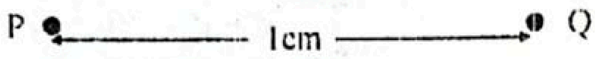
Electric Field

1993 A/L-8

1) What are the similarities and differences between gravitational forces and electrostatic forces? Two protons P and Q of mass 1.67 x 10-27 kg and charge + 1.6×10^{-9} C are placed 1 cm apart as shown in the figure. Show that the gravitational force acting between them is negligibly small when compared to the electrostatic force acting between them



(universal constant of gravitation $G = 6.67 \times 10^{-11}$ Nm^2kg^{-2}, $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2C^{-2}$)

Suppose the proton Q moves around the proton P which is at rest in a circle of radius 1 cm in the clockwise direction.

(i) Calculate the magnitude of the electric field intensity experienced by the proton P

(ii) If the proton Q make F number of revolutions per sec. the effective current I flowing around the circumference of the circle can be written as,
$I = ef$, where e is the proton charge.
Determine the magnitude and direction of the magnetic flux density produced by this current at the centre when $f = 10^3$ Hz. $\left(\frac{\mu_0}{4\pi} = 10^{-7}\,TmA^{-1}\right)$

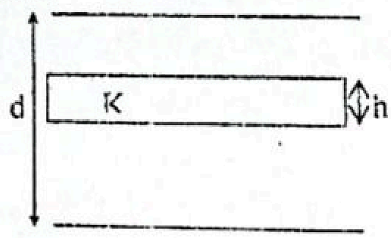
(iii) Is there a force on the proton P due to this magnetic field? Explain your answer.

(iv) If the moving proton Q is replaced by a thin circular loop of wire carrying the same current I repeat the calculations (i) and (ii) above.

1994 A/L-7 (b)

2) A parallel plate capacitor having plate area A carries a charge Q. If the capacitor is placed in air derive an expression for the electric field intensity E across the pates.

A parallel plate capacitor placed in air has a plate area A and a plate separation d. It is charged to charge Q by connecting a constant voltage source across the plates. The voltage source is then disconnected and a slab of dielectric constant k and thickness h is inserted between the plates as shown in the figure.



(i) Write down expressions for the electric field intensity
  (a) in the gap between the upper plate and the dielectric slab.
  (b) in the dielectric slab
  (c) in the gap between the dielectric and the lower plate

(ii) Derive an expression for the potential difference across the plates of the capacitor.

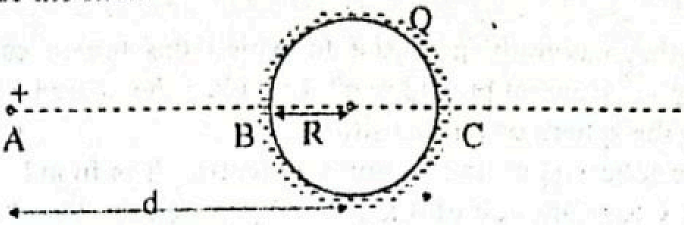
(iii) Hence or otherwise show that the effective capacitance of the capacitor is given by
$$\frac{k\varepsilon_0 A}{Kd - h(k-1)}$$

(iv) If the dielectric slab is inserted without disconnecting the voltage source what will be the final charge on the capacitor?

(v) In which situation it is easier to insert the dielectric slab? Explain your answer without doing any calculations.

1995 A/L-8

3) A charge Q is distributed uniformly over a thin spherical shell of radius R. Use the Gauss' theorem to show that the electric field intensity anywhere outside the shell is the same as if the charge Q were concentrated at the center of the shell. Find the electric field intensity inside the shell.



A particle of charge +q is released from rest from point A towards a uniformly charged thin spherical shell of radius R carrying charge – Q. As shown in the figure the particle is initially at a distance d from the center of the shell, and when released it passed through the two small holes situated diametrically opposite sides of the surface of the shell, without touching the shell.

(i) What is the electric potential energy of the charged particle
   (a) when it is at point A and (b) when it reaches the centre of the shell?

(ii) What is the kinetic energy of the particle when it is at the center of the shell?

(iii) How far from the center of the shell does the particle come to rest again?

(iv) State whether the velocity of the particle will increase, decrease, or remain constant while travelling from A to B. B to C and beyond C.

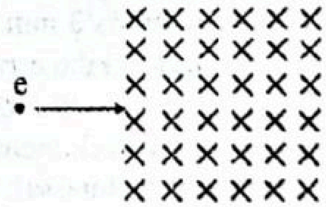
1996 – 7(b)

4) An electron is accelerated through a potential difference of 18.2 kV. The charge (q) and the mass of the electron are 1.6×10^{-19} C and 9.1×10^{-31} kg respectively.

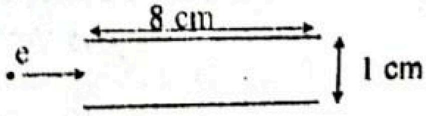
(i) Find the work done on the electron by the potential difference.

(ii) Assuming that the electron started from rest calculate the speed (v) of the electron after accelerating through the potential difference.

(iii) The electron then enters a region in which there is a uniform magnetic field of flux density. B = 0.2 T acting normal to the initial direction of motion of the electron as shown in the diagram. Calculate the force (F) on the electron due to the magnetic field and indicate its direction (Here F = qvB). Find the magnitude of an electric field that will make the electron move without any deviation. Indicate on a diagram the direction in which this electric field should be applied.



