1

(a) **(i)** line gives direction of force on a (small test) mass

(ii) line gives direction of force on a (small test) positive charge

(b) similarity: lines are radial / greater separation of lines with increased distance from the sphere/ lines normal to the surface

difference: gravitational lines directed towards sphere and electric lines directed away from sphere

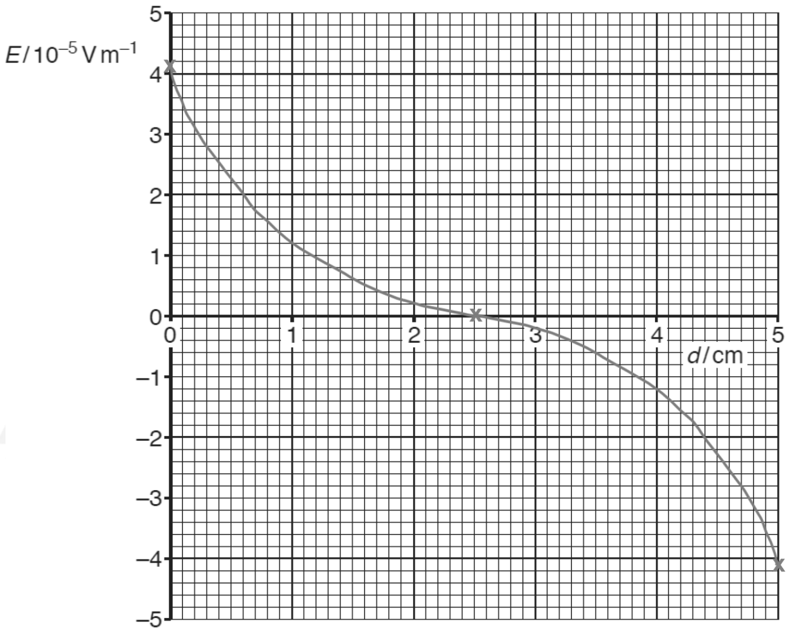
(c) **(i)**

$$E = \frac{Q}{4\pi\epsilon_0 r^2}$$

$$4.1 \times 10^{-5} = \frac{Q}{4\pi(8.85 \times 10^{-12})(0.025^2)} - \frac{Q}{4\pi(8.85 \times 10^{-12})(0.075^2)}$$

$$Q = 3.2 \times 10^{-18}\ C$$

(ii)



(iii) acceleration decreases (to zero at mid-point)
then acceleration increases in the opposite direction / increasing negative acceleration

2

(a)

$$Q = CV$$

$$E = \frac{1}{2}CV^2$$

(b) **(i)**

$$C_N = \frac{CL}{L - D}$$

(ii) (charge is unchanged by moving the plates so) $Q_N = CV$

(iii)

$$V_N = \frac{Q_N}{C_N} = \frac{CV}{\frac{CL}{L-D}} = \frac{V(L-D)}{L}$$

(c) oppositely charged plates attract, so energy stored decreases

3

(a) **(i)** $Q_A = CV$

(ii) $E_A = \frac{1}{2}CV^2$

(b) **(i)** some of the charge transfers to (the plates of) capacitor B because the p.d.s across the capacitors are not equal

(ii) $V_A = V_B$
$Q_A + Q_B = CV$
$CV_B + 3CV_B = CV \ (parallel\ same\ p.d.)$
$V_B = \frac{V}{4}$

(iii) Total final energy $= \frac{1}{2}(4C)\left(\frac{V}{4}\right)^2$
$= \frac{1}{8}CV^2$

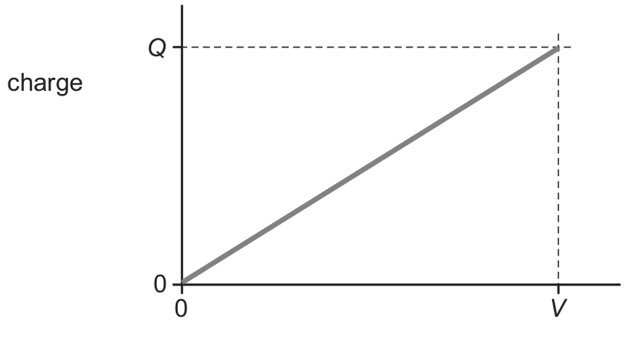
$\Delta E = \frac{1}{8}CV^2 - \frac{1}{2}CV^2$
$= -\frac{3}{8}CV^2$

Decrease in energy $\Delta E = \frac{3}{8}CV^2$

4

(a) Capacitance of a parallel-plate capacitor is the ratio of charges stored in a plate to the potential difference across the capacitor plates.

