ELECTRIC FIELDS
WORKSHEET
A-Level Physics 9702

MJ25/41/Q2

1 A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.

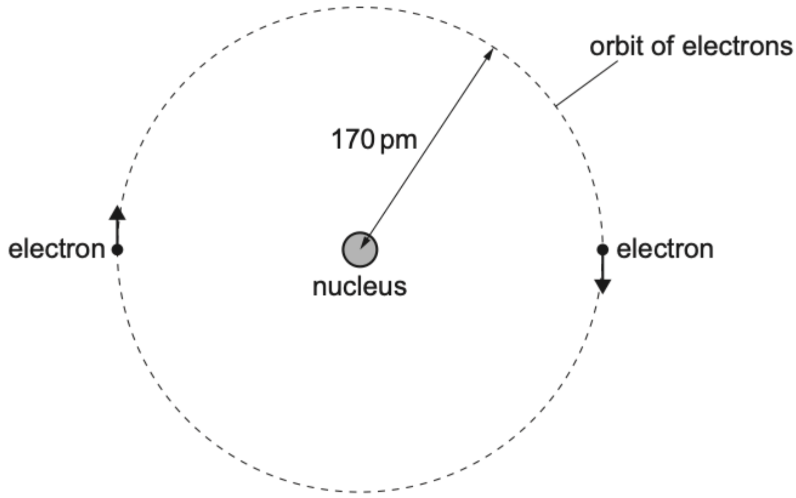

Fig. 2.1

(a) State Coulomb's law.

....

....

.... [2]

(b) **(i)** State the charge on the nucleus, in terms of the elementary charge *e*.

charge = ... *e* [1]

(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N.

[1]

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(c) Assume that the force in **(b)(ii)** is the only force on the electrons.

(i) Calculate the speed of the orbiting electrons.

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

(ii) Calculate the period of the orbit of the electrons.

period = ... s [2]

(d) In practice, the orbit of each electron is affected by the presence of the other electron.

(i) For the position of one of the electrons, determine the ratio

$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}.$$

ratio = ... [2]

(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron.

....

.... [1]

[Total: 11]

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2 Two parallel metal plates X and Y are separated by a distance of 0.041 m, as shown in Fig. 6.1.

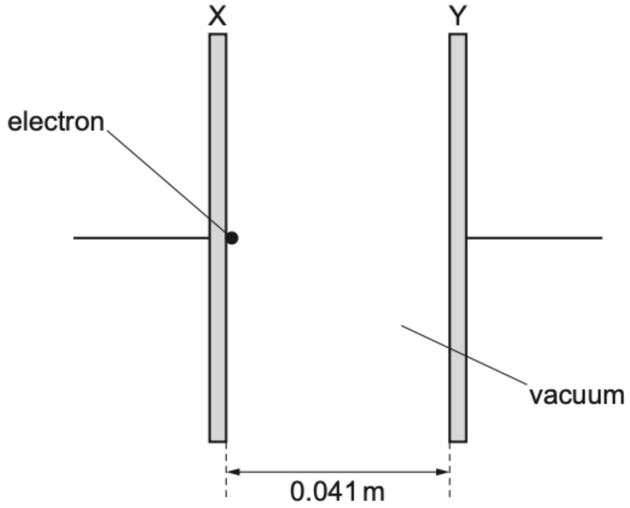

Fig. 6.1

There is a vacuum between the plates. An electron is at rest at the centre of plate X.

A potential difference (p.d.) of 58 kV is applied across the plates. This causes the electron to accelerate towards plate Y.

(a) On Fig. 6.1, use the symbols + and – to indicate which of plates X and Y is the positive plate and which is the negative plate. [1]

(b) **(i)** Calculate the electric field strength *E* between the plates. Give a unit with your answer.

E = ... unit .... [2]

(ii) Determine the acceleration of the electron.

acceleration = ... $m s^{-2}$ [2]

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(c) Many electrons are now accelerated from rest from plate X to plate Y in Fig. 6.1. When the electrons hit plate Y, the absorption of their kinetic energies results in the emission of electromagnetic waves.

(i) Show that the minimum wavelength of these electromagnetic waves is 21 pm.

[3]

(ii) State the region of the electromagnetic spectrum that contains these waves.

.... [1]

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3 **(a)** Define electric potential at a point. **MJ25/44/Q5**

....

....

.... [2]

(b) An isolated solid metal sphere of radius r is given a positive charge.

The potential at the surface of the sphere is 9.0×10^4 V. At a distance of $3r$ from the centre of the sphere, the electric field strength is 2.0×10^5 N C^{-1}.

(i) Determine the electric field strength at the surface of the sphere.

electric field strength = ... N C^{-1} [2]

(ii) Show that the radius of the sphere is 5.0 cm.

[2]

(iii) Calculate the charge on the sphere.

charge = ... C [2]

(iv) Use your answer in **(b)(iii)** to determine the capacitance of the sphere.

capacitance = ... F [2]

[Total: 10]

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4 The electric potential difference (p.d.) between two parallel plates is V, as shown in Fig. 2.3.

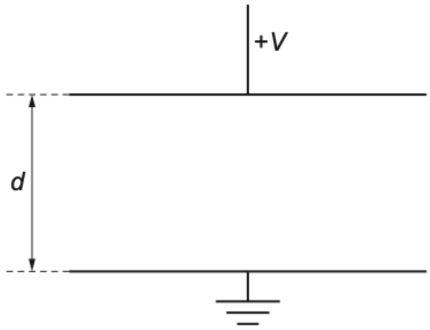

Fig. 2.3

The distance between the plates is d. The region between the plates is a vacuum.

On Fig. 2.4, sketch the variation of the electric potential with distance from the positive plate.

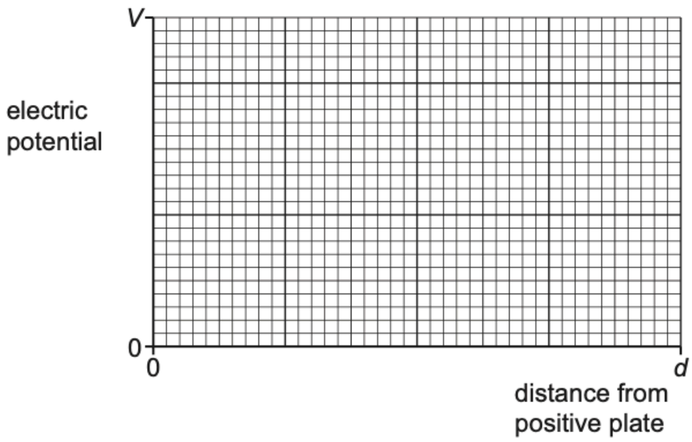

Fig. 2.4

[2]

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5 **(a)** State the relationship between electric field and electric potential. **ON24/41/Q5**

....

....

.... [2]

(b) Two charged isolated insulating spheres X and Y are near to each other, as shown in Fig. 5.1.

Fig. 5.1

P is a point on the line joining the centres of the spheres.

Explain why it is **not** possible for the total electric potential and the resultant electric field to simultaneously be zero at point P.

....

....

....

....

.... [3]

(c) The magnitudes of the charges on spheres X and Y in Fig. 5.1 are Q and $2Q$ respectively. The spheres may be considered as point charges at their centres.

Point P is a distance x from the centre of sphere X.

The electric potential at point P is zero.

(i) Show that the distance y of point P from the centre of sphere Y is equal to $2x$.

[2]

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(ii) State an expression, in terms of Q, x and the permittivity of free space ε_0, for the electric field strength E_X at P due to sphere X.

E_X = ... [1]

(iii) Determine an expression, in terms of Q, x and ε_0, for the resultant electric field strength E at point P due to the two spheres.

E = ... [2]

[Total: 10]

6 **(a)** State Coulomb's law. **ON24/42/Q6**

....

....

.... [2]

(b) Fig. 6.1 shows an isolated hollow conducting sphere that is positively charged.

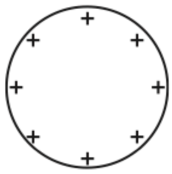

Fig. 6.1

On Fig. 6.1, draw field lines to represent the electric field outside the sphere. [3]

(c) Fig. 6.2 shows the variation of the electric field strength E with distance x from the centre of the sphere in **(b)**.

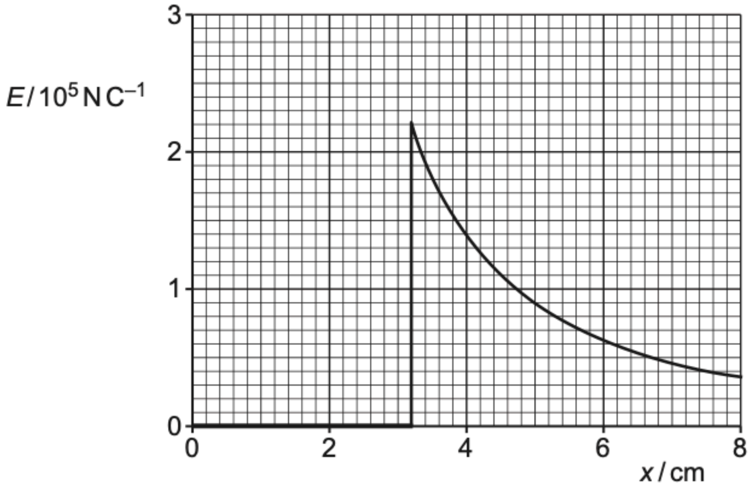

Fig. 6.2

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(i) Determine the radius, in cm, of the sphere.

radius = ... cm [1]

(ii) Calculate the charge on the sphere.

charge = ... C [3]

(iii) Suggest an explanation for the fact that the electric field inside the sphere is zero.

....

....

.... [1]

[Total: 10]

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7 **(a)** Define electric field.

....

....

.... [2]

(b) Fig. 5.1 shows two parallel conducting plates that are in a vacuum. The plates are separated by a distance of 6.7 cm and have a potential difference (p.d.) of 430 V between them.

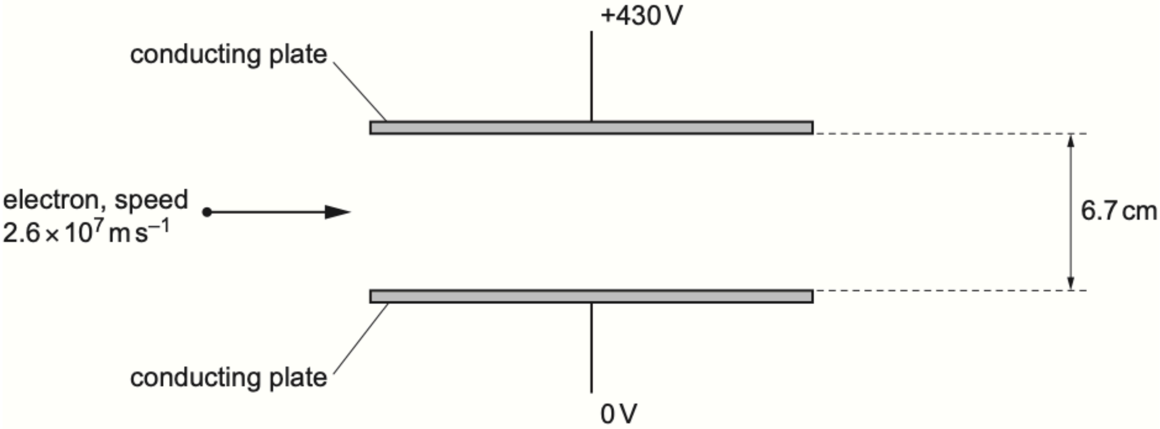

Fig. 5.1

(i) On Fig. 5.1, draw four field lines to represent the electric field between the plates. [2]

(ii) Determine the strength E of the electric field between the plates.

