TOPIC 19 Electric Field

1 A charge of 3 C is moved from infinity to a point X in an electric field. The work done in this process is 15 J. The electric potential at X is

A	45 V	**D**	5 V
B	22.5 V	**E**	0.2 V
C	15 V		

N76/II/22

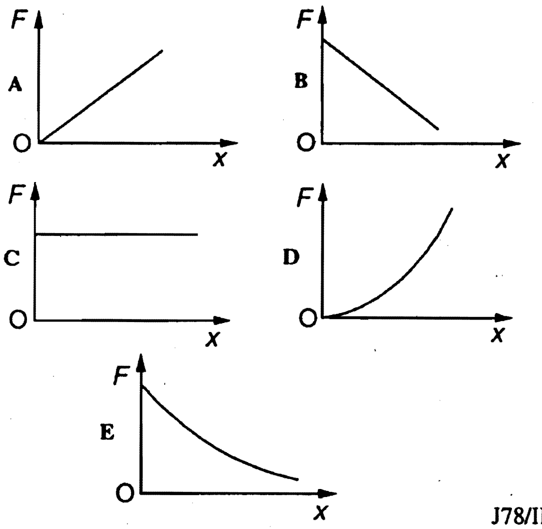
2 The electric potentials V are measured at distances x from P along a line PQ. The results are:

V/V	13	15	18	21	23
x/m	0.020	0.030	0.040	0.050	0.060

The component along PQ of the electric field for $x = 0.040$ m is approximately

A 75 V m^{-1} towards P.
B 300 V m^{-1} towards Q.
C 300 V m^{-1} towards P.
D 450 V m^{-1} towards Q.
E 450 V m^{-1} towards P. J78/II/22

3 Which one of the following graphs best indicates the relationship between the force F on an electron in the electric field between two oppositely charged large, parallel plates which are close to each other and the perpendicular distance x from the electron to one of the plates?



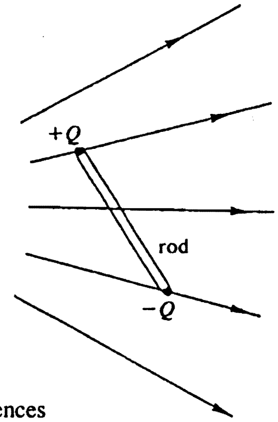
J78/II/29

4 When a Van de Graaff generator is running at its maximum voltage, charge leaks away from the dome at a rate of 64 μA. Charge is carried to the dome by a belt 4 cm wide running at a speed of 0.8 m s^{-1}. If all the charge on the belt were collected by the dome, the charge density on the belt would be

A	2.0×10^{6} C m^{-2}	**D**	0.5×10^{-3} C m^{-2}
B	0.5×10^{3} C m^{-2}	**E**	2.0×10^{-6} C m^{-2}
C	2.0×10^{-3} C m^{-2}		

N79/II/21

5 The diagram below shows an insulating rod with equal and opposite charges at its ends, placed in a non-uniform electric field for which field lines (lines of force) are shown.



The rod experiences

A a resultant force in the plane of the paper but no couple.
B a resultant force in the plane of the paper and a couple.
C a resultant force normal to the plane of the paper but no couple.
D a resultant force normal to the plane of the paper and a couple.
E a couple but no resultant force. J80/II/18; N86/I/18

6 A charge q is placed at a point P in an electric field of strength E which acts in the x-direction. At P the electric potential is V, the force on q in the x-direction is F and the electrostatic potential energy of the charge is U. Which one of the following sets of equations correctly expresses the relationships between E, F, q, U and V?

A	$F = qE$;	$U = qV$;	$V = -dE/dx$;	$U = -dF/dx$
B	$E = qF$;	$V = qU$;	$E = -dU/dx$;	$F = dV/dx$
C	$U = qF$;	$V = qE$;	$U = -dV/dx$;	$F = -dE/dx$
D	$V = qE$;	$U = qF$;	$F = dE/dx$;	$U = dF/dx$
E	$F = qE$;	$U = qV$;	$E = -dV/dx$;	$F = -dU/dx$

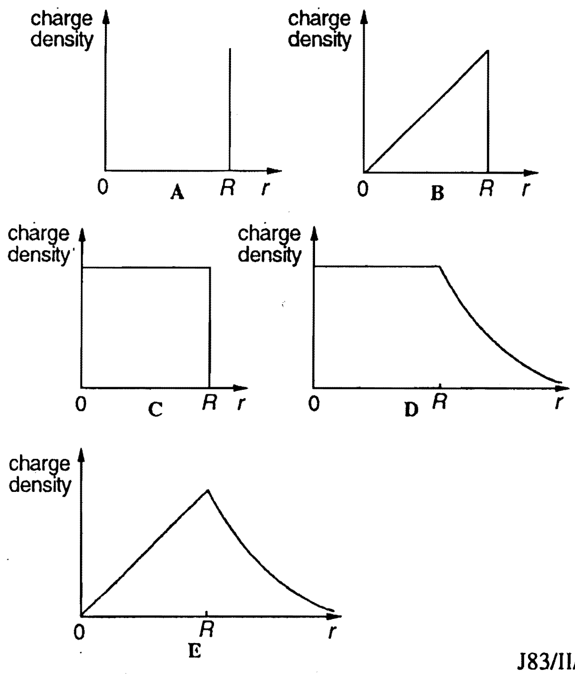
J80/II/20

7 A metal sphere of radius 0.1 m was insulated from its surroundings and given a large positive charge. A small charge was brought from a distant point to a point 0.5 m from the sphere's centre. The work done against the electric field was W and the force on the small charge in its final position was F. If the small charge had been moved to only 1 m from the centre of the sphere, what would have been the values for the work done and the force?

	work done	*force*
A	$W/4$	$F/4$
B	$W/4$	$F/2$
C	$W/2$	$F/4$
D	$W/2$	$F/2$
E	$W/2$	$F/\sqrt{2}$

J82/II/21

8 An isolated, solid metal sphere of radius R is given an electric charge. Which one of the following best represents the way in which the density of charge varies with distance r from the centre of the sphere?



J83/II/22

9 Fig. 1 below shows the important components of a large Van de Graaff generator operating in air at atmospheric pressure. When the electric field strength at the sphere's surface exceeds the breakdown field of the air, the sphere discharges by sparking.

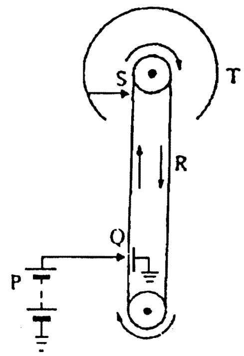


Fig. 1

Which one of the following determines the maximum potential attained by the sphere?

- **A** the e.m.f. of the battery P
- **B** the radius of curvature of the point Q
- **C** the speed of the belt R
- **D** the distance of the point S from the belt
- **E** the radius of the sphere T

J83/II/23

10 In discussing electric fields, the terms 'electric field strength', 'electric potential' and 'potential gradient' are used.

Which statement about these terms is correct?

- **A** Electric field strength at a point is the work done in bringing unit positive charge from infinity to the point.
- **B** Electric potential and potential gradient are both scalar quantities.
- **C** The potential gradient at a point is numerically equal to the electric field strength at that point.
- **D** Unit potential gradient exists between any two points, if one joule of work is done in transporting one coulomb of charge between the points.

