EXAMINATION QUESTIONS

(*The authors are responsible for the answers*)

CHAPTER I

(1) Show that the energy stored in a capacitor is given by the expression $\frac{1}{2}CV^2$.

An air capacitor of capacitance 0·005 microfarad is connected to a direct voltage of 500 volts, disconnected, and then immersed in oil with a dielectric constant of 2·5. Find the energy stored in the capacitor before and after immersion, and account for the difference. (*Lond. Univ., Elec. Tech.*)

Ans. Before immersion 625×10^{-6} J.; after immersion 250×10^{-6} J.

(2) A long straight cylindrical wire of very small diameter is suspended in free space and has on it a charge Q per unit length. Calculate directly from the inverse square law the strength of the electric field at a point far removed from the ends of the wire and at a distance x from the wire, where x is very large compared with the diameter of the wire. What will be the form of the equipotential surfaces and what will be the difference of potential between two points distant x_1 and x_2 from the wire?

If $Q = 0{\cdot}00333$ microcoulomb per metre, $x_1 = 2$ cm and $x_2 = 20$ cm, what is the difference of potential in volts between the two points?

(*Lond. Univ., Elec. Meas.*)

Ans. 136 V.

(3) Calculate the strength of the magnetic field at the centre of a single-turn square coil of 1 ft side when carrying a current of 20 amp. Prove the formula employed.

Ans. 59 A/m.

(4) A solenoid is 2 ft long and 1 in. diameter, and is uniformly wound with 600 turns of insulated wire. Calculate the strength of the magnetic field at the centre when the current is 2 amp. If a secondary coil of 50 turns is wound round the central part of the solenoid and is connected to a ballistic galvanometer through a resistance which makes the total resistance of the circuit 10,000 ohms, calculate the quantity of electricity discharged through the galvanometer on reversing the current of 2 amp in the primary winding. Estimate the error due to assuming the solenoid infinitely long.

(*Lond. Univ., Elec. Meas.*)

Ans. $19{\cdot}7 \times 10^2$ A/m; $1{\cdot}25 \times 10^{-8}$ coulomb; error 9 parts in 10,000.

(5) Draw diagrams showing the magnetic field around two parallel straight conductors carrying current (*a*) in the same direction, and (*b*) in opposite directions.

If two conductors 3 in. apart each carry 1,000 amp in the same direction, find the direction and magnitude per inch run of the force on each conductor.

(*Lond. Univ., Elec. Tech.*)

Ans. 6·78 grammes wt. (0·0666 newton) attraction.

(6) Two coils each of 20 cm diameter and 100 closely wound turns of fine wire are mounted coaxially 10 cm apart. A current of 1 amp is passed through the coils in series, the connections being such that the fields are additive. Plot a curve showing the field strength along the axis of the coils.

Prove any formula used. (*Lond. Univ., Elec. Meas.*)

(7) The demagnetization curve for a sample of permanent-magnet steel after hardening and ageing is as follows—

Permanent flux density in webers per square metre	0·65	0·59	0·52	0·43	0·31	0·14
Demagnetizing ampere-turns per centimetre .	4	12	20	28	36	44

The air-gap flux density in a moving-coil instrument where this steel is used is to be 0·09 Wb/m^2, the length of the single gap is to be 0·12 cm, and the area of the gap 10 cm^2. To ensure the necessary permanence, the ratio of the area of the gap divided by its length to the area of cross-section of the magnet divided by its length is to be 300. Assuming the leakage flux to be equal to the useful flux, and regarding all the leakage as being concentrated at the pole shoes, calculate the necessary length and cross-sectional area of the magnet.

To what extent is the above-mentioned ratio applicable to all permanent magnet steels?

Ans. 11·5 cm, 3·2 cm^2.

(8) What are the criteria of the most suitable characteristics of a permanent magnet for use in a measuring instrument such as a moving-coil ammeter? Deduce the magnetic condition in which the permanent magnet should be operated in order that its volume may be a minimum, assuming given gap dimensions and flux density in the gap.

(*Lond. Univ., Elec. Meas.*)

CHAPTER II

(9) What is meant by the dimensions of a quantity? Derive the dimensions of potential difference in the electrostatic system in terms of Mass, Length, and Time.

In the course of a calculation an expression of the following form was arrived at—

$$I = E\left\{\frac{1}{Z_1} + \frac{j\omega M}{Z_2}\left(\frac{1}{R} + \frac{C}{L}\right)\right\}$$

Show that there must have been an algebraical error, and point out the term or terms which require correction. (*Lond. Univ., Elec. Meas.*)

Ans. The term $\frac{C}{L}$ should be multiplied by some quantity having the dimensions of resistance (or impedance).

(10) The voltage V across the coils of a telephone receiver when a current I is flowing through them may be written

$$V = I\left(Z + \frac{A^2}{z}\right)$$

where $Z = R + j\omega L$

$A = 2B_0\frac{N}{\mathscr{R}}$

$z = r + j\left(\omega m + \frac{s}{\omega}\right)$

R = the resistance

L = the inductance, and

N = the number of turns of the receiver coils

B_0 = the flux density in the air gap

$\mathscr{R}$ = the reluctance of the magnetic circuit

and r, m, and s are the equivalent mechanical resistance, mass, and stiffness of the receiver diaphragm.

Suggest a suitable unit for each of the quatities involved.

Find the dimensions of each quantity, and so make a dimensional check of the equation. (*Lond. Univ., Elec. Meas.*)

Ans. Dimensions—

V—$[L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}\mu^{\frac{1}{2}}]$	s—$[MT^{-2}]$
I—$[L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$	A—$[L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}]$
Z—$[LT^{-1}\mu]$	B_0—$[L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$
z—$[MT^{-1}]$	$\mathscr{R}$—$[L^{-1}\mu^{-1}]$
r—$[MT^{-1}]$	R—$[LT^{-1}\mu]$
m—$[M]$	L—$[L\mu]$

(11) (i) The expression for the mean torque T of an electrodynamic wattmeter may be written,

$$T \propto M^p E^q Z^t$$

where M = the mutual inductance between fixed and moving coils
E = applied voltage
Z = impedance of the load circuit.

From the dimensions of quantities involved determine p, q, and t.

(ii) In the same way, determine a, b, c, and g in the following expression for the eddy current loss W per centimetre length of round wire—

$$W \propto f^a B_{max} d^c \rho^g$$

where f = frequency
B_{max} = maximum flux density
d = diameter of the wire
ρ = resistivity of the material.

Ans. (i) $p = 1$, $q = 2$, $t = -2$; (ii) $a = 2$, $b = 2$, $c = 4$, $g = -1$.

(12) Give a concise account of the M.K.S. (Giorgi) system of units, and compare the advantages and disadvantages of this system with those of the C.G.S. electromagnetic system. (*Lond. Univ., Elec. Meas.*)

(13) What is meant by the "dimensions" of an electrical or magnetic quantity?

Obtain the dimensions of resistance and magnetic flux in the C.G.S. electromagnetic system, and of charge and energy in the C.G.S. electrostatic system.

Briefly explain what is meant by a "rationalized" system of dimensions. (*Lond. Univ., Elec. Meas.*)

CHAPTER III

(14) Three non-inductive resistances of 1,000 ohms are star-connected to a three-phase supply with 200 volts between lines. What will be the reading on a voltmeter connected between one of the lines and the star point thus formed, if the voltmeter also has a non-inductive resistance of 1,000 ohms? (*Lond. Univ., Elec. Meas.*)

Ans. 86·6 volts.

