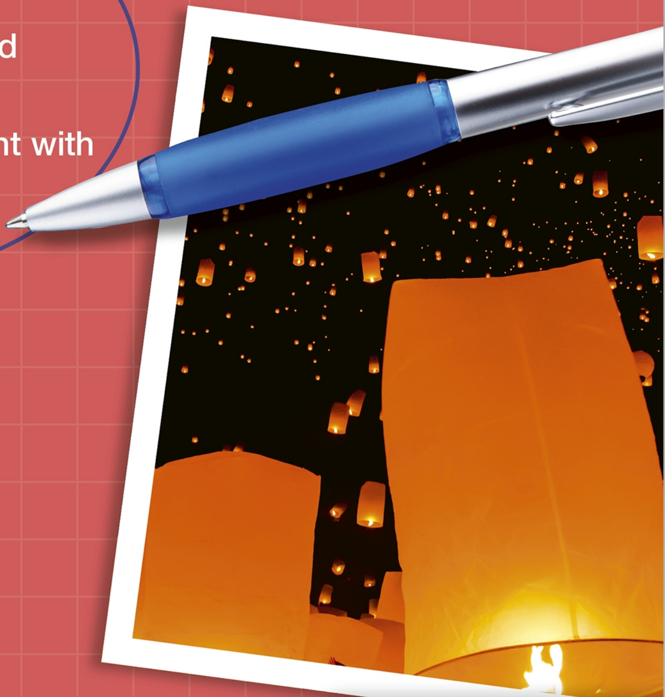
WORKBOOK

AQA A-LEVEL

Physics 2

TOPICS 6–9 and TOPIC 12

- Build confidence with practice questions
- Practise key maths and practical skills
- Prepare for assessment with exam-style questions



Jeremy Pollard

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WORKBOOK

AQA A-LEVEL

Physics 2

Year 2 Topics

- Thermal physics
- Fields and their consequences
- Nuclear physics
- Astrophysics
- Turning points in physics

Jeremy Pollard

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Contents

About this book

1 **This workbook** will help you to prepare for AQA A-level Physics Topics 6.2, 7–9 and 12.

2 **These topics** could be assessed in:

- A-level Paper 2, which lasts for 2 hours and covers Topics 6.2 (Thermal physics) and 7 and 8. Paper 2 is worth 34% of the A-level. There is a mixture of short- and long-answer questions, worth 60 marks, and 25 multiple-choice questions.
- A-level Paper 2, which assumes knowledge from Sections 1–6.1.
- A-level Paper 3, which lasts for 2 hours and covers practical skills and data analysis and Topics 9–12 or 13. Paper 3 is worth 32% of the A-level.

3 **For each topic** in this workbook there are:

- stimulus materials, including key terms and concepts
- short-answer questions that build up to exam-style questions
- spaces for you to write or plan your answers
- questions that test your mathematical skills

4 **Answering the questions** will help you to build your skills and meet the assessment objectives AO1 (knowledge and understanding), AO2 (application) and AO3 (analysis).

5 **Worked answers** are included throughout the practice questions to help you understand how to gain the most marks.

6 Icons next to the question will help you to identify:


where the practical elements of the course are covered


where your calculations skills are tested


where questions draw on synoptic knowledge, i.e. content from more than one topic

how long this question should take you

7 **You still need** to read your textbook and refer to your revision guides and lesson notes.

8 **Marks available** are indicated for all questions so that you can gauge the level of detail required in your answers.

9 **Timings** are given for the exam-style questions to make your practice as realistic as possible.

10 **Answers** are available at: **www.hoddereducation.co.uk/workbookanswers.**

6.2 Thermal physics

Thermal energy transfer

The first law of thermodynamics — the internal energy U of particles in a system can be increased when energy is transferred into it by heating or when work is done on it.

$$W = p\Delta V$$
$$Q = mc\Delta\theta$$
$$Q = ml$$

where W is work done, p is pressure, ΔV is change in volume, m is mass, c is specific heat capacity, Q is thermal energy, l is specific latent heat and $\Delta\theta$ is change in temperature.

