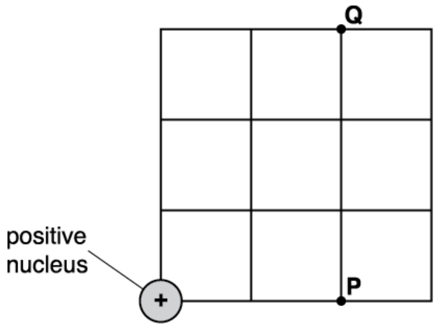
Electrical Fields

1. An electron at point **P** experiences an electric force of magnitude 1.8 μN due to the positive nucleus.



What is the magnitude of the force experienced by the same electron when it is at point **Q**?

A 0.28 μN
B 0.55 μN
C 1.0 μN
D 1.8 μN

Your answer

[1]

2. An isolated metal sphere is charged using a power supply.

Which single quantity can be used to determine the capacitance of the sphere?

A The diameter of the sphere.
B The charge on the sphere.
C The resistance of the metal.
D The e.m.f. of the power supply.

Your answer **[1]**

3 (a). Fig. 20.1 shows a positively charged metal sphere and a negatively charged metal plate.

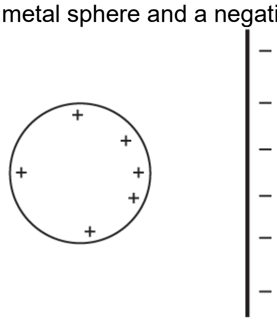


Fig. 20.1

On Fig. 20.1, draw a minimum of **five** electric field lines to show the field pattern between the sphere and the plate.

[2]

(b). Define *electric potential* at a point in space.

-- **[1]**

(c). A metal sphere is given a positive charge by connecting its surface briefly to the positive terminal of a power supply. The electric potential at the surface of the sphere is + 5.0 kV. The sphere has radius 1.5 cm.

i. Show that the charge Q on the surface of the sphere is 8.3×10^{-9} C.

[2]

ii. Fig. 20.2 shows the charged sphere from **(i)** suspended from a nylon thread and placed between two oppositely charged vertical plates.

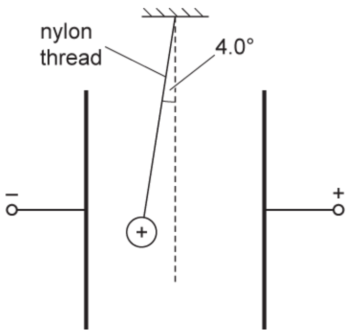


Fig. 20.2 (not to scale)

The weight of the sphere is 1.7×10^{-2} N. The string makes an angle of 4.0° with the vertical.

1. Show that the electric force on the charged sphere is 1.2×10^{-3} N.

[1]

2. Calculate the uniform electric field strength E between the parallel plates.

E = ... N C^{-1} **[2]**

4. The electric potential is -1.2×10^{-4} J C^{-1} at a point 1.2×10^{-5} m from an isolated electron.
An α-particle $^4_2$He passes through this point.

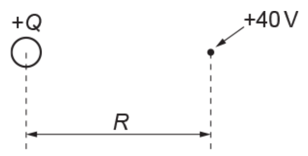
What is the magnitude of the electric potential at the mid-point between the α-particle and the electron at this instant?

A. -7.2×10^{-4} J C^{-1}
B. $+2.4 \times 10^{-4}$ J C^{-1}
C. $+4.8 \times 10^{-4}$ J C^{-1}
D. $+7.2 \times 10^{-4}$ J C^{-1}

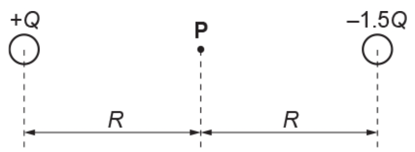
Your answer

[1]

5. The electric potential at a distance R from the centre of a charge $+Q$ is + 40 V.



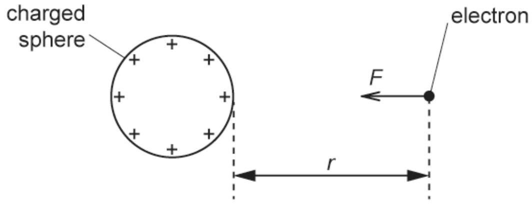
What is the potential at the point **P** for the arrangement of the charges $+Q$ and $-1.5Q$ as shown below?



A − 20 V
B − 60 V
C + 80 V
D + 100 V

Your answer **[1]**

6. An electron is released at a distance *r* from the surface of a positively charged sphere. It is attracted towards the centre of the sphere and moves until it touches the surface.



Which of the following statements is/are correct?

