

**Section B**

Answer **all** questions in this section.

0	1
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**Figure 1** shows a gas discharge tube devised by William Crookes in one of his investigations.

When a large potential difference is applied between the cathode and anode the paddle wheel is seen to rotate and travel along the rail towards the anode.

**Figure 1**

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Explain how this experiment led Crookes to conclude that cathode rays are particles and that these particles caused the movement of the paddle.

**[2 marks]**

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0	1	.	2
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Later experiments showed that cathode rays are electrons in motion.

Explain how cathode rays are produced in a gas discharge tube.

**[3 marks]**

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In a particular gas discharge tube, air molecules inside the tube are absorbed by the walls of the tube.

Suggest the effect that this absorption may have on the motion of the paddle wheel.

Give a reason for your answer.

**[2 marks]**

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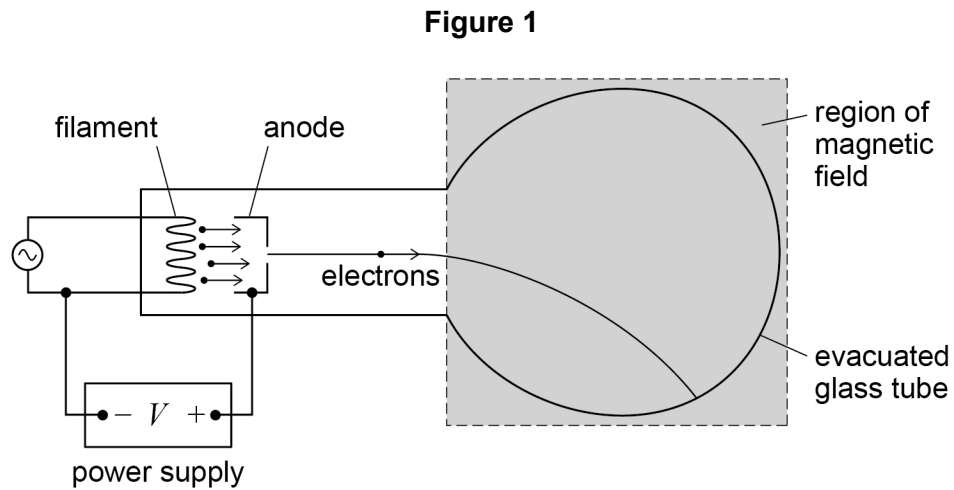
Question	Answers	Additional Comments/Guidelines	Mark
01.1	Cathode rays/electrons move from cathode toward anode	Accept move left to right.	1
	The paddle wheel has gained energy from cathode rays/electrons. ✓	Accept as alternatives for energy kinetic, energy/momentum/impulse ✓ Ignore references to force. Ignore references to applying a magnetic field.	1
01.2	Electrons are pulled out/escape from atoms OR gas atoms are ionised ✓	Condense molecules as alternative to atoms.	1
	(Positive ions generated near the cathode are attracted to the cathode causing free) electrons emitted from the cathode. ✓		1
	Electrons are accelerated toward the anode (by the potential difference) ✓	Do not accept attraction as an alternative to acceleration.	1
01.3	Reason: Idea of fewer electrons/cathode rays ✓ Effect: Paddle wheel rotates less ✓	Must score the reason mark to score the effect mark. Ignore references to air resistance.	2
	<b>OR</b> Reason: Idea of electrons/cathode rays have higher energy/speed/momentum ✓ Effect: Paddle wheel rotates more ✓		
<b>Total</b>			<b>7</b>

## Section B

Answer **all** questions in this section.

0 2

**Figure 1** shows apparatus which can be used to determine the specific charge of an electron.



Electrons are emitted from the filament and accelerated by a potential difference between the filament and anode to produce a beam. The beam is deflected into a circular path by applying a magnetic field perpendicular to the plane of the diagram.

0 2 . 1

Describe the process that releases the electrons emitted at the filament.

[3 marks]

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0 2 . 2

**Table 1** shows the data collected when determining the specific charge of the electron by the method shown in **Figure 1**.

**Table 1**

potential difference $V$ that accelerates the electrons	320 V
radius $r$ of circular path of the electrons in the magnetic field	4.0 cm
flux density $B$ of the applied magnetic field	1.5 mT

Show that the specific charge of the electron is given by the expression  $\frac{2V}{B^2 r^2}$

**[2 marks]**

0 2 . 3

Using data from **Table 1**, calculate a value for the specific charge of the electron. Give your answer to an appropriate number of significant figures.

**[2 marks]**

specific charge of the electron = \_\_\_\_\_ C kg<sup>-1</sup>

**Question 1 continues on the next page**

0	2	.	4
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At the time when Thomson measured the specific charge of the particles in cathode rays, the largest specific charge known was that of the hydrogen ion.

State how Thomson's result for the specific charge of each particle within a cathode ray compared with that for the hydrogen ion and explain what he concluded about the nature of the particles.

**[2 marks]**

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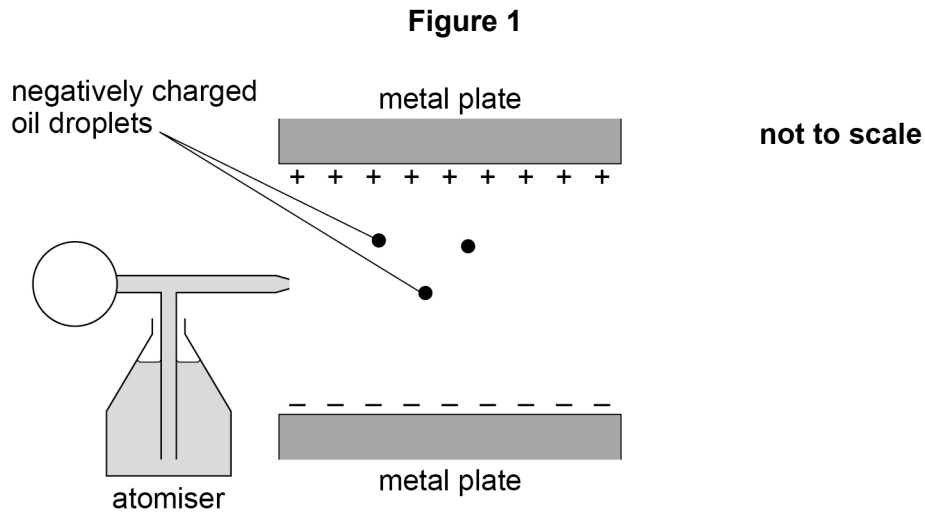
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Question	Answers	Additional Comments/Guidance	Mark
02.1	Filament / metal is heated due to the current through it ✓ Or temperature of the filament rises due to the current through it  (free / conduction) electrons gain sufficient/enough (kinetic) energy to leave (the metal surface) or Work function (defines work function) ≤ energy supplied to an electron/electron energy ✓  Thermionic emission ✓	Not electrons are heated Not heated due to the pd across it Allow by electrical power or electrically heated  Not allowed Reference to electrons leaving <u>atoms</u> or ionisation  Allow Energy supplied sufficient to overcome the work function	3
02.2	Use one of $\frac{1}{2}mv^2 = eV$ and $r = \frac{mv}{Be}$ or $\frac{mv^2}{r} = Bev$ to arrive at $\frac{Ber}{m} = v$ or $v = \sqrt{\frac{2eV}{m}}$ or $v^2 = \frac{2eV}{m}$ or $\frac{e}{m} = \frac{v}{Br}$ or $\frac{e}{m} = \frac{v^2}{2V}$ ✓  substitution in the other equation and manipulates <u>correctly</u> and <u>clearly</u> to give $\frac{e}{m} = \frac{2V}{B^2r^2}$ ✓	Condone $q$ for $e$ Substitution in other equation and correct manipulation  NB this is a show that so mark is not simply for stating the equation given I presented such that $v$ (velocity) and $V$ (voltage) are indistinguishable in manipulation then award only first mark	2

