Q1.

4 In a particular experiment, a high voltage is created by charging an isolated metal sphere, as illustrated in Fig. 4.1.

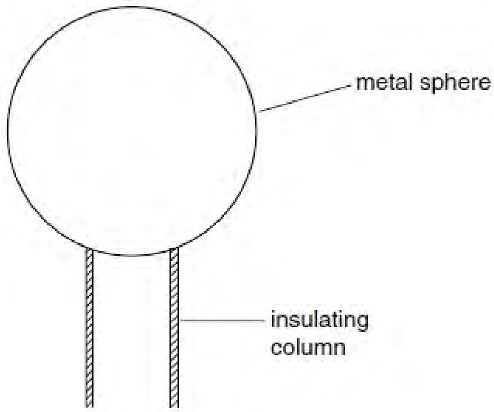


Fig. 4.1

The sphere has diameter 42 cm and any charge on its surface may be considered as if it were concentrated at its centre.

The air surrounding the sphere loses its insulating properties, causing a spark, when the electric field exceeds $20\,kV\,cm^{-1}$.

(a) By reference to an atom in the air, suggest the mechanism by which the electric field causes the air to become conducting.

....

....

....

.... [3]

(b) Calculate, for the charged sphere when a spark is about to occur,

(i) the charge on the sphere,

charge = ... C [3]

(ii) its potential.

potential = ... V [2]

(c) Under certain conditions, a spark sometimes occurs before the potential reaches that calculated in (b)(ii). Suggest a reason for this.

....

.... [1]

Q2.

1 (a) State the significance of the Millikan experiment.

....

.... [1]

(b) In the Millikan experiment, oil droplets were found to have the following charges.

1.56×10^{-19} C
4.88×10^{-19} C
1.64×10^{-19} C
3.14×10^{-19} C
4.76×10^{-19} C

Use these data to determine a value for the elementary charge. Explain your working.

....

....

elementary charge = ... C [2]

Q3.

5 An isolated conducting sphere of radius r is given a charge $+Q$. This charge may be assumed to act as a point charge situated at the centre of the sphere, as shown in Fig. 5.1.

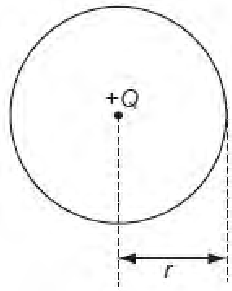


Fig. 5.1

Fig. 5.2. shows the variation with distance x from the centre of the sphere of the potential V due to the charge $+Q$.

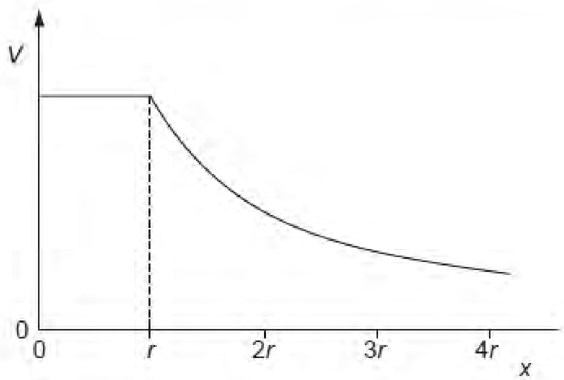
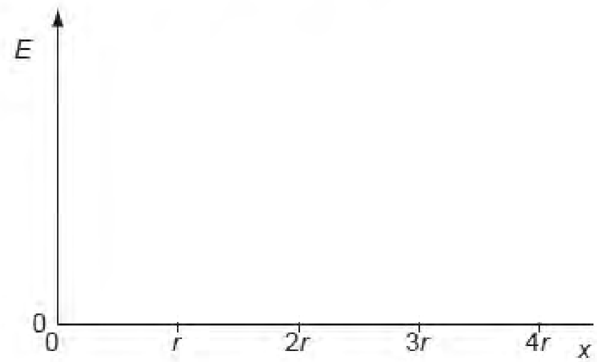


Fig. 5.2

(a) State the relation between electric field and potential.

....[1]

(b) Using the relation in **(a)**, on Fig. 5.3 sketch a graph to show the variation with distance x of the electric field E due to the charge $+Q$.



[3]

Fig. 5.3

Q4.

5 An isolated conducting sphere of radius r is placed in air. It is given a charge $+Q$. This charge may be assumed to act as a point charge situated at the centre of the sphere.

(a) **(i)** Define *electric field strength*.

....

.... [1]

(ii) State a formula for the electric field strength E at the surface of the sphere. Also, state the meaning of any other symbols used.

....

....

.... [2]

(b) The maximum field strength at the surface of the sphere before electrical breakdown (sparking) occurs is 2.0×10^6 V m^{-1}. The sphere has a radius r of 0.35 m.

Calculate the maximum values of

(i) the charge that can be stored on the sphere,

charge = ... C [2]

(ii) the potential at the surface of the sphere.

potential = ... V [2]

(c) Suggest the effect of the electric field on a single atom near the sphere's surface as electrical breakdown of the air occurs.

....

....

.... [2]

Q5.

3 Two charged points A and B are separated by a distance of 6.0 cm, as shown in Fig. 3.1.

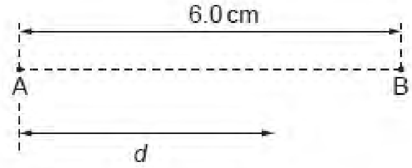


Fig. 3.1

The variation with distance *d* from A of the electric field strength *E* along the line AB is shown in Fig. 3.2.

