M1. (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 $\frac{1}{2}mv^2$) **(1)**

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

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

3

[10]

M2. (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]

M3. (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) (= 2.0×10^{-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)**
speed increases until drag become equal to (and opposite to) weight
(no resultant force) hence no acceleration **(1)**

max 3

[6]

M4. (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) $v\left(= \left(\frac{2E_k}{m}\right)^{1/2}\right) = \left(\frac{2 \times 4.0 \times 10^{-16}}{9.11 \times 10^{-31}}\right)^{1/2}$ **(1)**

= 3.0×10^7 m s^{-1} **(1)**

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

4

[8]

M5. (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)** (= 2.6×10^{-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]

M6. (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]

M7. (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]

M8. (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]

M9. (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]

M10. (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 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]

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

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

7

[10]

M11. (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 × 10^{-19} × 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]

M12. (a) (i) The number of electrons (per second) in the beam will increase **(1)** because the filament will become hotter and will emit more electrons (per 2 second) **(1)**

2

(ii) the speed (or kinetic energy) of the electrons will increase **(1)**

because the electrons (from the filament) are attracted towards the anode with a greater acceleration (or force) **(1)**

(or gain more kinetic energy in crossing a greater pd)

2

(b) (i) (magnetic) force on each electron in the beam is perpendicular to velocity **(1)**

no work is done on each electron by (magnetic) force so ke (or speed) is constant **(1)**

magnitude of (magnetic) force is constant because speed is constant **(1)**

(magnetic) force is always perpendicular to velocity so is centripetal **(1)**

max 3

(ii) rearranging $r = \frac{mv}{Be}$ gives $\frac{e}{m} = \frac{v}{Br}$ **(1)**

$\frac{e}{m} = \frac{7.4 \times 10^{6}}{6.0 \times 10^{-4} \times 68 \times 10^{-3}}$ = 1.81 × 10^{11} **(1)** C kg^{-1} **(1)**

for correct answer to 2 sf **(1)**

4

(iii) specific charge for the electron ≈ 2000 × specific charge of H^+ **(1)**

(accept = and accept any value between 1800 and 2000)

which was the largest known specific charge before the specific charge of the electron was determined/measured **(1)**

(or which could be due to a much greater charge or a much smaller mass of the electron)

2

[13]

M13. (a) (i) **either**

(at terminal speed (v)) the viscous force on the droplet = its weight (or mg or the force of gravity on it)

or

viscous force = $6\pi\eta rv$ (where r is the radius of the droplet and η is its viscosity) and weight (= mg) = $4\pi r^3\rho g/3$ ✓

$4\pi r^3\rho g/3 = 6\pi\eta rv$ ✓

(which gives $r = (9\eta v/2\rho g)^{½}$)

2

(ii) r (can be calculated as above then) used in the formula $m = 4\pi r^3\rho/3$ to find the droplet mess, m [owtte] ✓

alternatively; (from $6\pi\eta rv = mg$) (as all values are known use) $m = 6\pi\eta rv/g$ ✓

1

(b) (i) electric force (or QV/d) = the droplet weight (or mg) ✓

$$Q = \frac{mgd}{v} = \frac{6.8\times10^{-15}\times9.8(1)\times5.0\times10^{-3}}{690} = 4.8\times10^{-19}\ \text{C}$$ ✓

2 sf answer ✓

3

(ii) **any two from**

the charge on each droplet is a whole number × 1.6 × 10^{-19} C (or × charge of the electron) ✓

the least amount of charge (or the quantum of charge) is the charge of the electron ✓

the quantum of charge is 1.6 × 10^{-19} C [owtte] ✓

max 2

[8]

M14. (a) (i) diffraction ✓

1

(ii) the electrons in the beam must have the same wavelength ✓

otherwise electrons of different wavelengths (or speeds/velocities/energies/momenta) would diffract by different amounts (for the same order) [owtte] ✓

2

(b) (i) (eV = ½ *m* **v**^{2} gives) **either v** = $\sqrt{\frac{2eV}{m}}$

or 1.6 × 10^{-19} × 25000 = ½ × 9.1 × 10^{-31} × **v**^{2} ✓

$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 25000}{9.1 \times 10^{-31}}}$ = 9.4 × 10^{7} m s^{-1} ✓

p or *mv* (= 9.1 × 10^{-31} × 9.4 × 10^{7}) = 8.5 × 10^{-23} ✓

kg m s^{-1} (or N s) ✓

alternatives for first two marks

p or *mv* = $\sqrt{2meV}$ ✓ =

$\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 25000}$ ✓

4

(ii) **any two of the first three mark points**

increase of pd increases the speed (or velocity/energy/ momentum) of the electrons ✓

(so) the electron wavelength would be smaller ✓

(and) the electrons would diffract less (when they pass through the lenses) ✓

and

the image would show greater resolution (or be more detailed) ✓

max 3

[10]

M15. (a) force due to electric field acts (vertically) downwards on electrons ✓

vertical (component) of velocity of each electron increases ✓

horizontal (component of) velocity unchanged (so angle to initial direction increases) ✓