<b>02.3</b>	<p>Correct substitution <math>\frac{e}{m} = \frac{2 \times 320}{(1.5 \times 10^{-3})^2 \times 0.040^2}</math></p> <p>and answer <math>1.8 \times 10^{11}</math> ✓</p> <p>Answer to 2 sig figs ✓</p> <p>Allow for incorrect answer following incorrect substitution in equation</p>	<p>As answer is on the data sheet must see correct substitution with all correct powers of ten</p>	2
<b>02.4</b>	<p>The specific charge of the cathode rays/the particles was( much) larger/greater than the hydrogen ion/proton ✓</p> <p>This provided evidence that cathode rays were composed of electrons/particles which have a (very) small mass / have a high (negative) charge</p> <p>or</p> <p>Mass (much) smaller than the mass of a hydrogen (ion)/proton ✓</p>	<p>Not higher If mark 1 not given then 0 for the question</p> <p>Not lightest as substitute for mass</p>	2
<b>Total</b>			<b>9</b>

**Section B**Answer **all** questions in this section.**0 3****Figure 1** shows an experiment to measure the charge of the electron.

Negatively charged oil droplets are sprayed from the atomiser into the gap between the two horizontal metal plates. A potential difference is applied between the metal plates.

One of the droplets remains stationary.

**0 3 . 1**

Identify the forces acting on the stationary droplet.  
In your answer you should state the relationship between the forces.

The upthrust on the droplet due to the air it displaces is negligible.

**[2 marks]**


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0	3	.	2
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The potential difference between the plates is changed to zero and the droplet falls at a terminal velocity of  $1.0 \times 10^{-4} \text{ m s}^{-1}$ .

The density of the oil is  $880 \text{ kg m}^{-3}$

The viscosity of air is  $1.8 \times 10^{-5} \text{ N s m}^{-2}$

Show that the radius of the droplet is about  $1 \times 10^{-6} \text{ m}$ .

Assume that the droplet is spherical.

**[3 marks]**

0	3	.	3
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The potential difference between the plates is restored to its initial value and the droplet becomes stationary.

The charge on the droplet is  $-4.8 \times 10^{-19} \text{ C}$ .

A student suggests that, if the droplet splits into two spheres of equal size, both spheres would remain stationary.

Deduce whether this suggestion is correct.

**[3 marks]**

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Question	Answers	Additional Comments/Guidance	Mark	ID details
03.1	Weight/gravitational force AND electric/electrostatic force ✓  Equal (magnitudes) and opposite directions, AND one direction at least specified ✓	<p>The second mark is conditional on the first.</p> <p>First mark is for naming the two forces.            Condone 'electromagnetic' for 'electric'            Do not allow field or potential for force.            Allow "force due to electric field"; "force due to magnetic field"            Penalise additional forces in MP2.</p> <p>The second mark is for the relationship between them. Must include idea of size and direction.            e.g. weight down equals E force up/towards positive plate/away from negative plate.            Do not allow 'balanced' or 'in equilibrium' for equals</p> <p>The forces can be in the form of formulae for MP1 and MP2 (e.g. <math>Eq</math>, <math>EV/d</math>, <math>mg</math>)</p>	2	AO1 1a  AO2 1d

03.2	<p><math>m = 4\pi r^3 \rho / 3</math> and <math>mg = 6\pi \eta r v</math> seen ✓</p> <p><math>r^2 = 18 \eta v / 4 \rho g</math> is seen in in some form, in symbols or through substituted data, ✓</p> <p>Correct use of equations to obtain <math>r = 9.7 \times 10^{-7} \text{ m}</math> ✓</p>	<p>Do not allow backward calculaton</p> <p>Can be seen by substitution. Can be seen in single equation: <math>4\pi r^3 \rho g / 3 = 6\pi \eta r v</math></p> <p>Do not award if v and V confused</p> <p>Do not condone 1sf answer. Must be clear answer refers to r, not <math>r^2</math> for example.</p> <p>If no other mark given MP1 can be awarded if F used for mg, and/or volume AND density equations seen separately</p>	3	AO2 1h
03.3	<p>The number of excess electrons on the droplet is 3 ✓</p> <p>In order for each half to remain stationary, the charge would have to split equally OR Due to the quantisation of charge, the charge cannot split equally ✓</p> <p>It is not possible for both droplets to remain stationary / the student is wrong ✓</p>	<p>May be seen in terms of values of charge or e Award for idea that charge would have to be 1.5e</p> <p>Evidence for MP1 and MP2 may be seen together. E.g. charge on drops are e and 2e, OR <math>1.6 \times 10^{-19}</math> and <math>3.2 \times 10^{-19}</math></p> <p>Ignore reference to particles repelling each other</p>	3	<p>1 × AO3 2a 2 × AO3 2b</p>

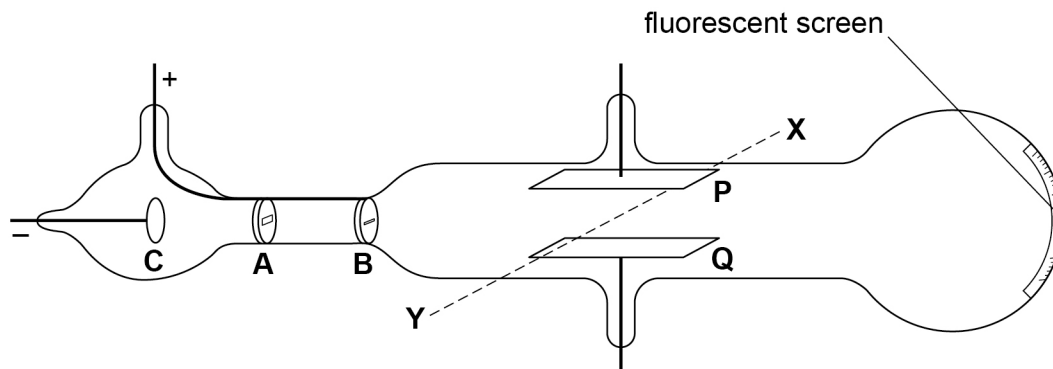
## Section B

Answer **all** questions in this section.

