

1. (a) (i) weight [or force of gravity] pulls droplet down (1)
no electric force to counteract weight (1)
viscous force increases with speed (1)
weight = viscous force at terminal speed (1)
- (ii) viscous force = $6\pi\eta r v$ (1)
weight = $\frac{4}{3}\pi r^3 \rho g$ (1)
 $\frac{4}{3}\pi r^3 \rho g = 6\pi\eta r v$ to give desired equation showing working (1) max 6
- (b) (i) $r^2 \left(= \frac{9\eta v}{2\rho g} \right) = \frac{9 \times 1.8 \times 10^{-5} \times 1.20 \times 10^{-3}}{2 \times 9.8 \times 950 \times 15.5}$ (1) ($= 6.7 \times 10^{-13} \text{ m}^2$)
 $r = 8.2 \times 10^{-7} \text{ (m)}$ (1)
 $m \left(= \frac{4}{3}\pi r^3 \rho \right) = \frac{4}{3}\pi \times (8.2 \times 10^{-7})^3 \times 950$ (1) ($= 2.2 \times 10^{-15} \text{ kg}$)
- (ii) $\frac{QV}{d} = mg$ [or $Q = \frac{mgd}{V}$] (1)
 $Q \left(= \frac{mgd}{V} \right) = \frac{2.2 \times 10^{-15} \times 9.8 \times 5.0 \times 10^{-3}}{225}$ (1)
 $Q = 4.8 \times 10^{-19} \text{ (1)}$ 6
- (c) charge on oil droplet always a multiple of a basic amount (1)
basic amount = $1.6 \times 10^{-19} \text{ C}$ (1)
which is the charge of the electron (1) max 2

[14]

2. (a) k.e. gained = electric p.e. lost [or work done by field] (1)
 $\left(\frac{1}{2} m v^2 = QV \right) \therefore v = \sqrt{\frac{2QV}{m}}$ (1)
 $\therefore v = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 1200}{9.11 \times 10^{-31}}}$ (1) ($= 2.05 \times 10^7 \text{ m s}^{-1}$) 3
- (b) $F (= BQv) = 0.080 \times 1.6 \times 10^{-19} \times 2.05 \times 10^7$ (1)
 $= 2.62 \times 10^{-13} \text{ N}$ [or $2.56 \times 10^{-13} \text{ N}$ if $v = 2.0 \times 10^7 \text{ m s}^{-1}$ is used] (1) 2

- (c) circular on first diagram (plan view) (1)
 curving correctly (i.e. upwards to right) (1)
 horizontally straight on second diagram (side view) (1) 3
- (d) (i) speed unchanged (1)
 because force remains perpendicular to velocity
 [or no work is done] (1)
- (ii) direction of force changes so force alters (1) max 2

[10]

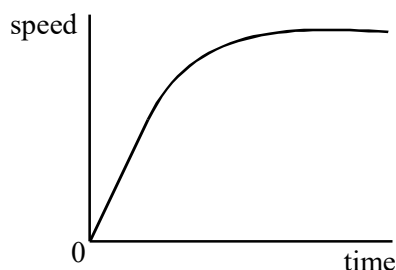
3. (a) (i) current heats the wire (1)
 electrons (in filament) gain (sufficient) k.e. (to leave the filament) (1)
- (ii) electrons would collide with gas atoms/molecules (1) 3
- (b) (i) k.e. = (eV = $1.6 \times 10^{-19} \times 3600$) = 5.8×10^{-16} (J) (1)

(ii) $\frac{1}{2}mv^2 = eV$ (1)

$$v = \left(\sqrt{\frac{2eV}{m}} \right) = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 3600}{9.1 \times 10^{-31}}} \text{ (1)} = 3.6 \times 10^7 \text{ ms}^{-1} \text{ (1)} \quad 4$$

[7]

4. (a)



- (i) correct shape - speed becomes constant (1)
 initial gradient not infinite [or negligible] (1)
- (ii) viscous force initially zero (1)
 resultant [or only] force (or ma) = mg (hence $a = g$) (1)
- (iii) viscous force increases with speed (1)