E = ... $\mathrm{N\,C^{-1}}$ [2]

(iii) An electron travels at a speed of $2.6 \times 10^7\,\mathrm{m\,s^{-1}}$ towards the region between the plates, as shown in Fig. 5.1.

On Fig. 5.1, draw the path of the electron as it moves between and beyond the plates. [2]

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8 **(a)** Define electric potential at a point. **MJ24/42/Q5**

....

....

.... [2]

(b) Two isolated charged metal spheres X and Y are near to each other in a vacuum. The centres of the spheres are 1.2 m apart, as shown in Fig. 5.1.

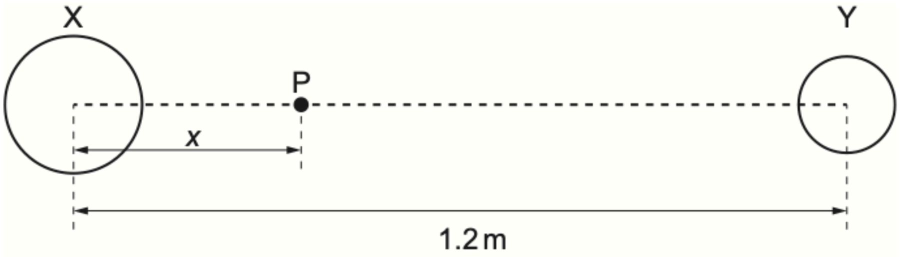

Fig. 5.1 (not to scale)

Point P is on the line joining the centres of spheres X and Y and is at a variable distance x from the centre of X.

Fig. 5.2 shows the variation with x of the total electric potential V due to the two spheres.

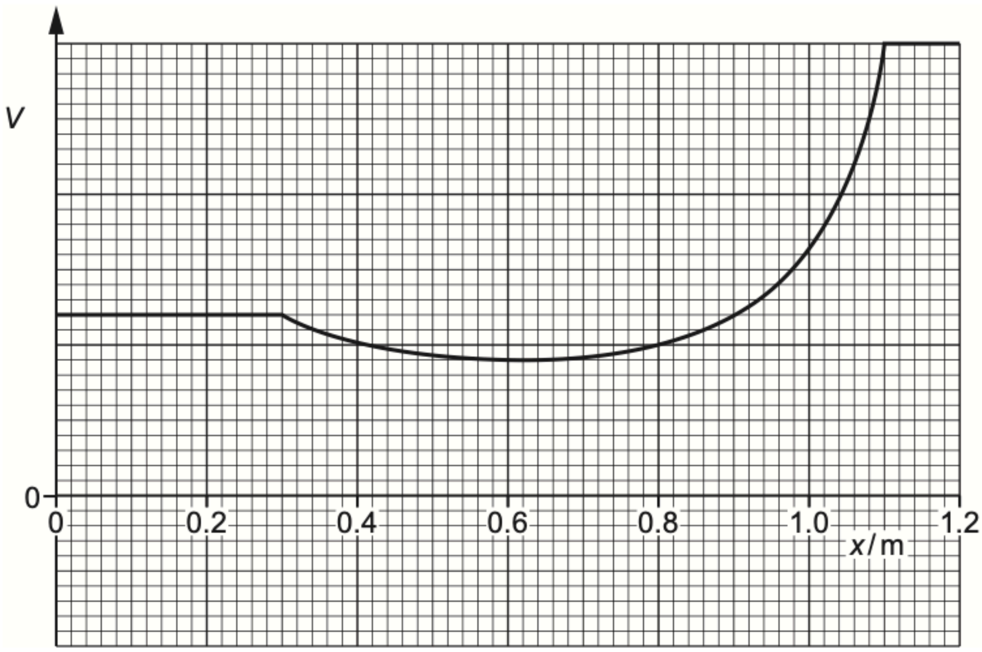

Fig. 5.2

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State **three** conclusions that may be drawn about the spheres from Fig. 5.2. The conclusions may be qualitative or quantitative.

1 ....

....

2 ....

....

3 ....

.... [3]

(c) A proton is held at rest on the line joining the centres of the spheres in **(b)** at the position where $x = 0.60\,m$.

The proton is released.

Describe and explain, without calculation, the subsequent motion of the proton.

....

....

.... [2]

[Total: 7]

9 **(a)** Define electric potential at a point. **ON23/41/Q5**

....

....

.... [2]

(b) Two isolated charged metal spheres X and Y are situated near to each other in a vacuum with their centres a distance of 24 m apart. Point P is at a variable distance x from the centre of sphere X on the line joining the centres of the spheres.

Fig. 5.1 shows the variation with x of the electric potential V due to the spheres at point P.

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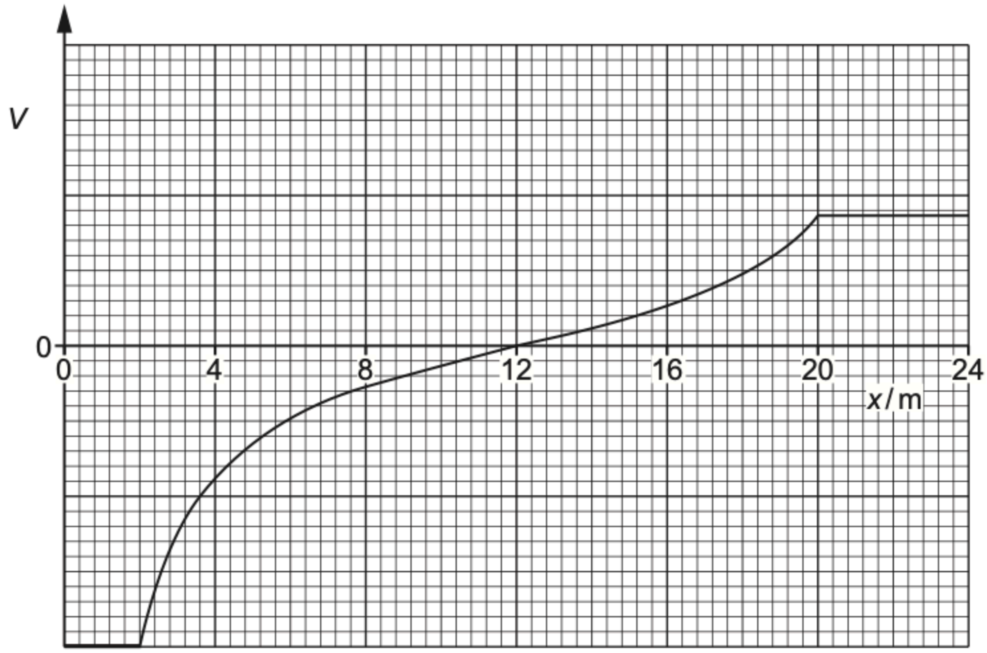

Fig. 5.1

State **three** conclusions that can be drawn about the spheres from Fig. 5.1. The conclusions may be qualitative or quantitative.

1 ....

....

2 ....

....

3 ....

.... [3]

(c) A positively charged particle is placed at point P in **(b)**, such that x = 12 m. The particle is released.

Describe and explain the subsequent motion of the particle.

....

....

....

....

.... [3]

[Total: 8]

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10 **(a)** State Coulomb's law. **ON23/42/Q5**

....

....

.... [2]

(b) Two identical oil droplets are in a vacuum. The centres of the droplets are a distance of 3.8×10^{-6} m apart. The droplets have equal charge and exert an electric force on each other of magnitude 6.3×10^{-17} N.

Determine the magnitude of the charge on each droplet.

charge = ... C [2]

(c) One of the oil droplets in **(b)** is now placed between two horizontal metal plates, as shown in Fig. 5.1.

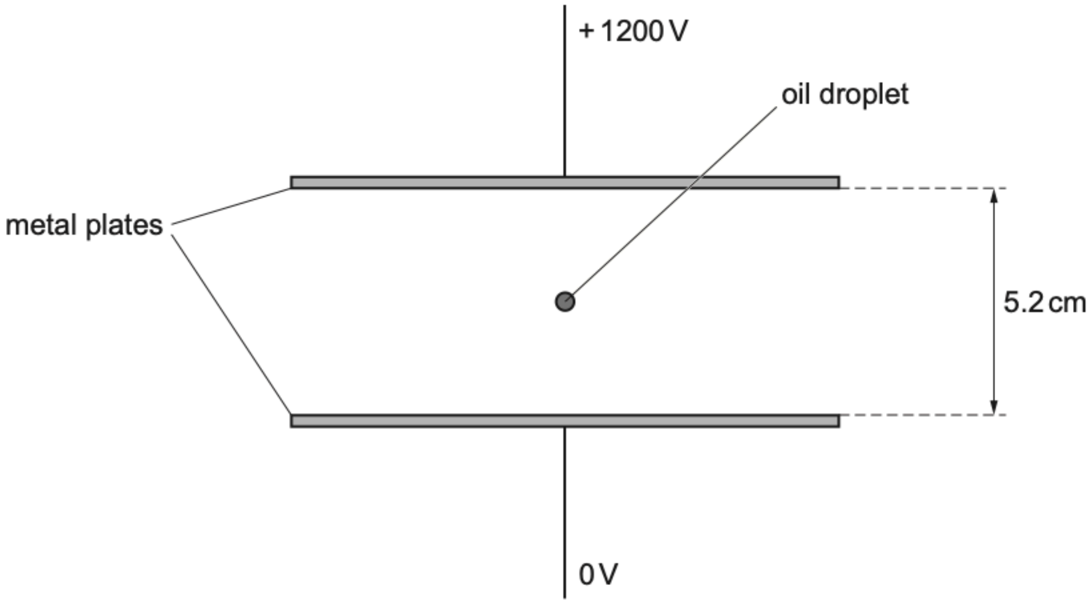

Fig. 5.1 (not to scale)

A potential difference (p.d.) of 1200 V is applied between the plates, with the top plate at the higher potential. The oil droplet is stationary and in equilibrium.

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(i) State the sign of the charge on the oil droplet.

.... [1]

(ii) On Fig. 5.1, draw four lines to represent the electric field between the plates. [3]

(iii) The distance between the plates is 5.2 cm.

Determine the mass of the oil droplet.

mass = ... kg [3]

[Total: 11]

March2023/42/Q4

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

....

....

....

.... [2]

(b) A charged sphere X is supported on an insulating stand. A second charged sphere Y is suspended by an insulating thread so that sphere Y is in equilibrium at the position shown in Fig. 4.1.

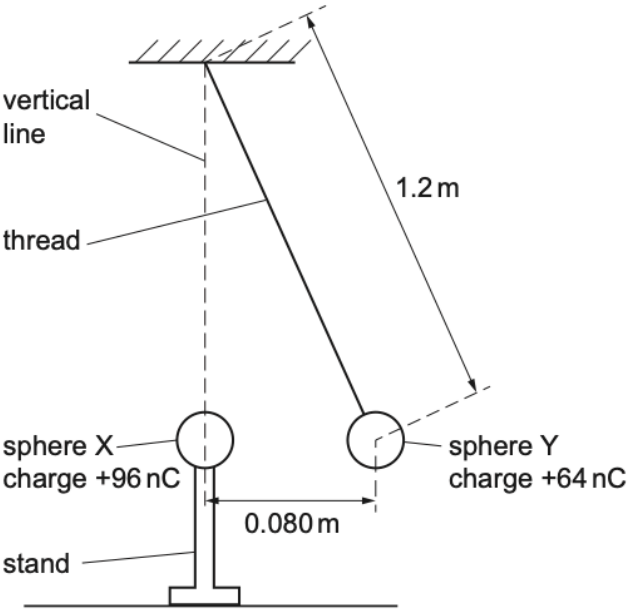

Fig. 4.1

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The charge on sphere X is +96 nC and the charge on sphere Y is +64 nC.
Assume that the spheres behave as point charges.