1 The area under the *F* against *r* graph is equal to work done on the electron.

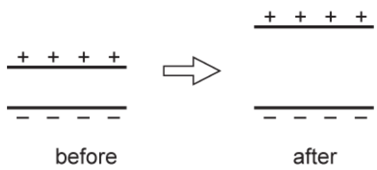
2 The electric field strength *E* at distance *r* is equal to $\frac{F}{1.6 \times 10^{-19}}$.

3 The work done on the electron is equal to *F* × *r*.

A Only 1
B Only 1 and 2
C Only 1 and 3
D 1, 2 and 3

Your answer [1]

7. Two isolated parallel capacitor plates have an equal and opposite charge.
The separation between the plates is doubled.
The charge on each plate remains the same but the potential difference between the plates doubles.



Which statement is correct?

A The capacitance of the capacitor doubles.
B The energy stored by the capacitor is halved.
C The permittivity of free space doubles.
D The electric field strength between the plates remains the same.

Your answer [1]

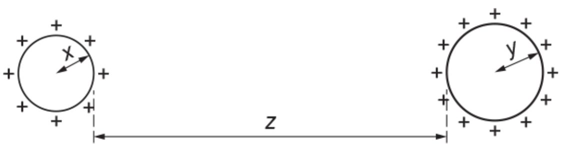
8. The electric field strength at a distance of 2.0×10^{-8} m from a nucleus is 3.3×10^{8} N C^{-1}.

What is the charge on the nucleus?

A 1.6×10^{-19} C
B 1.5×10^{-17} C
C 7.3×10^{-10} C
D 3.8×10^{-9} C

Your answer **[1]**

9. The diagram below shows two uniformly charged spheres separated by a large distance *z*.



The radius of the small sphere is x and the radius of the large sphere is *y*.

Which is the correct distance to use when determining the electric force between the charged spheres?

A *z*
B *x* + *z*
C *y* + *z*
D *x* + *y* + *z*

Your answer **[1]**

10. Which law indicates that charge is conserved?

A Lenz's law
B Coulomb's law
C Kirchhoff's first law
D Faraday's law of electromagnetic induction

Your answer **[1]**

11. The diagram below shows two oppositely charged spheres.

The magnitude of the charge on each sphere is the same.
The point **P** is on the line joining the centres of the spheres and is the same distance from the centre of each sphere.

Which statement is correct?

A A negatively charged particle at **P** will move to the right.
B The direction of the electric field at **P** is to the left.
C The electric potential at **P** is zero.
D The magnitude of the electric field strength at **P** is zero.

Your answer ☐ **[1]**

12. A capacitor consists of two parallel plates separated by air. The capacitor is connected across a d.c. supply. The charged capacitor is then disconnected and the separation between the plates is doubled.

Which statement is correct about the charge stored by the capacitor?

A The charge is the same.
B The charge doubles.
C The charge halves.
D The charge quarters.

Your answer ☐

[1]

13. Fig. 24 shows two horizontal metal plates in a vacuum.

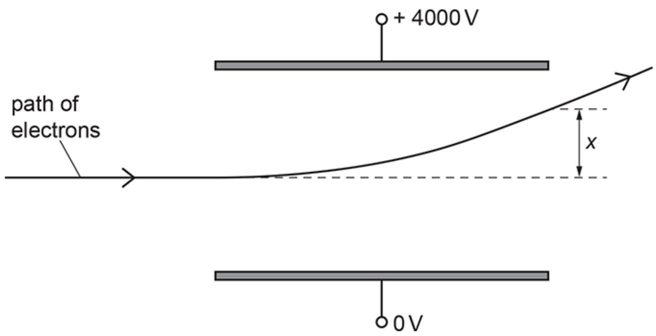


Fig. 24

The arrangement shown in **Fig. 24** is now used to investigate positrons emitted from a radioactive source.
The speed of the positrons is also 6.0×10^7 m s^{-1}.

The initial path of the positrons is the same as that of the electrons in **Fig. 24**.
On **Fig. 24**, sketch the path of the positrons between the plates. **[2]**

14 (a). A capacitor of capacitance 7.2 pF consists of two parallel metal plates separated by an insulator of thickness
1.2 mm. The area of overlap between the plates is 4.0×10^{-4} m^2. Calculate the permittivity of the insulator between the capacitor plates.

permittivity = ... F m^{-1} **[2]**

(b). Fig. 21 shows a circuit.

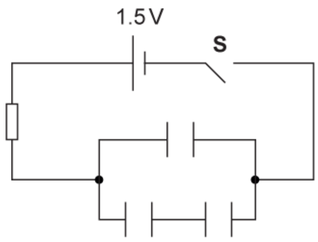


Fig. 21

The capacitance of each capacitor is 1000 μF. The resistance of the resistor is 10 kΩ. The cell has e.m.f. 1.5 V and negligible internal resistance.

i. Calculate the total capacitance *C* in the circuit.

