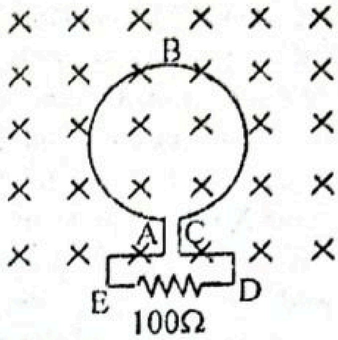
Electro Magnetic Induction

1991 A/L-8

1) State the laws of electromagnetic induction.

As shown in the figure a thin rigid wire is formed into a circular loop ABC and placed perpendicular to a uniform magnetic field which is directed into the plane of the paper. The loop is connected to a resistance of 100 Ω using thin connecting wires. The radius of the loop is 7 cm and the magnetic flux density of the field decreases with time at a constant rate of 10^{-2} T s^{-1}.



i) Neglecting the effect of connecting wires, calculate the magnitude of the e.m.f. induced in the loop.

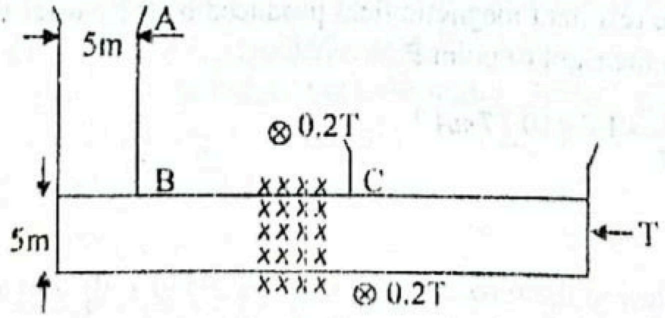
ii) Assuming that the resistances of the loop and connecting wires are negligible, find the magnitude of the current through 100 Ω.

iii) What is the direction of the current through 100 Ω resistor ? (from D to E or E to D)? Explain clearly how you arrived at the answer.

iv) When the current flows through the loop a tension is developed in the wire. Explain how this arises and calculate this tension at the instant when the magnitude of the magnetic flux density, threading the loop is 0.1 T.

1994 A/L

2) An L – shaped tube ABC of square cross – section of side 5 mm is connected to a large tank T containing a conducting liquid as shown in the diagram. A uniform magnetic field of flux density 0.2 T is acting in the direction indicated across the horizontal arm of the tube BC. A current of 6 A is passed vertically upwards along an entire cross section of the liquid



(i) Find the magnitude and direction of the force acting across the cross-section of the liquid

(ii) Find the pressure developed across the cross-section of the liquid due to the above force

(iii) If the density of the liquid is 1.2 x 10^3kg m^{-3} how high will the liquid level rise in the vertical arm AB due to this pressure? (Assume that the change in level of liquid in the tank is negligibly small)

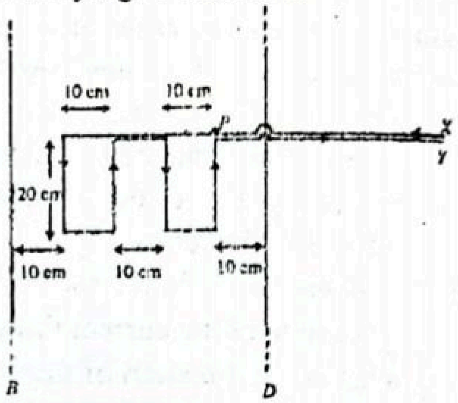
(iv) if the vertical arm AB of the tube is not there, what is the flow speed of the liquid?

1995 A/L

3) Write down Biot -Savart law in the form of a mathematical expression clearly identifying all the symbols you have used. Show in a diagram the directions of all the variables associated with the expression.

Write down an expression for the magnetic flux density B at a point which is situated at a distance r from a thin straight conductor of infinite length carrying a current I.

A wire XY bent to form two rectangular loops as shown in the figure and carrying a current of 10 A is placed symmetrically between two long straight parallel wires AB and CD so that their long sides run parallel to AB and CD. All wire sections of XY, which are parallel to the two long wires have a length of 20 cm and a separation of 10 cm as indicated on the diagram. Assume all the wires lie on the same pane.