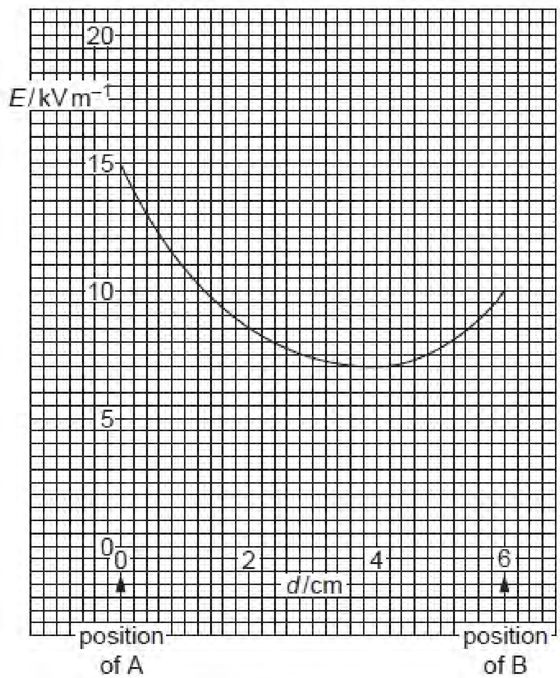


Fig. 3.2

An electron is emitted with negligible speed from A and travels along AB.

(a) State the relation between electric field strength *E* and potential *V*.

....

.... [2]

(b) The area below the line of the graph of Fig. 3.2 represents the potential difference between A and B.

Use Fig. 3.2 to determine the potential difference between A and B.

potential difference = ... V [4]

(c) Use your answer to **(b)** to calculate the speed of the electron as it reaches point B.

speed = ... m s^{-1} [2]

(d) **(i)** Use Fig. 3.2 to determine the value of *d* at which the electron has maximum acceleration.

d = ... cm [1]

(ii) Without any further calculation, describe the variation with distance *d* of the acceleration of the electron.

....

....

.... [2]

Q6.

4 (a) Define *electric potential* at a point.

....

....

.... [2]

(b) Two isolated point charges A and B are separated by a distance of 30.0 cm, as shown in Fig. 4.1.

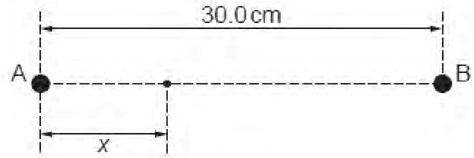


Fig. 4.1

The charge at A is + 3.6 × 10^{-9} C.
The variation with distance x from A along AB of the potential V is shown in Fig. 4.2.

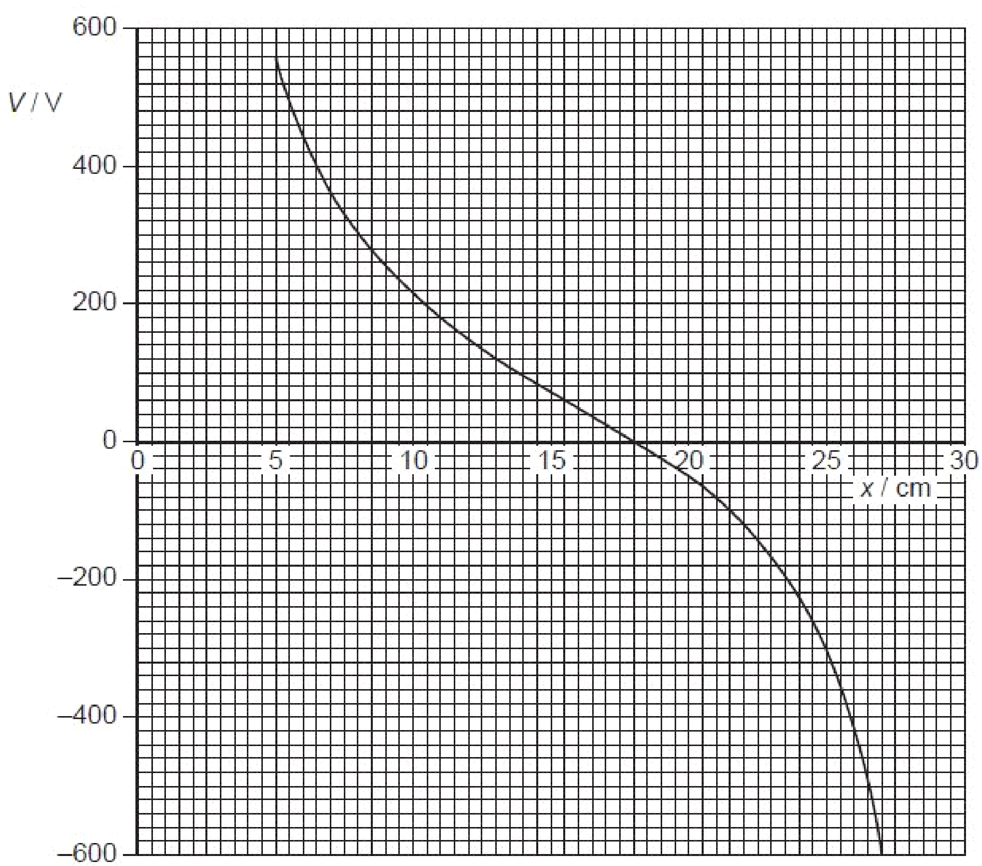


Fig. 4.2

(i) State the value of x at which the potential is zero.

x = ... cm [1]

(ii) Use your answer in **(i)** to determine the charge at B.

charge = ... C [3]

(c) A small test charge is now moved along the line AB in **(b)** from x = 5.0 cm to x = 27 cm. State and explain the value of x at which the force on the test charge will be maximum.

....

....

....

.... [3]

Q7.

4 (a) Explain what is meant by the *potential energy* of a body.

For Examiner's Use

....

....

.... [2]

(b) Two deuterium (^2_1H) nuclei each have initial kinetic energy E_K and are initially separated by a large distance.
The nuclei may be considered to be spheres of diameter 3.8×10^{-15} m with their masses and charges concentrated at their centres.
The nuclei move from their initial positions to their final position of just touching, as illustrated in Fig. 4.1.

