ELECTRIC FIELDS
WORKSHEET
A-Level Physics 9702

MJ24/41/Q5

1 **(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.

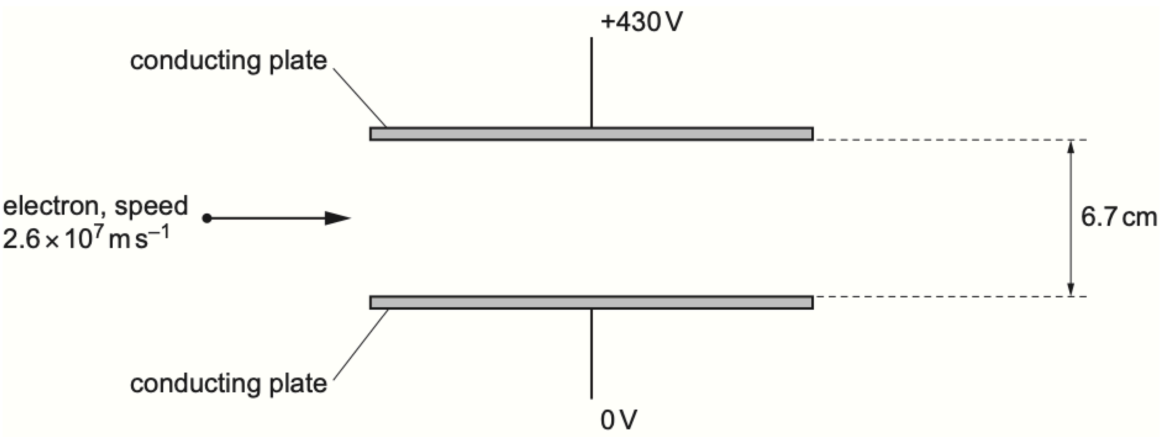


Fig. 5.1

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

(iii) An electron travels at a speed of 2.6×10^7 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]

2 **(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.

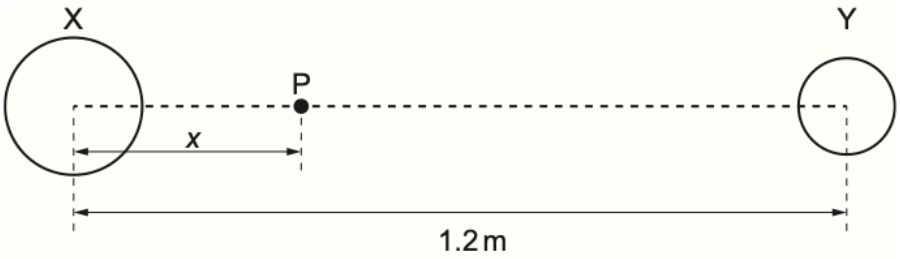


Fig. 5.1 (not to scale)

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.

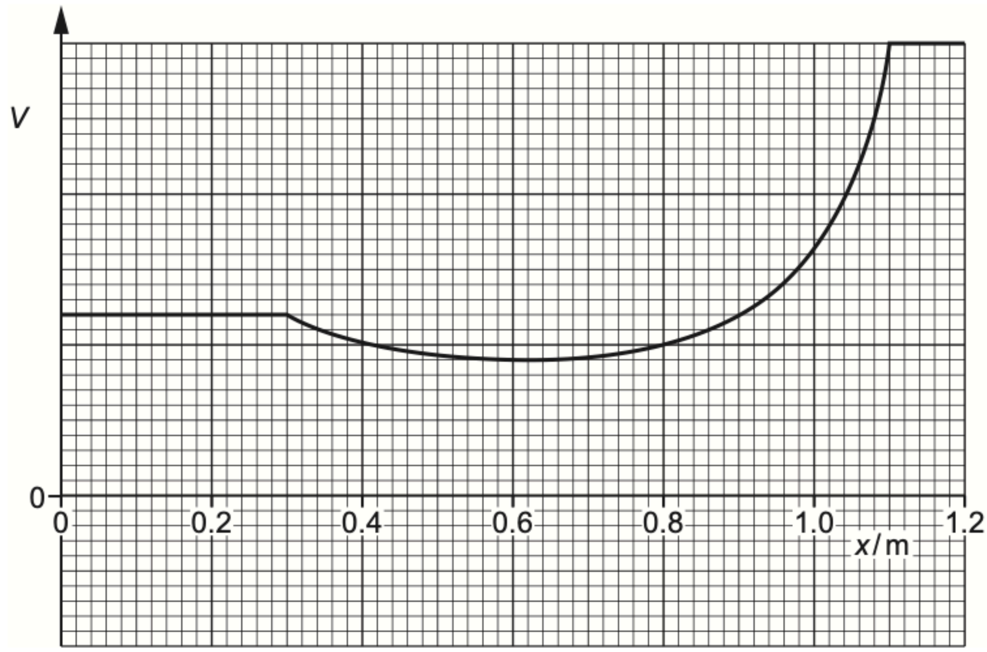


Fig. 5.2

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]

3 **(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.

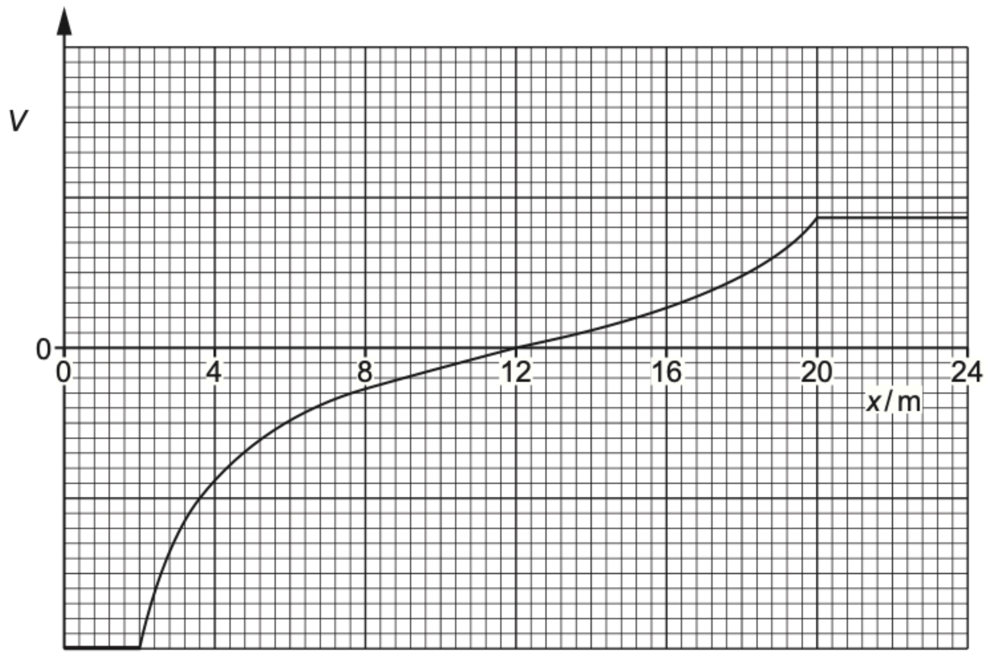


Fig. 5.1

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]

Cyrus Ishaq

ISL, BLL, BCCG, LGS, Roots IVY P5
+923008471504

PHYSICS WITH CYRUS

4 **(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.

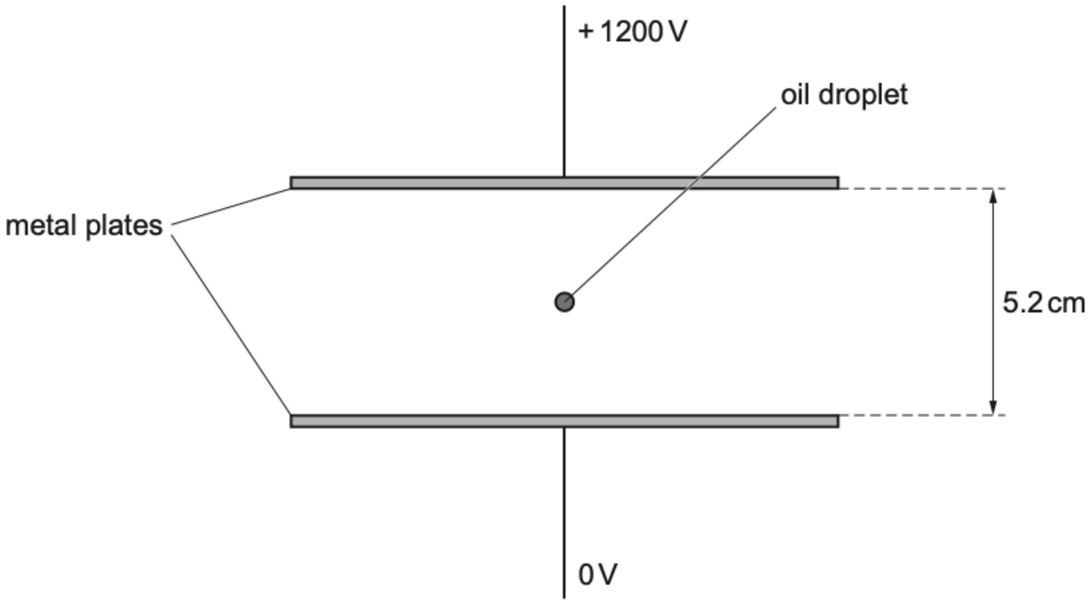


Fig. 5.1 (not to scale)

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.

(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

5 **(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.