(i) If the wire AB carries a current of 20 A in the upward direction ($\overrightarrow{BA}$) find the magnitude and the direction of the resultant force exerted on the wire XY by the magnetic field due to the current in wire AB.

(ii) Is the actual magnitude of the resultant force acting on XY equal to the value calculated in (i) ? Explain your answer.

(iii) Now in addition to the wire AB, the wire CD also carries a current of 20 A but in the opposite direction ($\overrightarrow{CD}$) find the magnitude of the resultant force acting on the wire XY by the magnetic fields due to the currents in AB and CD. You may arrive at your answer even without a calculation but in such cases a brief explanation is required.

(iv) Comment on the resultant magnetic field produced by the pair of wires belonging to XY which lie to the right of point P.

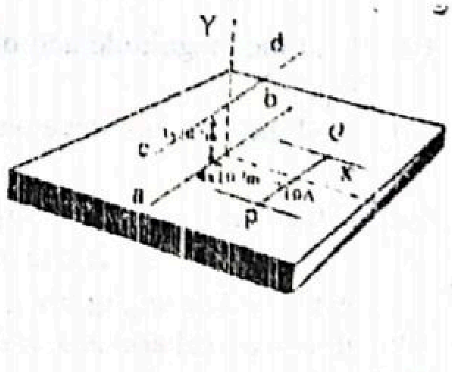
$$\frac{\mu_0}{4\pi} = 1.0\times10^{-7}\, TmA^{-1}$$

1997 A/L

4) State Biot Savart law in the form of an expression and identify all the symbols used.

Write down an expression for the magnetic flux density B at a point, a distance r from a long straight wire carrying a current I.

ab is a long straight wire placed on a table, and cd is a similar wire kept 3×10^{-2} m vertically above ab and run parallel to it, as shown in the figure. PQ is a small current carrying conductor placed on the table parallel to ab. The distance between ab and PQ is 4×10^{-2} m. PQ is free to move on two horizontal conducting rails. Length of PQ is 10^{-1} m and a current of 10A flows through it in the direction, P to Q.



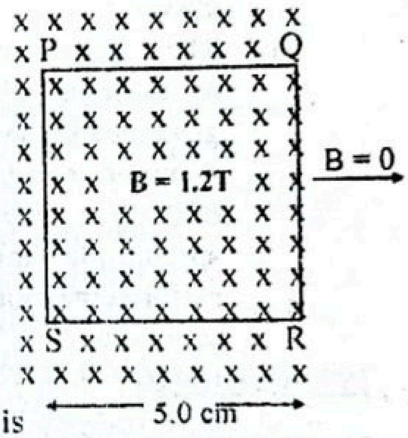
(i) If the write ab carries a current of 5 A in the direction a to b, find the magnitude and direction of the force acting on PQ due to this current $\left(\frac{\mu_0}{2\pi} = 2\times10^{-7}\,TmA^{-1}\right)$

(ii) In addition to the current in ab, if cd also carries a current of 6.25 a in the direction d to c, find the magnitude of the force acting on PQ due to this current. Indicate the direction of the force on a diagram.

(iii) If the mass of the conductor PQ is 10^{-4} kg find the Ndirection of motion, and the magnitude of the initial acceleration of PQ.

(iv) Find the magnitude and direction of the minimum current that should be setup in cd in order to lift PQ from rails.

5) a square coil PQRS of side 5.0 cm contains 200 turns and is positioned perpendicular to a uniform magnetic field of flux density B = 1.2 T as shown in the figure. It is then pulled at an uniform velocity to the right , to a region of zero magnetic field while keeping the plane of the coil perpendicular to the magnetic field. It takes 0.2 s for the whole coil to reach the field free region.



(i) Calculate the e.m.f. induced in the coil during the 0.2 s time period.

(ii) Name the side/sides of the coil in which the e.f.f. is induced and indicate the directionof the induced current on a diagram

(iii) If the resistance of the coil is 100Ω calculate the energy dissipated in the coil during the 0.2 s time interval.

(iv) Hence, deduce the work needed to pull the coil out of the field. State the law in physics that you have used to arrive at the answer.

