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I. MAGNETISM AND ELECTRICITY: QUESTIONS AND ANSWERS.

By W. S. Procter, A.M.I.E.E.

The maximum number of marks obtainable was the same for each question.

Q. 1. Explain what is meant by the terms "declination," "dip," and "magnetic meridian." You are given a coil of wire suspended vertically and connected to a sensitive galvanometer. Explain how you would use this apparatus to determine the direction of the magnetic meridian.

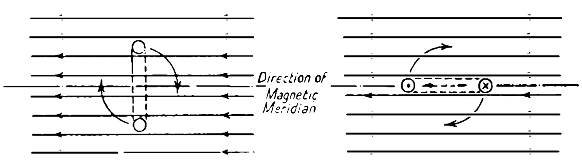
A. 1. When a freely suspended magnetic needle is placed in the earth's field, the needle takes up a position so that its magnetic axis lies along the lines of force of the field.

Magnetic meridian. The vertical plane containing the magnetic axis of the needle is termed the "magnetic meridian."

Declination. Since the magnetic and geographical N. poles do not coincide, there is an angle between the magnetic and geographical meridians which varies from place to place. This angle is called the variation or "declination" and the value at Greenwich at the present time is approximately 15° 6′ W.

Dip. The angle between the horizontal plane and the magnetic axis of the freely suspended needle is termed the inclination or angle of "dip." The present day angle of dip at Greenwich is approximately 66° 50′.

To determine the direction of the magnetic meridian with the apparatus given, use must be made of the principle discovered by Faraday, that if a conductor is made to cut magnetic lines of force an E.M.F. is generated in it. The value of the E.M.F. depends directly upon the number of lines cut per second. Thus, if the coil and galvanometer are joined in a simple series circuit and the coil is rotated at a uniform speed about its vertical axis, the reading of the galvanometer will be a measure of the E.M.F. generated at any time. When the plane of the coil is at right angles to the magnetic meridian, as in sketch (*a*), the conductors of the coil are moving parallel to the direction of the earth's field and, as no lines are being



(*a*) (*b*)

cut, no E.M.F. is generated. When the plane of the coil is in the magnetic meridian, as in sketch (*b*), the conductors are cutting the earth's field at right angles and a maximum E.M.F. is generated. By this means it is possible to locate the direction of the magnetic meridian if the position of the coil corresponding to a maximum deflection of the galvanometer is noted. In the execution of the experiment the following points are of importance:—

(*a*) The coil must be rotated at a uniform speed.
(*b*) The speed of the coil should be sufficiently high to obtain an appreciable reading on the galvanometer, but must allow the moving system of the instrument to attain the position corresponding to the E.M.F. generated.
(*c*) The coil should have as large a diameter as possible in order that the number of lines cut per second is a maximum.
(*d*) The coil should contain as many turns as possible so that the E.M.F. generated is high.

Q. 2. Explain what is meant by the "heating effect of a current." What is its relationship to the current and the resistance in a circuit? Why are electric lamps rated in watts? What is the resistance of a 100-watt lamp used on a 240-volt circuit?

A. 2. When an electric current flows through any conductor heat is generated and usually the temperature of the conductor rises. This is referred to as the "heating effect of a current" and is utilized in the working of electric fires, hot-wire ammeters, electric welding, incandescent lighting, etc. Heat is a form of energy and, from the principle of conservation of energy, the heat energy generated must be equivalent to the electrical energy expended in the conductor. The unit of electrical energy is the "joule" and from its definition:—

Electrical energy expended = $EIt = I^2Rt$ joules, where I = amperes, R = ohms, and t = seconds.

It follows, therefore, that the heat energy generated = I^2Rt joules.

Thus:—
(*a*) The heat generated varies directly as the square of the current.
(*b*) The heat generated varies directly as the resistance of the circuit.
(*c*) The heat generated varies directly as the time for which the current flows.

It is often more convenient to calculate the heat generated in calories.

Therefore, since 1 joule = 0.24 calories,
Heat in calories = $0.24\ I^2Rt$.

When a consumer wishes to buy an electric lamp, he is mainly interested in the amount of light that the lamp will give. With lamps of the same efficiency the amount of light energy emitted is proportional to the amount of electrical energy consumed. Hence, lamps are rated in watts to indicate their power consumption; power being the energy consumed in unit time. A 100-watt lamp, for instance, consumes 100 watt-hours in one hour and with an efficiency of, say, 0.5 watt per candle power the light is 200 c.p.

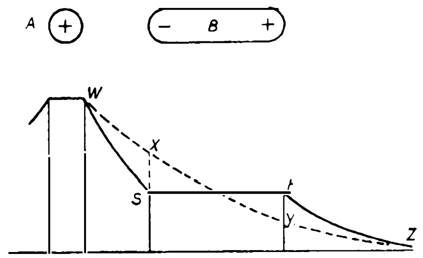
Power in watts (P) $= E \times I = \frac{E^2}{R}$ where E = volts and R = ohms.

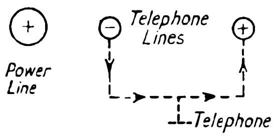
Therefore $R = \frac{E^2}{P} = \frac{240^2}{100}$ ohms for the 100-watt, 240-volt lamp = 576 ohms.

This is the " hot " resistance and is appreciably higher than the resistance when cold.

Q. 3. Explain what is meant by " electrostatic induction." A high tension power transmission line is in close proximity to an overhead telephone line. Distinguish between the effects produced in the telephone line when the power line is carrying (a) direct current, (b) alternating current.

A. 3. If an insulated metal ball A is charged to a high positive potential the electrostatic field surrounding the ball falls from a high intensity near the ball to a negligible value at a considerable distance away. This decrement of potential is shown by the curve *wxyz* in the sketch. If, now, a long insulated conductor B is placed in close proximity to A, the left hand end (as shown) of B is in a region of higher potential than the right hand end; the corresponding points on the potential curve being *x* and *y*. Since, however, B is a conductor, the two ends cannot be at different potentials and current flows from left to right until the potential is the same at both ends. The left end of B has now a negative potential as compared with the space immediately surrounding it. Similarly, the right end of B has an apparent positive charge compared with the field strength at that end.