0 4

**Figure 1** shows a diagram of a discharge tube used by JJ Thomson to investigate cathode rays.

Figure 1



The direction **XY** is horizontal and at right angles to the axis of the tube.

0 4 . 1

When correct connections are made to a high-voltage power supply, a cathode ray is produced. The cathode ray hits the centre of the fluorescent screen.

Describe how a cathode ray is produced in the discharge tube in **Figure 1**.

[2 marks]

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0 4 . 2

**P** and **Q** are metal plates that can be attached to a second power supply.

In an experiment, a potential difference (pd) is applied across **P** and **Q** so that **P** is positively charged and **Q** is negatively charged. This deflects the cathode ray.

Then a magnetic field is applied between the plates so that the cathode ray follows its original path to the centre of the screen.

What is the direction of the magnetic field?

Tick (✓) **one** box.

[1 mark]

from **P** to **Q**

from **Q** to **P**

from **X** to **Y**

from **Y** to **X**

0 4 . 3

Changes are made to the apparatus so that the particles in the cathode ray travel with a greater speed as they pass between plates **P** and **Q**.

Explain how the cathode ray is restored to its original path by adjusting:

- only the electric field strength between **P** and **Q**
- only the magnetic flux density.

[3 marks]

electric field strength only \_\_\_\_\_

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magnetic flux density only \_\_\_\_\_

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0 4 . 4

Using the apparatus in **Figure 1**, Thomson determined the specific charge of the particles in the cathode rays. Thomson compared this result with the specific charge of the hydrogen ion.

Discuss the significance of Thomson's results for the particles in cathode rays, when compared with the specific charge of the hydrogen ion.

[2 marks]

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Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	2 From ✓✓ (High) electric field pulls electrons from (gas) atoms/ ionises (gas) atoms positive ions in tube are accelerated to C/cathode and strike surface/electrons in surface Electrons (in cathode) emitted and accelerated towards A (and B) (to form cathode ray).	Do not award MP3 if there is a suggestion of a p.d. between A and B	2	AO1.1b  AO2.1e
4.2	Y to X ✓		1	AO2.1c
04.3	Reference to $v = E/B$ (when path straight) ✓ (Eg Electric force = magnetic force $Eq = Bqv$ $v = E/B$ ) (Therefore for greater $v$ ) Either increase E ✓ Or decrease B. ✓	For MP2 and MP3 there must be some correct supporting theory e.g. $F_M = Bqv$	3	AO3.1a

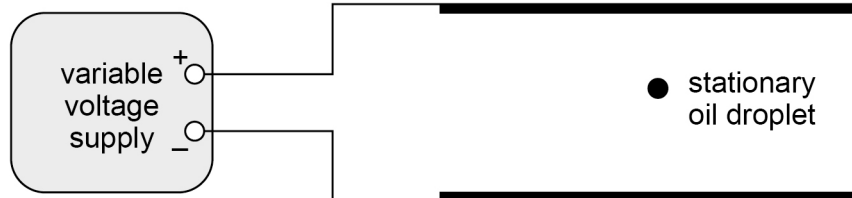
04.4	<p>(Magnitude of) specific charge much greater (approximately x 2000) specific charge of hydrogen (ion), (largest then known). ✓</p> <p>(If charges similar) Cathode rays particles <u>mass</u> much smaller than hydrogen ion and therefore smaller than atom. ✓</p>	<p>Do not condone “he deduced they were electrons”</p> <p>MP2 cannot be awarded if MP1 is incorrect.</p> <p>If no other creditable answer given, one mark can be awarded for stating that the sign of the specific charge of cathode ray is opposite to that of hydrogen ion.</p>	2	AO1.1a
<b>Total</b>			<b>8</b>	

0 5

Robert Millikan experimented with oil drops to determine a value for the electronic charge.

**Figure 4** shows a stationary oil droplet between two horizontal metal plates. The plates are connected to a variable voltage supply so that the upper plate is positive. The oil droplet has mass  $m$  and charge  $Q$ .

**Figure 4**



0 5 . 1

State and explain the sign of the charge on the oil droplet.

[1 mark]

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The variable voltage supply is set to zero volts. The oil drop falls. The constant speed  $v_1$  of the falling oil droplet is found to be  $3.8 \times 10^{-5} \text{ m s}^{-1}$  and the following measurements are recorded:

$$\begin{aligned} \text{density of oil} &= 910 \text{ kg m}^{-3} \\ \text{viscosity of air} &= 1.8 \times 10^{-5} \text{ N s m}^{-2} \end{aligned}$$

0 5 . 2

Show that the mass  $m$  of the oil droplet is about  $8 \times 10^{-16} \text{ kg}$ .

[3 marks]

**0 5 . 3**

The variable voltage supply is adjusted so that the oil droplet rises at a constant speed  $v_2$ . The potential difference (pd) across the plates is  $V$  and the distance between the plates is  $d$ .

In his experiment, Millikan measured the constant speed  $v_1$  of a falling droplet when the pd was zero. He compared this with the speed  $v_2$  of the same droplet when the droplet was made to rise.

Show that 
$$\frac{v_2}{v_1} = \frac{VQ}{dmg} - 1$$

**[2 marks]****0 5 . 4**

The following measurements are made for the droplet in Question **02.2** when it is rising at constant speed.

$$V = 715 \text{ V}$$

$$v_2 = 1.1 \times 10^{-4} \text{ m s}^{-1}$$

The separation of the plates  $d = 11.6 \text{ mm}$ .

Deduce, using the equation in Question **02.3**, whether the value of the charge for this droplet is consistent with the currently accepted value of the electronic charge.