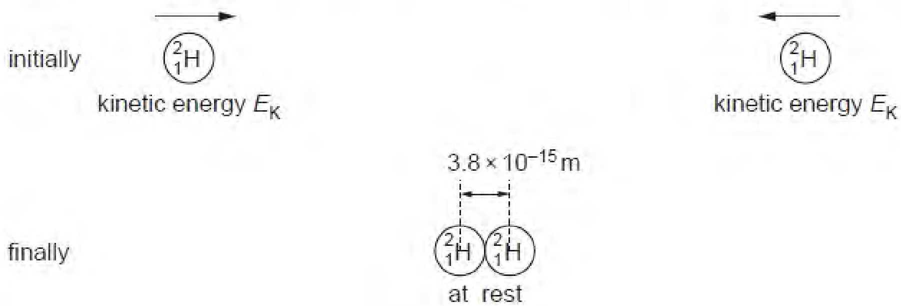


Fig. 4.1

(i) For the two nuclei approaching each other, calculate the total change in

1. gravitational potential energy,

energy = ... J [3]

2. electric potential energy.

energy = ... J [3]

(ii) Use your answers in **(i)** to show that the initial kinetic energy E_K of each nucleus is 0.19 MeV.

For Examiner's Use

[2]

(iii) The two nuclei may rebound from each other. Suggest one other effect that could happen to the two nuclei if the initial kinetic energy of each nucleus is greater than that calculated in **(ii)**.

....

....[1]

Q8.

4 Two point charges A and B each have a charge of $+6.4 \times 10^{-19}$ C. They are separated in a vacuum by a distance of 12.0 μm, as shown in Fig. 4.1.

For Examiner's Use

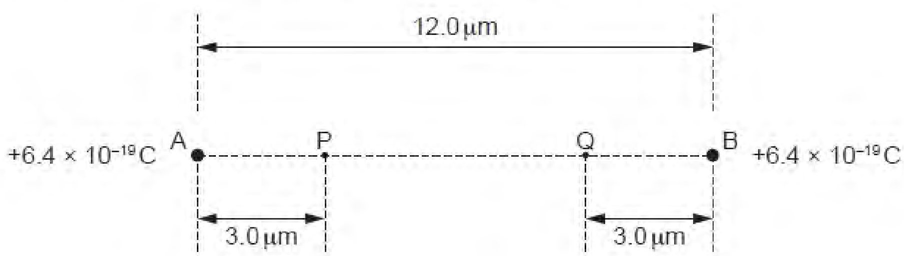


Fig. 4.1

Points P and Q are situated on the line AB. Point P is 3.0 μm from charge A and point Q is 3.0 μm from charge B.

(a) Calculate the force of repulsion between the charges A and B.

force = ... N [3]

(b) Explain why, without any calculation, when a small test charge is moved from point P to point Q, the net work done is zero.

....

....

.... [2]

(c) Calculate the work done by an electron in moving from the midpoint of line AB to point P.

work done = ... J [4]

Q9.

4 **(a)** Define *electric potential* at a point.

....

....

....[2]

(b) Two small spherical charged particles P and Q may be assumed to be point charges located at their centres. The particles are in a vacuum.

Particle P is fixed in position. Particle Q is moved along the line joining the two charges, as illustrated in Fig. 4.1.

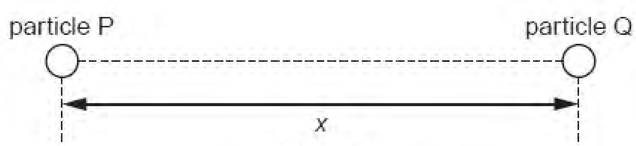


Fig. 4.1

The variation with separation x of the electric potential energy E_P of particle Q is shown in Fig. 4.2.

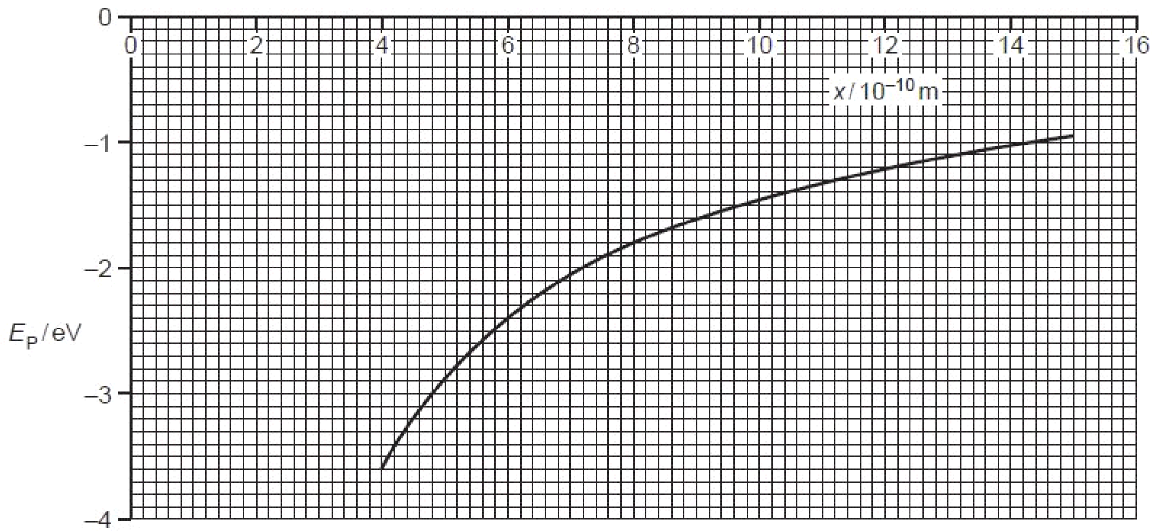


Fig. 4.2

(i) State how the magnitude of the electric field strength is related to potential gradient.

....

....[1]

(ii) Use your answer in **(i)** to show that the force on particle Q is proportional to the gradient of the curve of Fig. 4.2.

....

....

....[2]

For Examiner's Use

(c) The magnitude of the charge on each of the particles P and Q is 1.6×10^{-19} C. Calculate the separation of the particles at the point where particle Q has electric potential energy equal to −5.1 eV.

separation = ... m [4]

(d) By reference to Fig. 4.2, state and explain

(i) whether the two charges have the same, or opposite, sign,

....

....

....[2]

(ii) the effect, if any, on the shape of the graph of doubling the charge on particle P.

....

....

....[2]

Q10.

5 **(a)** Define *electric field strength*.

....

.... [1]

(b) An isolated metal sphere is to be used to store charge at high potential. The charge stored may be assumed to be a point charge at the centre of the sphere. The sphere has a radius of 25 cm. Electrical breakdown (a spark) occurs in the air surrounding the sphere when the electric field strength at the surface of the sphere exceeds $1.8 \times 10^4\ \text{V cm}^{-1}$.