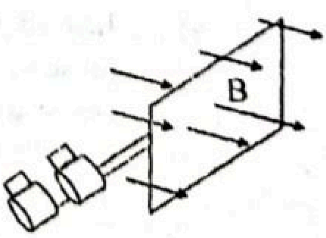
(ii) If the magnetic field is reduced to zero uniformly during the same time interval of 0.2 s. instead of pulling the coil, will you observe the same induced e.m.f. as in (i) . Give reasons for your answer.

1998 A/L

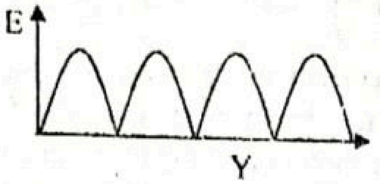
6) A coil wound round an armature in the form of a rectangular loop is shown in the figure (X). The loop contains N turns of wire each having length a and width b. The armature rotates at a constant angular velocity ω in a uniform magnetic field of flux density B.

(i) Show that the maximum e m.f. generated by the coil is NabBω.

(ii) The above arrangement can be modified to use as a dc generator, and obtain an e.m.f. (E) which varies with time (t) as shown in the figure (Y)



Explain with a labeled dingram how you would modify the above arrangement shown in figure (X) to achieve this

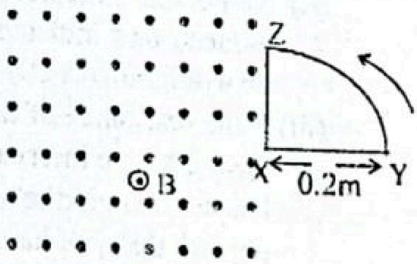


(iii) Now another identical loop is fixed to the same armature so that the plane of the loop is perpendicular to that of the former loop, and the armature is rotated with the above angular speed. Copy the figure (Y) and drew in the same time scale, the variation of e.m.f. when both outputs are connected in series. Clearly label all the curves.

(iv) The dogenerator mentioned in (ii) can be used as an electric motor by connecting an external voltage source across the output. Explain how a back e.m.f. is generated in the loop under this situation.
A motor has an internal resistance of 10Ω. When it is driven by a voltage source of 200V, a current of 6 A is found to be drawn from the supply at its operating speed. Find the back e.m.f. of the motor. Find also the current drawn by the motor at the moment it is turned on.

1999A/L-5(A)

7) (a) A flat loop of wire Xyz in the form of a quarter of a circle of radius 0.2 m rotates uniformly about the point X in the plane of the paper. The sense of rotation is given by the arrow. The loop passes in and out of a region of uniform magnetic field of flux density (B) 0.5 T as shown making one complete revolution in 0.8 seconds.



(i) What is the maximum magnetic flux through the loop during its rotation?

(ii) Plot with relevant values the variation of magnetic flux through the loop with time t during one complete revolution assuming that the loop is at the position indicated in the diagram at t = 0

(iii) what is the maximum magnitude of the induced e.m.f. generated in the loop.?

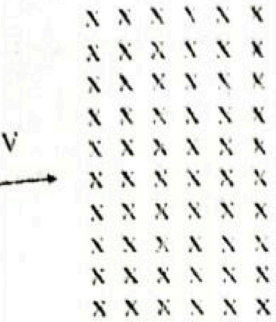
(iv) Draw the educed e.m.f. in the loop, with relevant values as a function of time on a time scale of 0-08 s with the same assumption for t = 0 as in (ii)

(v) Instead of a closed loop if only the two conducting wires XY and XZ are present. what ill be the maximum and minimum values of the induced e.m.f. across the ends X and Y or, X and Z of each wire?

(vi) Plot the variation of induced e.m.f. across one wire as a function of time for one complete revolution

2000 A/L

8) A proton enters perpendicular to a uniform magnetic field of flux density.



0.017 T with a velocity of $8.0 \times 10^5\ ms^{-1}$ as shown in the diagram where the magnetic field is directed into the paper. The charge and the mass of the proton are 1.6×10^{-19} C and 1.7×10^{-27} kg respectively.

(i) (a) Explain why the path of the proton in the magnetic field is circular. Find the radius of the path Copy the given diagram and draw a rough sketch of the path of the proton on it.

(b) If instead an electron enters with the same velocity in a similar manner how does its path differ from the path of the proton?