The length of the thread is 1.2 m and the centres of sphere X and sphere Y are separated horizontally by a distance of 0.080 m.

(i) On Fig. 4.2, draw and label all the forces acting on sphere Y.

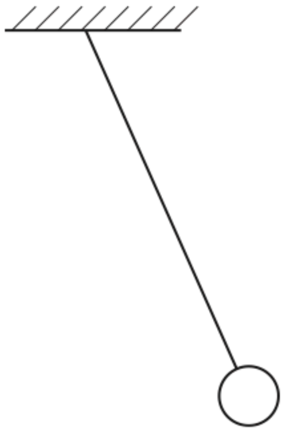

Fig. 4.2

[1]

(ii) Determine the mass of sphere Y.

mass = ... kg [4]

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(iii) Calculate the total electric potential energy stored between X and Y.

energy = ... J [1]

(c) An electron enters the region between two parallel plates P and Q, that are separated by a distance of 18 mm, as shown in Fig. 4.3.

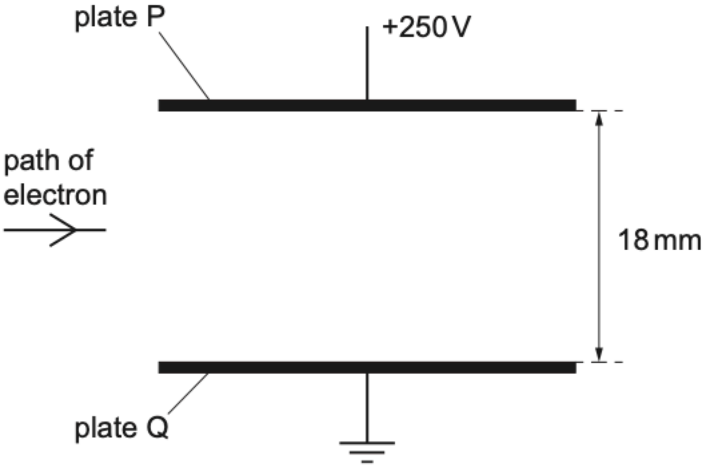

Fig. 4.3

The space between the plates is a vacuum.
The potential difference between the plates is 250 V. The electric field may be assumed to be uniform in the region between the plates and zero outside this region.

(i) State the direction of the electric force on the electron when between the plates.

.... [1]

(ii) Determine the magnitude of the force acting on the electron due to the electric field.

force = ... N [2]

(iii) Explain why the electron does **not** follow a circular path.

....

.... [1]

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12 **(a)** State what is indicated by the direction of an electric field line.

....

.... [2]

(b) Fig. 4.1 shows a pair of parallel metal plates with a potential difference (p.d.) of 2400 V between them.

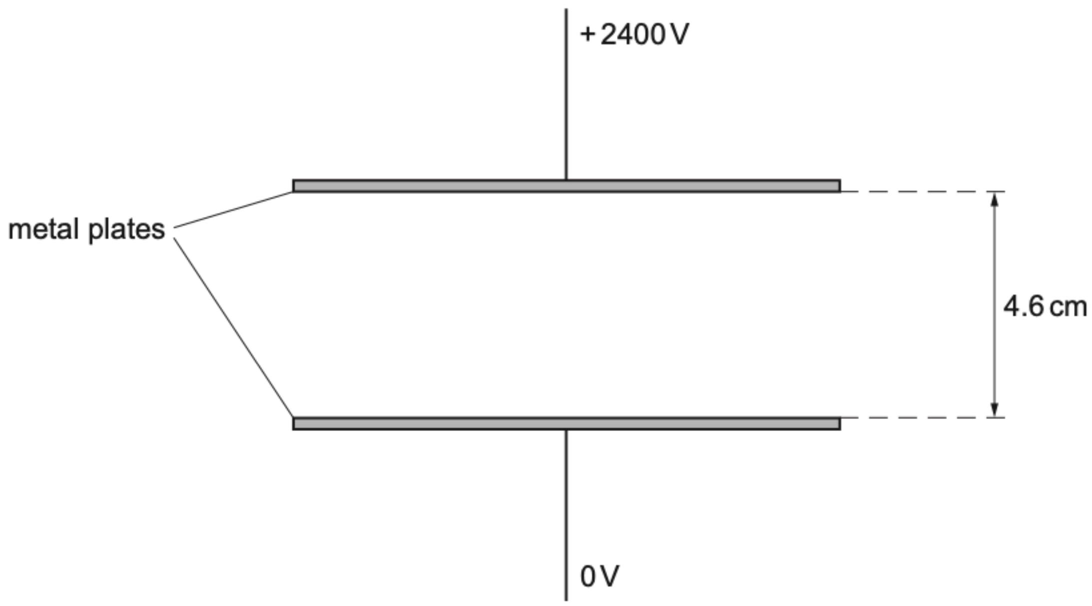

Fig. 4.1

The plates are separated by a distance of 4.6 cm. The plates are in a vacuum.

(i) On Fig. 4.1, draw five lines to represent the electric field in the region between the plates. [3]

(ii) Calculate the strength of the electric field between the plates.

electric field strength = ... $N C^{-1}$ [2]

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(c) A moving proton enters the region between the plates from the left, as shown in Fig. 4.2.

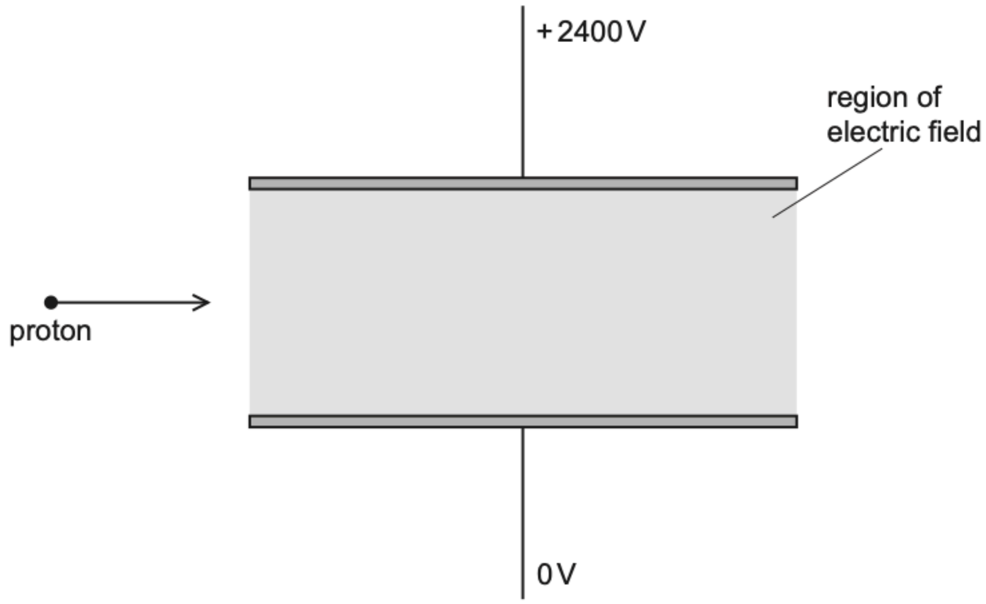

Fig. 4.2

(i) The proton is deflected by the electric field.

On Fig. 4.2, draw a line to show the path of the proton as it moves through and out of the region of the electric field. [2]

(ii) A helium nucleus (^4_2He) now enters the region of the electric field along the same initial path as the proton and travelling at the same initial speed.

State and explain how the final speed of the helium nucleus compares with the final speed of the proton after leaving the region of the electric field.

....

....

....

....

.... [3]

[Total: 12]

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

....

....

.... [2]

(b) An isolated conducting sphere is charged. Fig. 5.1 shows the variation of the potential *V* due to the sphere with displacement *x* from its centre.

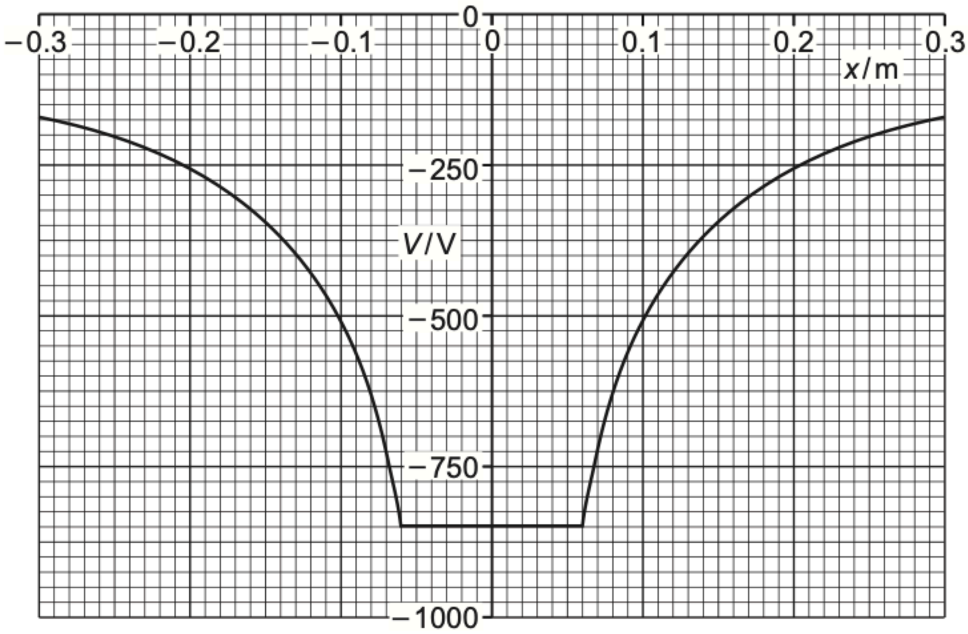

Fig. 5.1

Use Fig. 5.1 to determine:

(i) the radius of the sphere

radius = ... m [1]

(ii) the charge on the sphere.

charge = ... C [2]

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(c) Two spheres are identical to the sphere in **(b)**. Each sphere has the same charge as the sphere in **(b)**.

The spheres are held in a vacuum so that their centres are separated by a distance of 0.46 m. Assume that the charge on each sphere is a point charge at the centre of the sphere.

(i) Calculate the electric potential energy E_P of the two spheres.

E_P = ... J [2]

(ii) The two spheres are now released simultaneously so that they are free to move.

Describe and explain the subsequent motion of the spheres.

....

....

....

.... [3]

[Total: 10]

14 **(a)** State what is represented by an electric field line. **March22/42/Q4**

....

.... [2]

(b) Two point charges P and Q are placed 0.120 m apart as shown in Fig. 4.1.

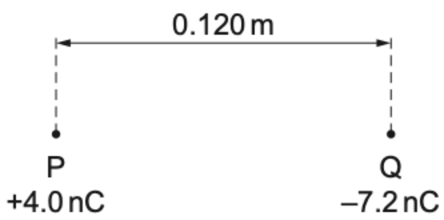

Fig. 4.1

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(i) The charge of P is +4.0 nC and the charge of Q is –7.2 nC.