Practice questions ?

1 Crushed ice (100 g) at an initial temperature of –14°C is put into a vacuum flask. It is heated with an electrical heater that supplies heat energy at a rate of 98 W. After 30 s, the temperature of the ice has risen to 0°C. Calculate the specific heat capacity of ice. (AO2) **1 mark**

A 4200 J kg^{-1} K^{-1}

B 2100 J kg^{-1} K^{-1}

C 420 J kg^{-1} K^{-1}

D 210 J kg^{-1} K^{-1}

2 Calculate the work done on the air inside a sealed bicycle pump of internal area 4.0 cm^2, at a normal air pressure of 101 kPa, when it is compressed by 20 cm. (AO2) **3 marks**

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3 As water freezes, which of the following does **not** happen? (AO1) **1 mark**

A Thermal energy is transferred from the water to the surroundings.

B The temperature decreases.

C Molecular motion of the water reduces.

D The intermolecular forces between the water molecules increase.

4 **a** Define the specific heat capacity of water. (AO1) **2 marks**

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b A jeweller is making some dress jewellery using an ingot of copper with a mass of 47 g. The ingot is heated to a temperature of 990°C before it is rapidly cooled inside an insulated copper can of mass 20 g containing 50 g of water, as shown in Figure 6.1. The temperature of both the water and the copper can is initially 84°C. The hot copper ingot heats the water and the can until their temperature reaches 100°C, before some of the water turns to steam.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}

specific heat capacity of copper = 390 J kg^{-1} K^{-1}

specific latent heat of vaporisation of water = 2.3 × 10^{6} J kg^{-1}

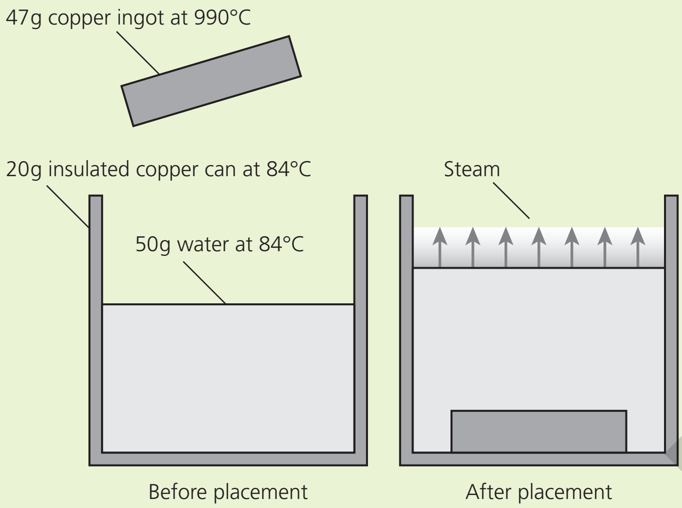

Figure 6.1

i Giving your answer to an appropriate number of significant figures, use the data in the question to calculate how much thermal energy is transferred from the copper block as it cools to 100°C. (AO2) **2 marks**

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ii Assuming that no thermal energy is lost to the surroundings, determine how much thermal energy is available to make steam. (AO2) **2 marks**

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iii Use your answer to part **bii** to determine the maximum mass of steam that could be generated as a result of this process. (AO2) **1 mark**

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Ideal gases

The empirical gas laws (involving pressure *p*, volume *V*, absolute temperature *T* and number of moles *n* of a gas) are:

$$p \propto \frac{1}{V} \qquad V \propto T \quad p \propto T \quad V \propto n$$

The ideal gas equation is:

$$pV = nRT \text{ or } pV = NkT$$

where *R* is the molar gas constant, *N* is the number of molecules and *k* is the Boltzmann constant.