This effect is known as " electrostatic induction " and is a common cause of interference with telephone lines.

When a high pressure power line runs near and parallel to a telephone line, one of the telephone lines is nearer to the power line than the other and a similar effect to that described above occurs. In this case, however, the near wire is connected to the more distant wire by the terminating telephone receivers. The equalizing current thus flows through the receivers and interferes with speech.

When the power line carries direct current, the equalizing currents will flow only when the power is switched on or off, or when the potential of the line changes due to varying load. These changes will cause clicks in the telephone receiver. When the power line carries alternating current, the potential of the line is constantly changing both in magnitude and direction. The potential equalizing currents will therefore alternate between the near and distant lines at the same frequency as the power supply. A hum will thus be produced in the telephone receiver.

Q. 4. Three similar insulated spheres are placed at the corners A, B, C, of a triangle. AB = 3 cms., AC = 4 cms., BC = 5 cms. The balls each have an electric charge, A of 5 positive units, B of 4 negative units, and C of 3 positive units. Show in a sketch the lines of electric force due to the electric charges. What is the magnitude and direction of the total force exerted on the ball at A?

A. 4. Sketch (*a*) shows the arrangement of the lines of force near the three spheres. " *x* " is a neutral point where no force would be exerted on an electric charge placed in this position.

The sphere A is subject to a repulsive force from C and a force of attraction from B. The force between any two charges is given by the formula :—

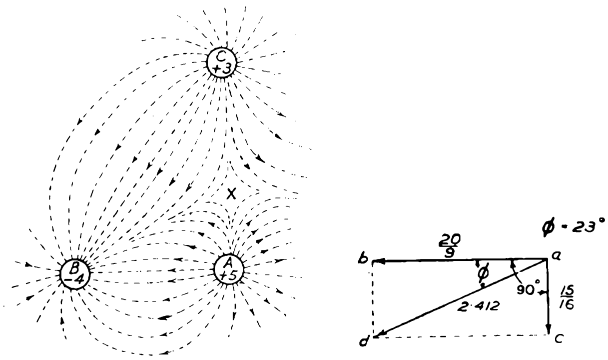
$$\text{Force} = \frac{Q_1 \times Q_2}{d^2} \text{ dynes, where}$$

Q_1 and Q_2 are the charges in electrostatic units, and d is the distance in cms. between the charges.

$$\therefore \text{ Force between A and C} = \frac{5 \times 3}{4^2} = \frac{15}{16} \text{ dynes.}$$

$$\text{Force between A and B} = \frac{5 \times 4}{3^2} = \frac{20}{9} \text{ dynes.}$$

Since $(BC)^2 = (AB)^2 + (AC)^2$, the figure ABC is a right angle triangle with the right angle at A. Thus, the two forces AC and AB act at right angles and their resultant can be found by application of the parallelogram of forces as in sketch (*b*).



(*a*) (*b*)

$$\text{The resultant } (ad)^2 = (ab)^2 + (ac)^2 = \left(\frac{20}{9}\right)^2 + \left(\frac{15}{16}\right)^2 = 5.818$$

$$\text{and} \quad ad = \sqrt{5.818} = 2.412 \text{ dynes.}$$

Let ϕ be the angle between the resultant force and the force ab. Then :—

$$\text{Tangent } \phi = \frac{bd}{ab} = \frac{15}{16} \div \frac{20}{9} = \frac{27}{64} = 0.4219.$$

$$\text{and} \quad \phi = 22^\circ\, 52' = 23^\circ \text{ approx.}$$

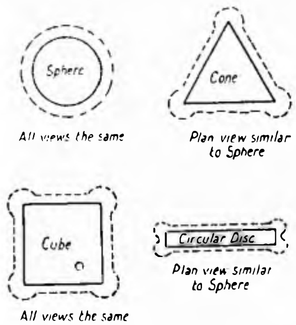
The resultant force on A is 2.412 dynes in magnitude and acts at an angle of 23° (approx.) with the line AB.

Q. 5. How does the shape of a charged body affect the distribution of the charge on its surface? Illustrate your answer by showing the distribution of the charge on the following isolated conductors: a sphere, a cone, a cube, and a circular disc. Explain the action of a sharp point on a highly charged conductor.

A. 5. A charge of electricity does not usually distribute evenly over the surface of a conductor, except where the curvature of the surface is regular as, for example, a sphere. Where there are edges or sharp corners on a body, the charge is more dense at the corners and edges than on the flatter parts. The sketches show the distribution of a charge on a sphere, a cone, a cube, and a circular disc.

The reason for the uneven density of charge may be seen from the following reasoning :—

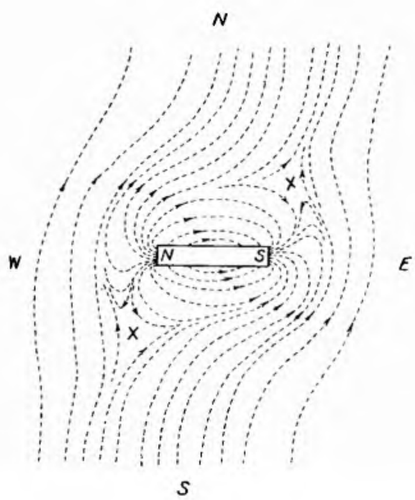
Consider two spherical conductors A and B of radii 10 cms. and 1 cm. respectively. Let the two spheres be in contact and impart to the combination a charge of, say, 110 μC. This charge will divide between the two spheres in the ratio of their capacities. The capacity of a sphere is, however, proportional to its radius. Therefore, the charges on A and B will be 100 μC and 10 μC respectively. The density of the charge on the surface of a sphere is the total charge divided by the surface area ($i.e.$, $4\pi r^2$). Thus, the density of charge on sphere A is $\frac{100}{4\pi \times 10^2}$ and on sphere B is $\frac{10}{4\pi \times 1^2}$ μC/sq. cm., *i.e.*, the density on the smaller sphere is 10 times that on the larger. If sphere B is replaced by one of smaller diameter, the ratio of the charge densities will be still higher and the arrangement then approximates to a single sphere having a sharp corner at one point.