N83/II/19; N99/I/16

11 Charge is sprayed on to the belt of a Van de Graaff generator by a sharp needle P (maintained at +5 kV) and is transferred to the dome via a second sharp needle Q, connected to the interior of the dome as shown in Fig. 2 below.

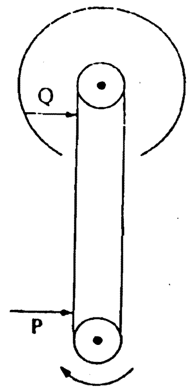
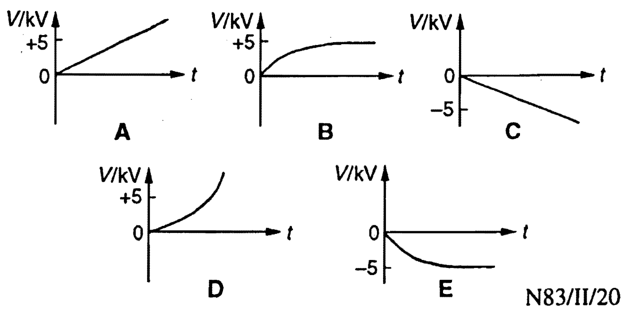


Fig. 2

Assuming that the insulation is perfect, which one of the graphs below shows how the potential V of the dome varies with time t when the belt starts to move at a steady speed?



N83/II/20

12 In Fig. 3 below, the point charge Q_1 causes an electric potential of 60 V and an electric field strength of 30 V m^{-1} at P, and the point charge Q_2 separately causes a potential of 120 V and a field strength of 40 V m^{-1} at P.

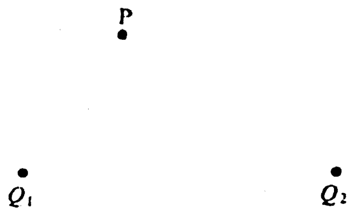


Fig. 3

Which one of the following gives possible values of potential and field strength at P due to the joint action of Q_1 and Q_2.

	potential/V	*field*/V m^{-1}
A	180	70
B	180	50
C	135	50
D	60	10
E	135	10

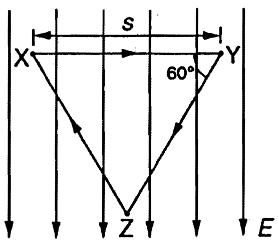
J84/II/21

13 Two small conducting spheres S_1 and S_2 hang by light, non-conducting threads from fixed points, P_1 and P_2, and are at the same level. S_1 has mass M and carries charge Q; S_2 has mass $2M$ and carries charge $2Q$. The repulsion between them causes the threads to make *small* angles θ_1 and θ_2 with the vertical. What is the approximate value of the ratio θ_1/θ_2 ?

A 4.0
B 2.0
C 1.0
D 0.5
E 0.25

J85/I/18

14 The diagram below shows three points X, Y and Z forming an equilateral triangle of side s in a uniform electric field of strength E. A unit positive test charge is moved from X to Y, from Y to Z, and from Z back to X.



Which one of the following correctly gives the work done against electrical forces in moving the charge along the various parts of this path?

	X to Y	Y to Z	Z to X
A	$+Es$	$+Es\cos 60°$	$-Es\cos 60°$
B	0	$-Es\cos 60°$	$+Es\cos 60°$
C	$+Es$	$+Es\sin 60°$	$-Es\sin 60°$
D	0	$+Es\sin 60°$	$-Es\sin 60°$
E	0	$-Es\sin 60°$	$+Es\sin 60°$

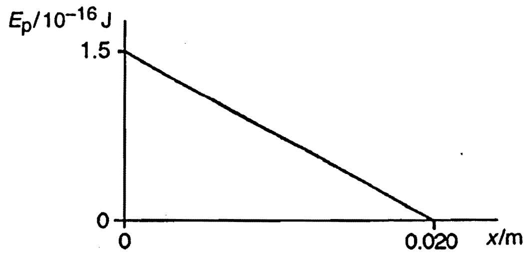
J85/I/19

15 Which *one* of the following statements about the electric potential at a point is correct?

A The potential is given by the rate of change of electric field strength with distance.
B The potential is defined as the work done per unit positive charge in moving one electron from the point to infinity.
C Alternative units for electrical potential are the joule and the volt.
D The potential due to a system of point charges is given by the sum of the potentials due to the individual charges.
E Two points in an electric field are at the same potential when a unit positive charge placed anywhere on the line joined them must remain stationary.

N85/I/16

16 Two charged plates are 0.020 m apart, producing a uniform electric field. The potential energy E_p of an electron in the field varies with displacement x from one of the plates as shown.

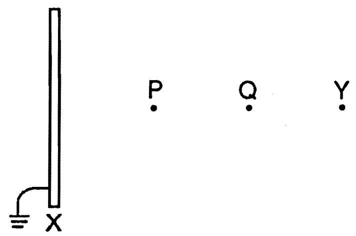


What is the magnitude of the force on the electron?

A 3.0×10^{-18} N
B 7.5×10^{-17} N
C 3.8×10^{-15} N
D 7.5×10^{-15} N

J86/I/5; J2000/I/6

17 A point charge is placed at Y in front of an earthed metal sheet X. P and Q are two points between X and Y as shown in the diagram.

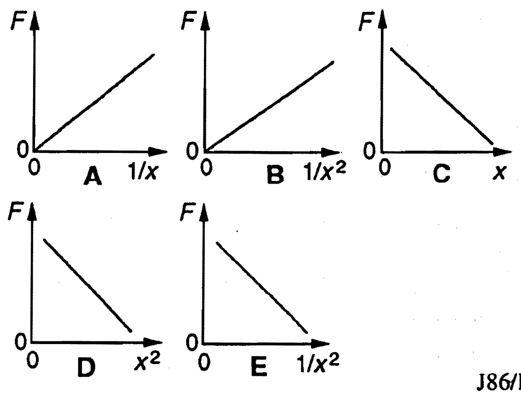


If the electric field strengths at P and Q are respectively E_P and E_Q, which one of the following statements is correct?

A $E_P = E_Q$
B $E_P = 0$
C $E_Q = 0$
D $E_P > E_Q$
E $E_Q > E_P$

J86/I/16

18 A point charge separated by a distance x in air from another point charge experiences a force of repulsion F. Which one of the following graphs shows how F and x are related?



J86/I/17

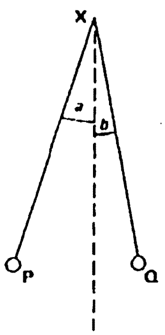
19 In the direction indicated by an electric field line.