Using the Avogadro constant N_A:

$$M_m = N_A m$$

where m is the molecular mass of one gas particle and M_m is the mass of 1 mole of gas molecules (molar mass).

Absolute zero is the temperature at which molecular motion stops: –273.15°C, the zero temperature, 0 K, of the absolute (Kelvin) scale.

$$T\,(\text{in K}) = T\,(\text{in °C}) + 273.15$$

Practice questions

5 An ideal gas is contained inside a sealed tin can with a volume of $0.0004\,\text{m}^3$. The pressure of the gas is 1.6×10^6 Pa at a temperature of 22°C. Calculate the number of moles of gas inside the tin can.

Take $R = 8.31\,\text{m}^2\,\text{kg}\,\text{s}^{-2}\,\text{K}^{-1}\,\text{mol}^{-1}$ (AO2) **1 mark**

A 3.5×10^{-6} ☐

B 2.16 ☐

C 0.29 ☐

D 0.26 ☐

6 Calculate the temperature of 0.03 moles of an ideal gas, sealed inside a football with an internal volume of $300\,\text{cm}^3$ at a pressure of 2.5 atm.

Take $R = 8.31\,\text{m}^2\,\text{kg}\,\text{s}^{-2}\,\text{K}^{-1}\,\text{mol}^{-1}$ and atmospheric pressure to be 101 kPa. (AO2) **3 marks**

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7 The gas laws are empirical in their nature. In this case, empirical means: (AO1) **1 mark**

A The laws are based on observations only. ☐

B The laws are based on previous models. ☐

C The laws are based on the work of other scientists. ☐

D The laws are based on theoretical first principles. ☐

Molecular kinetic theory model

Assumptions:

- a large number of identical, small, hard spherical gas molecules moving randomly with a mean velocity
- $V_{molecules} << V_{container}$
- all collisions are elastic
- all molecules obey Newton's laws of motion
- molecular separation >> molecular diameter
- no intermolecular forces
- time between collisions >> collision time

The pressure, volume, number of particles, their masses and their root mean square (rms) speeds c_{rms} are related by:

$$pV = \frac{1}{3}Nm(c_{rms})^2 \text{ and } p = \frac{1}{3}\rho(c_{rms})^2$$

where ρ is the density of the gas. If the average molecular kinetic energy is $\overline{E_k}$ then:

$$pV = \frac{2}{3} \times N \times \overline{E_k} \text{ or } \overline{E_k} = \frac{3}{2} \times \frac{n}{N} \times RT = \frac{3}{2} \times \frac{R}{N_A} \times T$$

or:

$$\overline{E_k} = \frac{3}{2}kT \text{ (for one particle)}$$

Practice questions ?

8 The pressure inside an inflated rugby ball is measured to be 62 kPa. The mass of the air inside the ball is 14 g and the volume of the ball is 4500 cm^3. Assuming that the air behaves as an ideal gas, calculate the rms speed of the air particles. (AO2) **4 marks**

Worked example

Step 1: The equation needed is:

$$p = \frac{1}{3}\rho(c_{rms})^2$$

Rearrange this to make c_{rms} the subject:

$$c_{rms} = \sqrt{\frac{3p}{\rho}} \quad ✓$$

Step 2: Calculate the density of the gas inside the rugby ball:

$$\rho = \frac{m}{V} = \frac{14 \times 10^{-3}\,\text{kg}}{4500 \times 10^{-6}\,\text{m}^3} = 3.1\,\text{kg}\,\text{m}^{-3} \quad ✓$$

Step 3: Insert the values for pressure and density into the equation:

$$c_{rms} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3 \times 62 \times 10^3\,\text{Pa}}{3.1\,\text{kg}\,\text{m}^{-3}}} = 244.9\,\text{m}\,\text{s}^{-1} \quad ✓$$

Step 4: Round to the appropriate number of significant figures: 244.9 = 240 m s^{-1} (2 s.f.) ✓