If a conductor having a sharp point is charged to a high potential, the density of the charge at the point becomes so great that electricity is discharged from the point. The air becomes charged by contact with the point and is then forcibly repelled. By this means a continual stream of charge-carrying air particles is driven from the point and, unless the charge on the conductor is renewed, it rapidly becomes discharged. The air current can be so strong that the flame of a lighted taper held near the point is visibly blown aside.

Q. 6. *Show by means of a diagram the magnetic lines of force due to the earth and a bar magnet when the magnet is placed horizontal with its north pole pointing west. Indicate on this diagram points where a compass needle would come to rest in any position.*

A. 6. The sketch shows the magnetic field required. The points marked " x " are neutral positions where the fields due



to the earth and the bar magnet are opposite in direction and equal in magnitude. A compass needle placed in one of these positions is not subject to a magnetic force and will therefore come to rest in any direction.

Q. 7. *Indicate clearly by means of sketches the magnetic circuit of a simple electric trembling bell. Using this sketch as a basis, explain the terms and show the connexion between magnetomotive force, reluctance, and magnetic flux.*

A. 7. In an electric trembler bell the magnetic forces, which cause the hammer to hit the gong, are first originated in the windings of the two coils A and B. When a current is passed through these coils (or solenoids) the magnetic lines of each turn combine with those of all other turns to produce a field as shown in sketch (*a*). This field is identical to that which would be produced if two bar magnets replaced the coils. In the design of the bell it is necessary to know the power of these coils to magnetize the iron cores that will be inserted in them. This power depends upon :—

(*a*) The strength of the current.

(*b*) The number of turns on the coil.

The power to magnetize, or " magnetomotive force " as it is called, is measured by the work necessary to move a unit pole once round the magnetic circuit against the magnetizing force.

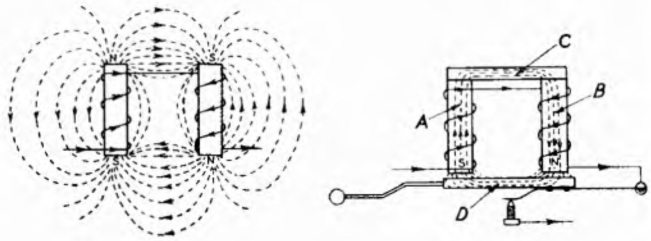
In order to obtain as great a pull as possible on the armature, the magnetic circuit should be arranged so that there is an easy path for the lines of force. The magnetic resistance of the path is termed the " reluctance," and depends upon :—

(*a*) The length of the path.

(*b*) The cross-sectional area of the path.

(*c*) The conducting power or permeability of the path.

The magnetic circuit of the trembler bell is shown in sketch (*b*) and comprises the two cores A and B, the yoke C, the armature D, and the two air gaps between the cores and the armature. The reluctance of all the iron parts of the circuit is very small compared with the reluctance of the air gaps owing to the very high permeability of iron as compared with air.



(*a*) (*b*)

With the magnetomotive force of the coils and the reluctance of the magnetic circuit fixed by design, the number of lines of force in the air gaps can be calculated. The total number of lines of force at any point in the circuit is referred to as the " flux " at that point. The flux depends directly upon the magnetomotive force and inversely upon the reluctance, *i.e.*,

$$\text{Flux} = \frac{\text{Magnetomotive force}}{\text{Reluctance}} \quad \text{where}$$

$$\text{Magnetomotive Force} = \frac{4\pi}{10} \times \text{No. of Turns} \times \text{Current in Amperes.}$$

$$\text{Reluctance} = \frac{\text{Length of magnetic circuit (cms.)}}{\text{Cross-sectional area of circuit (sq. cms.)} \times \text{permeability}}$$

The pull on the armature depends upon the square of the flux density in the air gaps and the area of the core faces, *i.e.*,

$$\text{Pull (dynes)} = \frac{(\text{flux density})^2 \times \text{Area (sq. cms.)}}{8\pi}$$

Q. 8. *Two condensers of $2\frac{1}{2}$ and $3\frac{1}{2}$ microfarads respectively are connected in series. What is their joint capacity? If the two condensers in series are connected to the terminals of a 60-volt battery with the positive terminal joined to earth, what will be the charge on each condenser and the potential of each of the terminals? Show in a diagram the potentials across the condensers.*

A. 8. If C is the joint capacity of the two condensers in series and C_1 and C_2 are their individual capacities, then

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{2}{5} + \frac{2}{7} = \frac{14+10}{35} = \frac{24}{35}$$

$$\therefore \quad C = \frac{35}{24} = 1\frac{11}{24} \text{ microfarads.}$$

When the two condensers in series are connected to a 60-volt battery, the charge on the combination in micro-coulombs (Q) is given by :—

$Q = C \times V$ where, C = joint capacity in microfarads,
and V = E.M.F. in volts.

$$\therefore \quad Q = \frac{35}{24} \times 60 = \frac{175}{2} = 87.5 \text{ micro-coulombs.}$$

The charge on each condenser must be the same and equal to 87.5 micro-coulombs, since the quantity of electricity added to plate A by the application of the battery must be the same as the quantity withdrawn from plate C.

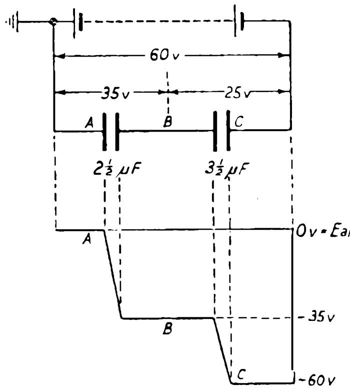
From the above relationship between Q,C, and V, the voltage across each condenser is :—

$$\text{Volts across } 2\tfrac{1}{2}\ \mu\text{F.} = \frac{Q}{C_1} = \frac{175}{2} \div \frac{5}{2} = 35 \text{ volts.}$$

$$\text{Volts across } 3\tfrac{1}{2}\ \mu\text{F.} = \frac{Q}{C_2} = \frac{175}{2} \div \frac{7}{2} = 25 \text{ volts.}$$

NOTE :—

The voltage across the $3\frac{1}{2}$ μF. condenser could have been found by subtracting 35v from 60v, but the above method gives a check on the calculations.