C = ... μF **[2]**

ii. The switch **S** is closed at time *t* = 0. There is zero potential difference across the capacitors at *t* = 0. Calculate the potential difference *V* across the resistor at time *t* = 12 s.

V = ... V **[2]**

15. A nucleus of hydrogen-3 ($^{3}_{1}H$) is unstable and it emits a beta-minus particle (electron).

The emitted beta-minus particle enters a region of uniform magnetic field.
Fig. 22.1 shows the path of the particle **before** it enters the magnetic field.

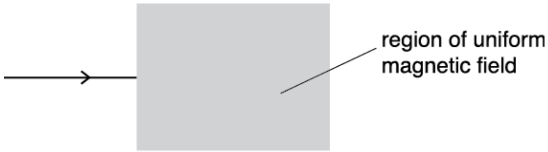


Fig. 22.1

The direction of the magnetic field is into the plane of the paper.
Describe and explain the path of the particle in the magnetic field.

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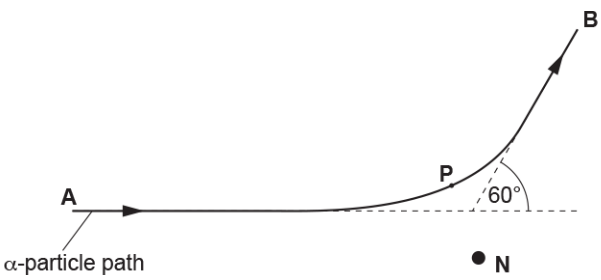
[2]

16. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil.
A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil.
The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



Another α-particle in the beam is deflected by the same gold nucleus **N** through an angle of 30°.

Sketch its path onto the diagram above. **[2]**

17. Fig. 21.3 shows two particles with the same charge but of opposite sign.

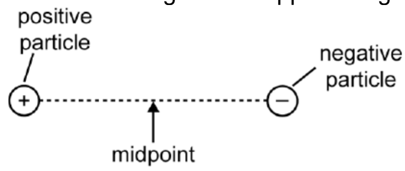


Fig. 21.3

State and explain the magnitude of the electric potential at the midpoint between the particles.

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[2]

18. Describe the similarities and the differences between the gravitational field of a point mass and the electric field of a point charge.

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[3]

19. A small thin rectangular slice of semiconducting material has width *a* and thickness *b* and carries a current *I*. The current is due to the movement of electrons. Each electron has charge –*e* and mean drift velocity *v*.
A uniform magnetic field of flux density *B* is perpendicular to the direction of the current and the top face of the slice as shown in Fig. 2.1.

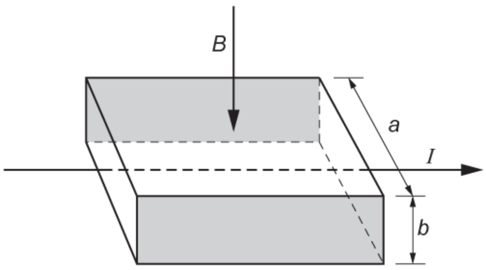


Fig. 2.1

As soon as the current is switched on, the moving electrons in the current are forced towards the shaded rear face of the slice where they are stored. This causes the shaded faces to act like charged parallel plates. Each electron in the current now experiences both electric and magnetic forces. The resultant force on each electron is now zero.

Write the expressions for the electric and magnetic forces acting on each electron and use these to show that the magnitude of the potential difference V between the shaded faces is given by

$$V = Bva.$$

[3]

20. Fig. 20.1 shows a capacitor connected to a power supply.

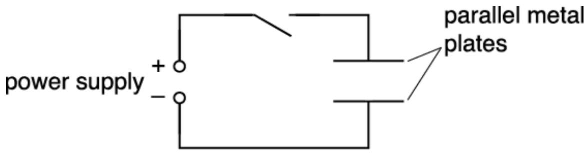


Fig. 20.1

The capacitor consists of two parallel metal plates separated by air.
The switch is closed to charge the capacitor.
The switch is then opened and the separation between the charged plates is **doubled**.
State and explain what happens to the energy stored by the capacitor.

[3]

21. A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 ($^{59}_{27}Co$) in a head-on collision.

i. Explain what happens to the electric potential energy of the proton-nucleus system.

[1]

ii. Calculate the **minimum** distance *R* between the proton and cobalt nucleus.