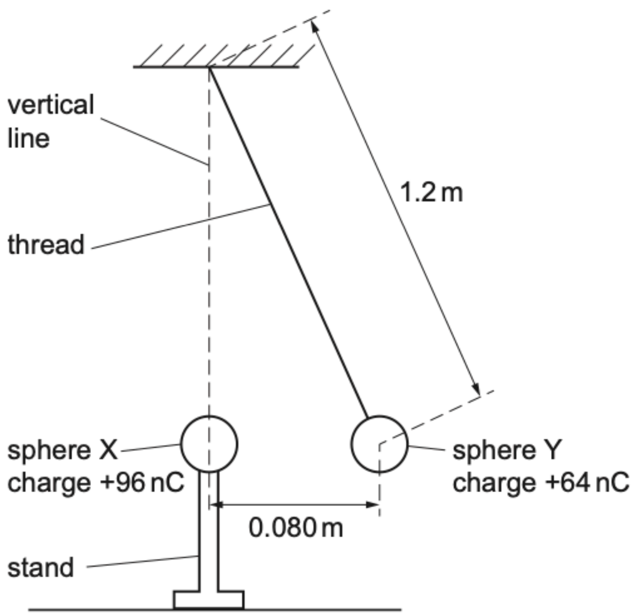


Fig. 4.1

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.

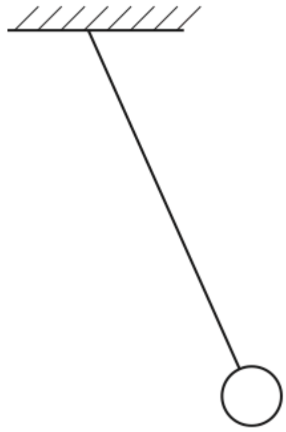


Fig. 4.2

[1]

(ii) Determine the mass of sphere Y.

mass = ... kg [4]

(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.

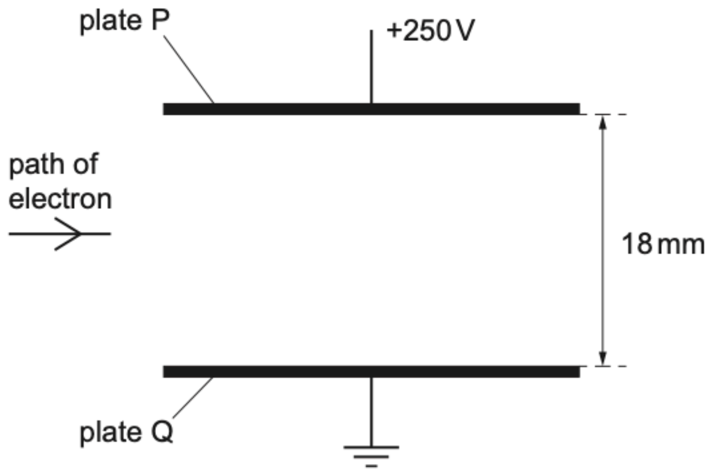


Fig. 4.3

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]

[Total: 12]

6 **(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.

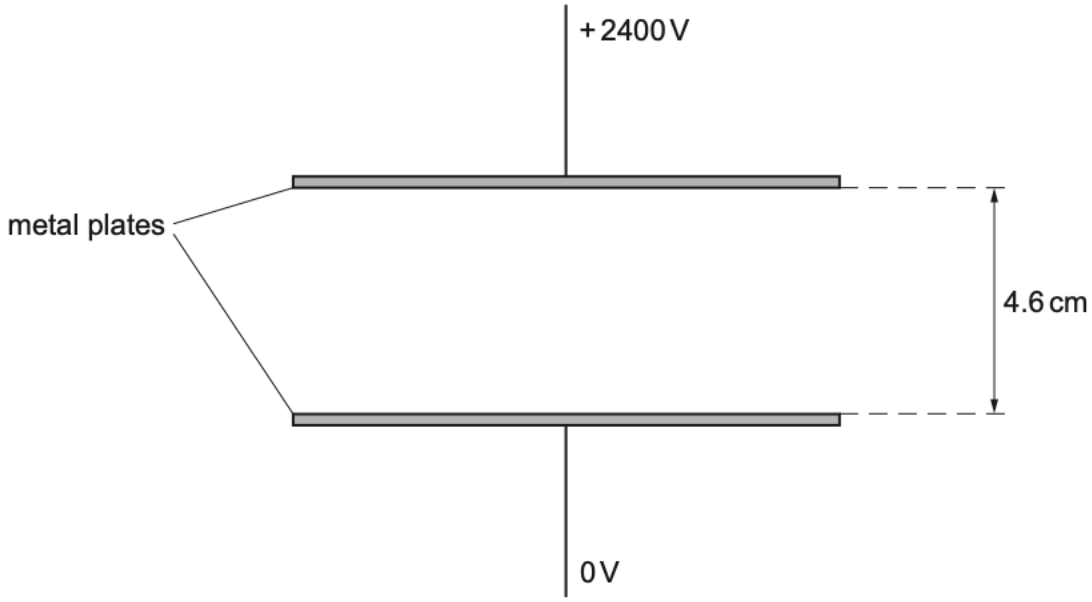


Fig. 4.1

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 = ... NC^{-1} [2]

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

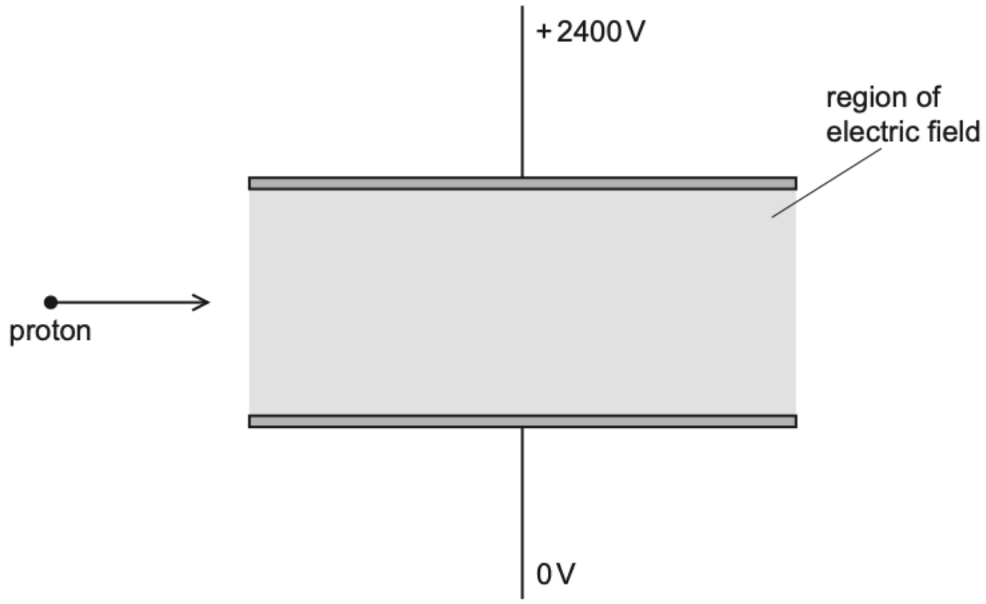


Fig. 4.2

(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]

7 **(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.

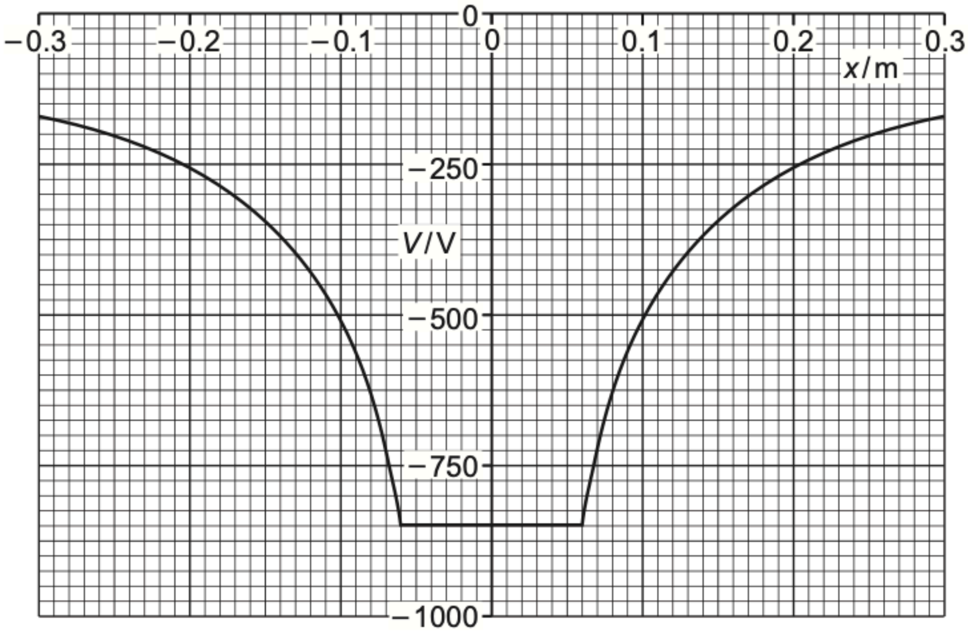


Fig. 5.1

Use Fig. 5.1 to determine:

(i) the radius of the sphere

radius = ... m [1]

(ii) the charge on the sphere.

charge = ... C [2]

(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]

8 **(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.

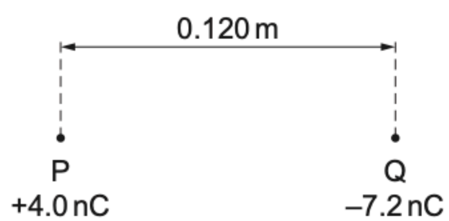


Fig. 4.1

(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.

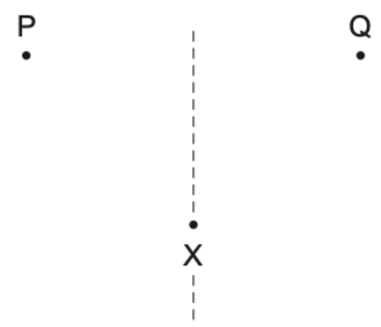


Fig. 4.2

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

[Total: 6]

9 **(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.