9 The density of oxygen molecules at STP (standard temperature and pressure) is 1.43 kg m^{-3}. STP is defined as a temperature of 0°C and a pressure of 100 kPa. Calculate the rms speed of oxygen molecules at STP. (AO2) **3 marks**

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10 An ideal gas is put into a container. Which of the following changes would produce the highest increase in the pressure of the gas? (AO1) **1 mark**

A doubling the volume of the container ◯

B doubling the number of molecules of the gas ◯

C doubling the rms speed of the molecules ◯

D doubling the temperature (measured in kelvin) ◯

Exam-style questions

48

1 **Required practical 8** is an investigation of Boyle's law (constant temperature) and Charles's law (constant pressure) for a gas.

Figure 6.2 shows part of the shock-absorber system on a car. It consists of a piston moving inside a sealed cylinder containing an ideal gas at a constant temperature of 290 K. The pressure p in the cylinder is 20×10^4 Pa when the volume V is 0.5×10^{-3} m^3.

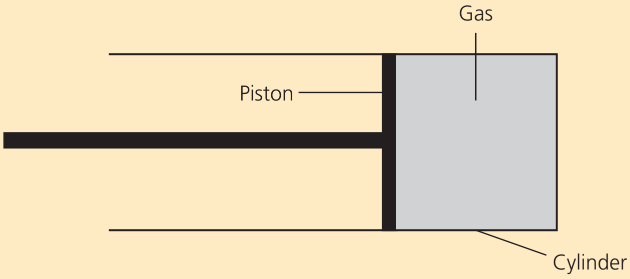

Figure 6.2 Part of a shock-absorber system

Figure 6.3 shows these data plotted on a pressure–volume graph.

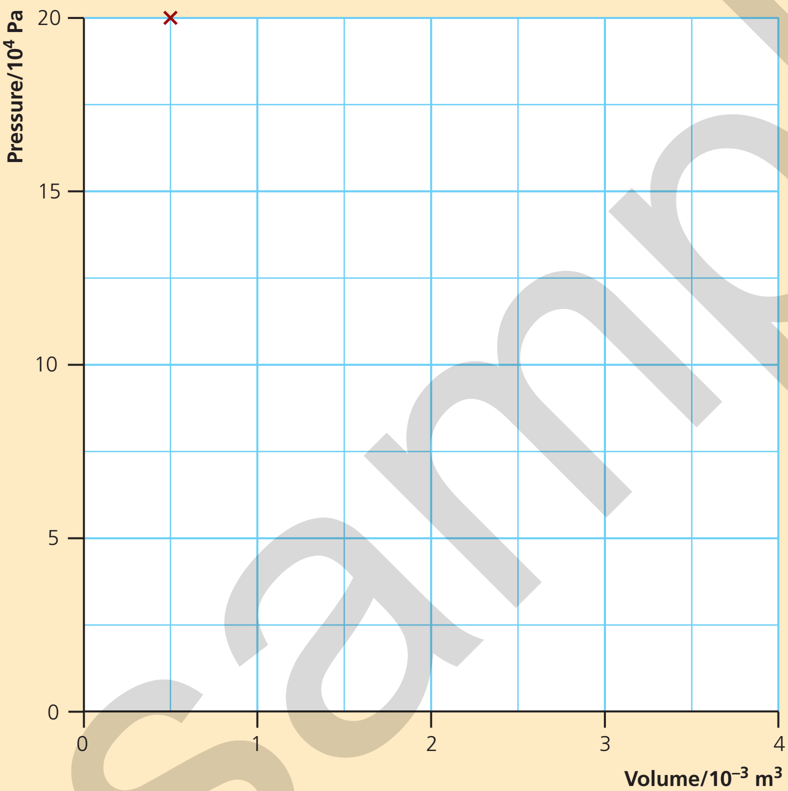

Figure 6.3

a Plot two more points on the graph and draw a best-fit line to show the variation of the pressure of the gas as the piston is slowly pulled out, increasing the volume. You can assume that the temperature of the gas remains constant. **3 marks**

b **i** Use the data to determine the number of molecules of the gas inside the cylinder. **2 marks**