(iv) The undeviated electron is then allowed to travel between two horizontal parallel plates. each 8cm long and separated by 1 cm as shown. If the potential difference between the plates is 200V, find the vertical deflection of the electron as it leaves the plates.



5) An electrostatic instrument has a hollow metallic spherical shell of radius 0.9 m mounted on an insulating support electrical breakdown will occur in the air outside the spherical shell when the electric field intensity at the surface of the shell exceeds 1.2×10^{8} V m^{-1}

(i) What is the maximum potential to which the sphere can be charged without occurring an electrical breakdown? Calculate the charge and the electrical energy stored on the sphere under this situation.

(ii) When the sphere is at its maximum potential it is found that charge leaks of the sphere at a constant rate of 8×10^{-4} C per second. Briefly describe a process by which the charge leaks off the sphere.

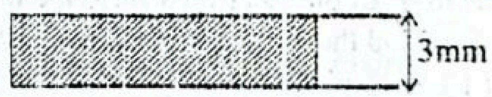
(iii) In order to maintain the maximum charge on the sphere at the value calculated (i) Charge has to be supplied continuously to the sphere at the above mentioned rate. This is done by bringing a source of charge inside the sphere and allowing it to touch the inner surface of the sphere. State the reason for adopting the above procedure to charge the sphere.

(iv) Calculate the rate at which the electrical energy is supplied to the sphere under this situation

$$\left[\frac{1}{4\pi\varepsilon_0} = 9\times10^{9}\,\mathrm{Nm^2C^{-2}}\right]$$

6) Write down an expression for the capacitance C of a parallel plate capacitor filled with a material of dielectric constant k. Identify the symbols used.

A dielectric slab of thickness 3 mm and of dielectric constant 4 is placed between the plates of a parallel plate capacitor.



The plates of the capacitor are square in shape, each of area 0.2×0.2 m^2 and their separation is 3 mm. The slab covers ¾ of the plate area of the capacitor as shown in the figure. Find the capacitance of t he system.

When a potential difference of 4 kV is established between the plates by connecting a battery across them. It was observed that the slab moved a distance of 1 mm during a short time interval.

(i) What would be the increase in capacitance and increase in energy stored in the capacitor due to the movement of the slab?

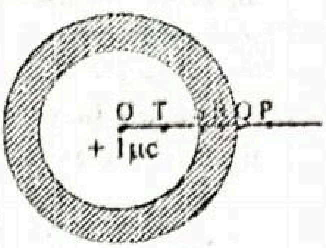
(ii) By taking this increase in energy to be equal to the work done on the slab, calculate the force exerted on the slab. Assume that the force on the slab remains constant during the short time interval mentioned above.

(iii) Find the energy supplied by the battery during the same time interval

($\varepsilon_0 = 9 \times 10^{-12}$ Fm^{-1})

2001 A/L-3

7) A point charge +1 μC is placed at the centre O of and isolated conducting spherical shell of inner radius 10 cm and outer radius 15 cm as show in the diagram. The points P, Q, R, S and T shown in the diagram are situated in such a way that OP=20 cm, OQ = 15 cm, OR = 12.5 cm OS = 10 cm and OT = 5cm



$$\left(\frac{1}{4\pi\varepsilon_0} = 9\times10^9\ NM^2C^{-2}\right)$$

(i) What are the induced charges on the inner and outer surfaces of the conducting shell?

(ii) Find the electric field intensities at points P, R and T . Sketch the variation of electric field intensity (E) with the distance (r) from the centre.

(iii) (a) find the electric potentials at pointes P, Q, R, and S

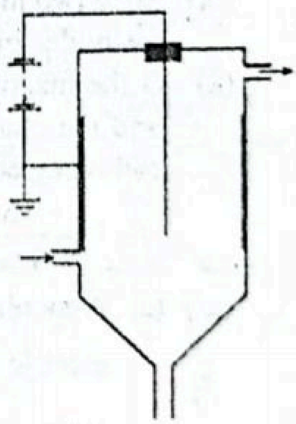
(b) Find the electric potential difference between the points T and S. Hence find the electric potential at point T.

(c) Sketch the variation of electric potential (V) with the distance (r) from the centre.

(iv) If an additional charge of -1μC is given to the conducting shell, Find the charge densities on the inner and outer surfaces of the conducting shell.

2002 A/L-4

8) Read the following passage carefully and answer the questions given below.



One important application of electrical discharge in gases is a device called an electrostatic precipitator. This device is used to remove particulate matter from combustion gases, thereby reducing air pollution. They are especially useful in coal power plants and in industrial plants that generate large quantities of smoke. Modern precipitators are able to eliminate more than 99% of the ash and dust (by weight) from the smoke. Figure shows an arrangement which gives the basic idea of the electrostatic precipitator.

A conducting wire running down the centre is maintained at a high potential relative to the grounded outer cylindrical conductor. Polluted gases enter at the bottom and pass through the electric field around the wire. The strong electric field near the wire causes a corona discharge around the wire and the formation of positive ions, electrons and negative ions, such as O_2^-. As the electrons and negative ions are accelerated towards the outer wall, the impurity particles in the streaming gas become charged by collisions and ion capture. Since these impurity particles become negatively charged they are drawn to the outer wall, where they stick. By periodically shaking or flushing the cylinder the impurity particles fall loose and are collected at the bottom.