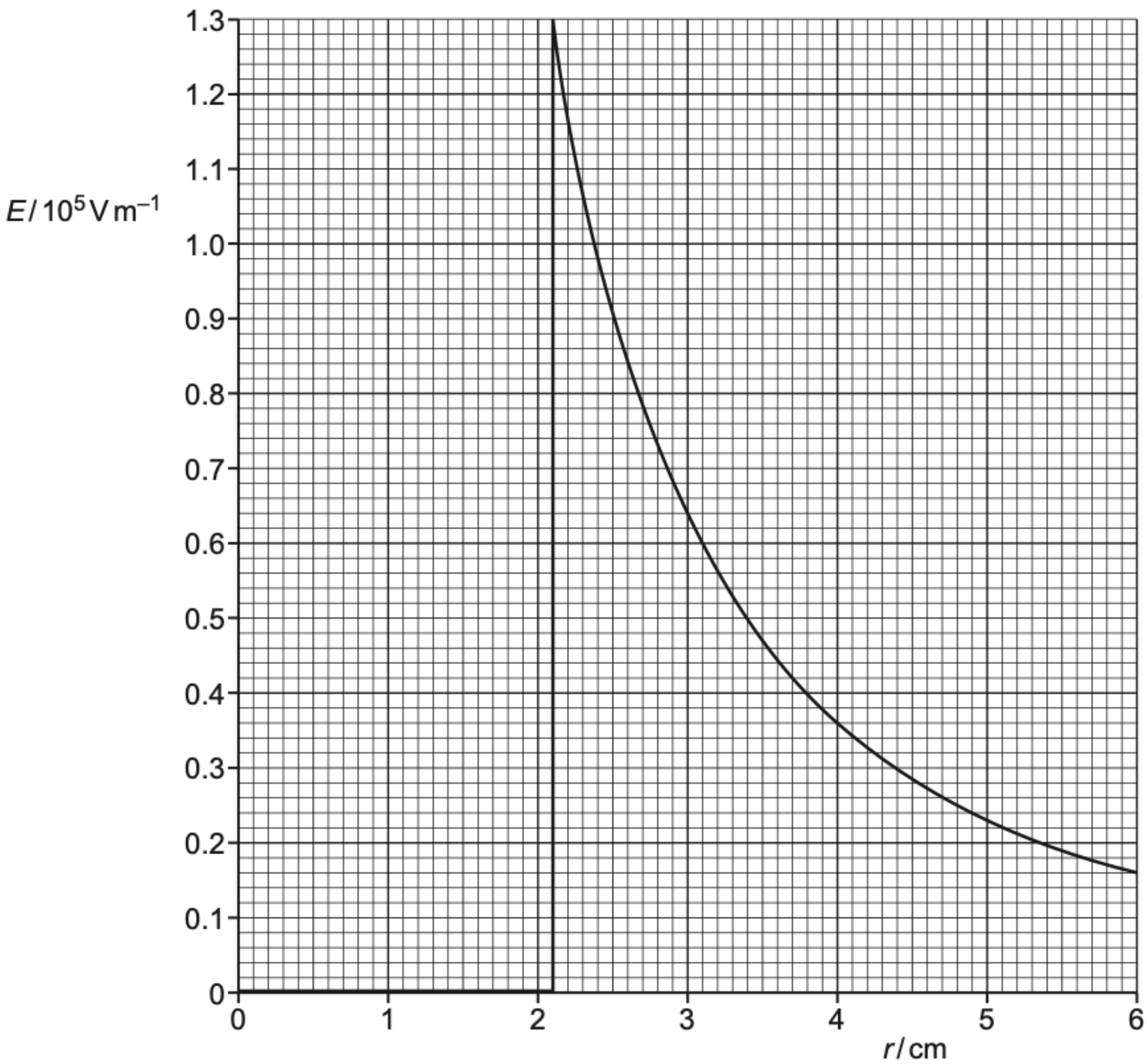


Fig. 6.1

Use data from Fig. 6.1 to:

(i) state the radius of the sphere

radius = ... cm [1]

(ii) calculate the charge on the sphere.

charge = ... C [2]

10 (a) (i) State what is meant by a *field of force*. **ON20/42/Q5**

....

....

.... [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.

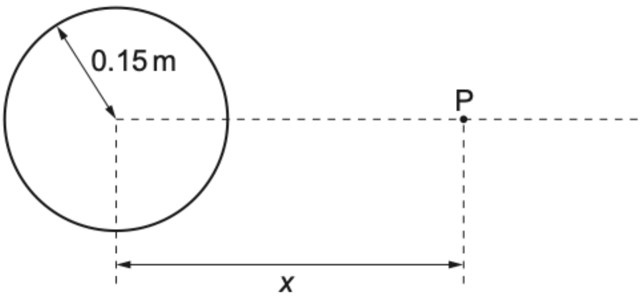


Fig. 5.1

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

Determine:

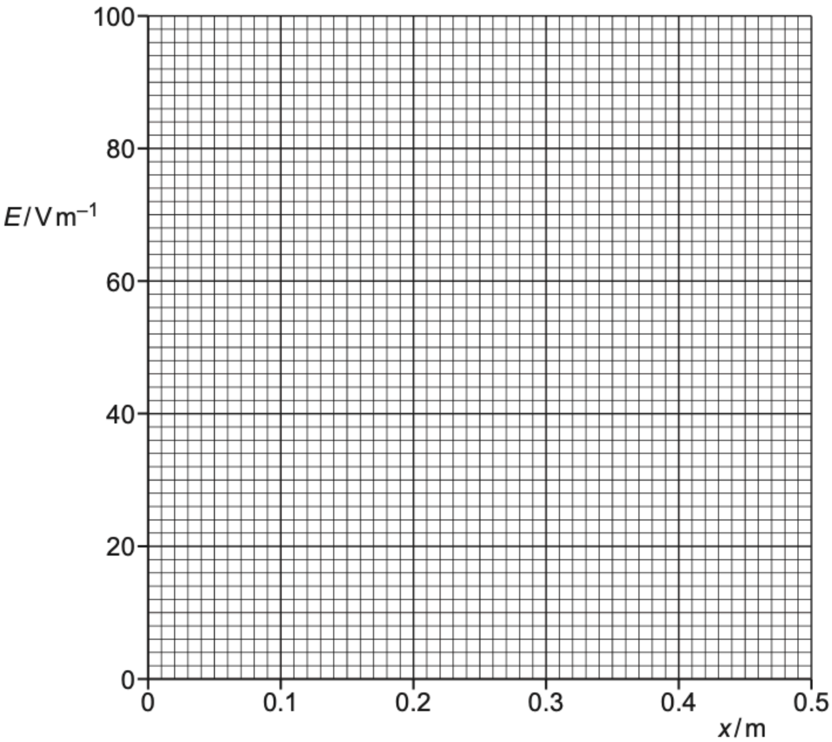
(i) the charge Q on the sphere

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]

11 **(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]

12 **(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.

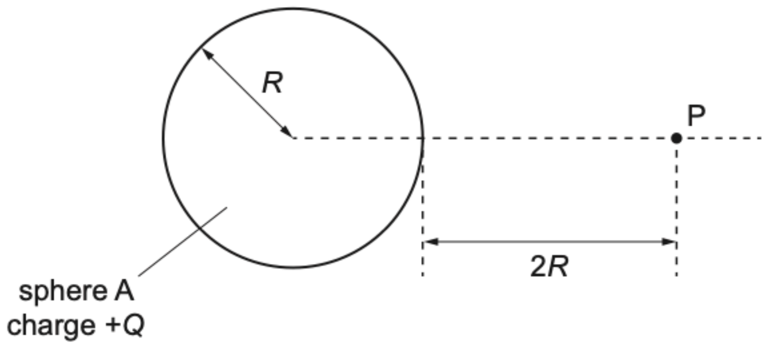


Fig. 5.1

A point P is distance $2R$ 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]

(c) A second identical solid metal sphere B is now placed near sphere A. The centres of the spheres are separated by a distance 6*R*, 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 2*E*, where *E* is the electric field strength determined in **(b)**.

....

....

.... [2]

[Total: 7]

13 **(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.

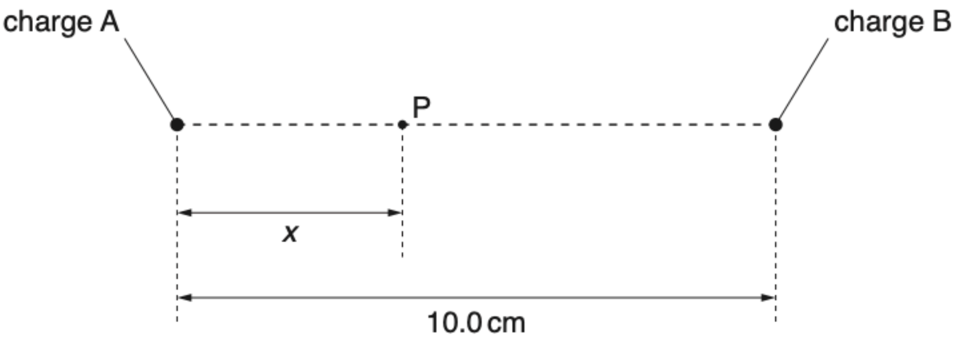


Fig. 6.1

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.

