2 The nuclear atom

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
2.1 The structure of atoms	1	State the position, relative masses and relative charges of protons, neutrons and electrons. Define mass number (*A*), and atomic number (*Z*) of an element. Deduce the nuclear symbol for an atom. Calculate the number of protons, neutrons and electrons in atoms and ions.	**Coursebook** Section 2.1 Test your understanding Questions 4–5 Exam-style Questions 3 and 5 **Workbook** Exercise 2.1 **Teacher's resource** PowerPoint 2, slides 2–4 Worksheet 2.1 Questions 1–2 End of Chapter 2 test Questions 1–7, 12
2.2 Isotopes	2	Define the term isotope. Compare the properties of the isotopes of an element. Calculate non-integer relative atomic masses and abundance of isotopes from given data. Interpretation of data from mass spectra relating to relative abundance of isotopes.	**Coursebook** Section 2.2 Test your understanding Questions 3, 9, 13–15, 17 **Workbook** Exercise 2.2 **Teacher's resource** PowerPoint 2, slides 5–6 Worksheet 2.1 Question 3 End of Chapter 2 test Questions 8–11, 13–15

BACKGROUND KNOWLEDGE

- Explain the term element and give examples of elements (Chapter 1).
- Understand how elements are arranged in the periodic table.
- Explain the terms atom, molecule, ion and isotope.
- Know the structure of an atom in terms of its subatomic particles.
- Know the difference between chemical and physical properties.

Syllabus overview

- The start of this chapter consolidates knowledge on the arrangements of protons, neutrons and electrons and their relative masses/charges. Students are then introduced to how to represent elements, their isotopes and ions using nuclear symbols.
- This chapter forms the foundation for the study of the electron configuration (Chapter 3) and the periodic table (Chapter 10). While explaining the properties of isotopes, students should be aware that the arrangement of electrons in an atom determines the chemical reactivity and that elements are arranged in order of atomic number in the periodic table.
- In calculations of relative atomic masses and abundances of isotopes, students are taught to interpret graphs (Higher Level) and to utilize their knowledge to solve algebraic problems in unfamiliar situations.
- There are many opportunities to stretch beyond the present chapter. For example, an introduction to Rutherford's gold foil experiment or how J. J. Thompson discovered electrons; the isotopic enrichment of uranium and the type of bonding in uranium hexafluoride; the use of a mass spectrometer in studying the fragmentation peaks of more complex molecules (Chapter 11).

2.1 The structure of atoms

LEARNING PLAN

Learning objectives	**Success criteria**
Describe the structure of an atom Understand the terms atomic number (*Z*) and mass number (*A*) Calculate the numbers of protons, neutrons and electrons in atoms and ions	Students should be able to describe the structure of the atom in terms of the locations of protons, neutrons and electrons. Students should be able to state the relative masses and charges of protons, neutrons and electrons. Students should be able to explain the terms mass number (*A*), atomic number (*Z*) and write the nuclear symbol for an atom given values of *A* and *Z*. Students should be able to work out the number of protons, neutrons and electrons in atoms. Students should be able to work out the number of protons, neutrons and electrons in ions.

Common misconceptions

Misconception	How to identify	How to overcome
Learners may confuse an atomic number and mass number when asked to write down a nuclear symbol.	Use Exam-style questions 3 and 5 from the Coursebook to ascertain whether students understand how to identify which number is atomic and which is mass in a nuclear symbol.	When both atomic number and mass number are given in a nuclear symbol, the mass number is written as a superscript and the atomic number is written as a subscript. The mass number is always bigger than the atomic number (unless we are talking about ${}^{1}_{1}H$, which has no neutrons). If only one number is given for an element, check with the data booklet to find out which one it is.
Learners may be confused about how to write the correct charges for ions.	Check students' notes/work on how they write charges for ions.	Charges are conventionally written as a number followed by a + or − sign, together as a superscript. For example, if an atom loses two electrons, it becomes an ion with a charge of 2+ (e.g., Mg^{2+}). It should not be written as +2, which would be confused with the oxidation number (covered in Chapter 10).

Starter ideas

1 Recap prior knowledge from pre-IB (15 minutes)

Resources: Students are provided with a few nuclear symbols, for example, ${}^{6}_{3}Li$ and ${}^{7}_{3}Li$ on the whiteboard.