The phenomenon known as corona discharge is often observed near sharp points of a conductor or thin conducting wires raised to a high potential. If the electric field intensity near the conductor is high enough (about $3\times10^6\ Vm^{-1}$ for dry air) it can cause an electrical discharge (break down) in air. This breakdown is initiated by the molecular ions and electrons present in air produced for example by cosmic rays. These ions and electrons accelerate rapidly towards the conductor under the action of the electric field. On their way to the conductor they collide with other molecules, and thereby create more ions and electrons.

$$\left[\frac{1}{2\pi\varepsilon_0} = 18\times10^9\ Nm^2C^{-2}\right]$$

(i) (a) What is the purpose of using this device in coal power plants?

(b) Do modern precipitators fulfill the purpose that you have mentioned above? Justify your answer.

(ii) Is the wire maintained at positive or negative potential?

(iii) What is the advantage of grounding the outer cylinder?

(iv) Draw the elective lines of force in the vicinity of the wire.

(v) Is there a current between the wire and the outer wall when the precipitator is in operation? Explain your answer.

(vi) Why are the polluted gases sent in at the bottom rather than at the top of the device?

(vii) What is the reason for maintaining the polarity as mentioned in (ii) above?

(viii) If an O_2^- ion and an electron are at a same distance from the wire, which one has the higher acceleration? Give reasons for your answer.

(ix) State two methods whereby some molecules in the air get ionized naturally. (One method is given in the paragraph)

(x) If the magnitude of the potential of the wire relative to the outer wall is V volts, and the charge per unit length on the wire is λ C m^{-1}, V is related to λ by the following equation

$$V = \frac{5}{2\pi\varepsilon_0}\lambda \qquad \text{Calculate } \lambda \text{ for } V = 90\text{ KV.}$$

(xi) (a) Assuming the wire to be very long, use Gauss' theorem to show that the electric field intensity E at a distance r from the wire is given by $E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r}$

{Hint: Select a cylindrical Gaussian surface of radius r and unit length of height that is coaxial with the wire.}

(b) Determine E at a distance r = 1 mm. Show that this value is grater than the breakdown electric field intensity for dry air.

<u>2004 A/L-3</u>

9) A particle of charge +q and mass m is moving along the positive x direction in a vacuum where the electric field is zero. This particle then enters at x = 0, a uniform electric field of intensity E extended over a large region, with velocity v as shown in figure 1. The electric field is directed along the negative x direction, Describe qualitatively the motion of the particle after entering the electric field. (Neglect the effects of gravity)

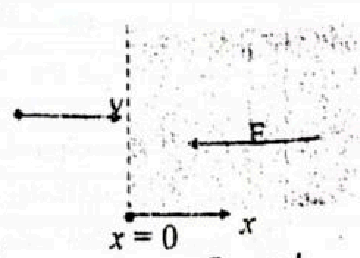


figure 1

Two particles P and Q each of charge +q and mass m, start to move at time t = 0 in a vacuum simultaneously with two initial velocities v_1 and v_2 respectively, $(v_1 - v_2)$ along the positive x direction from two points corresponding to x = 0 as shown in figure 2.

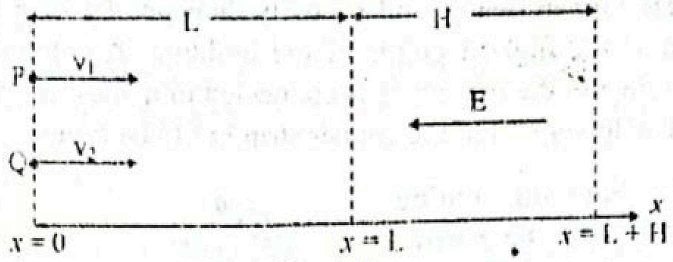


figure 2

(i) If the two particles travel in a field free region from x = 0 to x = L, obtain an expression for the separation d between the two particles, at the instant when the faster particle reaches x = L .

(ii) At x = L, the two particles enter a uniform electric field of intensity E directed along the negative x direction. If the electric field is extended from x = L to x = L + H as shown in figure 2, obtain an expression for the minimum value E_M of the intensity of the electric field required to turn both particles back and make them travel in the negative x direction.

(iii) Now consider a situation where E is greater than E_M

a) Obtain expressions for the times. t_P and t_Q. Spent by the particles P and Q respectively in the electric field.

b) When the intensity of the electric field E is equal to a certain value E_0, both particles P and Q, which had entered the electric field at different times due to the difference in initial velocities at x = 0 leave the electric field at x = L simultaneously. Write down an expression relating E_0 to other relevant parameters given above.

2005A/L-3

10) Read the following passage carefully and answer the questions given below.

A thundercloud is formed by a strong upddraft of warm and humid air. The humid air expands as it rises and its temperature decreases.

Usually thunderclouds have, two main centres of charge, with the lower charge being negative as shown in the figure (1). (Note that the figure is not drawn to a scale)

In this figure the negative charge centre and the positive charge centre are situated at heights h_1 and h_2 above the ground (G) respectively. The magnitude of the electric field intensity under a thundercloud is one of the factors which determines the possibility of a lightning flash to the ground. Because the earth is a good conductor compared to air, an approximate value for this electric field can be calculated using a technique called "method of images".