R = m **[3]**

22. A **proton** travels from point **P** to point **Q** in a uniform electric field as shown in Fig. 21.2.

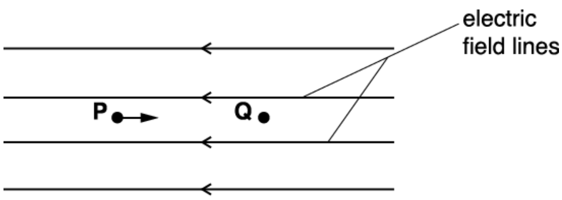


Fig. 21.2

The velocity of the proton at **P** is 7.2×10^6 m s^{-1} and the velocity at **Q** is 2.4×10^6 m s^{-1}. The distance between **P** and **Q** is 1.2 cm.

Calculate

i. the magnitude of the deceleration of the proton

deceleration = ... m s^{-2} **[2]**

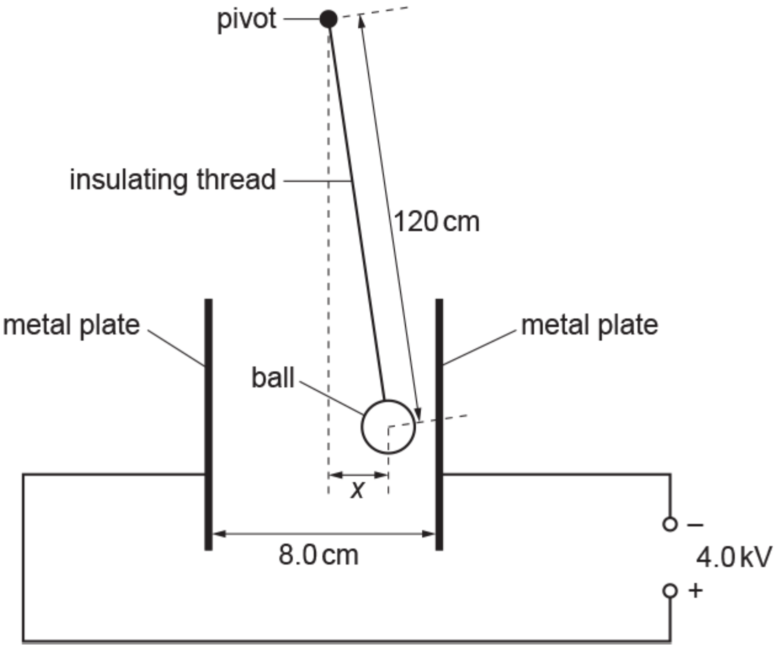
ii. the electric field strength *E*.

E = ... N C^{-1} **[2]**

23 (a). A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm. The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm.

The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm. The plates are connected to a 4.0 kV power supply.

The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement *x* from the vertical, as shown below. The diagram is **not** drawn to scale.



i. Show that the electric force acting on the charged ball is 4.5×10^{-4} N.

[2]

ii. Draw, on the diagram above, arrows which represent the **three** forces acting on the ball. Label each arrow with the name of the force it represents.

[2]

iii. By taking moments about the pivot, or otherwise, show that x = 1.8 cm.

[2]

(b). The ball is still positively charged.

The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.

Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.

---

[4]

(c). When the ball oscillates between the plates, the current in the external circuit is 3.2×10^{-8} A.

A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.

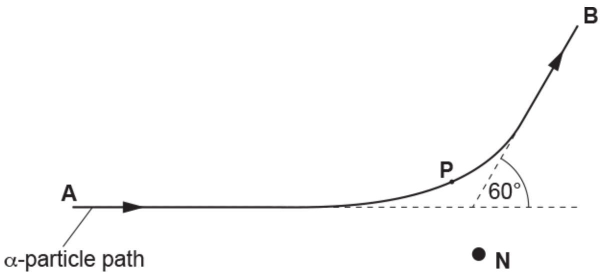
Calculate the frequency *f* of the oscillations of the ball.

f = ... Hz **[2]**

24. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The distance between **P** and **N** is 6.8×10^{-14} m.

Calculate the magnitude of the electrostatic force *F* between the α-particle $({}^{4}_{2}He)$ and the gold nucleus $({}^{197}_{79}Au)$ when the α-particle is at **P**.

F = ... N **[4]**

25. A positively charged particle is travelling in a uniform field.
Fig. 21.1 shows the particle travelling at right angles to the direction of the field.

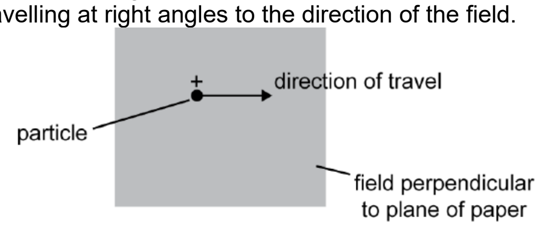


Fig. 21.1

Describe the motion of the particle in terms of the force it experiences when the field is

i. a magnetic field

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[2]

ii. an electric field.

