

## Structure 1.2.2

## Isotopes

## Nuclear identity, isotope notation, physical properties, relative atomic mass and abundance calculations

Covers: Structure 1.2.2 (SL + HL) - complete core notes, worked examples, exam technique, practice questions and full mark-scheme answers.

Level coding used throughout: SL + HL = examinable for all IB Chemistry students. There is no separate AHL extension within Structure 1.2.2.

## 0 Syllabus map

SL + HL

| IB syllabus point | Level   | What you must be able to do                                                                                  | Section |
|-------------------|---------|--------------------------------------------------------------------------------------------------------------|---------|
| Structure 1.2.2   | SL + HL | Define isotopes correctly: same element / same proton number, but different neutron numbers.                 | 1-3     |
| Structure 1.2.2   | SL + HL | Understand why isotopes have essentially the same chemical properties but can differ in physical properties. | 4       |
| Structure 1.2.2   | SL + HL | Calculate non-integer relative atomic masses and isotope abundances from supplied data.                      | 5-8     |

## WHAT THE IB IS REALLY TESTING

This topic is not just a definition. The high-value skills are: translating nuclear symbols into particle counts, distinguishing isotopes from ions, explaining properties from electron structure and mass, and setting up weighted-average calculations without losing track of percentages.

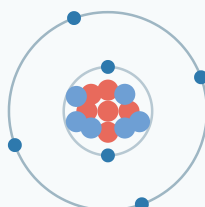
## 1 What is an isotope?

SL + HL

**Definition:** Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons. Therefore, they have the same atomic number,  $Z$ , but different mass numbers,  $A$ .

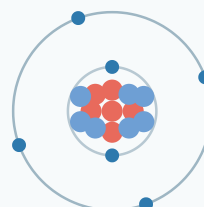
The element is fixed by the proton number. Changing the neutron number changes the isotope, not the element.

FIGURE 1 - ISOTOPES: SAME PROTON NUMBER, DIFFERENT NEUTRON NUMBER



carbon-12

6 p+ 6 n 6 e-



carbon-13

6 p+ 7 n 6 e-

**Same element:** same  $Z$  and same electron arrangement. **Different isotope:** different neutron number and mass.

## 2 Nuclear symbols and counting particles

SL + HL

Nuclear symbols package the key information into one notation. For an atom or ion written as  ${}^A_Z\text{X}^q$ :



**A** = mass number (protons + neutrons)

**Z** = atomic number (protons)

**X** = element symbol

**q** = ionic charge, if present

| Symbol | Meaning           | How to use it                                                         |
|--------|-------------------|-----------------------------------------------------------------------|
| Z      | Atomic number     | Number of protons. This identifies the element.                       |
| A      | Mass number       | Total nucleons = protons + neutrons.                                  |
| A - Z  | Neutron number    | Subtract atomic number from mass number.                              |
| charge | Net charge of ion | Electrons = Z - positive charge, or Z + magnitude of negative charge. |

### WORKED EXAMPLE 1 - PARTICLE COUNTS

For  ${}^{37}_{17}\text{Cl}^-$ : protons = 17; neutrons = 37 - 17 = 20; electrons = 18 because a 1- ion has gained one electron. The isotope information comes from A and Z; the charge only changes the electron count.

### FIGURE 2 - DO NOT CONFUSE ISOTOPES WITH IONS

#### ISOTOPE

- Changes in neutron number
- Proton number stays the same
- Electron count stays the same (neutral atom)
- Mass changes; chemical identity does not

#### ION

- Changes in electron number
- Proton number stays the same
- Neutron number does not define the charge
- Charge changes; element identity does not

*Exam shortcut: isotope = nucleus change; ion = electron change.*

### CLASSIC EXAM ERROR

Do not define isotopes as "atoms with different mass numbers" only. Different elements can also have different mass numbers. Your definition must explicitly state same proton number / same element and different neutron number.