(speed increases) until viscous force equals weight
[or zero acceleration/constant speed reached when
viscous force equals weight] (1)

6

(b) (i) $v_0 = \left(\frac{1.00 \times 10^{-3}}{12.8} \right) = 7.8 \times 10^{-5} \text{ m s}^{-1}$ (1)

(ii) $k \left(= \frac{g}{v_0} \right) = \frac{9.8}{7.8 \times 10^{-5}} (= 1.2(5) \times 10^5 \text{ (s}^{-1}\text{)})$ (1)

use $a = ge^{-kt}$ to calculate acceleration a correctly after suitable time
between $1\mu\text{s}$ and 0.2s (1)

state [or show] that acceleration is negligible during timing (1)

e.g. “ $t = 1 \text{ ms}$ gives $a = ge^{-125}$, which is negligible” would
score two marks

alternative (ii):

use $a = ge^{-kt}$ to calculate time, t , to fall to a suitable acceleration
between 0 and 0.2 ms^{-2} (1)

state or show that $t \ll 12.8\text{s}$ (1)

4

[10]

5. (a) (i) positive (1)

(ii) $QE \left(= \frac{QV}{d} \right) = mg$ (1)

$$Q \left(= \frac{mgd}{V} \right) = \frac{4.6 \times 10^{-16} \times 9.8 \times 40 \times 10^{-3}}{565} \text{ (1)} = 3.2 \times 10^{-19} \text{ C (1)}$$

(iii) two electrons (1)
missing (1)

max 5

(b) upwards (1)

the electrical force is increased (1)

so there is a net upward force (1)

as the weight and upthrust are the same (1)

max 2

[7]

6. (a) (i) arrow pointing towards centre of curvature (1)
 (ii) velocity [or direction of motion] is perpendicular to the direction of the force (1)
 work done is force \times distance moved in the direction of the force (1)
 no work done as there is no motion in the direction of the force (1) max 3

- (b) (i) 25mm (1)

$$\frac{1}{2}mv^2 = eV \text{ (1)}$$

$$\frac{mv^2}{r} = Bev \text{ (1)}$$

$$\frac{e}{m} = \frac{2V}{B^2 r^2} \text{ (1)} = \frac{2 \times 3200}{(7.6 \times 10^{-3})^2 \times 0.025^2} \text{ (1)} 1.8 \times 10^{11} \text{ C kg}^{-1} \text{ (1)} \quad 6$$

[9]

7. (a) (i) $V \left(= \frac{W}{Q} \right) = \frac{6.0 \times 10^{-16}}{1.60 \times 10^{-19}} \text{ (1)} = 3750 \text{ V (1)}$
 (ii) heats the filament [or cathode or wire] (1)
 to enable electrons to gain (sufficient) k.e. to leave filament [or cause thermionic emission] (1) 4

- (b) (i) electron moves towards positive plate
 curve in field (1)
 and straight beyond (1)

$$\text{(ii)} \quad t \left(= \frac{l}{v} = \frac{0.060}{3.6 \times 10^7} \right) = 1.67 \text{ ns (1)}$$

$$\text{(iii)} \quad y = -\frac{1}{2}at^2 \text{ (1)}$$

$$a = \frac{eV_p}{md} \text{ (1)}$$

$$\text{combine to give } \frac{e}{m} = \frac{2yd}{V_p t^2} \text{ (1)} = \frac{2 \times 12.5 \times 10^{-3} \times 25 \times 10^{-3}}{1250 \times (1.67 \times 10^{-9})^2} \text{ (1)}$$

$$= 1.8 \times 10^{11} \text{ C kg}^{-1} \text{ (1)} \quad \text{max 8}$$

[12]

8. (a) (use of $v = \frac{s}{t}$ gives) $v = \frac{2.0 \times 10^{-3}}{18.3} = 1.11 \times 10^{-4} \text{ m s}^{-1} \text{ (1)} \quad 1$

$$(b) \quad \frac{4}{3} \pi r^3 \rho g = 6 \pi v r \quad (1)$$

$$r = \left(\frac{9 \eta v}{2 \rho g} \right)^{\frac{1}{2}} \quad (1)$$

$$= \left(\frac{9 \times 1.8 \times 10^{-5} \times 1.11 \times 10^{-4}}{2 \times 970 \times 9.81} \right)^{\frac{1}{2}} \quad (1) (= 9.7 \times 10^{-7} \text{ m})$$