- **A** the electric field strength must increase.
- **B** the electric field strength must decrease.
- **C** the potential must remain constant.
- **D** the potential must increase.
- **E** the potential must decrease. N87/I/19

20 Which of the following statements about an electric field is **incorrect**?

- **A** The electric field strength due to a point charge varies as $1/r^2$ where r is the distance from the charge.
- **B** Electric field strength is a vector quantity.
- **C** The electric field strength at a point is a measure of the force exerted on a unit positive charge at that point.
- **D** The electric field strength is zero at all points where the potential is zero.
- **E** The electric field strength at a point is a measure of the potential gradient at that point. N88/I/19

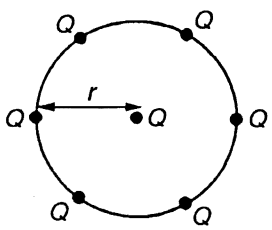
21 The diagram shows two small charged spheres **P** and **Q** of small mass which are hung by identical fine nylon threads from a fixed point **X**. It is found that, in equilibrium, the angle a is greater than the angle b.



Which one of the following statements **must** be correct?

- **A** The charge on **P** is numerically smaller than that on **Q**.
- **B** The charge on **P** is numerically greater than that on **Q**.
- **C** The mass of **P** is less than that of **Q**.
- **D** The mass of **P** is greater than that of **Q**.
- **E** The charges on **P** and **Q** are both positive. N88/I/20

22 A point charge is surrounded symmetrically by six identical charges at distance r as shown in the diagram.

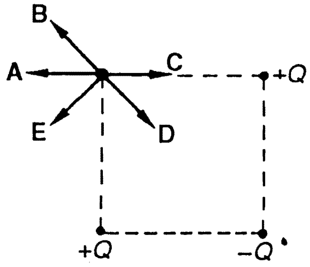


How much work is done by the forces of electrostatic repulsion when the point charge at the centre is removed to infinity?

- **A** zero
- **B** $\dfrac{6Q}{4\pi\epsilon_0 r}$
- **C** $\dfrac{6Q^2}{4\pi\epsilon_0 r}$
- **D** $\dfrac{6Q}{4\pi\epsilon_0 r^2}$
- **E** $\dfrac{6Q^2}{4\pi\epsilon_0 r^2}$

J89/I/16

23 Point charges, each of magnitude Q, are placed at three corners of a square as shown in the diagram. What is the direction of the resultant electric field at the fourth corner?



N89/I/16

24 The charge on the uranium nucleus is 1.5×10^{-17} C and the charge on the α-particle is 3.2×10^{-19} C.

What is the electrostatic force between a uranium nucleus and an α-particle when separated by a distance of 1.0×10^{-13} m?

- **A** 4.3×10^{-20} N
- **B** 4.3×10^{-13} N
- **C** 4.3 N
- **D** 4.3×10^{10} N

J90/I/19; J96/I/16

***25** What is the magnitude of the electric field strength at a distance r from an isolated stationary nucleus of proton number (atomic number) Z?

- **A** $\dfrac{Ze}{4\pi\epsilon_0 r}$
- **B** $\dfrac{Ze}{4\pi\epsilon_0 r^2}$
- **C** $\dfrac{Ze^2}{4\pi\epsilon_0 r}$
- **D** $\dfrac{(Ze)^2}{4\pi\epsilon_0 r^2}$
- **E** zero

N90/I/17

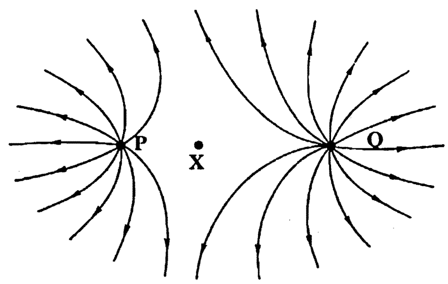
***26** A gold nucleus (radius r) is represented by the symbol $^{197}_{79}$Au.

Taking e as the elementary charge and ε_0 as the permittivity of free space, what is the electric field strength at the surface of an isolated gold nucleus?

- **A** zero
- **B** $\dfrac{79e}{4\pi\varepsilon_0 r^2}$
- **C** $\dfrac{197e}{4\pi\varepsilon_0 r^2}$
- **D** $\dfrac{79e^2}{4\pi\varepsilon_0 r^2}$
- **E** $\dfrac{197e^2}{4\pi\varepsilon_0 r^2}$

N93/I/14

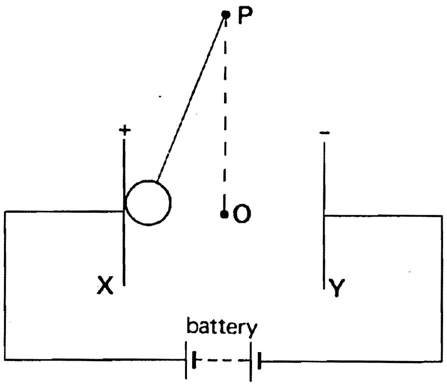
27 The diagram shows electric field lines around two isolated point charges **P** and **Q**. At **X** the field strength is zero.



Which of the following statements is true?

- **A** Q is a smaller charge than **P** because **X** is closer to **P** than **Q**.
- **B** Field strength is always proportional to the distance from **X**.
- **C** The potential at Q is less than the potential at **P**.
- **D** The field lines show that both charges are positive.
- **E** The potential at **X** is zero. J91/I/15

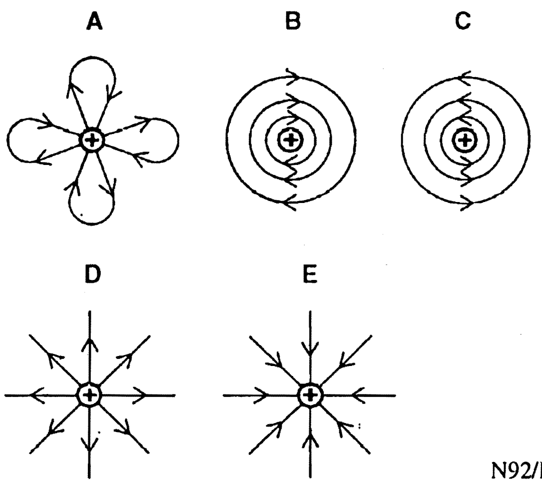
28 Two parallel plates **X** and **Y** are mounted vertically and given equal and opposite charges. A light uncharged conducting sphere is suspended by an insulating thread from point **P** vertically above the mid-point **O** of the line joining the centre of the plates.



If the sphere is initially placed in contact with **X** as shown in the diagram, which statement best describes its subsequent motion?

- **A** It remains in contact with plate **X**.
- **B** It moves to plate **Y** and sticks to it.
- **C** It moves back and forth continuously, touching each plate in turn.
- **D** It moves to point **O** and quickly comes to rest there.
- **E** It oscillates as a simple pendulum. J92/I/13

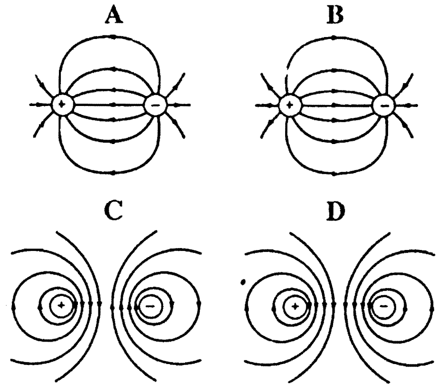
29 Which diagram best illustrates the electric field around a positive point charge?