(15) An alternating current circuit contains a coil of inductance L_1; near this, but not connected to it, is a coil of inductance L_2, across which is connected a resistance R. If the mutual inductance between the two coils is M, calculate the effective inductance and resistance of the first circuit. (*Lond. Univ., Elec. Meas.*)

Ans. Res. $= \dfrac{\omega^2 M^2 R}{R^2 + \omega^2 L_2^{\,2}}$; ind. $= \left(L_1 - \dfrac{\omega^2 M^2 L_2}{R^2 + \omega^2 L_2^{\,2}}\right)$

(16) An alternating current passes through a non-inductive resistance R and an inductance L in series. Find the value of the non-inductive resistance

which can be shunted across the inductance without altering the value of the main current. (*Lond. Univ., Elec. Meas.*)

Ans. $\frac{\omega^2 L^2}{2R}$.

(17) The impedances of the three phases of a star-connected load (no neutral wire) are $5 + j20$, $12 + j0$, and $1 - j10$ in order. The line voltage is 400 volts. Find the line currents. (*Lond. Univ., Elec. Meas.*)

Ans. $0{\cdot}5 - 29{\cdot}65j$, $16{\cdot}24 - 11{\cdot}5j$, $-16{\cdot}74 + 41{\cdot}15j$.

(18) Three branch circuits consisting respectively of (i) 5 ohms resistance and 0·025 henry inductance, (ii) 4 ohms resistance and 300 microfarads capacitance, (iii) 0·01 henry inductance and 500 microfarads capacitance, are connected in parallel. A resistance of 3 ohms is then connected in series with the combination. Using the symbolic "j" notation, calculate the currents in the main circuit, and in the three branches, when an alternating voltage $v = 100 \sin 314t$ is applied to the whole circuit.

Ans.
$$i = 20{\cdot}2 \sin (314t + 37° 55'),$$
$$i_1 = 6{\cdot}9 \sin (314t - 93° 20'),$$
$$i_2 = 5{\cdot}64 \sin (314t + 33° 35'),$$
$$i_3 = 19{\cdot}9 \sin (314t + 54° 10').$$

(19) Two coils. of self-inductance 0·01 henry and 10 henrys, and resistance 0·3 ohm and 300 ohms respectively, have a coefficient of coupling of 0·9.

Calculate the change in effective resistance of the first coil when a resistance of 100 ohms is connected to the terminals of the second, the frequency being 50 c/s. (*Lond. Univ., Elec. Meas.*)

Ans. 0·318 ohm.

(20) Explain the essential principle of the method of symmetrical components as applied to the solution of asymmetrical polyphase a.c. network problems.

Show how a direct measurement of the positive and negative sequence components of an unbalanced three-phase current system can be made. Give a diagram of connections and indicate what the observations signify with regard to the actual currents in the three lines. (*Lond. Univ., Elec. Meas.*)

(21) Explain, with the aid of a diagram of connections, a method of measuring the symmetrical components of the currents in an unbalanced 3-phase, 3-wire system.

If in such a system the line currents, in amperes, are

$$I_r = 10 - j2;\ I_y = -2 - j4;\ I_b = -8 + j6$$

calculate their symmetrical components. (*Lond. Univ., Elec. Meas.*)

Ans. $I_{R0} = I_{Y0} = I_{B0} = 0.$
$$I_{R1} = 7{\cdot}89 + j0{\cdot}732;\ I_{Y1} = a^2 I_{R1};\ I_{B1} = aI_{R1}$$
$$I_{R2} = 2{\cdot}113 - j2{\cdot}732;\ I_{Y2} = aI_{R2};\ I_{B2} = a^2 I_{R2}.$$

(22) An unbalanced star-connected load is supplied from symmetrical three-phase mains. The load impedances are Z_a, Z_b, Z_c and the positive phase sequence is a, b, c. Calculate the value of the positive phase-sequence current when the line voltage of the three-phase balanced supply is 400 V and $Z_a = 0 + j10\ \Omega$, $Z_b = 0 - j5\ \Omega$ and $Z_c = 10 + j0\Omega$.

(*Lond. Univ., Elec. Theory and Meas. Part III*)

Ans. 36·6 A.

CHAPTER IV

(23) Calculate the capacitance of a spherical capacitor if the diameter of the inner sphere is 20 cm, and that of the outer sphere is 30 cm, the space between

them being filled with a liquid with a relative permittivity of 2. Express your answer in microfarads.

Ans. $\frac{2}{3} \times 10^{-4}$ microfarad.

(24) A capacitor is made up of two parallel metal discs separated by three layers of dielectric of equal thickness but having relative permittivities of 2, 3, and 4 respectively. If the metal discs are 6 in. diameter and the distance between them 0·3 in., calculate the potential gradient in each dielectric and the total energy stored in each when a potential difference of 1,000 volts is applied between the discs.

Ans. 1,815, 1,210, 907·5 volts per cm; $13{\cdot}51 \times 10^{-6}$, $8{\cdot}98 \times 10^{-6}$, $6{\cdot}755 \times 10^{-6}$ J

(25) Calculate the capacitance of the following system—

Two conductors $\frac{3}{8}$ in. diameter, and 400 yd long, lying parallel to each other and to an earthed plane, their height above the plane being 3 ft. The conductors are 3 ft apart.

Ans. 1,980 micromicrofarads.

(26) Capacitance measurements on a three-phase cable were made as follows—

Capacitance per mile between the sheath and one conductor connected together and the other two conductors connected together = 0·45 microfarad.

Capacitance per mile between the three conductors connected together and the sheath = 0·50 microfarad.

The potential between the conductors is 3,300 volts and the frequency is 50 cycles per second.

Find the charging current flowing to each conductor in a 20-mile length of the cable. (*Lond. Univ., Elec. Meas.*)

Ans. 4·1 amp.

(27) Discuss the difficulties of constructing a standard capacitor for use in the high-voltage arm of a Schering bridge working on voltages above 100 kV.

A capacitor bushing forms arm *AB* of a Schering bridge, and a standard capacitor of 500 $\mu\mu$F capacitance and negligible loss forms arm *AD*. Arm *BC* consists of a non-inductive resistance of 300 ohms. When the bridge is balanced, the resistance and capacitor in parallel in the remaining arm *CD* have values of 72·6 ohms and 0·148 μF respectively. The frequency is 50 c/s. Calculate from first principles the capacitance and the dielectric loss angle of the bushing. (*Lond. Univ., Elec. Meas.*)

Ans. 121 $\mu\mu$F; 0° 11·6′.

CHAPTER V

(28) Annular shaped iron stampings are built up to form a ring 8 in. inside diameter and 10 in. outside diameter and 1 in. thick. The square cross-section is wound with 1,000 turns to form a toroidal coil. If the resistance of the wire is 200 ohms, and the relative permeability of the iron is 800, what current will flow under an impressed alternating voltage of 100 volts, 50 c/s?

What would be the effect of replacing the stampings by a solid iron core?

Ans. 0·288 amp.