(i) Show that the maximum charge that can be stored on the sphere is 12.5 μC.

[2]

(ii) Calculate the potential of the sphere for this maximum charge.

potential = ... V [2]

Q11.

4 A charged point mass is situated in a vacuum. A proton travels directly towards the mass, as illustrated in Fig. 4.1.

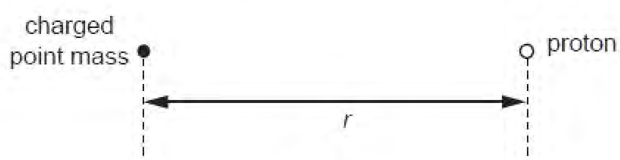


Fig. 4.1

When the separation of the mass and the proton is r, the electric potential energy of the system is U_P.

The variation with r of the potential energy U_P is shown in Fig. 4.2.

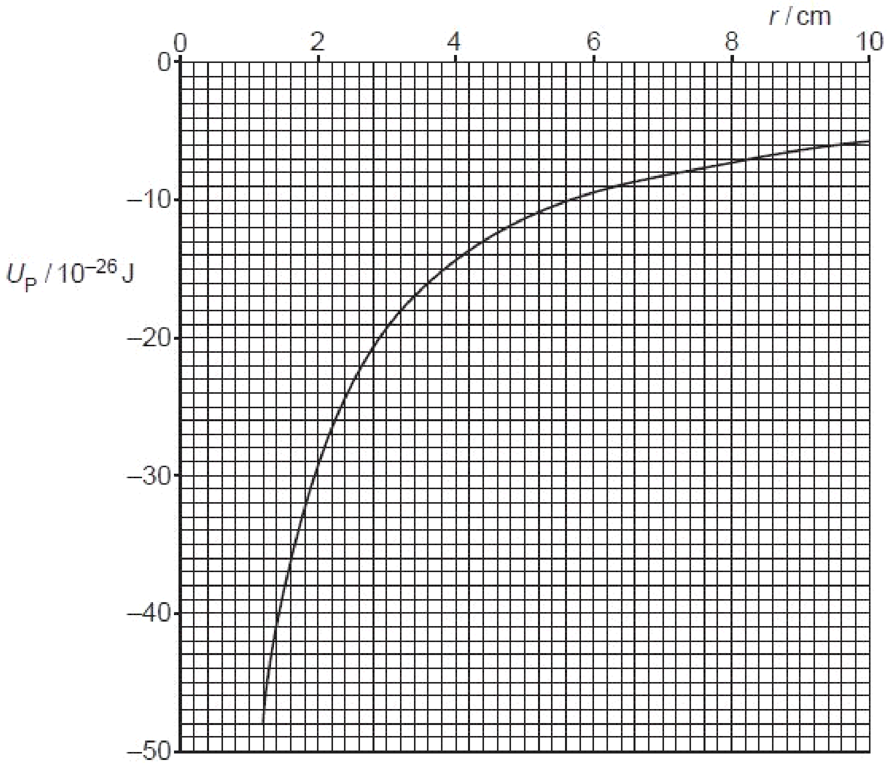


Fig. 4.2

(a) **(i)** Use Fig. 4.2 to state and explain whether the mass is charged positively or negatively.

....

....

.... [2]

(ii) The gradient at a point on the graph of Fig. 4.2 is G.
Show that the electric field strength E at this point due to the charged point mass is given by the expression

$$Eq = G$$

where q is the charge at this point.

....

....

.... [2]

(b) Use the expression in **(a)(ii)** and Fig. 4.2 to determine the electric field strength at a distance of 4.0 cm from the charged point mass.

field strength = ... $V m^{-1}$ [4]

Q12.

4 (a) Define *electric potential* at a point.

....

....

.... [2]

(b) A charged particle is accelerated from rest in a vacuum through a potential difference V. Show that the final speed v of the particle is given by the expression

$$v = \sqrt{\left(\frac{2Vq}{m}\right)}$$

where $\frac{q}{m}$ is the ratio of the charge to the mass (the specific charge) of the particle.

[2]

F
Exan
U

(c) A particle with specific charge $+9.58 \times 10^7\,\text{C kg}^{-1}$ is moving in a vacuum towards a fixed metal sphere, as illustrated in Fig. 4.1.

Fig. 4.1

The initial speed of the particle is $2.5 \times 10^5\,\text{m s}^{-1}$ when it is a long distance from the sphere.
The sphere is positively charged and has a potential of +470 V.

Use the expression in **(b)** to determine whether the particle will reach the surface of the sphere.

[3]

Q13.

4 **(a)** An insulated metal sphere of radius R is situated in a vacuum. The charge q on the sphere may be considered to be a point charge at the centre of the sphere.

For Examiner's Use

(i) State a formula, in terms of R and q, for the potential V on the surface of the sphere.

.... [1]

(ii) Define capacitance and hence show that the capacitance C of the sphere is given by the expression

$$C = 4\pi\varepsilon_0 R.$$

[1]

(b) An isolated metal sphere has radius 45 cm.

(i) Use the expression in **(a)(ii)** to calculate the capacitance, in picofarad, of the sphere.

capacitance = ... pF [2]

(ii) The sphere is charged to a potential of 9.0×10^5 V.
A spark occurs, partially discharging the sphere so that its potential is reduced to 3.6×10^5 V.

Determine the energy of the spark.

energy = ... J [3]

Q14.

use

2 An α-particle ($^{4}_{2}He$) is moving directly towards a stationary gold nucleus ($^{197}_{79}Au$).

The α-particle and the gold nucleus may be considered to be solid spheres with the charge and mass concentrated at the centre of each sphere.

When the two spheres are just touching, the separation of their centres is 9.6×10^{-15} m.

(a) The α-particle and the gold nucleus may be assumed to be an isolated system. Calculate, for the α-particle just in contact with the gold nucleus,

(i) its gravitational potential energy,

gravitational potential energy = ... J [3]

(ii) its electric potential energy.

electric potential energy = ... J [3]

(b) Using your answers in **(a)**, suggest why, when making calculations based on an α-particle scattering experiment, gravitational effects are not considered.

