1987), ref. 19, 89-90.

60 *The Electrician*, 36, 438-40, 1896

61 *Nature*, 111, 328-32, 1923, 331

62 *Sitzungsber. d. Berl. d. Wiss.*, 13 December 1888, 'On Electric Radiation', *Electric Waves* (1893), ch. XI, 171-85. *Wiedmann's Annalen*, 37, 395, 1889; 'On the Propagation of Electric Waves by Means of Wires', *Electric Waves* (1893), ch. XII, 160-70.

63 Lodge, *Advancing Science* (1931), 88

64 Hertz to Lodge, 7 February 1889; O'Hara and Pricha (1987), ref. 19, 91.

65 Lodge, Notebook 3-16, 12; Special Collections, SJL, University of Liverpool.

66 Lodge, *Past Years* (1931), 185. 'The Discharge of a Leyden Jar', *Nature*, 39, 470-

4, 14 March 1889. *The Electrician*, 22, 531-4, 15 March 1889. *Proc. Roy. Inst.*, 12, 413-24, 1889.

67 'On Lightning, Lightning Conductors, and Lightning Protectors', *The Electrician*, 22, 731-4; 23, 7-9, 39-42, 67-9, 355-6, 382-4, 407-10; 25 April, 3, 17, 24 May, 9, 16, 23 August 1889. *JIEE*, 18, 386-430, 475-80, 531-54, folding plate, 1889-90.

68 Lodge, Notebook 3-16, 20, 20, 21; Special Collections, SJL, Univ. of Liverpool.

69 Lodge, Notebook 3-16, 21; Special Collections, SJL, University of Liverpool.

70 Lodge, *Past Years* (1931), 185-6

71 Lodge, *Advancing Science* (1931), 84-5, quoting from a 'Sketch of the Principal Papers ...' published in *The Telegraphic Journal and Electrical Review*, 21, 312-5, 23 September 1887. See Thomson, *BA Report*, 57, 486-95, 1887; and *Phil. Mag.* (5), 24, 342, 1887; and FitzGerald, *Sci. Proc. RDS*, 4, 107, 142-62; *Scientific Writings* (1902), 142-62, 154. Thomson's proof is said to have been scribbled out there and then in a few lines on the blackboard; his earlier model was in *BA Report*, 50, 473, 1880.

72 *Phil. Mag.* (5), 28, 48-65. *Proc. Phys. Soc.*, 10, 143-63, 1889.

73 Hertz to Lodge, 21 July 1889; O'Hara and Pricha (1987), ref. 19, 93-4.

74 Hertz, *Electric Waves* (1893), 9. Hunt (1991), ref. 4, 157.

75 Lodge, *Past Years* (1931), 182-3. See H. G. J. Aitken, *Syntony and Spark – The Origins of Radio* (New York, 1976), 107-8, on the significance of this experiment.

76 *Nature*, 41, 368, 20 February 1890

77 *Nature*, 41, 462-3, 20 March 1890

78 'Electrical oscillations', *Proc. Phil. Soc. Glasgow*, 21, 216-24. The story about Lodge having to sleep on the park bench comes from the *Liverpool Daily Post* of 14 June 1938, and refers simply to a lecturing trip to Scotland. This, however, seems to be the most likely occasion.

79 *Nature*, 41, 295, 1890; 42, 172, 1890. FitzGerald's discovery is mentioned in Lodge's Presidential Address to the Liverpool Physical Society, 16 December 1889; *Research*, 2, 159-162, January 1890; reprinted in *Proceedings of the Liverpool Physical Society*, 1, 1-8, 8.

80 Lodge (1892), ref. 25, 2, 27. For further references on this, see ibid., 28-9; *Nature*, 50, 132-9, 1894, 132; *The Electrician*, 12, 87-91, 1897, 88; ibid., 52, 704, 1904; *Modern Views of Electricity*, third edition (London, 1907), 235-6; 'Waves in Wireless Work and Theory', *Harmsworth's Wireless Encyclpaedia* (London, 1924), 2225-30; *The Electrician*, 94, 174-5, 1925, 174; BA Report, 101, 556, 1931; *Advancing Science* (1931), 90; *Past Years* (1931), 183-5, 214, 225-9, 235. (Such a relatively late, and subdued, assertion of priority or equality is characteristic of Lodge. It has often been noted that he was always rather diffident about his own scientific achievements and abilities, that he never had that single-minded belief in himself which frequently drives others to the greatest success, and that he would not develop an idea and force it through to its logical conclusion. It is also relevant that he had been well schooled by FitzGerald in the art of gentlemanly reticence regarding the personal appropriation of scientific discoveries. FitzGerald himself was so successful in this respect that he is only remembered popularly for the proposal of relativistic contraction for which Lorentz insisted that he share the credit!)

81 *The Times*, 8 September 1888

82 *Elektrichestvo*, 5, 90, 1890; quoted in Khatsel A. Ioffe, 'Popov: Russia's

Marconi?', *Electronics and Wireless World*, July 561-5, 562.

83 Hughes to Heaviside, 6 June 1889: "Remember that I fully agree with Hertz's experiments and think Maxwell's electromagnetic theory of light probable – but the only point in doubt in my mind is the permeation of a current from the inside to the outside." (Quoted, R. Appleyard, *Pioneers of Electrical Communication* (Macmillan, 1930), 242.) If he then attributed his earlier experiments to Hertzian waves, he did not explicitly say so; nor did he bring up the subject when he met Hertz on the latter's visit to London in 1890.

Notes to Chapter Five

1 *The Electrician*, 26 September 1888

2 *The Times*, 8 September 1888

3 Paul J. Nahin, *Oliver Heaviside, Sage in Solitude* (IEEE Press, 1988), 63

4 On 24 June 1887, Heaviside wrote a letter to *The Electrician* in which he suggested that the term "Mac" be employed as the unit of inductance "... in honour of the man who knew something about self-induction and whose ideas are still to be fully appreciated. This was very much his own fault." This last remark, coming from a scientist who turned the complex exposition of ideas into an art form, was like a red rag to a bull to one offended reader (Amicus) who declared that "Mr Heaviside tells us that the term 'mac' is quite euphonious and unobjectionable. If that be granted, so too, is 'smack'; and for any scientist, who takes unwarrantable liberties with his readers, or who drags his personal feelings into public print, or makes ... perversions of the English language, smack is really the only proper term to use." Heaviside's reply is one to be relished. He wrote that he was applying a *scienticulometer* "To the investigation of a quite new phenomenon ... the learned grammaticulist. Up to the present time, however, I have failed to extract anything but froth, with a parting smack of vulgarity. Froth is excellent in its way, but is rather too insubstantial. As for the other, it is certainly not the thing to use, especially for so accomplished a literary critic, who should, I think, endeavour to copy the refined style of ... polite writers." Nahin (1988), ref. 3, 69-70.

5 *The Times*, 12 September 1888

6 *BA Report*, 1888. Lodge was upset at the official description of events which, despite being, as might be expected, the longest, has most of the barbed repartee, so obvious in other journals, surgically removed. Lodge wrote "I have just read what purports to be the lightning rod discussion at Bath, as reported in the annual volume of the British Association ... Speaking for myself I am made to talk a lot of nonsense and occasionally to say things the exact opposite of what I could have intended. I judge that the same thing applies to others but for myself I wish to disclaim all responsibility for the production." *The Electrician*, 19 September 1888.