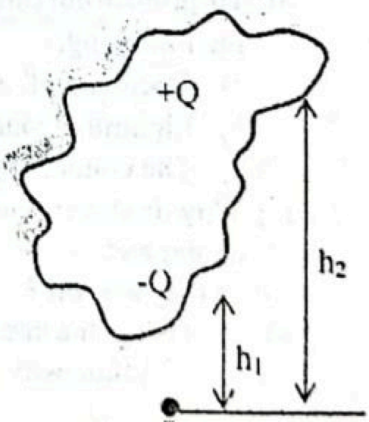


Figure (1)

A charge – Q will induce a positive charge on the surface of the earth as shown in figure (2) a). It can be seen that the same pattern of lines of force in figure (2) a) will be obtained if the earth did not exist and a positive charge +Q was placed, as in figure (2) b). Therefore the actual electric field intensity at the point P on the ground will be the same as the field intensity halfway between these two charges $-Q$ and its miorror image / $+Q$.

Lightning could cause human deaths and property damage. To save building, lightning conductors are fixed at the highest points of the building. A conductor like this has a pointed end on one side and the other side is connected to a thick copper strip which runs down the building. The lower end of the copper strip has to be grounded properly.

What should one not do during lightning? A discharge can be carried into a house through power lines, telephone wires or even through the water in pipe lines. Therefore we should avoid using electrical equipment such as televisions and telephones during lightning. If you are in outdoor, avoid taking shelter under isolated trees or shacks that are obviours targets.

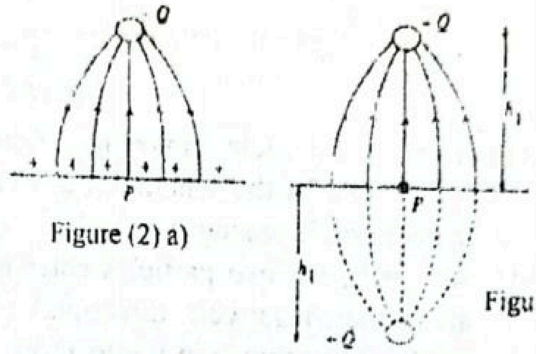


Figure (2) a)

Figure (2) b)

When a lightning stroke hits a tree, a large current flows along the wer channels in the trunk and it may enter a person who is either standing near or leaning on the tree. This current that enters a tree susequently flows along the surface of the ground. The potential difference produced between two points on the ground about 1 m, apart result in a fatal current flow through animals or people. One can minimize the effect of each a potential difference by keeping one's feet together.

i) If you are inside a house during lightning list two things that you should avoid doing.

ii) If you are at outdoor why is it dangerous to stand near or lean on a tall tree during lightning ?

iii) To protect buildings from lightning, lightning conductors are used. Give reasons for the following.

a) Open end of a lightning conductor should be pointed.

b) Lightning conductor should be pointed.

c) The connecting copper strip has to be thick

iv) Why do the air masses

a) expand   b) cool

as they ascend ?

v) a) Using the method of images, show that the magnitude of the resultant electric field intensity E at point P in figure (1) is given by,

$$E = \frac{Q}{2\pi \epsilon_0}\left[\frac{1}{h_1^2} - \frac{1}{h_2^2}\right]$$

b) Taking $Q = 20$ C, $h_1 = 3$ km and $h_2 = 6$ km. Calculate E. $\left[\frac{1}{2\pi \epsilon_0} = 1.80\times10^{10}\ Nm^2C^{-2}\right]$

What is the direction of this field?

Hence determine the induced surface charge density on the ground at point P.

$(\epsilon_0 = 8.85 \times 10^{-12} C^2N^{-1}m^{-2})$

vi) Suppose a single lightning stroke transfers a charge of -5C through a potential difference of 10^8V. Calculate the energy released by this lightning discharge assuming the potential difference remains constant. State two modes of dissipation of this energy.

vii) During lightning, cattle standing on the ground have high risk of getting killed even in the absence of a direct lightning strike. Suggest a reason for this.

2007 A/L-4

11)

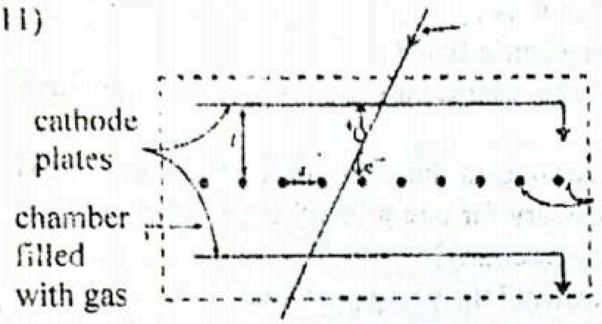


Figure (a)

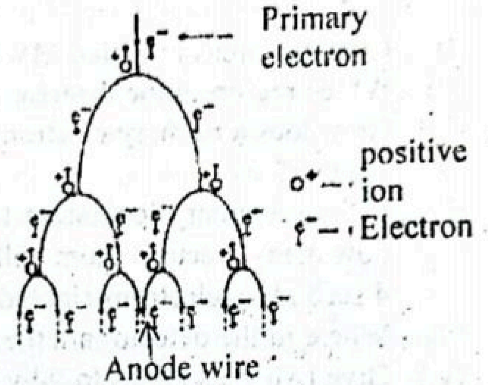


Figure (b)

Detection of photons and other subatomic particles is important in high energy particle physics. The multi wire proportional chamber (MWPC) is one of the detectors that is used for such purposes. Applications of MWPC can be found in a variety of fields such as nuclear medicine, protein crystallography, and particle track detection in high energy physics experiments. In its basic configuration, an MWPC consists of thin (~μ m diameter) parallel and equally spaced anode wires symmetrically placed between two thin metallic cathode plates as shown in figure (*a*). For proper operation, the gap l is normally three or four times larger than the wire spacing s (~2 mm). The cathodes are earthed and the anode wires are maintained at a positive high voltage (~3 kV) to produce an extremely large electric field around the wires. The chamber is filled with a gas mixture of 90% argon and 10% of molecular gas such as CO_2 or CH_4