With the connexions as shown in the sketch and considering the earth potential as zero, the potentials of the points marked are: A = O, B = − 35 volts, and C = − 60 volts.

Q. 9. One mile of copper wire of No. 14 gauge (diameter 0.08″) has a resistance of 8.5 ohms. What is its specific resistance per inch cube? The resistance per mile of a bronze wire of the same gauge is 18.2 ohms. What is the specific resistance of the bronze?

A. 9. The specific resistance of any material is defined as the resistance of a cube of the material with side of unit length. Therefore, specific resistance $= \rho = \dfrac{A \times R \times 10^6}{L}$ microhms per inch cube. Where R ohms is the resistance of a material of length L inches and cross sectional area A square inches.

$$\text{Specific resistance of copper} = \frac{\pi(0.08)^2 \times 8.5 \times 10^6}{4 \times 1760 \times 36} = 0.6744$$

microhms per inch cube.

Since the physical dimensions of the bronze wire are identical to those of the copper wire, the values of L and A in the above formula are the same. Under these conditions the specific resistance is directly proportional to the resistance per mile.

$$i.e., \frac{\text{Specific resistance of bronze}}{\text{Specific resistance of copper} = 0.6744} = \frac{18.2}{8.5}$$

$$\therefore \text{ Specific resistance of bronze} = \frac{18.2 \times 0.6744}{8.5} = 1.444$$

microhms per inch cube.

Q. 10. Explain what is meant by the following terms :— Moment of a magnet; Polarization of a cell; Retentivity; Permeability; Self-induction.

A. 10.

Moment of a magnet. The moment of a magnet is the product of the pole strength and the distance between the poles. Thus, if the pole strength is "m" units, and the distance between the poles is "l" cms. the magnetic moment "M" is given by :—$M = m \times l$. The distance between the poles of a bar magnet is usually slightly less than the length of the magnet. The moment is a constant for a given magnet and is used in calculations to indicate the twisting force or torque that would be exerted on the magnet if it were under the influence of another magnetic field.

Polarization of a cell. When a current is drawn from a cell, the molecules of the electrolyte are split up by the action of the current. In a simple cell, for example, the dilute sulphuric acid (H_2SO_4) is split up into its component parts hydrogen (H_2) and sulphate ions (SO_4). The hydrogen ions, which carry a positive charge of electricity, are attracted towards the copper plate and the negatively charged SO_4 ions travel to the zinc. The SO_4 ions combine with the zinc, but the hydrogen is deposited on the copper. This deposition of hydrogen on the positive plate is termed " polarization " and has a twofold effect which weakens the current through the cell :

(*a*) The gas has a high resistance.

(*b*) An E.M.F. opposite to that of the cell is set up.

All modern primary cells contain devices for the elimination of polarization.

Retentivity. Retentivity is the term used to indicate the power of a body for retaining magnetism. Soft iron will scarcely retain magnetism at all and is therefore said to have a low retentivity whilst hard steel will retain magnetism almost indefinitely and hence is said to have a high retentivity. The retentivity of a magnet depends upon its shape, upon the temperature, and also upon the mechanical circumstances in which the magnet is placed.

Permeability. The permeability of a substance may be defined as its conducting power for magnetic lines as compared with air. If a magnetizing force (H) of, say, 5 lines per sq. cm. is applied to a bar of iron and the resulting flux density (B) is 5000 lines per sq. cm., then the permeability of the iron is $B \div H = 1000$. The permeability of a particular material is not constant, but varies with the magnetizing force and temperature.

Self-induction. Any current carrying conductor has a magnetic field surrounding it, the strength of which depends upon the value of the current. When the current varies, the magnetic lines move inwards or outwards from the conductor and may cut across other parts of the same conductor or circuit. Whenever magnetic lines cut across a conductor, an E.M.F. is generated in such a direction as to oppose the change which produces it. Thus, if the current in a coil increases, the magnetic lines extend outwards and cut across other parts of the same coil and so induce an E.M.F. which tends to oppose the growth of the current. This effect is known as " self-induction."

Q. 11. Illustrate the principle of electrolysis by describing in detail the action which takes place when a current of electricity is passed through

(a) a solution of copper sulphate,

(b) water with a little sulphuric acid added.

Explain the meaning of the terms anode, cathode, and electrolyte.

A. 11. *Definitions.* A number of liquids are decomposed when a current of electricity is passed through them. This process is termed " electrolysis," the liquid is called the " electrolyte," and the containing vessel is called the " voltameter." The metal plate by which the current enters the liquid is termed the " anode " and that by which it leaves is the " cathode."

(*a*) *Electrolysis of copper sulphate.* When a current is passed through a solution of copper sulphate ($CuSO_4$) the molecules of the liquid are split up into two parts, copper (Cu) and a sulphate ion (SO_4). From the ionic theory these two parts (or ions as they are called) have equal charges of positive and negative electricity, respectively, which neutralized each other before the molecules were split up. The copper ion is attracted to the negative potential cathode and is deposited there as a metallic film. The sulphion, being negatively charged, is attracted to the anode where it is acted upon by the water in the solution to form sulphuric acid and oxygen. The chemical changes are thus expressed :—

$$CuSO_4 = Cu + SO_4$$
$$SO_4 + H_2O = H_2SO_4 + O$$

In this way, copper is continually withdrawn from the liquid and deposited on the cathode, oxygen is liberated at the anode, and the liquid becomes more and more acid.

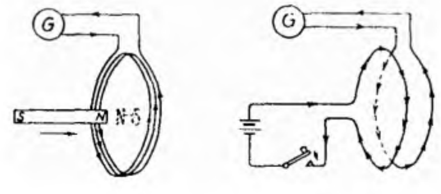
In the above actions, it was assumed that the electrodes were of such a material (*e.g.*, platinum) that the anode was not attacked by the sulphion SO_4. If copper is used, the SO_4 combines with the copper to form copper sulphate ($CuSO_4$) and the anode is dissolved into the liquid at the same rate as the copper of the liquid is deposited on the cathode.