7 Unless otherwise stated all the quotes I have used come from *Nature*'s report of the meeting, 4 October 1888, 546.

8 *The Electrician*, 21, 674, 28 Sep 1888

9 *The Times*, 14 September 1888

10 Preece to Lodge, 26 October 1888; Lodge Collection, University College London Library (UCL).

11 *Nature*, 6 April 1893, 556

12 *Nature*, 6 April 1893, 556

13 Preece to Lodge, 18 December 1895, UCL.
14 Lodge to Heaviside, 23 September 1888, UCL.

Notes to Chapter Six

1 R. F. Pocock, *The Early British Radio Industry* (Manchester, 1988), 92
2 *The Electrician*, 26, 685-6, 1891
3 PRO ref. ADM 116/570. W. P. Jolly, *Marconi* (London, 1972), 90.
4 *The Fortnightly Review*, 51, 173-81, 1892
5 *J. Franklin Inst.*, 136, 11-19, 81-98, 161-77, 259-79, 351-60, 01-12, quoting 267. Pocock (1988), ref. 1, 78-80.
6 *Comptes Rendus*, 111, 785-7 and 112, 90, 1890.
7 *Nature*, 18 August 1892, 384. *The Electrician*, 29 August 1892, 397-9, 397. There had been no clear idea among the early workers, including Branly himself, that the action was due to electromagnetic waves. See H. G. J. Aitken, *Syntony and Spark – The Origins of Radio* (New York, 1976), 104.
8 *The Times*, 22 November 1892
9 Liverpool Physical Society Minute Books, 1, 96, 101, Liverpool University Archives. See P. Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool, 1990), 83, 85.
10 *Nature*, 9 November 1893, 47. *Phil. Mag.* (5), 27, 94-5, January 1894. *Proc. Phys. Soc.*, 12, 461-2, 1894.
11 See Aitken, ref. 7, 103, 105, 172. "To stretch a point," says Aitken, the coherer was "the first solid-state device used in electronics"; some of Lodge's devices have been described as "prototypes of the crystal detector of later years". For W. H. Eccles, for example, writing in 1941, the single-point coherer was "probably the most sensitive detector ever devised", and the forerunner of the crystal detector and telephone combination. (Aitken, 104; R. A. Gregory and A. Ferguson, *RS Ob. Notices*, 3, 551-74, 1941; Eccles, *Proc. Phys. Soc.*, 54, 61-3, 1941, 62.)
12 O. Lodge, *Past Years* (London, 1931), 230. *Liverpool Daily Post*, 23 August 1940.
13 Notebook 3-17, 1, 160, 166, 206, University of Liverpool, Sydney Jones Library, Special Collections.
14 *Il Nuovo Cimento*, 35, 12-17, 1894
15 David Wilson, *Rutherford, Simple Genius* (London, 1983), 50, 53, 56-8. Rutherford's first published paper was on the 'Magnetisation of iron by high-frequency discharges', published in *Trans. NZ Institute*, 27, 481-513, 1894, and read to the Canterbury Philosophical Society on 7 November. (*The Collected Papers of Lord Rutherford of Nelson*, ed. J. Chadwick, 2 vols. (George Allen and Unwin Ltd, 1962), 25-57.) Lodge and Hertz had claimed that iron was not magnetic at very high frequencies, but Rutherford's researches had proved them wrong.
16 *Nature*, 50, 133-9, 160-1, 7 and 14 June 1894. Also published in *The Electrician*, 33, 153-5, 186-90, 204-5, 271-2, 362, 1894; and *Proc. Roy. Inst.*, 14, 321-49, March 1895. According to Aitken, "Lodge's reference [in the lecture] to the electric arc shows considerable prescience, for the use of this device as a generator of continuous waves was several years in the future." (ref. 7, 1976, 172) In addition, according to W. H. Eccles, "much of the short-wave technique of thirty years later

was also set forth in this discourse". (op. cit., 1941, 61)
17 O. Lodge, *The Work of Hertz and his Successors* (London, 1894), 27
18 M. E. Muirhead, *Alexander Muirhead* (Oxford, 1926), 39. Pocock (1988), ref. 1, 83.
19 Lodge, *Past Years* (1931), 112
20 *Nature*, 50, 182-3, 21 June 1894
21 *Nature*, 50, 408, 463, 1894. *The Electrician*, 33, 458, 17 August 1894. Lodge, *Past Years* (1931), 231-2, 235; *Advancing Science* (1931), 153, 157-66; *Discovery*, 11, 132, April 1930. *BA Report of the Centenary Meeting* (London, 1932), 557, 609-10. Aitken, for example, ref. 7, is quite clear about Lodge's title to the initial demonstration of radio telegraphy. He says that, in the sense that Lodge was the first to transmit and receive signals in Morse code, "he must be regarded as the inventor of radio telegraphy". (123) He also says that Lodge was the man "who completed the transfer" of the knowledge of Hertzian waves from science to technology (25), and that, by 1894, he had "assembled and demonstrated a complete functioning system of radio communication" (315).
22 *The Times*, 14 August 1894
23 *The Electrician*, 33, 458, 17 August 1894. Lodge, *Advancing Science* (London, 1931), 158. When he was no longer in the employ of the Marconi Company, Fleming, the only important witness to have previously denied the signalling, made the explicit statement that Marconi was "not the first person to transmit alphabetic signals by electromagnetic waves" and followed it with an accurate account of Lodge's experiments at Oxford. (*JRSA*, 86, 42-63, 26 November 1937). See Aitken, ref. 7, 122-3, 174, who points out that Degna Marconi, by changing an "unquestionable" into "questionable" (*My Father, Marconi*, New York 1962, 24), characteristically changes Fleming's statement "into an assertion of Marconi's priority". Among the most of the distinguished visitors from overseas at Lodge's lecture was the great Austrian physicist, Ludwig Boltzmann, who took the speaker to task for making the embarrassing gaffe of proclaiming Hertz as "no ordinary German"; Lodge, we are assured, quickly made amends. (Lodge, *Advancing Science* (1931), 162-3.)
24 T. H. Bridgewater, *A. A. Campbell Swinton*, second edition (London, 1982), 16
25 *The Electrician*, 33, 458, 17 August 1894. Lodge, *Advancing Science* (London, 1931), 160.
26 T. Besterman, *Bibliography of Sir Oliver Lodge* (Oxford), Foreword by Lodge (dated 1 March 1935), xi-xiv, quoting xii. *Nature*, 50, 463, 1894.
27 Pocock (1988), ref. 1, 100, makes the point. Marconi claimed that he discovered this "new arrangement" in August 1895. 'Wireless telegraphic communication', Nobel Lecture, 11 December 1909, *Nobel Lectures. Physics 1901-1921* (Elsevier, 1967), 196-222, 197-8.
28 FitzGerald to Lodge, 21 June 1897. Lodge Collection, University College London Library (UCL).
29 *The Electrician*, 33, 304-5, 1894
30 Translated by J. A. Fleming, *Principles of Electric Wave Telegraphy* (London, 1906), 425. Pocock (1988), ref. 1, 93-4.
31 Bose, *Proc. Roy. Soc.*, 59, 160-7, 1895; *The Electrician*, 36, 289-92, 1895. Anon., *The Electrician*, 36, 273, 1895.
32 Jolly (1972), ref. 3, 90
33 Wilson (1983), ref. 15, 95. Fleming (1906), ref. 30, 425. Pocock (1988), ref. 1,

94.

34 Campbell Swinton to Lodge, 13 March 1928, SPR, Lodge Collection. W. P. Jolly, *Sir Oliver Lodge* (London, 1974), 147-8.

35 Campbell Swinton to Preece, 30 March 1896. D. Marconi, *My Father, Marconi* (New York, 1962), illustration following p. 182. W. T. Baker, *A History of the Marconi Company* (London, 1970), illustration following p. 182.