Determine the distance from P of the point on the line joining the two charges where the electric potential is zero.

distance = ... m [2]

(ii) State and explain, without calculation, whether the electric field strength is zero at the same point at which the electric potential is zero.

....

....

.... [1]

(iii) An electron is positioned at point X, equidistant from both P and Q, as shown in Fig. 4.2.

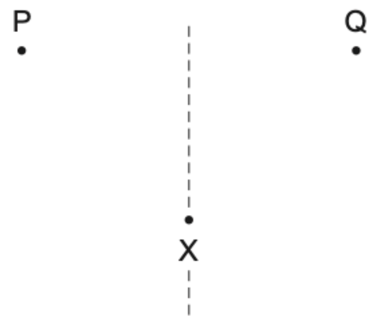

Fig. 4.2

On Fig. 4.2, draw an arrow to represent the direction of the resultant force acting on the electron. [1]

[Total: 6]

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15 **(a)** State a similarity between the gravitational field lines around a point mass and the electric field lines around a point charge.

....

.... [1]

(b) The variation with radius r of the electric field strength E due to an isolated charged sphere in a vacuum is shown in Fig. 6.1.

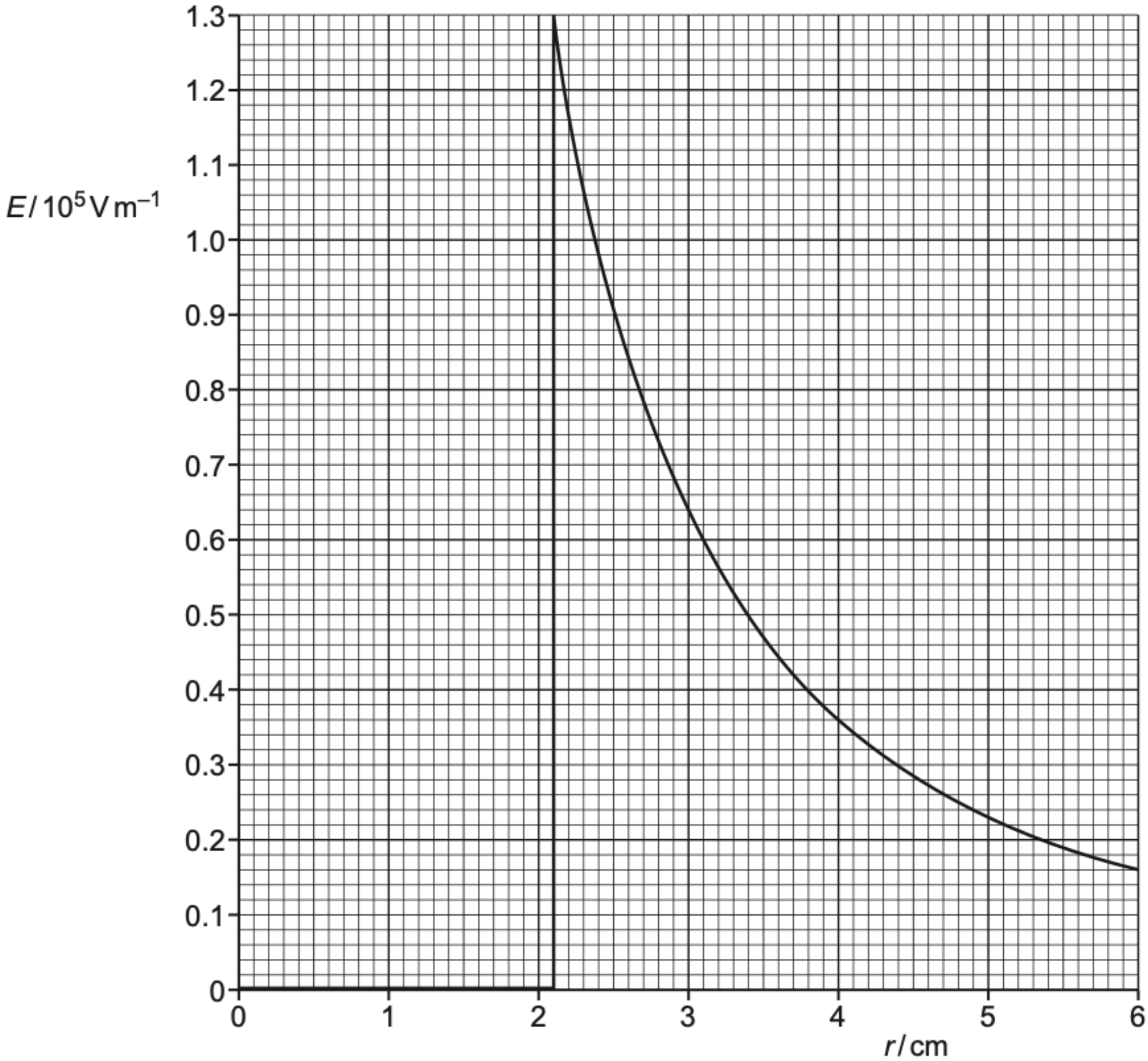

Fig. 6.1

Use data from Fig. 6.1 to:

(i) state the radius of the sphere

radius = ... cm [1]

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(ii) calculate the charge on the sphere.

charge = ... C [2]

ON20/42/Q5

16 (a) (i) State what is meant by a *field of force*.

....

....

.... [2]

(ii) State **one** similarity and **one** difference between the electric field due to a point charge and the gravitational field due to a point mass.

similarity: ....

....

....

difference: ....

....

....

[2]

(b) An isolated solid metal sphere of radius 0.15 m is situated in a vacuum, as illustrated in Fig. 5.1.

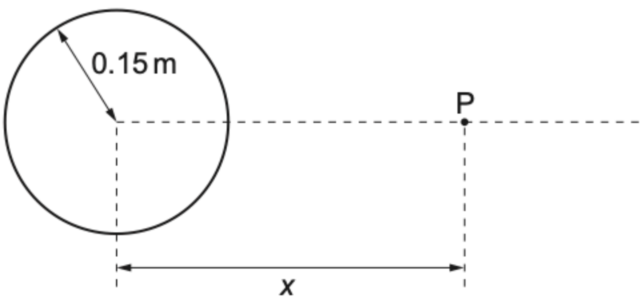

Fig. 5.1

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The electric field strength at the surface of the sphere is 84 V m^{-1}.

Determine:

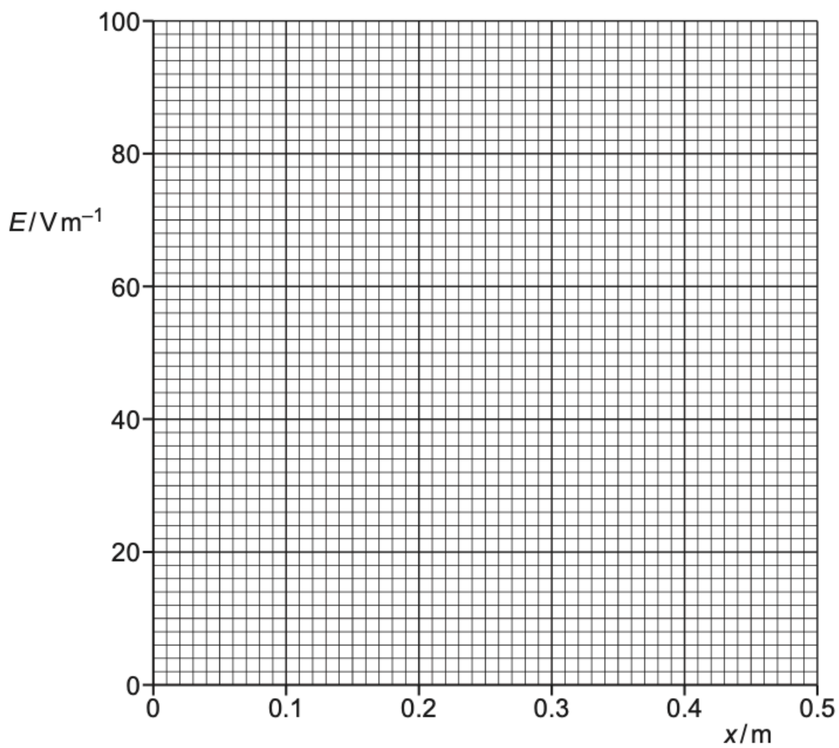
(i) the charge Q on the sphere

Q = ... C [2]

(ii) the electric field strength at point P, a distance x = 0.45 m from the centre of the sphere.

electric field strength = ... V m^{-1} [2]

(c) Use information from **(b)** to show, on the axes of Fig. 5.2, the variation of the electric field strength E with distance x from the centre of the sphere for values of x from x = 0 to x = 0.45 m.



[3]

[Total: 11]

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17 **(a)** **(i)** Define gravitational field. **MJ23/41/Q1**

....

.... [1]

(ii) Define electric field.

....

.... [1]

(iii) State **one** similarity and **one** difference between the gravitational potential due to a point mass and the electric potential due to a point charge.

similarity: ....

....

difference: ....

....

[2]

(b) An isolated uniform conducting sphere has mass M and charge Q.
The gravitational field strength at the surface of the sphere is g.
The electric field strength at the surface of the sphere is E.

(i) Show that

$$\frac{M}{Q} = \alpha \frac{g}{E}$$

where α is a constant.

[3]

(ii) Show that the numerical value of α is $1.35 \times 10^{20}\,\text{kg}^2\,\text{C}^{-2}$.

[1]

(c) Assume that the Earth is a uniform conducting sphere of mass 5.98×10^{24} kg.
The surface of the Earth carries a charge of -4.80×10^{5} C that is evenly distributed.

(i) Use the information in **(b)** to determine the electric field strength at the surface of the Earth. Give a unit with your answer.

electric field strength = ... unit .... [2]

(ii) State how the direction of the electric field at the surface of the Earth compares with the direction of the gravitational field.

.... [1]

[Total: 11]

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18 **(a)** State **one** similarity and **one** difference between the fields of force produced by an isolated point charge and by an isolated point mass.

similarity: ....

....

difference: ....

....
[2]

(b) An isolated solid metal sphere A of radius *R* has charge +*Q*, as illustrated in Fig. 5.1.

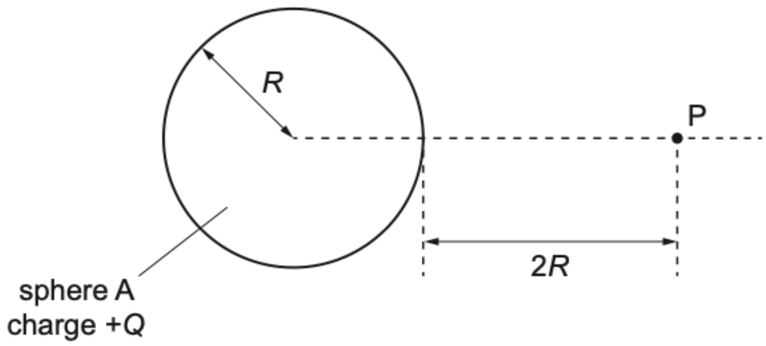

Fig. 5.1

A point P is distance 2*R* from the surface of the sphere.

Determine an expression that includes the terms *R* and *Q* for the electric field strength *E* at point P.

E = ... [2]

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(c) A second identical solid metal sphere B is now placed near sphere A. The centres of the spheres are separated by a distance $6R$, as shown in Fig. 5.2.