....

....[1]

(c) In the α-particle scattering experiment conducted in 1913, the maximum kinetic energy of the available α-particles was about 6 MeV. Suggest why, in this experiment, the radius of the target nucleus could not be determined.

....

....

....[2]

Q15.

4 A small charged metal sphere is situated in an earthed metal box. Fig. 4.1 illustrates the electric field between the sphere and the metal box.

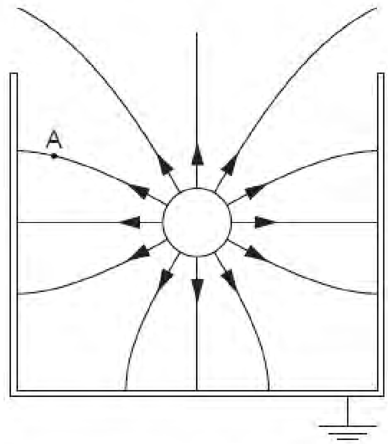


Fig. 4.1

(a) By reference to Fig. 4.1, state and explain

(i) whether the sphere is positively or negatively charged,

....

....

.... [2]

(ii) why it appears as if the charge on the sphere is concentrated at the centre of the sphere.

....

.... [1]

(b) On Fig. 4.1, draw an arrow to show the direction of the force on a stationary electron situated at point A. [2]

(c) The radius r of the sphere is 2.4 cm. The magnitude of the charge q on the sphere is 0.76 nC.

(i) Use the expression

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

to calculate a value for the magnitude of the potential V at the surface of the sphere.

V = ... V [2]

(ii) State the sign of the charge induced on the inside of the metal box. Hence explain whether the actual magnitude of the potential will be greater or smaller than the value calculated in **(i)**.

....

....

....

....[3]

(d) A lead sphere is placed in a lead box in free space, in a similar arrangement to that shown in Fig. 4.1. Explain why it is **not** possible for the gravitational field to have a similar shape to that of the electric field.

....

....

....[1]

Q16.

For Examiner's Use

5 (a) Define *electric potential* at a point.

....

....

.... [2]

(b) An α-particle is emitted from a radioactive source with kinetic energy of 4.8 MeV.

The α-particle travels in a vacuum directly towards a gold ($^{197}_{79}Au$) nucleus, as illustrated in Fig. 5.1.

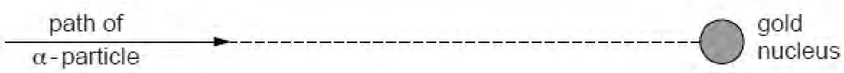


Fig. 5.1

The α-particle and the gold nucleus may be considered to be point charges in an isolated system.

(i) Explain why, as the α-particle approaches the gold nucleus, it comes to rest.

....

....

.... [2]

(ii) For the closest approach of the α-particle to the gold nucleus determine

1. their separation,

separation = ... m [3]

2. the magnitude of the force on the α-particle.

force = ... N [2]

Q17.

4 Two small charged metal spheres A and B are situated in a vacuum. The distance between the centres of the spheres is 12.0 cm, as shown in Fig. 4.1.

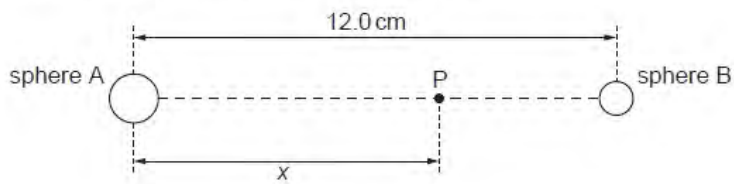
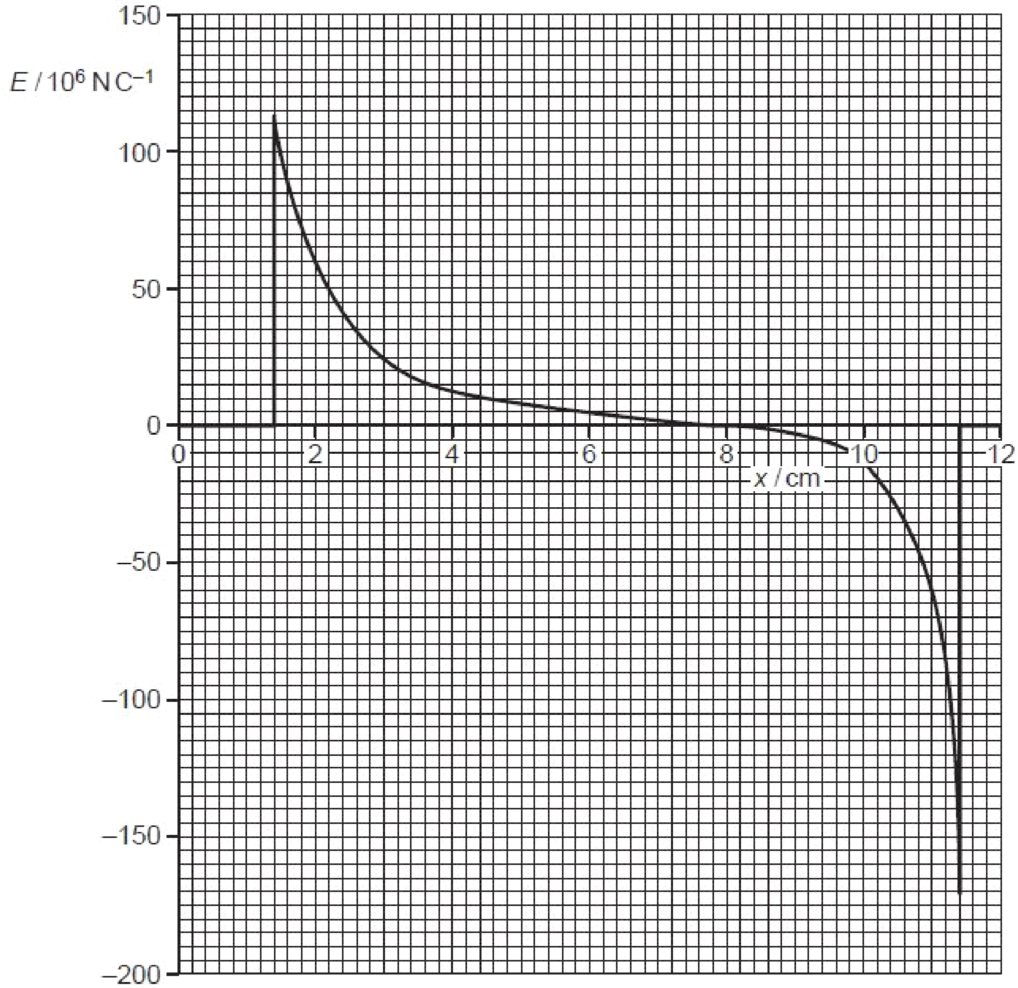