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

### 3 Reading and comparing isotope notation

SL + HL

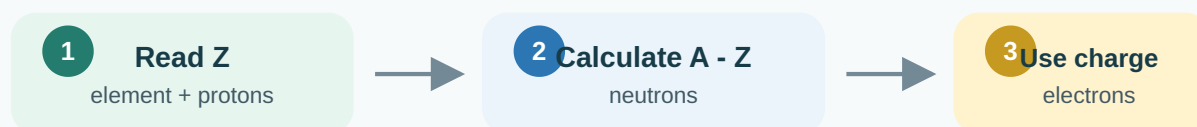
A quick comparison table is often the safest way to avoid confusion when atoms, isotopes and ions appear together.

| Species                      | p <sup>+</sup> | n  | e <sup>-</sup> | Key observation                                                      |
|------------------------------|----------------|----|----------------|----------------------------------------------------------------------|
| ${}^{24}_{12}\text{Mg}$      | 12             | 12 | 12             | Neutral magnesium-24 atom                                            |
| ${}^{25}_{12}\text{Mg}$      | 12             | 13 | 12             | Same element, different isotope                                      |
| ${}^{25}_{12}\text{Mg}^{2+}$ | 12             | 13 | 10             | Same isotope as row above, now an ion                                |
| ${}^{23}_{11}\text{Na}^{+}$  | 11             | 12 | 10             | Different element; happens to be isoelectronic with $\text{Mg}^{2+}$ |

#### FAST METHOD

**1.** Read Z first - this fixes the element and proton number. **2.** Calculate neutrons with  $A - Z$ . **3.** Only then use the ionic charge to adjust electrons. Keeping these three steps separate prevents nearly every notation error.

#### A RELIABLE THREE-STEP READING ROUTINE



**Important:** two species are isotopes only if their proton numbers are identical and their neutron numbers differ. Two species can have the same mass number without being isotopes; such species are called isobars, but that term is not required here.

#### EXAM PRECISION

If the question asks for the number of nucleons, give A. If it asks for neutrons, give  $A - Z$ . If it asks for electrons in an ion, use the charge after you have identified Z.

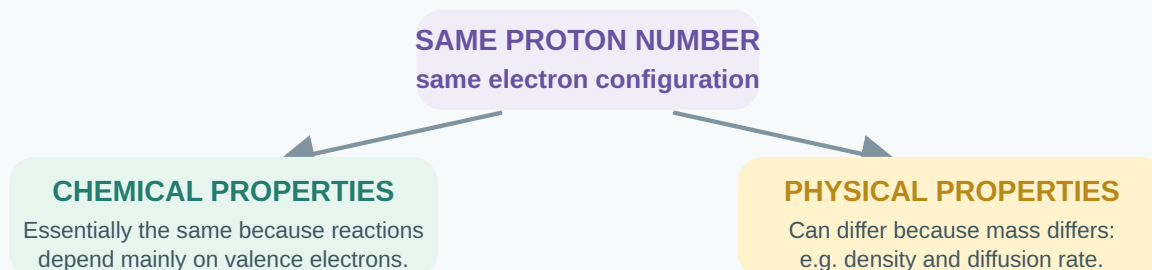
iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 4 Why isotopes have similar chemistry but different physical properties

SL + HL

FIGURE 3 - WHY CHEMICAL PROPERTIES MATCH BUT PHYSICAL PROPERTIES CAN DIFFER



**Chemical properties:** Isotopes of the same element have the same proton number and, for neutral atoms, the same number and arrangement of electrons. Since chemical reactions are governed mainly by electron arrangement - especially valence electrons - isotopes have essentially the same chemical behaviour.

**Physical properties:** Isotopes have different masses because they contain different numbers of neutrons. Any physical property influenced by particle mass can therefore differ slightly. Examples can include density and rates of diffusion.

| Statement                                                | Correct? | Reason                                                                      |
|----------------------------------------------------------|----------|-----------------------------------------------------------------------------|
| Two isotopes have different chemical symbols.            | No       | They are the same element, so X is unchanged; only A differs.               |
| Two isotopes can have different masses.                  | Yes      | Different neutron numbers give different nuclear masses.                    |
| Neutral isotopes have different valence electron counts. | No       | Same Z means the same electron count and ground-state electron arrangement. |
| A measurable physical property may differ slightly.      | Yes      | Mass-dependent behaviour can change.                                        |

### MARK-SCHEME WORDING

A strong two-part explanation is: same electron configuration -> similar chemical properties; different mass because of different neutron number -> some physical properties differ. Do not simply write "same number of electrons" without linking that fact to chemical behaviour.

