3 Electron configurations

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
3.1 The electromagnetic spectrum 3.2 The hydrogen atom spectrum	1–2	Explain how emission spectra are produced and distinguish between line and continuous spectra. Describe the qualitative relationship between wavelength, frequency, energy and colour of photons in the electromagnetic spectrum. Describe the line spectrum of hydrogen emission and explain how the series of lines provide evidence for the existence of quantised energy levels for electrons in the hydrogen atom.	**Coursebook** Sections 3.1 and 3.2 Test your understanding questions **Workbook** Exercises 3.1 and 3.2 **Teacher's resource** PowerPoint 3, slides 2–4 Worksheet 3.1 Question 4 Worksheet 3.2 Question 1 End of Chapter 3 test Questions 1–3
3.3 Electron configurations 3.4 Putting electrons into orbitals	1–2	Recall the maximum number of electrons that can fill the first four main energy levels. Explain what an atomic orbital is. Recall the shapes, orientations of the s and p sub-levels. State the number of orbitals; the order of energy and the maximum number of electrons of s, p, d and f sub-levels. Deduce the full and condensed electron configurations for atoms and ions up to $Z = 36$, applying the Aufbau principle, Hund's rule and the Pauli exclusion principle. Draw the orbital diagrams for atoms and ions up to $Z = 36$.	**Coursebook** Sections 3.3–3.4 **Workbook** Exercises 3.3–3.4 **Teacher's resource** PowerPoint 3, slides 5–9 Worksheet 3.1 Questions 1–3 End of Chapter 3 test Questions 4–11

Sub-chapter	Approximate number of learning hours	Learning content	Resources
3.5 Ionisation energy	2–3	Explain how the convergence limit in a hydrogen emission spectrum gives information about the first ionisation energy of a hydrogen atom. Define first ionisation energy and successive ionisation energy. Calculate the first ionisation energy from the wavelength or frequency of the convergence limit. Explain the trends in first ionisation energy down a group. Explain the trends in first ionisation energy across Periods 2 and 3. Predict successive ionisation energies for an element and explain how a plot of successive ionisation energies provides evidence for the existence of main energy levels and sub-levels.	**Coursebook** Sections 3.5 Test your understanding Questions 10–11 and 13 **Workbook** Exercises 3.5 **Teacher's resource** PowerPoint 3, slides 10–15 End of Chapter 3 test Questions 12–15

BACKGROUND KNOWLEDGE

- Calculate the number of electrons of atoms and ions up to Z = 36 (Chapter 2).
- Understand how the electronic configuration of a main group element is related to its position in the periodic table.
- Understand what an electromagnetic wave is and explain the meaning of speed, frequency and wavelength of a wave.
- Describe the main features of an electromagnetic spectrum, for example, its different regions and their orders of wavelength.
- Know that electrons are attracted to nuclei by electrostatic attraction and that it takes energy to remove electrons from an atom.
- Understand logarithmic graphs.

Syllabus overview

- In chemical reactions, electrons are transferred or shared (or unshared), so elements become combined to form new substances. To appreciate how chemical reactions occur, one needs to understand the electron configurations of atoms.
- This chapter starts with presenting the evidence from a hydrogen emission spectrum for the quantised energy levels of electrons. This can be explained with the (Rutherford-) Bohr model with defined circular energy levels for electrons and increasing convergency between them when electrons are further away from the nucleus. However, the Bohr model contradicts the Heisenberg's uncertainty principle, in which we cannot know where an electron is at any given moment in time, and does not take into account the wave nature of the electrons. The model of electron configuration needs modification and atomic orbitals, which are solutions of the Schrödinger equation for the hydrogen atom, are then introduced. Atomic orbitals are too small to be observed directly, but this model provides many accurate predictions on ionisation energies, which can be measured experimentally.