(*b*) *Electrolysis of water.* It is assumed that the quantity of sulphuric acid added is very small compared to the volume of water and is added only to reduce the resistance of the water. The water (H_2O) is split up by the current into its two components hydrogen and oxygen. The former is positively charged and therefore moves to the cathode whilst the latter being negatively charged moves to the anode. If the electrodes are of platinum so that oxidization does not occur, it is found that the volume of hydrogen liberated is twice that of the oxygen.

Q. 12. *How would you demonstrate the effects of electromagnetic induction using a coil of wire connected to a sensitive galvanometer, and (a) a bar magnet, (b) a second coil of wire connected to a battery? State the general principle which applies to the results of such experiments.*

A. 12. The following experiments may be made with the apparatus given to show the principles of electromagnetic induction :—

1. Move the N pole of the bar magnet quickly into the centre of the coil. A deflection of the galvanometer will occur only during the movement of the magnet, thus showing that an E.M.F. is generated in the coil while lines of force are cutting the conductors of the coil.
2. Move the magnet at various speeds and it will be found that the greatest deflection of the galvanometer occurs when the magnet is moved at the greatest speed. Thus the E.M.F. generated depends upon the rate at which lines of force cut the conductors of the coil.
3. Repeat experiment No. 1, and notice the direction of the galvanometer deflection. It will be found that the direction of the current induced into the coil is such as to produce a N pole on the side of the coil where the N pole of the magnet was inserted. If the S pole of the magnet is used instead of the N, it will be found that the direction of the induced current will be such as to produce a S pole on the side of the coil where the magnet was inserted. Since like poles repel, the magnet must have been moved against the force set up by the induced currents in the coil; *i.e.*, the induced current is in such a direction that it tends to oppose the motion which produces it. (See sketch (*a*)).



(*a*) (*b*)

4. Place the two coils of wire close together with their planes parallel. Connect up the battery to the second coil and a deflection of the galvanometer will occur at the moment of switching on. This verifies experiment No. 1, since an E.M.F. is generated only when the magnetic field is building up round the second coil and in so doing cuts across the conductors of the first coil.
5. By noting the direction of the induced current at the moment of switching on, it will be seen that the induced current is opposite to the direction of the current in the battery-connected coil (sketch (*b*)). The magnetic field produced by the induced current is therefore such that when it cuts across the conductors of the second coil an E.M.F. is generated which tends to oppose the current from the battery. A converse condition will be found to exist when the current is switched off from the second coil. Thus, the direction of the induced current is such that it tends to oppose the change which produces it.

The results of these experiments may be summarized as follows :—

1. An electromotive force is induced in a conductor whenever magnetic lines of force cut the conductor.
2. The magnitude of the E.M.F. induced depends upon the rate at which lines cut the conductor.
3. The direction of the induced current (and E.M.F.) is such that it tends to oppose the motion or change which produces it. This is known as Lenz's Law.

II. TELEPHONY, INTERMEDIATE : QUESTIONS AND ANSWERS.

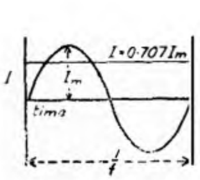
By W. S. PROCTER, A.M.I.E.E.

Q. 1. *What is meant by the effective value of an alternating current? Illustrate, by means of a sketch, the relation between instantaneous and effective values over a complete cycle.*

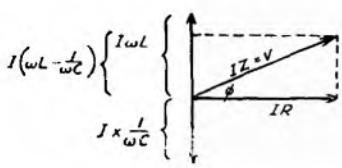
Show how the individual voltages across a resistance of R ohms, an inductance of L henrys, and a capacitance of C farads, respectively, in series, when a sinusoidal current of I amperes at a frequency of f cycles per second is passing, may be represented by vectors, and how the applied voltage and current may be similarly represented. (30 *marks*).

A. 1. The effective value of an alternating current is given by that value of direct current which, when applied to a given circuit for a given time, produces the same expenditure of energy as when the alternating current is applied to the same circuit for the same time.

Sketch (*a*) shows the relation between instantaneous and



(*a*)



(*b*)

effective values over a complete cycle for a sinusoidal wave. The instantaneous power, p, in an alternating current circuit is given by $p = vi$. Let $v = V_m \sin \omega t$, and $i = I_m \sin \omega t$, *i.e.*, the voltage and current waves are in phase. Then—

$$p = V_m I_m \sin^2 \omega t$$

$$= V_m I_m \times \tfrac{1}{2}(1 - \cos 2\omega t)$$

$$= \frac{V_m I_m}{2} - V_m I_m \cos 2\omega t \ldots\ldots\ldots\ldots\ldots (1)$$

The mean value of the power, P, over a complete period is the mean value of (1) over the period ; the mean value of the second term over any whole number of periods is zero. Hence—

$$P = VI = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}$$

$$\therefore\ V = V_m/\sqrt{2} = 0.707\ V_m \text{ and } I = I_m/\sqrt{2} = 0.707\ I_m$$

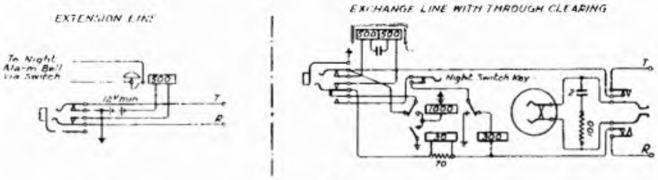
The effective value of an alternating current is therefore 0.707 of the maximum value for a sinusoidal wave.

