Mark schemes

1 (a) Experiments suggested cathode rays were negatively charged particles ✓

Particle has mass much smaller than mass of an atom / hydrogen ion
OR
Compares Specific charge with that of hydrogen ion / atom ✓

Particles were part of the substructure of matter / atoms ✓

Particles emitted in each case were the same
OR
Particles emitted were the same for different gases / for photoelectrons and particles from thermionic emission ✓

MAX 2

Specific charge defined =0

Millikan / Rutherford deductions=0

Do not allow small mass alone

Allow proton

Allow two correct deductions in 1 or 2 provided that the other comment is not relevant but does not contradict,

2

(b) (i) electrons collide with atoms of gas ✓ (condone molecules)

Reference to collisions with nucleus = 0 for the question

atoms / electrons are excited

or atoms / electrons change to higher energy states ✓

light / photon emitted when relaxation / de-excitation occurs or as electrons move / fall back to lower energy level ✓

Do not allow

- *collide with gas unless atoms mentioned later*
- *particles*
- *electrons absorbed by atoms*

Allow move from ground state

Allow return to ground state

3

(ii) $eV = ½ mv^2$ and $\frac{mv^2}{r} = Bev$ or $\frac{e}{m} = \frac{v}{Br}$ in any form ✓
or $\frac{e}{m} = \frac{2V}{B^2r^2}$

Correct substitution of data in the question allowing errors in powers of 10 ✓

1.9×10^{11} ✓

C kg^{-1} ✓

Do not allow

Must be seen

Substitution of values of e and m_e can gain 1st and last marks only

4

[9]

2 (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) ✓

$$Q = \frac{mgd}{v} = \frac{6.8 \times 10^{-15} \times 9.8(1) \times 5.0 \times 10^{-3}}{690} = 4.8 \times 10^{-19} \text{ C}$$ ✓

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]

3 (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]

4 (a) (i) electrons pulled out of (gas) atoms so (gas) atoms become (+) ions
OR
ionisation by collision (also) occurs
OR
(+) ions (that) hit cathode causing it to release electrons ✓

conduction due to electrons and positive ions ✓

; Allow 'electrons ionise atoms' as compensation mark (if no marks elsewhere)

2

(ii) ions and electrons (moving in opposite directions) collide (with each other) and recombine and emit photons ✓

Owtte

electrons excite gas atoms (by collision)
and photons are emitted when de-excitation occurs ✓

If light not photons given in 1st 2 mark points, 1 max for 1st two mark points

gas needs to be at sufficiently low pressure in order that the particles (or uncharged gas atoms / ions / electrons) in the gas are widely spaced ✓

Owtte

otherwise (+) ions and / or electrons / particles would be stopped by gas atoms OR so that ions / electrons are accelerated (or gain enough ke) to cause excitation ✓

3max

(b) Specific charge = charge / mass (and
charge(s) of ion does not depend on the type of gas) ✓

Mass of ion depends on the type of gas ✓

Accept Q / m in symbols Q / m but not e / m if e / m is specifically stated as specific charge

2

[7]

5 (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
∴ 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)**

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

7

[10]

6 (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]

7 (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]

8 (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) 25mm **(1)**

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

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

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

(6)

[9]

9 (a) (i) electrons are negatively charged so beam is attracted to positive plate [or repelled by negative plate or electron experiences force towards positive plate] **(1)**

(ii) beam does not spread out **(1)**
if speeds varied, faster electrons would be deflected less than slower electrons **(1)**

3

(b) (i) to give conduction electrons sufficient k.e. to leave metal [or to cause thermionic emission or electrons have insufficient ke. in a cold filament to leave filament] **(1)**

(ii) $\frac{1}{2}mv^2 = eV_A$ [or $v = \sqrt{\frac{2eV_A}{m}}$] **(1)**

2

(c) (i) into the plane of the diagram **(1)**
perpendicular to the diagram [or the electric field] **(1)**

(ii) $Bev = \frac{eV_p}{d}$ **(1)**

(iii) combine the two equations to give $\frac{e}{m} = \frac{V_p^2}{2V_A B^2 d^2}$ **(1)**

$\frac{e}{m} = \frac{4500^2}{2 \times 3700 \times (2.5 \times 10^{-3})^2 \times (50 \times 10^{-3})^2}$ **(1)**

1.75×10^{11} Ckg^{-1} **(1)**

max 5

[10]