- The electron configuration of an atom determines the position of the elements in the periodic table. The period, group number and the block of an element reflect the number of the main energy level, the number of outer-shell electrons and the highest energy sub-levels of the electrons in the element (Chapter 10). An understanding of the electron configuration also provides a starting point for discussing the chemical reactivity of elements (Chapter 10).
- The detailed analysis of the values of ionisation energies introduces students to the concept of shielding and electrostatic attraction between the electrons and the protons in the nucleus. Students practice with different formats of data presentation (table or graph) to analyse successive ionisation energies of various elements and apply their knowledge of electron configuration to explain these data.
- Discussing the history of the evolution of atomic orbital theory enables students to understand how experimentation, making observations and gathering evidence, suggesting new theories and developing new technologies to confirm the predictions of the theories have allowed the development of our knowledge on the microscopic world.

3.1 The electromagnetic spectrum and 3.2 The hydrogen atom spectrum

LEARNING PLAN

Learning objectives	Success criteria
Describe the emission spectrum of hydrogen	Students should be able to interpret the emission spectrum of hydrogen.
Understand how the lines in the emission spectrum of hydrogen arise	Students should be able to explain how the lines in the emission spectrum of hydrogen arise.
Describe the relationship between wavelength, frequency, energy and colour in the electromagnetic spectrum	Students should be able to describe qualitatively the relationship between wavelength, frequency, energy and colour in the electromagnetic spectrum.

Common misconceptions

Misconceptions	How to identify	How to overcome
Learners may confuse absorption and emission spectra	Show students the hydrogen emission spectrum and an absorption spectrum of an element (for example, search on shutterstock.com for 'hydrogen absorption spectrum') and ask them to identify which one is which.	An emission spectrum is produced when electrons, usually in the ground state, become excited when energy is supplied externally. When the electrons return to lower energy levels, photons of light are emitted. In the visible light regions, the emissions can be seen as discrete lines on a dark background.

Misconceptions	How to identify	How to overcome
		An absorption spectrum is produced when electrons in an atom absorb characteristic wavelengths of light to move from a lower to a higher energy level. The wavelength of the photons of light absorbed can be observed. In the visible light regions, the absorptions can be seen as discrete dark lines on a continuous coloured background.

Starter ideas

1 Recap prior knowledge from pre-IB (5 minutes)

Resources: Mini-white board and board pens.

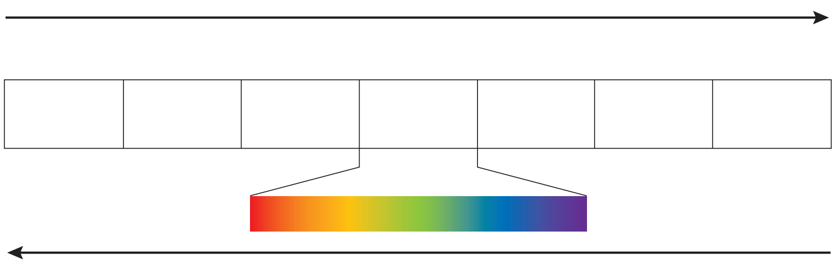
Description and purpose: Draw the Bohr model of an atom, labelling the subatomic particles and their positions.

What to do next: Teachers introduce the idea that electrons do not occupy defined 'planetary' orbits, as depicted in the nuclear atom model, but instead they are found in certain region of space with quantised energy.

Main teaching ideas

1 Labelling an electromagnetic spectrum (10 minutes)

Resources: An electromagnetic spectrum (Figure 3.1).



Description and purpose: Students label the different regions of radiation in an electromagnetic spectrum and identify the trends in frequency, energy and wavelength of the radiations. The purpose is to assess students' general knowledge of electromagnetic radiations and to link it to the different series in a hydrogen emission spectrum.

› **Differentiation ideas**

Support: The electromagnetic spectrum song; search this on vimeo.com, or this session on BBC Bitesize.

Stretch and challenge: Use $E = hf$ or $E = hc/\lambda$ to work out the approximate energies of each type of radiation using its wavelength. Convert between energy in Joules and energy in electron volts.