36 J. R. Wade to Prof. F. G. Baily, 18 June 1936, SPR, Lodge Collection. Jolly (1974), ref. 3, 148.

37 Pocock (1988), ref. 1, 94. V. S. Gabel, *Wireless World*, 18, 319, 1926.

38 Wilson (1983), ref. 15, 95-8, citing a letter of Rutherford, 15 March 1896, describing the Conversazione, and Lord Rayleigh, *The Life of Sir J. J. Thomson* (Cambridge, 1943).

39 Marconi to the Secretary of State for War, 20 May 1896, quoted Pocock (1988), ref. 1, 103.

40 BP 5, 028; the Complete Specification was filed on 2 March 1897; and the patent was issued on 2 July.

41 P. R. Mullis to 'Mr Faulkner', 20 October 1940, quoted E. C. Baker, *Sir William Preece, F.R.S.* (London, 1976), 267 and Pocock (1988), ref. 1, 115.

42 ibid. Baker (1976), ref. 41, 267.

43 Different accounts of this experiment and of the place it was carried out are given by Baker (1976), ref. 41, 267; Jolly (1972), ref. 3, 86-7; and Pocock (1988), ref. 1, 115. Baker says reception was at GPO South in Carter Lane, 300 yards away; Jolly says it was another PO building in Queen Victoria St, rather less than a mile distant; and Pocock puts it at the Savings Bank in Knightrider St.

44 PRO ref. ADM 116/523, quoted Pocock (1988), ref. 1, 90.

45 Jackson to Gavey, quoted Baker (1976), ref. 41, 269, 268.

46 Baker (1976), ref. 41, 279. The elevated wire aerials were not in the patent of 2 June. On the use of 'aerials' by such early workers as Thomson, Edison and Dolbear, see C. Süsskind, 'Observations of electromagnetic action before Hertz', *Isis*, 55, 23-42, 1964, 41. Edison, who had experimented in 1885 with an inductive system which he called 'Space Telegraphy', had used 100 feet high masts with overhead metal plates. Edison, who greatly admired the work done by Marconi on transatlantic transmissions, refused to sell the patent to anyone but Marconi; the deal was concluded satisfactorily in 1903. (Jolly (1972), ref. 3, 146, citing Matthew Josephson, *Edison* (London, 1959).) Marconi may, however, have owed more to Edison than the latter imagined, for he was undoubtedly influenced by the suggestions published by Tesla, who had been working for Edison at exactly the moment when the 'Space Telegraphy' was being developed.

47 Pocock (1988), ref. 1, 116

48 *Nature*, 54, 567, 8 October 1896. Rutherford to Lodge, 13 August 1896, UCL. Bose, *Phil. Mag.* (5), 43, 55, January 1897.

49 *Nature*, 54, 567, 8 October 1896. Lodge, *Past Years* (1931), 235.

50 *The Times*, 23 September 1896. *The Electrician*, 37, 702-3, 25 September 1896.

51 FitzGerald to Heaviside, 28 September 1896, quoted P. J. Nahin, *Oliver Heaviside: Sage in Solitude* (New York, 1988), 263. *The Times*, 24 September 1896.

52 *Westminster Gazette*, 14 December 1896

53 Pocock (1988), ref. 1, 139-40

54 *The Engineer*, 83, 271, 1897

55 Jackson to Marconi, undated; Jackson to C-in-C Devonport, 31 March 1897, quoted Pocock (1988), ref. 1, 119, 129.
56 Lodge to Thompson, 16 March, 1897; Thompson to Lodge, 12 April 1897; Lodge to Thompson, 14 March 1897. UCL.
57 Pocock (1988), ref. 1, 122. Jones to Davies, 16, 23, 28 May, 4 June 1897; National Library of Wales; quoted R. G. Roberts, *The Training of an Industrial Physicist. Oliver Lodge and Benjamin Davies. 1882-1940* (PhD Thesis, UMIST, July 1984), 3-27 to 3-30.
58 BP 11, 575 and BP 29, 069, 10 May and 8 December 1897. Quotation from Aitken (1976), ref. 7, 131. See also pp 132-139.
59 Preece to Lodge, 31 May 1897; Lodge to Thompson, 1 June 1897. UCL.
60 *Proc. Roy. Inst.*, 15 (ii), 467-70, 1897. Abstract in *The Electrician*, 39, 216-8, 11 June 1897.
61 *The Electrician*, 39, 207, 1897
62 *The Times*, 22 June 1897, 14 f
63 Righi to Lodge, 18 June 1897. UCL.
64 FitzGerald to Lodge, 18 June 1897. UCL.
65 FitzGerald to Lodge, 21 June 1897. UCL.
66 Thompson to Lodge, 30 June 1897. UCL.
67 *Electrical Review*, 9 July 1897. Pocock (1988), ref. 1, 106.
68 Jolly (1972), ref. 3, 40
69 *The Electrician*, 39, 686, 17 September 1897
70 *The Electrician*, 40, 133, 1897 (H. Benest, on Edison); 39, 869, 1897 (A. A. Campbell Swinton, on Tesla); 39, 832, 1897 (G. M. Minchin, on himself). There is a good case for saying, as we have seen from note 46, that the Marconi development stemmed ultimately from at least two of these.
71 FitzGerald to Lodge, 30 October 1897. UCL.
72 Kelvin to Lodge, 10 November 1897. UCL.
73 Minchin to Lodge, 13 September 1897. UCL.
74 Lodge to Davies, 28 October 1897; Roberts (1984), 3-10. Muirhead to Lodge, 1 November 1897. UCL.
75 Preece, letter of 1899, quoted in Baker (1976), ref. 41, 279.
76 The only printed source for this experiment seems to be the University College magazine, *The Sphinx*, 5, 149, 1898.
77 Pocock (1988), ref. 1, 140. *The Electrican*, 40, 112, 1897 (for Slaby).
78 Thompson to Lodge, 15 December 1897. UCL.
79 *Phil. Mag.* (5), 44, 444, November 1897
80 *The Electrican*, 40, 87-91, 12 November 1897, 91
81 US patent 609, 154
82 Muirhead to Lodge, 21 January 1897. UCL.
83 Physical Society of London lecture: abstract in *Proc. Phys. Soc.*, 16, 58-61, July 1898. In *Advancing Science* (1931), 125, Lodge wrote: "in those days I, for one, had not the smallest idea of general broadcasting". *The Sphinx*, 5, 149, 1898. See also *Trans. Liverpool Eng. Soc.*, 19, 141-3, 1898.
84 Lodge to Preece, 4 March 1898. Preece to Lodge, 7 March 1898. UCL. On 11 March, Lodge informed Preece that the "'coherer' plan ... may have scope in its proper place & I keep that going alongside the other. However, I believe the magnetic plan is best for ships and lighthouses & for long distances ..." (Baker (1976), ref. 41, 300).