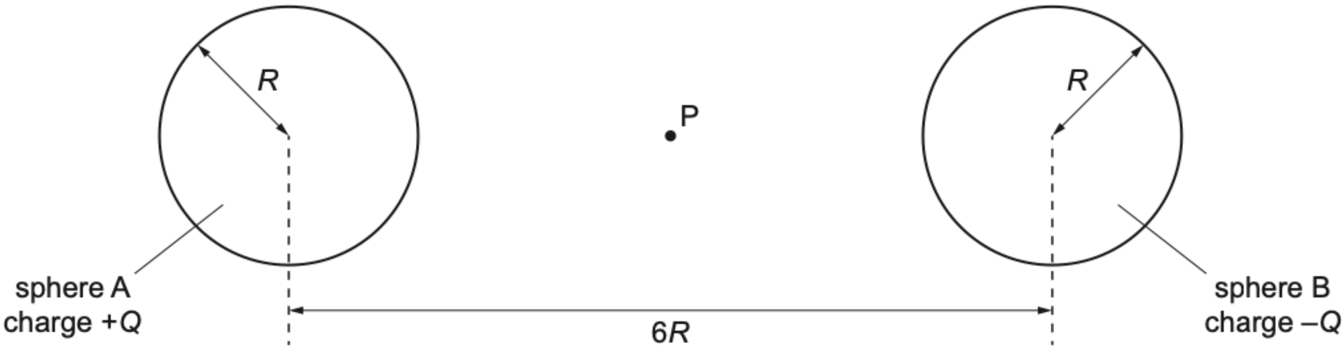

Fig. 5.2

Point P lies midway between spheres A and B.

Sphere B has charge $-Q$.

Explain why:

(i) the magnitude of the electric field strength at P is given by the sum of the magnitudes of the field strengths due to each sphere

....

.... [1]

(ii) the electric field strength at point P due to the charged metal spheres is not, in practice, equal to $2E$, where E is the electric field strength determined in **(b)**.

....

....

.... [2]

[Total: 7]

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19 **(a)** State an expression for the electric field strength E at a distance r from a point charge Q in a vacuum.
State the name of any other symbol used.

....

....

.... [2]

(b) Two point charges A and B are situated a distance 10.0 cm apart in a vacuum, as illustrated in Fig. 6.1.

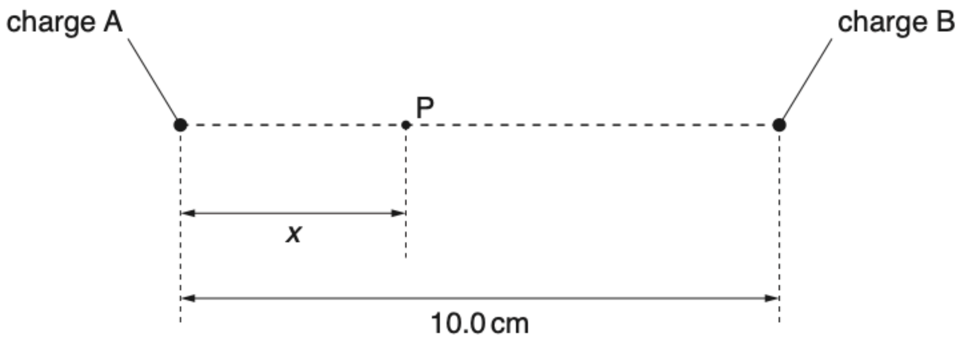

Fig. 6.1

A point P lies on the line joining the charges A and B. Point P is a distance x from A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 6.2.

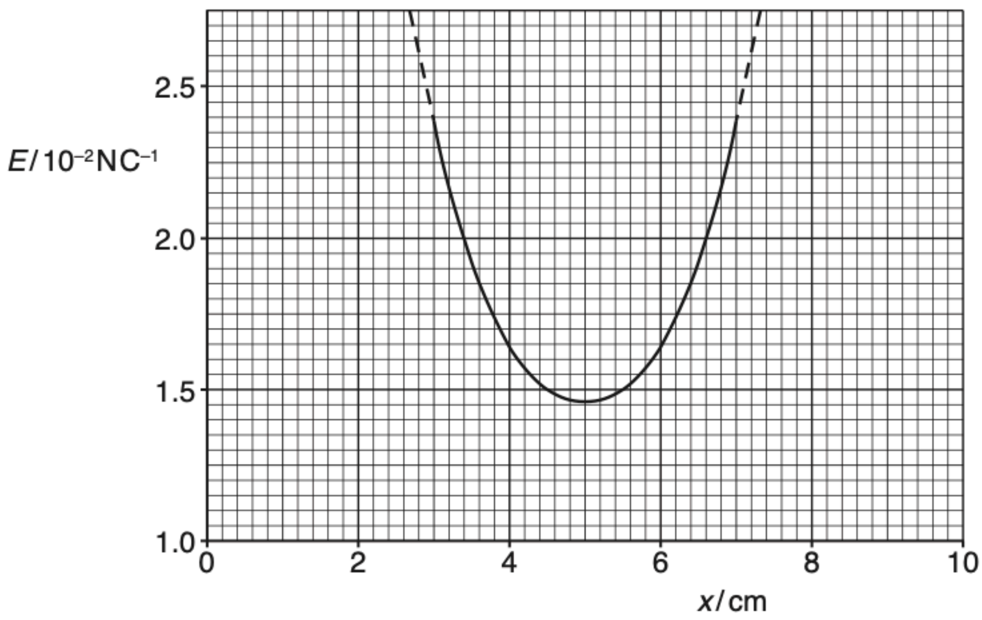

Fig. 6.2

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State and explain whether the charges A and B:

(i) have the same, or opposite, signs

....

....

.... [2]

(ii) have the same, or different, magnitudes.

....

....

.... [2]

(c) An electron is situated at point P.

Without calculation, state and explain the variation in the magnitude of the acceleration of the electron as it moves from the position where $x = 3\,\text{cm}$ to the position where $x = 7\,\text{cm}$.

....

....

....

....

....

.... [4]

[Total: 10]

20 **(a)** State

ON18/42/Q6

(i) what is meant by the *electric potential* at a point,

....

....

....[2]

(ii) the relationship between electric potential at a point and electric field strength at the point.

....

....

....[2]

(b) Two similar solid metal spheres A and B, each of radius R, are situated in a vacuum such that the separation of their centres is D, as shown in Fig. 6.1.

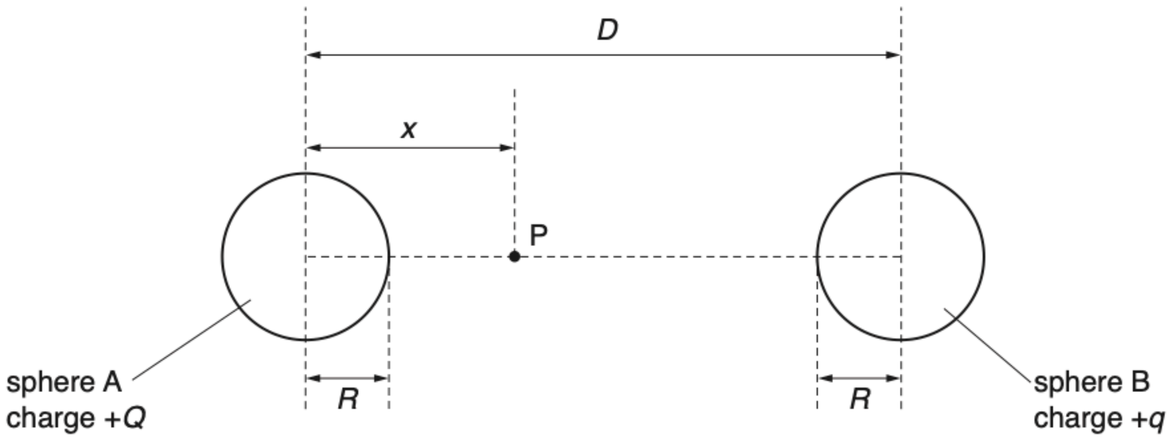
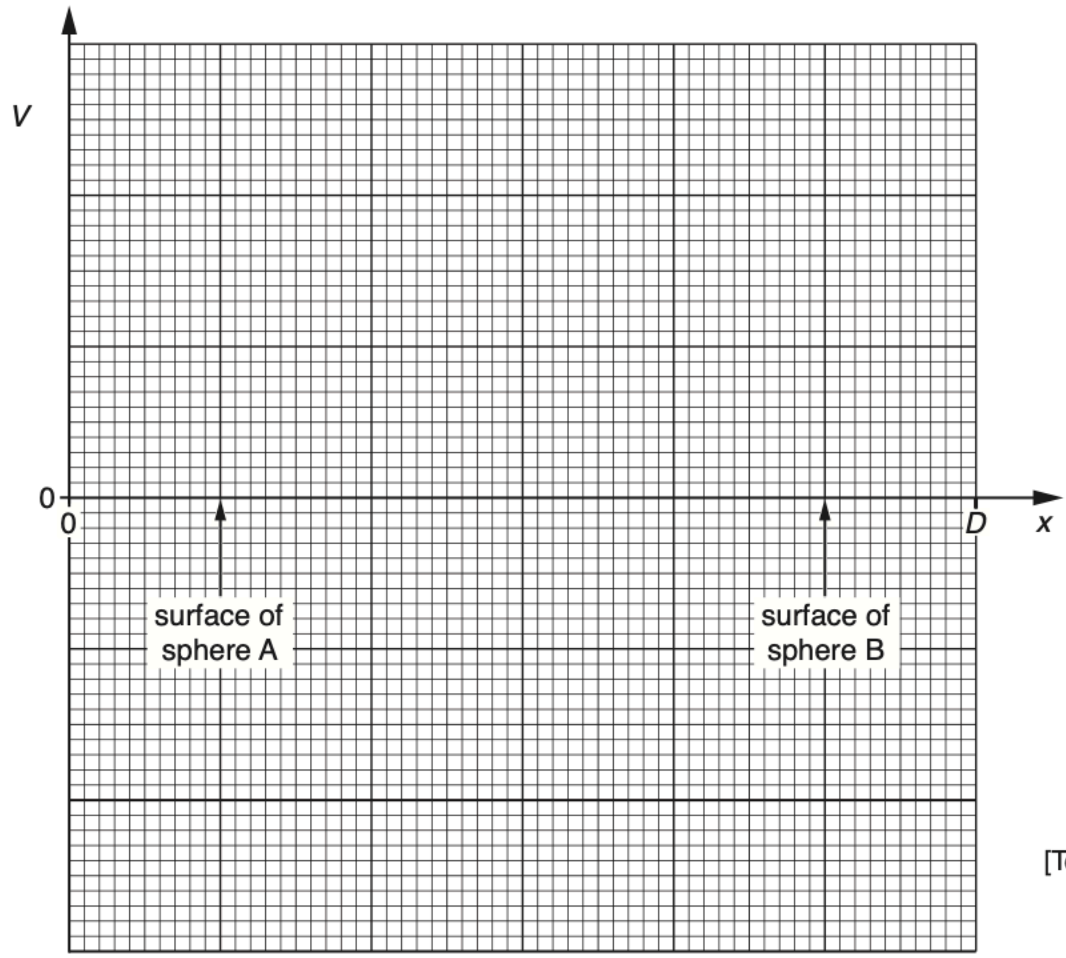


Fig. 6.1

The charge $+Q$ on sphere A is larger than the charge $+q$ on sphere B.

A movable point P is located on the line joining the centres of the two spheres. The point P is a distance x from the centre of sphere A.

