

Exercise walk-through

4.6

Nuclear structure, accelerators and tracks (statements 111–117, 120)

Pearson Edexcel · International A-Level · Physics

Scattering links observation to a model

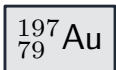
Observation / symbol	Supported conclusion
Most pass nearly straight	Most atomic volume is empty
Rare large deflections	Tiny, dense, positive nucleus
A_ZX	Proton number Z ; nucleon number A ; neutrons $A - Z$

The quark–lepton model organises particles

Family	Constituents / example
Baryon	Three quarks; proton uud
Meson	Quark + antiquark; pion
Lepton / antilepton	Electron / positron
Photon	Electromagnetic quantum

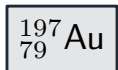
Exercise 2.1

2.1 For a neutral $^{197}_{79}\text{Au}$ atom, state proton, neutron and electron counts. Link two distinct observations from alpha scattering to conclusions about the atom. [5]



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2.1 Protons 79, neutrons $197 - 79 = 118$, electrons 79 for the neutral atom. Most alpha particles pass nearly straight through: most atomic volume is empty. Rare very large deflections require strong repulsion concentrated in a tiny positive nucleus containing most mass, unlike a diffuse-positive-charge model.

Exercise 2.2

2.2 Explain thermionic emission. An electron starts from rest and accelerates through 300 V in vacuum. Calculate its speed using $m_e = 9.11 \times 10^{-31}$ kg and $e = 1.60 \times 10^{-19}$ C, and comment on the non-relativistic assumption. [5]

heated metal



positive electrode



accelerating p.d. 300 V

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accelerating p.d. 300 V

2.2 Heating gives some electrons enough energy to leave a metal surface. Electric work becomes kinetic energy.

$$\frac{1}{2}m_e v^2 = eV \quad \Rightarrow \quad v = \sqrt{\frac{2eV}{m_e}}$$

$$v = \sqrt{\frac{2eV}{m_e}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \text{ C} \times 300 \text{ V}}{9.11 \times 10^{-31} \text{ kg}}} = 1.03 \times 10^7 \text{ m s}^{-1}$$

Rearrangement and speed. This is about $0.034c$, well below light speed, so the approximation is reasonable.

Exercise 2.3

2.3 A proton of momentum $3.0 \times 10^{-20} \text{ kg m s}^{-1}$ enters a perpendicular 0.50 T field. Calculate path radius and time for a half-circle. Use $m_p = 1.67 \times 10^{-27} \text{ kg}$ and $e = 1.60 \times 10^{-19} \text{ C}$. [4]

× × × ×



$p = 3.0 \times 10^{-20} \text{ kg m/s}; B = 0.50 \text{ T}$

× × × ×

3 Exam-style questions

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3 Exam-style questions

2.3 Magnetic force supplies centripetal resultant.

$$r = \frac{p}{eB} = \frac{3.0 \times 10^{-20} \text{ kg m s}^{-1}}{1.60 \times 10^{-19} \text{ C} \times 0.50 \text{ T}} = 0.375 \text{ m}$$

Radius. Half the non-relativistic period.

$$t_{1/2} = \frac{\pi m_p}{eB} = \frac{\pi \times 1.67 \times 10^{-27} \text{ kg}}{1.60 \times 10^{-19} \text{ C} \times 0.50 \text{ T}} = 6.56 \times 10^{-8} \text{ s}$$

Half-circle time.

Exercise 3.1

3.1 A proton starts from rest in a linear accelerator and crosses four accelerating gaps, each at 20 kV. Calculate its speed after the fourth gap. Explain why drift tubes become longer at constant supply frequency, why polarity must alternate, and what shielding inside a tube achieves. [6]

four gaps, each 20 kV



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3.1 Add the energy gains of all four gaps.

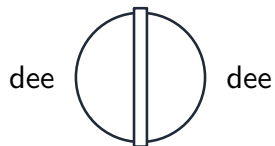
$$\frac{1}{2}m_p v^2 = 4eV_{\text{gap}} \Rightarrow v = \sqrt{\frac{8eV_{\text{gap}}}{m_p}}$$

$$v = \sqrt{\frac{8eV_{\text{gap}}}{m_p}} = \sqrt{\frac{8 \times 1.60 \times 10^{-19} \text{ C} \times 20 \times 10^3 \text{ V}}{1.67 \times 10^{-27} \text{ kg}}} = 3.92 \times 10^6 \text{ m s}^{-1}$$

Rearrangement and speed. At fixed frequency particles must spend approximately the same half-period inside each tube, so faster motion requires longer tubes. Polarity reverses while the particle is inside so the next gap again accelerates it. Conducting tubes shield the particle from the reversing electric field inside; energy changes mainly in gaps.

Exercise 3.2

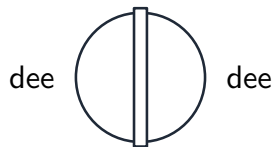
3.2 Explain the linked electric and magnetic processes that make a cyclotron accelerate particles repeatedly. Derive its period and explain why increasing radius does not increase the time in a dee in the non-relativistic model. State one limitation near light speed. [6]



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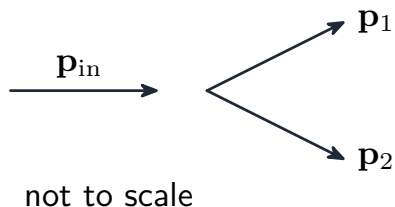
3.2 Electric field accelerates across the gap, increasing speed/energy. Perpendicular magnetic force curves motion within dees without doing work. Combining $qvB = mv^2/r$ with $T = 2\pi r/v$ gives:

$$T = \frac{2\pi m}{|q|B}$$

again. Relativistic effects alter the required timing near c , so the fixed-frequency non-relativistic synchronisation fails.

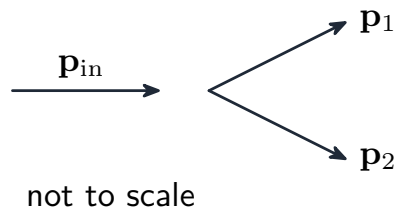
Exercise 3.3

3.3 An interaction has incoming momentum $(4.0, 0) \times 10^{-20} \text{ kg m s}^{-1}$. The only visible outgoing charged tracks have momenta $(2.0, 1.0)$ and $(1.0, -0.50)$ in the same units. Find the missing momentum vector and its magnitude. Explain why a neutral product can escape direct tracking, why high-energy collisions help investigate nucleons in two distinct ways, and why fast muons reaching the ground do not imply faster-than-light motion.^[7]



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3.3 Vector momentum conservation requires subtracting all visible outgoing momenta.

$$\mathbf{p}_{\text{miss}} = \mathbf{p}_{\text{in}} - \mathbf{p}_1 - \mathbf{p}_2 = (1.0, -0.50) \times 10^{-20} \text{ kg m s}^{-1}$$

Components.

Full solution 3.3

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Components.

$$p_{\text{miss}} = \sqrt{p_x^2 + p_y^2} = \sqrt{1.0^2 + 0.50^2} \times 10^{-20} \text{ kg m s}^{-1} = 1.12 \times 10^{-20} \text{ kg m s}^{-1}$$

Magnitude. Neutral particles do not directly ionise along a track in this detector model; later charged products may reveal them. High momentum gives shorter de Broglie wavelength and finer structural resolution. High collision energy can also create new massive particles. Fast muons have a longer average lifetime in the Earth's frame at speeds close to, but below, c .