85 *Nature*, 58, 61-2, 19 May 1898
86 Preece to Lodge, 10 March 1898. UCL.
87 Muirhead to Lodge, Tuesday, after 20 April 1897.
88 Jolly (1972), ref. 3, 56
89 Baker (1976), ref. 41, 300
90 Kemp's diary, quoted Jolly (1972), ref. 3, 58.
91 Baker (1976), ref. 41, 300
92 Preece to Lodge, 22 September 1898, UCL.
93 Lodge, *Past Years* (1931), 212-3 (quoting Lord Lister's Presidential Address). Lodge must have found it mildly irritating when Lister quoted Hertz as saying that Lodge would have proved that electric forces propagate in time, as required by Maxwell's theory, if he himself had not anticipated him. As Lodge pointed out (*Past Years*, 214), it had not been generally recognised – and certainly not by Hertz himself – that the waves which Lodge had "detected along wires followed exactly the same laws as the waves which Hertz had detected in space"; and, in fact, they were also in space, as he and Heaviside found, though guided by the wires. Lodge had given the complete theory in his *Philosophical Magazine* article of August 1888 even before the announcement of Hertz's results at the BA meeting in September. The whole series of experiments carried out in February and March 1888 were based on the explicit assumption that electric forces had a finite velocity.
94 *The Electrician*, 42, 269-71, 305-9, 366-8, 1898. *JIEE*, 1898, 840-2.
95 *The Electrician*, 42, 443-4, 445, 1899
96 *JIEE*, vol. 28, 1899. Jolly (1972), ref. 3, 58.
97 Lodge to Davies, 16 April, 5 May 1899; Roberts (1984), ref. 57, 3-38.
98 On Hughes, see C. Süsskind, 'Observations of electromagnetic action before Hertz', *Isis*, 55, 23-42, 1964. J. J. Fahie, *A History of Wireless Telegraphy* (Edinburgh and London, 1899). *The Electrician*, 43, 40-1, 5 May 1899. *Electrical Review*, 44, 883-5, 947, 1899. Hughes's manuscripts, which were examined much later, showed clearly that he thought the transmission was due to air conduction, and had no knowledge of electromagnetic waves. See A. A. Campbell Swinton, *JIEE*, 60, 442-5, 1922.
99 According to Lodge, *Past Years* (1931), 185: "Hertz himself hardly knew that he had discovered electric waves at first, or at least he didn't use that phrase; he was investigating the laws of the spreading of electric force in space." In 'George Francis FitzGerald 1851-1901', *Year-Book of the Royal Society* (London, 1902), 251-9, 253-4, Lodge argued that his friend undoubtedly "recognised more vividly than Hertz the full import of his experiments – the German title of which was far from representing the plain significance" of the English title, *Electric Waves*, supplied by Lord Kelvin in 1893. Lodge was saying, in effect, that the recognition that Hertz's experiments were about electric *waves* did not mean that he had always realised this, though the English title of the book contrived to give the impression that he had. Many people have failed to recognise this level of understanding in Lodge's work and have not realised that the prediction of electromagnetic waves was by no means an obvious development from Maxwell's theory, and was first made explicit by Lodge himself. The German title of Hertz's book was, in fact, *Arbreitung der Elektrischen Kraft*, which Lodge himself translated as the "outspreading of electric force". (*Nature*, 111, 328-32, 1923, 331)
100 For the prehistory of the coherer see Leonid Kryzhanovsky, 'The coherer: preparing the way for wireless', *Electronics World and Wireless World*, March

1992, 212-4, who traces it back to the resistors in glass tubes made by Franklin and Delaval in the eighteenth century. The best-known 'anticipations' of the Branly tube are the experiments of P. S. Munck in 1835 and of T. Calzecchi-Onesti, mentioned by Marconi, in 1884; in 1866 the Varley brothers even patented a device, based on a similar principle, for the protection of telegraph equipment from lightning. Lodge had himself given a talk on 'Coherers' at the Royal Institution on 25 February 1899, with Crookes in the chair as Vice-President. (*Proc. Roy. Inst.*, 16, 72-4, December 1900.)

101 *Electrical World*, November 1899, quoted Jolly (1972), ref. 3, 82.

102 Lodge, *The Times*, 11 November 1899 (for Ladysmith); Baker (1976), ref. 41, 303. *Trans. Liverpool Eng. Soc.*, 21, 149-53, 1900. See also Lodge and Muirhead, *Proc. Roy. Soc.*, A 82, 227-56, 26 May 1909.

103 *The Electrician*, 42, 269-71, 305-9, 366-8, 1898, 269.

104 *Proc. Roy. Soc.*, A 82, 227-56, 26 May 1909.

105 PRO ADM 116/570. Jolly (1974), ref. 34, 148; Jolly (1972), ref. 3, 88; Baker (1976), ref. 41, 279-80.

106 Jolly (1972), ref. 3, 89. On 28 January 1899 Jackson had told C-in-C Devonport that he had "extracted much useful information from Professor Lodge's work on Hertz's experiments, and from Hertz's book on oscillations, but certainly no idea of Morse signals being possible." (PRO ref. ADM 116/523, quoted Pocock (1988), ref. 1, 89.)

107 Baker (1976), ref. 41, 280

108 Lodge to Davies, 30 October 1901; Roberts (1984), ref. 57, 4-35.

109 *JIEE*, 1898, 840-2. See also Lodge, *Past Years* (1931), 210.

110 Baker (1976), ref. 41, 303

111 Lodge to Davies, 30 October 1901; Roberts (1984), ref. 57, 4-35.

112 BP 13, 521. *Proc. Roy. Soc.*, 70, 402-3, 1903. Jolly (1974), ref. 34, 152. *Birmingham Post*, 4 February 1903; *Pall Mall Gazette*, 26 February 1903.

113 *The Times*, 27 October 1906

114 Quotation from Aitken (1976), ref. 7, 164, who cites (on p. 177), S. G. Sturmey, *The Economic Development of Radio* (London, 1958), 20-1.

115 In proposing the vote of thanks for Lodge's Trueman Wood Lecture at the RSA on 10 December 1919, Wood himself informed the audience that: "It was interesting that the first public announcement of his researches into electrical waves was made into the very room they were now in." (*JRSA*, 68, 74, 1919)

116 'Wireless telegraphic communication', *Nobel Lectures. Physics 1901-1921* (Elsevier, 1967), 196-222.

117 Lodge to Porter, 7 October 1909, Liverpool University Archives.

118 Baker (1976), ref. 41, 304-8, quoting 308.

119 W. H. Eccles, 'Lodge and Wireless', *Proc. Phys. Soc.*, 54, 61-3, 1941

120 Lodge's first discussion of the use of cryogenics to reduce noise levels in receivers is in a letter to *Nature*, 115, 838, 30 May 1925.

121 Lodge comments on this in the Foreword, dated 1 March 1935, to T. Besterman, *Bibliography of Sir Oliver Lodge* (Oxford), xi-xiv, xiv, where he discusses at length his claim to priority in the invention of radio.

122 Aitken (1976), ref. 7, 46, 168, 258, 293-4. The lawsuit, which was initiated on 29 July 1916, had been brought by the Marconi Company against the US Government, who had used the tuned circuits without payment during the First World War. (US and German, but not British, patent law allowed a patent to be

claimed on the basis of prior publication, in this case the lectures of 1894.) It is interesting that Reginald Fessenden, who introduced continuous wave transmission into radio, referred, in another lawsuit involving the Marconi Company, to "the Lodge system (and later, Marconi's modification of it)" as being "based on the wrong principle". See Aitken (1976), 294.

123 It should, of course, be realised that "Lodge" and "Marconi" were both, to some extent, team-leaders rather than purely individual researchers. Lodge's team had included, at various times, Chattock, Howard, his assistants Davies and Robinson, and, later on, Alexander Muirhead, with G. F. FitzGerald acting as consultant. Marconi's team was almost equally powerful, with Kemp, Jackson, Fleming and, later, Round and Franklin.

124 In 'Wireless in 1894', an article written for *Discovery*, 11, 132, April 1930, Lodge wrote that his main complaint against Marconi was that the latter had not acknowledged what had gone before. Under pressure from Silvanus Thompson, Marconi had made an explicit public denial of his debts in letters to the *Saturday Review*, 3 May 1902, 556, and 24 May 1902, 666.