The sketch (*b*) shows how the individual voltages across a resistance of R ohms, an inductance of L henrys, and a capacitance of C farads, respectively, when a sinusoidal current of I amperes at a frequency of f cycles per second is passing, may be represented by vectors. The voltage across the resistance is represented in magnitude and sense by the vector IR ;

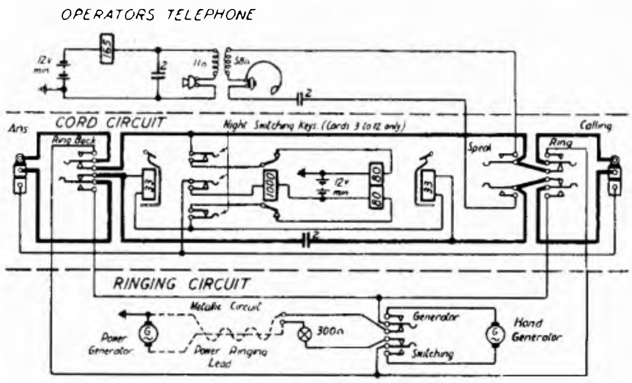
the voltage across the inductance is represented by the line $I\omega L$ which, due to the effect of the inductive reactance, is lagging 90° behind the vector IR; the voltage across the capacitance is equal to $I/\omega C$, and leads the vector IR by 90° due to the effect of the capacitive reactance. The resultant of these three vectors is the applied voltage $IZ = V$, where $Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$. The current is out of phase with the applied voltage by an angle ϕ given by $\phi = \tan^{-1} \dfrac{\omega L - \frac{1}{\omega C}}{R}$. If the value of this expression is positive, the current lags behind the applied voltage; if the expression is negative, then the current is leading the applied voltage.

Q. 2. Give diagrams showing the line and cord circuits at a private branch exchange switchboard of the central battery double cord type. Explain why it may be necessary to provide auxiliary apparatus in particular extension lines, and show how the additional apparatus would be connected. (30).

A. 2. The required diagrams are shown in sketches (*a*) and (*b*) respectively.

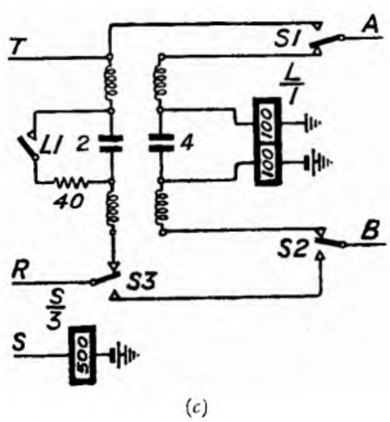


(*a*)



(*b*)

Auxiliary apparatus has to be fitted in an extension line when the loop resistance of that line is such that the current flowing would be insufficient to operate the supervisory signal in the cord circuit; this resistance varies from 50Ω to 150Ω, depending upon the type of clearing indicator. It is possible, however, that the loop resistance on an exchange to extension call is still within the limit dictated by transmission considerations. In this event, which is the more general case, the auxiliary equipment shown in sketch (*c*) is connected in the extension line at the P.B.X. and an ordinary C.B. telephone is fitted at the extension point. The circuit is arranged so that the equipment may be cut out of circuit when the extension line is extended to an exchange line, so that the extension point may be fed with transmitter current from the exchange, instead of from the auxiliary equipment.

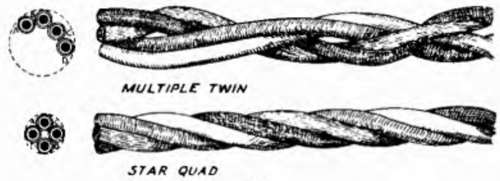


(*c*)

For very long lines, a local battery telephone is fitted at the extension point and, in these conditions, a simpler form of equipment is used in which the facility of cutting out the equipment on extension to exchange calls is not provided.

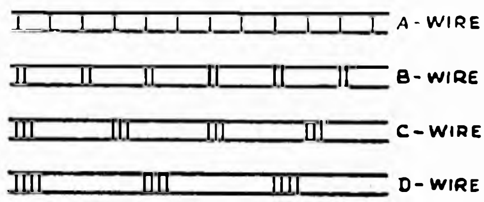
Q. 3. Describe, with the aid of sketches, the "Star quad" type of paper core cable. What advantages has this type of cable over the multiple twin type? (30).

A. 3. Sketch (*a*) shows the formation of a star quad and a multiple twin quad, and indicates the relative space taken by



(*a*)

the two types. The star quad consists of four wires revolving around a common axis, whilst the multiple twin quad consists of two twisted pairs twisted together. The A, B, C, and D wires of a star quad are marked by groups of 1, 2, 3, and 4 ink lines on the insulating paper at intervals, as shown in sketch (*b*). The groups of lines are so spaced that the number



(*b*)

of lines in, say, one yard length of paper, is the same for each of the four wires; by this means, it is ensured that the dielectric formed by the insulating paper and its markings shall be uniform for either pair of wires.

In some cables, the conductors are spirally wound with cellulose yarn or paper string, over which the insulating paper is applied. This ensures more uniform and constant capacity characteristics.

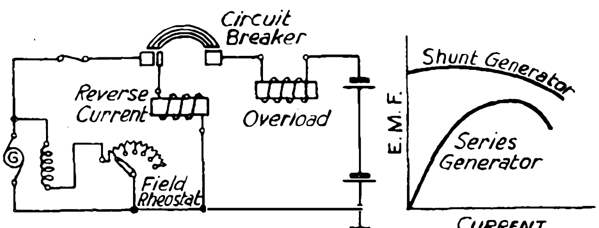
The quads are made up in layers, and the lay of adjacent quads in the same layer differs, the lay being chosen so as to ensure that cross-talk is as small as possible. The quads are stranded in layers, the direction of stranding alternating in successive layers. The outer layer is enclosed in a helical wrapping of white insulating paper; where the sheath contains antimony, however, the paper is coloured red instead of white. The cable is enclosed in a sheath of lead, or, alternatively, of lead-antimony alloy containing not less than 0.8 per cent. and not more than 1.0 per cent. of antimony.

Due to the closer arrangement of the wires in a star quad cable, about 40 per cent. more wires of the same gauge can be accommodated in a sheath of given diameter than is possible with multiple twin formation. For the same reason, however, the capacity of a star quad is higher, being about .066 μF per mile compared with .0625 μF per mile for multiple twin. The phantom/side capacity ratio for a star quad cable is 2.6 : 1 compared with a ratio of 1.6 : 1 for multiple twin. Thus, loading side and phantom of a star quad for equal attenuation results in a low cut off point on the phantom channel, whilst loading for equal cut off results in a high attenuation for the phantom channel. For these reasons, the phantoms of star quads are not used for telephone purposes, although they are available for signalling or by-product circuits.

