Mark schemes

Q1.

(a) Electrostatic force and magnetic force are

equal in magnitude

OR

opposite in direction / magnetic force down and electrostatic force up

OR

equal and opposite

✓

Electrostatic force and magnetic force are

equal in magnitude

AND

opposite in direction / magnetic force down and electrostatic force up

AND

Balanced **forces** / resultant force = 0

(so travels in a straight line according to Newton 1 /

no (vertical) acceleration according to Newton 2) ✓

Allow electric force / force from electric field / force due to potential difference / force due to plates for electrostatic force.

Ignore references to gravity.

Electric and magnetic forces being equal without reference to magnitude or opposite is not enough for MP1.

Ignore references to a vacuum so no collisions between particles.

Ignore references to the directions of fields.

Do not allow answers which suggest that the magnitude of magnetic field is equal to the magnitude of the electric field.

Condone cancel for balanced forces in mp2

Ignore counteract in mp2.

*Do not allow **horizontal** force for mp2.*

2

(b)

$Bev = \frac{eV_{(P)}}{d}$ **OR** $v = \frac{V_{(P)}}{dB}$ ✓

$\frac{1}{2}mv^2 = eV_{(A)}$ **OR** $\frac{e}{m} = \frac{v^2}{2V_{(A)}}$ ✓

Allow Q for e

Condone mixed up V_A and V_P or no subscripts in first 2 marking points.

$\frac{e}{m} = \frac{V_{(P)}^2}{2V_{(A)}d^2B^2}$ *or any valid rearrangement gains mp1, mp2, mp3*

Substituted data can gain MP1 and MP2 (in addition to MP3)

At least one correct from ✓

- $v = \frac{1.51\times10^3}{5\times10^{-2}\times1.59\times10^{-3}} (= 1.9\times10^7\text{ m s}^{-1})$
- $\frac{e}{m} = \frac{(\text{their v})^2}{2\times1\times10^3}$
- $\frac{e}{m} = \frac{(1.51\times10^3)^2}{2\times1\times10^3\times(5\times10^{-2})^2\times(1.59\times10^{-3})^2}$
- $\frac{e}{m} = \frac{V_{(P)}^2}{2V_{(A)}d^2B^2}$

Condone PoT errors in mp3

Do not credit values using 1.60×10^{-19} or 9.11×10^{-31} in mp3 or mp4

$1.8(0380523)\times10^{11}$ C kg^{-1}

without using 1.60×10^{-19} or 9.11×10^{-31} ✓

Do not allow 1.76×10^{11} for mp4 as this is from the data booklet not the data in the question.

If no other marks are awarded, condone max 1 for $\frac{e}{m} = \frac{V}{2d^2B^2}$ with any or no V subscript

4

[6]

Q2.

(a) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.**

Mark	Criteria
6	All three areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	All three areas covered, at least two in detail. Whilst there will be gaps, there should only be an occasional error.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant analysis.

Method
Field is off or with the switch open
Measure time and distance (for falling drop) (Measure distance using lines on microscope) calculate velocity using $v = \frac{s}{t}$
Calculation
(Just quoting formulae from the formulae and data booklet is not enough to partially address this area.)
$m = \frac{4}{3}\pi\rho r^3$
$mg = 6\pi\eta rv$
leading to $r = \sqrt{\frac{9\eta v}{2\rho g}}$
or $r = \sqrt{\frac{9\eta v}{2\rho g}}$ quoted
ρ is identified as the density of the **oil**
η is identified as the viscosity of the **air**

Principles/Assumptions

(This area is normally fully addressed by 2 statements.) Falls at terminal velocity since weight = viscous drag force / Stokes' law Air acts like a viscous fluid so Stokes' law applies.

Balanced forces according to Newton 1 or 2

Oil droplet is spherical (hence $V = \frac{4}{3}\pi r^3$)

Upthrust is negligible / can be ignored.

Any mention that air resistance is negligible or not present when field is off would not allow this area to be fully addressed.

Ignore reference to free fall.

Ignore details of Millikan's experiment that are not about determining *r*.