(b) **(i)**



(ii) Work done is the area under Q-V graph.

Hence, $W = \frac{1}{2}QV$

(c) **(i)**

	X	Y
final p.d.	$V/4$	$V/4$
final charge	$Q/4$	$3Q/4$

(ii) Total energy stored will be less than initially stored in capacitor X.

5

(a) Series charges: $Q_S = Q_1 = Q_2$
Series p.d: $V_s = V_1 + V_2$

Parallel charges: $Q_S = Q_1 + Q_2$
Parallel p.d: $V_s = V_1 + V_2$

(b) **(i)**

$$E = \frac{1}{2}CV^2$$
$$V = \sqrt{\frac{2E}{C}} = \sqrt{\frac{2 \times 19 \times 10^{-3}}{470 \times 10^{-6}}} = 9.0\ V$$

(ii)

$$C = \frac{Q}{V}$$
$$Q = 470 \times 10^{-6} \times 9.0$$
$$= 4.2 \times 10^{-3}\ C$$

(iii) Total charges unchanged
Total capacitance $= (470 + 180) \times 10^{-6}\ F$
$$E = \frac{1}{2}\frac{Q^2}{C} = \frac{(4.23 \times 10^{-3})^2}{2(650 \times 10^{-6})} = 14\ mJ$$

6

(a)

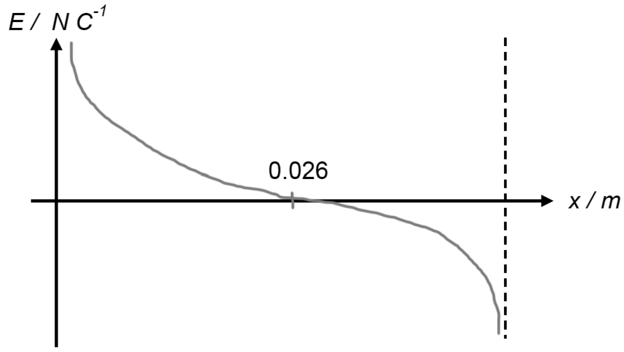
$$F = \frac{Qq}{4\pi\epsilon_0 r^2}$$
$$= \frac{(3.20 \times 10^{-7})^2}{4\pi(8.85 \times 10^{-12})(2 \times 0.50 \sin 30°)^2}$$
$$= 0.33616$$
$$0.34\ N$$

(b) By considering the forces on one sphere,

$$\tan\theta = \frac{F_E}{W}$$
$$m(9.81) = \frac{0.33616}{\tan 3.0°}$$
$$m = 0.65385$$
$$= 0.65\ kg$$

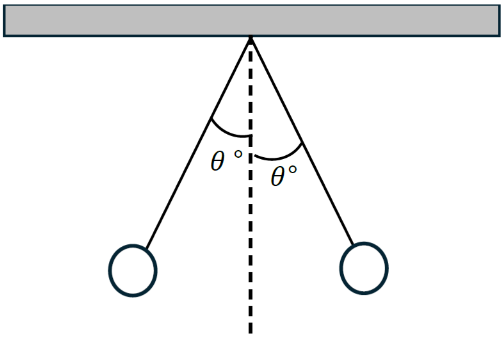
(c) **(i)** The electric potential at a point is the work done per unit positive charge in bringing a small test charge from infinity to that point.

(ii)



(iii) Since the electric field strength E is related to the potential as $E = -\frac{dV}{dx}$ and the graph is E against x. The potential difference between two points can be found by determining the area under the graph between the two points.