When a high energy charged subatomic particle passes through the detector it collides and ionizes the gas molecules (mainly argon atoms) along its path in the chamber producing a certain number of electron-positive ion pairs. This ionization is called the primary ionization. In the process of creating one electron-ion pair, the high energy particle loses about 30 eV from its kinetic energy. The primary electrons thus created move towards the anode wires and the positive ions to cathode plate due to the electric field present inside the chamber. When these primary electrons move closer to anode wires, the strong electric field that exists around the wire will accelerate them increasing their kinetic energies. Such energetic electrons, while moving towards the anode wires will collide with argon atoms producing more electron-ion pairs close to the wire. This process, called secondary ionization, is repeated many times producing a large number of electron-ion pairs. This will continue until all the electrons are collected by the anode wires. Figure (*b*) shows how a single primary electron will give rise to a large number of secondary electron-ion pairs through secondary ionization. This number is 10^3 in pure argon and its value can be about 10^6 in a mixture of argon and CO_2. The anode wires will finally collect all the electrons in a very short time leaving a could of positive ions around the wire, which slowly migrates towards the cathodes.

Electrons collected by anode wires can be observed as a current pulse which can later be converted to a voltage pulse. The pulse amplitude produced by MWPC is a measure of the energy loss by the particle during its passage through the detector. In addition the amplitude of the pulse depends on the detector properties such as the gas used. Voltage applied to anode wires, the gap between cathode plates, wire spacing and wire diameter.

(i) Give two areas in which MWPC finds applications.
(ii) Which region of the detector has the highest electric field?
(iii) How does a primary electron acquire energy to produce a secondary electron positive ion pair?
(iv) If the secondary ionization takes place according to the diagram given in figure (*b*) how many electron-atom collisions are necessary for one primary electron to produce 4 secondary electrons (including the primary electron)?
(v) Where in the detector are the majority of positive ions being produced?
(vi) Give two reasons as to why positive ion cloud takes a longer time to migrate to the cathode.
(vii) Give three properties of the detector that determine the amplitude of the pulse.
(viii) Use Gauss theorem to find an expression for the electric field intensity E at a distance r $(r > a)$ from the axis of a long straight wire of radius 'a' carrying charge per unit length λ.
(ix) What would happen to the amplitude of the pulse if the radius of the anode wires is reduced? (Give reasons for your answer)
(x) The figure (*c*) shows a section of an MWPC with two anode wires. Copy this diagram on to your answer sheet and draw the pattern of electric field lines inside this section.

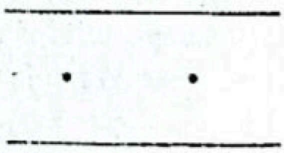


figure (c)

(xi) If a high energy charged particle entering the detector with a kinetic energy of 100 keV passes through the detector creating 100 primary electron-ion pairs, calculate the energy of the particle when it leaves the detector.

2009 A/L -4

12) Letters, numbers, images etc, printed by certain computer printers consist of a large number of very small circular dots just touching one another. The number of such dots per unit length is normally used to express the quality of the printers.

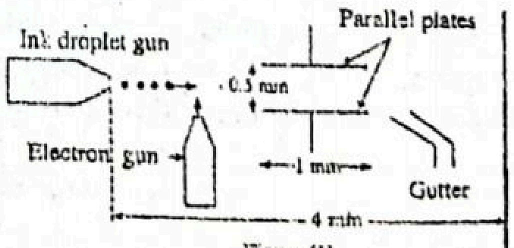


Figure (1)

A simplified diagram of a system, which illustrates only the relevant parts of the ink delivering process of such a printer, is given in figure (1). Use the dimensions shown in figure (1) in answering the questions, whenever necessary.

As shown in figure (1), the ink droplet gun sends a stream of neutral spherical ink droplets towards the paper on which the printing is to be done, and the appropriate movements of the system will gibe rise to printing. In order to print letters, numbers and images on the paper, only some of these droplets must be allowed to hit the paper and the rest of the droplets must be prevented from reaching the paper.

This is done by charging only those droplets, that must be prevented from hitting the paper, using an electron gun and deflecting them into a gutter by means of an electric field produced by a pair of parallel plates.

a) i) Assume that each spherical droplet emitted from the ink droplets, gun has a diameter D and each droplet produces a circular dot whose diameter is 25% larger than D when it strikes the paper. Find the value D must have for the printer to be able to print 200 dots per cm.

ii) Ink droplet gun shoots droplets horizontally towards the paper with a velocity of 20 ms^{-1}. Calculate the vertical displacement of a neutral droplet due to gravity when it hits the paper, which is placed vertically 4 gun away from the ink droplet gun. Shown that this deflection is much smaller than the diameter of a dot printed on the paper.

b) Each droplet, which has to be deflected into the gutter is given a charge of -1.5×10^{-10}C by allowing a very narrow beam of electrons from the electron gun to strike the droplets, under suitable conditions. A potential difference of 50 V is applied between the parallel plates.