(29) A ring 1 ft mean diameter is made of round iron 1 in. diameter, and is uniformly wound with 500 turns of copper wire 0·05 in. diameter. A second winding of 1,000 turns of wire 0·025 in. diameter is uniformly wound over the first. Assuming the iron to have a relative permeability of 800, calculate the

self-inductance of each winding and the mutual inductance between them; express your answers in practical units.

Ans. 0·133, 0·532, 0·266 henry.

(30) Define the practical unit of mutual inductance.

Two coils with terminals T_1T_2 and T_3T_4 respectively are placed side by side. Measured separately, the inductance of the first coil is 1,200 microhenrys, and that of the second coil is 800 microhenrys.

With T_2 joined to T_3 the inductance between T_1 and T_4 is 2,500 microhenrys. What is the mutual inductance between the two coils, and what would be the inductance between T_1 and T_3 with T_2 joined to T_4?

Prove any formula used. (*Lond. Univ., Elec. Tech.*)

Ans. $M = 250$ microhenrys, $L = 1,500$ microhenrys.

(31) A toroidal coil is uniformly wound with 250 turns. The core is of marble with a rectangular cross-section $2\frac{1}{2}$ in. deep and 2 in. wide; the outer diameter of the toroid is 6 in., and the inner diameter is 2 in.

Find the inductance of the toroid, proving any formula used.

(*Lond. Univ., Elec. Meas.*)

Ans. 0·873 millihenry.

(32) Explain the advantages of using a mutual inductance as a primary standard of inductance.

Estimate the mutual inductance between two parallel coaxial single-turn circular coils of diameter 40 cm and 4 cm respectively. The planes of the coils are 25 cm apart.

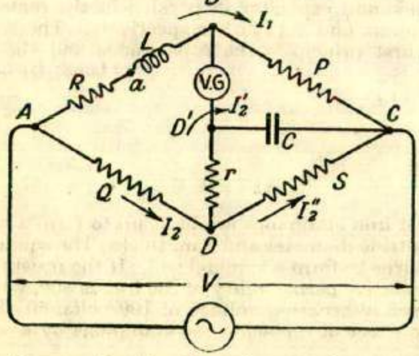
Justify the expressions used in this calculation.

(*Lond. Univ., Elec. Meas.*)

Ans. 0·00096 μH.

CHAPTER VI

(33) The diagram gives the connection of Anderson's bridge for measuring the inductance L and resistance R of an unknown impedance between the points A and B. Find R and L if balance is obtained when $Q = S = 1,000$ ohms, $P = 500$ ohms, $r = 200$ ohms, and $C = 2\mu$F.



Draw a vector diagram showing the voltage and current at every point of the network when the voltage across AC is 10 volts and the frequency is 100 cycles per second. (*Lond. Univ., Elec. Meas.*)

Ans. $R = 500$ ohms, $L = 1·4$ henrys.

(34) Explain how an inductance may be measured by comparison with a standard capacitor in an alternating-current bridge.

The four arms of a Wheatstone bridge arrangement are as follows: AB is an inductive resistance Lr_1, BC is a non-inductive resistance r_3, CD is a capacitor of capacitance C shunted by a resistance r_4, DA is a non-inductive resistance r_2. An alternating-current supply is connected between the points A and C and a telephone receiver across the points B and D. Work out the conditions for balance and show that the result is independent of the frequency of the supply. (*C. and G. Final, Elec. Eng., II.*)

Ans. $r_1r_4 = r_2r_3 = \frac{L}{C}$.

(35) In a balanced bridge network, AB is a resistance of 500 ohms in series with an inductance of 0·18 henry, BC and DA are non-inductive resistances of 1,000 ohms, and CD consists of a resistance R in series with a capacitance C. A potential difference of 5 volts at a frequency of $5{,}000/2\pi$ is established between the points A and C.

Draw to scale a vector diagram showing the currents and potential differences in the bridge, and from it determine the values of R and C.

Check the result algebraically. (*Lond. Univ., Elec. Meas.*)

Ans. 472 ohms; 0·235 μF.

(36) It is required to measure the inductance and resistance of an iron-cored choke of about 1 henry at frequencies varying from 50 to 3,000 c/s and with direct current flowing through it. An oscillator, standard capacitors, and non-inductive resistance boxes are available.

Describe a suitable a.c. bridge and detector, mentioning any precautions necessary to ensure accuracy in the result. Derive the equation of balance of the bridge used. (*Lond. Univ., Elec. Meas.*)

(37) Describe a suitable a.c. bridge method for measuring, at a frequency of 500 cycles per second, the self-inductance and effective resistance of a coil of approximately 0·2 henry inductance and 5 ohms resistance. Draw the vector diagram for the balance conditions and give the equations for balance. (*Univ. Lond., Elec. Meas.*)

(38) Describe briefly the construction and method of adjustment of one type of vibration galvanometer. Compare its advantages and disadvantages with those of a telephone receiver for use in a.c. measurements at various frequencies.

Derive an expression for the sensitivity of the tuned galvanometer, showing how it is dependent on frequency and damping. (*Lond. Univ., Elec. Meas.*)

(39) A 4-arm unbalanced a.c. bridge is supplied from a source having negligible impedance. The bridge has non-reactive resistors of equal resistance R in adjacent arms. The third arm has an inductor of resistance R and reactance X, where X is numerically equal to R. The fourth arm has a variable non-reactive resistor. The detector is connected between the junction of the first and second arms and the junction of the third and fourth arms and has a resistance R and negligible reactance. Determine the value of the variable resistor when the detector current is in quadrature with the supply current. (*Lond. Univ., Elec. Theory and Meas., Part III*)

Ans. 1·37 R.

(40) A T-network has series arms AB and BD, each being a coil of inductance 3 μH and loss resistance 6 Ω at 12 Mc/s. The shunt arm BE is a variable resistor R, and the series arms are bridged by a calibrated variable capacitor C connected between A and D. A voltage at 12 Mc/s is applied between A and E.

Show that there is one combination of R and C for which no voltage appears between D and E, and evaluate these two quantities.

An unknown capacitance connected between A and D can be measured by noting the change in C required to restore the null condition. Explain the advantages of this method. *(Lond. Univ., Elec. Meas.)*

Ans. $R = 4{,}250\ \Omega$; $C = 29 \cdot 4\ \mu\mu F$.

(41) A balanced bridge has the following components connected between its five nodes, A, B, C, D and E—

Between A and B:	1,000 ohms resistance
„ B „ C:	1,000 „ „
„ C „ D:	an inductor
„ D „ A:	218 ohms resistance
„ A „ E:	469 „ „
„ E „ B:	10 μF capacitance
„ E „ C:	a detector
„ B „ D:	a power supply (a.c.)

Derive the equations of balance and hence deduce the resistance and inductance of the inductor. *(Lond. Univ., Elec. Theory and Meas., Part III)*

Ans. $R = 218\ \Omega$; $L = 7 \cdot 89$ H.

CHAPTER VII

(42) The four arms of a Wheatstone bridge have the following resistances: AB 100, BC 10, CD 4, DA 50 ohms.

A galvanometer of 20 ohms resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of 10 volts is maintained across AC. *(Lond. Univ., Elec. Tech.)*

Ans. 0·00513 amp.

(43) Describe the Kelvin double bridge for the comparison of small resistances.