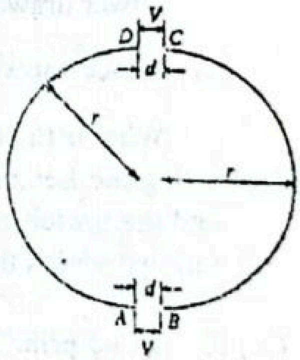
(ii) Deduce the radius of the orbit of an a particle entering this magnetic field with the same velocity in a similar manner.

(iii) If a neutron enters the magnetic field in the similar manner. Show its path on the diagram drawn in (i) (a) Label the path

(iv) If a suitable uniform electric field is now applied in addition to the magnetic field the deflection of particles due to the magnetic field can be nullified. Find the magnitude and direction of this electric field for a proton. Will there be any change of the velocity of the particles in this situation? Give the reason for your answer.

2002 A/L

9) A Proton of charge q and mass m is set up to travel along the path ABCDEA through small holes on parallel plate as shown in the diagram. It has been done by applying uniform eclectic fields between the plates and uniform magnetic fields out side the plates. AB and CD are straight paths of length d and BC and DA are semicircular paths of radius r. Each pair of plates is subjected to a potential difference of V. Neglect gravity. Answer the questions in terms of given symbols.



(i) (a) Write down expressions for the electric fields between the plates. Indicate their directions.

(b) The proton is initially released from rest at the hole A. Obtain expressions for the energy and the speed of the proton at B.

(ii) (a) Derive an expression for the magnetic flux density along the path BC. Indicate its direction.

(b) What is the speed of the proton when it enters the hole C? Give the reason for your answer.

(iii) (a) Obtain expressions for the new energy and the speed of the proton when it leaves the hole D..

(b) Will the magnetic flux density obtained in (ii) (a) sufficient to guide the proton along the path DA? (Yes/No). If not, obtain an expression for it.

(iv) Explain briefly how this set up can be used to accelerate the proton to a higher energy without changing the magnitude of V.

(v) Can this process be done in air? If not, suggest a suitable solution?

10) The figure (*a*) shows an arrangement that consists of a bar XY of mass m and resistance R placed on two parallel smooth horizontal conducting rails with negligible resistance, separated by a distance l. A uniform magnetic field with a flux density B is applied perpendicular to the plane of the rails (into the paper) and throughout the region between the rails. A battery of e.m.f. E with negligible internal resistance connected to the rails produces a current through the bar.

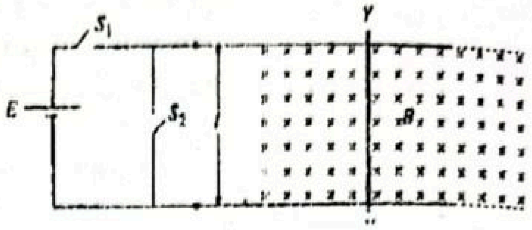


figure (a)

(i) When the bar XY is at rest on the rails, the switch S_1 is closed, while keeping switch S_2 opened.
Write down an expression using the given symbols for the force experienced by bar XY at this instant, due to the magnetic field. What is the direction of this force?

(ii) Consider an instant at which the bar is moving at a speed v which is less than its maximum speed.

(a) Write down an expression for the magnitude of the back e.m.f. induced across the bar at this instant.

(b) Obtain expressions for the current through the bar, the force on the bar, and the power drawn from the battery at this instant.

(c) Hence show that the maximum speed that the bar XY can attain is given by $\frac{E}{Bl}$.

What is the current through the bar when it is moving at the maximum speed?

(iii) Using the Lenz's law show that the bar can be decelerated if the switch S_1 is opened and the switch S_2 is closed at any instant while it is moving. What is the mechanism through which the kinetic energy of the bar is converted to heat during this process?

(iv) The above principle is used in the device known as linear motor which has many applications. One such application is launching of an aircraft from a ship. As shown in figure (*b*), the aircraft is mounted on the moving bar and when it reaches the required speed, the aircraft is detached from the bar and allowed to take-off. The bar is then decelerated as mentioned in part (iii) above.

figure (b)

Suppose the combination of the bar and the aircraft has a mass of 20 000 kg, the separation between the rails is 10 m, the magnetic flux density is 2 T, and the resistance of the bar is 100 Ω.

(a) Calculate the e.m.f. that should be provided by the battery to achieve a maximum speed of 100 ms^{-1}.

(a) Hence calculate the initial acceleration of the aircraft.