(allow C.E for v from (a))

3

$$(c) \quad qE = mg \quad (1)$$

$$m = \frac{4}{3} \pi r^3 \rho = \frac{4}{3} \pi (9.7 \times 10^{-7})^3 \times 970 = 3.7 \times 10^{-15} \text{ kg} \quad (1)$$

$$q (= \frac{mg}{E}) = \frac{3.7 \times 10^{-15} \times 9.81}{57 \times 10^3} = 6.37 \times 10^{-19} \text{ C} \quad (1)$$

(allow C.E. for value of mass m)

3

[7]

9. (a) (i) filament heated by an electric current
 [or metal heated by nearby hot wire filament] (1)
 (conduction) electrons in the metal gain sufficient
 kinetic energy to leave the metal/cathode/filament (1)
- (ii) temperature of filament depends on the current
 or low current so small heating effect] (1)
 kinetic energy of electrons depends on temperature of filament (1)
 electrons must do work (or overcome work function) to leave
 metal (1)
 electrons have insufficient (kinetic) energy to leave
 metal/cathode/filament (or overcome work function)
 if the current is too low (1)
- (b) (i) $E_k (= eV = 1.6 \times 10^{-19} \times 4200) = 6.7 \times 10^{-16} \text{ (J)} \quad (1)$

4

- (ii) (use of $E_k = \frac{1}{2}mv^2$ gives) $\frac{1}{2}mv^2 = 6.7 \times 10^{-16}$ (J) (1)
(allow C.E. for value of E_k)

$$v = \left(\frac{2 \times 6.7 \times 10^{-16}}{9.1 \times 10^{-31}} \right)^{1/2} \quad (1)$$

$$= 3.8 \times 10^7 \text{ m s}^{-1} \quad (1)$$

4

[8]

10. (a) path curves upwards from O to P
path is tangential to curve at P and straight beyond P

2

- (b) (i) magnetic field exerts a force on a moving charge/electron (1)
magnetic force has a downwards component (at all points)
[or magnetic force < electric force] (1)

- (ii) magnetic force = Bev (1)

$$\text{electric force} \left(= \frac{eV_p}{d} \right) = eE \quad (1)$$

$$Bev = eE \quad \left(\text{gives } v = \frac{E}{B} \right) \quad (1)$$

5

- (c) work done (or eV) = gain of kinetic energy (or $\frac{1}{2}mv^2$) (1)

$$\frac{e}{m} = \frac{v^2}{2V} \quad (1)$$

$$= \frac{(3.2 \times 10^7)^2}{2 \times 2900} = 1.8 \times 10^{11} \text{ C kg}^{-1} \quad (1)$$

3

[10]

11. (a) (i) (vertically) upwards (1)

- (ii) $mg = qE$, $\therefore \frac{q}{m} = \frac{g}{E}$ (1)

$$\frac{9.8}{4.9 \times 10^5} \quad (1) \quad (= 2.0 \times 10^{-5} \text{ C kg}^{-1})$$

3

- (b) initial downwards acceleration due to weight (or gravity) (1)
viscous force/drag/friction (or resistance) due to air
increases with increase in speed (1)
increases until drag become equal to (and opposite to) weight
(no resultant force) hence no acceleration (1)

max 3

[6]

12. (a) magnetic force perpendicular to (direction of) motion (or velocity) (1)
force does not change speed (or force does no work) (1)
force causes direction of motion to change (1)
force (or acceleration) is centripetal/ acts towards centre of curvature (1)
velocity is tangential (1)

max 3
QWC 2

- (b) (i) magnetic force = Bev (1)
centripetal acceleration = $\frac{v^2}{r}$, $\therefore Bev = \frac{mv^2}{r}$ (1) (gives $v = \frac{Ber}{m}$)