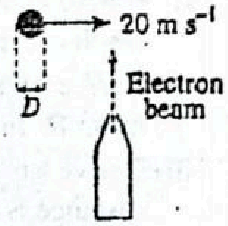


Figure (2)

i) If the droplets move across the electron beam as shown in figure (2) find the time required for a droplet to pass the electron beam.

ii) Assuring that all electrons, which strike the droplet are uniformly distributed over the surface of the droplet, calculate the electric current due to the emitted electrons from the electron gun during the charging process.

c) i) Find the electric field intensity between parallel places.

ii) What must be the direction of the electric field?

d) The mass of a charged droplet is given as 4.0×10^{-11} kg. Find the angle θ that the gutter must make with the horizontal direction so that the charged droplets travel straight into the gutter as shown in figure (3) .(Neglect the effect of gravity)

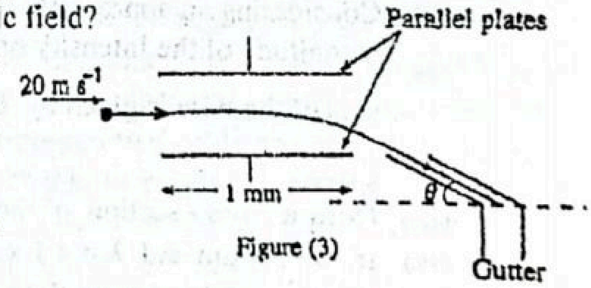


Figure (3)

2012 A/L-8

13) Two metal plates A and B kept parallel to each other in a vacuum are connected to a voltage source as shown in figure (1). A molecular ion of mass m and charge +q starting from rest from the plate. A accelerates towards the metal plate B under the influence of the voltage V maintained between the plates.

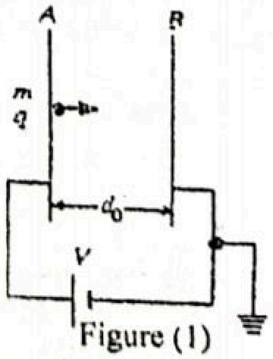


Figure (1)

a) i) Write down an expression for the kinetic energy gained by the ion when B reaches the plate B.

ii) Derive an expression for the velocity (υ) required by the ion when it reaches the plate B.

iii) If d_0 is the distance between the plates derive an expression for the time (t) taken by the molecular ion to reach the plate B.

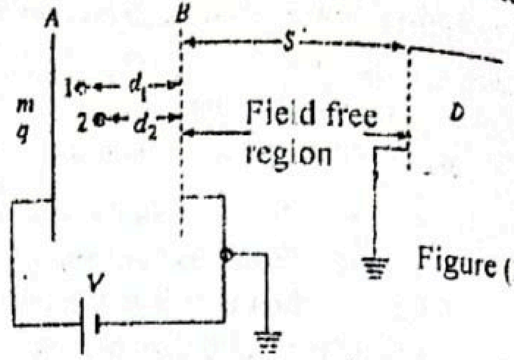


Figure (2)

b) Suppose the metal plate B is now replaced with a metal wire mesh so that the ions moving through the region AB could enter a field free region and move towards an ion detector D placed at a distance S from the wire mesh B as shown in figure (2)

Consider two molecular ions 1 and 2 of mass m and charge +q suddenly being formed at time t = 0 at distances d_1 and d_2 from the wire mesh B as shown in figure (2). If they start from rest and move towards B under the electric field.

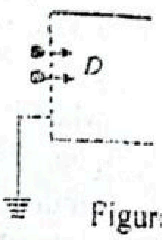


Figure (3)

i) Derive expression for times t_1 and t_2 taken by the ions 1 and 2 to reach the mesh B and indicate which ion reaches the mesh first.

ii) Derive expression for velocities υ_1 and υ_2 of ions 1 and 2 when they reach the mesh B. Indicate which ion has the higher velocity when they reach B.

iii) Derive an expression in terms of t_1, t_2, υ_1 and υ_2 for the suitable value for the distance S at which the detector. D has to be placed so that it detects both ions 1 and 2 in the same time as shown in figure (3)

2015 A/L-8

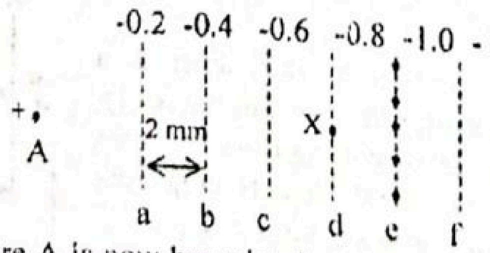
14) a) A long thin conducting straight cylindrical wire A of a radius has a charge per unit length $+\lambda$. Practically this can be done by connecting the wire to a positive potential with respect to ground.

(i) Where does the given charge of the wire physically reside?

(ii) Considering an appropriate Gaussian surface around the wire, show that the magnitude of the Intensity of the electric field E at distance r ($\geq$ a) from the axis of the wire is given by $E = \dfrac{\lambda}{2\pi\varepsilon_0 r}$ where ε_0 is the permittivity of free space.

(iii) Draw a cross - section of the wire, and draw the equipotential lines around it.

(iv) If a = 10 μm and $\lambda = 8.1 \times 10^{-8}$ C m^{-1}, calculate the magnitude of the intensity of the electric field on the surface of the wire, (Take ε_0 to be 9×10^{-12} F m^{-1}, and π as 3.)