N92/I/15

30 A positive charge and a negative charge of equal magnitude are placed a short distance apart.

Which diagram best represents the associated electric field?



J93/I/15; J97/I/17

31 In an experiment to demonstrate Coulomb's law in electrostatics, the force F between two small charged spheres is measured for various distances r between their centres.

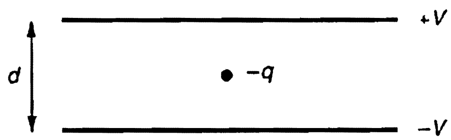
A graph is plotted of lg F (y-axis) against lg r (x-axis).

What is the slope of this graph?

A -2 **B** $-\frac{1}{2}$ **C** $-\lg 2$ **D** $+\frac{1}{2}$ **E** $+2$

J93/I/16

32 An oil droplet has a charge $-q$ and is situated between two parallel horizontal metal plates as shown in the diagram.



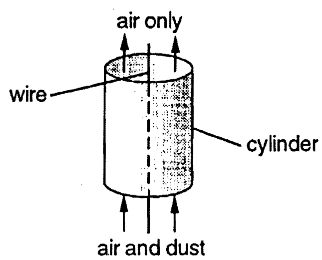
The separation of the plates is d. The droplet is observed to be stationary when the upper plate is at potential $+V$ and the lower at potential $-V$.

For this to occur, the weight of the droplet is equal in magnitude to

A $\frac{Vq}{d}$ **B** $\frac{2Vq}{d}$ **C** $\frac{Vd}{q}$ **D** $\frac{2Vq}{d}$

J94/I/15

33 Dust particles may be extracted from air using the electric field between a wire and a metal cylinder.



The electric field removes electrons from some air molecules, thus forming ions. These ions then become attached to dust particles. The charged dust particles then move to the inside of the cylinder

Which combination of ion charge and potentials must apply?

	ion charge	*wire potential*	*cylinder potential*
A	positive	+10 kV	0
B	positive	0	+10 kV
C	negative	0	+10 kV
D	negative	−10 kV	0

N94/I/13

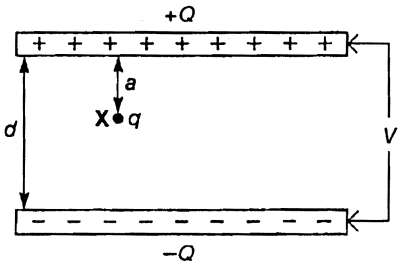
34 The potential difference between a pair of similar, parallel, conducting plates is known.

What additional information is needed in order to find the electric field strength between the plates?

A separation of the plates
B separation and area of the plates
C permittivity of the medium; separation of the plates
D permittivity of the medium; separation and area of the plates

N94/I/17

35 A point charge q is situated at **X** between two parallel plates which have a potential difference V and carry charges $+Q$ and $-Q$.

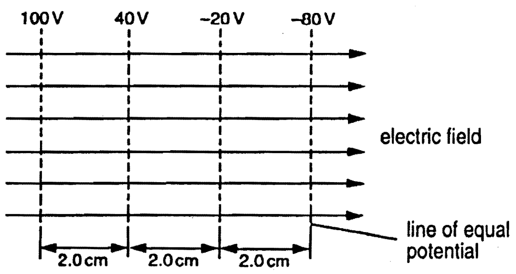


What is the electric field strength at **X**?

A $\dfrac{V}{d}$ **B** $\dfrac{Vq}{d}$ **C** $\dfrac{Q}{4\pi\varepsilon_0 a^2}$ **D** $\dfrac{qQ}{4\pi\varepsilon_0 a^2}$

J95/I/16

36 The diagram shows a uniform electric field in which the lines of equal potential are spaced 2.0 cm apart.

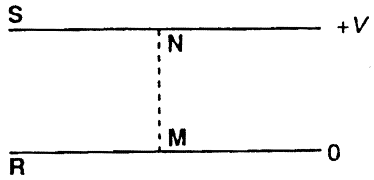


What is the value of the electric force that is exerted on a charge of +5.0 μC when placed in the field?

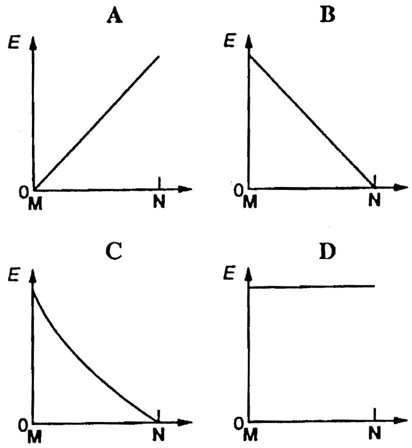
A 6.0×10^{-6} N
B 1.5×10^{-2} N
C 3.0×10^{3} N
D 6.0×10^{8} N

N95/I/17; N2000/I/16

37 Two horizontal conducting plates **R** and **S** are a fixed distance apart. Plate **S** is at potential $+V$ with respect to plate **R**. **MN** is a line perpendicular to the plates.



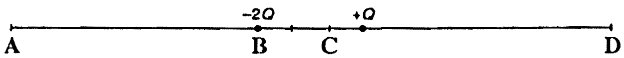
Which graph shows how the magnitude E of the electric field strength varies along the line **MN**?



N96/I/15

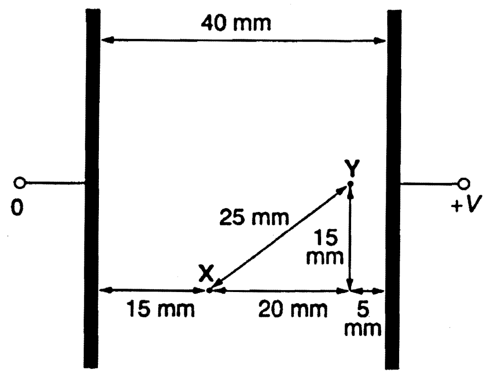
38 Two point charges $-2Q$ and $+Q$ are situated as shown.

At which point could the resultant electric field due to these charges be zero?



N96/I/16

39 Two large plane parallel conducting plates are situated 40 mm apart as shown. The potential difference between the plates is V.

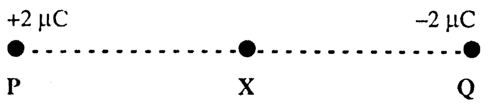


What is the potential difference between point **X** and point **Y**?

A $\frac{15}{40}V$ **B** $\frac{20}{40}V$ **C** $\frac{25}{40}V$ **D** $\frac{40}{40}V$

J97/I/16

40 Charges of +2 μC and −2 μC are situated at points **P** and **Q** respectively, as shown. **X** is midway between **P** and **Q**.