Description and purpose: Ask students to explain to each other in pairs what the numbers and the symbols stand for. Ask students to draw a diagram of one isotope of the Li atom to clearly describe the numbers and locations of the subatomic particles. This peer assessment will allow you to assess students' prior knowledge and allow students to practise using scientific terminology to explain answers to each other.

What to do next: If the majority of students can describe the numbers of protons, neutrons and electrons, and are clearly aware of their locations in the atom, you can move on to practice with more examples of atoms with bigger atomic/mass numbers and with ions. If some students have not done chemistry as a specialised subject before, then you will need to explain the concepts of atomic number, mass number and the locations of subatomic particles.

› **Language focus:** Use of correct terms to describe parts of nuclear symbols.

Main teaching ideas

1 Calculating the numbers of subatomic particles (20 minutes)

Resources: A periodic table

1. Easy (small atoms): Symbols in Table **2.2** in the Coursebook
2. Medium (bigger atoms): Test your understanding question 4 from the Coursebook
3. Hard (ions): Test your understanding question 5 from the Coursebook
4. Challenging (polyatomic ions): NH_4^+, CO_3^{2-}, $[Fe(CN)_6]^{3-}$.

Description and purpose: This exercise gives students practice on how to use the atomic number and mass number to work out the numbers of protons, neutrons and electrons. The level of questions increases in difficulty, and students can be given the choice to choose which level to start on.

› **Differentiation ideas**

Support: Four stations can be set up around the lab with easy to challenging questions. The teacher can position themself at the 'easy' station to assess the levels of ability of the students and offer help with calculations.

Stretch and challenge: Students can be sent to stations to tackle questions of more appropriate levels. Once finished, students can search online for the compositions of protons and neutrons in terms of quarks, the fractional charges on 'up' and 'down' quarks and the origin of the names of the different types of quarks.

2 Construct a mind map for the term atom (15 minutes)

Resources: Poster paper and coloured pens, Coursebook chapter 2 and search BBC Bitesize on the internet for 'atomic structure'.

Description and purpose: This activity allows students to cooperate and contribute meaningfully to a revision task. Students will be given the learning objectives and success criteria of the sub-chapter and asked to create a mind map to explain the concepts covered. This gives students a visual representation of the information and can also be kept for future revision purposes.

› **Differentiation ideas**

Support: Collaborative learning, students can be allocated to mixed-ability groups, so they can learn from their peers. Group work encourages more discussions and allows teachers to give verbal support accordingly.

Stretch and challenge: Students will assess other groups' mind maps and decide whether they address the success criteria of the learning objectives.

› **Assessment ideas:** They can give 'two wishes and a star' to the piece of work from another group.

› **Language focus:** Contextualising scientific terms through visuals.

Plenary ideas

1 Spot the mistakes in the table (10 minutes)

Resources: A table of atoms and ions as follows:

Species	Number of protons	Number of neutrons	Number of electrons
$^{24}_{12}Mg$	12	24	12
$^{202}_{80}Hg$	80	122	122
$^{41}_{19}K^{+}$	22	19	20
$^{34}_{16}S^{2-}$	16	16	16

Description and purpose: This exercise gives students an opportunity to apply their knowledge and requires them to pay attention to details (the charges).

2.2 Isotopes

LEARNING PLAN

Learning objectives	Success criteria
Understand the term isotope	Students should be able to explain the term isotope.
Understand that isotopes of an element have the same chemical properties but different physical properties	Students should be able to give examples of physical properties that are different for isotopes.
Calculate the relative atomic mass (A_r) from the relative abundances of isotopes	Students should be able to determine the relative atomic mass of a sample of an element given the natural abundances.
Calculate the relative abundance of an isotope from the relative atomic mass	Students should be able to determine the natural abundance of the isotopes in a sample given the relative atomic mass.
Understand that the abundance of isotopes in a sample can be determined from a mass spectrum	Students should be able to name the instrument that is used to find the isotopic composition of an element so that its relative atomic mass can be determined.
Understand how to calculate relative atomic mass from a mass spectrum	Students should be able to use mass spectra to determine the relative atomic mass (A_r) of an element.