Give the theory of the bridge, and detail the arrangements necessary in order that the greatest precision possible may be obtained. *(Lond. Univ., Elec. Meas.)*

(44) Describe with a diagram of connections the loss-of-charge method of determining the insulation resistance of a length of cable. Prove the formula used for this determination, and calculate the insulation resistance of a short length of cable in which the voltage falls from 100 to 80 in 20 sec, the capacitance being 0·0003 microfarad. *(Lond. Univ., Elec. Tech.)*

Ans. 298,000 megohms.

(45) Describe a method by which the insulation resistance to earth of each of a pair of live mains can be measured by a voltmeter of known resistance. Discuss the limitations of the method.

The following readings were taken with a 250 volt, 1,000 ohms per volt, voltmeter—

Between two mains . . .	218 volts
Positive main to earth . .	188 volts
Negative main to earth . .	10 volts

Calculate the insulation resistance of each main. *(Lond. Univ., Elec. Meas.)*

Ans. Positive 500,000 Ω; negative 26,600 Ω.

(46) A moving-coil galvanometer has a sensitivity of 4 cm per microampere, with a scale 1 metre distant, and the time of free oscillation is 2·8 sec.

If the galvanometer is dead beat when the total circuit resistance (coil and external circuit) is 2,500 ohms, find the moment of inertia of the moving system.

Prove any formula used. (*Lond. Univ., Elec. Meas.*)

Ans. $2 \cdot 7 \times 10^{-7}$ kg-m².

(47) What is meant by critical damping, and to what extent should this condition be approached in the case of an ordinary moving-coil type of instrument?

The coil of a moving-coil galvanometer has 300 turns and is suspended in a uniform magnetic field of 0·1 Wb/m² by a phosphor-bronze strip, of which the torsion constant is 2×10^{-7} newton-metre per radian. The coil is 2 cm wide and $2\frac{1}{2}$ cm high, with a moment of inertia of $1 \cdot 5 \times 10^{-7}$kg-m².

If the galvanometer resistance is 200 ohms, calculate the value of the resistance which, when connected across the galvanometer terminals, will give critical damping. Assume the damping to be entirely electromagnetic.

Ans. 450 ohms.

CHAPTER VIII

(48) In the measurement of a low resistance by means of a potentiometer the following readings were obtained—

Voltage drop across low resistance under test . .	0·83942 volt
Voltage drop across a 0·1 ohm standard resistance connected in series with the "unknown"	1·01575 volt

The resistance of the standard at the temperature of the test is 0·10014 ohm. Upon setting the potentiometer dials to zero and breaking the current passing through the "unknown" resistance, the thermal e.m.f. of the latter produced a galvanometer deflection equivalent to 23 microvolts, the direction of the deflection being the same as that produced by an increase of the potentiometer reading during the voltage drop measurements.

Calculate the resistance of the "unknown."

Ans. $0 \cdot 08276_0$ ohm.

(49) Explain the principle of one type of co-ordinate a.c. potentiometer. Draw a diagram of the scheme of connections and describe how the potentiometer is standardized.

Measurements for the determination of the impedance of a coil were made on a co-ordinate potentiometer as follows—

Voltage across a 1 Ω standard resistance in series with the coil, + 0·952 V on in-phase dial, − 0·34 V on quadrature dial.

Voltage across a 10 : 1 potential divider connected to the terminals of the coil, + 1·35 V on in-phase dial, + 1·128 V on quadrature dial.

Calculate the resistance and the reactance of the coil.

(*Lond. Univ., Elec. Meas.*)

Ans. $R = 8 \cdot 82\ \Omega;\ X = 15\ \Omega$.

(50) A current of 10 A at a frequency of 50 c/s was passed through the primary of a mutual inductor having a negligible phase defect. The voltages at the primary and secondary terminals were measured on a co-ordinate potentiometer and are given below.

With secondary winding open-circuited,
- secondary volts $-2 \cdot 72 + j\,1 \cdot 57$
- primary volts $-0 \cdot 211 + j\,0 \cdot 352$

With secondary winding short-circuited,
- primary volts $-0 \cdot 051 + j\,0 \cdot 329$

The phase of the primary current relative to the potentiometer current was the *same* in both tests.

Determine the self- and mutual inductances of the inductor.
(*Lond. Univ., Elec. Theory and Meas., Part III*)

Ans. $M = 1{\cdot}0$ mH, $L_1 = 0{\cdot}114$ mH, $L_2 = 18{\cdot}06$ mH.

(51) Describe two d.c.-a.c. transfer devices which might be used for standardizing a.c. potentiometers, one for low frequencies and the other for high frequencies. State the advantages and disadvantages of each device. Discuss the errors of potentiometer measurements at high frequencies.
(*Lond. Univ., Elec. Theory and Meas., Part III*)

CHAPTER IX

(52) What are the conditions to be fulfilled by a ballistic galvanometer? Describe the construction of such an instrument, and explain how to determine the constant and the logarithmic decrement.

The periodic time of an undamped reflecting ballistic galvanometer is 10 sec, and a current of 0·1 mA gives a steady deflection of 200 scale divisions. Find the quantity of electricity which produces a swing of 100 divisions. What is the quantity of electricity corresponding to this swing if the instrument has a decrement of 1·03? (*C. and G. Final*)

Ans. 0·0000795 coulomb; 0·000121 coulomb.

(53) Explain carefully how the construction of a fluxmeter differs from that of a moving-coil ammeter or voltmeter.

A certain fluxmeter has the following constants—

Air-gap flux density, 5×10^{-3} Wb/m².
Turns on moving coil, 40.
Area of moving coil, 7·5 cm.²

If a 10-turn search coil of 2 cm² area, which is connected to the fluxmeter, is reversed in a uniform field of flux density 5×10^{-2} Wb/m², calculate the deflection of the meter.

Why is it necessary to keep the resistance of the moving coil, and of the search coil and leads, low? How may a correction for an unavoidably high resistance in the search coil be made?

Ans. $76\frac{1}{2}°$.

(54) State the theory underlying the action of the Chattock magnetic potentiometer. Describe the instrument, and show how it can be calibrated and used in conjunction with a ballistic galvanometer for the measurement of difference of magnetic potential.

The constant of a given potentiometer was obtained by aid of a coil of 300 turns in which a current of 0·6 amp was reversed. The resulting throw of the galvanometer was 157 scale divisions. It was then used to measure the magnetic potential difference between two points and the throw was 304 scale divisions. Find the magnetic potential difference, and state the units in which it is measured. (*Lond. Univ., Elec. Meas.*)

Ans. 695 amperes.

(55) Describe a method for finding the *B-H* curve of bar specimens.

An iron ring of 3·5 sq. cm cross-sectional area with a mean length of 100 cm is wound with a magnetizing winding of 100 turns. A secondary coil with 200 turns of wire is connected to a ballistic galvanometer having a constant of 1 microcoulomb per scale division, the total resistance of the secondary circuit being 2,000 ohms. On reversing a current of 10 amp in the magnetizing coil, the galvanometer gave a throw of 100 scale divisions. Calculate the flux density in the specimen and the value of the permeability at this flux density.
(*C. and G. Final*)

Ans. $B = 1{\cdot}428$, $\mu_r = 1{,}136$.

(56) Describe a standard form of apparatus for measuring the iron losses in steel sheets at specified values of flux density and frequency by means of a wattmeter.