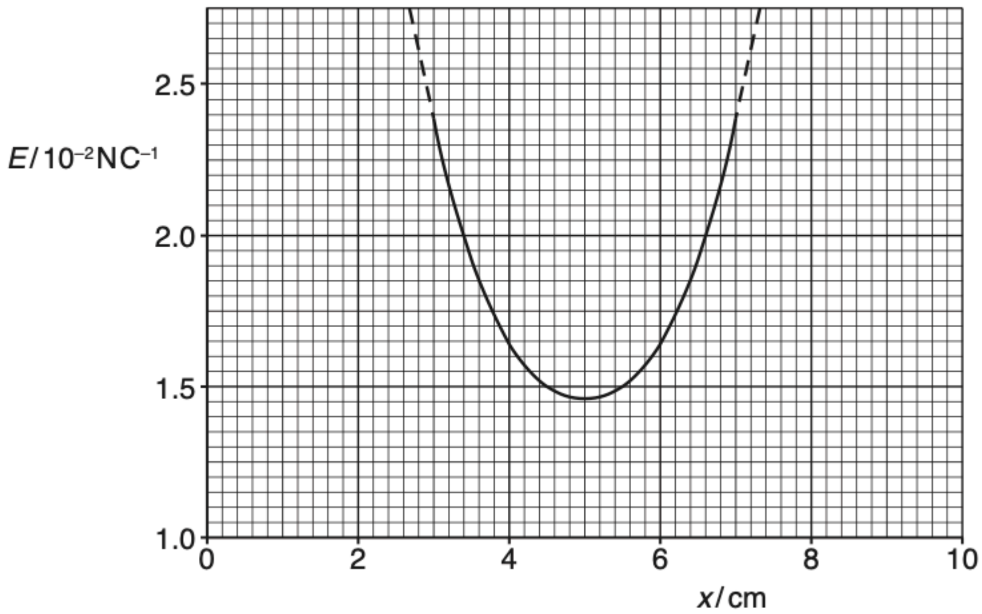


Fig. 6.2

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]

14 **(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.

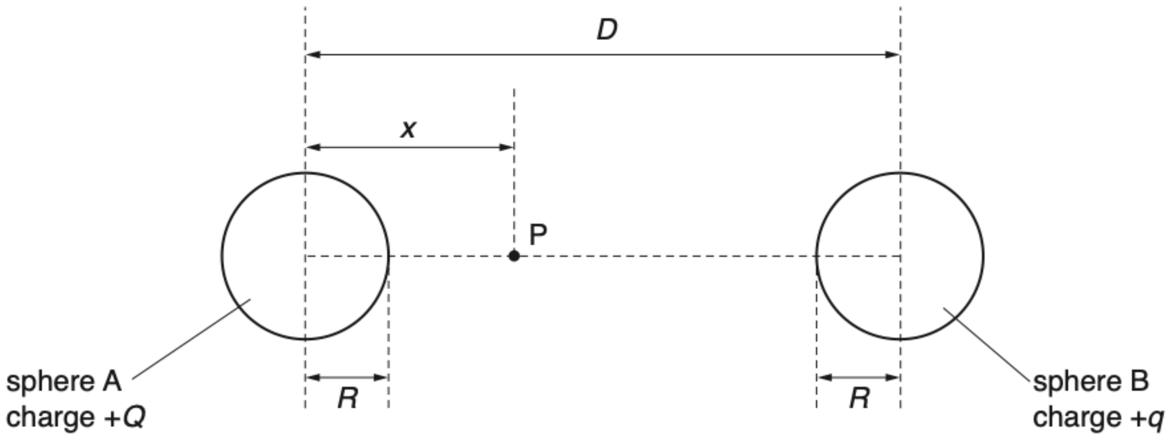
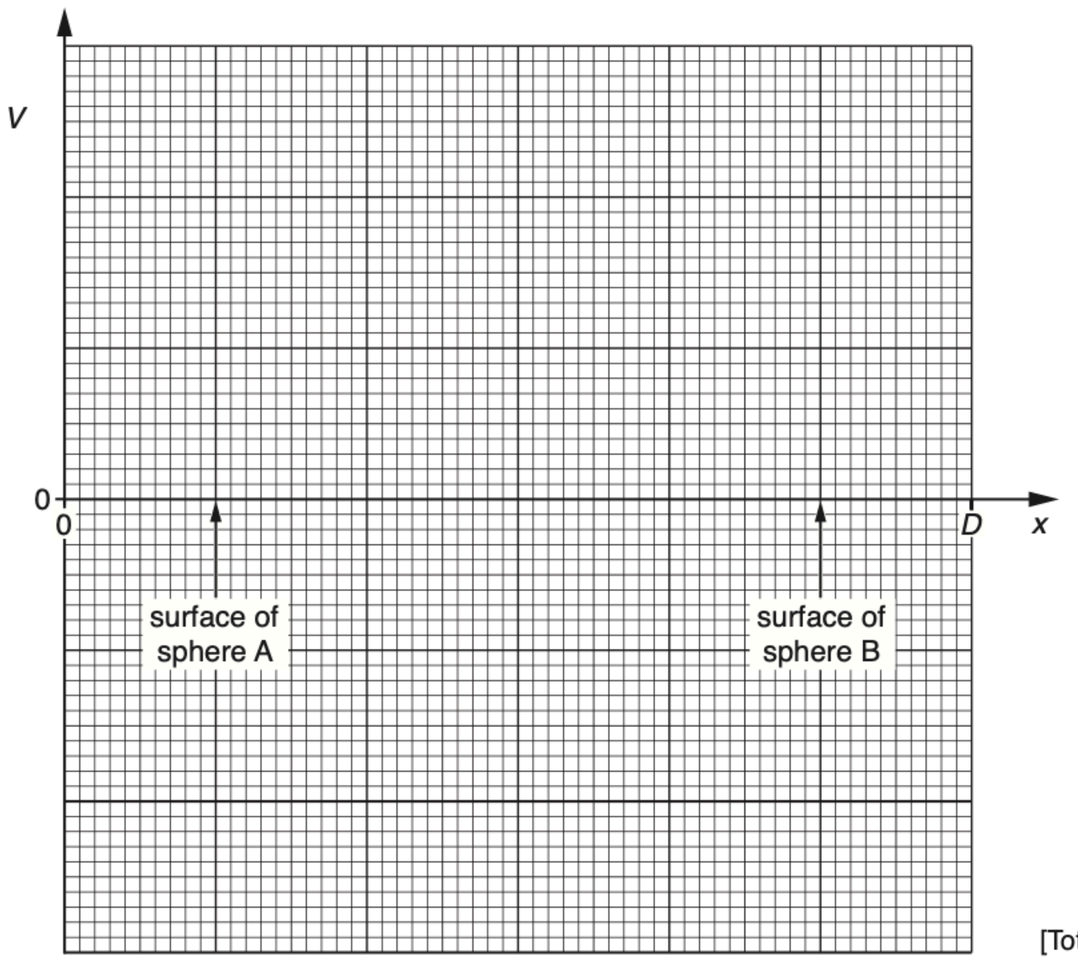


Fig. 6.1

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]

15 **(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.

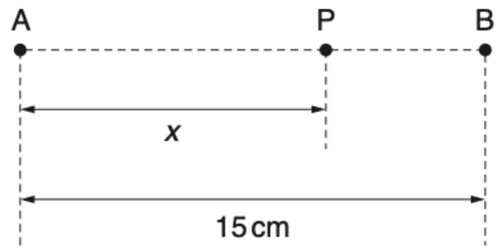


Fig. 5.1

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.

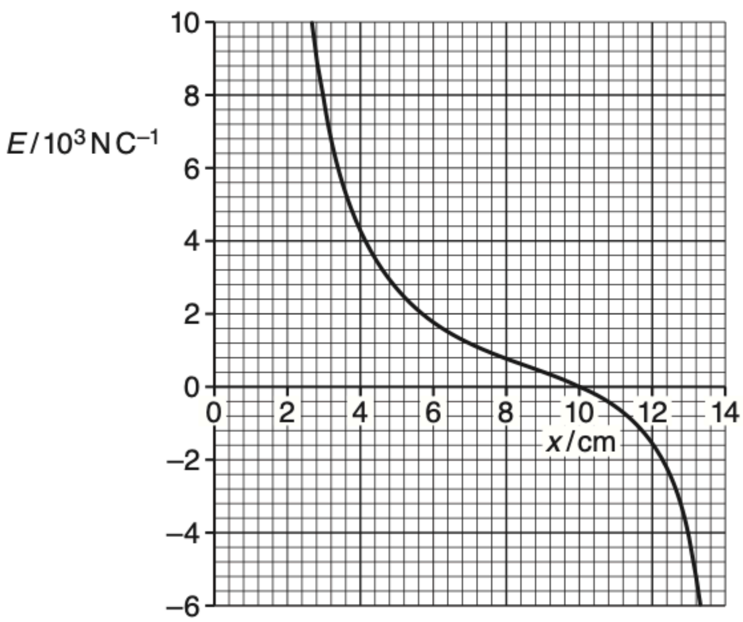


Fig. 5.2

(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]

(ii) State why, although charge A is a point charge, the electric field strength between $x = 3$ cm and $x = 7$ 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]

16 **(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.

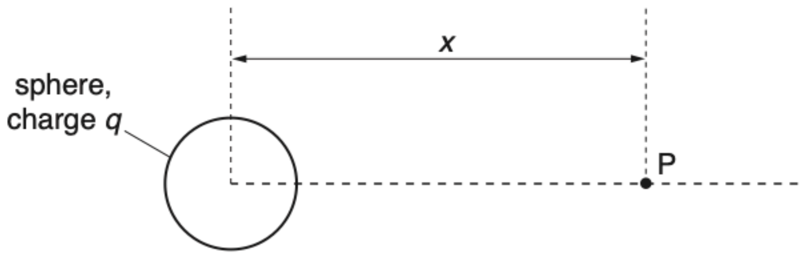


Fig. 6.1

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.

