

Electron diffraction and wave–particle duality worksheet

35–40 minutes independent practice + 15–20 minutes review | 38 marks

AQA AS Physics 7407 • First-year A Level 7408

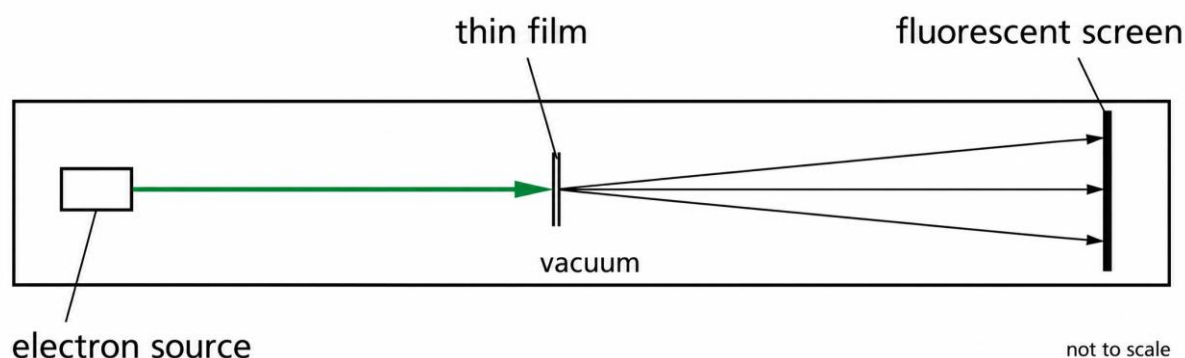
Specification points covered

AQA AS 7407 / first-year A Level 7408: 3.2.2.4 — electron diffraction, wave–particle duality, $\lambda = h/p = h/(mv)$, momentum changes, peer review and validation.

Supporting content: 3.2.2.1 — photoelectric evidence; 3.2.2.2 — electronvolts; 3.4.1.6 — momentum; 3.4.1.8 — kinetic energy. Instrument-specific relationships are supplied.

A thin-film quality check

A sensor manufacturer tests a very thin protective film before approving a production batch. Electrons pass through a test area containing many small, differently oriented crystals and form diffraction rings on a fluorescent screen. The team must choose a beam setting that gives measurable rings, then decide what the observations show about electrons.



Use $h = 6.63 \times 10^{-34} \text{ J s}$, $m_e = 9.11 \times 10^{-31} \text{ kg}$ and $e = 1.60 \times 10^{-19} \text{ C}$. $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$; $1 \text{ pm} = 10^{-12} \text{ m}$. Use the non-relativistic model throughout. Show calculations in blank spaces and explanations on ruled lines. Diagrams are schematic: do not measure them.

1. Describe the electron beam [2 marks]

(a) State what is meant by wave–particle duality. [1 mark]

(b) In an initial low-energy test, electrons have de Broglie wavelength 180 pm. Calculate the momentum of one electron. [1 mark]



2. Choose the test-beam energy [7 marks]

The electron source accelerates electrons from rest through a potential difference U . Assume the kinetic energy gained is $E_k = eU$ and that there are no energy losses before the film.

(a) For $U = 1.20$ kV, calculate the electron speed and de Broglie wavelength. Give the wavelength in pm. [3 marks]

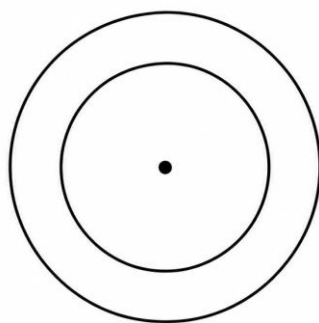
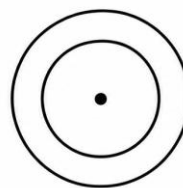
(b) The first test requires a wavelength between 30 pm and 40 pm, inclusive. Is 1.20 kV a suitable setting? Justify your decision. [1 mark]

(c) A technician says, "Doubling U halves the wavelength." Use $E_k = eU$ and $E_k = \frac{1}{2}m_e v^2$ to obtain an expression for λ in terms of U . Use it to correct the claim, stating the voltage multiplier that would halve λ . [3 marks]



3. Interpret the diffraction pattern [8 marks]

The two screen patterns below are obtained with the same film containing many differently oriented crystals, the same film-to-screen distance and the same alignment, but different electron momenta. Corresponding rings are smaller in Pattern B. Their drawn size ratio is not a measured result.