On Fig. 6.2, sketch a graph to show the variation with x of the electric potential V between the centres of the two spheres.



[4]

[Total: 8]

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21 **(a)** State what is meant by *electric field strength*. **MJ19/41/Q5**

....

....

.... [2]

(b) Two point charges A and B are situated a distance 15 cm apart in a vacuum, as illustrated in Fig. 5.1.

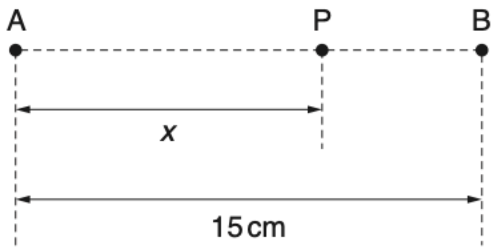

Fig. 5.1

Point P lies on the line joining the charges and is a distance *x* from charge A.

The variation with distance *x* of the electric field strength *E* at point P is shown in Fig. 5.2.

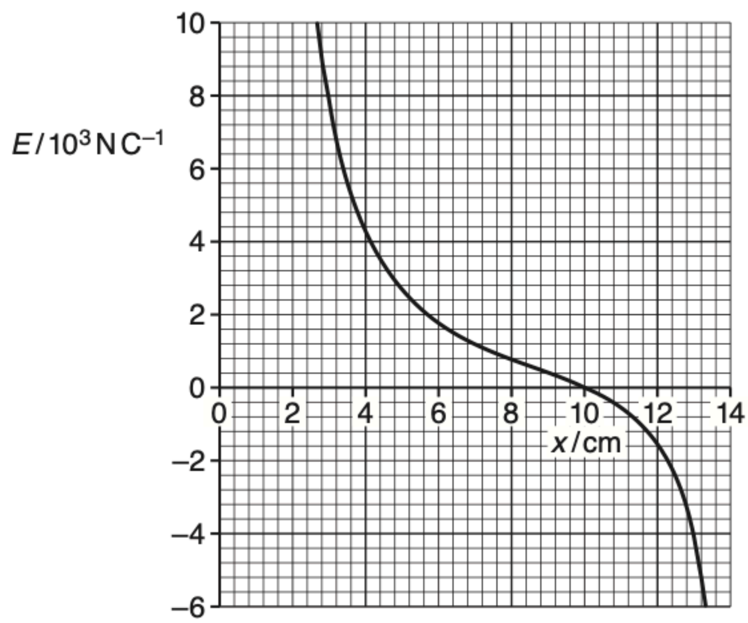

Fig. 5.2

(i) By reference to the direction of the electric field, state and explain whether the charges A and B have the same, or opposite, signs.

....

....

.... [2]

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(ii) State why, although charge A is a point charge, the electric field strength between $x = 3\,\text{cm}$ and $x = 7\,\text{cm}$ does not obey an inverse-square law.

....

.... [1]

(iii) Use Fig. 5.2 to determine the ratio

$$\frac{\text{magnitude of charge A}}{\text{magnitude of charge B}}.$$

ratio = ... [3]

[Total: 8]

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22 **(a)** For any point outside a spherical conductor, the charge on the sphere may be considered to act as a point charge at its centre. By reference to electric field lines, explain this.

....

....

....

....[2]

(b) An isolated spherical conductor has charge q, as shown in Fig. 6.1.

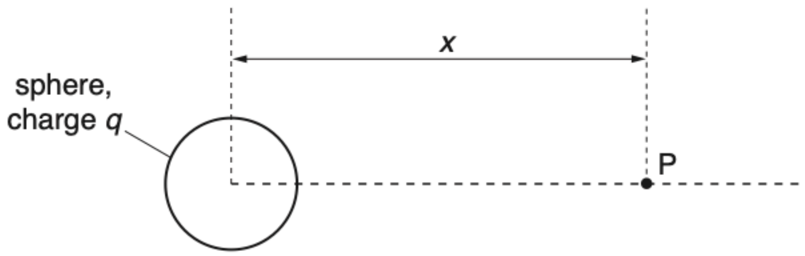

Fig. 6.1

Point P is a movable point that, at any one time, is a distance x from the centre of the sphere.

The variation with distance x of the electric potential V at point P due to the charge on the sphere is shown in Fig. 6.2.

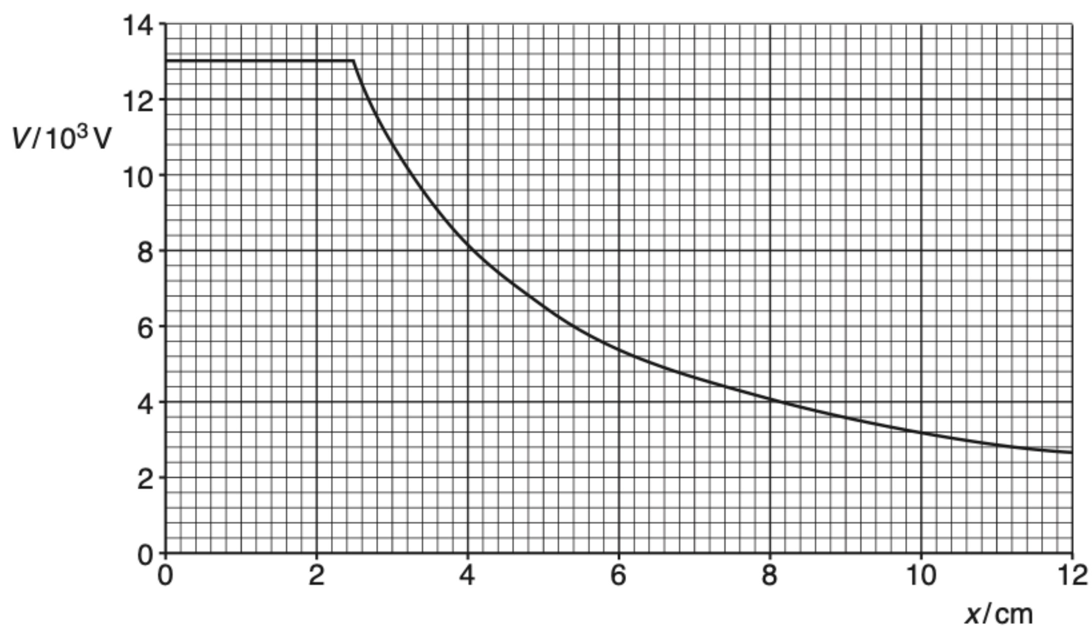

Fig. 6.2

Use Fig. 6.2 to determine

(i) the electric field strength E at point P where $x = 6.0$ cm,

E = ... NC^{-1} [3]

(ii) the radius R of the sphere. Explain your answer.

R = ... cm [2]

[Total: 7]

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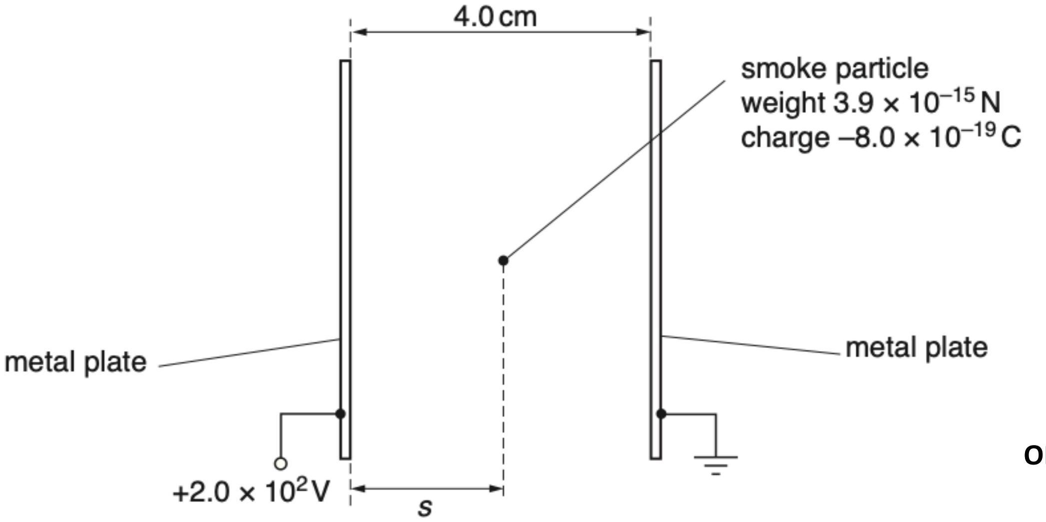
23 **(a)** Define the *coulomb*.

....[1]

(b) Two vertical metal plates in a vacuum have a separation of 4.0 cm. A potential difference of 2.0×10^2 V is applied between the plates. Fig. 5.1 shows a side view of this arrangement.



ON17/22/Q5

Fig. 5.1

A smoke particle is in the uniform electric field between the plates. The particle has weight 3.9×10^{-15} N and charge -8.0×10^{-19} C.

(i) Show that the electric force acting on the particle is 4.0×10^{-15} N.

[2]

(ii) On Fig. 5.1, draw labelled arrows to show the directions of the two forces acting on the smoke particle. [1]

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(iii) The resultant force acting on the particle is F.

Determine

1. the magnitude of F,

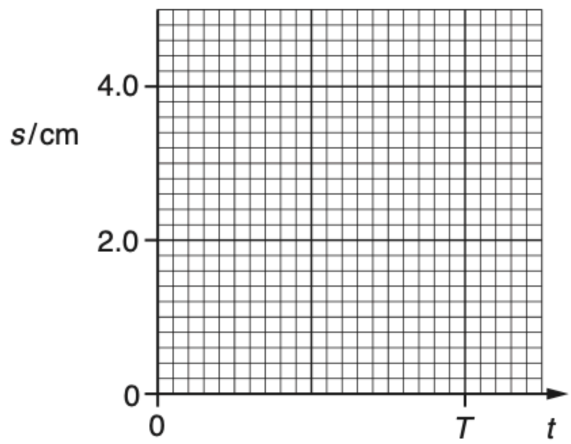
magnitude = ... N

2. the angle of F to the horizontal.

angle = ... °
[3]

(c) The electric field in **(b)** is switched on at time $t = 0$ when the particle is at a horizontal displacement $s = 2.0\,\text{cm}$ from the left-hand plate. At time $t = 0$ the horizontal velocity of the particle is zero. The particle is then moved by the electric field until it hits a plate at time $t = T$.

On Fig. 5.2, sketch the variation with time t of the horizontal displacement s of the particle from the left-hand plate.



