A sample of bromine was analysed in a time of flight (TOF) mass spectrometer and found to contain two isotopes, $^{79}\text{Br}$ and $^{81}\text{Br}$.

After electron impact ionisation, all of the ions were accelerated to the same kinetic energy (KE) and then travelled through a flight tube that was 0.950 m long.

(a) The $^{79}\text{Br}^+$ ions took $6.69 \times 10^{-4}$ s to travel through the flight tube.

Calculate the mass, in kg, of one ion of $^{79}\text{Br}^+$

Calculate the time taken for the $^{81}\text{Br}^+$ ions to travel through the same flight tube.

The Avogadro constant, $L = 6.022 \times 10^{23}$ mol$^{-1}$

$$KE = \frac{1}{2}mv^2 \quad \text{where} \quad m = \text{mass (kg)} \quad \text{and} \quad v = \text{speed (m s}^{-1})$$

$$v = \frac{d}{t} \quad \text{where} \quad d = \text{distance (m)} \quad \text{and} \quad t = \text{time (s)}$$

Mass of one ion of $^{79}\text{Br}^+$ ______________________ kg

Time taken by $^{81}\text{Br}^+$ ions ______________________ s

(b) Explain how ions are detected and relative abundance is measured in a TOF mass spectrometer.

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(2)

(Total 7 marks)
This question is about s-block metals.

(a) Give the full electron configuration for the calcium ion, Ca$^{2+}$

(b) Explain why the second ionisation energy of calcium is lower than the second ionisation energy of potassium.

(c) Identify the s-block metal that has the highest first ionisation energy.

(d) Give the formula of the hydroxide of the element in Group 2, from Mg to Ba, that is least soluble in water.
A student added 6 cm$^3$ of 0.25 mol dm$^{-3}$ barium chloride solution to 8 cm$^3$ of 0.15 mol dm$^{-3}$ sodium sulfate solution. The student filtered off the precipitate and collected the filtrate.

Give an ionic equation for the formation of the precipitate. Show by calculation which reagent is in excess. Calculate the total volume of the other reagent which should be used by the student so that the filtrate contains only one solute.

Ionic equation _______________________________________________________

Reagent in excess _____________________________________________________

Total volume of other reagent ___________________________________________

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(f) A sample of strontium has a relative atomic mass of 87.7 and consists of three isotopes, \(^{86}\text{Sr}\), \(^{88}\text{Sr}\) and \(^{88}\text{Sr}\).

In this sample, the ratio of abundances of the isotopes\(^{86}\text{Sr}:^{88}\text{Sr}\) is 1:1.

State why the isotopes of strontium have identical chemical properties.
Calculate the percentage abundance of the \(^{88}\text{Sr}\) isotope in this sample.

Why isotopes of strontium have identical chemical properties
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

Percentage abundance of \(^{88}\text{Sr}\) ____________________ %

(4)

(g) A time of flight (TOF) mass spectrum was obtained for a sample of barium that contains the isotopes \(^{136}\text{Ba}\), \(^{137}\text{Ba}\) and \(^{138}\text{Ba}\).

The sample of barium was ionised by electron impact.

Identify the ion with the longest time of flight.
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(1)
(h) A $^{137}$Ba$^+$ ion travels through the flight tube of a TOF mass spectrometer with a kinetic energy of $3.65 \times 10^{-16}$ J. This ion takes $2.71 \times 10^{-5}$ s to reach the detector.

KE = $\frac{1}{2}mv^2$ where $m = \text{mass (kg)}$ and $v = \text{speed (m s}^{-1})$

The Avogadro constant, $L = 6.022 \times 10^{23}$ mol$^{-1}$

Calculate the length of the flight tube in metres.

Give your answer to the appropriate number of significant figures.

Length of flight tube ____________________ m

(Total 18 marks)

3. Magnesium exists as three isotopes: $^{24}$Mg, $^{25}$Mg and $^{26}$Mg

(a) In terms of sub-atomic particles, state the difference between the three isotopes of magnesium.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(1)
(b) State how, if at all, the chemical properties of these isotopes differ.

Give a reason for your answer.

Chemical properties

Reason

(2)

(c) \(^{25}\text{Mg}\) atoms make up 10.0\% by mass in a sample of magnesium.