iBLaurel

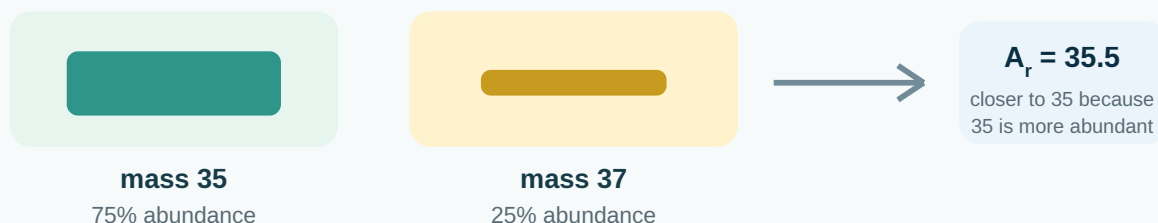
Premium IB tuition - Physics, Chemistry, Maths

## 5 Relative atomic mass: why it is usually non-integer

SL + HL

Most naturally occurring elements contain a mixture of isotopes. The relative atomic mass,  $A_r$ , therefore reflects both which isotopes are present and how abundant each isotope is. It is a **weighted mean**, not a simple average.

FIGURE 4 - RELATIVE ATOMIC MASS IS A WEIGHTED MEAN



Core calculation:

$$A_r = [\text{sum of (isotope mass x percentage abundance)}] / 100$$

### WHAT "WEIGHTED" MEANS

A more abundant isotope contributes more strongly to the mean. If 75% of atoms have mass 35 and 25% have mass 37, the mean lies much closer to 35 than to 37.

### PRECISION POINT

Use the isotopic masses supplied in the question. If the data give 34.968 and 36.966, use those values. Do not replace them with mass numbers 35 and 37 unless the question itself uses those approximate masses.

### WHY $A_r$ HAS NO UNIT

Relative atomic mass is a ratio relative to the carbon-12 standard, so it is dimensionless. Values such as 35.45 are therefore written without g or u when the quantity is  $A_r$ .

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 6 Calculating relative atomic mass from isotope abundance data

SL + HL

Method: multiply each isotope mass by its abundance, add the contributions, then divide by the total abundance (usually 100 for percentages).

### WEIGHTED-MEAN WORKFLOW

1

Multiply each isotope mass by its abundance

2

Add the weighted contributions

3

Divide by 100 if using %

4

Check the answer lies between the isotope masses

### WORKED EXAMPLE 2 - TWO ISOTOPES

Element X contains 75.0% X-35 and 25.0% X-37. Calculate  $A_r$ .

$$A_r = [(35 \times 75.0) + (37 \times 25.0)] / 100 = (2625 + 925) / 100 = 35.50$$

The answer is sensible because 35.50 lies between 35 and 37 and is closer to 35, the more abundant isotope.

### WORKED EXAMPLE 3 - THREE ISOTOPES

Element Y contains 20.0% Y-24, 30.0% Y-25 and 50.0% Y-26.

$$A_r = [(24 \times 20.0) + (25 \times 30.0) + (26 \times 50.0)] / 100 = (480 + 750 + 1300) / 100 = 25.30$$

### USING FRACTIONAL ABUNDANCES

If abundances are given as fractions such as 0.7577 and 0.2423, they already add to 1. Multiply and add directly - do not divide by 100 again.

### EXAM CHECK

Before moving on, ask: (i) do the abundances total 100% or 1? (ii) is my  $A_r$  between the lightest and heaviest isotope masses? (iii) is it pulled toward the most abundant isotope?

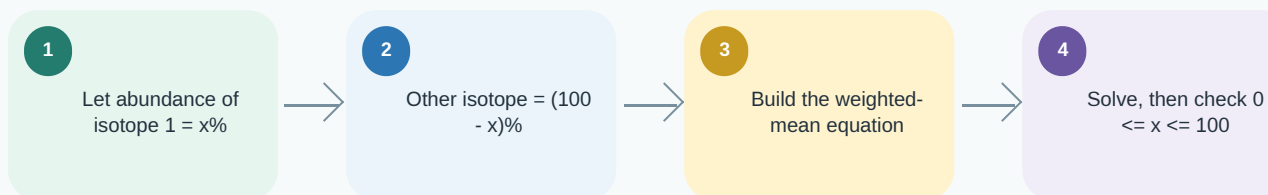
# iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 7 Finding an isotope abundance from relative atomic mass

SL + HL

FIGURE 5 - FINDING AN UNKNOWN ISOTOPE ABUNDANCE



For two isotopes, the abundances must add to 100%. This is the key algebra step.