The following test results were obtained on a sample of steel stampings at 50 c/s—

Volts	Amperes	Watts
4·9	0·20	9·5
69·3	0·30	16·8
91·8	0·46	27·5
100·5	0·52	32·5
110·5	0·64	39·0
118·0	0·77	44·8

Mean width of the plates, 3 cm; mean thickness, 0·0489 cm; number of plates, 51; total weight, 24·2 lb; number of magnetizing turns in coil, 600. Allowing 2 watts copper loss in the magnetizing winding, calculate the iron loss in watts per pound at a flux density of 1 Wb/m^2, and 50 c/s.

Ans. **1·18 W/lb.**

(57) Describe a method of using an a.c. potentiometer for measuring the loss in an iron ring made up of thin stampings. Explain how the loss may be calculated in terms of the maximum density, and state any assumptions made. (*Lond. Univ., Elec. Meas.*)

CHAPTER X

(58) An open space is illuminated by four lamps each giving 300 candelas in every direction below the horizontal. They are suspended 23 ft above the ground at the corners of a rectangle 20 ft by 15 ft. Calculate the illumination in lumens per sq. ft of a horizontal surface 3 ft above the ground (*a*) at the middle of the shorter side, and (*b*) at the mid-point of the rectangle.

Describe briefly a portable photometer suitable for testing the accuracy of your calculations.

Ans. **1·72 lm/ft^2; 1·83 lm/ft^2.**

(59) Define the following terms: (*a*) mean spherical intensity; (*b*) lumen; (*c*) illumination; (*d*) brightness. What is the illumination at the edge of a circular table 6 ft in diameter lit by one 100 cd lamp 4 ft above the centre?

Ans. **3·2 lm/ft^2.**

(60) Describe a good type of portable illumination photometer suitable for outdoor use; explain how it can be calibrated and discuss the various sources of error in its use.

If two lamps giving 500 candelas in every direction are suspended 30 ft high and 100 ft apart, compare the illumination of the horizontal road surface under one lamp with that midway between them.

Ans. **3·76 : 1.**

(61) How would you determine the constants α and β in the expression

Luminous intensity $= \alpha V^{\beta}$ for a glow lamp, where V is the lamp voltage?

Taking the value $\beta = 4{\cdot}5$ for a tungsten-filament vacuum lamp, determine the percentage variation of luminous intensity due to a voltage variation of ± 4 per cent from the normal value.

Ans. **19·2 per cent above normal, 16·75 below normal.**

(62) A road is to be illuminated by means of lamps supported at a height of 20 ft, and arranged 100 ft apart. Determine the necessary distribution of luminous intensity in a vertical plane in order that the lamps may produce a uniform horizontal illumination on the ground along a line vertically beneath a pair of lamps. The illumination due to a lamp at a greater distance than 50 ft may be neglected.

Ans. $I_\theta = \dfrac{I_0}{\cos^3\theta}$, where θ is the angle between the line vertically down through the lamp and the line joining the lamp to any point on the road between the lamps.

$I_0 = I$ vertically under a lamp.

(63) Define luminous flux, luminous intensity, and illumination, and state and define the units in which they are measured.

Describe the construction and use of a photo-electric photometer.

(64) Describe an apparatus by means of which the mean spherical intensity of a 1,000-watt gas-filled lamp can be determined by a single reading. Explain the principle involved and discuss the precautions which must be taken to ensure accuracy.

CHAPTER XI

(65) Describe with connection diagram how the peak value of a high voltage may be measured by means of a neon tube. Explain how the method is applied to the calibration of an extra-high-voltage voltmeter. How would you arrange to detect with certainty the striking of the neon tube?

(*C. and G. Final*)

(66) What methods may be used in testing cables for dielectric strength at very high voltages? Explain the difficulties that occur when tests with alternating voltages are made on long lengths of cable, and state what difference there is (if any) in the dielectric strength of (*a*) paper (*b*) air, when tested respectively with alternating and direct voltages.

(67) Describe an equipment for the production of high voltages for surge or impulse tests. Explain the action of the circuit described, and show precisely how the shape of the impulse wave can be controlled.

(*C. and G. Final*)

CHAPTER XII

(68) Describe the Murray loop method of localizing an earth fault on a length of cable.

In a test for a fault to earth on a 520 yd length of cable having a resistance of 1·10 ohms per 1,000 yd, the faulty cable is looped with a sound cable of the same length but having a resistance per 1,000 yd of 2·29 ohms. The resistances of the other two arms of the testing network, at balance, are in the ratio 2·7 : 1. Calculate the distance of the fault from the testing end of the cable.

Ans. 432 yd.

(69) Describe a method by which the position of a fault to earth on a long feeder may be found approximately by a "loop" test.

What methods may be used for finding the position of the fault when a break in the conductor occurs without affecting the insulation resistance very seriously?

CHAPTER XIII

(70) Show that, if α_1 be the resistance-temperature coefficient of a conductor at $t_1°$ *C* expressed as a fraction, the coefficient at $t_2°$ C is given by

$$\alpha_2 = \frac{1}{\frac{1}{\alpha_1} + (t_2 - t_1)}$$

A specimen of copper wire has a resistivity of $1{\cdot}6 \times 10^{-6}$ ohm-cm at 0°C, and a temperature coefficient of $\frac{1}{254{\cdot}5}$ at 20°C. Find the temperature coefficient and the resistivity at 60°C.

(*C. and G. Final*)

Ans. $\frac{1}{294{\cdot}5}$. $2{\cdot}009 \times 10^{-6}$ ohm-cm.

(71) Describe a method for measuring the temperature rise in the field-magnet windings of a direct-current generator? Explain briefly how the final temperature rise of a machine may be estimated from the curve of temperature rise at the beginning of the heat run.

(72) Describe suitable methods for the measurement of the temperature of the following—

(*a*) The centre portion of the winding of a field coil on an electrical machine.
(*b*) A small quantity of molten metal.
(*c*) The interior of a furnace.

State why each method described is the most suitable for its purpose.

(73) Describe how the measurement of temperature can be made electrically—

(*a*) by thermocouples,
(*b*) by a bridge method suitable for moderately high temperatures,
(*c*) at very high temperatures.

Discuss the precautions necessary to avoid error in each case.

(*Lond. Univ., Elec. Theory and Meas., Part III*)

CHAPTER XIV

(74) An electromagnet of the type used for moving-coil loudspeakers has a central circular core and uniform air gap. The field in the air gap is uniform and radial. The electromagnet is arranged with the central core vertical so that an aluminium ring placed in the gap at the top of the central core could fall freely through the air gap under gravity. If the density of the radial flux is B and the ring has a cross-sectional area A with mean circumference L, and the material has a resistivity ρ and a density D, derive an expression for the velocity attained by the ring at any instant after it has begun to fall.

(*Lond. Univ., Elec. Meas.*)

Ans. $v = \frac{g\rho D}{B^2}\left[1 - e^{-\frac{B^2}{\rho D}t}\right]$.

CHAPTER XV

(75) An electromotive force, $e = 2{,}000 \sin \omega t + 400 \sin 3\omega t + 100 \sin 5\omega t$ is connected to a circuit consisting of a resistance of 10 ohms, a variable inductance, and a capacitance of 30 microfarads arranged in series with a

thermal ammeter. Find the value of the inductance which will give resonance with the triple-frequency component of the voltage and estimate the readings on the ammeter and on a thermal voltmeter connected across the supply when resonant conditions exist. ($\omega = 300$.)