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ii Use your answer to part **bi** to calculate the total kinetic energy of the gas molecules. **3 marks**

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c The molecular kinetic theory model of an ideal gas describes the behaviour of an ideal gas under different pressures, volumes and temperatures. State four assumptions of this model. **4 marks**

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2 A student carried out an experiment to measure l_v, the specific latent heat of vaporisation of water. She was told that the equation:

$$VIt = ml_v + E$$

could be used to determine l_v and E is the thermal energy lost to the surroundings.

She used the equipment shown in Figure 6.4.

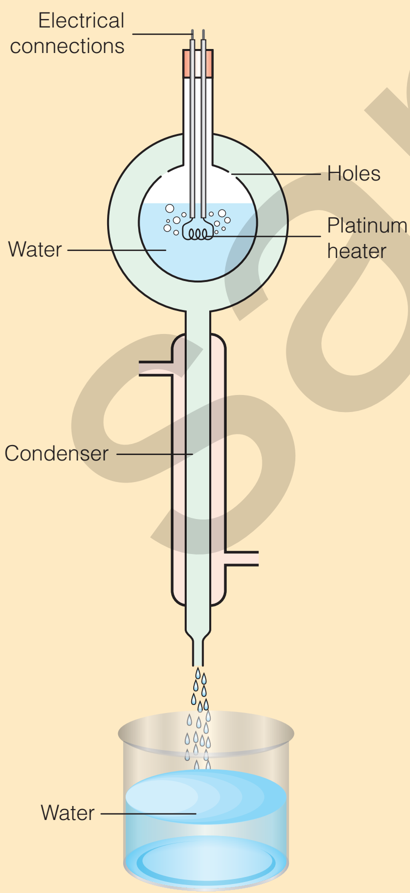

Figure 6.4 Equipment to measure specific latent heat of vaporisation of water

a **i** Complete the following table, stating the measuring instrument that could be used to measure the values needed in the equation, and suggesting a suitable resolution for the instruments. **4 marks**

Value	Measuring instrument	Suggested resolution
V		
I		
t		
m		

ii Use Figure 6.4 to describe a procedure to determine the value of l_v. The student is told the following conditions must apply to her experiment.

- The initial volume of water is 200 cm^3.
- I must not exceed 5.0 A.
- The result for l_v must be obtained using a graphical method.
- The experimental procedure must involve only one independent variable. **4 marks**

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iii Complete the following table, detailing two safety precautions that should be addressed in this experiment. **2 marks**

Hazard	Risk	Control measure

b The student collects the data shown in Table 6.1.

Table 6.1

Time, *t*/s	60	120	180	240	300
Mass of water in beaker, *m*/g	1.1	2.8	4.3	5.9	7.6

i Plot the data on the grid in Figure 6.5 and draw a suitable line of best fit. **2 marks**

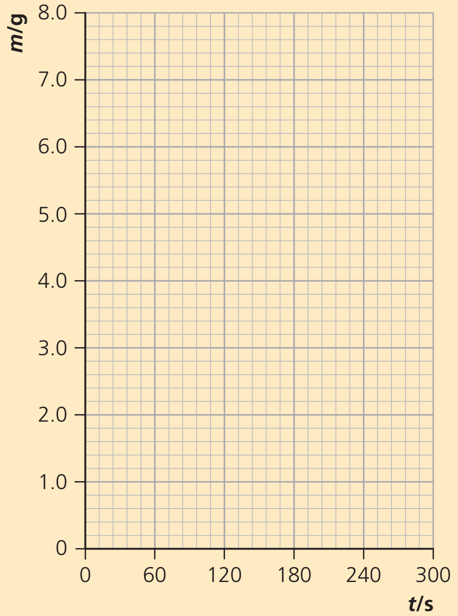

Figure 6.5

ii Use your graph to calculate a value for l_v in kJ kg^{-1}. **4 marks**

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l_v = ... kJ kg^{-1}

iii Use your graph to determine the thermal energy E lost in this experiment. **3 marks**