2 The hydrogen emission spectrum (20 minutes)

Resources: A hydrogen discharge tube and a spectroscope (or a prism).

Description and purpose: This activity allows students to visualise the hydrogen emission spectrum, and they can also compare the line spectrum with the continuous spectrum observed when looking at sunlight through a spectroscope.

Differentiation ideas

Support: Provide students with detailed summary notes on how the hydrogen emission spectrum is produced and how it provides evidence for quantised energy levels of electrons in a hydrogen atom. Ask students to highlight the notes and summarise in their own words how electromagnetic radiation of specific wavelengths is produced. Bring to the students' attention that the lines converging nearer to the violet end, showing that the main energy levels become closer when electrons are further from the nucleus.

Stretch and challenge: Students can be provided with Figure **3.3** from the Coursebook and explain how the lines are produced in front of the class.

More detailed information can be extracted from the hydrogen emission spectrum. Students can research Rydberg's equation on chemguide.co.uk.

3 Design a leaflet on the hydrogen emission spectrum (45 minutes)

Resources: Coloured pens and A4 paper (or on a computer).

Description and purpose: Students need to design an information leaflet to explain the hydrogen emission spectrum to their peers. The following points must be addressed on the leaflet: describe the experimental setup and how to observe the hydrogen emission spectrum; describe the emission spectrum of the hydrogen atom, including the relationships between the lines and energy transitions to the first, second and third energy levels; how the line spectrum provides evidence for the existence of electrons in discrete energy levels, which converge at higher energies; explain the differences between an absorption and an emission spectrum, a line spectrum and a continuous spectrum.

Language focus: Students can describe and explain the emission spectrum clearly and concisely and use the key terms correctly.

Differentiation ideas

Support: 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: Calculation of the ionisation energy of hydrogen (in kJ/mol) and the energy required to ionise a single hydrogen atom in J and eV.

Parts a and b of question 6 in the 2009 UK Chemistry Olympiad (available on edu.rsc.org).

Plenary ideas

1 Draw and label an energy level diagram for the hydrogen atom (10 minutes)

Resources: Pen and paper.

Description and purpose: Students need to show 1) energy levels converge at higher energy; 2) clear labels for energy levels on the y axis; 3) series of lines, which give rise to emissions in the UV and visible regions of the spectrum. This activity assesses whether the students have achieved their learning objectives.

3.3 Electron configurations and 3.4 Putting electrons into orbitals

LEARNING PLAN

Learning objectives	Success criteria
Write full and condensed electron configurations for atoms and ions up to $Z = 36$ Understand what orbitals are and recognise diagrams of s and p orbitals Draw orbital diagrams for atoms and ions up to $Z = 36$	Students should be able to deduce full and condensed electron configurations for atoms and ions up to $Z = 36$. Students should be able to explain the term orbital and recognise the shapes of an s orbital and the three p orbitals. Students should be able to draw orbital diagrams for atoms and ions up to $Z = 36$.

Common misconceptions

Misconceptions	How to identify	How to overcome
Learners do not know how to explain what an orbital is	Ask students to describe where electrons are found in an atom.	An orbital is not a physically defined space (for example, like an orbit in the Bohr model of atoms) but is defined as a region of high probability of finding an electron. For example, in an s orbital, electrons can be mostly found in the region depicted by the spherical shape. A 2s orbital has a very similar shape to the 1s orbital, but the electrons in a 2s orbital spend significantly more time further away from the nucleus than those in the 1s orbital. Heisenberg's uncertainty principle states that one cannot precisely define the position of an electron at any instant of time due to inherent uncertainties in the measurements we can do.
Learners may not fully understand the concept of the spin of an electron	Ask students to explain their understanding of the spin of an electron.	This is often visualised using the classical interpretation of a ball spinning on its axis, but 'spin' represents the angular momentum of every electron and is a purely quantum mechanics term. Electrons with opposite spins interact differently with an external magnetic field, and this can be observed in experiments. Protons and neutrons also have characteristic spins.