6

(b) Max ✓✓

- Substitution into $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times (1.2 \times 10^{-6})^3$
- Substitution of *m* = *ρ* = 880 × their volume
- Substitution of $Q = \frac{dmg}{V} = \frac{6.0\times10^{-8} \times \text{their mass} \times 9.81}{467}$

Max 2 if no equations are seen but only substitution (one for a correct substitution and one for correct answer)

MP1 and MP2 require substitutions.

Q = 8.0(3) × 10^{-19} (C) ✓

Need ≥ 2 sf (no ecf in mp3)

3

(c) % uncertainty in *Q* = 3 × 4 + 1 + 0.1 + 0.2 + 2 = ((±)15(.3)%) $✓_{1a}$

Allow fractional uncertainties in $✓_{1a}$

uncertainty in $Q = \frac{15}{100} \times 8.02 \times 10^{-19} = (\pm)1.2 \times 10^{-19}$ (C) $✓_{2a}$

Alternative method for ✓$_1$ and ✓$_2$

max value of *Q* =

$$\frac{4\pi\times(1.2\times10^{-6}\times1.04)^3\times880\times1.01\times6\times10^{-8}\times1.02\times9.81\times1.001}{3\times467\times0.998}$$

(= 9.3(3) × 10^{-19} C)

OR

min value of *Q* =

$$\frac{4\pi\times(1.2\times10^{-6}\times0.96)^3\times880\times0.99\times6\times10^{-8}\times0.98\times9.81\times0.999}{3\times467\times1.002}$$

(= 6.8(7) × 10^{-19} C)$✓_{1b}$

Correct use of max or min value with 8(.02) × 10^{-19} or half the range using max and min

if their max and/or min comes from a correct method with up to one error in each$✓_{2b}$

Allow ecf for Q and % uncertainty

✓3 is independent if 1 × 10^{-19} is used or an answer that rounds to 1 × 10^{-19}.

Alternatives for ✓3

the possible range overlaps 4, 5, 6 electrons (allow 4, 5 or 5, 6 or 4, 6)

Allow a calculated max and/or min value of Q (8 ± 1) × 10^{-19} (expect 7 or 9) is not an (integer) multiple of 1.6 × 10^{-19}

Condone because the uncertainty (not % uncertainty) is too close to 1.6 × 10^{-19}.

Range or uncertainty or % uncertainty is too large is not enough without explicit comparison of absolute uncertainty with 1.60 × 10^{-19} in some form.

$$1.2 \times 10^{-19} > \frac{1.60 \times 10^{-19}}{2}$$

therefore it is not possible to confirm charge quantisation (as any value is possible) ✓3

3

[12]

Q3.

(a) Idea that filament/metal is heated (by an electric current), giving (some) electrons in the metal (sufficient) energy to leave the surface ✓

Allow references to the work function (but not just ϕ)

Thermionic emission is not enough by itself.

Do not allow heating of electrons.

Reject 'accelerated' (unless it is clearly after they leave the metal) / 'ionise'

Ignore references to processes that take place after electron leaves the metal

Ignore references to free electrons inside the metal

1

(b) Use of $\frac{1}{2}mv^2 = eV$

To give v = 1.33 × 10^7 (m s^{-1}) ✓

Must see 500V for the potential difference (not 506.3V or 493.7V)

≥ 3 SF required.

1.325 × 10^7 (do not allow 1.32 × 10^7)

1

(c) Suggestion that, for diffraction to be demonstrated, hole diameter should be of same order of size as wavelength ✓

Do not allow λ < gap or gap < λ for MP1

(Must refer to gap not just anode)

Discussions in terms of crystalline diffraction can score MP1 and MP2.

Evidence of $\lambda = \frac{h}{p}$ **OR** $\lambda = \frac{h}{\sqrt{2meV}}$

to give 5.5 × 10^{-11} (m) OR 5.6 × 10^{-11} (m) ✓

Must calculate λ for MP2.

Condone use of 506.3V or 492.7V as penalised in 1.2

Allow 1 SF or order of magnitude calculation.