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E = ... J

c i The student looks up the value for the specific latent heat of vaporisation for water in an online data table. She finds the value to be 2260 kJ kg^{-1}. Use the value that you determined in bii to determine the percentage error in her value. **1 mark**

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Percentage error in l_v = ... %

ii Suggest and explain **two** ways to reduce the error that you calculated in ci. **2 marks**

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12.1 The discovery of the electron

Cathode rays

When an electric current passes through a low-pressure gas, a faint glow appears to move from the cathode to the anode, as shown in Figure 12.1.

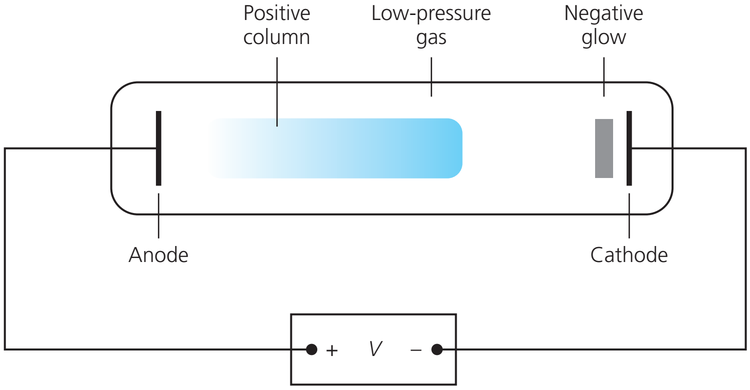

Figure 12.1 Cathode ray tube

These 'rays' were known as cathode rays and are now known to be beams of electrons.

Practice questions

1 Explain why beams of electrons became known as 'cathode rays'. (AO1) **1 mark**

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2 Explain why different low-pressure gases glow with different colours when a beam of electrons passes through them. (AO1) **2 marks**

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3 Explain why the direction of the path of a beam of electrons within a discharge tube will change when a magnetic field is brought up close to the tube. (AO1) **2 marks**

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4 Explain why it is possible to use Fleming's left hand rule to conclude that the electrons inside 'cathode rays' are negatively charged. (AO1) **3 marks**

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Thermionic emission of electrons

Electric current passing through a metal filament cathode inside a vacuum causes conducting electrons (mass *m* and charge *e*) at the surface of the metal to heat up, gain kinetic energy and escape the surface. They are repelled from the cathode and attracted towards an anode. The higher the pd *V* between the two electrodes, the higher the kinetic energy of the electrons.

$$\text{work done on the electron} = \frac{1}{2}mv^2 = eV$$

Practice questions ?

5 An electron deflection tube accelerates electrons with a pd of 3500 V. Ignoring relativistic effects, calculate the speed of the electrons in the beam. (AO2) **2 marks**

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6 Explain how thermionic emission of electrons by an 'electron gun' occurs and why it requires the gun to be inside a vacuum. (AO1) **2 marks**

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7 In 1901, Owen Richardson proposed the following equation to describe thermionic emission:

$$I = 0.3 \times 10^6 \times AT^2 e^{-\frac{\phi}{kT}}$$

where *A* is the area of the thermionic emitter, *T* is its temperature, ϕ is its work function and *k* is the Boltzmann constant. Tungsten is used as the coil of a thermionic emitter, operating at a temperature of 3000 K. The length of the filament is 53.3 cm with a diameter of 46 μm and the work function of tungsten is 4.5 eV. Calculate the thermionic current *I*. (AO2) **4 marks**

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8 The original Geissler tubes and induction coils used by J.J. Thomson could operate up to 100 000 V. Calculate the kinetic energy of the electrons in the beam at this potential difference. (AO2) **2 marks**

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Specific charge of the electron

The charge-to-mass ratio $\frac{e}{m}$ can be determined by passing a beam of electrons through a vacuum where an electric field acts in the opposite direction to a magnetic field, as shown in Figure 12.2.