11) A uniform magnetic field of flux density B exists in a certain region of space. As shown in figure 1 an electron of mass m and charge e, is projected with velocity υ perpendicular to the field. The electron moves along a circle of radius R.

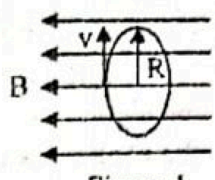


Figure 1

a) i) Derive an expression for R.

ii) Obtain an expression for the number of revolutions, f_1 per unit time that the electron makes.

b) When a charged particle like an electron moves along a circle it emits electromagnetic waves with a frequency which is equal to its own frequency, f_1 of revolution. Microwave oven are produced by allowing electrons to move in circular paths in a magnetic field as described above. The unit which produces microwaves in a microwave ovens in known as a magnetron.

i) A magnetron in a microwave oven emits microwaves with frequency 2450 MHz. Determine the magnetic flux density B. needed to produce wuch microwaves ($m = 9.0 \times 10^{-3}$ kg. $e = 1.6 \times 10^{-19}$ C) Round off your answer to the second decimal place.

ii) Such a uniform magnetic field could be produced inside a current carrying solenoid.

1) Long. closely wound solenoid with a turns per unit length carries a current *I*. Write down an expression for the magnetic flux density B in the solenoid along its axis.

2) For a current of I = 10A. what should be the value of n in order to produce B calculated in b) i) above. (Take $\mu_0 = 10^{-6}$ Tm A^{-1}).

3) Sketch the magnetic flux lines in and around such a solenoid.

c) If the directions of the initial velocity of the projected electron in (a) above makes an angle θ to the direction of the uniform magnetic field, the path of the electron is a helix as shown in figure 2.

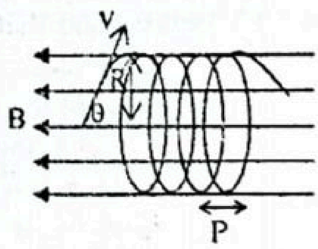


Figure 2

i) Build arguments to prove that the path of the electron is a helix

ii) Deduce an expression for the radius R' of the helical path

iii) As shown in the figure the distance travelled by the electron along the axis of the helix per revolution is called the pitch p of the helix. Obtain an expression for p.

iv) Show that the ratio $\frac{R'}{P}$ depends only on θ.

12) Two identical planar electrodes are placed parallel to each other with a separation of d as shown in figure (1). A magnetic field of flux density B can be established between the electrodes in the direction shown in the figure. A beam of ions enters the magnetic field region with speed u parallel to LM as indicated in figure (1). Each ion has mass m and charge +q. The magnetic field is turned on at time $t = t_0$. Assume that the motion of the ions will not be affected by the medium through which they travel.

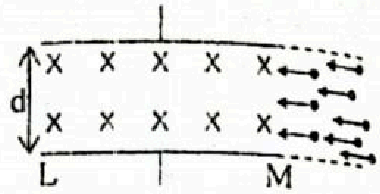


Figure (1)

(a) Obtain an expression for the radius R of the circular path followed by an ion which enters the magnetic field at time $t = t_0$ in terms of v, B, m and q.

(b) consider three ions which enter the magnetic field simultaneously at time $t = t_0$ from positions P (very close to the top electrode), Q and R as indicated in the figure (2).

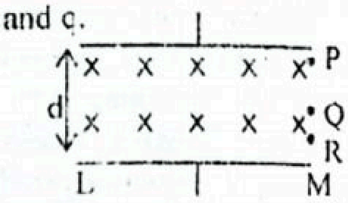


Figure (2)

Obtain an expression for the magnetic flux density B in terms of v, m, q and d for the ion entering the field region from position P to travel just touching the edge M of he electrode LM. Copy figure (2) and draw the paths of the ions entering the magnetic field from positions P, Q and R for this situation.

(c) Assume that the ions hitting the electrode LM get gradually and uniformly accumulated on the surface of the electrode.

(i) As the ions get accumulated on the electrode LM, what is the direction of the electric field being developed between the electrodes due to accumulated ions? Assume that the electric field is confined only to the space between the two electrodes.

(ii) Once of the accumulation of the ions on the electrode has begun, the path for the ions entering the field region is not a part of a circle. What is the reason for this?