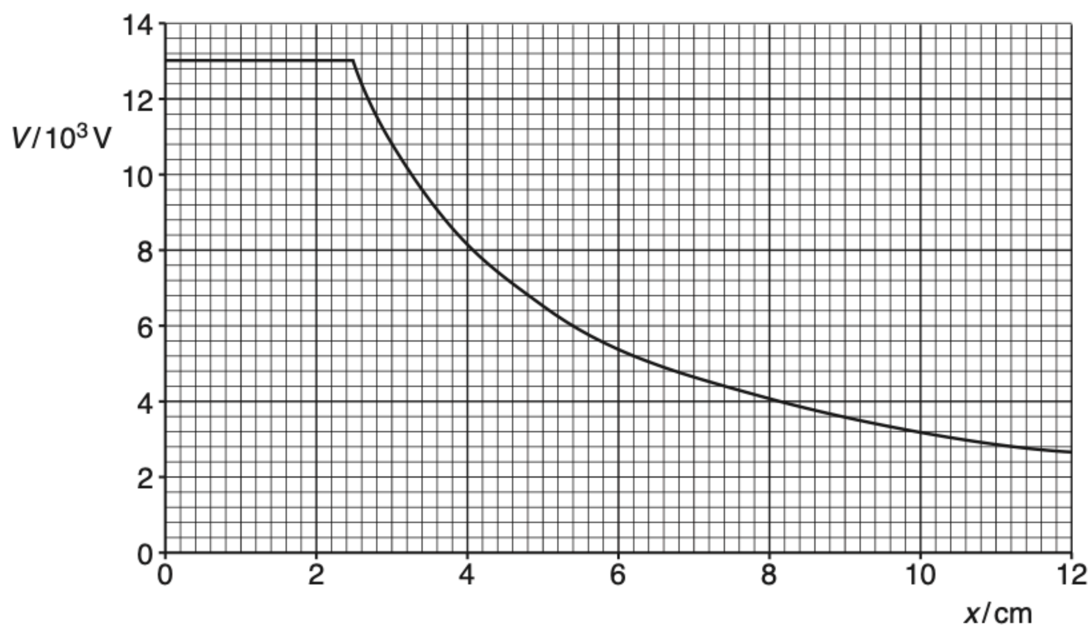


Fig. 6.2

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.

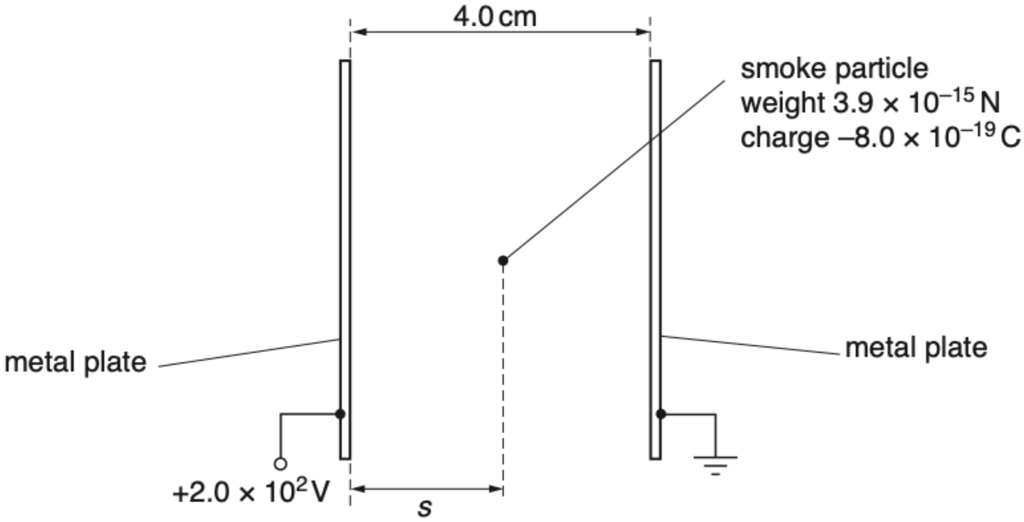
R = ... cm [2]

[Total: 7]

17 **(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]

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

Determine

1. the magnitude of F,

magnitude = ... N

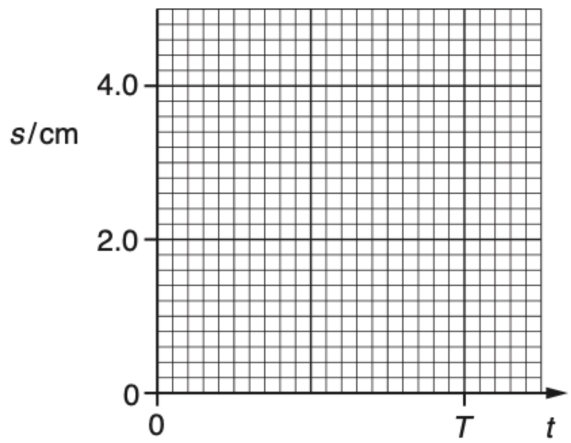
2. the angle of F to the horizontal.

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]

18 **(a)** Define *electric field strength*. **ON17/21/Q6**

....

.... [1]

(b) Two parallel metal plates in a vacuum are separated by a distance of 15 mm, as shown in Fig. 6.1.

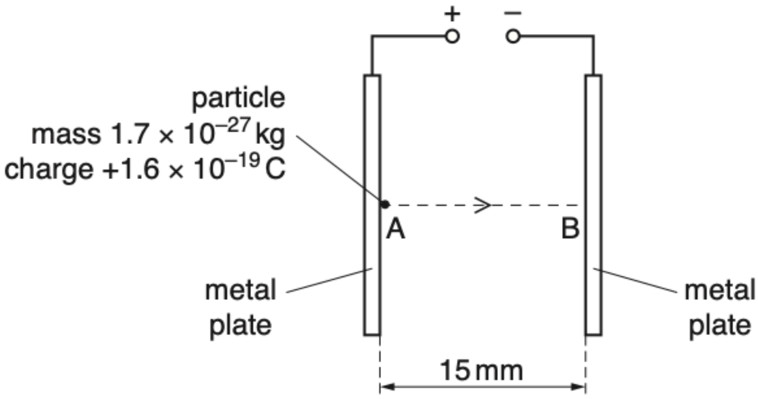


Fig. 6.1

A uniform electric field is produced between the plates by applying a potential difference between them.

A particle of mass 1.7×10^{-27} kg and charge $+1.6 \times 10^{-19}$ C is initially at rest at point A on one plate. The particle is moved by the electric field to point B on the other plate. The particle reaches point B with kinetic energy 2.4×10^{-16} J.

(i) Calculate the speed of the particle at point B.

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

(ii) State the work done by the electric field to move the particle from A to B.

work done = ... J [1]

(iii) Use your answer in **(ii)** to determine the force on the particle.

force = ... N [2]

(iv) Determine the potential difference between the plates.

potential difference = ... V [3]

(v) On Fig. 6.2, sketch a graph to show the variation of the kinetic energy of the particle with the distance *x* from point A along the line AB.
Numerical values for the kinetic energy are not required.

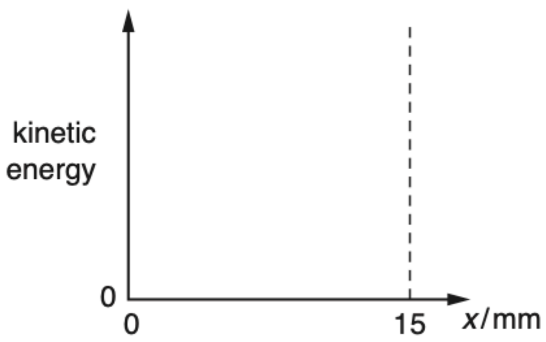


Fig. 6.2

[1]

[Total: 10]

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

....

....[1]

(b) An electron is accelerated from point A to point B by a uniform electric field, as illustrated in Fig. 3.1.

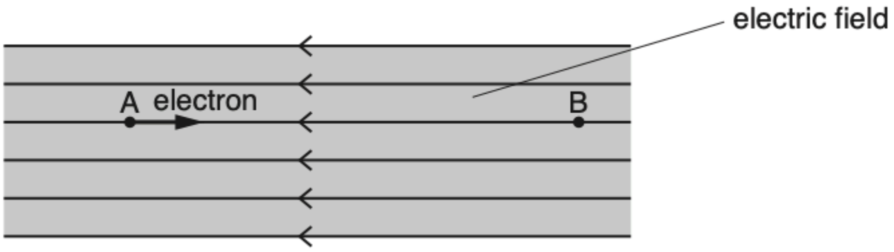


Fig. 3.1

The distance between A and B is 12 mm. The velocity of the electron at A is 2.5 $km\,s^{-1}$ and at B is 18 $Mm\,s^{-1}$.

Calculate

(i) the acceleration of the electron,

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

(ii) the change in kinetic energy of the electron,

change in kinetic energy = ... J [3]

(iii) the electric field strength.

electric field strength = ... $V m^{-1}$ [3]

(c) An α-particle moves from A to B in the electric field in **(b)**.

Describe and explain how the change in the kinetic energy of the α-particle compares with that of the electron. Numerical values are not required.

....

....

....

....

....[3]

[Total: 12]

MJ17/21/Q5

20 An α-particle is travelling in a vacuum towards the centre of a gold nucleus, as illustrated in Fig. 5.1.

Fig. 5.1

The gold nucleus has charge 79*e*.
The gold nucleus and the α-particle may be assumed to behave as point charges.
At a large distance from the gold nucleus, the α-particle has energy 7.7×10^{-13} J.

(a) The α-particle does not collide with the gold nucleus. Show that the radius of the gold nucleus must be less than 4.7×10^{-14} m.

[3]

(b) Determine the acceleration of the α-particle for a separation of 4.7×10^{-14} m between the centres of the gold nucleus and of the α-particle.

acceleration = ... $m s^{-2}$ [3]

(c) In an α-particle scattering experiment, the beam of α-particles is incident on a very thin gold foil.
Suggest why the gold foil must be very thin.

....

....[1]

[Total: 7]

21 **(a)** State Coulomb's law. **MJ17/42/Q6**

....

....

....[2]

(b) Two charged metal spheres A and B are situated in a vacuum, as illustrated in Fig. 6.1.