Ans. 0·0411 henry; 31·7 amp; 1,442 volts.

(76) Derive an expression for the r.m.s. value of a complex wave-form of voltage.

Analysis of the wave-form of the voltage generated by an alternator shows that there are third and fifth harmonics having amplitudes equal, respectively, to 30 per cent and 20 per cent of that of the fundamental. The third harmonic lags behind the fundamental by 20 degrees and the fifth harmonic by 10 degrees. A dynamometer voltmeter connected to the alternator terminals gives the same reading as is produced by 150 volts d.c. Derive an expression for the instantaneous value of the voltage in the circuit.

(*Lond. Univ., Elec. Meas.*)

Ans. $v = 200 \sin \omega t + 60 \sin \left(3\,\omega t - \frac{\pi}{3}\right) + 40 \sin \left(5\,\omega t - \frac{5}{18}\pi\right)$.

(77) Explain why alternating voltage and current wave-forms usually contain no even harmonics. In what practical instances may even harmonics occur?

A rectifier gives a current wave which has a sinusoidal form but with the negative half-wave completely suppressed. The maximum height of the wave is 100 amp. Determine (i) the steady component and (ii) the fundamental of the wave. (*Lond. Univ., Elec. Meas.*)

Ans. 31·8 amp; 50 sin θ.

(78) A voltage, represented by 300 sin ωt volts, is applied to a circuit consisting of a non-inductive resistance of 20 ohms in series with a luminous discharge lamp and produces a current represented by

$$(5 \sin \omega t - 2 \sin 3\,\omega t) \text{ amp}$$

Calculate the power absorbed by the resistance and by the lamp; also the power factor of the lamp and of the complete circuit.

(*Lond. Univ., Elec. Meas.*)

Ans. 290 watts; 460 watts; 0·838; 0·93.

(79) Describe and give the theory underlying the operation of some form of electric harmonic analyser. A certain periodic wave that repeats itself every half-cycle is found to have ordinates y corresponding to angles θ degrees as follows—

θ	0	15	30	45	60	75	90	105	120	135	150	165	180
y	1·4	3·9	5·2	5·5	5·3	5·0	5·2	5·7	6·4	6·3	4·9	2·0	− 2·7

Determine the amplitude and phase of the third harmonic present in the wave. (*Lond. Univ., Elec. Meas.*)

Ans. 1·83, leading $22\frac{1}{2}°$ relative to the fundamental.

(80) Explain how the amplitude of the harmonics in a supply voltage of complex wave-form may be determined experimentally with the aid of a dynamometer wattmeter and a beat-frequency oscillator of pure wave-form.

A single-phase load takes a current of

$$4 \sin \left(\omega t + \frac{\pi}{6}\right) + 1{\cdot}5 \sin \left(3\omega t + \frac{\pi}{3}\right) \text{ amperes}$$

from a source represented by 360 sin ωt volts. Calculate the power dissipated by the circuit and the circuit power factor. (*Lond. Univ., Elec. Meas.*)

Ans. 623·5 W; 0·837.

(81) A coil of 200 turns, wound on a rectangular former 10 cm long and 8 cm wide, is placed with its longer side parallel with and 5 cm distant from a current-carrying conductor, the plane of the coil being arranged so that it contains the conductor.

Calculate the e.m.f. induced in the coil by a current

$$i = 10 \sin 314t + 5 \sin 942t$$

flowing in the conductor. What is the mutual inductance between the coil and the conductor?

Ans. $e = -[0{\cdot}012 \cos 314\,t + 0{\cdot}018 \cos 942\,t]$; $M = 3{\cdot}82$ microhenrys.

(82) A critically-damped Duddell oscillograph is required to reproduce the 13th harmonic of a 50 c/s wave with relative amplitude correct to within 2 per cent.

What should be the natural frequency of the movement?

What will the relative phase angle departure of the 13th harmonic be? (*Lond. Univ., Elec. Meas.*)

Ans. 4,590 c/s; 16° 7′.

(83) Sketch and describe briefly the essential features of a cathode-ray tube and suggest a simple method of providing a time-base that is practically linear.

Derive an expression for the electrostatic deflection in centimetres per volt. State any approximations used. Assume that the screen is flat and perpendicular to the centre line of the tube and neglect fringing effects at the edges of the deflecting plates. (*Lond. Univ., Elec. Meas.*)

CHAPTER XVI

(84) A capacitor of capacitance C, charged to a voltage V, is discharged at $t = 0$ through a resistance R in series with a leaky capacitor of capacitance C_2 and leakage conductance G, initially uncharged. Derive an expression for the voltage that will develop across C_2.

(*Lond. Univ., Elec. Theory and Meas., Part III*)

Ans. $v = \dfrac{V}{C_2R(m_1 - m_2)}\left(e^{m_1 t} - e^{m_2 t}\right)$

where m_1 and m_2 are the roots of the equation

$$D^2 + D\left[\frac{G}{C_2} + \frac{1}{C_2R} + \frac{1}{CR}\right] + \frac{G}{RC_2C} = 0$$

(85) Derive an expression for the current in a circuit containing resistance and inductance, due to an alternating voltage connected to the circuit at time $t = 0$.

If the resistance is 10·0 ohms, the inductance 2·5 henrys, and the circuit is connected to a 200 volt, 50 c/s supply at the instant when the voltage is a maximum, draw the first four cycles of the current wave.

(86) A sinusoidal voltage of 1,000 V and frequency 50 cycles per second is suddenly switched on to an inductive circuit of reactance 40 ohms and resistance 2·5 ohms. If the switch is closed when the instantaneous value of the voltage is zero, what will be the value of the current half a cycle later in time? (*Lond. Univ., Elec. Meas.*)

Ans. 4·01 A.

(87) Derive an expression from which the instantaneous current flowing in a circuit of inductance L and resistance R may be calculated at any time t after applying a voltage $V \cos(\omega t + \phi)$.

From the expression find the ratio of the maximum value to which the current rises to the steady-state maximum value, when the voltage is applied at the instant when it is zero, taking $R = 20$ ohms, $L = 0{\cdot}1$ henry, and $\omega = 1{,}000\pi$.

(*Lond. Univ., Elec. Meas.*)

Ans. $i = \dfrac{V}{\sqrt{R^2 + \omega^2 L^2}} \sin(\omega t + \phi + \alpha) + Ae^{-\frac{Rt}{L}}$, where $\alpha = \tan^{-1}\dfrac{R}{\omega L}$ and A is a constant depending on the initial conditions; 1·8 (approx.).

(88) Two coils, A and B, have mutual inductance between them, coil A having an inductance of 1 H. When the two coils are connected in series, it is found that the total inductance is either 2·3 H or 0·7 H, depending upon the method of connection.

The series connection is now removed and a p.d. given by

$$v = 100 \sin 314\, t \text{ volts}$$

is switched across A at an instant 10 milliseconds after the instant of zero voltage, B being on open circuit.

Assuming that the coils have no resistance, find (*a*) the maximum value of the current in A, (*b*) the value of the e.m.f. across B, 12 milliseconds after the switch was closed, and (*c*) the current in A at this instant.

Sketch the waveform of the primary current.

Deduce an expression (without evaluating it) for the current, if the coil A has resistance. (*Lond. Univ., Elec. Theory and Meas., Part III*)

Ans. (*a*) 0·636 A; (*b*) 23·5 V; (*c*) 0·573 A.