Misconceptions	How to identify	How to overcome
Learners confuse the difference between the various terms main energy level, sub-level and orbital	Question students on the maximum number of electrons that can fit into 1) the fourth main energy level; 2) the 4p sub-level; and 3) a 4p orbital.	The main energy level is given an integer number, *n*, and can hold a maximum of $2n^2$ electrons. So, the fourth main energy level can hold 32 electrons. A main energy is further divided into sub-levels (s, p, d and f), and each sub-level can hold a specific number of electrons. The fourth main energy level is made up of 4s, 4p, 4d and 4f sub-levels, and the 4p sub-level can hold a maximum of six electrons. Each sub-level can be made up degenerate orbitals. Each p sub-level has 3 × p orbitals and each orbital holds a maximum of 2 electrons. The relationships between the main energy level, sub-level and orbitals can be visualised using orbital diagrams.

Starter ideas

1 Filling the gaps on the principle of the hydrogen emission spectrum (10 minutes)

Resources: Worksheet 3.2.

Description and purpose: Students fill the gaps to recap knowledge from the previous lesson.

What to do next: Teachers can gauge students' understanding of the emission spectrum and if they are ready to move onto the atomic orbital model of electron configuration.

› **Language focus:** Use and application of keywords.

Main teaching ideas

1 Application of the Aufbau principle, Hund's rule and the Pauli exclusion principle to write complete and condensed electron configuration for atoms and ions (45 minutes)

Resources:

1. Easy: Li, N, Mg, P, Ca atoms
2. Medium: Li^{+}, N^{3-}, Mg^{2+}, S^{2-}, Ti, Mn, Zn, As, Br
3. Hard: Cu, Cr, Cu^{+}, Cr^{3+}, Fe^{2+}, Fe^{3+}, Ga^{3+}, Br^{-}.

Description and purpose: Firstly, introduce the Aufbau principle, Hund's rule and the Pauli exclusion principle with specific examples (emphasise the exceptions of Cr and Cu). Secondly, go through the order in which electrons are removed when atoms are ionised. Students can then apply their knowledge and choose questions of different levels of difficulty to practice.

› **Differentiation ideas**

Support: Start from the easy level; teachers can give support accordingly.

Stretch and challenge: Students can produce orbital diagrams for more complex electron configurations.

Research into quantum numbers (principal, angular momentum quantum number, magnetic moment quantum number and spin quantum number).

2 Multiple-choice questions on unpaired electrons or occupied orbitals (15 minutes)

Resources: Teacher's resource End of Chapter 3 test questions 6–10.

Description and purpose: Students should attempt these questions under time pressure. They need to apply their knowledge of electron configurations quickly and accurately before deciding on the answers.

› Differentiation ideas

Support: Teachers assess the answers and give support whilst going through the explanations.

Stretch and challenge: Students explain the answers to their peers in front of the class. This requires the students to synthesise their knowledge and express their ideas coherently.

Plenary ideas

1 A table on the maximum number of electrons in an energy level/sub-level/orbital (5 minutes)

Resources: A table as follows:

Region	Maximum number of electrons
a 3d orbital	
the 2p sub-level	
the fourth energy level	

Description and purpose: This activity assesses students' understanding of the differences between energy level, sub-level and orbital.

2 True or false in the electron configurations (10 minutes)

Resources: A table as follows:

Electron configurations	True	False
Cu^{+} $1s^22s^22p^63s^23p^64s^13d^9$		
Mn^{5+} $1s^22s^22p^63s^23p^63d^3$		
Ga^{3+} $1s^22s^22p^63s^23p^63d^94p^1$		

Description and purpose: Students should decide on whether the electron configurations are correct and how to correct them if they are false. By learning from errors, students can understand the concepts better and not answer a true/false type of question just by guessing.