Fig. 4.1 (not to scale)

The charge on each sphere may be assumed to be a point charge at the centre of the sphere.
Point P is a movable point that lies on the line joining the centres of the spheres and is distance x from the centre of sphere A.
The variation with distance x of the electric field strength E at point P is shown in Fig. 4.2.



(a) State the evidence provided by Fig. 4.2 for the statements that

(i) the spheres are conductors,

....

....[1]

(ii) the charges on the spheres are either both positive or both negative.

....

....

....[2]

(b) **(i)** State the relation between electric field strength E and potential gradient at a point.

....

.... [1]

(ii) Use Fig. 4.2 to state and explain the distance x at which the rate of change of potential with distance is

1. maximum,

....

....

.... [2]

2. minimum.

....

....

.... [2]

Q18.

3 **(a)** State what is meant by a line of force in

For Examiner's Use

(i) a gravitational field,

....

.... [1]

(ii) an electric field.

....

.... [2]

(b) A charged metal sphere is isolated in space.
State one similarity and one difference between the gravitational force field and the electric force field around the sphere.

similarity: ....

....

difference: ....

....

....
[3]

(c) Two horizontal metal plates are separated by a distance of 1.8 cm in a vacuum.
A potential difference of 270 V is maintained between the plates, as shown in Fig. 3.1.

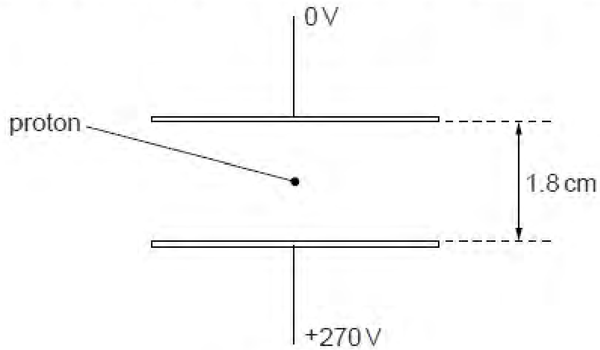


Fig. 3.1

A proton is in the space between the plates.
Explain quantitatively why, when predicting the motion of the proton between the plates, the gravitational field is not taken into consideration.

[4]

Q19.

4 An α-particle and a proton are at rest a distance 20 μm apart in a vacuum, as illustrated in Fig. 4.1.

For Examiner's Use

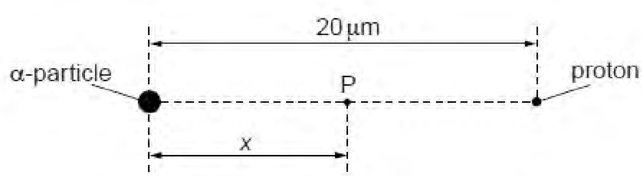


Fig. 4.1

(a) **(i)** State Coulomb's law.

....

....

.... [2]

(ii) The α-particle and the proton may be considered to be point charges.
Calculate the electric force between the α-particle and the proton.

force = ... N [2]

(b) **(i)** Define *electric field strength*.

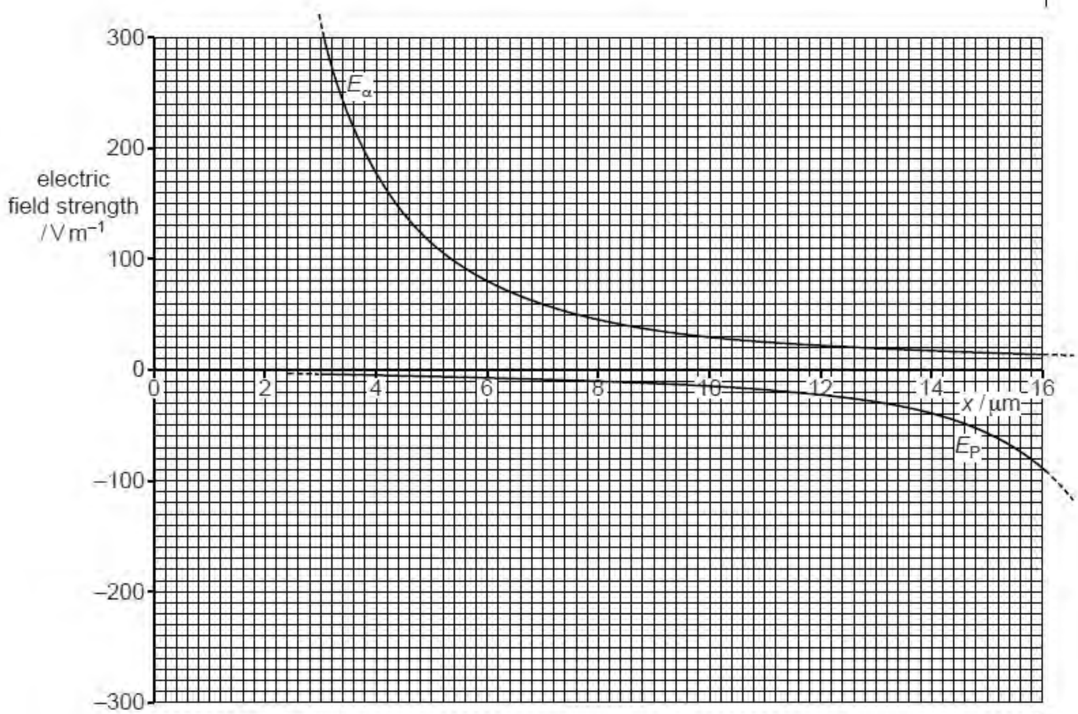
....