(iii) After a certain period of time has elapsed, the ions entering the field region tends to travel along a straight line without deviation. If V_0 is the voltage across the electrodes once this state (steady state) has been reached, obtain an expression for v in terms of V_0, B and d.

(d) As the blood contains charged ions, blood flow detectors based on the above principle can be used to find the speed of blood flow through arteries. Here the two parallel plate electrodes are placed touching the walls of the artery as shown in figure (3), and, blood flow speed is determined by measuring the voltage across electrodes at the steady state.

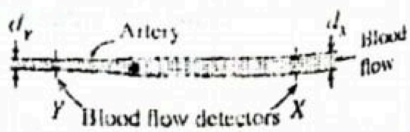


Figure (3)

(i) If the flux density of the applied magnetic field at a certain location X of an artery is $B_x = 0.08$ T and the measured voltage across the electrodes at X is $V_x = 2.16 \times 10^{-4}$ V, determine the speed of blood flow at X using the expression obtained in (c) (iii). The internal diameter of the artery at X is $d_x = 3 \times 10^{-3}$ m.

(ii) In order to investigate the possible change in diameter of the artery at another location Y, a similar device is placed at Y. When the magnetic field applied at Y is set to $B_Y = 0.05$ T, the measured voltage across the electrodes at Y is $V_Y = 1.80 \times 10^{-4}$ V. Find the internal diameter d_Y of the artery at Y.

2016 A/L – 8

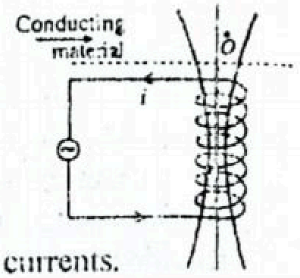
13) Read the following passage and answer the questions.

Induction heating technology is of choice in many industrial, domestic and medical applications due to its advantages such as less heating time, localized heating, direct heating and efficient synergy consumption. The operating principle of induction heating is based on the law of the electromagnetic induction discovered by Michael Faraday in 183i. The two major components in an inculcation heating system are a coil of wire (often a copper coil) producing a time varying magnetic field upon receiving a high frequency alternating current, and an electrically conducting material that generates heat. The magnetic field also changes its direction as the direction as the alternating current changes. When a conducting material is exposed to such a time - varying magnetic field, current loops called eddy currents are induced in the conducting material . As the magnetic field changes its direction rapidly the eddy currents also change their directions rapidly. The eddy currents always form closed loops inside conducting materials in planes perpendicular to the varying magnetic field. Eddy currents, generate Joule heat. (*I^2R type heat*) due to the existence of resistance of the material.

When the magnetic field created is stronger or when the electrical conductivity is higher or when the rate of change of magnetic field is larger, the eddy currents that are developed become larger. The eddy currents which are generated by high frequency alternating current in the coil will exist only within a limited thickness near the surface of the material due to what is called skin effect.

The skin effect is the tendency of any high frequency electric current to distribute it self in a conductor with the current density being largest near the surface of the conductor and decreasing very rapidly with the depth of the conductor. This thickness across which eddy currents are distributed becomes even smaller due the mutual attraction between the alternating current in the coil and the eddy current loops. This is called the proximity effect. In addition to the Joule heating, an additional heat is also produced within the material due to a phenomenon called hysteretic effect. It occurs only in ferromagnetic materials such as some stainless steel, cast iron, nickel, etc. In response to the varying magnetic field produced by the alternating current, the magnetic domains in these materials repeatedly change their orientations. The energy required to turn them around finally is converted to heat. The rate at which the heat is generated due to hysteretic effect increases with the frequency, of the varying magnetic field. Commercially available induction heating systems operate at frequencies approximately from 60 Hz to about 1 MHz and deliver power in the range from a few watts to several Megawatts.

The cookers that are available in the market as induction cookers operate on this principle. In an induction cooker, a coil of copper wire is mounted just under the surface of the cooker top where the cooking out is placed, without touching it, and an alternating electric current is sent through the coil. The entire bottom of the cooking pot itself acts as the conducting material that generates the heat. The varying magnetic field produced by the coil enters the bottom of the cooking pot creating eddy currents and hysteretic losses, generating heat. In order to make use of both effects for heat generation, the cooking pots or the bottoms of the cooking pots are made of ferromagnetic materials such as some stain steel or cast iron.



a) State Faraday's law of electromagnetic induction in words.

b) Name **two** fields of application where induction heating is used.

c) Write down the **two** heating processes involved in the induction heating.

d) Write down **three** factors which give rise to larger eddy currents.

e) Write down the **two** effects which limit the eddy currents to be within a limited thickness near the surface of the material.

f) Copy the given diagram and answer the following questions.