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[2]

26 (a). Fig. 22.1 shows two horizontal metal plates in a vacuum.

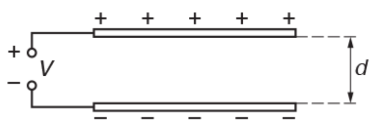

Fig. 22.1

The plates are connected to a power supply. The potential difference *V* between the plates is constant. The magnitude of the charge on each plate is *Q*. The separation between the plates is *d*.

Fig. 22.2 shows the variation with *d* of the charge *Q* on the positive plate.

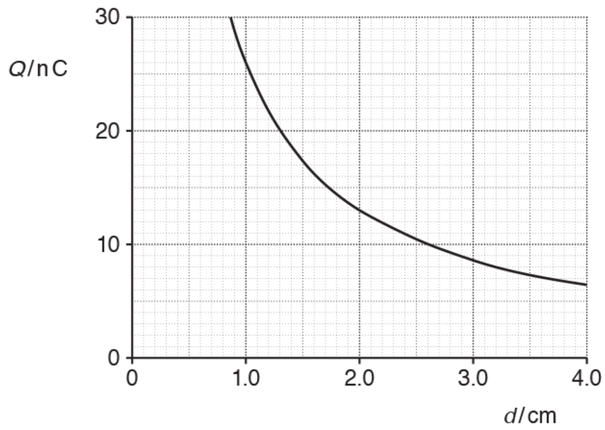

Fig. 22.2

i. Use Fig. 22.2 to propose and carry out a test to show that *Q* is inversely proportional to *d*.

Test proposed:

Working:

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[2]

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ii. Use capacitor equations to show that Q is inversely proportional to d.

[2]

(b). Fig. 22.3 shows a negatively charged oil drop between two oppositely charged horizontal plates in a vacuum.

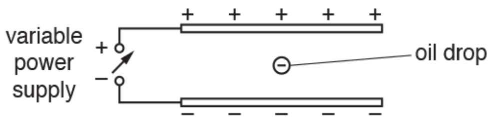

Fig. 22.3

The plates are fixed and connected to a variable power supply. The weight of the oil drop is 1.8×10^{-14} N.

i. The power supply is adjusted so that the potential difference between the plates is 200 V when the oil drop becomes **stationary**.

State the magnitude of the vertical electric force F_E acting on the charged oil drop.

F_E = ...N **[1]**

ii. The potential difference between the plates is now increased to 600 V. The oil drop accelerates upwards.

Calculate the acceleration a of the oil drop.

a = ...ms^{-2} **[3]**

27. Electrons in a beam are accelerated from rest by a potential difference *V* between two vertical plates before entering a uniform electric field of electric field strength *E* between two horizontal parallel plates, a distance 2*d* apart.

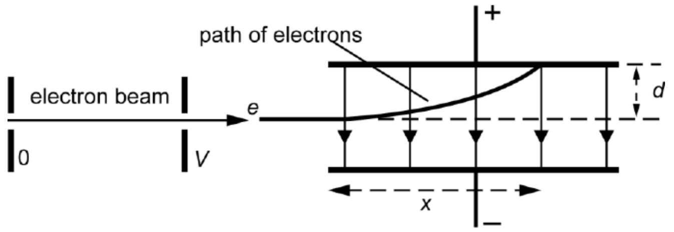

Fig. 2.1

The path of the electrons is shown in Fig. 2.1. The electron beam travels a horizontal distance *x* parallel to the plates before hitting the top plate. The beam has been deflected through a vertical distance *d*.

Show that *x* is related to *V* by the equation

$$x^2 = \frac{4dV}{E}.$$

[5]

28. Fig. 21.2 shows two parallel vertical metal plates connected to a battery.

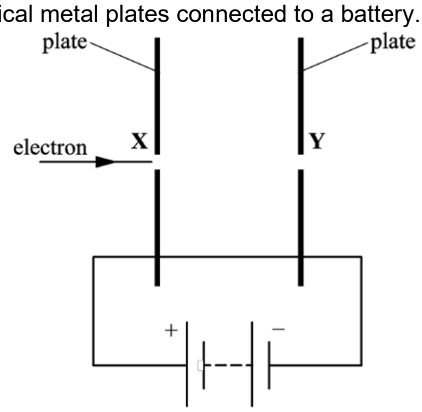

Fig. 21.2

The plates are placed in a vacuum and have a separation of 1.2 cm. The uniform electric field strength between the plates is 1500 V m^{-1}. An electron travels through holes **X** and **Y** in the plates. The electron has a horizontal velocity of 5.0×10^6 m s^{-1} when it enters hole **X**.

i. Draw five lines on **Fig. 21.2** to represent the electric field between the parallel plates.