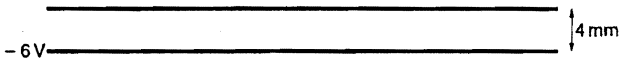


Which of the following correctly describes the electric field and the electric potential at point **X**?

	electric field	*electric potential*
A	towards **Q**	zero
B	towards **Q**	negative
C	towards **P**	zero
D	towards **P**	positive

N97/I/16

41 Two large horizontal metal plates are separated by 4 mm. The lower plate is at a potential of −6 V.



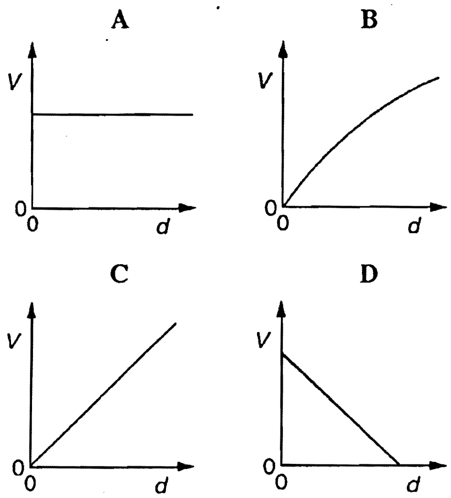
What potential should be applied to the upper plate to create an electric field of strength 4000 V m^{-1} **upwards** in the space between the plates?

A +22 V
B +10 V
C −10 V
D −22 V

J98/I/16

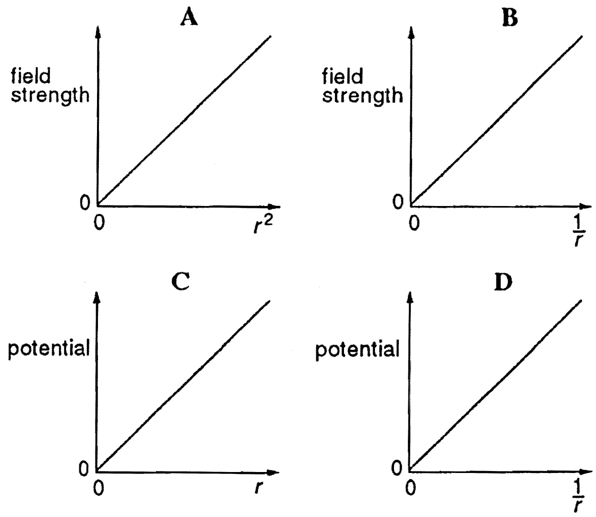
42 A constant electric field is to be maintained between two large parallel plates for which the separation *d* can be varied.

Which graph shows how the potential difference *V* between the plates must be adjusted to keep the field strength at a constant value?



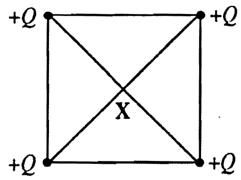
J99/I/17

43 Which graph correctly relates the electric field strength or electric potential in the field of a point charge, with distance *r* from the charge?



J2000/I/17

44 Four identical point charges are arranged at the corners of a square as shown.



Which statement about the values of the electric field strength *E* and the electric potential *V* at point **X** in the middle of the square is true?

	E	*V*
A	not zero	zero
B	not zero	not zero
C	zero	not zero
D	zero	zero

N2000/I/15

45 *(a)* A thundercloud at a potential of 10^7 V with respect to Earth delivers a lightning stroke to Earth of 50 C of charge. Calculate the energy dissipated if the p.d. remains constant.

(b) Calculate the speed of an electron accelerated from rest in a vacuum by a p.d. of 10^7 V, assuming Newtonian mechanics.

[Specific charge of the electron = -1.76×10^{11} C kg^{-1}.]

(c) Is this result possible?

J76/I/7

46 Write down expressions for the electric field *E* at the surface and the potential *V* of an isolated spherical conductor of radius *R* carrying a charge *q*.

If air ionises in an electric field greater than 3.0×10^6 V m^{-1}, what is the maximum operating potential of a Van de Graaff generator with a spherical dome of radius 6.0 cm?

J80/I/7

47 A charge Q is placed at the centre of a hollow, conducting sphere that is initially uncharged. What is then the net charge on *(a)* the inner surface, *(b)* the outer surface, of the sphere? Explain your reasoning. J81/I/8

48 A gold nucleus has a radius of about 5×10^{-15} m and contains 79 protons. Assuming that the protons are uniformly distributed in the nucleus, find the electric field strength at the surface of the nucleus. J82/I/7

49 The two protons in a helium nucleus are about 1.5×10^{-15} m apart. Find the electrostatic force between them. How much work must be done against this force in bringing two protons from infinity to this separation? N82/I/7

50 Write down an expression for the electric field E at the surface of an isolated spherical conductor of radius r carrying a charge Q.

*The $^{238}_{92}$U nucleus, which may be assumed to be spherical, has a radius of about 7×10^{-15} m. What is the electric field at the surface of the nucleus? N83/I/11

51 A capacitor is constructed from two concentric spheres, the inner sphere being charged positively and the outer being earthed as shown in Fig. 4.

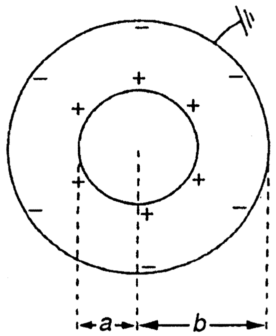


Fig. 4

Draw three sketch graphs, using the same scales, to show how the electric field $E(r)$ due to

(i) the charges on the inner sphere alone,

(ii) the charges on the outer sphere alone,

(iii) the combination of all charges,

varies with distance r from the centre. J85/III/5

52 Estimate the ratio of the electrostatic force to the gravitational force between the protons in a helium nucleus. N85/III/5

53 Explain whether it is possible for the electric field strength to be zero at a point where the electric potential is *not* zero. N86/III/6

54 Two large metal plates are oppositely charged and placed a distance D apart. A conductor of thickness d is situated centrally between the plates (see Fig. 5).

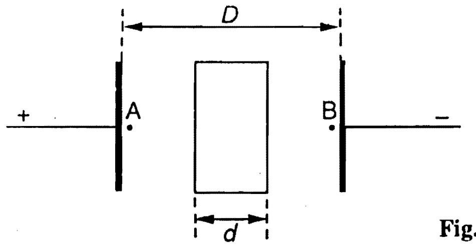


Fig. 5

Draw sketch graphs, one in each case, to show the variation from A to B of

(a) the electric field strength,

(b) the electric potential. J87/III/6

55 A and B are two identical conducting spheres, each carrying a charge $+Q$. They are placed in a vacuum with their centres distance d apart as shown in Fig. 6.

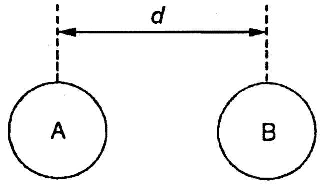


Fig. 6

Explain why the force F between them is **not** given by the expression

$$F = \frac{Q^2}{4\pi\epsilon_0 d^2}$$

[3] N87/III/4

56 Write down a general expression relating electric field strength to electric potential. Hence, explain why the electric potential on the surface of an isolated charged conductor is everywhere the same. [4] J88/III/5

57 *(a)* Two ions **A** and **B** are separated by a distance of 0.72 nm in a vacuum, as shown in Fig. 7. **A** has a charge of $+3.2 \times 10^{-19}$ C and **B** has a charge of -1.6×10^{-19} C. What force does **A** exert on **B**? [3]

(b) Without making detailed calculations, draw labelled arrows on Fig. 7 to represent

(i) the field E_A at the point X due to the charge at **A** only,

(ii) the field E_B at X due to the charge at **B** only,

(iii) the resultant field E at X due to both charges. [4]

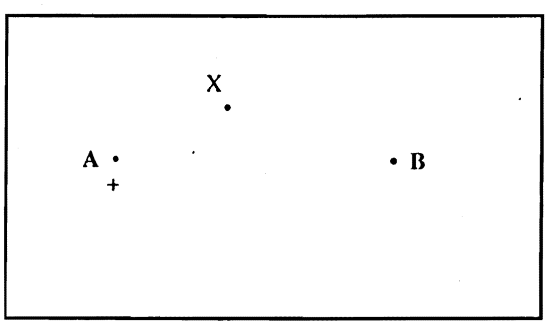


Fig. 7

(c) Sketch on the diagram, lines representing the electric field caused by the two ions in the region within the rectangle. Include the field line passing through X. [3]
N91/II/6

57 *(b)* Two small point charges $+Q_1$ and $+Q_2$ are placed at **X** and **Y** respectively and are separated by a distance r as shown in Fig. 8.