The absence of a phantom telephone channel permits the phantom/side capacity unbalance being left at a higher figure than is permissible for a multiple twin cable, with the result that star quad trunk cables may be balanced simply by systematic jointing in place of test selection. Further, the absence of telephone phantom channels is compensated by the increased number of pairs obtained in a cable of given diameter. The termination of the cable, in turn, is simplified due to the absence of transformers, except, of course, where required for by-product circuits.

Q. 4. Why are shunt-wound generators used for charging secondary cells? Sketch the connexions of the electromagnetic switch or circuit breaker which is provided in the charging circuit, and explain how it operates. How is the voltage of the generator regulated? (30).

A. 4. In a series-wound generator, the current which flows through the armature also flows through the field winding. Thus, as the current increases, the terminal E.M.F. also increases due to an approximately linear law; with a further increase in current, the terminal E.M.F. reaches a maximum value when the field becomes saturated; an increase of current beyond this point causes the terminal E.M.F. to decrease due to the increasing ohmic drop in the machine. This is shown in sketch (*b*), which shows the general form of the external characteristics of series and shunt generators.



(a) (b)

If such a generator were to be used for charging secondary cells, there would be a difficulty in running the machine up to the voltage required. Further, the increase in the E.M.F. of the cells during charge would reduce the terminal E.M.F. of the generator down to the point where it would fail to excite.

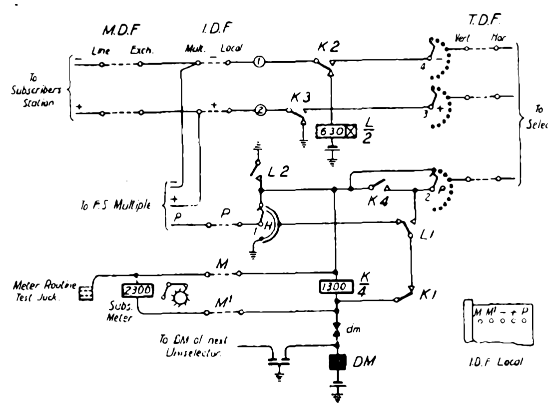
With a shunt-wound generator, an increase in the current reduces the terminal E.M.F. only slightly. Moreover, with the machine on open circuit, the field winding can be regarded as being in series with the armature; the generator will therefore build up its own field and will give full voltage on no load. When a shunt generator is used for charging secondary cells, the increase in the E.M.F. of the cells reduces the current flowing, but this causes an increase in the terminal E.M.F. of the generator which counteracts, in some degree, the reduction in the current.

The connexions of the circuit breaker provided in the charging circuit are shown in sketch (*a*). The breaker consists essentially of a switch having a powerful spring and retained in the closed position by a catch which may be withdrawn by the operation of either the " overload " or " reverse current " coils. The overload coil is set to operate at some current value slightly in excess of the maximum charging rate for the cells, whilst the polarized reverse current coil operates with a current reversal such as would occur with any failure of the generator. The overload coil protects the battery from an excessive current, and the reverse current coil prevents the battery from discharging through the generator.

The voltage of the generator may be regulated by including an adjustable resistance or rheostat in series with the field winding as shown in sketch (*a*). By this means, the current flowing through the field winding—and hence the flux set up across the armature—may be varied.

Q. 5. Sketch and describe the circuit arrangements of a subscriber's uniselector at an automatic exchange. Include in your sketch arrangements for guarding the switch during its homing movement. (35).

A. 5. The circuit arrangements of a subscriber's uniselector at an automatic exchange having positive battery metering are shown in the sketch. The circuit provides for guarding the switch during its homing movement.



When the subscriber removes the receiver, relay L operates and closes a circuit for the driving magnet through **L2**, P-wiper, and **L1**. The driving magnet operates, so causing the interrupter springs, *dm*, to break and disconnect the driving magnet circuit. The armature is restored and this movement steps the wipers on to the next bank contacts. Relay K is extended through K1 and **L1** to the P-wire of the first outlet; if this is engaged, earth will be connected to the P-wire. Relay K is therefore unable to operate, and the driving magnet circuit is closed through the P-wiper to the busy earth. The cycle of operations just described recurs, and the wipers step to the next bank contacts.

The P-wiper is of the bridging type and bridges two adjacent contacts when passing from one to the next. This is to prevent a momentary disconnexion at the P-wiper when it is passing from one busy outlet to another; otherwise, relay K, which is short-circuited by the busy earths, might operate and switch the line through to a busy outlet.

When the wipers are stepped to the bank contacts of a free outlet, the P-wire is found to be disconnected; relay K, previously short-circuited by the earth on each side, now operates to the earth at **L2**. The driving magnet remains normal, as the current flowing through it when in series with 1300 ohms is much below the operate value. The negative and positive wires are switched through at **K2** and **K3**, disconnecting relay L; the P-wire of the seized outlet is earthed at **K4**, so busying the outlet; and the driving magnet is disconnected at **K1**, since relay L will shortly be released. Relay L is slow-releasing and during the period of the release lag, the selector seized connects earth to the P-wire to replace that at **L2**. When relay L releases, L1 prepares the homing circuit for the uniselector on the termination of the call.

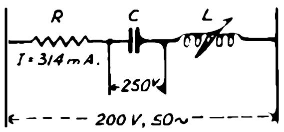
At a later stage, a positive battery is connected to the P-wre when the called subscriber answers, and the increased current flowing through the meter causes its operation; the positive battery is removed after a period of about 350 mS, and the meter remains operated from the current normally flowing in the circuit.

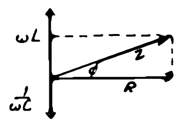
On the termination of the call, the calling subscriber replaces the receiver and the guarding and holding earth on the P-wire is removed, so releasing relay K; K1 closes a circuit for the driving magnet through the homing arc and wiper, and the wipers are stepped round until the first bank contact—the home position—is reached.