Notes to Chapter Seven

1 G. W. de Tunzelmann, *Knowledge*, 1 October 1990, 234-5. Lodge, *Nature*, 50, 133-9, 7 June 1894.

2 Lodge, *JIEE*, 111, 785, 1890; *Lightning Conductors and Lightning Guards* (Whittaker, 1892), 382-4.

3 Branly, *Comptes Rendus*, 111, 785, 1890; 112, 90, 1891.

4 *Nature*, 43, 288, 22 January 1891

5 *Nature*, 46, 384, 18 August 1892

6 *Nature*, 49, 47, 9 November 1893

7 *Nature*, 49, 47, 9 November 1893

8 *Nature*, 49, 142, 7 December 1893; 50, 94, 24 May 1894.

9 G. W. de Tunzelmann, *Knowledge*, 1 October 1990, 234-5

10 W. L. Bragg and G. Porter (eds.), *The Royal Institution Library of Science, Physical Sciences* (Elsevier, 1970), 4: 320.

11 *Nature*, 57, 334, 3 February 1898

12 *Nature*, 49, 142, 7 December 1893, and the 1894 lecture reports.

13 W. L. Bragg and G. Porter (eds.), *The Royal Institution Library of Science, Physical Sciences* (Elsevier, 1970), 5: 233.

11 H. Fröhlich, *Proc. Roy. Soc.*, A 188, 521-42, 1947

15 G. Dearnley, M. Stoneham and Morgan, *Rep. Prog. Phys.*, 33, 1129-97, 1970

16 *Nature*, 57, 334, 3 February 1898

17 *Nature*, 57, 334-5, 3 February 1898

18 *Nature*, 57, 334-5, 3 February 1898

19 *Nature*, 57, 612, 28 April 1898

20 *Nature*, 50, 408 and 463, 1894

21 C. G. Ashley, in *Cyclopedia of Telephony and Telegraphy* (American Technical Society, Chicago, 1911), 4: 137.

22 H. M. Dowsett, *Wireless Telephony and Broadcasting* (Gresham, 1923).

Notes to Chapter Eight

1 *Nature*, 50, 133-9 and 160-1, 7 and 14 June 1894, 138.
2 Notebook 3-17, 230, University of Liverpool, Sydney Jones Library, Special Collections.
3 ibid. Dr M. A. Houlden's discovery of the two notebook entries in the 1980s established that the experiments took place in June 1894, and not at a later date, as has been supposed by some authorities.
4 *Signalling across Space without Wires*, fourth edition (London, 1908), 33.
5 Quoted in F. Graham Smith, *Radio Astronomy*, fourth edition (Penguin Books, Harmondsworth, Middlesex, 1974, first edition), 18-19.
6 Presidential Address to the Liverpool Physical Society, 16 December 1889. *Research*, 2, 159-162, January 1890; reprinted in *Proceedings of the Liverpool Physical Society*, 1, 1-8, quoting p. 5.
7 *Liverpool Daily Post*, 24 March 1896
8 *Encyclopaedia Britannica*, ninth edition (1882), 16, 159-84
9 *BA Report*, 63, 682, 1893
10 *Nature*, 48, 526, 1893; *BA Report*, 63, 682, 1893.
11 Liverpool Physical Society, Minute Book, 1, 96-7. Liverpool University Archives.
12 Tesla, *J. Franklin Inst.*, 136, 11-19, 81-98, 161-77, 259-79, 351-60, 01-12. Rowland F. Pocock, *The early British radio industry* (Manchester, 1988), 78-80.
13 FitzGerald to Lodge, 14 November 1992, UCL Collection, quoted in P. Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool, 1990), 99. Referring to his assistant, Frederick Trouton, FitzGerald writes: "Trouton objects that we should have magnetic storms when near comets' tails as we have been occasionally. I reply maybe there were and maybe comets' tails are whisking so rapidly that breadth narrow and density small." Robinson's experiment is described in Liverpool Physical Society, Minute Book, 1, 97; Liverpool University Archives.
14 *The Electrician*, 31, 390, 11 August 1893
15 Quotation from 'Sunspots, magnetic storms, comets' tails, atmospheric electrcicty and aurorae', *The Electrician*, 46, 287-8, 14 December 1900; *Scientific Writings*, ed. J. Larmor (Dublin, 1902), 531-3, 531. MS of 'Striae of vacuum tubes applies to aurorae' (dated 1893), published in *Scientific Writings*, 548-50.
16 *Nature*, 28 September 1893; *Scientific Writings*, 301-2.
17 ibid., 302.
18 The early sporadic attempts at radio astronomy are described in standard works on the history of astronomy such as John North, *The Fontana History of Astronomy and Cosmology* (London, 1994), 544.
19 J. Erskine-Murray, *A Handbook of Wireless Telegraphy* (London, 1913), 314-30. Pocock (1988), ref. 12, 73.
20 Quoted in Paul J. Nahin, *Oliver Heaviside, Sage in Solitude* (New York, 1988), 273.
21 Marconi's diary entry is quoted in W. P. Jolly, *Marconi* (London, 1972), 106.
22 *New York Times*, 15 December 1901
23 Lodge, *The Times*, 20 and 24 December 1901
24 Marconi, 'A note on the effect of daylight upon the propagation of electromagnetic impulses', *Proc. Roy. Soc.*, 70, 2 June 1902.
25 A. E. Kennelly, *Electrical World and Engineer*, 39, 473, 15 March 1902

26 *Electrmagnetic Theory*, 3 vols. (1922, first edition 1912), vol. 3, ch. 10, 331; originally published as 'Theory of electric telegraphy', in *Encyclopaedia Britannica*, tenth edition (1902).
27 *Proc. Roy. Soc.*, 87, 79-99, August 1912; *The Electrician*, 71, 969-70, 19 September 1913. Marconi in his Nobel Lecture of 11 December 1909 shows no sign of interest in, or even knowledge of, this theory, attributing long distance transmission, rather, to earth conduction. See 'Wireless telegraphic communication', *Nobel Lectures. Physics 1901-1921* (Elsevier, 1967), 196-222, esp. 205-7.
28 *JIEE*, 52, 333-52, 2 March 1914 (The Fifth Kelvin Lecture, delivered on 22 January).
29 *Phil. Mag.* (6), 48, 1025-6, December 1924
30 E. V. Appleton and M. F. Barnett, *Nature*, 115, 333-4, 1925
31 Simon Mitton (ed.), *Cambridge Encyclopaedia of Astronomy* (London, 1977), 50
32 *Proc. Inst. Radio Engineers*, 20, 1920-32, December 1932, and 21, 1387-98, October 1933.
33 *Proc. Inst. Radio Engineers*, 28, 68-70, 1940
34 F. Graham Smith, *Radio Astronomy* (1974), 69-70
35 Hey, *Nature*, 157, 47, 1946; *The Radio Universe*, third edition (Oxford, 1983, first edition 1971), 3. Appleton, *Nature*, 156, 534, 1945. F. Graham Smith, *Radio Astronomy* (1974), 69-70.
36 'Discussion on the Theory of Relativity', *Monthly Notices RAS*, 80, 96-118, 20 December 1919, 108.
37 *Nature*, 104, 354, 4 December 1919 (dated 30 November)
38 'Discussion on the Theory of Relativity', ref. 34, 108-9. Eddington, *Space, Time and Gravitation* (1920).
39 *Phil. Mag.* (6), 41, 549-57, April 1921, 552
40 *Nature*, 279, 381, 1979
41 *Phil. Mag.* (6), 39, 626-8, 1920 (dated 13 February)
42 *Phil. Mag.* (6), 41, 549-57, April 1921, 549
43 W. Israel, 'Dark stars: the evolution of an idea', in S. W. Hawking and W. Israel (eds.), *300 Years of Gravitation* (Cambridge, 1987), 199-276, 205.
44 A. Hewish, S. J. Bell, J. D. H. Pilkington, P. F. Scott and R. A. Collins, *Nature*, 217, 709-713, 1968.
45 *Phil. Mag.* (6), 41, 549-57, April 1921, 551
46 W. Israel (1987), ref. 40, 204
47 *Evolution and Creation* (London, 1926), 87. He had previously given his opinion that: "The state of matter in or near a nucleus may be compared to the state inside a star like the companion of Sirius, except that gravitation is inoperative." (*Nature*, 116, 869-71, 12 December 1925, 870.)
48 X-ray identification: M. Oda, P. Gorenstein, H. Gursky, E. Kellogg, E. Schreier, H. Tannanbaum and R. Giacconi, *Astrophys. J. (Letters)*, 166, L1, 1971. Radio identification: L. Braes and G. K. Miley, *Nature*, 232, 246, 1971; R. M. Hjellming and C. M. Wade, *Astrophys. J. (Letters)*, 168, L21, 1971. Optical identification: B. L. Webster and P. Murdin, *Nature*, 235, 37-8, 1972; C. T. Bolton, *Nature: Physical Science*, 240, 124-7, 1972.