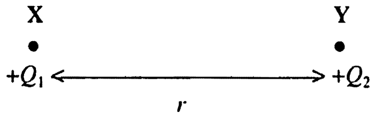


Fig. 8

(i) Draw on Fig. 8 the direction of the electric field which Q_1 causes at **Y**.

(ii) What is the value of the electric field strength which Q_1 causes at **Y**?

(iii) What is the force which Q_1 causes on Q_2?

(iv) Sketch on Fig. 8 the pattern of the electric field. [5] J92/II/1 (part)

58 *(a)* Distinguish between

(i) *gravitational force* and *gravitational field strength*,

(ii) *electric potential* and *electric potential energy*. [3]

**(b)* An α-particle approaches a stationary gold nucleus.

The gold nucleus is represented by $^{197}_{79}$Au.

(i) Calculate the charge on the gold nucleus.

charge = ...C

(ii) 1. Calculate the electric potential due to the gold nucleus at a distance of 2.5×10^{-12} m from its centre. Assume that the gold nucleus is a point charge.

potential = ...

2. Hence determine the electric potential energy of the α-particle when the separation of the gold nucleus and the α-particle is 2.5×10^{-12}m

energy = ... J [5]

**(c)* (i) Write down the relation between the total potential energy E_T of the α-particle, its gravitational potential energy E_G and its electric potential energy E_E.

(ii) Without any calculation, suggest why, in an α-particle scattering experiment

1. gravitational effects are ignored,

2. when calculating electric potential, the direction of approach of the α-particle to the nucleus need not be considered. [3]
N98/II/2

60 *(a)* Two isolated metal spheres have charges of $+Q$ and $-Q$, as illustrated in Fig. 9.

Fig. 9

On Fig. 9, draw lines to represent the electric field in the region between the spheres. [3]

(b) A metal sphere C is attached to an insulating rod and suspended on a fibre as shown in Fig. 10.

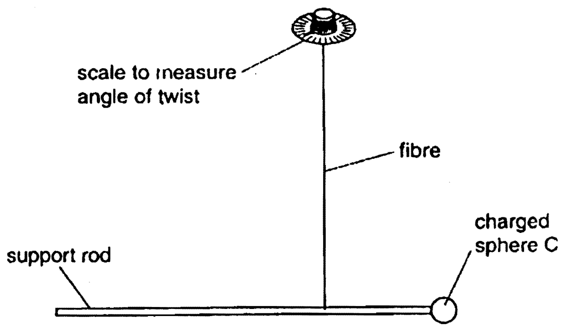


Fig. 10 (side view)

The support rod can rotate in a horizontal plane about the fibre. The fibre is held at its upper end so that the fibre may be twisted and the angle of twist measured. Sphere C is charged. A second sphere S, carrying the same charge as C, is then brought close to C at the same horizontal level. The two spheres, which may be assumed to behave as point charges at the centres of the spheres, repel each other and the support rod rotates as illustrated in Fig. 11.

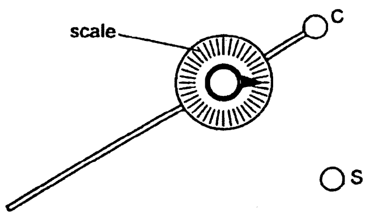


Fig. 11 (top view)

The upper end of the fibre is twisted to return the support rod to its original position, as illustrated in Fig. 12. When the fibre is twisted, it produces a torque on the support rod which is proportional to the angle of twist θ.

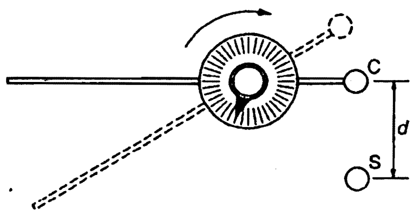


Fig. 12 (top view)

(i) Explain what is meant by a *torque*. [2]

(ii) Show that the angle of twist θ gives a measure of the force of repulsion between the two spheres. [3]

(iii) In one particular experiment, the angle of twist is β when the separation of the centres of the spheres is d and the charge on each sphere is $+Q$. State and explain the value, in terms of β, of the new angle of twist when

1. the separation is increased to $2d$ and the charge on each sphere remains at $+Q$,

2. the charge on sphere S is halved ($\frac{1}{2}Q$), the charge on sphere C remains at $+Q$ and the separation is returned to d. [4]

N2000/II/5

Long Questions

61 Define *electric field strength E* and *electric potential V.* Name suitable SI units for these quantities.

Deduce the relationship between E and V. N76/III/6 (part)

62 State *Coulomb's law* explaining carefully the meaning of the terms in any equation you quote.

Define *electric potential at a point.* Hence, deduce a formula for the potential at the surface of a charged, isolated spherical conductor in free space, in terms of its radius and total charge.

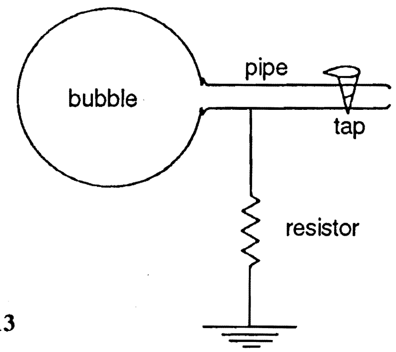


Fig. 13

A charged spherical soap bubble on the end of a small metal pipe is losing gas through the tap and losing charge through the resistor (see Fig. 13). The tap is continuously adjusted so that the current in the resistor is kept constant. Show that, under these conditions, the radius of the bubble will decrease at a constant rate. If the resistor has the value 10^{12} Ω, calculate how long a bubble of 5 cm radius would take to collapse, assuming that it did not burst.

[$\epsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}.] J77/III/4 (part)

63 Two similar corks, each of mass 5.0×10^{-4} kg, are suspended by conducting threads, each 2.0×10^{-1} m long, from a point of high potential. The threads separate so that they enclose an angle of 30°. Calculate the charge on each cork.

[Permittivity of free space, $\epsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}; acceleration of free fall, $g = 9.8$ m s^{-2}.] N78/III/6 (part)

64 Define *electric potential at a point* and *electric field strength.* A strip of stiff, conducting paper, pivoted at its centre of gravity, is placed between two large parallel fixed metal plates. The plates are connected to a high voltage supply. The paper is observed first to oscillate, then come to rest pointing towards the plates. Account for this.