The direction of the alternating current in a coil at a certain instant of time is shown in the figure. Consider a situation where the magnitude of this current is increasing with time. A conducting material is placed just above the coil as shown in the figure.

i) Show the direction of the magnetic field created in this situation by drawing an arrow on one field line.

ii) Draw one loop of eddy current in the material near the position *O* and show the direction of the eddy current when the alternating current is increasing.

iii) Use Lenz's law to explain how you determined the direction of the eddy current loop that you have drawn in (*ii*) above.

g) Explain how the increase of the frequency of alternating current, increasing the rate of heating in the material.

h) Consider a situation where a time - varying magnetic field enters a disk of radius R, thickness b and resistively ρ. If the flux density B of the applied magnetic filed varies sinusoidally as $B = B_0 \sin w_t$ where B_0 is the amplitude of the flux density of the magnetic field, w is the angular frequency and t is the time, then based on a very simplified model the average power generated by the eddy currents in the disk can be given by, $P = k\ B_0^2\ w^2$ where $k = \frac{\pi R^4 b}{16\rho}$.

If $k = 0.5\ m^4\ \Omega^{-1}$, $w = 6000$ rad s^{-1} and $B_0 = 7.5 \times 10^{-3}\ T$, calculate the average power generated in the disk.

i) In transformers, the core is heated up due to eddy currents and it contributes to energy loss in the form of heat. How is this energy loss minimized in transformers?

2017 A/L- 9 (A)

14) a) Explain briefly how the back electromotive force (e.m.f.) is produced in a direct current motor. Name the laws in physics which determine (*i*) the magnitude and (*ii*) the direction of the back e.m.f. respectively.

b) Write down an expression for the back e.m.f. E produced by a direct current motor when it draws a current of I from a battery. The internal resistance of the motor coil is r and the terminal voltage of the battery is V.

c) If $V = 80\ V$ and $r = 1.5\ \Omega$ calculate the following quantities when the motor operates with full load drawing a current of $4.0\ A$.

i) Back e.m.f. (E) produced by the motor

ii) Power given to the motor.

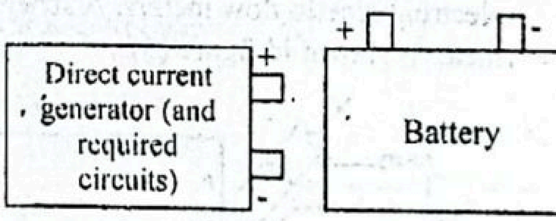
iii) The mechanical power output and the efficiency of the motor. (Neglect any energy losses due to friction.)

d) Assume that the values given for r and the current ($4.0\ A$) in (*c*) above for the motor are the values when the coil is at the room temperature of 30^0C. After running the motor for several hours it was found that the current in the coil had dropped to $3.6\ A$ with voltage V remaining unaltered at $80\ V$. Calculate the new temperature of the coil. Temperature coefficient of resistance of the material of the coil is 0.004^0C^{-1} r at 0^0C.

e) In electric motor vehicles, direct current motors driven by batteries are used to rotate the wheels of the vehicles. During the application of brakes, the same motor in such vehicles is made to operate as a direct current generator, and part of the kinetic energy of the vehicle is used to drive the generator. The generator output is then used to recharge the battery of the same vehicle.

i) How do you operate a direct current motor as a direct current generator?

ii) Copy the two diagrams in the figure to your answer script and show how you would connect the direct current generator output to charge the battery.



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15) A copper strip of width d and thickness t carries a current I from top to bottom as shown in figure 1(a). The strip is kept in a uniform magnetic field of flux density B directed perpendicular and into the plane of the strip. Cross-sectional view of the same arrangement is also shown in figure 1(b). The charge carriers are electrons and they drift with drift speed v_d.