[2]

[Total: 9]

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1 (a)	(electric) force is (directly) proportional to product of charges force (between point charges) is inversely proportional to the square of their separation	**B1** **B1**	**Ignore** any symbols unless they are defined. **Ignore** any symbols unless they are defined.
2(b)(i)	charge = **(+)2*e***	**A1**	
2(b)(ii)	$F = 2 \times (1.60 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (170 \times 10^{-12})^2] = 1.6 \times 10^{-8}$ N	**A1**	Full substitution and answer needed.
2(c)(i)	$F = mv^2 / r$ $v = \sqrt{[(1.6 \times 10^{-8} \times 170 \times 10^{-12}) / (9.11 \times 10^{-31})]}$ $= \mathbf{1.7 \times 10^{6}\ m\ s^{-1}}$	**C1** **A1**	 No ECF from (b)(ii). Correct to at least 2 significant figures. AFC. (1.73) (Unrounded *F* gives 1.72).
2(c)(ii)	*either:* $F = mr\omega^2$ and $\omega = 2\pi / T$ $F = 4\pi^2 mr / T^2$ $T = \sqrt{[(4\pi^2 \times 9.11 \times 10^{-31} \times 170 \times 10^{-12}) / (1.6 \times 10^{-8})]}$ $= \mathbf{6.2 \times 10^{-16}\ s}$ *or:* $v = 2\pi r / T$ $T = (2\pi \times 170 \times 10^{-12}) / (1.73 \times 10^{6})$ $= \mathbf{6.2 \times 10^{-16}\ s}$	 **C1** **A1** **(C1)** **(A1)**	 Possible ECF of POT error from **(c)(i)**. Correct to at least 2 significant figures. AFC. (6.18). (Unrounded *F* gives 6.20). Possible ECF from **(c)(i)**. Correct to at least 2 significant figures. AFC. (6.17). Rounded *v* gives **6.3 × 10^{-16} s** AFC (6.28).
2(d)(i)	$E \propto Q / r^2$ ratio = $[1.6 \times 10^{-19} \times (170 \times 10^{-12})^2] / [3.2 \times 10^{-19} \times (340 \times 10^{-12})^2]$ $= \mathbf{0.13}$	**C1** **A1**	**Allow** '*x*' for '*r*'. Allow any equation of the form $E = kQ / r^2$. Correct to at least 2 significant figures. AFC. (0.125)

2 (a)	plate X marked as negative and plate Y marked as positive	**B1**	**Allow** omission of one label if the other one is correct.
6(b)(i)	$E = V / x$ $= (58 \times 10^3) / 0.041$ $= \mathbf{1.4 \times 10^{6}\ N\ C^{-1}}$	**C1** **A1**	**Allow** '*d*' or 'Δx' for '*x*'. Correct to at least 2 significant figures. AFC. (1.41) Unit needed with answer. **Allow** V m^{-1} for N C^{-1}.
6(b)(ii)	$ma = eE$ $a = (1.60 \times 10^{-19} \times 1.41 \times 10^{6}) / (9.11 \times 10^{-31})$ $= \mathbf{2.5 \times 10^{17}\ m\ s^{-2}}$	**C1** **A1**	**Allow** '*q*' or '*Q*' for '*e*'. Possible ECF from **(b)(i)**. Correct to at least 2 significant figures. AFC. (2.48 from unrounded *E*, 2.46 from rounded *E*)
6(c)(i)	$eV = hc / \lambda$ or $eV = hf$ and $f = c / \lambda$ $(1.60 \times 10^{-19} \times 58 \times 10^{3}) = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$ clear conversion from m to pm leading to leading to λ = 21 pm	**C1** **M1** **A1**	**Allow** '*q*' or '*Q*' for '*e*'. **Allow** $\frac{1}{2}mv^2$ with use of $v^2 = (u^2 +)\ 2as$ for eV. Full substitution needed. M1 mark implies C1. **Allow** '½ × 9.11 × 10^{-31} × 2 × 2.5 × 10^{17} × 0.041' for left-hand side (but no ECF from **(b)(ii)** unless value of *a* does lead to 21 pm. May be seen either as a 10^{12} factor in the M1 working, or calculation of λ as 2.1 × 10^{-11} m then converted to 21 pm.
6(c)(ii)	X-rays	**B1**	

3 a)	work done per unit charge work done (on charge) in moving positive charge from infinity (to the point)	B1 B1	Ratio must be clear. **Allow** 'energy' for 'work done'. **Ignore** any symbols unless they are defined. **Ignore** any reference to units.
5(b)(i)	electric field strength inversely proportional to distance^2 $E = 3^2 \times 2.0 \times 10^5$ $= \mathbf{1.8 \times 10^6\ N\ C^{-1}}$	C1 A1	Allow in symbols without explanation. Deduction that E at r is 9 times E at $3r$ implies C1. Correct to at least 2 significant figures. AFC.
5(b)(ii)	$V = Q / 4\pi\varepsilon_0 r$ and $E = Q / 4\pi\varepsilon_0 r^2$ so $E = V / r$ $r = (9.0 \times 10^4) / (1.8 \times 10^6) = 0.050\text{ m} = 5.0\text{ cm}$	B1 A1	This mark is not just for quoting $E = V / d$. Allow 'x' for 'r' throughout. Working and answer (with unit conversion) needed. No ECF from **(b)(i)**. **Allow** '9' for '9.0'. **Allow** r to 1 significant figure.
5(b)(iii)	$Q = 4\pi\varepsilon_0 Vr$ $= 4\pi \times 8.85 \times 10^{-12} \times 9.0 \times 10^4 \times 0.050$ $= \mathbf{5.0 \times 10^{-7}\ C}$	C1 A1	*or* $Q = 4\pi\varepsilon_0 Er^2$ $= 4\pi \times 8.85 \times 10^{-12} \times 1.8 \times 10^6 \times 0.050^2$ (C1) Correct to at least 2 significant figures. AFC. (5.00). Possible ECF from **(b)(i)** if alternative method used. No ECF from **(b)(ii)**.
5(b)(iv)	$C = Q / V$ $= (5.0 \times 10^{-7}) / (9.0 \times 10^4)$ $= \mathbf{5.6 \times 10^{-12}\ F}$	C1 A1	**Allow** $C = 4\pi\varepsilon_0 r$ for the C1 mark. Possible ECF from **(b)(iii)**. Correct to at least 2 significant figures. AFC. (5.56). **Allow** 5.6 pF for AFC.

4 (c)	straight line with non-zero gradient from 0 to *d*	**B1**
	line with negative gradient from (0, *V*) to (*d*, 0)	**B1**

5 a)	(electric) field equals (electric) potential gradient	**M1**
	reference to minus sign	**A1**
5(b)	• for potential to be zero, one potential must be positive and the other potential must be negative • for potential to be zero, the charges must have opposite sign • for field to be zero, the fields (due to X and Y) must be in opposite directions • for field to be zero, the charges must have the same sign • the signs of the charges cannot (simultaneously) be both the same and opposite (so not possible) *Any three points, 1 mark each*	**B3**
5(c)(i)	$V_X = (–)\ Q / 4\pi\varepsilon_0 x$ **and** $V_Y = (–)\ 2Q / 4\pi\varepsilon_0 y$	**C1**
	($V_X + V_Y = 0$ so) $Q / 4\pi\varepsilon_0 x = 2Q / 4\pi\varepsilon_0 y$ leading to $y = 2x$	**A1**
5(c)(ii)	$E_X = Q / 4\pi\varepsilon_0 x^2$	**A1**
5(c)(iii)	$E_Y = 2Q / 4\pi\varepsilon_0 (2x)^2$ $(= Q / 8\pi\varepsilon_0 x^2)$	**C1**
	(opposite charges so fields in same direction so magnitudes add): $E = (Q / 4\pi\varepsilon_0 x^2) + (Q / 8\pi\varepsilon_0 x^2)$ $= 3Q / 8\pi\varepsilon_0 x^2$	**A1**

6 a)	(electric) force is (directly) proportional to product of charges	**B1**
	force (between point charges) is inversely proportional to the square of their separation	**B1**
6(b)	at least four straight, radial lines to/from surface of sphere	**B1**
	at least four straight radial lines drawn, approximately equally spaced	**B1**
	arrows pointing away from the surface of the sphere	**B1**
6(c)(i)	radius = 3.2 cm	**A1**
6(c)(ii)	$E = Q / (4\pi\varepsilon_0 x^2)$	**C1**
	Q = e.g. $2.2 \times 10^5 \times 4\pi \times 8.85 \times 10^{-12} \times 0.032^2$	**C1**
	$= 2.5 \times 10^{-8}$ C	**A1**
6(c)(iii)	• the (positive) charge is all the way around the surface • a charge placed inside the sphere is pulled equally in all directions • if the field was not zero, the charges would move (until field is zero) • electric field lines go from positive charge to negative charge, and there are no negative charges inside the sphere *Any point, 1 mark*	**B1**

7 (a)	force per unit charge	**B1**
	force on positive charge	**B1**
5(b)(i)	four straight vertical parallel lines, approximately evenly spaced	**B1**
	arrows downwards	**B1**
5(b)(ii)	$E = V / d$	**C1**
	$E = 430 / 0.067$ $= 6.4 \times 10^3$ N C^{-1}	**A1**
5(b)(iii)	smooth curve within plates and straight lines outside plates	**B1**
	direction of deflection shown as upwards	**B1**

8 (a)	work done per unit charge	**B1**
	work (done) moving positive charge from infinity (to the point)	**B1**
5(b)	*Any three points from*: *Up to 2 points from*: • radius of sphere X is 0.30 m • radius of sphere Y is 0.10 m • radius of X is treble the radius of Y *Up to 2 points from*: • charge on X is positive • charge on Y is positive • spheres X and Y carry charges of the same sign *Up to 1 point from*: • (magnitudes of) charges on the spheres are equal • charges on the spheres have the same magnitude	**B3**
5(c)	proton remains at rest (in the position of release)	**M1**
	potential energy of proton is (already) at its minimum **or** (electric) forces (from spheres) on proton are equal and opposite **or** no resultant (electric) force on proton **or** resultant electric field strength (at proton) is zero	**A1**

9 (a)	work done per unit charge	**B1**
	work (done on charge) moving positive charge from infinity (to the point)	**B1**
5(b)	*Any three points from*: *Up to 2 points from*: • radius of sphere X is 2.0 m • radius of sphere Y is 4.0 m • radius of Y is double the radius of X *Up to 2 points from*: • charge on X is negative • charge on Y is positive • spheres carry opposite charges *Up to 1 point from*: • magnitudes of charges on the spheres are equal	**B3**
5(c)	particle is attracted to X or repelled from Y **or** resultant force on particle is towards X / away from Y / to the left	**B1**
	particle accelerates towards X / away from Y / to the left	**B1**
	(magnitude of) acceleration of particle increases	**B1**

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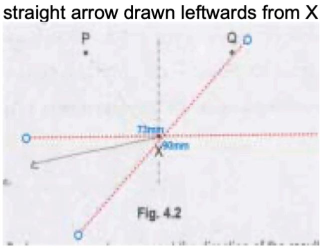
5(a)	(electric) force is (directly) proportional to product of charges	B1
	(electric) force (between point charges) is inversely proportional to the square of their separation	B1
5(b)	$F = Q^2 / 4\pi\varepsilon_0 x^2$ $6.3 \times 10^{-17} = Q^2 / [4\pi \times 8.85 \times 10^{-12} \times (3.8 \times 10^{-6})^2]$	C1
	charge = 3.2×10^{-19} C	A1
5(c)(i)	negative	B1
5(c)(ii)	four straight lines perpendicular to the plates, starting on one plate and finishing on the other	B1
	lines equally spaced	B1
	arrows indicating direction downwards	B1
5(c)(iii)	$E = V / d$	C1
	$mg = EQ$	C1
	mass = $(1200 \times 3.2 \times 10^{-19}) / (9.81 \times 0.052)$ = 7.5×10^{-16} kg	A1