Notes to Chapter Nine

1 Recalled in Lodge to Larmor, 1 January 1902. Lodge Collection, University College, London (UCL). Quoted in Bruce J. Hunt, *The Maxwellians* (Cornell University Press, Ithaca and London, 1991), 30.
2 *Nature*, 27, 304-6, 328-30, 1883 (lecture at the London Institution, 28 December 1882); reprinted in *Modern Views of Electricity*, third edition (London, 1907).
3 *Modern Views of Electricity* (Macmillan, London, 1889), 177-216.
4 Ref. 2 (1907), 380.
5 Michelson and Morley, *Am. J. Sc.*, 34, 333-45, November 1887; Phil. Mag. (5), 24, 449-63, December 1887. FitzGerald, *Science*, 13, 390, 17 May 1889. Lodge, *Nature*, 46, 164-5, 16 June 1892. P. Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool, 1990), 54-7. Bruce J. Hunt, *BJHS*, 21, 67-76, 1988.
6 'On the theory of magneto and dynamo machines', published in 16 parts in *The Electrician* between 10 December 1881 and 5 March 1886.
7 *BA Rep.*, 61, 560, 1891; *Phil. Trans.*, A 184, 727-804, 1893 (read 31 March 1892); *Phil. Trans.*, A 189, 146-66, 1897 (read 19 January 1897).
8 MS notes on 'Absolute rest and motion', 20 May 1893; Lodge notebook 3-17, 8, Special Collections, SJL, University of Liverpool; quoted Rowlands (1991), ref. 5, 90. *Phil. Mag.* (5), 46, 343-4, and 414-26, 1898. See Tetu Hirosige, 'The ether, the mechanistic worldview, and the origin of the theory of relativity', *HSPS*, 7, 3-82, 1976, 42-3.
9 Larmor, *Phil. Trans.*, A 186, 695-743, 1895, 699-700.
10 *The Electrician*, 38, 644, 12 March 1897. See also *Nature*, 67, 450-3, 12 March 1903. The concept of electron spin was partly anticipated by FitzGerald in remarks made at the BA meeting at Bradford in 1900. (*Nature*, 62, 564, 1900; report by C. H. Lees.)
11 *Nature*, 57, 121-5, 19 December 1897
12 *Proc. Roy. Inst.*, 15, 419, 1897; *The Electrician*, 39, 104, 1897.
13 *The Electrician*, 39, 735, 1897.
14 Lodge, *Advancing Science* (London, 1931), 179.
15 Lecture on 'Modern Views on Matter', 5 March 1900; *Proc. Liverpool. Lit. and Phil. Soc.*, 54, 91-103, 1900; *The Sphinx*, 7, 237, 239, 1900.
16 *The Electrician*, 46, 250, 7 December 1900.
17 *Nature*, 81, 425-6, 456, 485-6, 7, 14, 21 October 1909.
18 *JIEE*, 32, 45-115, February 1903 (lecture of 27 November 1902).
19 *Nature*, 67, 450-3, 12 March 1903 (lecture at Bedford College, 5 February). *The Sphinx*, 10, 105, 1903; *Annual Report of Liverpool Physical Society*, 1902/3, 2 (lecture of 13 February).
20 *Nature*, 68, 127-9, 11 June 1903. *Modern Views on Matter* (The Romanes Lecture) (Oxford, 1903).
21 Anon., 'Physics at the British Association', *Nature*, 68, 609-11, 22 October 1903, 611 (BA at Southport, 10 September). See A Keller, *The Infancy of Atomic Physics* (Oxford, 1983), 111.
22 *Electrons* (London, January 1907, preface dated July 1906), 213-4, 168.
23 *Phil. Mag.* (6), 13, 488-506, April 1907.
24 *Proc. Liverpool Lit. and Phil. Soc.*, 69, 43-65, 1935, 59-60 (Roscoe Lecture, 14 November 1927). *Atoms and Rays* (London, 1924), 198.

25 *BA Rep.*, 77, 452, 1907
26 *The Contemporary Review*, 93, 536-46, May 1908 (lecture at the Royal Institution, 21 February).
27 *J. Soc. Chem. Ind.*, 27, 731-9, 31 July 1908, 737 (Hurter Memorial Lecture, 12 March).
28 *Phil. Mag.* (6), 39, 170-4, February 1920, 173.
29 *BA Rep.*, 93, 424-5, 1923
30 *Nature*, 110, 696-7, 25 November 1922
31 *Phil. Mag.* (7), 8, 576-84, October 1929, 581.
32 *Nature*, 107, 716-9, 748-51, 784, 814-5, 1921, 751.
33 *Phil. Mag.* (7), 15, 706-26, March 1933, 708.
34 *BA Rep.*, 93, 424-5, 1923
35 Lodge to Larmor, 8 March 1930; Lodge Archives, Private Collection; W. P. Jolly *Sir Oliver Lodge* (1974), 231.
36 *JIEE*, 66, 1005-20, October 1928 (19th Kelvin Lecture, 19 April).
37 *Atoms and Rays* (London, 1924)
38 *Proc. Liverpool Lit. and Phil. Soc.*, 67, 19-42, 1921. Lodge's notes on conversation with Einstein on 13 June 1933; Lodge Archives, Private Collection; Jolly (1974), ref. 31, 231-2.
39 'The Ether: Modern Theories and their Applications', *Harmsworth's Wireless Encyclopedia* (London, March 1924), 876-82.
40 *Nature*, 123, 645-8, 27 April 1929, 645-6.
41 *Nature*, 126, 804-5, 22 November 1930.
42 Lodge (1883), ref. 2, 305.
43 *My Philosophy* (London, 1933); based on *The Ether of Space* (London, 1909).
44 Text in *Nature*, 135, 11-12, 5 January 1935 (film made on 6 December 1934).