Do not ignore PoT for calculation.

Ignore incorrect conversion to nm if m value given.

Idea that this diameter is smaller than an atom / too small for hole to be made **and** therefore this apparatus cannot be used (for this speed/wavelength) / the student is **incorrect** ✓

Condone the idea that the student is correct in principle but this particular setup will not work.

Do not allow ecf to MP3 unless their calculated hole diameter is of the order of 10^{-10} m or smaller in MP2.

3

(d) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.**

Mark	Criteria
6	All three areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant analysis.

For each area (bullet point), consider whether the response is fully addressed, partially addressed or not addressed. Typically, any missing points mean that the area is partially addressed.

Significance
Very large e/m (compared to value for hydrogen ion).
(Hydrogen ion had largest known specific charge at the time.)
Therefore particles have very small mass / very large charge (condone light for small mass)

Experimental procedures and measurements
For a full answer everything should be directly measurable (not Electric Field, Kinetic Energy, velocity)
Except no details are required for measurement of B

Determination of e/m
Answers should end in e/m =
Expected to be in steps but can carry the algebra through
Allow use of measured Electric Field here.
A full answer should not include e or m as part of the calculation (likely to be found in working out v)

If methods are mixed up this can be treated as full credit for one of procedures or determination or as a partial for both.

The minimum response required to address an area fully is given below

Fine Beam Tube

Experimental procedure and measurements
fine beam tube described / diagram including low pressure gas, (Perpendicular) magnetic field to cause electrons to move in a circle

Radius of curved path *r*, Accelerating voltage *V*, Magnetic flux density *B*

Determination of e/m

($\frac{1}{2}mv^2 = eV$ and $r = \frac{mv}{Be}$)

$\frac{e}{m} = \frac{2V}{r^2B^2}$

Correct Alternative Methods

Crossed Fields

Experimental procedure and measurements

Parallel plates with voltage applied.

Magnetic field applied to produce balanced forces Accelerating voltage V_A

When beam is horizontal: plate voltage V_p, separation *d*, magnetic flux density *B*

Determination of e/m

$\left(\frac{eV_p}{d} = Bev \Rightarrow\right) v = \frac{V_p}{dB}$ (allow $\frac{E}{B}$ from measured E)

$\left(\frac{1}{2}mv^2 = eV_A \Rightarrow\right) \frac{e}{m} = \frac{v^2}{2V_A}$ or $\frac{e}{m} = \frac{V_p^2}{2d^2B^2V_A}$ or $\frac{e}{m} = \frac{E^2}{2B^2V_A}$

Measure deflected distance

Experimental procedure and measurements

Initial balanced magnetic and electrical forces to produce horizontal beam

Measure magnetic flux density B, plate p.d. V, distance between plates d and length of plates *x*

With no magnetic field, measure vertical deflection *y*

Determination of e/m

$\left(\frac{eV}{d} = Bev \Rightarrow\right) v = \frac{V}{dB}$ (allow $\frac{E}{B}$ from measured E)

Horizontal motion: $t = \frac{x}{v}$

Vertical motion: $\left(y = 0t + \frac{1}{2}at^2 = \frac{1}{2}at^2 \Rightarrow\right) a = 2y/t^2$

$\left(a = \frac{F}{m} = \frac{eV}{dm} \Rightarrow\right) \frac{e}{m} = \frac{da}{V}$

or any of $\frac{e}{m} = \frac{2dy}{Vt^2} = \frac{2dyv^2}{Vx^2} = \frac{2yV}{dx^2B^2}$

Measure deflected angle

Experimental procedure and measurements

Initial balanced magnetic and electrical forces to produce horizontal beam

Measure magnetic flux density B, plate p.d. V, distance between plates d and length of plates *x*

With no magnetic field, measure angle *θ* beam is deflected through

Determination of e/m

$\left(\frac{eV}{d} = Bev \Rightarrow\right) v = \frac{V}{dB}$ (allow $\frac{E}{B}$ from measured *E*)

