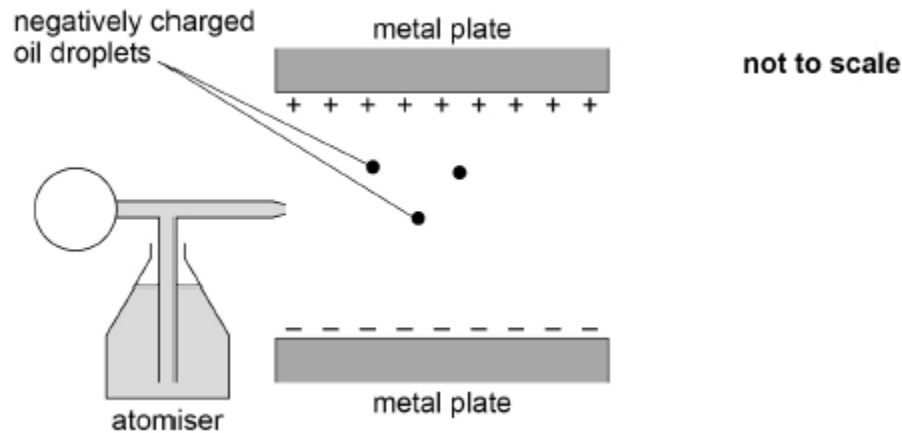


1.

The diagram 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.

- (a) 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.

Weight/gravitational force AND electric/electrostatic force ✓
Equal (magnitudes) and opposite directions,
AND one direction at least specified

w ↓ F_e ↑

(2)

- (b) 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 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.

$$\begin{aligned}
 mg &= 6\pi\eta rv & \rho &= \frac{m}{V} = \frac{m}{\frac{4}{3}\pi r^3} \longrightarrow m = \frac{4}{3}\pi r^3 \rho \\
 \frac{4}{3}\pi r^3 \rho g &= 6\pi\eta rv & \longrightarrow r &= \sqrt{\frac{9\eta v}{2\rho g}} = \sqrt{\frac{9 \times 1.8 \times 10^{-5} \times 1 \times 10^{-4}}{2 \times 880 \times 9.81}} = 9.68 \times 10^{-7} \text{ m} \\
 & & & \approx 1 \times 10^{-6} \text{ m}
 \end{aligned}$$

(3)

- (c) 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.

$$W = Fe$$

$$mg = \frac{Ve}{d}$$

$$\frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}} = 3 \text{ electrons}$$

The number of excess electrons on the droplet is 3 ✓

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 ✓

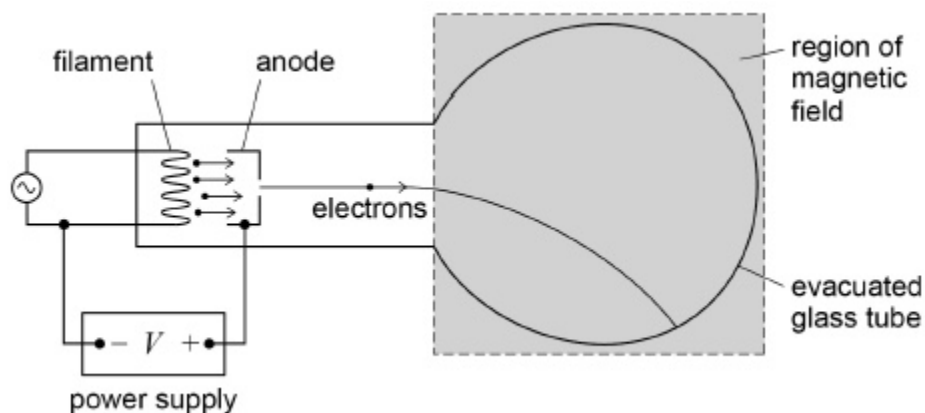
It is not possible for both droplets to remain stationary / the student is wrong ✓

(3)

(Total 8 marks)

2.

The diagram 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.

(a) Describe the process that releases the electrons emitted at the filament.

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) $\leq$ energy supplied to an electron/electron energy ✓
Thermionic emission ✓

(3)

- (b) The table shows the data collected when determining the specific charge of the electron by the method shown in the diagram.

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 $\frac{2V}{B^2 r^2}$

Handwritten derivation:

$$\frac{mv}{r} = Bev \rightarrow e = \frac{mv}{Br} \quad \text{speed}$$

$$e = \frac{m^2 v^2}{B^2 r^2} = \frac{m^2 \left(\frac{2Ve}{m} \right)}{B^2 r^2}$$

$$KE = \frac{1}{2} mv^2 \rightarrow VQ = \frac{1}{2} mv^2 \rightarrow v^2 = \frac{2VQ}{m} = \frac{2Ve}{m}$$

$$PD \ V = \frac{W}{Q} = \frac{KE}{Q} \rightarrow KE = VQ$$

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

- (c) Using data from the table, calculate a value for the specific charge of the electron. Give your answer to an appropriate number of significant figures.

$$\frac{e}{m} = \frac{2V}{B^2 r^2} = \frac{2 \times 320}{(1.5 \times 10^{-3})^2 \times (4 \times 10^{-2})^2} = 1.78 \times 10^{11} \text{ C/kg} \approx 1.8 \times 10^{11} \text{ C/kg}$$

specific charge of the electron = _____ C kg⁻¹

(2)

- (d) 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.