Notes to Chapter Ten

1 FitzGerald to Lodge, 21 June 1897; Lodge Collection, University College London Library (UCL).
2 Righi to Lodge, 18 June 1897. UCL.
3 Bose to Lodge, 24 February 1897, UCL.
4 *Nature*, 50, 182, 1894. Lodge, *Signalling across space without wires*, 3rd edn.
5 *The Electrician*, 37, 458, 17 August 1894
6 Lodge, *Past Years* (1931), 231
7 Lodge, *Advancing Science* (Ernest Benn Ltd, London, 1933), 122
8 M. E. Muirhead, *Alexander Muirhead*, (published privately, Oxford, 1926), 39; quoted Rowland F. Pocock, *The early British radio industry* (Manchester University Press, 1988), 83.
9 Hugh G. J. Aitken, *Syntony and Spark – The Origins of Radio* (Wiley, New York, 1976), 125
10 Minutes of the Liverpool Physical Society, 21 November 1892. Minute Book 1, 96, Liverpool University Archives.
11 ibid., 19 December 1892. Minute Book 1, 101.
12 J. Arthur Hill (ed), *Letters from Sir Oliver Lodge* (1914), 42.
13 Lodge, *Past Years* (1931), 182
14 Rutherford to Lodge, 13 August 1896, UCL.

15 *Nature*, 54, 567, 8 October 1896
16 Arthur Stuart Eve, *Life and Letters of the Right Hon. Lord Rutherford, OM*, 44
17 Lodge, *The Electrician*, 12 November 1897, 87-91
18 *The Liverpool Courier*, 22 September 1896
19 *Nature*, 54, 567, 8 October 1896
20 *The Times*, 23 September 1896
21 Unfortunately I can find no record, other than ref. 16, of the 'Rutherford and his broken apparatus' story despite a very intensive survey of historical sources for this particular BA meeting. The story may, therefore, say more about the esteem in which Rutherford was held than any actual historical events. My main evidence for this statement is the factual inaccuracies contained in parts of the book, most notably, as I say in the main text; Eve believed that Marconi was at the meeting and it was his personal announcement that proclaimed the birth of the radio age. Even Preece, who later saw himself as the father of wireless, might have been a bit upset at that. Such is the power of the media hype that subsequently marked Marconi as the inventor of wireless. Nevertheless it is indicative of the importance of that statement that Eve simply assumed it was Marconi.
22 Lodge, *Advancing Science* (1933), 123
23 FitzGerald to Lodge, 18 September 1898, UCL. "I made my pilgrimage to the 'Sage of Devon' yesterday and had a long talk with him and he bought me a most dangerous bicycle ride through lovely lanes as steep as the roof of a house and as crooked as a corkscrew."
24 Heaviside to Lodge, 3 February 1897, UCL.
25 According to Pocock, Kelvin took Lodge up on his offer and, as a result, missed most of the paper given by Preece on submarine cabling and hence suggested that the loss of this scientific "lion" from Preece's audience "helped to exacerbate the ill feeling which ... existed between Lodge and Preece. Pocock (1988), ref. 8, 104. It should be obvious, however that the offer was made by Lodge at the end of the sitting that Kelvin was supposed to have missed!
26 *The Times*, 24 September 1896
27 FitzGerald to Heaviside, 28 September 1896, quoted Paul J. Nahin, *Oliver Heaviside, Sage in Solitude* (IEEE Press, New York, 1988), 263.
28 Heaviside to FitzGerald, reply to 27, 30 September 1896, Royal Dublin Society, FitzGerald archives (RDS), 14/28.
29 See note 31.
30 For details on this debate I have drawn mainly on refs 26 and 27; *The Electrician*, 37, 702-3, 25 September 1896; and *Engineering*, 23 October 1896, 523.
31 See Nahin (1988), ref. 27, 177.
32 *The Electrician*, 37, 702-3, 25 September 1896,
33 Kelvin to Preece, 25 September 1896, copy made for FitzGerald, RDS, 23/81.
34 Nahin (1988), ref. 27; notes in brackets are Nahin's comments.
35 Heaviside to FitzGerald, reply to 37, 30 September 1896, RDS 14/28.
36 Heaviside to Lodge, 6 October 1897, UCL.
37 Preece to Lodge, 7 March 1898, UCL.
38 FitzGerald to Lodge, 10 March 1898, UCL.
39 Preece to Lodge, 15 March 1898, UCL.
40 Heaviside to Lodge, 25 October 1896 and 24 September 1888. UCL.
41 Kelvin to Lodge, 10 November 1897, UCL.
42 I get this impression from his apparent disregard, in his letters for the feelings of

mere mortals such as Lodge. His favourite word in these letters appears to be "absurd". Whilst a degree of impartiality is as it should be, an alternative interpretation might be that he was just tactless, perhaps because of his insularity.

43 Pocock (1988), ref. 8, 114-117. Interestingly enough, Pocock also records the extremely unimpressive appearance of Marconi's original equipment. A primitive receiver which was a "large sized tubular bottle" containing "some bright filings or metal particles" and which differed dramatically from that contained in his patent. The absence of a decoherer is also notable. Far be it from me to suggest that Preece had Marconi modify his equipment so that it took on a more Lodgeian form, but Pocock records a drastic improvement within a month of that first meeting with Preece.

44 Heaviside to Lodge, 23 June 1897, UCL.

45 J. C. Bose, *Phil. Mag.* (5), 43, 55, January 1897.

46 Kelvin to Lodge, 8 December 1896, UCL.

47 *The Electrician*, 37, 685, 25 September 1896

48 E. C. Baker, *Sir William Preece, FRS, Victorian Engineer Extraordinary* (Hutchinson, London, 1976), 268-9, quoting Jackson to Gavey, 1897.

49 ibid.

50 Righi to Lodge, 18 June 1897, UCL. For details of the debt that Righi's and Marconi's equipment owed to Lodge's apparatus see Pocock, ref. 8, 99-100.

51 *La Tribuna, Rome*, July 1897 contained the following interview quoted by W. P. Jolly, *Marconi* (Constable, London, 1972), 16-17: "'Did you study physics at Bologna under Professor Righi?' 'I studied under the renowned Professor Vincenzo Rosa at the Livorno Lyceum and would be most happy that it is known that he was my only physics master.'"

52 Kelvin to Lodge, 22 June 1897, UCL.

53 S. P. Thompson to Lodge, 11 April 1897, UCL.

54 Lodge to S. P. Thompson, 1 June 1897, UCL.

55 W. H. Preece, Friday evening discourse to the Royal Institution, 4th June 1897, quoted Baker (1976), ref. 48, 269.

56 S. P. Thompson to Lodge, 4 December 1897, UCL.

57 'Signalling through space without wires', *Nature*, 56, 163-4, 17 June 1897

58 See Lodge to Kelvin, 25 September 1897, University of Cambridge Library: "The Editor of Nature in reply to Prof Lodge's inquiry writes today that in his opinion the letter on 'Hertz waves and metallic enclosures' is more suitable for a specially electrical paper. It is therefore returned herewith." Lodge, *Phil. Mag.* (5), 44, 444, November 1897.

59 FitzGerald to Lodge, 1 November, 1897; Muirhead to Lodge, 1 November 1897; Rayleigh to Lodge, 27 September 1897; Kelvin to Lodge, 10 November 1897. UCL.