(v) The wire A is now brought close to a region of a uniform electric field in which the equipotential surfaces are planar and normal to the plane of the paper. The axis of the wire is also normal to the plane of the paper. The dashed lines a, b, c, d, e, and f shown in figure represent the cross –sections of the above mentioned equipotentia surfaces as seen on the plane of the paper. These dashed lines represent the equipotential lines corresponding to the electric field. and the respective voltages (in kv) of these equipotential lines are also shown in the figure. Distance between any two equipotential lines in 2 mm.

In this arrangement the wire A is connected to a positive potential with respect to the ground, and can be considered as an anode.

1) Copy the anode and the equipotential lines to the answer script and draw the eelctric field lines from the positions marked with dots on the equipotentials line e up to the anode wire A.
2) Calculate the intensity of the electric field E_0 between two equipotential lines.

b) Part of an arrangement used for the detection of high energy particles and photons is similar to the one described in part (a) (v) above. Suppose that such an arrangement with an anode A having a charger per unit length $+\lambda = 8.1 \times 10^{-8}$ C m^{-1} is housed in a chamber filled with an inert gas (Argon) at atmospheric pressure.

Consider a situation in which a photon enters the chamber and collides with an argon atom at X creating a photoelectron and an argon ion. Such and electron called a primary electron. The energy needed to creat one such electron ion pair in argon gas is 30 eV. (1eV = 1.6×10^{-19} J, charge of an electron e = 1.6×10^{-19} C)

i) Write down an expression for the magnitude of the initial acceleration of the primary photoelectron due to the electric field mentioned in (a)(v)(1) above in terms of m, e and E_0 where m and e are the mass and charge of an electron respectively.
ii) Explain, why the electron moves towards anode A with a drift velocity v_d without accelerating continuously.
iii) Suppose that the primary electron which started from rest is moving along the electric field mentioned in (a)(v)(1) above. If the average distance moved by the primary electron between two successive collisions with argon atoms is 0.5 μm, calculate the increase in kinetic energy of the primary electron between two collisions in eV due to the electric field between two collisions, and show that the primary electron having this energy is unable to remove another electron upon colliding with another argon atom. (Consider that the energy required for an electron to remove an electron from an argon atom is 30 eV)
iv) When this primary electron is close to the anode it experiences a high electric field given by the expression stated in (a)(ii) above. Under this condition, the primary electron gains sufficient energy between collisions to create electron ion pairs and the secondary electrons produced in this manner in turn creat more electron ion pairs before getting collected at the anode. Total number of secondary electrons produced by a single primary electron in this manner is called the amplification factor for the gas. Ability to collect charges by the anode wire indicates that is has the property of capacitance. a small voltage is generated across this capacitor.

   If the detector capacitance is 5 pF and the voltage generated across this capacitor due to secondary electrons produced by the primary electrons is 0.96 mV find the charge collected by the anode.
v) Hence find the amplification factor for the gas.

15) (a) i) A current I flows through a thin wire of very small length Δl. Show that the magnetic flux density ΔB at a point with a perpendicular distance d away from this wire, is given by $\frac{\mu_0 I \Delta l}{4\pi d^2}$

ii) A current I flows through a flat circular coil of radius R with N number of turns as shown in figure (1). Obtain an expression for the magnitude of the magnetic flux density B at the centre of the coil.

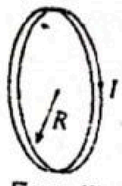


Figure (1)

iii) Two such coils are placed coaxially with a separation R as shown in figure 2(a). The current I flows through both coils in the same direction. Figure 2(b) shows the vertical cross section of the coils through the common axis.

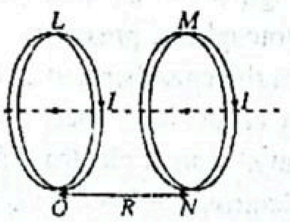


Figure 2(a)

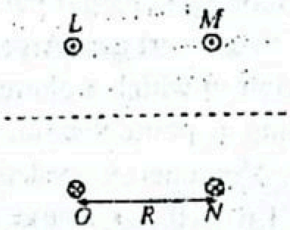


Figure 2(b)

Copy the figure 2(b) onto the answer script and draw the magnetic field lines to illustrate the magnetic field due to both coils.

(b) The apparatus shown in figure (3) can be used to determine the charge to mass ratio $\left(\frac{e}{m_e}\right)$ of an electron. The vacuum tube has a filament cathode C, electrodes A_1, and A_2 and a vertical fluorescent screen S with grid lines. The path of the electron beam can be seen on the fluorescent screen.