(ii) $\frac{mv^2}{r} = Bev$ gives $\frac{e}{m} = \frac{v}{Br}$ (1)

$$= \frac{3.2 \times 10^7}{7.3 \times 10^{-3} \times 25 \times 10^{-3}} \quad (1)$$

$$= 1.75 \times 10^{11} \text{ C kg}^{-1} \quad (1)$$

5

[8]

13. (a) (i) metal wire emits electrons when heated (1)
conduction electrons in metal gain kinetic energy when
wire is heated (1)
(ii) electrons from wire would be absorbed/scattered/stopped by
gas atoms
or collide with gas atoms and lose kinetic energy or speed (1)
(iii) electrons carry negative charge so anode needs to
be positive (to attract them) (1)

4

(b) (i) E_k (or $\frac{1}{2}mv^2$) (= work done or eV) = $1.6 \times 10^{-19} \times 2500$ (1)
 = 4.0×10^{-16} J (1)

(ii) $v = \left(\frac{2E_k}{m} \right)^{1/2} = \left(\frac{2 \times 4.0 \times 10^{-16}}{9.11 \times 10^{-31}} \right)^{1/2}$ (1)

= 3.0×10^7 m s⁻¹ (1)

(allow C.E. for value of E_k from (i))

4

[8]

14. (i) electrons [or ions] present (1)
 electrons/ions accelerated by electric field
 [or electrons and ions collide] (1)
 excitation/ionisation of gas atoms/ions/molecules/particles occur (1)
 photons emitted on return to lower energy or ground state (1)
- (ii) electrons/ions do not gain enough kinetic energy (to produce ionisation) (1)
 because too many atoms/ions/molecules/particles present (1)

max 4
 QWC 1

[4]

15. (a) (i) positive (1)
 (ii) electric force directed **upwards** = weight (1)
 [or $\frac{QV}{d} = mg$]

2

(b) (i) $v = \frac{1.20 \times 10^{-3}}{13.8} = 8.7 \times 10^{-5}$ m s⁻¹ (1)

- (ii) weight [or mg] = $\frac{4}{3} \pi r^3 \rho g$ (1)
 (since speed constant) viscous force = $6 \pi \eta r v$ (1)
 $\therefore \frac{4}{3} \pi r^3 \rho g = 6 \pi \eta r v$ to give desired equation (1)

(iii) rearrange equation to give $r = \left(\frac{9 \eta v}{2 \rho g} \right)^{1/2}$ (1)

$\left\{ = \left(\frac{9 \times 1.8 \times 8.7 \times 10^{-5}}{2 \times 960 \times 9.8} \right)^{1/2} \right\} = 8.7 \times 10^{-7}$ m (1) (8.65×10^{-7} m)

(allow C.E. for value of v from (i), but not 3rd mark)

$m (= \frac{4}{3} \pi r^3 \rho) = \frac{4}{3} \pi (8.65 \times 10^{-7})^3 \times 960$ (1) ($= 2.6 \times 10^{-15}$ kg)

(iv) $\frac{QV}{d} = mg$ (1)

$$Q = \frac{2.6 \times 10^{-15} \times 9.8 \times 6.0 \times 10^{-3}}{320} \quad (1)$$

$$= 4.8 \times 10^{-19} \text{ C} \quad (1) \quad (4.78 \times 10^{-19} \text{ C})$$

10

[12]

16. (a) (i) unit A: supplies current/power/energy to the filament or heats the filament (1)
0 – 50 V (1)
- (ii) unit B: to make the anode positive w.r.t. the filament, so that electrons are attracted/accelerated to the anode (1)
> 250 V (1) max 3

- (b) (i) beam current or intensity is reduced (1)
(because) fewer electrons are emitted (per sec) from the filament (1)
[or no beam as no electrons emitted if voltage of A reduced enough (1)
(only)]
- (ii) electrons travel faster [or more kinetic energy] (1)
(because the force of) attraction to the anode is greater (1) 4

[7]

17. (a) force due to electric field is vertically upwards and proportional (or related to) plate pd (1)
at $V = V_c$, force due to field is equal and opposite to the weight of the droplet (1)
no resultant force (or forces balance) at V_c (droplet remains stationary) (1) 3