For an incoming call, it is necessary to disconnect relay L from the line to prevent premature tripping of the ringing current, as well as to clear the lines of bridged apparatus which would interfere with speech. Accordingly, when the line is seized by a final selector, relay K operates to the busy earth connected to the P-wire at the final selector bank; **K2** and **K3** disconnect relay L and earth, and extend the lines to the home bank contacts of the switch; as these contacts are left disconnected, no interference with the lines is caused by this. On release of the line, the earth on the incoming P-wire is removed, and relay K is released.

Q. 6. *A resistance, a condenser, and a variable inductance are connected in series across 200-volt alternating current mains, the frequency being 50 cycles per second. The maximum current which can be obtained by varying the inductance is 314 milliamperes, and the pressure across the condenser, which has negligible resistance, is then 250 volts. Calculate the capacity of the condenser, and the values of the inductance and the effective resistance in the circuit. (Take π = 3.14).* (35).

A. 6. The connexions of the resistance, condenser, and adjustable inductance are shown in the sketch. From the vector





diagram, it will be seen that the impedance, Z, is a minimum—and, hence, the current flowing is a maximum—when the inductive and capacitative reactances are equal in magnitude, that is, when $\omega L = 1/\omega C$. The maximum current is then given by $I = E/R$, whence $R = E/I$. In the case quoted, $R = 200/0.314 = 637$ ohms.

The p.d. across the condenser is given by $1/\omega C$ and this is given as 250 volts. Hence,

$$1/\omega C = 250$$

$$\omega C = 1/250$$

$$C = \frac{1}{250 \times \omega} = \frac{1}{2 \times 3.14 \times 50 \times 250}$$

$$= .000004 \text{ farad}$$

$$= 4\ \mu F.$$

From the formula,

$$\omega L = \frac{1}{\omega C}$$

$$L = \frac{1}{\omega^2 C} = \frac{1}{(2 \times 3.14 \times 50)^2 \times .000004}$$

$$= 2.5 \text{ henrys.}$$

Q. 7. *What are the principal features of the " Record and Demand " system of trunk working? Mention the operating facilities which are provided in connexion with the trunk position cord circuits.* (35).

A. 7. The principal features of the " Record and Demand " system of trunk working are :—

(i) A multiple of the record circuit answering equipment over the suite of positions to give calling subscribers greater access to trunk operators.

(ii) A multiple of the outgoing trunk circuits over the suite to give operators access to any outgoing trunk, as required.

(iii) Card index files on the positions to give operators information as to routes, alternative routes, and rates for any objective exchange.

(iv) Visual idle indicating lamps on each group of outgoing trunks to indicate (*a*) the first free trunk in the group, and (*b*) whether the group is temporarily subject to delay working.

(v) Chargeable time indicators to show, by an illuminated display, the duration of the call.

(vi) Sleeve control cord circuits.

The operating facilities provided by the sleeve control cord circuit are :—

(*a*) Speaking on either cord.
(*b*) Ringing on either cord.
(*c*) Dialling and keysending on either cord.
(*d*) Transfer of an incoming call to another position from either cord.
(*e*) Re-ringing on either cord.
(*f*) High impedance monitoring.

Q. 8. *Give a short account of a theory regarding the chemical reactions which occur in a secondary cell during a cycle of charge and discharge. Show, by means of a sketch, what would be the general shape of a curve representing the variations in the voltage of a cell during a normal charging period. Indicate on the sketch the point at which you would expect the cell to commence " gassing " freely.* (35).

A. 8. When the cell is charged, the active material of the positive plates is lead peroxide, PbO_2, and that of the negative plates is metallic lead in a spongy state. When the cell discharges, the sulphuric acid, H_2SO_4, is dissociated into H_2 and SO_4 ions. The H_2 ions move through the electrolyte to the positive plate and there reduce the peroxide to monoxide, PbO, which then combines with the sulphuric acid to form lead sulphate. These chemical reactions may be written as follows :—

$$PbO_2 + H_2 \longrightarrow PbO + H_2O$$

$$PbO + H_2SO_4 \longrightarrow PbSO_4 + H_2O$$

or, combining the two processes, the action at the positive plate during discharge is—

$$PbO_2 + H_2 + H_2SO_4 \longrightarrow PbSO_4 + 2H_2O$$

This action is purely chemical, as distinguished from electro-chemical, and, therefore, has no effect upon the E.M.F. of the cell.

At the negative plate, the SO_4 ions combine with the lead to form lead sulphate or, symbolically—

$$Pb + SO_4 \longrightarrow PbSO_4$$

The lead sulphate formed is not the ordinary lead sulphate, which is insoluble, but is probably a more complex compound.

When the cell is being re-charged, the H_2 ions move to the negative plate and the SO_4 ions to the positive. The chemical reactions which occur are then the reverse of those given above and may be written—

$$PbSO_4 + H_2 \longrightarrow Pb + H_2SO_4$$

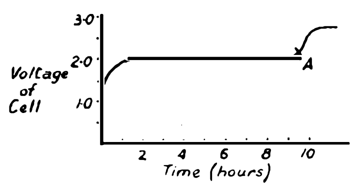
at the negative plate, and

$$PbSO_4 + SO_4 + 2H_2O \longrightarrow PbO_2 + 2H_2SO_4$$

at the positive plate.

As the cell approaches full charge, the amount of lead sulphate present on the plates is insufficient to combine with all the ions reaching the plates. As a result, hydrogen gas is liberated at the positive plate, whilst oxygen is given off at the negative plate from the combination of the SO_4 ions with water, H_2O, to give O and H_2SO_4. This condition is termed " gassing " and indicates that the cell is practically fully charged.

The general shape of the curve representing the variations in the voltage of a cell during a normal charging period is indicated in the sketch. The voltage of the cell rises rapidly



to about 2.0 volts during the first hour of the charge, and then remains steady for some hours. As the cell approaches the fully-charged condition, the voltage again rises and about the point marked " A " in the sketch, gassing commences.

(To be continued.)

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