[2]

ii. Calculate the final speed of the electron as it leaves hole **Y**.

speed = ... m s^{-1} **[3]**

29. Fig. 21.1 shows two oppositely charged ions to the left of a point **X**.

Fig. 21.1

The separation between the centres of the ions is 3.0×10^{-10} m. Each ion has charge of magnitude 1.6×10^{-19} C.

i. Explain why the direction of the **resultant** electric field strength at point **X** is to the left.

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[2]

ii. Calculate the minimum energy in eV required to completely separate the ions.

energy = ... eV **[3]**

30. Fig. 24 shows two horizontal metal plates in a vacuum.

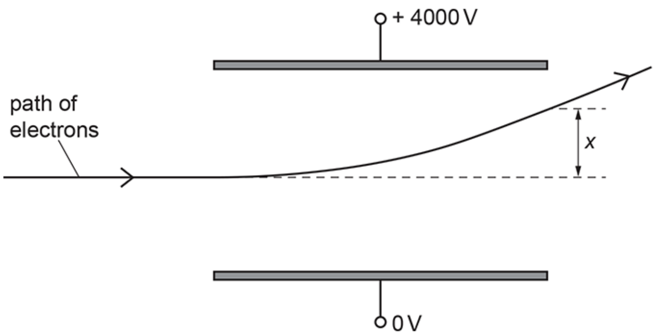

Fig. 24

The diagram is **not** drawn to scale.
Electrons travelling horizontally enter the space between the charged plates and are deflected vertically.

The potential difference between the plates is 4000 V.
The distance between the plates is 0.08 m.
The initial speed of the electrons is 6.0×10^{7} m s^{-1}.
The vertical deflection of the electrons at the far end of the plates is x.

i. Show that the vertical acceleration a of an electron between the plates is 8.8×10^{15} m s^{-2}.

[3]

ii. The length of each plate is 0.12 m.

Show that the time t taken by the electron to travel this length is 2.0×10^{-9} s.

[1]

iii. Calculate the vertical deflection x of the electron.

x = ... m **[2]**

31. A student wishes to determine the permittivity ε of paper using a capacitor made in the laboratory.

The capacitor consists of two large parallel aluminium plates separated by a very thin sheet of paper.

The capacitor is initially charged to a potential difference V_0 using a battery. The capacitor is then discharged through a fixed resistor of resistance 1.0 MΩ.

The potential difference V across the capacitor after a time t is recorded by a data-logger. The student uses the data to draw the ln$V$ against t graph shown in Fig. 22.

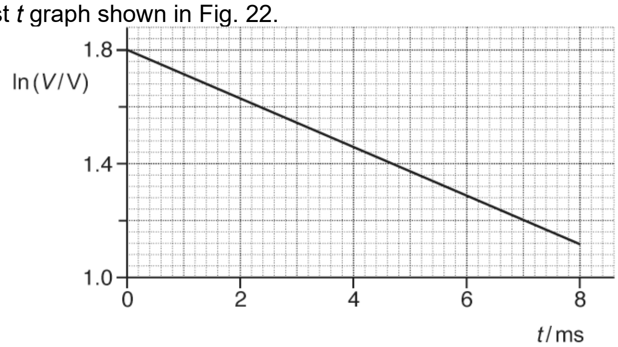

Fig. 22

Use Fig. 22 to determine the capacitance C of the capacitor. Describe how the student can then use this value of C to determine a value for ε.
In your description, mention any additional measurements required on the capacitor.

[6]

32. Fig. 21.1 shows two identical negatively charged conducting spheres.

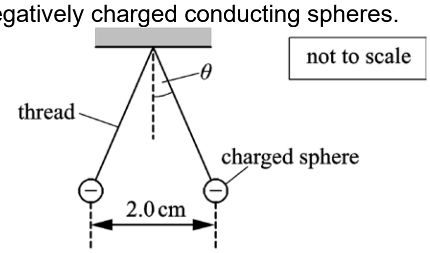

Fig. 21.1

The spheres are tiny and each is suspended from a nylon thread. Each sphere has mass 6.0×10^{-5} kg and charge -4.0×10^{-9} C. The separation between the centres of the spheres is 2.0 cm.

i. Explain why the spheres are separated as shown in **Fig. 21.1**.

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[2]

ii. Calculate the angle θ made by each thread with the vertical.