CHAPTER XVIII

(89) The coil of a 150-volt moving-iron voltmeter has a resistance of 400 ohms and an inductance of 0·75 henry. The current drawn by the instrument when placed on a 150 volt d.c. supply is 0·05 amp. Estimate–

(*a*) The temperature coefficient of the instrument per degree centigrade.

(*b*) The alteration of the reading between direct current and alternating current at 100 c/s.

(*c*) The capacitance of the capacitor necessary to eliminate this frequency error. Show the method of connecting the capacitor.

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·00066 ohm/ohm/°C; 1·17 per cent low at 100 c/s; 0·111 microfarad in parallel with the series resistance.

(90) Derive an expression for the torque of a moving-iron ammeter.

A resonating circuit was made by connecting a moving-iron ammeter in series with a 2·5 μF capacitor, and the resonance frequency, f in c/s, was determined with an ammeter deflection θ radians. It was found that f varied with θ in accordance with the expression

$$f = 1{,}000e^{-\theta/6}$$

The control torque of the ammeter is 11×10^{-6} newton-metre per radian. Determine the current in the circuit when $\theta = 1{\cdot}5$ radians.

(*Lond. Univ., Elec. Theory and Meas., Part III*)

Ans. 77 mA.

(91) The control spring of a moving-iron ammeter exerts a torque of 5 dyne-cm per degree [5×10^{-7} newton-metre per degree], and the inductance of the coil varies with the pointer deflection according to—

Deflection (degrees) .	20	40	60	80
Inductance (μH) . .	657	700	750	790

Determine the deflection produced by a current of 0·5 A.

Derive any expression used, and suggest a suitable method for measuring the variation of inductance with deflection.

(*Lond. Univ., Elec. Meas.*)

Ans. 31°.

(92) A moving-coil ammeter, a thermal ammeter, and a resistance of 100 ohms are connected in series with a rectifying device across a sinusoidal alternating supply at 200 volts. If the device has a resistance of 100 ohms to current in one direction, and of 500 ohms to current in the opposite direction, calculate the readings on the two ammeters, the power taken from the mains, and that dissipated in the rectifying device.

Ans. 0·3 amp; 0·74 amp; 133·3 watts; 77·8 watts.

(93) Give a sketch showing the construction of a moving-coil voltmeter.

If the moving coil consists of 100 turns wound on a square former which has a length of 3 cm and the flux density in the air gap is 0·06 Wb/m², calculate the torque acting on the coil when it is carrying a current of 12 milliamp.

Ans. 0·66 g-cm ($6{\cdot}48 \times 10^{-5}$ newton-metre).

(94) An instrument spring, constructed of phosphor-bronze strip, has the following dimensions: length of strip, 370 mm; thickness of strip, 0·073 mm; breadth of strip, 0·51 mm.

If E (Young's modulus for phosphor-bronze) be taken as $1{\cdot}15 \times 10^6$ kg per cm², estimate the approximate torque exerted by the spring when it is turned through an angle of 90°.

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·0805 g-cm ($0{\cdot}79 \times 10^{-5}$ newton-metre).

(95) The moving coil of a permanent-magnet ammeter is wound with 10 turns of copper wire, and has a resistance of 0·1 ohm. The total torque exerted by the control springs is 0·02 g-cm ($1{\cdot}96 \times 10^{-6}$ newton-metre) per degree. When the terminals are connected to a Grassot fluxmeter, and a scale angle of 90° is traversed by the ammeter pointer, a linkage of 3×10^{-3} weber-turns is indicated.

Estimate the temperature coefficient of the ammeter when operating off a shunt having a drop of 0·075 volt at full load.

Ans. 0·00062 ohm/ohm/° C.

(96) State the causes of change of accuracy in moving-coil instruments with change of temperature. Explain how compensation is made in ammeters for change of electrical resistance of the moving coil with change of temperature.

It is required to construct a resistor of 5·0 ohms with a resistance-temperature coefficient of 8×10^{-5} per °C. Platinoid and manganin wire of cross-sectional area 0·4 mm² are available and are to be connected in series. Calculate the lengths required if the resistivity of platinoid is 34·4 microhm-cm, and its resistance-temperature coefficient is $2{\cdot}5 \times 10^{-4}$ per °C; corresponding figures for manganin are 48 microhm-cm, and 2×10^{-5} per °C. All figures refer to 0°C. (*Lond. Univ., Elec. Meas.*)

Ans. 151·3 cm platinoid.
308 cm manganin.

(97) A dynamometer ammeter is fitted with two field coils having a total resistance of 3·0 ohms and a total inductance of 0·12 henry, and a moving coil of resistance 30 ohms and inductance 0·003 henry. Calculate the temperature coefficient for changes of external temperature, and the error in reading when the instrument is calibrated with direct current and used on alternating current, 50 c/s, for each of the following arrangements—

(*a*) When the moving coil is shunted direct across the field coils.

(*b*) When the moving coil is shunted across a non-inductive resistance placed in series with the field coils.

(*c*) When connected as in (*b*), the non-inductive resistance having a value of 10 ohms, a suitable swamp resistance being placed in series with the moving coil. (*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·004, 41·1 per cent low; 0·0024, 0·04 per cent low; 0·0006, 0·003 per cent low.

(98) Find the expression for the deflection of a quadrant electrometer in terms of the potentials of the two pairs of quadrants and the needle.

Hence explain the use of the instrument as (i) a voltmeter, and (ii) a wattmeter.

(99) Explain the action of a shaded-pole ammeter, showing by means of a sketch the direction of movement of the disc relative to the magnet poles. How is adequate damping secured, and how is the spread of the scale controlled? What are the advantages of this type of instrument for switchboard use, and to what errors is it subject? (*Lond. Univ., Elec. Meas.*)

(100) Describe the principle and action of a shaded-pole motor. Explain how the torque is produced; show clearly in which direction it acts, and in what way it depends on the frequency.

How is the shaded-pole device applied in a.c. ammeters?

(*Lond. Univ., Elec. Meas.*)

(101) A metal rectifier is used for the measurement of a sinusoidal alternating current. The rectifier consists of four units arranged in bridge, each unit having approximate forward and reverse resistances of 5 ohms and 500 ohms respectively. The moving-coil indicator has a resistance of 20 ohms. Determine the indication when the r.m.s. input current is 4 milliamperes.

(*Lond. Univ., Elec. Meas.*)

Ans. 3·26 mA.

CHAPTER XIX

(102) A soft-iron voltmeter for a maximum reading of 120 volts has an inductance of 0·6 henry and a total resistance of 2,400 ohms. It is calibrated to read correctly on a 60 c/s circuit. What series resistance would be necessary to increase its range to 600 volts? Draw up suitable workshop instructions for making up the resistance. (*Lond. Univ., Elec. Meas.*)

Ans. 9,660 ohms.

(103) The capacitance of an electrostatic voltmeter reading from 0 to 2,000 volts increases uniformly from 45 to 55 micromicrofarads as the pointer moves from zero to full-scale deflection. It is required to increase the range of the instrument to 20,000 volts by means of an external air capacitor.

Calculate the area of a pair of capacitor plates suitable for the purpose. If the capacitor is adjusted to make the full-scale reading correct, what will be the error per cent at half-scale reading?

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 175 sq. cm, assuming the distance between plates to be 2·5 cm; 8·9 per cent high.