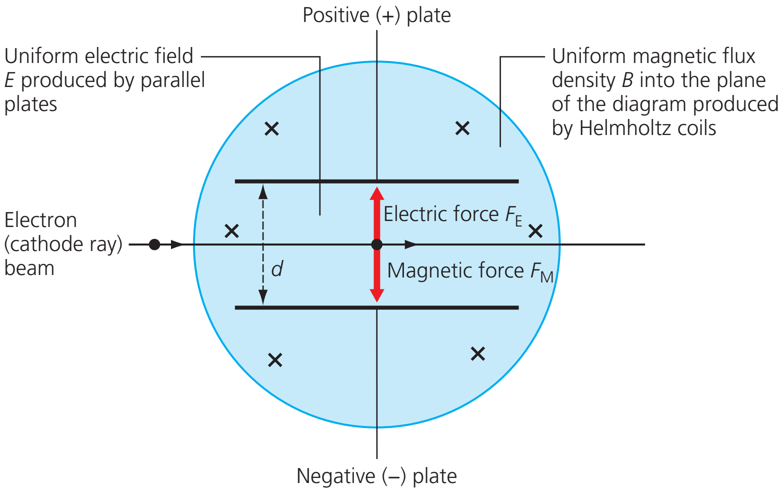

Figure 12.2 Experimental setup to measure specific charge of the electron

$$F_E = F_M \Rightarrow \frac{eV}{d} = Bev \Rightarrow v = \frac{V}{Bd}$$

The electric field is switched off and the magnetic field is adjusted to make the electron beam move in a circle:

$$Bev = \frac{mv^2}{r} \quad \Rightarrow \quad v = \frac{Ber}{m}$$

Hence:

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

In 1897, J.J. Thomson concluded that:

- cathode rays were not a new form of electromagnetic wave
- electrons are negatively charged
- the charge-to-mass ratio for all electrons is the same

Practice questions ?

9 **a** Explain why the apparatus shown in Figure 12.2 can also be described as a 'velocity selector' for electron beams. (AO1) **2 marks**

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b Explain why Thomson concluded that electrons were negatively charged. (AO1) **1 mark**

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10 In an experiment to determine the specific charge of the electron, a student accelerated electrons within a fine beam tube. They passed into an electric field between two parallel plates, 50 mm apart with a potential difference of 375 V. A magnetic field perpendicular to the direction of motion of the beam with a magnitude of 0.75 mT was able to make the beam move in a straight line, correcting the deflection due to the electric field. The electric field was then switched off and the electrons were observed to travel in a circular path with a diameter of 155 mm. Calculate the specific charge of the electron. (AO2) **2 marks**

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11 Modern experiments have shown that the specific charge of the electron is $1.76 \times 10^{11}\,C\,kg^{-1}$, and, using proton beams (H^+ ions), the specific charge of the proton is $9.6 \times 10^{7}\,C\,kg^{-1}$. Calculate the electron to proton mass ratio. (AO2) **3 marks**

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Principle of Millikan's determination of the electronic charge, *e*

In 1913, Robert Millikan measured the charge on the electron independently of its mass as shown in Figure 12.3.