**[3 marks]**

Question 2 continues on the next page



Question	Answers	Additional comments/Guidance	Mark	AO
05.1	(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	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
05.2	(In free fall at terminal speed) $mg = 6\pi\eta rv$ ✓  Use of $m = \text{volume} \times \text{density}$ 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	3 x AO2

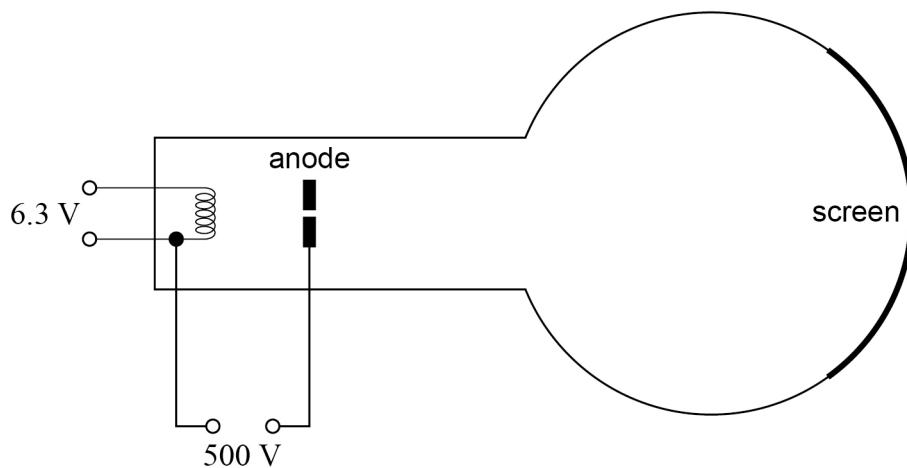
Question	Answers	Additional comments/Guidance	Mark	AO
05.3	$\frac{vQ}{d} - mg = 6\pi\eta rv_2$ ✓ Convincing algebra combining with $mg = 6\pi\eta rv_1$ to give $v_2/v_1 = \text{answer}$ ✓	MP2 is contingent on MP1	2	2 x AO2

Question	Answers	Additional comments/Guidance	Mark	AO
05.4	Use of equation from 02.3 ✓ to show $Q = 4.9 \times 10^{-19} \text{ C}$ ✓  Evidence of dividing their $Q$ by $1.6 \times 10^{-19}$ to give a consistent conclusion ✓	Use of means by substitution or manipulation Accept answer that rounds to between 4.8 and $5.0 \times 10^{-19} \text{ C}$ Using the 'show that' value for the mass gives $Q = 4.96 \times 10^{-19} \text{ C}$ Only condone ecf in MP3 for an arithmetic error in the determination of $Q$ .	3	2 x AO2 1 x AO3

Question	Answers	Additional comments/Guidance	Mark	AO
05.5	<p>(Value of viscosity) affects calculation of mass/radius of droplet ✓</p> <p>Smaller value of viscosity gives smaller force on droplet so smaller calculated weight/mass ✓</p> <p>Ref to appropriate equation AND as mass is smaller then <math>Q</math> smaller (therefore <math>e</math> smaller). ✓</p>	<p>‘affects’ can be either increase or decrease in MP1</p> <p>In MP2 allow use of relationship between the radius of the drop and the viscosity.</p> <p>Evidence of MP1 is likely to be seen in MP2.</p> <p>Do not condone use of <math>mg = 6\pi\eta r v</math> on its own</p> <p>Appropriate means either the equation from <b>02.3</b> or relationship between weight and electric field force (e.g weight = <math>mg = EQ</math>)</p>	3	3 x AO3
Total			12	

**Section B**Answer **all** questions in this section.**0 6**

In **Figure 1**, a beam of electrons travels through the aperture in the anode and hits the screen.

**Figure 1****0 6 . 1**

Explain how the electrons that form the beam are emitted.

**[1 mark]**


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**0 6 . 2**

Show that the maximum speed of the electrons in the beam is about  $1.3 \times 10^7 \text{ m s}^{-1}$ .

**[1 mark]**

0	6	.	3
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A student suggests that the apparatus can be used to demonstrate the wave properties of electrons in the beam, provided that the aperture in the anode has a suitable diameter.

Discuss whether the student is correct.  
Support your answer with a calculation.

**[3 marks]**

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**Question 1 continues on the next page**

0	6	.	4
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In 1897, J J Thomson determined a value for the specific charge of an unknown particle.

The unknown particle is now known to be the electron.

Describe **one** method to determine the specific charge of the electron.

Your answer should include:

- a description of the apparatus used and the measurements made
- a description of how the specific charge can be determined using these measurements
- an explanation of the conclusion made by Thomson from the value that he determined.

**[6 marks]**

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Question	Answers	Additional comments/Guidance	Mark	AO
06.1	Idea that filament/metal is heated (by an electric current), giving (some) electrons in the metal (sufficient) energy to leave the surface ✓	<p>Allow references to the work function (but not just <math>\phi</math>)</p> <p>Thermionic emission is not enough by itself.</p> <p>Do not allow heating of electrons.</p> <p>Reject 'accelerated' (unless it is clearly after they leave the metal) / 'ionise'</p> <p>Ignore references to processes that take place after electron leaves the metal</p> <p>Ignore references to free electrons inside the metal</p>	1	1 × AO1

Question	Answers	Additional comments /Guidance	Mark	AO
06.2	<p>Use of <math>\frac{1}{2}mv^2 = eV</math></p> <p>To give <math>v = 1.33 \times 10^7 \text{ (m s}^{-1}\text{)} \checkmark</math></p>	<p>Must see 500V for the potential difference (not 506.3V or 493.7V)</p> <p>≥ 3 SF required.</p> <p>1.325 × 10<sup>7</sup> (do not allow 1.32 × 10<sup>7</sup>)</p>	1	1 × AO2

Question	Answers	Additional comments/Guidance	Mark	AO
06.3	<p>Suggestion that, for diffraction to be demonstrated, hole diameter should be of same order of size as wavelength ✓</p> <p>Evidence of <math>\lambda = \frac{h}{p}</math> <b>OR</b> <math>\lambda = \frac{h}{\sqrt{2meV}}</math></p> <p>to give <math>5.5 \times 10^{-11}</math> (m) OR <math>5.6 \times 10^{-11}</math> (m) ✓</p> <p>Idea that this diameter is smaller than an atom / too small for hole to be made <b>and</b> therefore this apparatus cannot be used (for this speed/wavelength) / the student is <b>incorrect</b> ✓</p>	<p>Do not allow <math>\lambda &lt; \text{gap}</math> or <math>\text{gap} &lt; \lambda</math> for MP1 (Must refer to gap not just anode)</p> <p>Discussions in terms of crystalline diffraction can score MP1 and MP2.</p> <p>Must calculate <math>\lambda</math> for MP2.</p> <p>Condone use of 506.3V or 492.7V as penalised in 1.2</p> <p>Allow 1 SF or order of magnitude calculation.</p> <p>Do not ignore PoT for calculation.</p> <p>Ignore incorrect conversion to nm if m value given.</p> <p>Condone the idea that the student is correct in principle but this particular setup will not work.</p> <p>Do not allow ecf to MP3 unless their calculated hole diameter is of the order of <math>10^{-10}</math> m or smaller in MP2.</p>	3	3 × AO3