3 Decide which type of radiation would be emitted during the following transitions in a hydrogen emission spectrum (5 minutes)

Resources: 2p → 1s, 3d → 2s, 4f → 2p, 6d → 1s, 5p → 3s, 4d → 1s, 5f → 2p.

Description and purpose: This exercise requires students to combine their knowledge of the hydrogen emission spectrum and electron configuration, so teachers can assess whether they have achieved the learning objectives from the two different subchapters.

3.5 Ionisation energy

LEARNING PLAN

Learning objectives	Success criteria
Understand that the ionisation energy for hydrogen can be calculated from the emission spectrum	Students should be able to describe how the ionisation energy for hydrogen can be deduced from the emission spectrum.
	Students should be able to calculate the first ionisation energy from the wavelength or frequency of the convergence limit.
Understand what information about the electron structure of atoms can be deduced from successive ionisation energy data	Students should be able to interpret successive ionisation energy data and deduce the group an atom is in.
Understand trends in first ionisation energy down a group and across a period	Students should be able to recall and explain the trends in first ionisation energy down a group and across a period.

Common misconceptions

Misconceptions	How to identify	How to overcome
Some students think electrons 'share' the electrostatic attraction from protons	Explain why Mg^{2+} has a higher ionisation energy than Mg^{+}.	Ionisation energy is required to overcome the electrostatic attraction between the positive nuclei and the negative outer-shell electrons, taking into account the effect of shielding by inner-shell electrons. As the second electron in Mg is removed from the same main energy level and sub-level as the first electron, there is no change in shielding. However, fewer electrons remaining means there is less repulsion between the electrons, so, after the first electron is removed, the electrons move a little closer to the nucleus and are more attracted to the nucleus (electrostatic attraction is inversely proportional to the square of the distance between the oppositely charged particles). It is important for students to understand the reason that the second ionisation energy is always higher is not because there are fewer electrons 'sharing' the attraction from the protons.

Starter ideas

1 Revision on the electron configuration of atoms and ions (10 minutes)

Resources: Mini-white board and board pens.

Description and purpose: Ask students to pair up and quiz each other on the electron configurations of atoms and ions up to Z = 36.

What to do next: Ask students which electrons will be removed first in an atom if some energy is supplied to the atom.

Main teaching ideas

1 Calculating the first ionisation energy from the convergence limit wavelength or frequency (45 minutes)

Resources: Test your understanding questions 10 and 11 from the Coursebook

Description and purpose: Teachers explain what first ionisation energy is and why it can be deduced from the convergence limit of the Lyman series in a hydrogen atom. By using $E = hf$ and $c = \lambda f$, students can work out the ionisation energy from the wavelength or the frequency at the convergency limit.

Differentiation ideas

Support: Teachers show a worked example on the board for students to follow.

Stretch and challenge: Students can work independently and self-assess their answers.

2 Identifying the trends and discontinuities in successive ionisation energies of potassium (45 minutes)

Resources: Figure **3.32** in the Coursebook and internet for research.

Description and purpose: Give students the definition of ionisation energies and ask them to look for evidence of the main energy levels of electrons in the potassium atom. Discussion on the use of a log scale for the ionisation energy plot and how scientific data can be manipulated to influence the interpretation of a conclusion.

Differentiation ideas

Support: Students can write out the electronic configuration for a potassium atom and the teacher can point out that the electrons with higher energies are removed first. Students should be able to match the increase in the graph with the different main energy levels from which the electrons are being removed.

Stretch and challenge: Students can come up with their own explanations for the general increase in successive ionisation energies and present them to the class. Students can plot a graph for the first five successive ionisation energies for silicon (search the data on the internet) and identify evidence for the removal of electrons from different sub-levels (3p → 3s, as shown by a smaller increase in ionisation energy from the second to the third electron being removed) and the removal of electrons from different main energy levels (3s → 2p, as shown by a larger increase in ionisation energy from the fourth to the fifth electron being removed). The graph should not be plotted on a log scale, to show the increase from the second to the third ionisation energy.