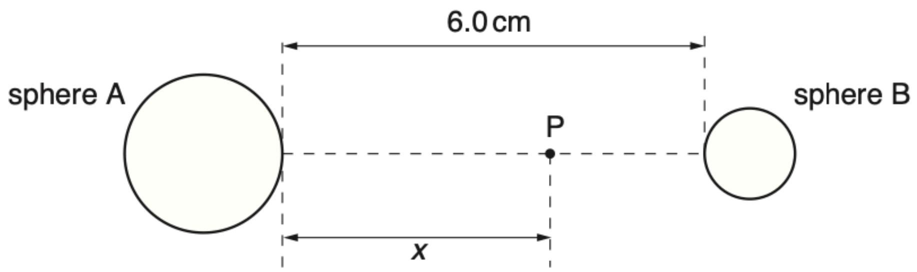
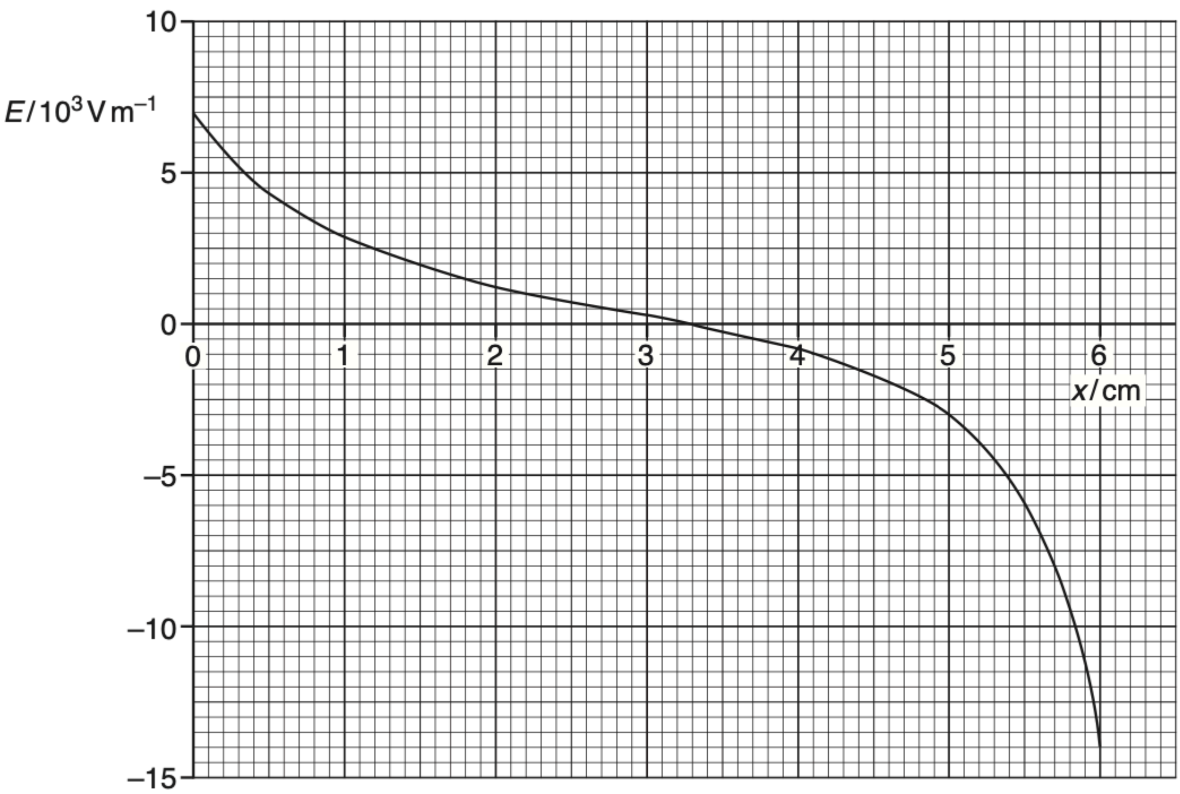


Fig. 6.1

The shortest distance between the surfaces of the spheres is 6.0 cm.

A movable point P lies along the line joining the centres of the two spheres, a distance *x* from the surface of sphere A.

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



(i) Use Fig. 6.2 to explain whether the two spheres have charges of the same, or opposite, sign.

....

....

....

.... [2]

(ii) A proton is at point P where $x = 5.0$ cm.
Use data from Fig. 6.2 to determine the acceleration of the proton.

acceleration = ... m s^{-2} [3]

(c) Use data from Fig. 6.2 to state the value of x at which the rate of change of electric potential is maximum. Give the reason for the value you have chosen.

....

....

.... [2]

[Total: 9]

March2018/42/Q7

22 **(a)** State what is meant by *electric potential* at a point.

....

....

.... [2]

(b) The centres of two charged metal spheres A and B are separated by a distance of 44.0 cm, as shown in Fig. 7.1.

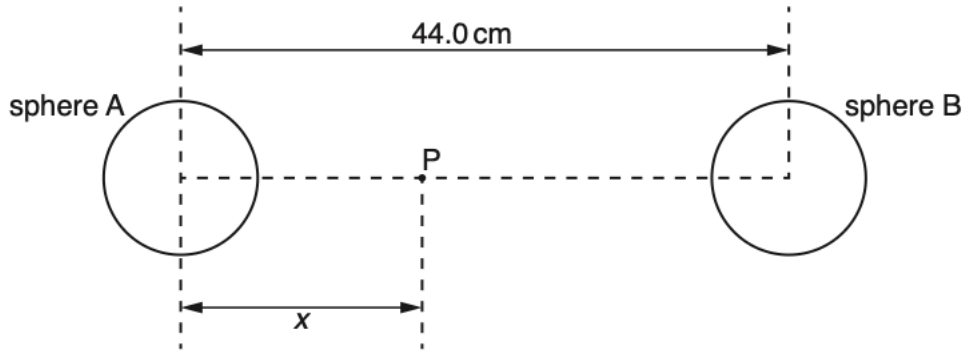


Fig. 7.1 (not to scale)

A moveable point P lies on the line joining the centres of the two spheres. Point P is a distance x from the centre of sphere A. The variation with distance x of the electric potential V at point P is shown in Fig. 7.2.

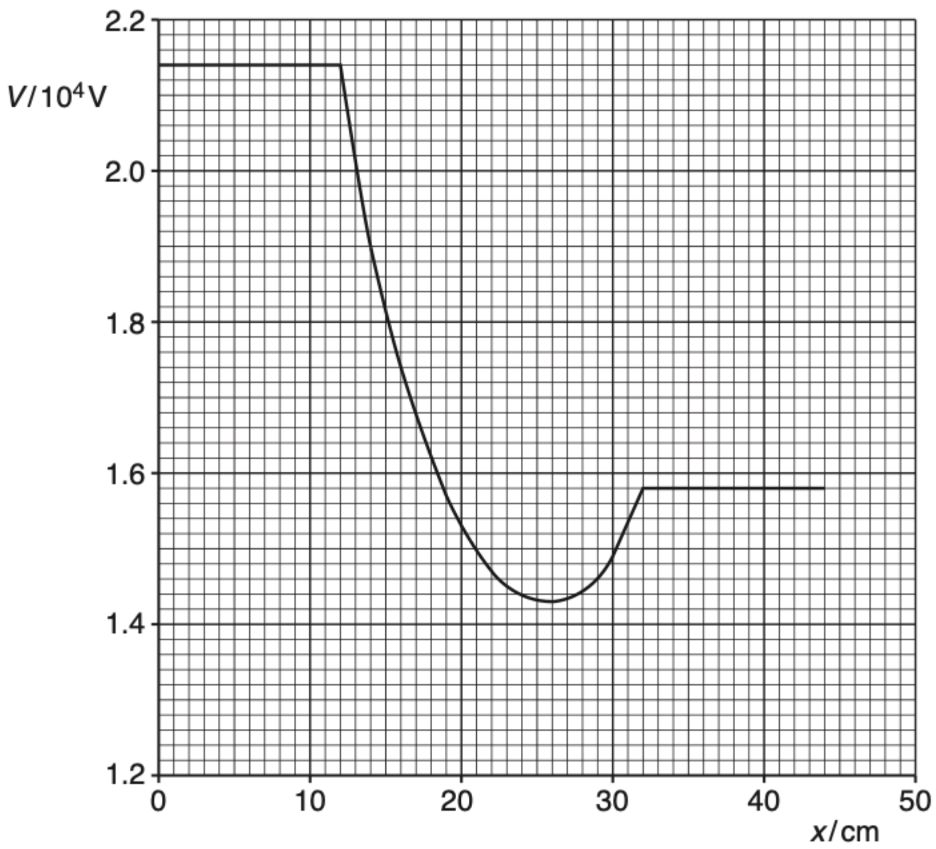


Fig. 7.2

(i) Use Fig. 7.2 to state and explain whether the two spheres have charges of the same, or opposite, sign.

....

....

....[1]

(ii) A positively-charged particle is at rest on the surface of sphere A.

The particle moves freely from the surface of sphere A to the surface of sphere B.

1. Describe qualitatively the variation, if any, with distance x of the speed of the particle as it

moves from x = 12 cm to x = 25 cm ....

....

passes through x = 26 cm ....

....

moves from $x = 27$ cm to $x = 31$ cm ....

....

reaches $x = 32$ cm ....

....[4]

2. The particle has charge 3.2×10^{-19} C and mass 6.6×10^{-27} kg.

Calculate the maximum speed of the particle.

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

[Total: 9]

ON16/41/Q5

23 Two small solid metal spheres A and B have equal radii and are in a vacuum. Their centres are 15 cm apart.
Sphere A has charge +3.0 pC and sphere B has charge +12 pC. The arrangement is illustrated in Fig. 5.1.

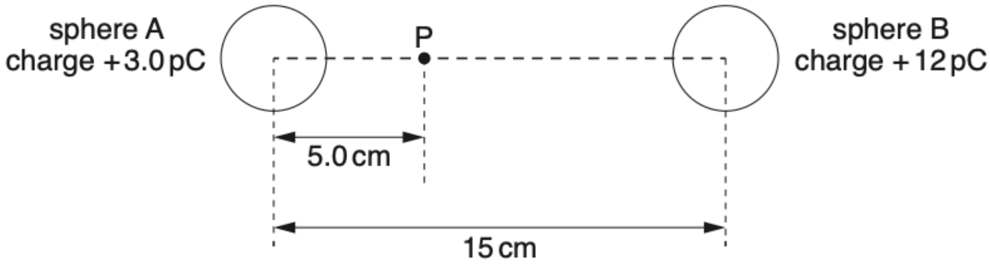


Fig. 5.1

Point P lies on the line joining the centres of the spheres and is a distance of 5.0 cm from the centre of sphere A.