### WORKED EXAMPLE 4 - SOLVING FOR X

Element Z has two isotopes, Z-10 and Z-11. Its  $A_r$  is 10.81. Let the abundance of Z-11 be  $x\%$ , so Z-10 is  $(100 - x)\%$ .

$$[11x + 10(100 - x)] / 100 = 10.81$$

$$11x + 1000 - 10x = 1081 \rightarrow x = 81\%$$

Therefore Z-11 = 81% and Z-10 = 19%.

### ALTERNATIVE SHORTCUT FOR TWO ISOTOPES

If the masses are  $m_1$  and  $m_2$  and the mean is  $A_r$ , you can reason from distances on a number line. The mean lies closer to the more abundant isotope. Algebra is safer in an exam, but the number-line idea is an excellent check.

FIGURE 6 - SANITY CHECK: THE MEAN MUST LIE BETWEEN THE ISOTOPE MASSES

If your answer is outside the isotope mass range, it is impossible.



iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 8 Mixed-isotope problems and exam traps

SL + HL

### WORKED EXAMPLE 5 - ONE MISSING ABUNDANCE

Element Q has three isotopes: Q-62 = 60.0%, Q-64 = 25.0%, Q-66 = ?.

First find the missing abundance:  $100 - 60.0 - 25.0 = 15.0\%$ .

$$A_r = [(62 \times 60.0) + (64 \times 25.0) + (66 \times 15.0)] / 100 = 63.10$$

| Common error                                 | Why it fails                                         | Fix                                             |
|----------------------------------------------|------------------------------------------------------|-------------------------------------------------|
| Taking an ordinary mean of isotope masses    | Ignores relative abundance                           | Use a weighted mean                             |
| Percentages do not add to 100                | The composition is incomplete or copied incorrectly  | Find missing abundance first                    |
| Dividing by 100 when abundances are decimals | Applies the percentage conversion twice              | If fractions add to 1, just sum mass x fraction |
| Answer outside isotope mass range            | A weighted mean cannot lie outside its inputs        | Recheck arithmetic and abundance units          |
| Calling $A_r$ a mass number                  | Mass number belongs to one isotope and is an integer | $A_r$ is a weighted mean for the element        |

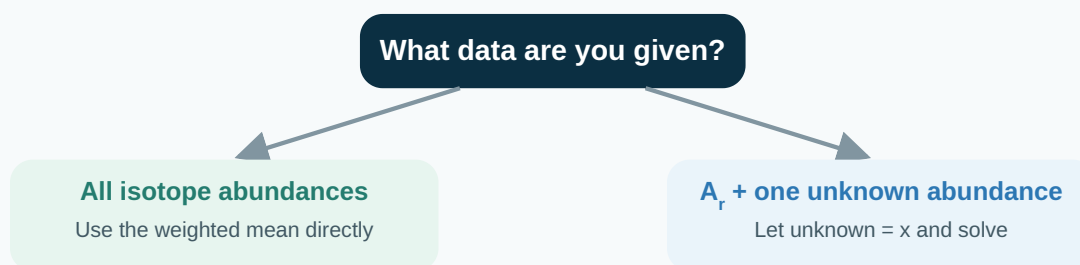
### CONNECTION TO ISOTOPE TRACERS

Because isotopes of an element have essentially the same chemistry but can be distinguished by mass or radioactivity, an isotope can be used to follow where atoms move during a process. This is a useful conceptual link to reaction-mechanism evidence, but detailed tracer examples are not required for Structure 1.2.2.

### LOOKING AHEAD TO STRUCTURE 1.2.3

Mass spectra can show isotope identity and relative abundance directly. The interpretation of isotope peaks belongs to Structure 1.2.3 (AHL); the calculations here are the foundation for that topic.

