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Velocity selectors and particle identification

Electromagnetism 3 Analysing volcanic gas samples

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 36 marks

Specification points covered

6.3.2(a–c) Magnetic orbits and velocity selection using crossed fields.

6.2.3(a), 6.2.1(d) Uniform electric fields and electric force.

All ion masses, charge states and detector criteria needed are supplied.

Use $e = 1.60 \times 10^{-19}$ C and $1\ u = 1.66 \times 10^{-27}$ kg. Treat the supplied isotope masses as exact multiples of u.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Read the two-stage instrument

A laboratory investigates noble gases from a volcanic monitoring site. Its source supplies a range of ion speeds. A selector prepares a known-speed beam, then a separate magnetic analyser sorts the transmitted ions by their paths.

The selector plates have gap d = 12.0 mm. The upper plate is at $+V_s$ and the lower plate is at 0 V. A uniform field $B_s = 0.0800$ T is perpendicular to the page; its direction is to be found. The required selected speed is 6.00×10^4 m s^{-1}.

In the analyser, $B_a = 0.200$ T points out of the page. The ions enter to the right and are positively charged. Neglect fringing, collisions and interactions between ions. Unless changed, use these baseline settings.

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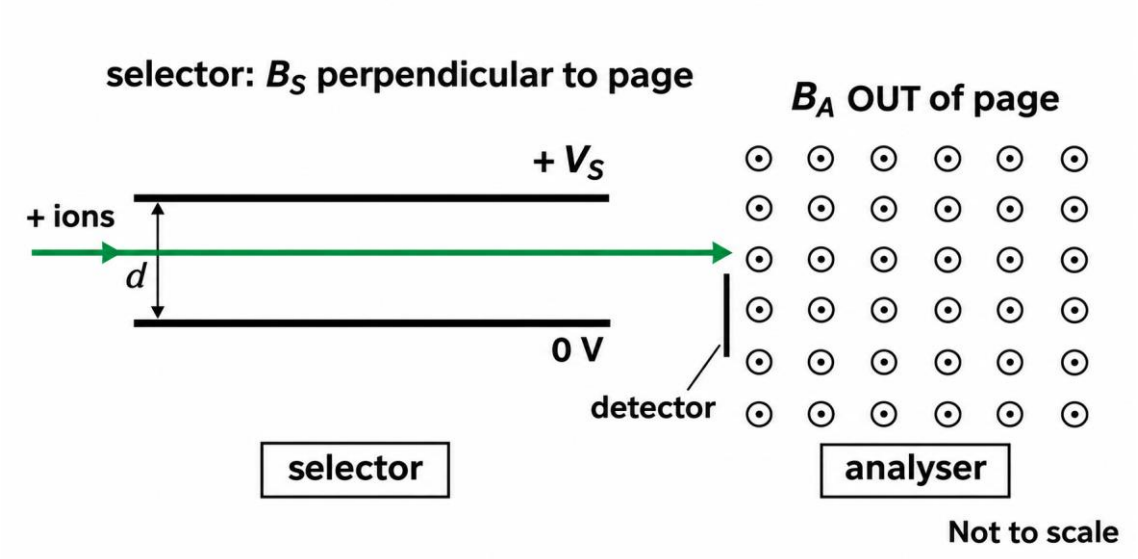


Figure 1 Selector and separate analyser

1(a) Which stage is intended to transmit a straight beam at one selected speed, and which stage changes the direction of that transmitted beam? **[1 mark]**

1(b) In the analyser, an ion follows a semicircle and returns to the entry-side detector plane. Its detector is x below the entry aperture. Express the orbit radius in terms of x. **[1 mark]**

2 Balance the selector forces

2(a) State the electric force direction on a positive ion between the selector plates. **[1 mark]**

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2(b) Choose the direction of B_s, into or out of the page, that lets the magnetic force oppose the electric force. Justify your choice. **[2 marks]**

2(c) Derive $v = E/B_s$ for an undeflected ion. Explain why the selected speed is independent of ion mass and charge magnitude. **[2 marks]**

2(d) At the chosen field directions, state the initial deflection of a positive ion travelling (i) faster and (ii) slower than the selected speed. Explain. **[2 marks]**

3 Set and test the selector

3(a) Calculate the required electric field strength and plate p.d. for the baseline selected speed. **[2 marks]**

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3(b) Keep the same plate p.d. and gap but select 4.00×10^4 m s^{-1}. Find the required B_s magnitude. **[1 mark]**

3(c) Relative to the baseline settings, both E and B_s increase by a factor of 1.50. What happens to the selected speed? **[1 mark]**

3(d) A negative ion travels right at the baseline selected speed. Explain why it can also pass straight through the selector at the same plate and field settings. **[2 marks]**

4 Interpret the magnetic analyser

4(a) For the baseline selected speed, calculate the analyser radii for singly charged ions of masses 20u and 22u. **[2 marks]**

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4(b) Find their detector distances below the entry aperture and the separation of the two peaks. **[2 marks]**

4(c) A further singly charged positive ion is detected 130.7 mm below entry. Infer its mass in kg and in u. **[3 marks]**

4(d) Could an ion with twice the mass and twice the charge magnitude follow the same analyser path at the same selected speed? Explain. **[1 mark]**

5 Read a detector scan

Table 1 is a baseline scan. Peak positions are rounded readings, not isotope mass data.

Table 1

Peak	Distance below entry / mm
A	124.5
B	130.7
C	136.9

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5(a) Assign the 20u and 22u singly charged ions to peaks in Table 1. **[1 mark]**

5(b) The selector is reset to transmit a speed 10% greater, while B_a is unchanged. Predict the new detector positions for the 20u and 22u ions. **[1 mark]**

5(c) The source accelerating voltage changes, but the selector settings remain at baseline. Assume the source still supplies ions at the selected speed. Must the detector peaks shift simply because of that voltage change? Explain. **[2 marks]**

6 Choose a resolving setting

6(a) The laboratory can use B_a = 0.180 T or 0.300 T. At the baseline selected speed, calculate the 20u–22u detector separation for each setting. **[2 marks]**

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6(b) For each of those fields, calculate the larger detector distance, for the 22u ion. The detector extends 160 mm below entry. **[2 marks]**

6(c) A supplied detector criterion requires separation of at least 12.0 mm and both peaks within its 160 mm span. Choose an analyser field and justify against both conditions. **[1 mark]**

6(d) In a separate experiment the selector is removed. These singly charged ions instead accelerate from rest through the same p.d. before entering the analyser. Find r_{22}/r_{20}, and compare it with the fixed-speed ratio. **[2 marks]**

6(e) Correct both errors: “The selector works because the electric and magnetic fields cancel. Its selected speed tells us which isotope is present.” **[2 marks]**

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