(d)

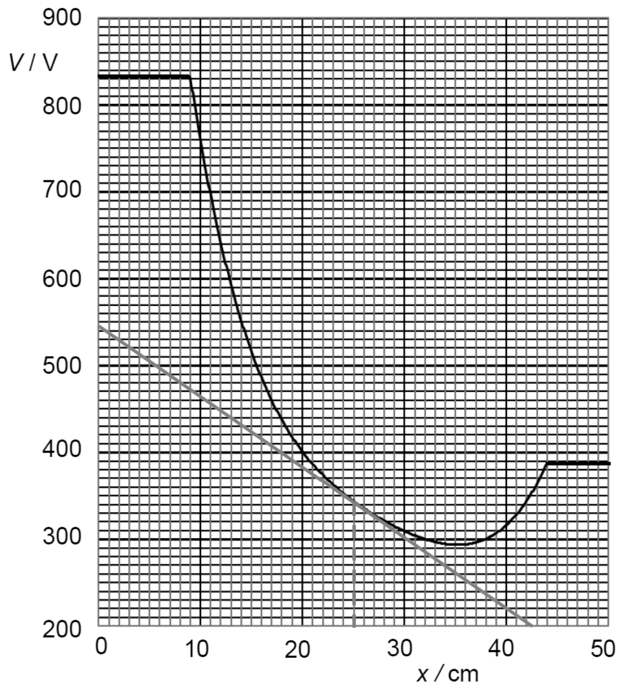


Each spheres will be deflected by the same, but smaller than before angle θ from the vertical.

7

(a) **(i)** Direction of the electric field at $x = 25.0\ cm$ is towards the right.
Electric field is always directed towards lower potential.

(ii)



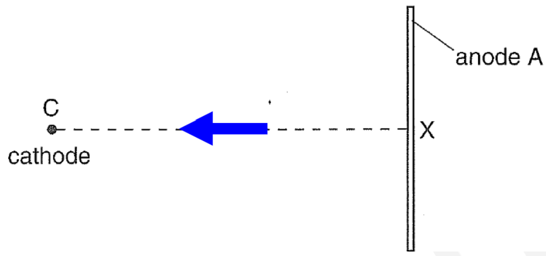
(iii) Mobile charge carriers within a conductor will always re-distribute until a certain equilibrium state where the electric field within it is zero. Zero electric field means that there is zero potential gradient, and hence constant potential.

(b) The ion will accelerate to the right until $x = 35.0\ cm$, then the ion will decelerate and momentarily come to rest at $x = 42.0\ cm$and accelerate back to the left and momentarily stops at $x = 25.0\ cm$ before accelerating to the right again, repeating the motion.

8

(a) The electric field strength at a point is defined as the electric force exerted per unit positive charge acting on a test charge placed at that point.

(b) **(i)**



(ii) At $d = 2cm$, $E = 2.4\ kV\ m^{-1}$
$F = qE$
$= (1.60 \times 10^{-19})(2.4 \times 10^{3})$
$= 3.84 \times 10^{-16}\ N$

(c) **(i)** Work done on charge $= Fd$
$q\Delta V = Fd$
$\Delta V = \dfrac{Fd}{q}$
$= \dfrac{(3.84 \times 10^{-16})(4.0 \times 10^{-2})}{1.60 \times 10^{-19}}$
$= 96\ V$

(ii) Under-estimate because (by observation) the area under graph is greater than $96\ V$.

9

(a) A field of force (or force field) is a region of space in which a particle experiences a force due to a physical property that it possesses.