....

....[2]

(ii) A point P is distance x from the α-particle along the line joining the α-particle to the proton (see Fig. 4.1). The variation with distance x of the electric field strength E_α due to the α-particle alone is shown in Fig. 4.2.

For Examiner's Use



The variation with distance x of the electric field strength E_P due to the proton alone is also shown in Fig. 4.2.

1. Explain why the two separate electric fields have opposite signs.

....

....

....[2]

2. On Fig. 4.2, sketch the variation with x of the combined electric field due to the α-particle and the proton for values of x from 4 μm to 16 μm. [3]

Q20.

3 **(a)** Define *electric potential* at a point.

For Examiner's Use

....

....

....[2]

(b) Two point charges A and B are separated by a distance of 20 nm in a vacuum, as illustrated in Fig. 3.1.

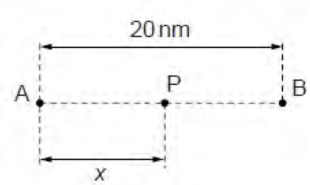


Fig. 3.1

A point P is a distance x from A along the line AB.
The variation with distance x of the electric potential V_A due to charge A alone is shown in Fig. 3.2.

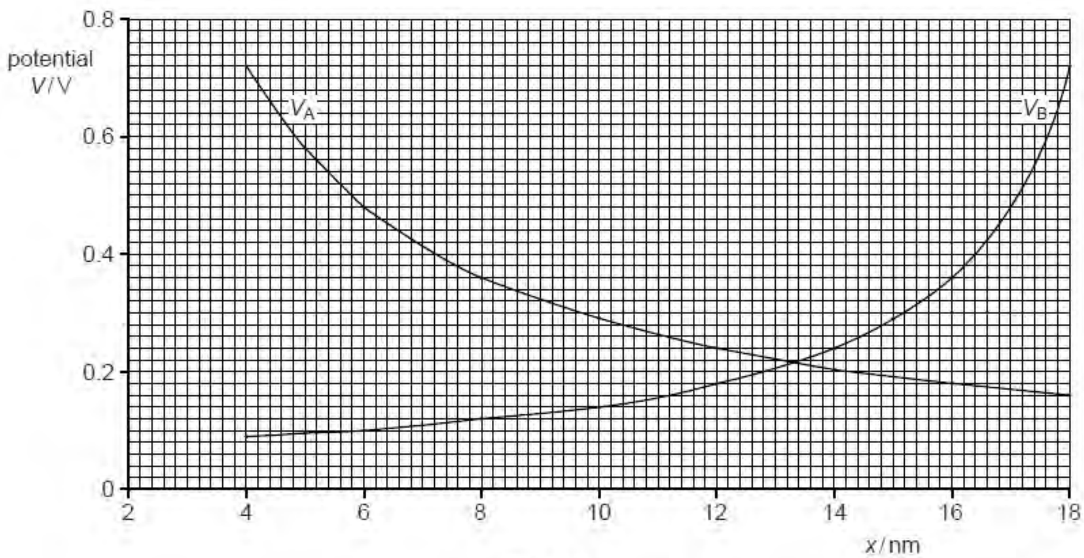


Fig. 3.2

The variation with distance x of the electric potential V_B due to charge B alone is also shown in Fig. 3.2.

(i) State and explain whether the charges A and B are of the same, or opposite, sign.

For Examiner's Use

....

....

....[2]

(ii) By reference to Fig. 3.2, state how the combined electric potential due to both charges may be determined.

....

....[1]

(iii) Without any calculation, use Fig. 3.2 to estimate the distance x at which the combined electric potential of the two charges is a minimum.

x = ... nm [1]

(iv) The point P is a distance x = 10 nm from A.
An α-particle has kinetic energy E_K when at infinity.

Use Fig. 3.2 to determine the minimum value of E_K such that the α-particle may travel from infinity to point P.

E_K = ... J [3]

Q21.

5 An isolated solid metal sphere of radius r is given a positive charge. The distance from the centre of the sphere is x.

(a) The electric potential at the surface of the sphere is V_0.

On the axes of Fig. 5.1, sketch a graph to show the variation with distance x of the electric potential due to the charged sphere, for values of x from x = 0 to x = 4r.

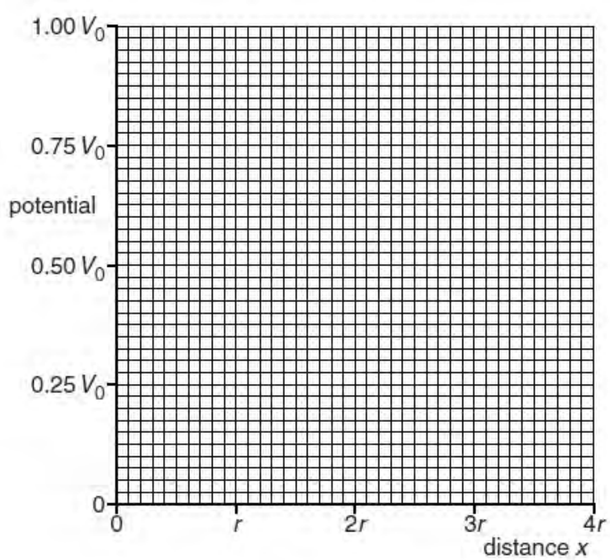


Fig. 5.1

[3]

(b) The electric field strength at the surface of the sphere is E_0.

On the axes of Fig. 5.2, sketch a graph to show the variation with distance x of the electric field strength due to the charged sphere, for values of x from $x = 0$ to $x = 4r$.