10 (a) (i) There is a (constant) force acting which is (always) at right angles / perpendicular to the path / motion / velocity / direction of travel / to the beam
Or mentions a centripetal force ✓

First mark is for condition for circular motion

Not speed

Second mark is for a statement relating to the origin of the force

Force is at right angles to the magnetic field <u>and</u> the electron motion
Or
<u>direction</u> given by left hand rule ✓

Any mention of attraction to the plates is talk out (TO)

2

(ii) States $Bev = \frac{mv^2}{r}$ and evidence of correct intermediate stage showing

manipulation of the formula
or

Quotes $r = \frac{mv}{Be}$ from formula sheet and change of subject to *v =Ber / m* seen

Accept delete marks

or rewrite as $Be = \frac{mv}{r}$

or rearrangement as $\frac{v^2}{v} = \frac{Ber}{m}$

1

(iii) States $Bev = \frac{eV}{d}$

or $F = Bev$ $F = \frac{eV}{d}$ (or $F = Ee$ *and* $E = \frac{V}{d}$ in any form)

Allow use of e *or* Q

<u>and</u>

states $v = \frac{V}{Bd}$✓

No mark for just quoting final equation. There must be evidence of useful starting equations

1

(b) Equates the formulae for *v* and shows $\frac{e}{m}$ equated to $\frac{V}{B^2 rd}$

Must include 'e / m =' not just 'specific charge ='

Note there is no ecf. Candidates who use an incorrect equation in (a) (iii) will lose this mark unless they restart from first principles

Condone Q / m

1

(c) Using band marking

Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response.
Level 1 (1−2 marks)
Answer is largely incomplete. It may contain valid points which are not clearly linked to an argument structure. Unstructured answer. Errors in the use of technical terms, spelling, punctuation and grammar or lack of fluency.
Level 2 (3−4 marks)
Answer has some omissions but is generally supported by some of the relevant points below: - the argument shows some attempt at structure - the ideas are expressed with reasonable clarity but with a few errors in the use of technical terms, spelling, punctuation and grammar.
Level 3 (5−6 marks)
Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below: - argument is well structured with minimum repetition or irrelevant points - accurate and clear expression of ideas with only minor errors in the use of technical terms, spelling and punctuation and grammar.

A

Measure the terminal speed of the falling droplet

At the terminal speed weight = viscous force (+ upthrust)

$mg = 6\pi\eta rv$ and $m = 4\pi r^3\rho / 3$ so $r^2 = \dfrac{9\eta v}{2\rho g}$

r could be determined as density of drop, viscosity of air and *g* are known (*r* is the only unknown)

B

m can be determined if *r* is known

Apply pd between the plates so electric field = V / d and adjust until droplet is stationary

$QV / d = mg$ so *Q* can be found

C

Make a number of measurements to find *Q*

Results for *Q* are in multiples of 1.6×10^{-19}C so *Q* can be found

e.g.

1-2

Superficial with some sensible comments about the procedure with significant errors in attempts at use of equations. May do one part of A B or C reasonably well. Relevant Equations without little explanation may be worth 1

3-4

Should cover most of the point in two of A, B & C coherently

A & B may be well done in an answer that is easy to follow

OR B and C may be well explained but there may be significant errors or omissions in the determination of r

OR a bit of all A B and C with significant errors or omissions

5-6

Will cover the points made in A B & C with few omissions in an answer that is easy to follow

The candidate will define some terms used in equations

1-2

Attempt to explain how to determine radius with detail of how to use data

OR

Makes a relevant point about some part of the procedure about the determination

3-4

Radius determination explained with sensible equations

Explanation of how to use data to find mass of the drop

Idea of holding the drop stationary

5-6

Answer includes all steps to determine the charge of a droplet with correct equations showing how to use the measurements

For highest mark the answer should include idea of interpreting results of many measurements

6

[11]

11

(a) (i) $V\left(=\frac{W}{Q}\right)=\frac{6.0\times10^{-16}}{1.60\times10^{-19}}$ **(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) $t\left(=\frac{l}{v}=\frac{0.060}{3.6\times10^{7}}\right)$ = 1.67 ns **(1)**

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

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

combine to give $\frac{e}{m}=\frac{2yd}{V_pt^2}$ **(1)** = $\frac{2\times12.5\times10^{-3}\times25\times10^{-3}}{1250\times(1.67\times10^{-9})^2}$ **(1)**

= 1.8×10^{11} C kg^{-1} **(1)**

(max 8)

[12]