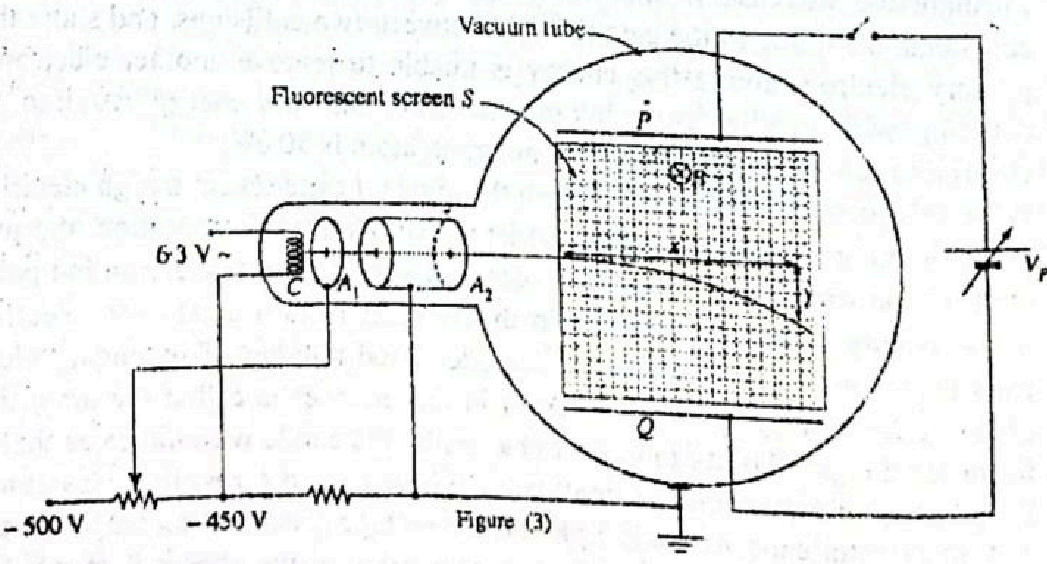


Figure (3)

(i) The function of the electrode A_1 is to control the intensity of the electron beam. What is the function of the electrode A_2?

(ii) If a negative voltage (-V) is applied to electrode A_1, obtain an expression for the speed of an electron travelling through the electrode A_2. (Charge of an electron is $-e$ and mass of an electron is m_e)

(iii) The spherical part of the tube is placed between two flat circular coils carrying the same current as shown in figure (4). Thereby a uniform magnetic field B is applied perpendicularly to the screen S. This makes the electrons move in a circular path.

If the radius of the path of the electron beam is r, obtain an expression for the ratio $\left(\frac{e}{m_e}\right)$ of the electron.

(c) A dc voltage can be applied between two parallel metal plates P and Q as shown in figure (3). The plates P and Q are separated by a distance d as shown in figure (4). While the magnetic field B is applied, the potential difference between the plates V_{PQ} can be adjusted until there is no deflection of the electron beam. This process can be utilized as an utilized as an alternative way to determine the speed of the electrons.

(i) Draw the electric and magnetic forces acting on an electron within the plates P and Q, after the above adjustment is done.

(ii) Obtain an expression for the speed of the electrons in terms of d, B and V_{PQ}.

(iii) When $B = 1$ mT and $V_{PQ} = 0$, the radius of the path of the electrons is 6 cm. When $V_{PQ} = 840$ V, there is no deflection of the electron beam. The separation between the plates P and Q is 8 cm.

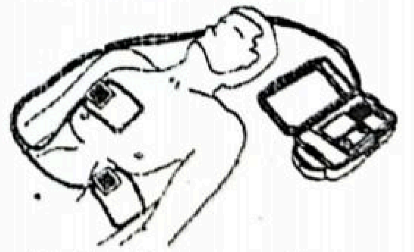
Calculate

(1) the speed of an electron, and

(2) the charge to mass ratio $\left(\frac{e}{m_e}\right)$ of an electron.

2020 A/L-8

16)A defibrillator is a medical instrument that is used to restore the rhythmic pattern of heart after a cardiac arrest of a patient. It gives a high energy electric shock in a short burst to the heart through a set of electrodes across the patient's chest by discharging charge stored in a capacitor.



a) A defibrillator delivers 48J of energy to a heart patient by discharging a capacitor initially charged to a potential difference of 400 V.

i) Derive an expression for the energy stored W in a capacitor in terms of capacitance C and the potential difference V across the capacitor.

ii) What is the capacitance of the capacitor in the device?

iii) Calculate the amount of charge stored in the capacitor.

iv) Assuming that the total charge calculated in part (iii) was stuffiest to pass a constant current through the body with 12 ms time period, calculate this constant current.

v) What is the effective resistance of the path of the current calculated in (a) (iv) above?

b) i) A parallel plate capacitor is filled with a medium of dielectric constant k. Derive an expression for electric field intensity E in the medium in terms of charge stored in the capacitor Q, plate area A, permittivity of free space ε_0 and k, by using Gauss's law.

ii) If the charged capacitor mentioned in (a) above is a parallel plate capacitor with plate area of 80 cm^2 filled with a medium of dielectric constant k = 5000, what is the value of the electric field intensity in the medium. $E_0 = 9.0 \times 10^{-12}$ F m^{-1}.

iii) Determine the separation d between the plates of this capacitor.

c) i) In order to apply an electric shock with the appropriate energy based on the patient. Five capacitors of equal capacitance mentioned in (a) above and equal potential difference 400 V across each capacitor have been connected in series instead of one capacitor. Calculate maximum energy that can be supplied to a patient after connecting five capacitors in series?

ii) What would be the maximum energy that can be supplied to patient if five capacitors of equal capacitance mentioned in above part (a) are connected in parallel with a potential difference of 400 V?

iii) Out if series and parallel connections of capacitors mentioned in (c) (i) and (c) (ii) above the series connection is recommended for the defibrillator. Giving reasons briefly explain this.

d) i) What factors determine the process of point or corona discharge?

ii) If the breakdown electric field intensity of the medium mentioned in (b) (ii) above is 8.0×10^8 V m^{-1}, will this capacitor get damaged? Give reasons.

e) Suppose the capacitor in (b) above is initially charged to Q0 using a potential difference of V0. If the charge and the potential difference of the capacitor after 12 ms are equal to $0.37Q_0$ and $3.37V_0$ respectively, what percentage of energy stored in the capacitor has been released to the patient during this period. [Take $(0.37)^2 = 0.14$]