θ = ... ° **[4]**

33. Fig. 21.2 shows a uniformly charged sphere of radius R.

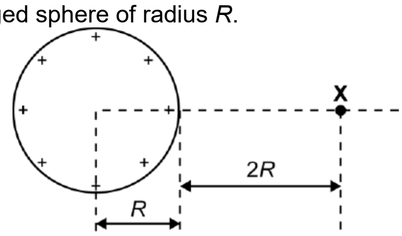


Fig. 21.2

The electric potential at point **X** is +1800 V. Point **X** is at a distance of 2R from the **surface** of the sphere.

i. Calculate the electric potential V at the surface of the sphere.

V = ... V **[2]**

ii. The radius of the sphere is 4.0 cm.

Calculate

1. the surface charge Q on the sphere

Q = ... C **[2]**

2. the electric field strength E at the surface of the sphere.

E = ... N C^{-1} **[2]**

34. * Fig. 22.4 shows an arrangement used by a student to investigate the forces experienced by a small length of charged gold foil placed in a uniform electric field.

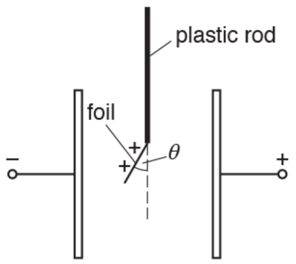


Fig. 22.4

The two vertical metal plates are connected to a high-voltage supply.

The foil is given a positive charge by briefly touching it to the positive plate.

The angle θ made with the vertical by the foil in the electric field is given by the expression $\tan\theta = \frac{qE}{W}$

where q is the charge on the foil, E is the electric field strength between the plates and W is the weight of the foil.

The angle θ can be determined by taking photographs with the camera of a mobile phone.

Describe how the student can safely conduct an experiment to investigate the relationship between θ and E. Identify any variables that must be controlled.

----

[6]

35. Fig. 3.1 shows a simple representation of a hydrogen iodide molecule. It consists of two ions ${}^{1}_{1}H^{+}$ and ${}^{127}_{53}I^{-}$, held together by electric forces.

Fig. 3.1

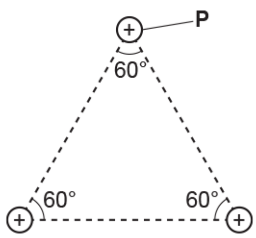
i. Draw on Fig. 3.1 a minimum of five lines to show the electric field pattern between the ions.

[2]

ii. The charge on each ion has a magnitude *e* of 1.6×10^{-19} C. The ions are to be treated as point charges 5.0×10^{-10} m apart. Calculate the magnitude of the resultant electric field strength *E* at the **mid-point** between the ions.

E = ... N C^{-1} **[4]**

36 (a). The diagram below shows the arrangement of the 3 protons inside the nucleus of lithium-6 (${}^{6}_{3}Li$).



The separation between each proton is about 1.0×10^{-15} m.

i. Calculate the magnitude of the repulsive electric force *F* experienced by the proton **P**.

F = ... N **[4]**

ii. On the diagram above, draw an arrow to show the direction of the electric force *F* experienced by **P**.

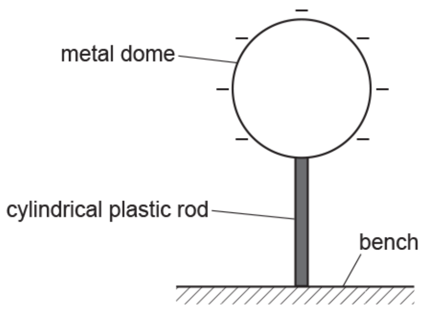
[1]

iii. Explain how protons stay within the nucleus of lithium-6.

---

[2]

(b). A spherical metal dome shown below is charged to a potential of −12 kV.



The dome is supported by a cylindrical plastic rod. The radius of the dome is 0.19 m.

i. Show that the magnitude of the total charge *Q* on the dome is 2.5×10^{-7} C.

[2]

ii. The dome discharges slowly through the plastic rod.
It takes 78 hours for the dome to completely discharge.

1 Show that the mean current *I* in the plastic rod is about 9×10^{-13} A.

[2]

2 The average potential difference across the plastic rod during discharge is 6000 V.
The rod has cross-sectional area 1.1×10^{-4} m^2 and length 0.38 m.

Calculate the resistivity *ρ* of the plastic.

ρ = ... Ωm **[3]**

37. The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_{9}F$) is made from the isotope of oxygen-18 ($^{18}_{8}O$).

$$^{18}_{8}O + ^{1}_{1}p \rightarrow ^{18}_{9}F + ^{1}_{0}n + \gamma$$

The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of 0.25×10^{-11} J.
The binding energy of the $^{18}_{8}O$ nucleus is 2.24×10^{-11} J and the binding energy of the $^{18}_{9}F$ nucleus is 2.20×10^{-11} J.
The proton and the neutron have zero binding energy.

i. Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

---

[2]

ii. Estimate the minimum wavelength λ of the gamma ray photon (γ).