- (b) (i) electric force (or qV/d) = weight (or mg) (1)
- $$q \left(= \frac{mgd}{V} \right) = \frac{6.2 \times 10^{-14} \times 9.8 \times 6.0 \times 10^{-3}}{5700} \quad (1)$$
- $$= 6.4 \times 10^{-19} \text{ C} \quad (1)$$
- (ii) for pd > 5700 (V), droplet moves upwards (1)
due to increased electric force (1)
droplet reaches terminal velocity (1) max 5

[8]

18. (a) each electron experiences an electrostatic force (vertically) upwards (1)
 this force does not change as the electron moves across the field (1)
 each electron (therefore) has a (constant) acceleration vertically upwards (1)
 velocity of each electron has a constant horizontal component of velocity (1)
 [or has an increasing vertical component of velocity]
 so the direction of motion/velocity becomes closer and closer to a
 vertical line (as electron moves across the field) (1)
 [or angle to the vertical becomes less]

Max 4
QWC 1

- (b) (i) (for beam to be undeflected)
 force due to electric field, eE (or qE) (1)
 equals force due to magnetic field, Bev (1) (gives $v = \frac{E}{B}$)

(ii) (k.e. at anode) = $\frac{1}{2}mv^2 = eV_A$ (1)
 gives $\frac{e}{m} = \frac{v^2}{2V_A}$ (1) (i.e. = $\frac{E^2}{2B^2V_A}$)

(iii) $E(= \frac{V}{d}) = \frac{3800}{50 \times 10^{-3}}$ (1) (= 7.6×10^4 (V m⁻¹))
 $\frac{e}{m} = \left(\frac{E^2}{2B^2V_A} \right) = \frac{(7.6 \times 10^4)^2}{2 \times (1.9 \times 10^{-3})^2 \times 4500}$ (1)
 = 1.8×10^{11} C kg⁻¹ (1)

7

[11]

19. (a) (i) emission of (conduction) electrons from a
 heated metal (surface) or filament/cathode (1)
 work done on electron = eV (1)
 (ii) gain of kinetic energy (or $\frac{1}{2}mv^2$) = eV ; rearrange to
 give required equation (1)

3

- (b) (i) work done = force \times distance moved in direction of force (1)
 force (due to magnetic field) is at right angles to the direction of motion/velocity
 [or no movement in the direction of the magnetic force
 \therefore no work done] (1)
 electrons do not collide with atoms (1)

any two (1)(1)

[alternative for 1st and 2nd marks
 (magnetic) force has no component along direction of motion (1)
 no acceleration along direction of motion (1)
 or acceleration perpendicular to velocity]

$$r = \frac{mv}{Be} \left(\text{or } Bev = \frac{mv^2}{r} \right) \quad (1)$$

$$v^2 = \frac{2eV}{m} \quad (1)$$

$$\therefore r^2 \left(= \frac{m^2 v^2}{B^2 e^2} \right) = \frac{m^2}{B^2 e^2} \times \frac{2eV}{m} = \frac{2mV}{B^2 e} \quad (1)$$

(iii) (rearranging the equation gives) $\frac{e}{m} = \frac{2V}{B^2 r^2} \quad (1)$

$$\frac{e}{m} = \frac{2 \times 530}{(3.1 \times 10^{-3})^2 \times (25 \times 10^{-3})^2} = 1.7(6) \times 10^{11} \text{ Ckg}^{-1} \quad (1)$$

7

[10]

20. (a) (i) current heats the wire (1)
 electrons (in filament) gain sufficient k.e. (to leave the filament) (1)
 (ii) electrons would collide (or be absorbed or scattered) by gas atoms (or molecules) (1)

3

(b) (i) k.e. (= eV) = $1.6 \times 10^{-19} \times 3900$ (1) = 6.2×10^{-16} (J) (1)

(ii) (rearrange $\frac{1}{2} m v^2 = eV$ to give)

$$v \left(= \sqrt{\frac{2eV}{m}} \right) = \left(\frac{2 \times 1.6 \times 10^{-19} \times 3900}{9.1 \times 10^{-31}} \right)^{1/2} \quad (1) = 3.7 \times 10^7 \text{ m s}^{-1}$$

4

[7]