### QUICK DECISION TREE FOR ISOTOPE CALCULATIONS



iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 9 One-page summary

SL + HL

| If the question says...              | Your answer must contain...                                                                                             |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| "Define isotopes"                    | Same element / same proton number; different neutron number.                                                            |
| "Deduce p, n, e"                     | $p = Z$ ; $n = A - Z$ ; adjust e only for ionic charge.                                                                 |
| "Why same chemical properties?"      | Same electron configuration / same valence electron arrangement, so similar chemical behaviour.                         |
| "Why different physical properties?" | Different neutron number $\rightarrow$ different mass $\rightarrow$ some mass-dependent physical properties can differ. |
| "Calculate $A_r$ "                   | Weighted mean: $\text{sum}(\text{mass} \times \text{abundance})$ ; divide by 100 if using percentages.                  |
| "Find abundance"                     | Let one abundance = x; use $100 - x$ for the other; build weighted-mean equation and solve.                             |
| "Check your answer"                  | Abundances total 100%; $A_r$ lies between isotope masses and nearer the more abundant isotope.                          |

### FIVE FACTS TO MEMORISE

1.  $Z$  = proton number. 2.  $A$  = protons + neutrons. 3. Isotopes: same  $Z$ , different neutrons. 4. Chemical behaviour follows electron arrangement. 5.  $A_r$  is a weighted mean, so abundance matters.

#### Definition test

Never give only "different mass numbers". Always include **same element / same proton number** and **different neutron number**.

#### Particle-count test

Read  $Z \rightarrow$  calculate  $A - Z \rightarrow$  adjust electrons for charge. Keep those steps separate.

#### Property test

Same electron arrangement explains similar chemistry.  
Different mass explains possible physical-property differences.

#### Calculation test

Use a weighted mean, check abundance units, and make sure the mean lies inside the isotope mass range.

### DO NOT MEMORISE UNNECESSARY ISOTOPE EXAMPLES

The syllabus does not require specific isotope examples to be learned. Use examples to understand the pattern, but prioritise the definition, particle counting, property explanation and quantitative skills.

### 30-SECOND EXAM ROUTINE

Underline the data units. Decide whether abundance is % or fraction. Write the weighted-mean expression before touching the calculator. After calculating, check the answer lies within the isotope mass range.

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 10 Practice questions - Part A

SL + HL

Attempt these under timed conditions: roughly 1.5 minutes per mark. Full answers with mark-scheme wording follow in Sections 12-13.

## Part A - Multiple choice

1. Which pair represents isotopes of the same element?

- A.  $^{35}_{17}\text{Cl}$  and  $^{37}_{17}\text{Cl}$                       C.  $^{23}_{11}\text{Na}$  and  $^{24}_{12}\text{Mg}$   
B.  $^{35}_{17}\text{Cl}$  and  $^{35}_{18}\text{Ar}$                       D.  $^{14}_6\text{C}$  and  $^{14}_7\text{N}$

2. How many neutrons and electrons are present in  $^{25}_{12}\text{Mg}^{2+}$ ?

- A. 12 n, 12 e-                      C. 13 n, 14 e-  
B. 13 n, 10 e-                      D. 25 n, 10 e-

3. Why do isotopes of an element have essentially the same chemical properties?

- A. Same mass number                      C. Same electron configuration  
B. Same neutron number                      D. Same physical state

4. Element X consists of 70.0% X-63 and 30.0% X-65. What is  $A_r$ ?

- A. 63.0                      C. 64.0  
B. 63.6                      D. 64.4

5. Which statement must be true for a naturally occurring element with two isotopes of masses 10 and 11 and  $A_r = 10.81$ ?

- A. isotope 10 is more abundant                      C. abundances are equal  
B. isotope 11 is more abundant                      D. isotope 11 has fewer neutrons

6. An element contains isotopes of relative mass 84, 86 and 87. Which value could be its  $A_r$ ?

- A. 83.7                      C. 87.4  
B. 84.9                      D. 88.0

## MCQ EXAM HABIT

For numerical questions, eliminate impossible answers first:  $A_r$  must lie between the lightest and heaviest isotope masses.  
For definition questions, look for the option that explicitly refers to proton number and neutron number.

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

**10 Practice questions - Part B**

SL + HL

**Part B - Structured questions**

7. Define the term isotope. [2]

8. Complete the particle counts for  $^{56}_{26}\text{Fe}^{2+}$  and  $^{58}_{26}\text{Fe}^{3+}$ . State the number of protons, neutrons and electrons in each species. [4]

9. Explain why isotopes of the same element have essentially the same chemical properties but can have different physical properties. [4]

10. Element Q contains 60.0% Q-62, 25.0% Q-64 and 15.0% Q-66. Calculate  $A_r$  for Q. [3]

11. Element R has two isotopes, R-10 and R-11. Its  $A_r$  is 10.81. Calculate the percentage abundance of each isotope. [4]

12. Element S has isotopes with relative isotopic masses 27.98, 28.98 and 29.97. Their abundances are 92.2%, 4.7% and 3.1%, respectively. Calculate  $A_r$  to two decimal places. [3]

13. A student states: "Because isotopes have different masses, they must react differently in ordinary chemical reactions." Evaluate this statement. [2]

14. A tracer experiment replaces some atoms of an element with another isotope of the same element. Explain why this can allow the atoms to be followed without substantially changing the chemical pathway. [2]

**BEFORE YOU CHECK THE MARK SCHEME**

For every explanation, identify the causal link the mark scheme wants. For every calculation, show the weighted-mean equation rather than writing only the calculator answer.