(104) Discuss the reasons why the errors of a current transformer are usually greater with relatively small loads than at rated full load.

At its rated load of 25 VA, a 100/5-ampere current transformer has an iron loss of 0·2 W and a magnetizing current of 1·5 A. Calculate its ratio error and phase angle when supplying rated output to a meter having a ratio of resistance to reactance of 5. (*Lond. Univ., Elec. Meas.*)

Ans. − 1·07 per cent; 0° 45′.

(105) Why is it important to use high-grade magnetic material for the laminations of current transformers? Discuss some of the advantages gained by substituting nickel-iron for silicon-iron in current transformer construction. (*Lond. Univ., Elec. Meas.*)

(106) An 8/1 current transformer has an accurate current ratio when the secondary is short-circuited. The inductance of the secondary is 60 millihenrys and its resistance is 0·5 ohm, and the frequency is 50 c/s. Estimate the current ratio and phase-angle error when the instrument load has a resistance of 0·4 ohm and an inductance of 0·7 millihenry. State the assumptions made. (*Lond. Univ., Elec. Meas.*)

Ans. 8·001; 0° 2′ assuming no iron loss, constant permeability, and magnetizing current = 1 per cent of primary current.

(107) A voltage transformer, ratio 1,000/100 volts, has the following constants—

Primary resistance . . .	94·5 ohms
Secondary resistance . .	0·86 ohm
Primary reactance . . .	66·2 ohms
Equivalent reactance . .	66·2 ohms
Magnetizing current . .	0·02 amp at 0·4 power factor

Calculate—

(i) The phase angle at no load between primary and secondary voltages.

(ii) The load in volt-amperes at unity power factor at which the phase angle will be zero. (*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0° 4′, 18·1 volt-amperes.

(108) The primary magnetizing current of a nickel-iron-cored current transformer with bar primary. nominal ratio 100/1, operating on an external burden of 1·6 ohms non-inductive, the secondary winding resistance being 0·2 ohm, is 1·9 amp, lagging 40·6° to the secondary volts reversed, there being 100 secondary turns. With 1·0 amp flowing in the secondary calculate—

(*a*) The actual ratio of primary to secondary current.

(*b*) The phase angle between them, in minutes. (*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 101·45, 42 min.

(109) Discuss the advantages and disadvantages of using a highly permeable alloy for the construction of the cores of current transformers. Explain the meaning of the term *burden*.

A bar-type current transformer of toroidal construction requires 400 ampere-turns to magnetize it, and 300 ampere-turns to supply the iron losses, for each volt per turn induced in the secondary winding at rated frequency. Across the secondary terminals is connected an impedance of 2 ohms with a phase angle ϕ, and the resistance of the secondary winding is 0·5 ohm. The nominal ratio is 1,000/5 amperes, and it is required to minimize both ratio and phase errors. Determine the necessary values of N and ϕ, where N is the number of secondary turns. (*Lond. Univ., Elec. Meas.*)

Ans. 194; 64° 40′.

CHAPTER XX

(110) In a test by the three-voltmeter method, the following readings were obtained: Across the mains, 180 volts; across the non-inductive resistance of 6 ohms, 88 volts; across the load, 106 volts. Calculate the self-inductance and effective resistance of the load and the power supplied to it.

Ans. Eff. res. = 5·22 Ω; Reactance = 5·0 Ω; Power = 1,120 W.

(111) Describe the two-wattmeter method of measuring power in a three-phase circuit.

If the readings of the wattmeter are 3 kW and 1 kW respectively, the latter reading being obtained after reversing the connections to the current coil of the wattmeter, calculate the power and the power factor.

Ans. 2 kW, 0·277.

(112) A small single-phase transformer is connected across a single-phase supply in series with a low-resistance ammeter A_1. In parallel with the transformer and across the same terminals is connected a resistance of 100 ohms in series with another ammeter A_2. A third ammeter A_3 is placed directly in series with the supply mains. If the readings on the three ammeters are: A_1, 10·0 amp; A_2, 1·0 amp; A_3, 10·5 amp, find (*a*) the watts input into the transformer; (*b*) the power factor of the load due to the transformer.

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 462·5 W; 0·462.

(113) The power flowing in a three-phase, three-wire, balanced-load system is measured by the two-wattmeter method. The reading on wattmeter *A* is 5,000 watts, and on wattmeter *B* is − 1,000 watts.

(*a*) What is the power factor of the system?

(*b*) If the voltage of the circuit is 440, what is the value of capacitance which must be introduced into each phase to cause the whole of the power measured to appear on wattmeter *A*?

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·359; 5·43 ohms.

(114) A dynamometer-pattern wattmeter has a field system which may be considered as long compared with the diameter of the moving coil. The flux density *B* in the field coils is 0·01 Wb/m². The mean diameter of the moving coil is 3 cm, and it is wound with 500 turns of copper wire.

If the current through the moving coil is 0·05 amp and the wattmeter is measuring the power flowing in a circuit having a power factor of 0·7, estimate the torque, if the axes of the field and moving coils are at (*a*) 45°, and (*b*) 90°.

(*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·89 g-cm ($8{\cdot}74 \times 10^{-5}$ newton-metre); 1·26 g-cm ($1{\cdot}2 \times 10^{-4}$ newton-metre)

CHAPTER XXI

(115) Show that the eddy-current torque on a metallic disc rotating between the poles of a permanent magnet is directly proportional to the angular velocity of the disc. How would the torque be expected to vary with the position of the magnet poles relative to the axis of the disc? What use is made of this device in the construction of energy meters, and what part does it play in the operating mechanism? (*Lond. Univ., Elec. Meas.*)

(116) In a simple bipolar form of a.c. energy meter, the distance between the pole centres is 1·5 cm and the effective radius of action is 2·5 cm. The fluxes produced by the series and shunt magnets are $3{\cdot}5 \times 10^{-6}$ and $2{\cdot}75 \times 10^{-6}$

weber (r.m.s.) respectively, their phase displacement being 82°. The aluminium driving disc is 0·06 cm thick and its resistivity may be taken as 3 microhm-cm.

Neglecting the edge effect of the disc, calculate its speed if the brake magnet exerts a braking torque of $7 \cdot 5 \times 10^{-7}$ newton-metre when the speed is 1 revolution per minute. Frequency = 50 c/s.

Ans. 40·4 r.p.m.

(117) A large consumer has a kVA demand and a kVAh tariff, measured (by mutual agreement) by "sine" and "cosine" watt-hour type meters, each equipped with a Merz demand-indicator. The tariff is 10s. per month per kVA + ½d. per kVAh. Render the consumer his bill for one month of 30 days, based on the following readings: "Sine" meter advance 90,000 reactive-kVAh, demand indicator 150 reactive-kVA. "Cosine" meter advance 120,000 kWh, demand indicator 200 kW.

What are his average monthly power factor and load factor, and his total cost per *unit*? (*A.M.I.E.E., Meters and Meas. Insts.*)

Ans. 0·719d. per unit. Average load factor = Average power factor = 0·8.

CHAPTER XXII

(118) Describe a direct-reading frequency meter for measuring a frequency of the order of *either* (*a*) 50 cycles per second *or* (*b*) 500 cycles per second. Suggest a suitable method for calibrating the instrument.

(*Lond. Univ., Elec. Meas.*)

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