Values of the high voltage V and period of oscillation T are as follows:

V/kV	52	67	98	198
T/s	1.92	1.49	1.02	0.51

By means of an appropriate logarithmic graph, or otherwise, determine the law relating V with T.

Assuming that induced charge is proportional to inducing field strength, show that the torque for a small angular displacement of the strip is proportional to V^2 and hence that the form of the law you have found is to be expected theoretically. J79/III/4

65 Electric field strength at a point may be defined as 'force per unit charge' on a charge placed at the point. Show how this leads to a general expression relating E_x, the x-component of the field strength, to the potential gradient in the x-direction. Explain the significance of the sign in your expression.

J80/III/4 (part)

66 At two instants, $t = 0$ s and $t = 2.0 \times 10^{-7}$ s, the velocity of an electron moving in a vacuum in the (x, y) plane is as indicated by the vectors in Figs. 14 (i) and 14 (ii) respectively.

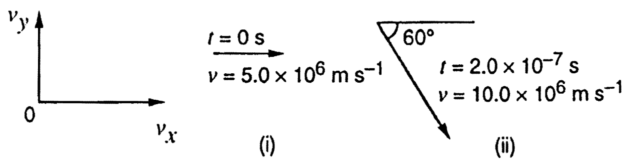


Fig. 14

(*a*) By drawing a vector diagram to scale, find the change of velocity which takes place over this time interval.

(*b*) Hence find the magnitude and direction of the acceleration of the electron over this interval.

(*c*) Assuming that the acceleration of the electron has been caused by the application of a uniform electric field of intensity E, find the magnitude and direction of E. (Neglect the effect of gravity.)

(*d*) Describe qualitatively the subsequent motion of the electron in this uniform electric field.

[Specific charge of electron, $e/m_e = 1.76 \times 10^{11}$ C kg^{-1}.]

N80/I/13 (part)

67 In an early model of the hydrogen atom, an electron of mass m_e and charge $-e$ is considered to move in a circular orbit of radius r about a stationary proton of charge $+e$.

(*a*) Assuming that the electrostatic attraction between the electron and proton provides the centripetal force, find an expression for the angular velocity ω of the electron in terms of e, r, m_e and ϵ_0, the relative permittivity of a vacuum.

(c) Show that the total energy of the electron (the sum of its kinetic energy and its electrostatic potential energy) is $-L^2/2m_e r^2$. N80/I/14 (part)

68 Write equations for Coulomb's law in electrostatics and Newton's law of gravitation. Identify the symbols in the equations.

Explain what is meant by the *electric potential* of a conductor. Deduce, from first principles, an expression for the potential of an isolated, charged conducting sphere.

Electrons 'leak' easily from the surface of many stars so that such stars acquire a positive charge. This charging stops when the charge on the star is so large that protons in the surface also begin to be repelled. This occurs when the sum of the gravitational potential energy and the electric potential energy of a proton near the surface is zero.

(a) Write down the equation relating these two energies.

(b) Show that, in the steady state, the maximum charge carried by a star of given mass is independent of its radius.

J81/III/3

69 A Van de Graaff generator has a spherical dome of radius 0.20 m. The insulation of the air breaks down when the potential gradient near the surface of the dome reach 3.0×10^6 V m^{-1}. The dome sparks into the nearby air at a rate of one spark every two seconds and each spark completely discharges the dome. Calculate

(a) the maximum charge on the dome,

(b) the current carried by the belt,

(c) the mean power to drive the belt if friction is negligible. N81/III/3 (part)

70 *(a)* State the relation between the intensity of an electric field and the corresponding potential. What is the analogous expression for a gravitational field? Write down the units of electrostatic field and potential and of gravitational field and potential.

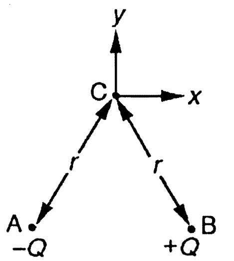


Fig. 15

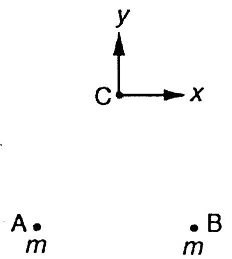


Fig. 16

ABC is a triangle in which CA = CB = r. In Fig. 15 charges −Q and +Q are placed at A and B respectively and, in Fig. 16, equal point masses m are situated at A and B.

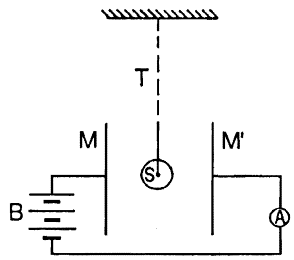
(i) In Fig. 15, in which direction relative to the x- and y-directions does the resultant electric field at C act

(ii) In Fig. 16, in which direction relative to the x- and y-directions does the resultant gravitational field at C act?

(iii) Find the electrostatic and gravitational potential at C.

J82/I/15 (part)

71



A small conducting sphere S is suspended from a very long insulating thread T between metal plates MM'. The plates are connected to a battery B and a sensitive current-measuring device A. After being given an initial displacement, the sphere moves to one of the plates, touches it, moves rapidly to the other, touches that, and this oscillation process repeats itself. Explain, in general terms, *(a)* why this happens, *(b)* why A registers a current.

Deduce expressions for

(i) the charge on the sphere in terms of its radius R and the battery p.d. V when in contact with M (assuming that the sphere acts as if 'isolated');

(ii) the electrostatic force on the sphere in terms of R, V, and the distance x between the metal plates (assuming that the field is uniform),

(iii) the acceleration of the sphere in terms of R, V, x and m, the mass of the sphere (assuming that gravity plays no part);

(iv) the time for the sphere to go from M to M' (assuming the $x \gg R$ and that the impacts are totally inelastic).

Hence show that the frequency of oscillation might be expected to be proportional to V/x and to $(R/m)^{1/2}$.

J82/III/5 (part)

72 *(a)* Describe, by means of diagrams and mathematical equations the forces due to

(i) a gravitational field,

(ii) an electric field,

*(iii) a magnetic field

which would act on a stationary electron.