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

## 11 Answers & mark-scheme notes - Part A and Q7-10

SL + HL

### Part A

- 1. A.** Same atomic number (17) but different mass numbers, so the neutron numbers differ.
- 2. B.** Neutrons = 25 - 12 = 13; Mg<sup>2+</sup> has lost two electrons, so electrons = 12 - 2 = 10.
- 3. C.** Chemical behaviour is governed mainly by electron arrangement; isotopes of the same element have the same electron configuration.
- 4. B.**  $A_r = (63 \times 0.700) + (65 \times 0.300) = 44.1 + 19.5 = \mathbf{63.6}$ .
- 5. B.** 10.81 lies much closer to 11 than 10, so isotope 11 must be more abundant.
- 6. B.** A weighted mean must lie between 84 and 87; 84.9 is the only possible value.

### Part B

#### 7. [2] Define isotope

Atoms of the same element / same proton number [1] with different numbers of neutrons [1]. Different mass numbers can be accepted only when linked to the same element.

#### 8. [4] Particle counts

$^{56}_{26}\text{Fe}^{2+}$   
 26 p+  
 30 n  
 24 e-

$^{58}_{26}\text{Fe}^{3+}$   
 26 p+  
 32 n  
 23 e-

Award [1] for each fully correct neutron/electron pair after the common proton count is identified; maximum [4].

#### 9. [4] Similar chemistry, different physical properties

Same proton number gives the same number and arrangement of electrons in neutral atoms [1]; chemical reactions depend mainly on electron arrangement / valence electrons [1], so chemical properties are essentially the same [1]. Different neutron numbers give different masses, so mass-dependent physical properties can differ [1].

#### 10. [3] Relative atomic mass

$$A_r = [(62 \times 60.0) + (64 \times 25.0) + (66 \times 15.0)] / 100 [1]$$

$$= (3720 + 1600 + 990) / 100 [1] = \mathbf{63.10 [1]}$$

iBLaurel

Premium IB tuition - Physics, Chemistry, Maths

**11 Answers & mark-scheme notes - Q11-14**

SL + HL

**11. [4] Find isotope abundance**

Let abundance of R-11 = x%, so R-10 = (100 - x)% [1].

$$[11x + 10(100 - x)] / 100 = 10.81 \text{ [1]}$$

Solving gives x = 81 [1]. Therefore R-11 = 81% and R-10 = 19% [1].

**12. [3] Use precise isotopic masses**

$$\begin{aligned} A_r &= (27.98 \times 0.922) + (28.98 \times 0.047) + (29.97 \times 0.031) \text{ [1]} \\ &= 25.79756 + 1.36206 + 0.92907 \text{ [1]} = 28.09 \text{ (2 d.p.) [1]} \end{aligned}$$

**13. [2] Evaluate the statement**

The statement is generally incorrect for ordinary chemistry [1]. Isotopes have the same electron configuration, so they show essentially the same chemical behaviour; the principal difference is mass, which affects physical properties and can produce only small isotope effects [1].

**14. [2] Isotope tracer**

The isotope has the same proton number and essentially the same electron arrangement, so it follows nearly the same chemistry [1]. Its different mass or radioactive signature allows it to be distinguished / tracked [1].

**FINAL EXAMINER CHECK****CALCULATIONS**

Show the weighted-mean equation, not only a calculator answer.

**UNITS**

Keep  $A_r$  unitless. Check whether abundance data are % or fractions.

**EXPLANATIONS**

Link electron arrangement to chemical properties and mass difference to physical properties.

**FINAL EXAMINER CHECK**

For full marks, use precise nuclear-language wording, show your weighted-mean set-up, and check that your calculated  $A_r$  is physically sensible.

# iBLaurel

Premium IB tuition - Physics, Chemistry, Maths