3

(b) (i) magnetic flux density should be reversed and adjusted in strength (gradually until the beam is undeflected) ✓

1

(ii) magnetic (field) force = Bev

and electric (field) force = eV / d ✓

(Accept Q or q as symbol for e (charge of electron)

$Bev = eV/d$ (for no deflection) gives $v = V / Bd$ ✓

2

(c) (gain of) kinetic energy of electron = work done by anode pd or $\frac{1}{2} m v^2 = e V_{(A)}$ ✓

$$\frac{e}{m}\left(= \frac{v^2}{2V_{(A)}}\right) = \frac{(3.9 \times 10^7)^2}{2 \times 4200}$$ ✓

$= 1.8 \times 10^{11}$ C kg^{-1}.

3

[9]

M16. (a) (i) (at terminal velocity v), weight of droplet (or mg) = viscous drag (or $6\pi\eta r v$) ✓

Backward working 3 marks max;

viscous force (= $6\pi\eta r v$) = $6\pi \times 1.8 \times 10^{-5} \times 1.0 \times 10^{-6} \times 1.1 \times 10^{-4} = 3.7 \times 10^{-14}$ N ✓

mass (m) of droplet = ($4\pi r^3 / 3$) × ρ , (where r is the droplet radius) ✓

weight = mg =

$$\frac{4}{3}\pi(1.0 \times 1.0^{-6})^3 \times 880 \times 9.8 = 3.6 \times 10^{-14}\text{N}$$ ✓

(allow 3.7)

(therefore) ($4\pi r^3 / 3$) × $\rho g = 6\pi\eta r v$ (or rearranged) ✓

(hence) r (= $(9\eta v / 2\rho g)^{1/2}$

$$= \frac{9 \times 1.8 \times 10^{-5} \times 1.1 \times 10^{-4}}{2 \times 880 \times 9.8}) \text{ gives } \quad r = 1.0(3) \times 10^{-6}\ m$$ ✓

(therefore) viscous force = weight as required for constant velocity ✓

note; some evidence of calculation needed to give final mark

Allow final answer for r in the range 1 to 1.05 × 10^{-6} to any number of sig figs

4

(ii) $\boldsymbol{m} = ((4\pi r^3/3) \times \rho) = \frac{4}{3}\pi (1.0 \times 10^{-6})^3 \times 880\ ) = 3.7 \times 10^{-15}$ kg ✓

Allow ecf for r from a(i) in a correct calculation that gives m in the range 3.6 to 4.0 × 10^{-15} kg

(or correct calculation of $6\pi\eta r v / g$)

1

(iii) electric force (or QV / d) = droplet weight (or *mg*) ✓

Allow ecf m (or r) from a(ii) (or a(i)).

$$Q = \left(\frac{mgd}{V} \right) = \frac{3.7\times10^{-15}\times9.8\times6.0\times10^{-3}}{680}$$ ✓

Accept values in 1st mark line

[or Q (= viscous force × *d / V*

Use of e instead of Q or q = 2 marks max

$= 6\pi \times 1.8\times10^{-5}\times 1.0\times10^{-6}\times 1.1\times10^{-4}\times 6.0\times10^{-4} / 680$ ✓]

For the 2nd mark, allow use of viscous force calculation. Use of viscous force method does not get 1st mark.

$Q = 3.2 \times 10^{-19}$C ✓

If both methods are given and only one method gives Q = ne (where n = integer >1), ignore other method for 2nd mark and 3rd mark.

For the final mark, Q must be within n e ± 0.2×10^{-19} from a correct calculation.

3

(b) The weight of the second droplet is greater than the maximum electric force on it ✓

Alternative for 1st mark;

weight = drag force + elec force (owtte)

Scheme using V for next 5 marks;

If n =1 for the second droplet , pd to hold it = 1580 V (= *mgd / e*) ✓

which is not possible as V max = 1000 V ✓

If n = 2 , it would be held at rest by a pd of 790 V (= 1580 / 2 or 680 × 4.3 / 3.7 V) ✓

if n > 2 , it would be held at rest by a pd of less than 790 V (or 790 / n V) ✓

So n =1(e) must be the droplet charge ✓

Alternative schemes for last 5 marks

Q scheme *Using QV /d = mg for a stationary droplet gives Q = mgd / V = 2.53 − 10^{-19} C* ✓

which is not possible as Q = integer x e ✓

(so) Q (=ne) < 2.53 × 10^{-19} C ✓ owtte)

Calculation to show

Q= 1e fits above condition ✓

Q= 2e does not fit above condition ✓

F scheme*;- Calc of mg to give 4.2 ($\pm$0.2) × 10^{-14} N* ✓

Calc for Q = 1e of QV / d to give 2.6($\pm$0.2) × 10^{-14} N ✓

Calc for Q =2e of QV / d to give 5.3 ($\pm$0.2)× 10^{-14}N ✓

mg> elec force for Q =1e or <2e for Q=2e ✓

So n =1(e) must be the droplet charge ✓

Max 4

[12]