The specific charge of the cathode rays/the particles was(much) larger/greater than the hydrogen ion/proton ✓

2
2

This provided evidence that cathode rays were composed of electrons/particles which have a (very) small mass / have a high (negative) charge

OR

Mass (much) smaller than the mass of a hydrogen (ion)/proton

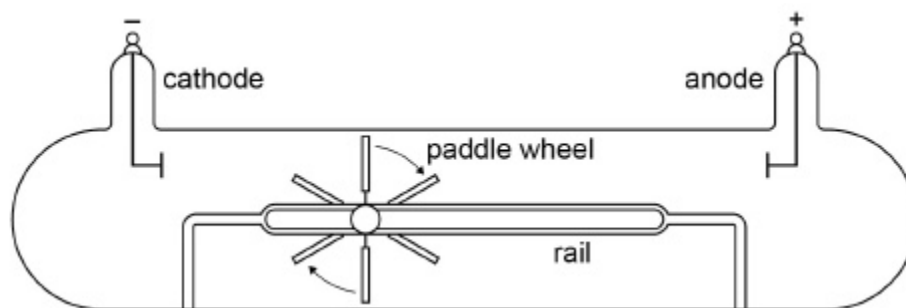
(2)

(Total 9 marks)

3.

The diagram 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.



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

Cathode rays/electrons move from cathode toward anode

The paddle wheel has gained energy from cathode rays/electrons.

(2)

- (b) Later experiments showed that cathode rays are electrons in motion.

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

Electrons are pulled out/escape from atoms OR gas atoms are ionised ✓

Condense molecules as alternative to atoms.

(Positive ions generated near the cathode are attracted to the cathode causing free) electrons emitted from the cathode. ✓

Electrons are accelerated toward the anode (by the potential difference) ✓

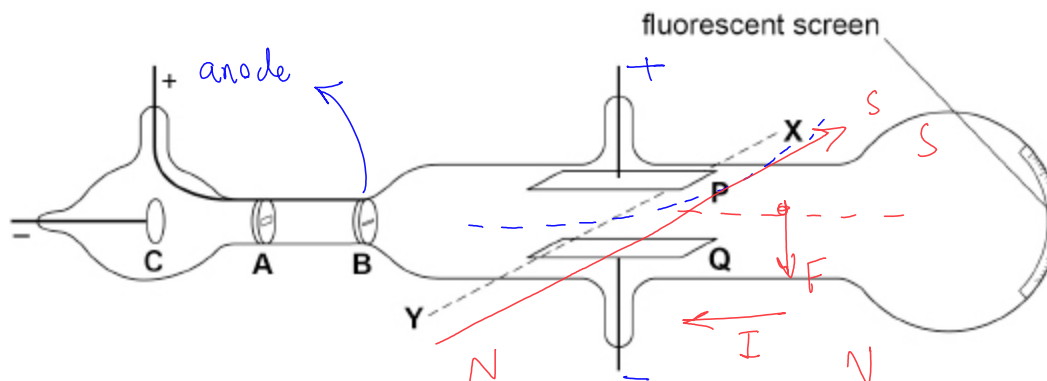
(3)

Give a reason for your answer.

Effect: Paddle wheel rotates more ✓

(Total 7 marks)

The figure shows a diagram of a discharge tube used by JJ Thomson to investigate cathode rays.



(a) 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.

(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).

- (b) **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.

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

☐

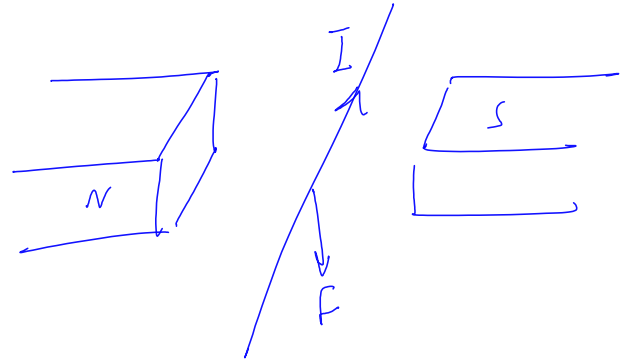
from **Q** to **P**

☐

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

☐

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

☒


(1)

- (c) 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.

electric field strength only _____

magnetic flux density only _____

(3)

- (d) Using the apparatus in the figure above, 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)

(Total 8 marks)