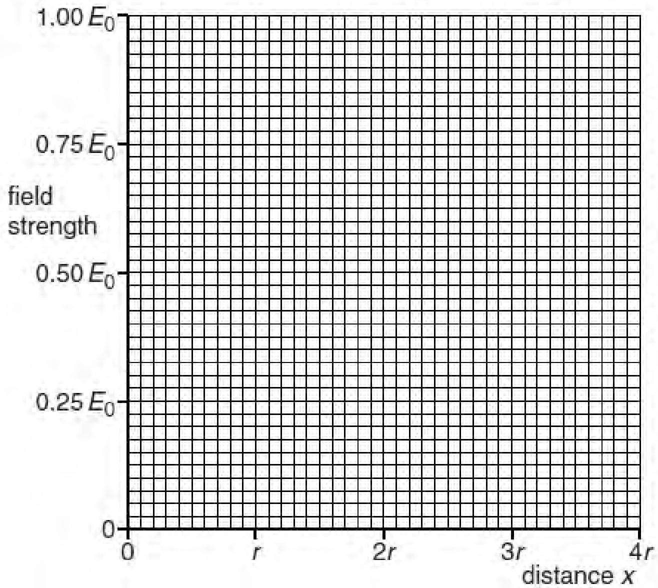


Fig. 5.2

[3]

Q22.

4 A helium nucleus contains two protons.

In a model of the helium nucleus, each proton is considered to be a charged point mass. The separation of these point masses is assumed to be 2.0×10^{-15} m.

(a) For the two protons in this model, calculate

(i) the electrostatic force,

electrostatic force = ... N [2]

(ii) the gravitational force.

gravitational force = ... N [2]

(b) Using your answers in (a), suggest why

(i) there must be some other force between the protons in the nucleus,

....

....

....

.... [3]

(ii) this additional force must have a short range.

....

....

.... [2]

Q23.

5 (a) Define *electric potential* at a point.

....

....

.... [2]

(b) An isolated solid metal sphere is positively charged.

The variation of the potential V with distance x from the centre of the sphere is shown in Fig. 5.1.

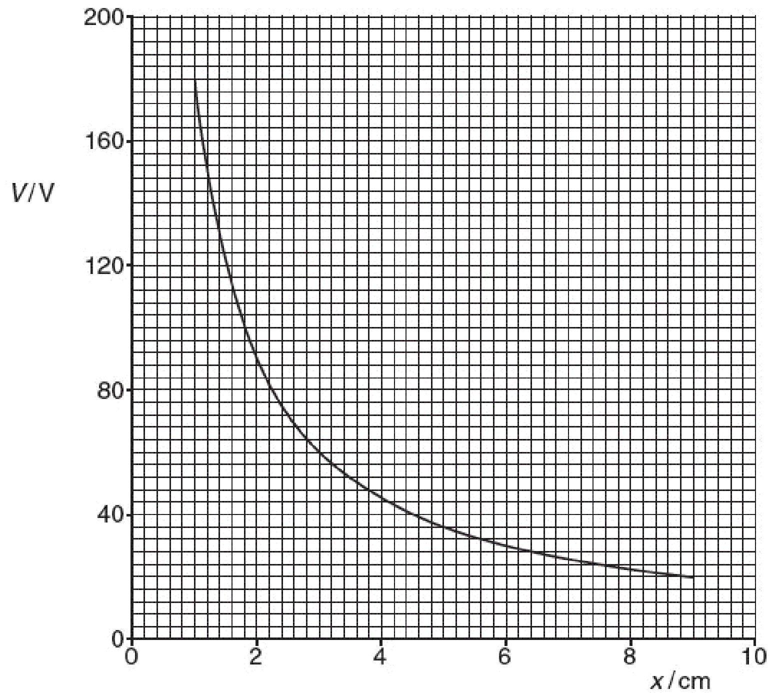


Fig. 5.1

Use Fig. 5.1 to suggest

(i) why the radius of the sphere cannot be greater than 1.0 cm,

....

.... [1]

(ii) that the charge on the sphere behaves as if it were a point charge.

[3]

(c) Assuming that the charge on the sphere does behave as a point charge, use data from Fig. 5.1 to determine the charge on the sphere.

charge = ... C [2]

Q24.

5 **(a)** Define *electric potential* at a point.

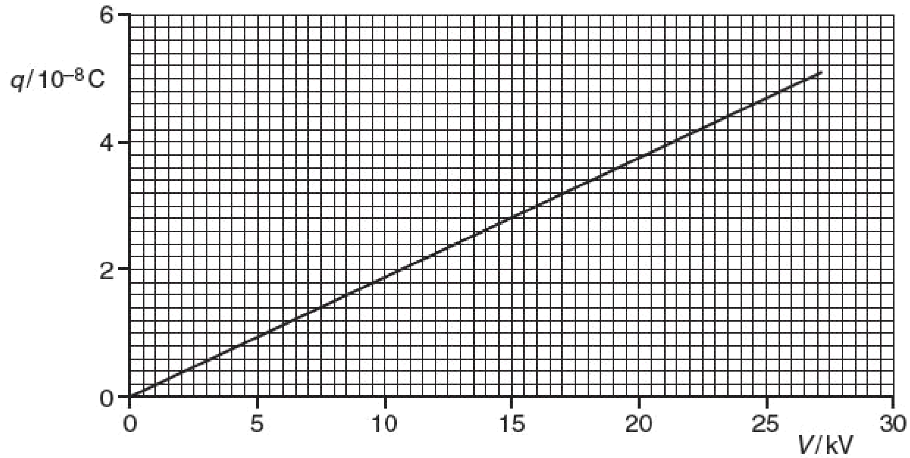
....

....

.... [2]

(b) An isolated metal sphere is charged to a potential V. The charge on the sphere is q. The charge on the sphere may be considered to act as a point charge at the centre of the sphere.

The variation with potential V of the charge q on the sphere is shown in Fig. 5.1.



Use Fig. 5.1 to determine

(i) the radius of the sphere,

radius = ... m [2]

(ii) the energy required to increase the potential of the sphere from zero to 24 kV.

energy = ... J [3]

(c) The sphere in **(b)** discharges by causing sparks when the electric field strength at the surface of the sphere is greater than $2.0 \times 10^6\,V\,m^{-1}$.

Use your answer in **(b)(i)** to calculate the maximum potential to which the sphere can be charged.

potential = ... V [3]