Question	Answers	Additional comments/Guidance	Mark	AO																
06.4	<p>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.</p> <table border="1" data-bbox="280 475 925 1259"> <thead> <tr> <th data-bbox="280 475 371 523">Mark</th> <th data-bbox="371 475 925 523">Criteria</th> </tr> </thead> <tbody> <tr> <td data-bbox="280 523 371 663">6</td> <td data-bbox="371 523 925 663">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.</td> </tr> <tr> <td data-bbox="280 663 371 775">5</td> <td data-bbox="371 663 925 775">A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.</td> </tr> <tr> <td data-bbox="280 775 371 916">4</td> <td data-bbox="371 775 925 916">Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td> </tr> <tr> <td data-bbox="280 916 371 1056">3</td> <td data-bbox="371 916 925 1056">One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td> </tr> <tr> <td data-bbox="280 1056 371 1136">2</td> <td data-bbox="371 1056 925 1136">Only one area discussed, or makes a partial attempt at two areas.</td> </tr> <tr> <td data-bbox="280 1136 371 1216">1</td> <td data-bbox="371 1136 925 1216">None of the three areas covered without significant error.</td> </tr> <tr> <td data-bbox="280 1216 371 1259">0</td> <td data-bbox="371 1216 925 1259">No relevant analysis.</td> </tr> </tbody> </table>	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.	<p>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.</p> <p><b>Significance</b> Very large <math>e/m</math> (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)</p> <p><b>Experimental procedures and measurements</b> For a full answer everything should be directly measurable (not Electric Field, Kinetic Energy, velocity) Except no details are required for measurement of B</p> <p><b>Determination of <math>e/m</math></b> Answers should end in <math>e/m =</math> Expected to be in steps but can carry the algebra through Allow use of measured Electric Field here. A full answer should not include <math>e</math> or <math>m</math> as part of the calculation (likely to be found in working out <math>v</math>)</p> <p><b>If methods are mixed up this can be treated as full credit for one of procedures or determination or as a partial for both.</b></p> <p><b>The minimum response required to address an area fully is given below</b></p> <p><b>Fine Beam Tube</b></p> <p><b>Experimental procedure and measurements</b> fine beam tube described / diagram including low pressure gas, (Perpendicular) magnetic field to cause electrons to move in a circle</p> <p>Radius of curved path <math>r</math>, Accelerating voltage <math>V</math>, Magnetic flux density <math>B</math></p> <p><b>Determination of <math>e/m</math></b> <math>\left(\frac{1}{2}mv^2 = eV \text{ and } r = \frac{mv}{Be}\right)</math> <math>\frac{e}{m} = \frac{2V}{r^2B^2}</math></p>	6	<p>4 × AO1</p> <p>1 × AO2</p> <p>1 × AO3</p>
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.																			
<b>Total</b>			<b>11</b>																	

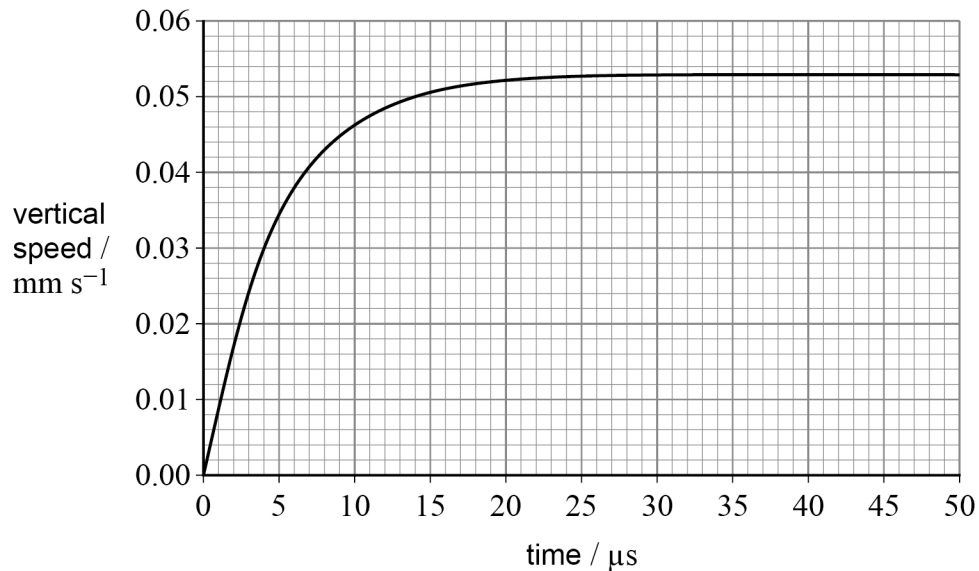
0 7

In an experiment to determine the electronic charge, a charged oil drop falls from rest between two uncharged plates.

The oil drop has a weight of  $1.2 \times 10^{-14}$  N and a radius of  $6.8 \times 10^{-7}$  m. Ignore the buoyancy force of the air on the oil drop.

**Figure 2** shows the variation of the vertical speed of the oil drop with time.

**Figure 2**



0 7 . 1

Calculate the viscosity of the air between the plates.

**[3 marks]**

viscosity = \_\_\_\_\_ N s m<sup>-2</sup>

07.2

During the experiment, an electric field is produced between the plates and is adjusted until the oil drop is stationary.

The electric field strength is  $18.8 \text{ kV m}^{-1}$ .

Discuss whether the outcome of the experiment is consistent with the accepted value for electronic charge.

**[3 marks]**

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Question	Answers	Additional comments/Guidance	Mark	AO
07.1	<p>(Reads off terminal speed from graph) to give <math>0.053 \pm 0.005 \text{ mm s}^{-1}</math> ✓</p> <p>Evidence of <math>mg = 6\pi\eta r v</math> ✓</p> <p>Substitutions seen to give <math>1.8 \times 10^{-5} \text{ (N s m}^{-2}\text{)}</math> ✓</p>	<p>Allow PoT error in MP1 If MP1 not given, allow ecf if read off misread</p> <p>Do not accept work from a gradient.</p> <p><math>W</math> or <math>mg</math> or <math>1.2 \times 10^{-14} = 6\pi\eta r v</math> is enough for MP2 Condone <math>\frac{4}{3}\pi r^3 \rho g = 6\pi\eta r v</math> for MP2.</p> <p>Calculator value = <math>1.766425562 \times 10^{-5}</math></p>	3	<p>2 × AO2</p> <p>1 × AO3</p>