Magnesium has \(A_r = 24.3\)

Use this information to deduce the percentages of the other two magnesium isotopes present in the sample.

\[^{24}\text{Mg}\] percentage = ________ \%  \quad \[^{26}\text{Mg}\] percentage = ________ \%

(4)
(d) In a TOF mass spectrometer, ions are accelerated to the same kinetic energy (KE).

\[
KE = \frac{1}{2}mv^2 \quad \text{where } m = \text{mass (kg)} \text{ and } v = \text{velocity (m s}^{-1})
\]

\[
v = \frac{d}{t} \quad \text{where } d = \text{distance (m)} \text{ and } t = \text{time (s)}
\]

In a TOF mass spectrometer, each $^{25}\text{Mg}^+$ ion is accelerated to a kinetic energy of $4.52 \times 10^{-16}$ J and the time of flight is $1.44 \times 10^{-5}$ s.
Calculate the distance travelled, in metres, in the TOF drift region.
(The Avogadro constant \( L = 6.022 \times 10^{23} \text{ mol}^{-1} \)

\[
\text{Distance} = \underline{\underline{\underbrace{\overbrace{\text{m}}^{\text{m}}}}} \\
(4)
\]
(Total 11 marks)
Mark schemes

1. (a) \[ \frac{79}{(1000 \times 6.022 \times 10^{23})} = 1.31 \times 10^{-25} \text{ kg} \]

Then either follow **method 1** or **method 2** below.

*Do not mix and match methods*

**Method 1**

\[ V_{79} = \frac{d}{t} = \frac{0.950}{6.69 \times 10^{-4}} \]

\[ = 1420 \text{ ms}^{-1} \]

*In method 1, M2 can be awarded in M3*

\[ \text{KE} = \frac{1}{2} mv^2 \]

\[ = \frac{1}{2} \times 1.312 \times 10^{-25} \times (1420)^2 \]

\[ = 1.32 \times 10^{-19} \text{ J} \]

*Mark consequential to their velocity and mass. Allow mass of 79 etc.*

\[ V_{81} = \sqrt{\left(\frac{2\text{KE}}{m}\right)} \]

\[ = \sqrt{1.963 \times 10^6} \]

\[ = 1.40 \times 10^3 \text{ ms}^{-1} \]

(allow 1.398 \times 10^3 - 1.402 \times 10^3)

*Mark consequential to their velocity and mass. Allow mass of 81 etc.*

\[ t = \frac{d}{v} = \frac{0.950}{V_{81}} \]

\[ = 6.80 \times 10^{-4} \text{ s} \]

*Mark consequential to their M4
Accept 6.77 – 6.80 \times 10^{-4} \text{ s}*

**Method 2**

\[ m_1 (d/t_1)^2 = m_2 (d/t_2)^2 \]

or

\[ m_1 / t_1^2 = m_2 / t_2^2 \]
\[ t_2^2 = t_1^2 \left( \frac{m_2}{m_1} \right) \]
Or
\[ t_2^2 = (6.69 \times 10^{-4})^2 \times (81/79) \]
\[ t_2^2 = 4.59 \times 10^{-7} \]

Mark consequential to their M3

\[ t = 6.77 \times 10^{-4} \text{ s} \]

Mark consequential to their M4
Accept \( 6.77 - 6.80 \times 10^{-4} \text{ s} \)

(b) ion hits the detector / negative plate and gains an electron

Not positive plate

(relative) abundance is proportional to (the size of) the current

2. (a) \( 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ (4s^0) \)

(b) **M1** In Ca\(^{+}\) (outer) electron(s) is further from nucleus

Or Ca\(^{+}\) loses electron from a higher (energy) orbital

Or Ca\(^{+}\) loses electron from a 4(s) orbital or 4th energy level or 4th energy shell and
K\(^{+}\) loses electron from a 3(p) orbital or 3rd energy level or 3rd energy shell

*Must be comparative*

*Allow converse arguments*

**M2** More shielding (in Ca\(^{+}\))

(c) Be /Beryllium

(d) Mg(OH)\(_2\)
(e) \[ \text{Ba}^{2+} + \text{SO}_{4}^{2-} \rightarrow \text{BaSO}_4 \]