**Pattern A****Pattern B**

schematic — not to scale

(a) Explain why a ring diffraction pattern provides evidence that electrons have wave properties. Identify where in the apparatus the diffraction occurs. [2 marks]

(b) Which pattern corresponds to the greater electron momentum? Explain the full chain linking momentum to the observed ring sizes. [3 marks]

(c) For the beam giving Pattern A, the number of electrons reaching the film each second is doubled, but each electron has the same momentum as before. Predict the ring diameters and brightness. Assume the screen responds linearly and scattering probabilities are unchanged. [2 marks]

(d) After a thin-film sample is changed, the ring diameters change even though the beam momentum is unchanged. A learner concludes that $\lambda = h/p$ has failed. Give one reason why this conclusion is not justified. [1 mark]



4. Keep the ring inside the measuring region [7 marks]

For this same film and fixed geometry, a calibration model relates the diameter D of one chosen ring to accelerating voltage U : $D\sqrt{U} = \text{constant}$. This relationship is supplied; it is not a law you need to recall. At $U = 1200 \text{ V}$, $D = 28.0 \text{ mm}$. Use U in volts consistently. The instrument can measure this ring reliably only when $24.0 \text{ mm} \leq D \leq 32.0 \text{ mm}$.

(a) Use the calibration model to calculate D at $U = 2700 \text{ V}$. [2 marks]

(b) During a check on the same film, D is measured as 21.0 mm . Calculate the accelerating voltage implied by the calibration model. [2 marks]

(c) Only three preset voltages are available: 675 V , 1200 V and 2700 V . Calculate D at 675 V , then use all three settings to choose the only preset that meets the stated measurement requirement. [2 marks]

(d) The team moves the screen farther from the film. Explain why the original calibration cannot then be used without a new check. [1 mark]



5. Electrons that lose energy in the film [6 marks]

In a separate low-energy investigation, an electron reaches the film with kinetic energy 400 eV and loses 100 eV in an inelastic collision. Ignore recoil energy in the calculation. The instrument can select electrons by their kinetic energy after the film.

(a) Calculate the de Broglie wavelength, in pm, of this electron after the collision. [3 marks]

(b) Before the collision the electron wavelength was 61.4 pm. Determine the percentage increase in wavelength. Explain why it is not equal to the percentage decrease in kinetic energy. [2 marks]

(c) The team wants to compare diffraction using only electrons with the original 400 eV kinetic energy. Explain why the instrument should reject the 300 eV electrons. [1 mark]



6. Evaluate the model and an alternative probe [8 marks]

The team reviews the electron model and considers whether a proton beam could replace the electron beam. No detailed knowledge of proton diffraction equipment is required.

(a) When electrons are sent through the film one at a time, individual localised detections build up a diffraction pattern. Explain why neither a purely classical particle model nor a purely classical continuous-wave model describes both observations. [2 marks]

(b) The team compares its evidence with the photoelectric effect. Explain how the photoelectric effect supports the particle nature of electromagnetic radiation. Include the threshold frequency in your explanation. [2 marks]

(c) The team claims its data support $\lambda = h/p$. Suggest two ways that peer review and independent testing could strengthen confidence in this claim. [2 marks]

(d) A proposed proton beam has the same de Broglie wavelength as the electron beam. State how the two momenta compare, then calculate v_p/v_e . Use $m_p = 1.67 \times 10^{-27}$ kg and the supplied electron mass. [2 marks]

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