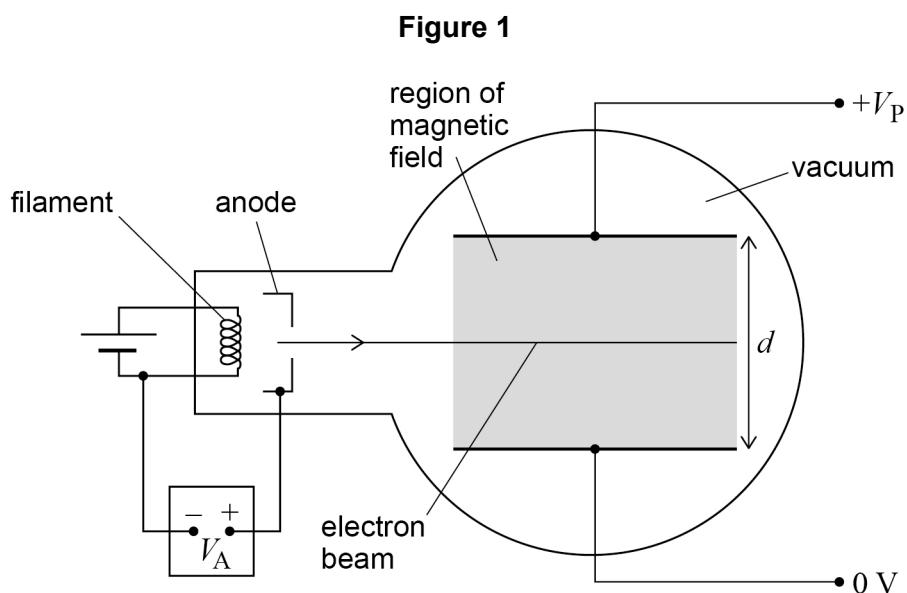
Question	Answers	Additional comments/Guidance	Mark	AO
07.2	Evidence of $EQ = mg$ ✓ $Q = 6.4 \times 10^{-19}$ (C) ✓ Divides their $Q$ by $e$ to get number of electrons <b>and</b> makes sensible comment consistent with their value ✓	By substitution – allow PoT error for $E$ in MP1 Allow $EQ = mg$ without substitution for MP1 Expect to see 4.0 or $3.99 \approx 4$ and therefore yes Condone for MP3 only (max 1) Use of $E = Q/4\pi\epsilon_0 r$ which gives $Q = 6.04 \approx 6$ so yes.	3	2 × AO2 1 × AO3
Total			6	

## Section B

Answer **all** questions in this section.

0 8 . 1

**Figure 1** shows apparatus used in an experiment to measure the specific charge of the electron.



Electrons are accelerated by the potential difference  $V_A$ .

The electrons then enter the region between two parallel metal plates, shown shaded in **Figure 1**. The parallel metal plates are separated by a distance  $d$  with a potential difference  $V_P$  across them. In the same region there is a uniform magnetic field of flux density  $B$  into the plane of the diagram.

Explain why the electron beam is undeflected in the shaded region shown in **Figure 1**.  
[2 marks]

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0	8	.	2
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Determine, using the following data, a value for the specific charge of the electron.

$$B = 1.59 \text{ mT}$$

$$V_p = 1.51 \text{ kV}$$

$$d = 5.0 \text{ cm}$$

$$V_A = 1.00 \text{ kV}$$

**[4 marks]**

specific charge = \_\_\_\_\_ C kg<sup>-1</sup>

6

Question	Answers	Additional comments/Guidance	Mark	AO
08.1	<p>Electrostatic force and magnetic force are equal in magnitude OR opposite in direction / magnetic force down and electrostatic force up OR equal and opposite</p> <p>✓</p> <p>Electrostatic force and magnetic force are equal in magnitude AND opposite in direction / magnetic force down and electrostatic force up</p> <p>AND</p> <p>Balanced <b>forces</b> / resultant force = 0 (so travels in a straight line according to Newton 1 / no (vertical) acceleration according to Newton 2) ✓</p>	<p>Allow electric force / force from electric field / force due to potential difference / force due to plates for electrostatic force.</p> <p>Ignore references to gravity.</p> <p>Electric and magnetic forces being equal without reference to magnitude or opposite is not enough for MP1.</p> <p>Ignore references to a vacuum so no collisions between particles.</p> <p>Ignore references to the directions of fields.</p> <p>Do not allow answers which suggest that the magnitude of magnetic field is equal to the magnitude of the electric field.</p> <p>Condone cancel for balanced forces in mp2 Ignore counteract in mp2. Do not allow <b>horizontal</b> force for mp2.</p>	2	2 AO2

Question	Answers	Additional comments/Guidance	Mark	AO
08.2	$Bev = \frac{eV_{(P)}}{d} \text{ OR } v = \frac{V_{(P)}}{dB} \checkmark$ $\frac{1}{2}mv^2 = eV_{(A)} \text{ OR } \frac{e}{m} = \frac{v^2}{2V_{(A)}} \checkmark$ <p>At least one correct from <math>\checkmark</math></p> <ul style="list-style-type: none"> <li>• <math>v = \frac{1.51 \times 10^3}{5 \times 10^{-2} \times 1.59 \times 10^{-3}} (= 1.9 \times 10^7 \text{ m s}^{-1})</math></li> <li>• <math>\frac{e}{m} = \frac{(\text{their } v)^2}{2 \times 1 \times 10^3}</math></li> <li>• <math>\frac{e}{m} = \frac{(1.51 \times 10^3)^2}{2 \times 1 \times 10^3 \times (5 \times 10^{-2})^2 \times (1.59 \times 10^{-3})^2}</math></li> <li>• <math>\frac{e}{m} = \frac{V_{(P)}^2}{2V_{(A)}d^2B^2}</math></li> </ul> <p><math>1.8(0380523) \times 10^{11} \text{ C kg}^{-1}</math> without using <math>1.60 \times 10^{-19}</math> or <math>9.11 \times 10^{-31} \checkmark</math></p>	<p>Allow <math>Q</math> for <math>e</math></p> <p>Condone mixed up <math>V_A</math> and <math>V_P</math> or no subscripts in first 2 marking points.</p> <p><math>\frac{e}{m} = \frac{V_{(P)}^2}{2V_{(A)}d^2B^2}</math> or any valid rearrangement gains mp1, mp2, mp3</p> <p>Substituted data can gain MP1 and MP2 (in addition to MP3)</p> <p>Condone PoT errors in mp3</p> <p>Do not credit values using <math>1.60 \times 10^{-19}</math> or <math>9.11 \times 10^{-31}</math> in mp3 or mp4</p> <p>Do not allow <math>1.76 \times 10^{11}</math> for mp4 as this is from the data booklet not the data in the question.</p> <p>If no other marks are awarded, condone max 1 for <math>\frac{e}{m} = \frac{V}{2d^2B^2}</math> with any or no <math>V</math> subscript</p>	4	1 AO1 3 AO2
<b>Total</b>			<b>6</b>	



09.2

On one occasion, the radius of a droplet was determined to be  $1.20 \times 10^{-6}$  m.  
When the droplet was stationary, the voltmeter reading was 467 V.