11

a)	(electric) force is (directly) proportional to product of charges	B1
	force (between point charges) is inversely proportional to the square of their separation	B1
4(b)(i)	arrows showing tension upwards in direction of string, electric force horizontally to the right and weight vertically downwards and all three labelled	B1
4(b)(ii)	$F_E = \dfrac{96 \times 10^{-9} \times 64 \times 10^{-9}}{4 \times \pi \times 8.85 \times 10^{-12} \times 0.080^2}$ (= 8.63×10^{-3} N)	C1
	either angle to vertical = $\sin^{-1} 0.080 / 1.2$ (= 3.82°)	C1
	weight = $F_E / \tan 3.82 = 8.63 \times 10^{-3} / \tan 3.82$ (= 0.129 N)	C1
	mass = 0.129 / 9.81 = 0.013 kg	A1
	or $T \sin\theta = mg$ **and** $T \cos\theta = F_E$ **or** $\tan\theta = mg / F_E$	(C1)
	$\tan\theta = 1.2 / 0.080$	(C1)
	$m = (1.2 \times 8.63 \times 10^{-3}) / (0.080 \times 9.81)$ = 0.013 kg	(A1)
4(b)(iii)	$E_p = \dfrac{Q_1 Q_2}{4\pi\varepsilon_o r} = \dfrac{96 \times 10^{-9} \times 64 \times 10^{-9}}{4 \times \pi \times 8.85 \times 10^{-12} \times 0.080}$ = 6.9×10^{-4} J	A1
4(c)(i)	towards the top of the page / towards plate P	B1
4(c)(ii)	$F = QE$ **and** $E = V / d$	C1
	$F = 1.6 \times 10^{-19} \times 250 / 0.018$ = 2.2×10^{-15} N	A1
4(c)(iii)	**either** the force is not (always) perpendicular to the velocity **or** the force is always in the same direction	B1

12 (a)		(field line indicates) direction of force	B1
		force on a positive charge	B1
4(b)(i)		one straight line perpendicular to plates, starting on one plate and finishing on the other	B1
		five straight lines perpendicular to plates between the plates, uniformly spaced	B1
		downwards arrows on lines	B1
4(b)(ii)		$E = V / d$	C1
		$= 2400 / 0.046$ $= 5.2 \times 10^4$ N C^{-1}	A1
4(c)(i)		smooth curve in region of field and straight line outside field	B1
		direction of deflection shown as downwards in region of field	B1
4(c)(ii)		helium nucleus has double the charge but four times the mass	B1
		velocity parallel to plates same and acceleration perpendicular to plates smaller (for helium)	B1
		final speed is lower (for helium)	B1

13 (a)	work done per unit charge	B1
	work done (on charge) in moving positive charge from infinity (to the point)	B1
5(b)(i)	radius = 0.060 m	A1
5(b)(ii)	$V = Q / 4\pi\varepsilon_0 x$ $Q = (–)\ 850 \times 4\pi \times 8.85 \times 10^{-12} \times 0.060$ **or** $Q = (–)\ 850 \times 0.060 / 8.99 \times 10^9$ (*any correct pair of V and x values from curve*)	C1
	$Q = – 5.7 \times 10^{-9}$ C	A1
5(c)(i)	$E_P = Q^2 / 4\pi\varepsilon_0 x$ $= (5.67 \times 10^{-9})^2 / (4\pi \times 8.85 \times 10^{-12} \times 0.46)$	C1
	$= 6.3 \times 10^{-7}$ J	A1
5(c)(ii)	• force is repulsive so spheres move apart • force in direction of motion so speed increases • potential energy converted to kinetic energy so speed increases • force decreases with distance so acceleration decreases • momentum is conserved (at zero) (and masses are equal) so velocities are always equal and opposite *Any three points, 1 mark each*	B3

14 (a)	direction of force	B1
	force on a positive charge	B1
4(b)(i)	$V = \dfrac{Q}{4\pi\varepsilon_o r}$ $\dfrac{4.0\times10^{-9}}{4\pi\varepsilon_o x} + \dfrac{-7.2\times10^{-9}}{4\pi\varepsilon_o(0.120 - x)} = 0$ $4(0.120 - x) = 7.2x$	C1
	x = 0.043 m	A1
4(b)(ii)	fields are in the same direction so no	B1
4(b)(iii)	straight arrow drawn leftwards from X in direction between extended line joining Q and X and the horizontal 	B1

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15 6(a)	(both have) radial field lines	**B1**
6(b)(i)	**2.1** cm	**B1**
6(b)(ii)	$E = \dfrac{Q}{4\pi\varepsilon_o r^2}$ e.g. r = 2.1 cm, E = 1.30 × 10^5 V m^{-1} $Q = 4\pi\varepsilon_o r^2 E$ $= 4\times\pi\times 8.85\times 10^{-12}\times 0.021^2\times 1.30\times 10^5$	**C1**
	$= 6.4\times 10^{-9} C$	**A1**

16 5(a)(i)	region (of space)	**B1**
	where a particle experiences a force	**B1**
5(a)(ii)	similarity – any one point from: • both have an inverse square variation • both decrease with distance • both are radial	**B1**
	difference – any one point from: • gravitational field always towards (the mass) • electric field can be towards or away from (the charge)	**B1**
5(b)(i)	$E = Q / 4\pi\varepsilon_0 x^2$	**C1**
	$Q = 4\pi \times 8.85 \times 10^{-12} \times 84 \times 0.15^2$ $= 2.1 \times 10^{-10}$ C	**A1**
5(b)(ii)	$E = 84 \times (0.15 / 0.45)^2$ **or** $E = (2.1 \times 10^{-10}) / (4\pi \times 8.85 \times 10^{-12} \times 0.45^2)$	**C1**
	E = 9.3 V m^{-1}	**A1**
5(c)	line at E = 0 from x = 0 to x = 0.15 m	**B1**
	smooth curve with decreasing negative gradient throughout, from x = 0.15 m to x = 0.45 m, passing through (0.15, 84)	**B1**
	line passing through (0.45, 9.3)	**B1**

17 1(a)(i)	force per unit mass	**B1**
1(a)(ii)	force per unit positive charge	**B1**
1(a)(iii)	similarity: • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance *Any point, 1 mark*	**B1**
	difference: • gravitational potential is (always) negative • electric potential can be positive or negative *Any point, 1 mark*	**B1**
1(b)(i)	$g = GM / r^2$	**M1**
	$E = Q / 4\pi\varepsilon_0 r^2$	**M1**
	algebra showing the elimination of r leading to $M / Q = (1 / 4\pi G\varepsilon_0)\ (g / E)$	**A1**
1(b)(ii)	$\alpha = 1 / (4\pi \times 6.67 \times 10^{-11} \times 8.85 \times 10^{-12}) = 1.35 \times 10^{20}$ (kg^2 C^{-2}) **or** $\alpha = (8.99 \times 10^9) / (6.67 \times 10^{-11}) = 1.35 \times 10^{20}$ (kg^2 C^{-2})	**A1**
1(c)(i)	$E = \alpha g Q / M$ $= (1.35 \times 10^{20} \times 9.81 \times 4.80 \times 10^5) / (5.98 \times 10^{24})$	**C1**
	= 106 N C^{-1} **or** 106 V m^{-1}	**A1**
1(c)(ii)	same (direction)	**B1**

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18	5(a)	similarity: both are radial **or** both have inverse square (variations)	**B1**
		difference: direction is always/only towards the mass **or** direction can be towards or away from charge	**B1**
	5(b)	field strength = $Q / 4\pi\varepsilon_0 x^2$	**C1**
		$E = Q / 36\pi\varepsilon_0 R^2$	**A1**
	5(c)(i)	fields (due to each sphere) are in same direction	**B1**
	5(c)(ii)	charges on spheres attract/affect each other **or** charge distribution on each sphere distorted by the other sphere **or** charges on the surface of the spheres move	**B1**
		spheres are not point charges (at their centres)	**B1**

19	6(a)	$(E =)\ Q / 4\pi\varepsilon_0 r^2$	**M1**
		where ε_0 is permittivity (of free space)	**A1**
	6(b)(i)	field does not change direction/field does not become zero	**M1**
		so (charges have) opposite (sign)	**A1**
	6(b)(ii)	minimum is at the midpoint (between the charges)	**M1**
		so (magnitudes are the) same	**A1**
	6(c)	force = field strength × charge **and** force = mass × acceleration **or** acceleration is proportional to field strength	**B1**
		(from $x = 3.0$ cm) to $x = 5.0$ cm: acceleration decreases	**B1**
		at $x = 5.0$ cm: acceleration is a minimum	**B1**
		from $x = 5.0$ cm (to $x = 7.0$ cm): acceleration increases	**B1**

20	(a)(i)	work done per unit charge	**B1**
		work done moving positive charge from infinity (to the point)	**B1**
	6(a)(ii)	field strength = potential gradient	**M1**
		negative sign included **or** directions discussed	**A1**
	6(b)	horizontal straight lines, at non-zero potential, within the spheres	**B1**
		magnitude of potential greater at surface of sphere A than at surface of sphere B	**B1**
		concave curve between A and B, with a minimum nearer to B	**B1**
		lines show *V* <u>positive</u> all the way from 0 to *D*	**B1**

21	(a)	force per unit charge	**B1**
		(force on) positive charge	**B1**
	5(b)(i)	field changes <u>direction</u> (between A and B)/field is zero at a point (between A and B)	**M1**
		so charges have same sign	**A1**
	5(b)(ii)	Any one from: • field is (also) influenced by charge B • charge A is not isolated/is not the only charge present • field is due to two/both charges • field is the resultant of two fields	**B1**
	5(b)(iii)	$E = Q / (4\pi\varepsilon_0 x^2)$	**C1**
		at x = 10 cm, $E_A = E_B$	**C1**
		$Q_A / 10^2 = Q_B / 5^2$ $Q_A / Q_B = 4.0$	**A1**

22 6(a)	electric field lines are radial/normal to surface (of sphere)	**B1**
	electric field lines <u>appear</u> to originate from centre (of sphere)	**B1**
6(b)(i)	tangent drawn at x = 6.0 cm and gradient calculation attempted	**C1**
	$E = 9.0 \times 10^4$ N C^{-1} (*1 mark if in range ±1.2; 2 marks if in range ±0.6*)	**A2**
	or	
	correct pair of values of V and x read from curved part of graph and substituted into $V = q/4\pi\varepsilon_0 x$	**(C1)**
	to give $q = 3.6 \times 10^{-8}$ C	**(C1)**
	(then $E = q/4\pi\varepsilon_0 x^2$ and x = 6 cm gives) $E = 9.0 \times 10^4$ N C^{-1}	**(A1)**
	or	
	($E = q/4\pi\varepsilon_0 x^2$ and $V = q/4\pi\varepsilon_0 x$ and so) $E = V/x$	**(C1)**
	giving $E = 5.4 \times 10^3 / 0.060$	**(C1)**
	$= 9.0 \times 10^4$ N C^{-1}	**(A1)**
6(b)(ii)	(R =) 2.5 cm	**B1**
	potential inside a conductor is constant **or** field strength inside a conductor zero (so gradient is zero)	**B1**

23 a)	(coulomb is) ampere second	**B1**
5(b)(i)	$E = V/d$ **or** $E = F/Q$	**C1**
	$F = VQ/d$ $F = (2.0 \times 10^2 \times 8.0 \times 10^{-19})/4.0 \times 10^{-2} = 4.0 \times 10^{-15}$ N	**A1**
5(b)(ii)	arrow pointing to the left labelled 'electric force' **and** arrow pointing downwards labelled 'weight'	**B1**
5(b)(iii)	**1.** resultant force $= \sqrt{[(3.9 \times 10^{-15})^2 + (4.0 \times 10^{-15})^2]}$	**C1**
	$= 5.6 \times 10^{-15}$ N	**A1**
	2. angle = $\tan^{-1} (3.9 \times 10^{-15} / 4.0 \times 10^{-15})$ = 44ϒ	**A1**
5(c)	downward sloping line from (0, 2.0)	**M1**
	magnitude of gradient of line increases with time and line ends at (T, 0)	**A1**