Plenary ideas

1 Deduction of the group number of an element (10 minutes)

Resources: Test your understanding question 13 from the Coursebook.

Graph data–these can be found online by searching for 'successive ionisation energy of sodium' or 'aluminium' or 'silicon'.

Description and purpose: Students need to identify the group of an element from limited data of successive ionisation energy. This is a quick exercise to assess if students can apply their knowledge (of electron configuration and ionisation energy) and skills (to extract information from a table or a graph) to solve unseen problems.

2 Calculating the enthalpy change of $M(g) \rightarrow M(g)^{2+} + 2e^-$ (10 minutes)

Resources: A list of elements and their first four ionisation energies (IEs). For example:

Element	First IE (kJ/mol)	Second IE (kJ/mol)	Third IE (kJ/mol)	Fourth IE (kJ/mol)
Be	890	1757	14 849	21 007
Si	787	1577	3232	4356
Cl	1251	2298	3822	5159

Description and purpose: Students need to recognise what the equation in the question represents – the energy required to remove the first and second electrons from the atom. Then, it is just a simple addition of the first two successive ionisation energies.

› **Assessment idea:** This exercise assesses if students understand how to represent word definitions using symbol equations and if they can analyse and use information from a table.

3 A past paper question on first ionisation energy (10 minutes)

Resources: 2019 May HL paper TZ2 Q3 b(iii).

Description and purpose: Students need to apply their knowledge to this slightly unusual question, to assess if they are secure with the factors which affect the magnitude of the first ionisation energy. They can self-assess their answers with the mark scheme.

Assessment ideas

- Test your understanding questions from the Coursebook.
- Give students the keywords from the topic to write a glossary – an example should be given at the beginning of this activity to show the level of detail required for the definitions.
- Give students a periodic table and different atoms/ions to work out their electron configurations.
- Provide students with 'wrong/brief answers' on explaining the trends in ionisation energy and ask them to identify the mistakes and rewrite the sentences.
- Give students data on successive ionisation energies to identify the group number of an element.
- Students write five multiple-choice questions on electron configuration using the syllabus points; the questions can be attempted in groups and peer assessed.

Homework ideas

- Questions from the Workbook (exercises 3.1–3.5).
- Questions from the Coursebook.
- Sheet showing wrong electron configurations and ask students to correct the mistakes. Peer review each other's work.
- Draw a mind map of 'electron configuration', which can be assessed by peers, who can add to it, or by a teacher.
- Sketch successive ionisation energies of calcium using a logarithmic scale (y axis for the ionisation energy and x axis for the number of electrons removed) and explain the shape of the graph.
- Prepare a 10-minute presentation on the hydrogen emission spectrum–how it is produced, what it looks like, the evidence it provides for the existence of quantised energy levels of electrons in an atom, explain how the convergence limit provides information on first ionisation energy of a hydrogen atom.
- Two stars and a wish: students use this to assess their understanding using the success criteria for this chapter.

Links to digital resources

- Emission spectrum vs absorption spectrum (search on shutterstock.com for 'hydrogen absorption spectrum')
- The electromagnetic spectrum song (search on vimeo.com for 'electromagnetic spectrum song')
- Extension on the hydrogen emission spectrum (search 'Rydberg's equation' on chemguide.co.uk)
- Extension question on the calculation of energies of electrons in atoms 2009 UK Chemistry Olympiad question 6 parts a and b (search on the Royal Society of Chemistry website for 'olympiad past papers')

CROSS-CURRICULAR LINKS

- Maths: Basic arithmetic calculations; extract information from graphs.
- Physics: Describe how wavelength and frequency are related for travelling waves.
  The order of frequencies, energies, and wavelengths of various electromagnetic radiations.
  Understand what photons are.
- TOK: How to interpret indirect evidence that can only be detected using technology.
  The limitations of scientific knowledge, e.g., the solutions of the Schrödinger equation and Heisenberg's uncertainty principle.