Show that the charge on the droplet was approximately  $8 \times 10^{-19}$  C.

$$\text{density of oil} = 880 \text{ kg m}^{-3}$$

**[3 marks]**



Question	Answers	Additional comments/Guidance	Mark	AO																
9.1	<p>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.</p> <table border="1" data-bbox="280 528 1088 1316"> <thead> <tr> <th>Mark</th> <th>Criteria</th> </tr> </thead> <tbody> <tr> <td>6</td> <td>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.</td> </tr> <tr> <td>5</td> <td>All three areas covered, at least two in detail. Whilst there will be gaps, there should only be an occasional error.</td> </tr> <tr> <td>4</td> <td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.</td> </tr> <tr> <td>3</td> <td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td> </tr> <tr> <td>2</td> <td>Only one area discussed, or makes a partial attempt at two areas.</td> </tr> <tr> <td>1</td> <td>None of the three areas covered without significant error.</td> </tr> <tr> <td>0</td> <td>No relevant analysis.</td> </tr> </tbody> </table>	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.	<p><b>Method</b> Field is off or with the switch open Measure time and distance (for falling drop) (Measure distance using lines on microscope) calculate velocity using <math>v = \frac{s}{t}</math></p> <p><b>Calculation</b> (Just quoting formulae from the formulae and data booklet is not enough to partially address this area.) <math>m = \frac{4}{3}\pi\rho r^3</math> <math>mg = 6\pi\eta r v</math> leading to <math>r = \sqrt{\frac{9\eta v}{2\rho g}}</math> or <math>r = \sqrt{\frac{9\eta v}{2\rho g}}</math> quoted</p> <p><math>\rho</math> is identified as the density of the <b>oil</b> <math>\eta</math> is identified as the viscosity of the <b>air</b></p> <p><b>Principles/Assumptions</b> (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 <math>V = \frac{4}{3}\pi r^3</math>) 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.</p>	6	6 AO1
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.																			
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0	No relevant analysis.																			

## MARK SCHEME – A-LEVEL PHYSICS – 7408/3BD – JUNE 2024

		Ignore details of Millikan's experiment that are not about determining $r$ .		
Question	Answers	Additional comments/Guidance	Mark	AO
09.2	Max ✓✓ <ul style="list-style-type: none"> <li>• Substitution into <math>V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times (1.2 \times 10^{-6})^3</math></li> <li>• Substitution of <math>m = \rho V = 880 \times \text{their volume}</math></li> <li>• Substitution of <math>Q = \frac{dmg}{V} = \frac{6.0 \times 10^{-3} \times \text{their mass} \times 9.81}{467}</math></li> </ul> $Q = 8.0(3) \times 10^{-19} \text{ (C)} \checkmark$	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.  Need $\geq 2$ sf (no ecf in mp3)	3	3 AO2

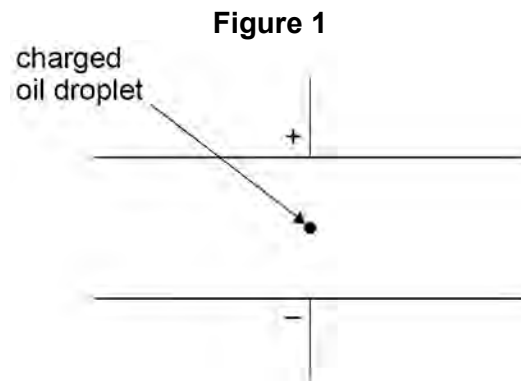
Question	Answers	Additional comments/Guidance	Mark	AO
09.3	<p>% uncertainty in <math>Q = 3 \times 4 + 1 + 0.1 + 0.2 + 2 = ((\pm)15(.3)\%) \checkmark_{1a}</math></p> <p>uncertainty in <math>Q = \frac{15}{100} \times 8.02 \times 10^{-19} = (\pm)1.2 \times 10^{-19} \text{ (C)} \checkmark_{2a}</math></p> <p><b>Alternative method for <math>\checkmark_1</math> and <math>\checkmark_2</math></b>  max value of <math>Q =</math>  <math display="block">\frac{4\pi \times (1.2 \times 10^{-6} \times 1.04)^3 \times 880 \times 1.01 \times 6 \times 10^{-3} \times 1.02 \times 9.81 \times 1.001}{3 \times 467 \times 0.998}</math> <math>(= 9.3(3) \times 10^{-19} \text{ C})</math>  <b>OR</b>  min value of <math>Q =</math>  <math display="block">\frac{4\pi \times (1.2 \times 10^{-6} \times 0.96)^3 \times 880 \times 0.99 \times 6 \times 10^{-3} \times 0.98 \times 9.81 \times 0.999}{3 \times 467 \times 1.002}</math> <math>(= 6.8(7) \times 10^{-19} \text{ C}) \checkmark_{1b}</math></p> <p>Correct use of max or min value with <math>8(.02) \times 10^{-19}</math> 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 <math>\checkmark_{2b}</math></p> <p><math>1.2 \times 10^{-19} &gt; \frac{1.60 \times 10^{-19}}{2}</math></p> <p>therefore it is not possible to confirm charge quantisation (as any value is possible) <math>\checkmark_3</math></p>	<p>Allow fractional uncertainties in <math>\checkmark_{1a}</math></p> <p>Allow ecf for <math>Q</math> and % uncertainty</p> <p><math>\checkmark_3</math> is independent if <math>1 \times 10^{-19}</math> is used or an answer that rounds to <math>1 \times 10^{-19}</math>.</p> <p><b>Alternatives for <math>\checkmark_3</math></b>  the possible range overlaps 4, 5, 6 electrons (allow 4, 5 or 5, 6 or 4, 6)</p> <p>Allow a calculated max and/or min value of <math>Q</math> (<math>8 \pm 1) \times 10^{-19}</math> (expect 7 or 9) is not an (integer) multiple of <math>1.6 \times 10^{-19}</math></p> <p>Condone because the uncertainty (not % uncertainty) is too close to <math>1.6 \times 10^{-19}</math>.</p> <p>Range or uncertainty or % uncertainty is too large is not enough without explicit comparison of absolute uncertainty with <math>1.60 \times 10^{-19}</math> in some form.</p>	3	2 AO2 1 AO3
<b>Total</b>			<b>12</b>	

### Section B

Answer **all** questions in this section.

1 0

In an experiment to measure the charge of the electron, a spherical charged oil droplet of unknown mass is observed between two horizontal parallel metal plates, as shown in **Figure 1**.



1 0

. 1

The droplet falls vertically at its terminal speed when the potential difference (pd) between the plates is zero.

A droplet of radius  $r$  falls at its terminal velocity,  $v$ .

Derive an expression for  $r$  in terms of  $v$ ,  $\eta$ ,  $\rho$  and  $g$ , where  $\eta$  is the viscosity of air and  $\rho$  is the density of the oil droplet.

**[2 marks]**

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1 0

. 2

Explain how the mass of the oil droplet can be calculated from its radius and other relevant data.

**[1 mark]**

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**1 0** . **3**

A potential difference (pd) is applied across the plates and is adjusted until the droplet is held stationary. The two horizontal parallel metal plates are 15.0 mm apart. The mass of the droplet is  $3.4 \times 10^{-15}$  kg.