Common misconceptions

Misconceptions	How to identify	How to overcome
Learners may confuse the difference between mass number and relative atomic mass	Ask students to define these two terms and give respective examples. Give students an example of a nuclear symbol, for example, ${}^{7}_{3}Li$, and ask them why the mass number 7 is different from what is shown as the relative atomic mass in the periodic table in the IB data booklet.	Mass number (represented by the symbol A) is the number protons + the number of neutrons in an atom. It is always an integer. Every isotope has its own mass number. The relative atomic mass (represented by the symbol A_r) of an element is the weighted average mass of the naturally occurring isotopes of the element relative to the mass of $\frac{1}{12}$ of an atom of carbon-12. It is usually not an integer and is shown to two decimal places in the IB data booklet. It takes into account the percentage abundances of the stable isotopes of an element and is calculated as an average value for the isotopes. A_r has a value similar to A because the relative masses of protons and neutrons are approximately one.

Misconceptions	How to identify	How to overcome
Learners may confuse a spectrometer with a spectrophotometer	Ask students to name the instrument used for measuring the percentage abundances of the different isotopes of an element.	A spectrometer measures a given characteristic of a substance. For example, a mass spectrometer measures how the mass to charge ratio changes for a mixture of ionic species. A spectrophotometer is one type of spectrometer that measures light. For example, a UV-VIS spectrophotometer can measure the absorbance or emission of UV/visible electromagnetic radiation.

Starter ideas

1 True or false (10 minutes)

Resources: Test your understanding question 3 from the Coursebook.

Description and purpose: Ask students to write down their answers on mini-whiteboards and (if they finish early) correct the statements that they think are incorrect.

What to do next: This activity allows teachers to recap knowledge from the previous lesson. By learning from errors, students can understand the concepts better and not answer a true/false type of question just by guessing and relying on luck!

2 Atoms, ions and isotopes (10 minutes)

Resources: Use the table of atoms/ions in Test your understanding question 9 from the Coursebook.

Description and purpose: Ask students to identify

- atoms
- positive ions and negative ions
- isotopes from the table.

What to do next: This activity allows teachers to recap knowledge from the previous lesson. Students need to apply their understanding of definitions of atoms, ions and isotopes and the charges of subatomic particles to solve these questions. For more able students, they can write out the nuclear symbols for these atoms and ions using a periodic table.

3 Calculations of relative atomic masses (10 minutes)

Resources: Questions on relative atomic mass calculations from isotope data (Workbook exercise 2.2).

Description and purpose: Students complete questions to check their understanding from the previous lesson.

What to do next: This activity allows teachers to recap knowledge from the previous lesson. By learning from errors, students can grasp the concepts and move on to collect data from a mass spectrum.

Main teaching ideas

1 Calculating relative atomic mass and percentage abundances (30 minutes)

Resources:

1. Easy (two isotopes with percentage abundances given): Test your understanding question 13 from the Coursebook
2. Medium (three/four isotopes with percentage abundances given): Test your understanding questions 14 and 15 from the Coursebook
3. Hard (work out the percentage abundances, given the relative atomic mass): Test your understanding question 17 from the Coursebook

4 Challenging (work out the percentage abundances for more than two isotopes): Iron has four types of naturally occurring isotopes, ^{54}Fe, ^{56}Fe, ^{57}Fe and ^{58}Fe, with relative atomic masses of 53.940, 55.935, 56.935 and 57.933. Given that the relative atomic mass of Fe is 55.845, the natural abundances of ^{54}Fe is 5.845% and that of ^{56}Fe is 91.754%, what are the percentage abundances of ^{57}Fe and ^{58}Fe?

Description and purpose: This exercise gives students practice on how to calculate relative atomic mass or reverse the calculation to work out percentage abundances. The use of either one (hard level) or two (challenging level) unknowns can help reinforce a student's mathematical skill in solving linear equations. The level of questions increases in difficulty, and students can choose which level to start on.

› **Differentiation ideas**

Support: Start from the easy level; students may need clarification on the concept of percentage.

Stretch and challenge: Start with calculations of percentage abundances of two or more isotopes from a more complex dataset (hard and challenging levels).

2 Use mass spectra data to work out relative atomic masses of atoms (30 minutes)

Resources: Graph of mass spectra for different elements (for example, Workbook exercise 2.2).