(a) Suggest why the electric field strength in both spheres is zero.

....

....

.... [2]

(b) Show that the electric field strength is zero at point P. Explain your working.

[3]

(c) Calculate the electric potential at point P.

electric potential = ... V [2]

(d) A silver-107 nucleus ($^{107}_{47}Ag$) has speed *v* when it is a long distance from point P.

Use your answer in **(c)** to calculate the minimum value of speed *v* such that the nucleus can reach point P.

speed = ... $m\,s^{-1}$ [3]

[Total: 10]

24 Two solid metal spheres A and B, each of radius 1.5 cm, are situated in a vacuum. Their centres are separated by a distance of 20.0 cm, as shown in Fig. 6.1.

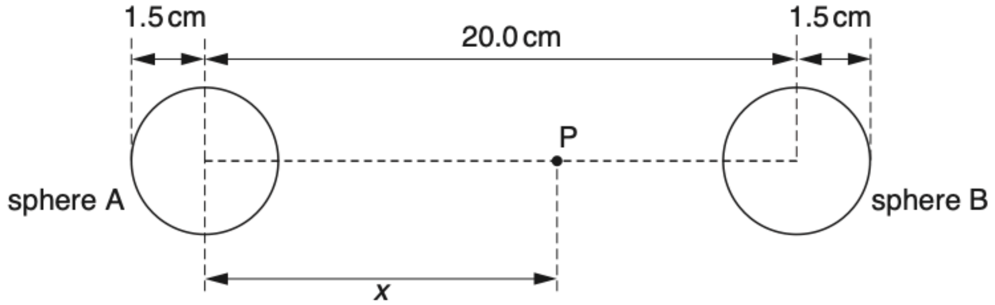


Fig. 6.1 (not to scale)

Both spheres are positively charged.

Point P lies on the line joining the centres of the two spheres, at a 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. 6.2.

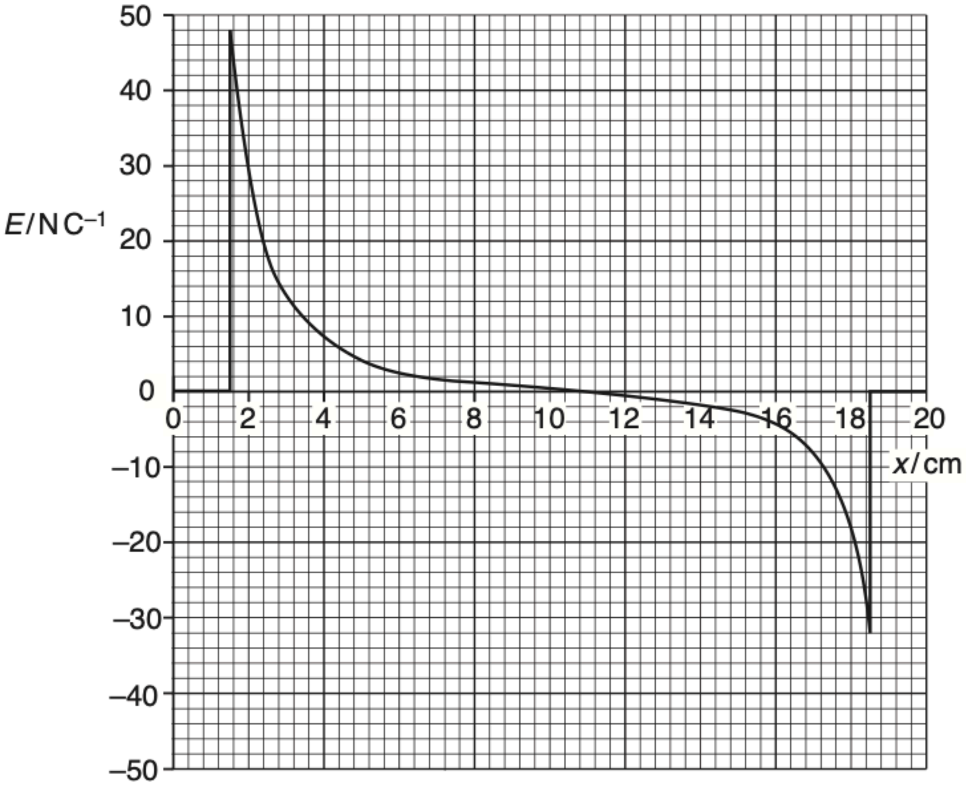


Fig. 6.2

(a) Use Fig. 6.2 to determine the ratio

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

Explain your working.

ratio = ... [3]

(b) The variation with distance *x* of the electric potential *V* at point P is shown in Fig. 6.3.

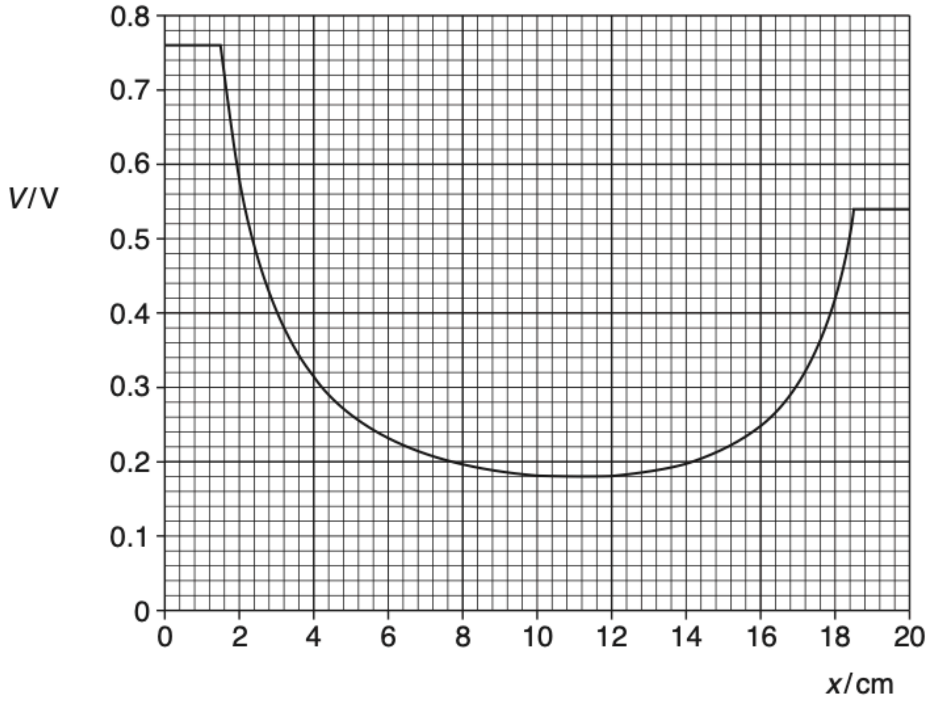


Fig. 6.3

An α-particle is initially at rest on the surface of sphere A.
The α-particle moves along the line joining the centres of the two spheres.

Determine, for the α-particle as it moves between the two spheres,

(i) its maximum speed,

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

(ii) its speed on reaching the surface of sphere B.

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

[Total: 8]

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

2	(a)	work done per unit charge	B1
		work (done) moving positive charge from infinity (to the point)	B1
2	(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
2	(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

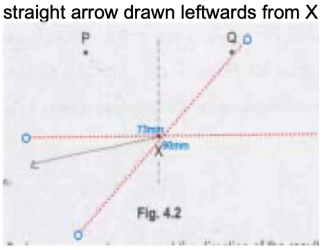
3	(a)	work done per unit charge	B1
		work (done on charge) moving positive charge from infinity (to the point)	B1
3	(b)	*Any three points from*: *Up to 2 points from*: • radius of sphere X is 2.0 m • radius of sphere Y is 4.0 m • radius of Y is double the radius of X *Up to 2 points from*: • charge on 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
3	(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

4	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
4	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
4	(c)(i)	negative	B1
4	(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
4	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

5	4(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
5	(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
5	(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)
5	(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
5	(c)(i)	towards the top of the page / towards plate P	B1
5	(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
5	(c)(iii)	**either** the force is not (always) perpendicular to the velocity **or** the force is always in the same direction	B1

6 (a)	(field line indicates) direction of force	**B1**
	force on a positive charge	**B1**
6 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**
6 b)(ii)	$E = V / d$	**C1**
	$= 2400 / 0.046$ $= 5.2 \times 10^{4}$ N C^{-1}	**A1**
6 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**
6 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**

7 (a)	work done per unit charge	**B1**
	work done (on charge) in moving positive charge from infinity (to the point)	**B1**
7 b)(i)	radius = 0.060 m	**A1**
7 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**
7 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**
7 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**

8 (a)	direction of force	**B1**
	force on a positive charge	**B1**
8 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**
8 b)(ii)	fields are in the same direction so no	**B1**
8 b)(iii)	straight arrow drawn leftwards from X in direction between extended line joining Q and X and the horizontal 	**B1**

9	(a)	(both have) radial field lines	B1
9	(b)(i)	**2.1** cm	B1
9	(b)(ii)	$E = \frac{Q}{4\pi\varepsilon_o r^2}$ 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

10	(a)(i)	region (of space)	B1
		where a particle experiences a force	B1
10	(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
10	(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
10	(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
10	(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

11	(a)(i)	force per unit mass	B1
11	(a)(ii)	force per unit positive charge	B1
11	(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
11	(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
11	(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
11	(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
11	(c)(ii)	same (direction)	B1

12	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
12	5(b)	field strength = $Q / 4\pi\varepsilon_0 x^2$	C1
		$E = Q / 36\pi\varepsilon_0 R^2$	A1
12	(c)(i)	fields (due to each sphere) are in same direction	B1
12	(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