The droplet is held stationary when the pd across the plates is 1560 V.

Calculate the charge of the oil droplet.

**[2 marks]**

charge = \_\_\_\_\_ C

**1 0** . **4**

A student carries out Millikan's oil drop experiment and obtains the following results for the charges on the oil drops that were investigated.

$$-9.6 \times 10^{-19} \text{ C}$$

$$-12.8 \times 10^{-19} \text{ C}$$

$$-6.4 \times 10^{-19} \text{ C}$$

Discuss the extent to which the student's results support Millikan's conclusion and how the student's conclusion should be different.

**[3 marks]**

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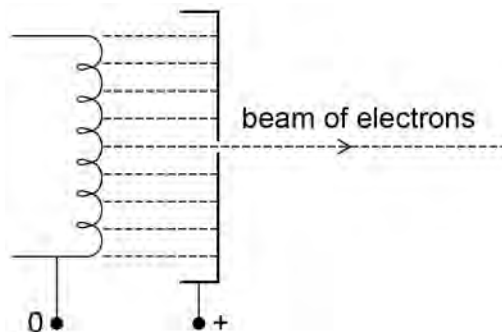
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Question	Answers	Additional Comments/Guidance	Mark	
10.1	At terminal speed ( $v$ ), the viscous force on the droplet = its weight $6\pi\eta r v = 4\pi r^3 \rho g / 3$ ✓  Manipulation leading to $r = (9 \eta v / 2 \rho g)^{1/2}$ ✓	For weight: allow $mg$ or the force of gravity on it For viscous force: allow 'drag' or 'resistance' or 'friction' Not upthrust.	1  1	
10.2	$r$ (can be calculated as above then ) used in the formula $m = 4\pi r^3 \rho / 3$ to find the droplet mass, $m$ ✓ (WTTE) Alternative ; (from $6\pi\eta r v = mg$ : as all values are known use) $m = 6\pi\eta r v / g$ ✓		1	
10.3	electric force (or $QV/d$ ) = the droplet weight (or $mg$ ) ✓ $Q =$ $\frac{mgd}{V} = \frac{3.4 \times 10^{-15} \times 9.8(1) \times 15.0 \times 10^{-3}}{1560} = 3.2 \times 10^{-19} \text{ C}$ ✓	Do not give 1 <sup>st</sup> mark if $eV/d$ given instead of $QV/d$	1  1	
10.4	Millikan's conclusion: Electron charge is $(-1.6 \times 10^{-19} \text{ C})$ (WTTE) ✓  The charge on each droplet is a whole number $\times 1.6 \times 10^{-19} \text{ C}$ which agrees with Millikan ✓  Student's results suggest $-3.2 \times 10^{-19} \text{ C}$ as smallest quantum of charge ✓	allow multiple or $n$ , where $n$ is an integer	3	

1 1

**Figure 2** shows a narrow beam of electrons produced by attracting the electrons emitted from a filament wire, to a positively charged metal plate which has a small hole in it.

**Figure 2**

1 1

. 1

Explain why an electric current through the filament wire causes the wire to emit electrons.

**[2 marks]**

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1 1

. 2

Explain why the filament wire and the metal plates must be in an evacuated tube.

**[1 mark]**

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**1 1** . **3** The potential difference between the filament wire and the metal plate is 4800 V.

Calculate the de Broglie wavelength of the electrons in the beam.

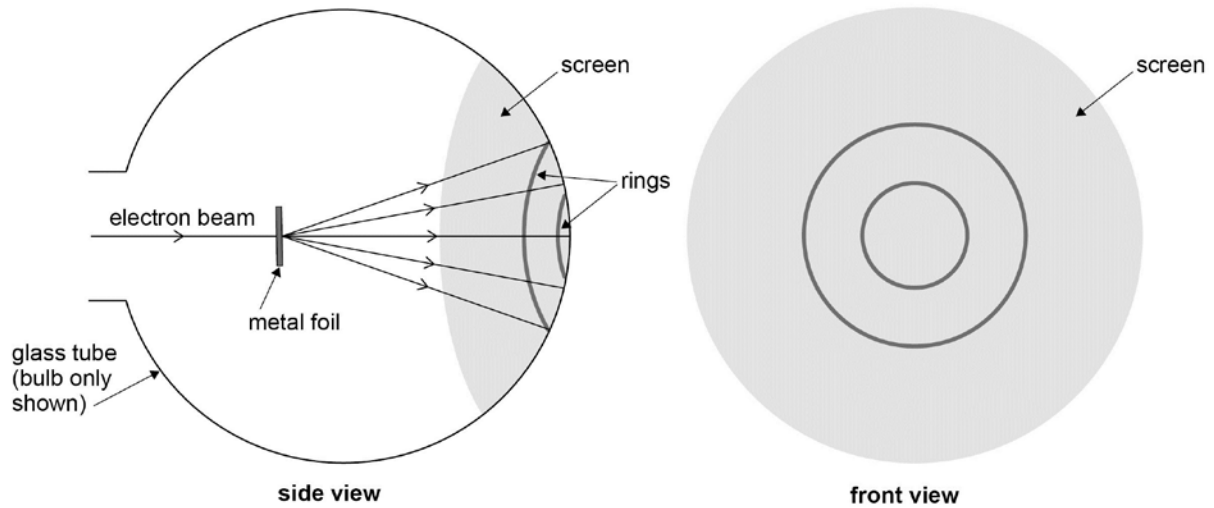
**[4 marks]**

wavelength = \_\_\_\_\_ m

**Question 2 continues on the next page**

The beam is directed at a thin metal foil between the metal plate and a fluorescent screen at the end of the tube, as shown in **Figure 3**. The electrons that pass through the metal foil cause a pattern of concentric rings on the screen.

**Figure 3**



1 1 . 4

The potential difference between the filament and the metal plate is increased. State and explain the effect this has on the diameter of the rings. **[3 marks]**

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11.1	current heats the wire ✓ electrons (in filament) gain sufficient KE (to leave the filament) ✓		1 1	
11.2	electrons would collide (or be absorbed or scattered) by gas atoms (or molecules) ✓		1	
11.3	Rearrange $\frac{1}{2} m v^2 = eV$ to give $v = (2eV/m)^{1/2}$ or correct substitution in equation ✓  $v = \left( \frac{2 \times 1.6 \times 10^{-19} \times 4800}{9.1 \times 10^{-31}} \right)^{1/2} = 4.1 \times 10^7 \text{ m s}^{-1} \checkmark$  $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.1 \times 10^7} \checkmark = 1.8 \times 10^{-11} \text{ m} \checkmark$		1 1 1 1	
11.4	Increasing the pd increases the speed (or kinetic energy or momentum) of the electrons ✓ which decreases their de Broglie wavelength ✓ so they are diffracted less so the rings become smaller ✓	www.mathswithmatt.co.uk	1 1 1	