Description and purpose: Explanation of what a mass spectrometer is (Figures **2.7** and **2.8** from the Coursebook) and its use in determining relative atomic masses. Go through data collected from a mass spectrometer and show students how it can be interpreted. Students can then use mass spectrum graphs to work out relative atomic mass. This activity gives students the opportunity to see mass spectral data and analyse them to work out the relative atomic masses of elements.

› **Differentiation ideas**

Support: Students can be given easier mass spectral data with only two isotopes present. They can work collaboratively; students can be allocated to mixed-ability groups, so they can learn from their peers. Group work encourages more discussions and allows teachers to give verbal support accordingly.

Stretch and challenge: Students can have access to more complex mass spectral data from elements with more than two isotopes. Once finished, encourage them to investigate the operational details of a mass spectrometer. They can present a leaflet on the five different stages of the mass spectrometer and attempt to use their knowledge of forces on moving charges to prove why the mass to charge ratio affects the radius of deflection of ions in a magnetic field in the mass spectrometer.

Plenary ideas

1 Create exam-style questions on this topic with answers and swap with other students (10 minutes)

Resources: A periodic table and access to percentage abundances of stable isotopes by searching the internet for 'percentage abundance of stable isotopes'. Or students could come up with their own imaginary elements.

Description and purpose: This exercise gives students an opportunity to apply their knowledge and think about how they could ask relevant questions about the subject.

› **Assessment ideas:** They can then ask these questions to their peers and mark their work.

2 Reflection on this chapter (10 minutes)

Resources: Syllabus points from this chapter (in the Coursebook).

Description and purpose: This exercise gives students an opportunity to reflect on their learning and understand if they have a secure grasp of the content covered in this chapter.

› **Assessment ideas:** Students can give themselves green, yellow or red for each syllabus point, and the teacher can check the understanding of the students.

3 Keyword glossary (10 minutes)

Resources: A list of words covered in this chapter to define: atomic number, mass number, nucleon, nucleus, ion, isotope, relative atomic mass, weighted average/mean, mass to charge ratio.

Description and purpose: Students are asked to produce a glossary of the words encountered in this chapter. An example should be given at the beginning of this activity to show the level of detail required for the definitions. This activity helps students to reflect on their own understanding.

› **Assessment ideas:** Teachers can ask students to use the word in a sentence and can offer verbal support to help students to construct a logical sentence.

Assessment ideas

- Give students a periodic table and some different atoms/molecules/ions to work out the number of protons, neutrons and electrons.
- Quiz on working out the number of protons, neutrons and electrons in an atom/molecule/ion.
- Extension: How did scientists come up with the model of the atom? What experiments did they do? How did these experiments help them to understand atomic structure?
- Calculations of percentage abundances from relative atomic masses, working backwards (extend using elements with more than two isotopes).
- Give students common misconceptions and ask them to work out where the mistakes are.
- Test your understanding questions from the Coursebook.
- *Mind map* of the whole chapter can be assessed by peers, who can add to it, or by the teacher.
- Students explain why a mass spectrometer is useful and what it is commonly used for.

Homework ideas

- Sheet showing mistakes with the numbers of protons, neutrons and electrons and students need to correct the mistakes. Peers assess each other's work.
- Research on the uses of different types of isotopes. For example, ^{14}C, its use in carbon dating and the controversy it caused in the authenticity of the Turin shroud, or the use of radioactive isotopes in nuclear medicine.
- Make a model of an atom.
- Exam-style questions from the Coursebook.
- Review the syllabus points and highlight each one as green, yellow or red, depending on the level of understanding of the content.
- Build a mind map of the topic to highlight key points from the chapter.

Links to digital resources

- The history of the atom (search the internet with keywords 'history, atom, theory')
- Atomic structure revision (search BBC bitesize for 'atomic structure')
- Gold foil experiment (search the internet with keywords 'chemistry simulations, gold foil, rutherford')
- Summary notes and more practice questions on the atom (search on ibchem.com with keywords 'atomic theory')
- Table of isotopic masses and natural abundances from the University of Alberta (search the internet for 'percentage abundance of stable isotopes')
- Isotopes and mass spectrometry (search the Khan academy website for 'isotopes and mass spectrometry')

CROSS-CURRICULAR LINKS

- Physics: Similar content used when looking at atomic structure in physics.
- TOK/Philosophy: Looking at abstract concepts. Using models and assumptions to come up with scientific theory.
- Maths: Manipulating data, working out percentages using mathematical formulas.