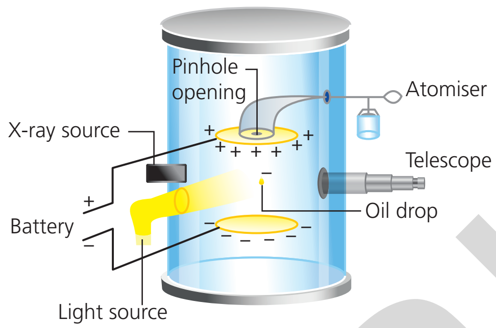

Figure 12.3 Millikan's experimental apparatus

A charged oil drop is stationary between two oppositely charged plates, balanced by the upwards electrical force and its weight. Millikan used X-rays to ionise the oil drops with different integer charges. By selecting different drops to measure, he measured a value of *e* and in the process proved that charge is quantised.

Practice questions ?

12 a An oil drop of mass 3.3×10^{-15} kg with a single excess negative charge ($n = 1$) is held stationary in a Millikan's apparatus by a voltage V applied between two metal plates 25 mm apart. Calculate the voltage V between the two metal plates. (AO2) **2 marks**

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b Describe how Stokes' law can be used to determine the weight of the oil drop in a Millikan's oil drop experiment. (AO1) **2 marks**

13 Using Millikan's method, a student measured the speed an oil drop, v, falling through the air inside the apparatus to be 0.5 mm s^{-1}. The density of the oil ρ is 866 kg m^{-3} and the viscosity of air η is 1.8×10^{-5} N s m^{-1}. The drag force F_D acting on the oil drop is given by Stokes' law:

$$F_D = 6\pi\eta r v$$

Use Stokes' law to measure the radius of the drop and hence calculate the mass of the oil drop. (AO2) **5 marks**

14 In a Millikan's apparatus, the two metal plates are a distance of 5.0 mm apart. An oil drop, with a mass of 1.4×10^{-15} kg and a charge of 6.4×10^{-19} C, is held stationary by an electric field applied between the two plates. Ignoring the upthrust due to the air, calculate:

a the electric field strength between the two plates (AO2) **3 marks**

b the potential difference across the plates (AO2) **2 marks**

Exam-style questions

1 An electron gun produces a beam of electrons inside a vacuum tube, as shown in Figure 12.4.

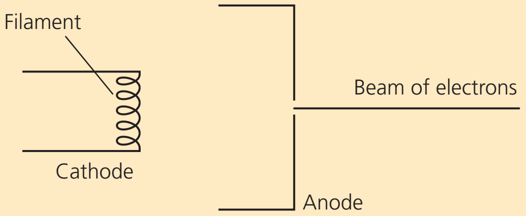

Figure 12.4

a **i** The filament current is increased. Describe and explain the effect that this has on the electron beam. **2 marks**

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ii The anode potential is now increased. Describe and explain the effect that this has on the electron beam. **2 marks**

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b The electron beam is fired into a uniform magnetic field perpendicular to the direction of motion of the beam, as shown in Figure 12.5.

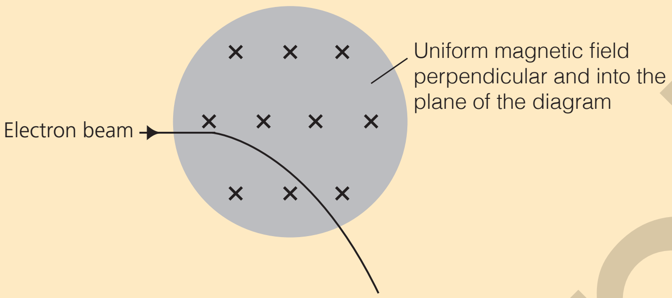

Figure 12.5

i The electrons now move in a circular path at a constant velocity inside the magnetic field. Explain why the electrons move in this way. **3 marks**

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ii The radius of curvature of the beam is 68 mm when the magnetic field density is 0.60 mT, and the electrons within the beam have a velocity of $7.4 \times 10^6\,m\,s^{-1}$. Calculate the specific charge of the electrons, giving your answer to an appropriate number of significant figures. **4 marks**

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iii Describe the historical significance of the value of the specific charge of the electron when compared to the specific charge of the H^+ ion. **2 marks**

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