λ = m **[3]**

iii. Fluorine-18 is a positron emitter.
Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

---

[2]

38. Electrons in a beam are accelerated from rest by a potential difference *V* between two vertical plates before entering a uniform electric field of electric field strength *E* between two horizontal parallel plates, a distance 2*d* apart.

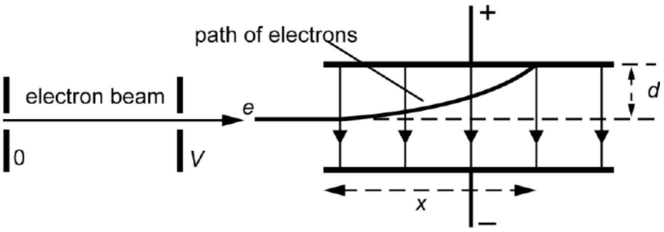


Fig. 2.1

The path of the electrons is shown in Fig. 2.1. The electron beam travels a horizontal distance *x* parallel to the plates before hitting the top plate. The beam has been deflected through a vertical distance *d*.

For different values of the accelerating p.d. *V*, the horizontal distance *x* is recorded. A table of results is shown with a third column giving values of x^2 including the absolute uncertainties.

V / V	*x* / cm	x^2 / cm^2
500	3.3 ± 0.1	10.9 ± 0.7
600	3.6 ± 0.1	13.0 ± 0.7
700	3.9 ± 0.1	15.2 ± 0.8
800	4.2 ± 0.1	17.6 ± 0.8
900	4.5 ± 0.1	20.3 ± 0.9
1000	4.7 ± 0.1	

i. Complete the missing value in the table, including the absolute uncertainty.

[1]

ii. Fig. 2.2 shows the axes for a graph of x^2 on the *y*-axis against *V* on the *x*-axis. The first four points have been plotted including error bars for x^2. Use data from the table to complete the graph.

[2]

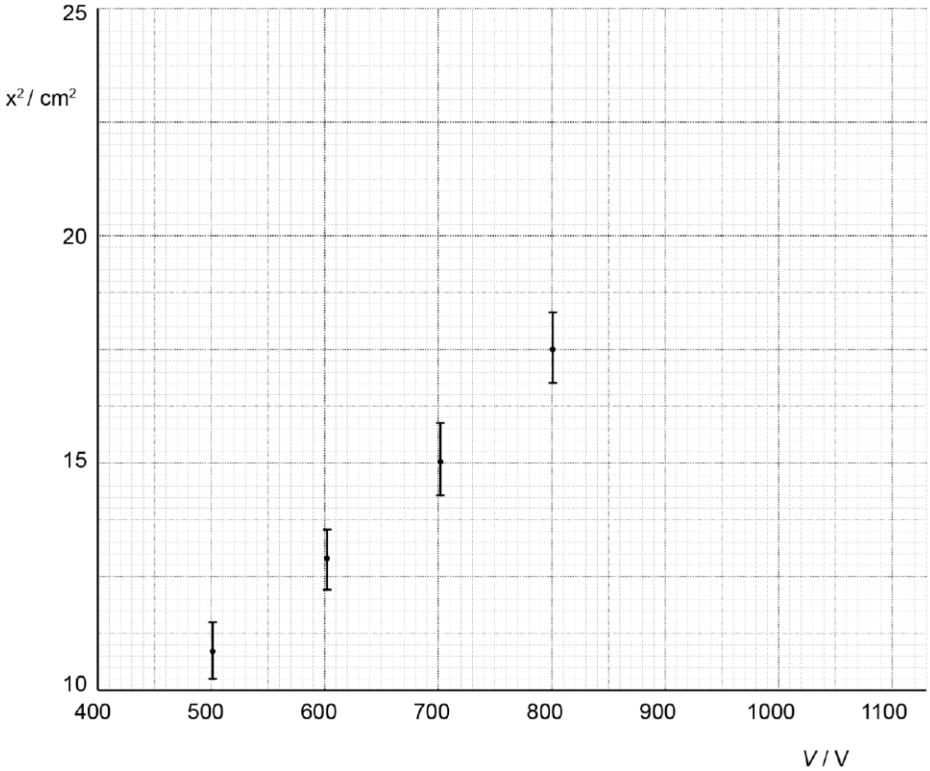


Fig. 2.2

iii. The separation of the horizontal plates is 4.0 ± 0.1 cm.
Use the graph to determine a value for E. Include the absolute uncertainty and an appropriate unit in your answer

E = ...±.......................unit....................... **[4]**

END OF QUESTION PAPER