(b) **(i)** $F = qE$
$= \dfrac{q\Delta V}{d}$
$= (1.60 \times 10^{-19})\left(\dfrac{2400}{0.06}\right)$
$= 6.40 \times 10^{-15}$
$a = \dfrac{F}{m}$
$= \dfrac{6.40 \times 10^{-15}}{9.11 \times 10^{-31}}$
$= 7.025 \times 10^{15}\ m\ s^{-2}$ (upwards)

(ii) $t = \dfrac{s_X}{u_X}$

$$= \frac{0.16}{3.7 \times 10^7 \cos 20°}$$
$$= 4.60 \times 10^{-9}\ s$$

(iii) Considering whether electron collides with top plate:

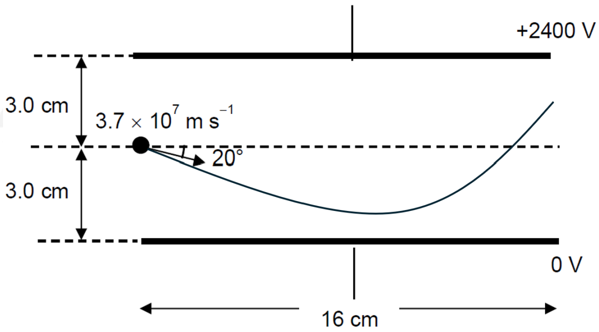
$$s_y = u_y t + \frac{1}{2} a_y t^2$$
$$= (3.7 \times 10^7 \sin 20°)(4.6018 \times 10^{-9}) + \frac{1}{2}(-7.0252 \times 10^{15})(4.6018 \times 10^{-9})^2$$
$= -0.0162\ m$ (which is lesser than $-0.030\ m$)

Considering whether electron collides with bottom plate:
When $v_y = 0$

$$0 = u_y + a_y t$$
$$t = \frac{-(3.7 \times 10^7 \sin 20°)}{-7.0252 \times 10^{15}}$$
$$= 1.8013 \times 10^{-9}$$
$$s_y = u_y t + \frac{1}{2} a_y t^2$$
$$= (3.7 \times 10^7 \sin 20°)(1.8013 \times 10^{-9}) + \frac{1}{2}(-7.0252 \times 10^{15})(1.8013 \times 10^{-9})^2$$
$= 0.0114\ m$ (which is less than $0.030\ m$)

Therefore, the electron will not collide with neither the top nor bottom plate.

(iv)



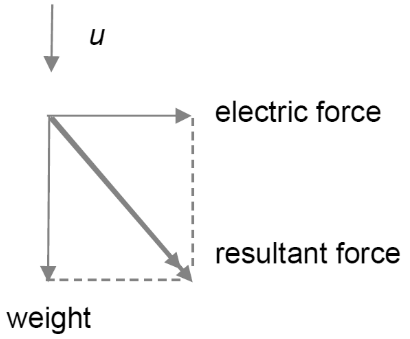
(v) For an electron in a uniform electric field, it is a parabolic path.

10

(a)
$$F_E = \frac{q\Delta V}{d}$$
$$= 0.78 \times 10^{-6}\left(\frac{2000}{5.0}\right)$$
$$= 3.12 \times 10^{-4}\ N$$

Direction is rightwards towards Q

(b) **(i)**



(ii) The weight of particle X has the same order of magnitude as the electric force.

(c) Horizontally,

$s_X = 5.0, u_X = 0, a_X = \dfrac{3.12 \times 10^{-4}}{4.9 \times 10^{-4}/9.81} = 6.25\ m\ s^{-2}$

$v_x^2 = u_x^2 + 2a_x s_x$

$v_x = 7.91\ m\ s^{-1}$

$s_X = \dfrac{1}{2}a_x t^2$

$t = 1.26\ s$

Vertically,

$v_y = u_y + a_y t$

$v_y = 23 + (9.81)(1.26)$

$= 35.4\ m\ s^{-1}$

Resultant velocity $v = \sqrt{7.91^2 + 35.4^2}$

$= 36.3\ m\ s^{-1}$

(d) Since electric force and weight are of constant magnitudes and directions, the resultant force would also be of constant magnitude and direction. As the velocity has a component along the resultant force and a component perpendicular to it, the path taken by the particle would be parabolic.

(e) $\Delta V = 2000\ V$

$\Delta U = q\Delta V$

$= (-0.78 \times 10^{-6})\big(1000 - (-1000)\big)$

$= -1.56 \times 10^{-3}\ J$