13	(a)	$(E =)\ Q / 4\pi\varepsilon_0 r^2$	M1
		where ε_0 is permittivity (of free space)	A1
13	b)(i)	field does not change direction/field does not become zero	M1
		so (charges have) opposite (sign)	A1
13	b)(ii)	minimum is at the midpoint (between the charges)	M1
		so (magnitudes are the) same	A1
13	(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

14	(a)(i)	work done per unit charge	B1
		work done moving positive charge from infinity (to the point)	B1
14	a)(ii)	field strength = potential gradient	M1
		negative sign included **or** directions discussed	A1
14	5(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 positive all the way from 0 to D	B1

15	(a)	force per unit charge	B1
		(force on) positive charge	B1
15	b)(i)	field changes direction (between A and B)/field is zero at a point (between A and B)	M1
		so charges have same sign	A1
15	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
15	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

16	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**
16	(b)(i)	tangent drawn at x = 6.0 cm and gradient calculation attempted	**C1**
		$E = 9.0 \times 10^4\,\mathrm{N\,C^{-1}}$ *(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 $q = 3.6 \times 10^{-8}\,\mathrm{C}$	**(C1)**
		(then $E = q/4\pi\varepsilon_0 x^2$ and x = 6 cm gives) $E = 9.0 \times 10^4\,\mathrm{N\,C^{-1}}$	**(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)**
		$= 9.0 \times 10^4\,\mathrm{N\,C^{-1}}$	**(A1)**
16	(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**

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

18	3(a)	force <u>per</u> unit positive charge	**B1**
18	(b)(i)	$E_K = ½mv^2$	**C1**
		$2.4 \times 10^{-16} = ½ \times 1.7 \times 10^{-27} \times v^2$ $v = 5.3 \times 10^5\,\mathrm{m\,s^{-1}}$	**A1**
18	(b)(ii)	work done $= 2.4 \times 10^{-16}\,\mathrm{J}$	**A1**
18	b)(iii)	$W = Fs$	**C1**
		$F = 2.4 \times 10^{-16} / 15 \times 10^{-3}$ $= 1.6 \times 10^{-14}\,\mathrm{N}$	**A1**
18	b)(iv)	$V = Fd/Q$ **or** $V = W/Q$ **or** $E = V/d$ **and** $E = F/Q$	**C1**
		$V = (1.6 \times 10^{-14} \times 15 \times 10^{-3}) / 1.6 \times 10^{-19}$ **or** $2.4 \times 10^{-16} / 1.6 \times 10^{-19}$	**C1**
		= 1500 V	**A1**
18	(b)(v)	straight line with positive gradient starting at the origin and going as far as x = 15 mm	**B1**

19 3(a)	force per unit (positive) charge	B1
19 (b)(i)	$a = (v^2 - u^2) / 2s$ $= [(18 \times 10^6)^2 - (2.5 \times 10^3)^2] / (2 \times 12 \times 10^{-3})$	B1
	$= 1.3\ (1.35) \times 10^{16}\ \text{m s}^{-2}$	A1
19 (b)(ii)	KE = $\frac{1}{2} mv^2$ **or** $\frac{1}{2} m(v^2 - u^2)$	C1
	change in KE $= 0.5 \times 9.11 \times 10^{-31} \times [(18 \times 10^6)^2 - (2.5 \times 10^3)^2]$	B1
	$= 1.5\ (1.48) \times 10^{-16}\ \text{J}$	A1
19 b)(iii)	$E = F / e = ma / e$ **or** $eV = \Delta\text{KE}$ so $E = \Delta\text{KE} / (e \times d)$	C1
	$E = (9.11 \times 10^{-31} \times 1.35 \times 10^{16}) / 1.60 \times 10^{-19}$ **or** $E = (1.48 \times 10^{-16}) / (12 \times 10^{-3} \times 1.60 \times 10^{-19})$	C1
	$= 7.7\ (7.69) \times 10^4\ \text{V m}^{-1}$	A1
19 3(c)	charge on α opposite to electron/charge on α is positive	B1
	ΔKE is negative/KE reduced	B1
	charge of α greater/twice that of electron causes larger/twice ΔKE (in magnitude)	B1

20 (a)	(loss in) kinetic energy of α-particle = $Qq / 4\pi\varepsilon_0 r$ **or** $7.7 \times 10^{-13} = Qq / 4\pi\varepsilon_0 r$	C1
	$7.7 \times 10^{-13} = 8.99 \times 10^9 \times 79 \times 2 \times (1.60 \times 10^{-19})^2 / r$	M1
	$r = 4.7 \times 10^{-14}\ \text{m}$ r is closest distance of approach so radius less than this	A1
20 (b)	force = $Qq / 4\pi\varepsilon_0 r^2 = 4\text{u} \times a$	C1
	$8.99 \times 10^9 \times 79 \times 2 \times (1.60 \times 10^{-19})^2 / (4.7 \times 10^{-14})^2 = 4 \times 1.66 \times 10^{-27} \times a$	C1
	$a = 2.5 \times 10^{27}\ \text{m s}^{-2}$	A1
20 (c)	so that single interactions between nucleus and α-particle can be studied **or** so that multiple deflections with nucleus do not occur	B1

21 5(a)	force proportional to product of charges and inversely proportional to the square of the separation	M1
	reference to point charges	A1
21 (b)(i)	(near to each sphere,) fields are in opposite directions **or** point (between spheres) where fields are equal and opposite **or** point (between spheres) where field strength is zero	M1
	so same (sign of charge)	A1
21 (b)(ii)	(at x = 5.0 cm,) $E = 3.0 \times 10^3\ \text{V m}^{-1}$ **and** $a = qE / m$	C1
	$E = (1.60 \times 10^{-19} \times 3.0 \times 10^3) / (1.67 \times 10^{-27})$	C1
	$= 2.9 \times 10^{11}\ \text{m s}^{-2}$	A1
21 5(c)	field strength or E is potential gradient **or** field strength is rate of change of (electric) potential	M1
	(field strength) maximum at x = 6 cm	A1

22 7(a)	work done per unit charge		B1
	(work done) moving positive charge from infinity (to the point)		B1
22 (b)(i)	potential always same sign / potential is always positive so same sign of charge		B1
22 (b)(ii)	1	*from x = 12 cm to x = 25 cm:* speed increases and *from x = 27 cm to x = 31 cm*: speed decreases	B1
		(*from x = 12 cm to x = 25 cm:* speed increases) at decreasing rate or (*from x = 27 cm to x = 31 cm*: speed decreases) at increasing rate	B1
		at x = 26 cm: speed maximum	B1
		at 32 cm: speed still decreasing	B1
	2	$q\,\Delta V = ½mv^2$ $3.2 \times 10^{-19} \times (2.14 - 1.43) \times 10^4 = ½ \times 6.6 \times 10^{-27} \times v^2$ $v^2 = 6.88 \times 10^{11}$	C1
	v = **8.3 × 10^5** m s^{-1} (8.30)		A1

23 **(a)** in an electric field, charges (in a conductor) would move — B1

no movement of charge so zero field strength
or
charge moves until $F = 0$ / $E = 0$ — B1 [2]

or

charges in metal do not move — (B1)
no (resultant) force on charges so no (electric) field — (B1)

(b) at P, $E_A = (3.0 \times 10^{-12}) / [4\pi\varepsilon_0(5.0 \times 10^{-2})^2]$ (= 10.79 N C^{-1}) — M1

at P, $E_B = (12 \times 10^{-12}) / [4\pi\varepsilon_0(10 \times 10^{-2})^2]$ (= 10.79 N C^{-1}) — M1

or

$(3.0 \times 10^{-12}) / [4\pi\varepsilon_0(5.0 \times 10^{-2})^2] - (12 \times 10^{-12}) / [4\pi\varepsilon_0(10 \times 10^{-2})^2] = 0$
or
$(3.0 \times 10^{-12}) / [4\pi\varepsilon_0(5.0 \times 10^{-2})^2] = (12 \times 10^{-12}) / [4\pi\varepsilon_0(10 \times 10^{-2})^2]$ — (M2)

fields due to charged spheres are (equal and) <u>opposite in direction</u>, so $E = 0$ — A1 [3]

(c) potential $= 8.99 \times 10^9 \{(3.0 \times 10^{-12}) / (5.0 \times 10^{-2}) + (12 \times 10^{-12}) / (10 \times 10^{-2})\}$ — C1

= 1.62 V — A1 [2]

(d) $½mv^2 = qV$

$E_K = ½ \times 107 \times 1.66 \times 10^{-27} \times v^2$ — C1

$qV = 47 \times 1.60 \times 10^{-19} \times 1.62$ — C1

$v^2 = 1.37 \times 10^8$

$v = 1.2 \times 10^4$ m s^{-1} — A1 [3]

24 **(a)**	$E = 0$ *or* $E_A = (–)E_B$ (at $x = 11$ cm)	B1	
	$Q_A / x^2 = Q_B / (20 – x)^2 = 11^2 / 9^2$	C1	
	Q_A / Q_B or ratio = 1.5	A1	[3]
	or		
	$E \propto Q$ because r same *or* $E = Q / 4\pi\varepsilon_0 r^2$ and r same	(B1)	
	$Q_A / Q_B = 48 / 32$	(C1)	
	Q_A / Q_B or ratio = 1.5	(A1)	
(b) (i)	for max. speed, $\Delta V = (0.76 – 0.18)$ V or $\Delta V = 0.58$ V	C1	
	$q\Delta V = ½mv^2$		
	$2 \times (1.60 \times 10^{-19}) \times 0.58 = ½ \times 4 \times 1.66 \times 10^{-27} \times v^2$	C1	
	$v^2 = 5.59 \times 10^7$		
	$v = 7.5 \times 10^3$ m s^{-1}	A1	[3]
(ii)	$\Delta V = 0.22$ V	C1	
	$2 \times (1.60 \times 10^{-19}) \times 0.22 = ½ \times 4 \times 1.66 \times 10^{-27} \times v^2$		
	$v^2 = 2.12 \times 10^7$		
	$v = 4.6 \times 10^3$ m s^{-1}	A1	[2]