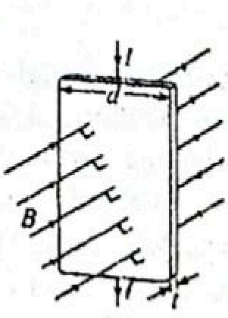

Figure 1(a)

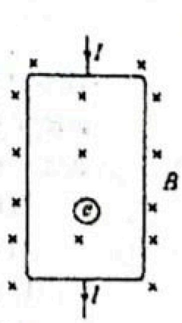

Figure 1(b)

a) i) what is the direction of the magnetic force acting on the electron (e) shown in figure 1(b)? Copy the figure 1(b) to your answer script and clearly draw an arrow on the electron to indicate the direction of this force.

ii) Now if you replace the copper strip shown in figure 1(b) with another strip having positively charged carriers, what is the direction of the magnetic force acting on a positively charged carrier?

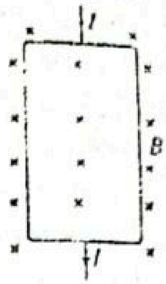

Figure (2)

b) i) As time goes on, in the copper strip described in (a)(i) above, there would be a new equilibrium situation with regard to the charges residing. Copy figure (2) to you answer script and illustrate this new equilibrium situation using '+' to represent positive charges and '–' to represent negative charges.

ii) Explain the reason to have the equilibrium condition as mentioned in (b) (i).

iii) Briefly describe how you would use this effect to verify that holes in a p-type semiconductor are positively charged carriers.

c) i) Derive an expression for the Hall voltage V_H in terms of v_d, B and d.

ii) The current I flowing through a conductor, such as copper, can be written as $I = neAv_d$, where all symbols have their usual meaning.

1) Derive the equation $I = neAv_d$.

2) Obtain an expression for V_H for the copper strip in terms of n, e, t, I and B.

3) Consider a copper strip of thickness 1×10^{-3} m in a uniform magnetic field of 0.5T. If $I = 48A$ and $V_H = 1.5 \times 10^{-6}$ V, calculate the number of charge carriers per unit volume in copper. Take $e = 1.6 \times 10^{-19}$ C.

d) Cardiologists monitor the flow speed of blood through an artery using an electromagnetic flow meters. A schematic diagram of the relevant parts of such a flow meter is shown id figure (3).

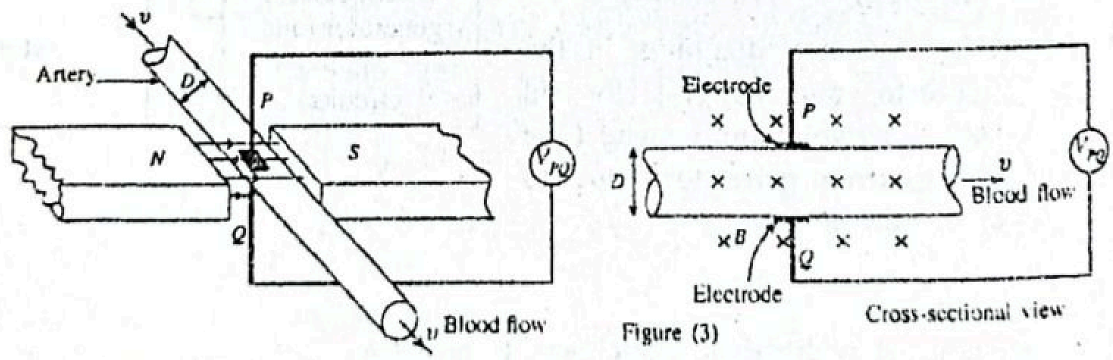

Figure (3)

Blood plasma has a high concentration of Na^+ and Cl^- ions moving through the artery with the blood at the same speed v and same direction as the blood flow. Assume that the ions in the blood behave as charge carriers.

i) When the blood flows through the artery shown in figure (3), what is the polarity of the electrode p? Give the reason for your answer.

ii) If the flux density of the uniform magnetic field applied to the system is B and the diameter of the artery is D, write down an expression for the magnitude of the voltage V_{PQ} across the two electrodes P and Q in terms of v, B and D.

iii) If $V_{PQ} = 160\ \mu V$, D = 5 mm and $B = 2 \times 10^3$ gauss (1 gauss = 10^{-4} T), calculate the value of speed v of the blood through the artery.