Horizontal motion: $t = \frac{x}{v}$

$v_y = v \tan \theta$

Vertical motion ($v_y = 0 + at = at \Rightarrow$)$a = \frac{v_y}{t}$

$\left(a = \frac{F}{m} = \frac{eV}{dm} \Rightarrow\right)\frac{e}{m} = \frac{da}{V}$

Incorrect Methods

Milikan's Oil drop / use of measured weight / Gas tube / Crooke's tube / Discharge tube

Partial credit for one area ONLY can be awarded for a good treatment that includes all of the following

- At least one experimental detail
- Some measurements
- Some calculation

Quantum Jumping or anything else

These cannot address areas 1 and 2

Ignore use of undescribed velocity selector, mass spectrometer, ...

No credit for measure Q and m and divide them.

6

[11]

Q4.

(a) (Reads off terminal speed from graph) to give 0.053 ± 0.0005 mm s^{-1} ✓

Evidence of $mg = 6\pi\eta rv$ ✓

Substitutions seen to give 1.8×10^{-5} (N s m^{-2}) ✓

Allow PoT error in MP1

If MP1 not given, allow ecf if read off misread

Do not accept work from a gradient.

W or $1.2 \times 10^{-14} = 6\pi\eta rv$ is enough for MP2.

Condone $\frac{4}{3}\pi r^3\rho g = 6\pi\eta rv$ for MP2.

Calculator value = $1.766425562 \times 10^{-5}$

3

(b) Evidence of $EQ = mg$ ✓

$Q = 6.4 \times 10^{-19}$ (C) ✓

Divides their Q by e to get number of electrons **and** makes sensible comment consistent with their value ✓

By substitution - allow PoT error for E in MP1

Allow EQ = mg without substitution for MP1

Expect to see 4.0 or 3.99 ≈ 4 and therefore yes

Condone for MP3 only (max 1)

Use of $E = Q/4\pi\varepsilon_0 r^2$ which gives Q = 6.04 ≈ 6 so yes.

3

[6]

Q5.

(a) Drop stationary so

Electric force is opposite (in direction) to the weight

AND

electric field downwards/top plate positive/(electric) force towards positive plate so Q negative ✓

Give credit to answers shown on the diagram

Allow forces expressed in symbols

Do not allow suggestion that viscous force is involved

Accept idea that the drop is attracted towards the positive plate.

Accept bottom plate negative as an alternative to top plate positive.

1

(b) (In free fall at terminal speed)

$mg = 6\pi\eta rv$ ✓

Use of m = volume × density AND $V = \frac{4}{3}\pi r^3$ ✓

(to give $r = 5.9 \times 10^{-7}$ m)

(use of volume of sphere and density)

to give answer that rounds to $m = 7.7 \times 10^{-16}$ (kg) ✓

At least 2 sf.

3

(c) $\frac{VQ}{d} - mg = 6\pi\eta rv_2$ ✓

Convincing algebra combining with $mg = 6\pi\eta rv_1$

to give v_2/v_1 = answer ✓

MP2 is contingent on MP1

2

(d) Use of equation from **(c)** ✓

to show Q = 4.9 × 10^{-19} C ✓

Evidence of dividing their Q by 1.6 × 10^{-19} to give a consistent conclusion ✓

Use of means by substitution or manipulation
Accept answer that rounds to between 4.8 and 5.0 × 10^{-19} C
Using the 'show that' value for the mass gives
Q = 4.96 × 10^{-19} C
Only condone ecf in MP3 for an arithmetic error in the determination of Q.

3

(e) Value of viscosity affects calculation of mass/radius of droplet ✓

'affects' can be either increase or decrease in MP1

Smaller value of viscosity gives smaller force on droplet so smaller calculated weight/mass ✓

In MP2 allow use of relationship between the radius of the drop and the viscosity.
Evidence of MP1 is likely to be seen in MP2.
Do not condone use of $mg = 6\pi\eta rv$ on its own

Ref to equation

AND

as mass is smaller then Q smaller (therefore e smaller). ✓

Appropriate means either the equation from **(c)** *or relationship between weight and electric field force (e.g weight = $mg = EQ$)*

3

[12]