60 Aitken (1976), ref. 9, 80-175

61 Lodge, *Advancing Science* (1933), 164-165

62 *Nature*, 50, 182

63 Aitken (1976), ref. 60, 120

64 S. P. Thompson, 'The inventor of wireless telegraphy', *The Saturday Review*, 5 April 1902, 424.

65 Lodge, *Past Years* (1931), 232-3

66 Lodge, *Past Years* (1931), 232

67 FitzGerald to Lodge, 27 June 1897, UCL.

68 FitzGerald to Lodge, 21 June 1897, UCL.
69 Lodge, *Talks about wireless* (Cassel and Co, 1925), 38-39
70 Lodge to Hill, 11 December 1914, J. Arthur Hill (ed.), *Letters from Sir Oliver Lodge* (Cassel and Co), 48
71 *Nature*, 14 November 1913, 323
72 *The Electrician*, 17 August 1894, 458
73 ibid.
74 Preece to Lodge, 15 October 1896, UCL.
75 Heaviside to Lodge, 23 June 1897, UCL.
76 Pocock (1988), ref. 8, 115-7
77 *BA Report*, 1887, quoted Nahin (1988), ref. 27, 77
78 Baker (1976), ref. 48, 270
79 *The Electrician*, 39, 686, 17 September 1897
80 Lodge, *The Electrician*, 12 November 1897, 87-91, 91
81 *The Times*, 12 October 1906
82 S. P. Thompson, 'The inventor of wireless telegraphy', *The Saturday Review*, 93, 425, 5 April 1902
83 G. Marconi, 'The inventor of wireless telegraphy: a reply', *The Saturday Review*, 93, 555
84 S. P. Thompson, 'Wireless telegraphy: a rejoinder', *The Saturday Review*, 93, 598, 10 May 1902
85 ibid.
86 S. P. Thompson, The inventor of wireless telegraphy', *The Saturday Review*, 93, 697, 31 May 1902
87 *The Times*, 9 October and 22 October 1906
88 *The Times*, 12 and 23 October; 12 October; 16 October; 17 October 1906.
89 *The Times*, 29 October 1906
90 *The Electrician*, 45, 773, 14 September 1900, 773
91 Lodge, *Past Years* (1931), 338
92 *The Harvest of a Quiet Eye*, Alan L Mackay (IOP)

Notes to Chapter Eleven

1 S. P. Thompson, *J. Soc. Arts*, 25 November 1887, 20-49.
2 R. H. Golde, *Lightning Protection*, (Arnold, London, 1973).
3 Lodge, *Lightning Conductors and Lightning Guards*, (Whittaker and Co., London, 1892).
4 Lodge, *Past Years – An Autobiography*, (Holder and Stoughton, London, 1931).
5 Lodge, *Nature*, 41, 368, 1890.
6 Lodge, *Nature*, 50, 133-139, 1894.
7 J. J. Fahie, *A History of Wireless Telegraphy* (Blackwood, Edinburgh, 1899)
8 For a more detailed description of the invention of the coherer seeLodge, *Signalling Through Space Without Wires – The Work of Hertz and his Successors*, third edition (The Electrician, London, 1902) and V. J. Phillips, *Early Radio Wave Detectors* (Peregrinus, London, 1980).
9 P. Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool Uuniverity Press, 1990)
10 10 May 1897, 11, 575

11 Lodge and Muirhead, 10 July, 16, 405; 11 August, 18,644; 8 December, 29, 069; Lodge alone, 13 December, 29, 505.
12 H. G. J. Aitken, *Syntony and Spark – The Origins of Radio* (Wiley, New York, 1976).
13 Cyril Franklin, Unpublished diary, Archives of Birmingham Museum of Science and Technology.
14 A. F. Collins, *Electrical World and Engineer*, 1 August 1903, 173-176.
15 O. J. Lodge and A. Muirhead, *Proc. Roy. Soc.*, 82, 227-256, 1908-9.
16 Patent 14 June 1902, 13, 521
17 Birmingham Museum of Science & Industry has a device labelled "Lodge Electrolytic Detector 1911".
18 W. P. Jolly, *Sir Oliver Lodge* (Constable, London, 1974).
19 *Popular Wireless*, 29 May and 18 September 1926.
20 27 April 1898, 9712
21 US Patent 149,797, 20 January 1874. British Patent, 4685, 10 December 1877; German Patent 2355, 14 December 1877.
22 C. W. Rice and E. W. Kellogg, *Trans. Am. Inst. Elec. Engrs.*, 44, 461-80, April 1925.
23 29 January 1903, 2162
24 Eric Keown, *The Story of Lodge* (Browne, London, 1954).
25 Archives of Lodge Plugs.
26 Personal Communication, Lodge Ceramics.
27 O. J. Lodge and J. W. Clark, *Proc. Roy. Soc.*, 26, 214-39, 1884.
28 *Engineering*, 5 June 1885, 627-628.
29 9 August 1884, 11,120
30 See ref. 13.
31 British Patent 24,305, 1903
32 2 December 1905, 25, 047 and 25,047A.
33 Archives of Lodge-Cottrell.
34 Personal Communication, Lodge Sturtevant.
35 Sir Oliver Lodge, Fifth Kelvin Lecture, *JIEE*, 52, 22-352, 1914.

Notes to Chapter Twelve

This chapter is based on a contribution to *The Radioscientist* and has drawn heavily on the following sources:

1 Peter Rowlands, *Oliver Lodge and the Liverpool Physical Society* (Liverpool University Press, 1990)
2 Hugh G. J. Aitken, *Syntony and Spark – The Origins of Radio* (Wiley, New York, 1976)
3 Paul J. Nahin, *Oliver Heaviside, Sage in Solitude* (IEEE Press, New York, 1988)
4 Oliver Lodge, *Modern Views of Electricity*, third edition (London, 1907, first edition 1889)

INDEX

Notes on Contributors

Peter Andrews, Reader in Physics, University of Liverpool.

Brian Austin, Senior Lecturer in Electrical Engineering and Electronics, University of Liverpool.

David Edwards, Honorary Senior Research Fellow in Physics, University of Liverpool, and organiser, with Peter Rowlands, of the Liverpool MSc course in the History of Science and Technology.

Nicholas Godlee, grandson of Sir Oliver Lodge, Consultant Clinical Oncologist, University College Hospital, London.

David King, recent MSc for work on the Liverpool Cyclotron and currently researching the medical applications.

Oliver R. W. W. Lodge, grandson of Sir Oliver Lodge, a Bencher of Lincoln's Inn and formerly Regional Chairman of Industrial Tribunals.

Peter Rowlands, Research Fellow in Physics, University of Liverpool, and author of *Oliver Lodge and the Liverpool Physical Society*.

David Sealey, recent MSc for work on the British Association, and currently researching the career of Oliver Heaviside for a PhD at the University of Lancaster.

J. Patrick Wilson, Lecturer in Electronics and Honorary Senior Research Fellow in Communication and Neuroscience, Keele University.

OLIVER LODGE AND THE INVENTION OF RADIO

On 14 August 1894, at the British Association meeting at Oxford, Oliver Lodge, Professor of Physics at University College, Liverpool, gave the first public demonstration of the transmission of information by radio using Morse code. Though this fact is no longer seriously in dispute, its exact significance in the history of radio technology is yet to be established. Taking a fresh look at the evidence, the authors of this book aim to show that the Oxford demonstration was not an isolated event, but, at once, both the culmination of a twenty-year research programme beginning with the most important physical theory of the nineteenth century, and the starting-point for a world-wide development of radio technology which has continued to this day.

The authors, a team of scientists, engineers and historians from the Universities of Liverpool, Keele and Lancaster, together with members of the family who had personal knowledge of Lodge himself, have used previously unpublished manuscript sources to develop a series of new perspectives on Lodge as man, as scientist, as technologist and as polymath of the late Victorian period. Many illustrations, also, are included, some of which are published here for the first time. Lodge's work is put into the context of the overall development of radio technology during his lifetime, and the personal and commercial considerations which caused him to be excluded from the popular version of the invention of this technology are examined in detail. The interaction of scientific, technological and social factors provides a fascinating story.

ISBN 1-873694-02-4

9 781873 694022

PD PUBLICATIONS