Time of flight mass spectrometry

AQA 7404 and 7405 · AS and A level

Use $E_k = \frac{1}{2}mv^2$ and $d = vt$. Avogadro constant = 6.02×10^{23} mol^{-1}. Assume constant speed in the drift region.

Name _____ Date _____

1. Speed from flight time

An ion travels 1.50 m along the drift region in 3.75×10^{-5} s. Calculate its speed.

2. Mass of one ion

An ion has a speed of 5.00×10^{4} m s^{-1} and a kinetic energy of 6.25×10^{-17} J. Calculate the mass of this ion in kg.

3. From molar mass to speed

Singly charged ions have a molar mass of 48.0 g mol^{-1} and each has kinetic energy 6.00×10^{-17} J. Find the speed in the drift region.

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4. From energy to flight time

An ion of mass 8.00×10^{-26} kg has kinetic energy 1.00×10^{-16} J. The drift region is 1.20 m long. Calculate the flight time in seconds.

5. Comparing two isotopes

Ions of two isotopes have the same kinetic energy and travel the same distance. The ion of mass 63.0 u takes 28.0 µs. The other ion has mass 65.0 u.

Calculate the flight time of the 65.0 u ion in µs. Explain which ion reaches the detector first.

6. Find an isotopic mass

Two singly charged ions travel the same path with the same kinetic energy. A reference ion of mass 64.0 u takes 24.0 µs. An unknown ion takes 27.0 µs.

Calculate the mass of the unknown ion in u.

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7. Convert a flight time into molar mass

An ion takes 33.0 μs to travel 1.32 m. Its kinetic energy is 8.00×10^{-17} J. Calculate the molar mass of the ions in g mol^{-1}.

8. A timing calculation

An ion drifts 0.960 m in 24.0 μs. A student writes 24.0 μs = 24.0×10^{-3} s and calculates a speed of 40.0 m s^{-1}.

Calculate the correct speed. The student then uses their speed to calculate the ion mass from its known kinetic energy. By what factor is their mass different, and in which direction?

9. Extra challenge · Correct a delayed timer

Identical singly charged ions each have kinetic energy 1.04×10^{-16} J. Two runs use drift distances 0.700 m and 1.300 m. The timings are 23.50 μs and 38.50 μs, respectively. Each measured time includes the same fixed delay as well as the drift time.

Find the delay and the molar mass of the ions. Explain the direction of the mass error if the full time is treated as the drift time.

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Worked answers

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1. Speed from flight time

$v = d \div t = 1.50 \div (3.75 \times 10^{-5}) = 4.00 \times 10^{4}$ m s^{-1}.

2. Mass of one ion

Rearrange $E_k = \frac{1}{2}mv^2$ to $m = 2E_k \div v^2$. Substituting gives $(2 \times 6.25 \times 10^{-17}) \div (5.00 \times 10^{4})^2 = 5.00 \times 10^{-26}$ kg.

3. From molar mass to speed

First convert 48.0 g mol^{-1} to 0.0480 kg mol^{-1}. Mass per ion = $0.0480 \div (6.02 \times 10^{23}) = 7.973\ldots \times 10^{-26}$ kg.

$v = \sqrt{(2E_k \div m)} = \sqrt{((2 \times 6.00 \times 10^{-17}) \div (7.973\ldots \times 10^{-26}))} = 3.88 \times 10^{4}$ m s^{-1}.

4. From energy to flight time

$v = \sqrt{((2 \times 1.00 \times 10^{-16}) \div (8.00 \times 10^{-26}))} = 5.00 \times 10^{4}$ m s^{-1}.

$t = d \div v = 1.20 \div (5.00 \times 10^{4}) = 2.40 \times 10^{-5}$ s.

5. Comparing two isotopes

With the kinetic energy fixed, $v = \sqrt{(2E_k \div m)}$. The 63.0 u ion travels faster, so it reaches the detector first.

At the same drift distance, flight time is proportional to $\sqrt{m}$. Therefore $t = 28.0 \times \sqrt{(65.0 \div 63.0)} = 28.4$ µs. The mass units cancel in the ratio.

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Worked answers

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6. Find an isotopic mass

At fixed distance and kinetic energy, flight time is proportional to the square root of mass. The mass ratio is the square of the time ratio.

$m = 64.0 \times (27.0 \div 24.0)^2 = 81.0$ u.

7. Convert a flight time into molar mass

Convert 33.0 µs to 33.0×10^{-6} s. $v = 1.32 \div (33.0 \times 10^{-6}) = 4.00 \times 10^4$ m s^{-1}.

$m = (2 \times 8.00 \times 10^{-17}) \div (4.00 \times 10^4)^2 = 1.00 \times 10^{-25}$ kg for one ion.

Molar mass $= (1.00 \times 10^{-25}) \times (6.02 \times 10^{23}) \times 1000 = 60.2$ g mol^{-1}.

8. A timing calculation

24.0 µs $= 24.0 \times 10^{-6}$ s, so $v = 0.960 \div (24.0 \times 10^{-6}) = 4.00 \times 10^4$ m s^{-1}.

Their speed is one thousandth of the correct speed. For fixed kinetic energy, $m = 2E_k \div v^2$, so their calculated mass is 10^6 times too large.

9. Extra challenge · Correct a delayed timer

The added distance is 0.600 m and the added time is 15.00 µs. The delay cancels in the difference, so $v = 0.600 \div (15.00 \times 10^{-6}) = 4.00 \times 10^4$ m s^{-1}.

The drift time for the shorter run is $0.700 \div v = 17.50$ µs. The delay is $23.50 - 17.50 = 6.00$ µs. $m = 2E_k/v^2 = 1.30 \times 10^{-25}$ kg; $M = 1.30 \times 10^{-25} \times 6.02 \times 10^{23} \times 1000 = 78.3$ g mol^{-1}.

Treating the full time as the drift time underestimates v and therefore overestimates m.

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