1. (a) (i) weight [or force of gravity] pulls droplet down **(1)**
no electric force to counteract weight s **(1)**
viscous force increases with speed**(1)**
weight = viscous force at terminal speed**(1)**

(ii) viscous force = $6\pi\eta r\upsilon$ **(1)**

weight = $\frac{4}{3}\pi r^3\rho g$ **(1)**

$\frac{4}{3}\pi r^3\rho g = 6\pi\eta r\upsilon$ to give desired equation showing working **(1)** max 6

(b) (i) $r^2 \left(= \frac{9\eta\upsilon}{2\rho g}\right) = \frac{9\times1.8\times10^{-5}\times1.20\times10^{-3}}{2\times9.8\times950\times15.5}$ **(1)** (= 6.7×10^{-13} m^2)

$r = 8.2 \times 10^{-7}$ (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)** (= 2.2×10^{-15} kg)

(ii) $\frac{QV}{d} = mg$ [or $Q = \frac{mgd}{V}$] **(1)**

$Q\left(= \frac{mgd}{V}\right) = \frac{2.2\times10^{-15}\times9.8\times5.0\times10^{-3}}{225}$ **(1)**

$Q = 4.8 \times 10^{-19}$ **(1)** 6

(c) charge on oil droplet always a multiple of a basic amount **(1)**
basic amount = 1.6×10^{-19} 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)**

($\frac{1}{2}m\upsilon^2 = QV$) $\therefore\ \upsilon = \sqrt{\frac{2QV}{m}}$ **(1)**

$\therefore \upsilon = \sqrt{\frac{2\times1.60\times10^{-19}\times1200}{9.11\times10^{-31}}}$ **(1)** (= 2.05×10^7 m s^{-1}) 3

(b) F (= $BQ\upsilon$) = $0.080 \times 1.6 \times 10^{-19} \times 2.05 \times 10^7$ **(1)**
= 2.62×10^{-13} N [or 2.56×10^{-13} N if $\upsilon = 2.0\times10^7$ 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

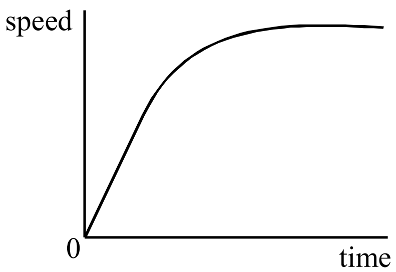
(b) (i) k.e. = (eV = $1.6 \times 10^{-19} \times 3600$) = 5.8×10^{-16}(J) **(1)**

(ii) $\frac{1}{2} m\upsilon 2 = eV$ **(1)**

$\upsilon = \left(\sqrt{\frac{2eV}{m}}\right) = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 3600}{9.1 \times 10^{-31}}}$ **(1)** $= 3.6 \times 10^{7}\ \text{ms}^{-1}$ **(1)** 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) $\upsilon_0 = \left(\frac{1.00 \times 10^{-3}}{12.8}\right) = 7.8 \times 10^{-5}$ m s^{-1} **(1)**

(ii) $k \left(= \frac{g}{\upsilon_0}\right) = \frac{9.8}{7.8 \times 10^{-5}}$ (= 1.2(5) × 10^5 (s^{-1})) **(1)**

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

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

e.g. "t = 1 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 << 12.8s **(1)** 4

[10]

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

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

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

$\frac{1}{2}m\upsilon^2 = eV$ **(1)**

$\frac{m\upsilon^2}{r} = Be\upsilon$ **(1)**

$\frac{e}{m} = \frac{2V}{B^2r^2}$ **(1)** $= \frac{2 \times 3200}{(7.6 \times 10^{-3})^2 \times 0.025^2}$ **(1)** 1.8×10^{11} Ckg $^{-1}$ **(1)** 6

[9]

7. (a) (i) $V\left(= \frac{W}{Q}\right) = \frac{6.0 \times 10^{-16}}{1.60 \times 10^{-19}}$ **(1)**= 3750 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)**

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

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

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

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

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

[12]

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

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

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

$= \left(\frac{9\times1.8\times10^{-5}\times1.11\times10^{-4}}{2\times970\times9.81}\right)^{1/2}$ **(1)** (= 9.7×10^{-7}m)

(allow C.E for v from (a)) 3

(c) $qE = mg$ **(1)**

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

$q\ (= \frac{mg}{E}) = \frac{3.7\times10^{-15}\times9.81}{57\times10^3} = 6.37 \times 10^{-19}$ C **(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)** 4

(b) (i) E_k (= $eV = 1.6 \times 10^{-19} \times 4200$) = 6.7×10^{-16} (J) **(1)**

(ii) (use of $E_k = ½mv^2$ gives) $½mv^2 = 6.7 \times 10^{-16}$ (J) **(1)**
(allow C.E. for value of E_k)

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

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

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

$Bev = eE$ (gives $v = \frac{E}{B}$) **(1)** 5

(c) work done (or eV) = gain of kinetic energy (or $½mv^2$) **(1)**

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

$$= \frac{(3.2 \times 10^7)^2}{2 \times 2900} = 1.8 \times 10^{11} \text{ C kg}^{-1}$$ **(1)** 3

[10]

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

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

$$\frac{9.8}{4.9 \times 10^5}$$ **(1)** $(= 2.0 \times 10^{-5}$ 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)**

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

$= 1.75 \times 10^{11}$ C kg $^{-1}$ **(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)**
$= 4.0 \times 10^{-16}$ J **(1)**

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

$= 3.0 \times 10^7$ 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)**

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

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

$$q\left(= \frac{mgd}{V}\right) = \frac{6.2 \times 10^{-14} \times 9.8 \times 6.0 \times 10^{-3}}{5700}$$ **(1)**

$= 6.4 \times 10^{-19}$C **(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 × distance moved in direction offeree **(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
∴ 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]

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

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

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

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

$$\frac{e}{m} = \frac{2 \times 530}{(3.1 \times 10^{-3})^2 \times (25 \times 10^{-3})^2} = 1.7(6) \times 10^{11}\,\mathrm{C\,kg^{-1}}$$ **(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 ½ $m v^2 = eV$ to give)

$v\ (= (2eV/m)^{1/2}) = \left(\frac{2 \times 1.6 \times 10^{-19} \times 3900}{9.1 \times 10^{-31}}\right)^{1/2}$ **(1)** = 3.7×10^7 m s^{-1} 4

[7]