Show how each of your answers would change, if at all, when the electron moves at right angles to each field. [9]

(b) (i) Give an expression for the electric field at a distance d from a point charge of magnitude Q, defining any other symbols you use. [3]

(ii) Explain to what extent an isolated, positively charged conducting sphere may be considered to act as a point charge. [3]

(c) A helium ($^4_2$He) nucleus travelling at a speed of 7.0×10^6 m s^{-1} strikes a gold ($^{197}_{79}$Au) film. By considering only the electrostatic repulsion, what is the closest possible distance of approach between the helium and gold nuclei? Explain your calculation carefully. [5]

Discuss briefly the effect of gravitational attraction on your answer. [2] N88/III/13

73 *(a)* By reference to Coulomb's law in electrostatics and Newton's law of gravitation, explain what is meant by an *inverse square law field.* [3]

(b) Define *electric potential* and distinguish it clearly from electric potential energy. [4]

(c) Explain, with the aid of diagrams illustrating charge distributions, how it is possible for a conductor to be

(i) at earth potential but carry a net positive charge,

(ii) at a positive potential with respect to earth but with no net charge. [6]

(d) A charged, polished metal sphere has a radius of 0.20 m. The insulation of the air breaks down when the electric field near the surface of the sphere reaches 3.0×10^6 V m^{-1}. Assuming that the charge on the sphere acts as if it were all situated at the centre, calculate for this sphere

(i) the maximum charge,

(ii) the maximum potential. [5]

Discuss the effect on the maximum potential of having a sphere with the same radius but with a rough surface. [4] J89/III/12

74 *(a)* What is meant by the term *electric field strength*? [2]

(b) Calculate the force exerted on a proton, which has a charge of $+1.6 \times 10^{-19}$ C, when it is in a uniform electric field of field strength 2.7×10^5 N C^{-1}. [2]

(c) A proton is moved in a vacuum by a uniform electric field of 2.7×10^5 N C^{-1} from A to B, a distance of 0.0078 m. (Fig. 17.)

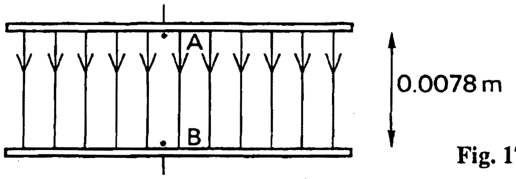


Fig. 17

(i) How much work is done by the field on the proton? [2]

(ii) What is the gain in the kinetic energy of the proton? [1]

(iii) Calculate the difference in potential between A and B.

State whether A or B is at the higher potential. [3]

(d) In an electron microscope, an electron lens has two cylinders which are at potentials of +500 V and −100 V respectively. An electron beam passes at high speed into the lens from the left. A cross-section of the two cylinders is shown full scale in Fig. 18, together with dotted lines showing points of the same potential at different places within the cylinders. Use the diagram, where necessary measuring distances on it with a ruler, to

(i) find the potential difference between X and Y, [1]

(ii) find the loss in kinetic energy of an electron moving in a vacuum between X and Y, [2]

(iii) find the approximate value of the electric field strength at Z, [3]

(iv) sketch a graph showing how the potential varies along the axis of the lens, [2]

(v) sketch, on the same x-axis drawn in (iv), a graph showing how the speed of the electron varies as it passes from X to Y. [2]

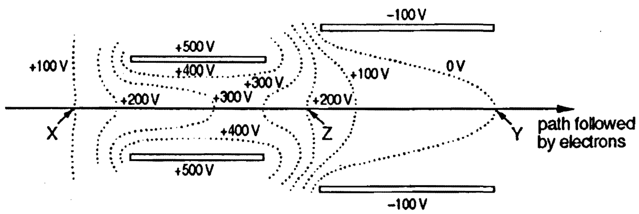


Fig. 18 J93/III/14

75 *(b)* (i) State what is meant by

1 a *gravitational* field of force,

2 an *electric* field of force.

(ii) For each field in *(b)* (i), discuss whether or not the force produced is in the direction of the field.

(iii) The Y-plates of a cathode-ray oscilloscope have a separation of 0.80 cm and a potential difference between them of 120 V. Give a quantitative explanation as to why the gravitational force due to the Earth is not considered when predicting the motion of an electron between the plates. [8]

(c) (i) Two electrons are situated a certain distance apart in space. Calculate the ratio

$$\frac{\text{electric force between the electrons}}{\text{gravitational force between the electrons}}$$

(ii) Give a quantitative explanation of the effect on this ratio of replacing one of the electrons with a proton. [6]

N95/III/6 (part)

76 Fig. 19 illustrates an isolated conducting sphere which has been charged positively.

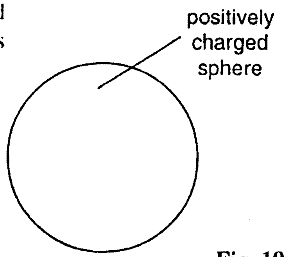


Fig. 19

For points on the surface or outside the sphere, the charge on the sphere behaves as if it were concentrated at the centre.

(a) Copy Fig. 19 and on your diagram draw

(i) the electric field lines (label these lines *E*),

(ii) lines joining points of equal potential (label these lines *V*). [4]

(b) Measurements of the distance *x* from the centre of the sphere and the corresponding values of the potential *V* are given in Fig. 20.

x / *cm*	*V* / *V*
19	1.50×10^5
25	1.14×10^5
32	0.89×10^5
39	0.73×10^5

Fig. 20

(i) Without drawing a graph, use the data to verify that the potential *V* is inversely proportional to the distance *x*.

(ii) The potential at the surface of the sphere is 1.9×10^5 V. Calculate the radius of the sphere. [4]

(c) Using your answer to *(b)*(ii), determine

(i) the charge on the sphere,

*(ii) the capacitance of the sphere. [4]

J98/III/3 (part)

77 *(d)* The potential in the gravitational field of a point mass decreases with decreasing distance from the mass. In the electric field of a point charge, electric potential may increase or decrease with decreasing distance from the charge. Explain this difference. [2]

**(e)* The radius of a lithium ($^7_3$Li) nucleus is 2.3×10^{-15} m, and the radius of a proton is 1.2×10^{-15} m.

(i) Calculate the electric potential energy of a proton when it is just in contact with a lithium nucleus. You may assume that the proton and the lithium nucleus act as point charges.

(ii) By reference to your answer to (i), suggest why particle accelerators used for research into the composition of nuclei are referred to as 'high energy' accelerators. [5]

J99/III/3 (part)

78 *(a)* Define *electric field strength* and state an SI unit of electric field strength. [2]

(b) Fig. 21 illustrates two plates A and B, a distance 30 mm apart in a vacuum, with A at a potential of –4.2V and B at zero potential. Electrons are emitted from B and move directly towards A.

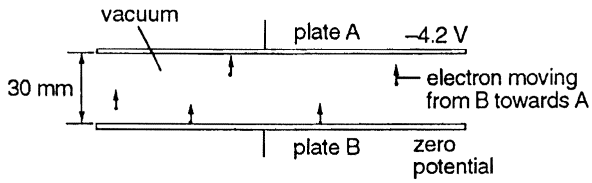


Fig. 21

Calculate

(i) the electric field, assumed uniform, between the plates,

(ii) the velocity with which the electrons need to be emitted in order to reach plate A. [5]

(c) State, with a reason, what your answer to *(b)*(ii) would have been if the distance between the plates had been doubled to 60 mm, while keeping the potentials the same. [2]

**(d)* The arrangement described in *(b)* is made use of in experiments on the photoelectric effect. The kinetic energy of the photoelectrons emitted from plate B can be determined by measuring the potential required just to prevent photoelectrons from reaching plate A, the stopping potential.

Describe

(i) the conditions necessary for the photoelectric effect to be observed,

(ii) how the stopping potential varies with the frequency of the electromagnetic radiation,

(iii) how the stopping potential varies with the intensity of the electromagnetic radiation,

(iv) the conclusions drawn from photoelectric experiments about the nature of electromagnetic radiation. [8]

**(e)* Describe experimental evidence for the wave nature of particles. [3]