*Ignore state symbols*

\[ n \text{ BaCl}_2 (6/1000 \times 0.25) = 1.5 \times 10^{-3} \text{ and } n \text{ Na}_2\text{SO}_4 = (8/1000 \times 0.15) = 1.2 \times 10^{-3} \]

and \( \text{BaCl}_2 \) /barium chloride in excess

*Working required or } 3 \times 10^{-4} \text{ of BaCl}_2

10 cm\(^3\) (of 0.15 mol dm\(^{-3}\) sodium sulfate)

*or 0.01dm\(^3\)*

(f) \( \text{M1} \) Same electronic configuration / same number of electrons (in outer shell) / all have 37 electrons (1)

*Ignore protons and neutrons unless incorrect numbers*

*Not just electrons determine chemical properties*

\[ M2 \frac{86x + 87x + 88(100-2x)}{100} = 87.7 \]

*Alternative M2:*

\[ 86 + 87 + 88y = 87.7 \]

\[ 1 + 1 + y \]

\( M3 \) \( x = 10\% \) (or \( x = 0.1 \))

\( M3 \ y = 8 \)

\( M4 \) (% abundance of 88 isotope is \( 100 - 2x10 \)) = \( 80(0.0)\% \)

*\( M4 \) % of 88 isotope is \( 100 - 10y = 80(0.0) \) %

*Allow other alternative methods*

(g) \( ^{138}\text{Ba}^+ \)
(h) \[ m = \frac{137 \times 10^{-3}}{6.022 \times 10^{-23}} = 2.275 \times 10^{-25} \text{ (kg)} \]

*Calculation of \( m \) in kg*

*If not converted to kg, max 4*

*If not divided by \( L \) lose \( M1 \) and \( M5 \), max 3*

\[ v^2 = \frac{2KE}{m} = \frac{2 \times 3.65 \times 10^{-16}}{2.275 \times 10^{-25}} = 3.2088 \times 10^9 \]

*For re-arrangement*

\[ v = \sqrt{\frac{2KE}{m}} \quad (v = 5.6646 \times 10^4) \]

*For expression with square root*

\[ d = (5.6646 \times 10^4 \times 2.71 \times 10^{-5}) = 1.53 - 1.54 \text{ (m)} \]

*\( M5 \) must be to 3sf

*If not converted to kg, answer = 0.0485-0.0486 (3sf). This scores 4 marks*

Alternative method

\[ m = \frac{137 \times 10^{-3}}{6.022 \times 10^{-23}} = 2.275 \times 10^{-25} \]

*\( M1 \) Calculation of \( m \) in kg*

\[ v = \frac{d}{t} \]

*\( M2, M3 \) and \( M4 \) are for algebraic expressions or correct expressions with numbers*

\[ d^2 = \frac{KE \times 2t^2}{m} \]

\[ d = \sqrt{\frac{KE \times 2t^2}{m}} \quad (= \sqrt{(3.65 \times 10^{-16} \times 2 \times (2.71 \times 10^{-5})^2 / 2.275 \times 10^{-25})}) \]

\[ d = 1.53 - 1.54 \text{ (m)} \]

*\( M5 \) must be to 3sf*

[18]
(a) $^{24}\text{Mg}$ has 12n; $^{25}\text{Mg}$ has 13n; $^{26}\text{Mg}$ has 14n

OR They have different numbers of neutrons

(b) No difference in chemical properties

Because all have the same electronic structure (configuration)

OR they have the same number of outer electrons

(c) If fraction with mass 24 = $x$

Fraction with mass 26 = $0.900 - x$

Fraction with mass 25 = 0.100

\[ A_r = 24x + (25 \times 0.100) + 26(0.900 - x) \]

24.3 = 24x + 2.50 + 23.4 − 26x

2x = 1.60

$x = 0.800$ i.e. percentage $^{24}\text{Mg} = 80.0\%$ (80.0\% 3sf)

$^{26}\text{Mg} = 0.900 - 0.800 = 0.100$ i.e percentage $^{26}\text{Mg} = 10.0\%$

(d) \[ m = \frac{25/1000}{6.022 \times 10^{23}} \]

\[ v^2 = 2ke/m \text{ or } v^2 = \frac{2 \times (4.52 \times 10^{-16}) \times (6.022 \times 10^{23})}{25/1000} \]

\[ V = \sqrt{2.18 \times 10^{10}} = 1.48 \times 10^5 \text{ (ms}^{-1}) \]

\[ D = vt = 1.48 \times 10^5 \times 1.44 \times 10^{-5} \]

\[ D = 2.13 \text{ (m)} \]