11 Classification of organic compounds

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
11.1 The structures of organic molecules 11.2 Homologous series and functional groups	3–4	Recognise the different types of formulas of organic compounds and understand how to interconvert them. Explain what a homologous series is and compare the properties of compounds in the same homologous series. Recognise the functional groups of different homologous series and explain what functional groups are. Identify compounds as saturated or unsaturated.	**Coursebook** Sections 11.1–11.2 Test your understanding Questions 1–6 **Workbook** Exercises 11.1–11.2 **Teacher's resource** PowerPoint 11, slides 2–21 Worksheet 11.1 Question 2 End of Chapter 11 test Question 8
11.3 Naming organic molecules 11.4 Isomers	4–5	Apply *IUPAC nomenclature* to name saturated or mono-unsaturated compounds having up to six carbon atoms. Explain what structural isomers are and recognise chain, positional and functional group isomers. Explain the meaning of primary, secondary and tertiary when applied to alcohols, halogenoalkanes and amines.	**Coursebook** Sections 11.3 and 11.4 Test your understanding Questions 8,12,14,17–18 **Workbook** Exercises 11.3–11.4 **Teacher's resource** PowerPoint 11, slides 5–12, 14–17 and 20 Worksheet 11.1 Question 1 End of Chapter 11 test Questions 1–4

Sub-chapter	Approximate number of learning hours	Learning content	Resources
11.4 Isomers	3–4	Explain what stereoisomers are. Identify *cis–trans* isomers and explain how they form in alkenes and cycloalkanes. Explain what a chiral carbon atom is and the meaning of optical activity, enantiomer and racemic mixture. Explain optical isomerism and recognise enantiomers. Draw a pair of enantiomers showing the 3D arrangements of atoms.	**Coursebook** Section 11.4 Test your understanding Questions 29–30 and 33 **Workbook** Exercise 11.4 **Teacher's resource** PowerPoint 11, slides 22–25 End of Chapter 11 test Question 5–7 and 12
11.5 Spectroscopic identification of organic compounds	7	Deduce information from mass spectra, including information on the molecular ion and the fragmentation patterns. Use infrared (IR) spectra to identify the type of bond present in compounds and understand the meaning of wavenumbers. Understand what greenhouse gases are. Interpret ^{1}H nuclear magnetic resonance (NMR) spectra to deduce the structures of organic molecules, understanding the splitting pattern. Combine data from different analytical techniques to determine the structure of compounds.	**Coursebook** Section 11.5 Test your understanding Questions 34, 35, 39-43 **Workbook** Exercise 11.5 **Teacher's resource** PowerPoint 11, slides 26–30 Worksheet 11.1 Questions 3– 4 End of Chapter 11 test Questions 9–11 and 13–15

BACKGROUND KNOWLEDGE

- Mass spectrometry (Chapter 2).
- Empirical and molecular formula calculations (Chapter 4).
- Identify the nature of intermolecular forces between organic molecules (Chapter 7).
- Know that the strength of the London forces depends on the size / molar mass of the molecules (Chapter 7).
- Draw Lewis formulas for simple molecules (Chapter 7)
- Draw the shapes of different molecular geometries in 3D (Chapter 7).
- Know the functional groups of the monomers that can form addition and condensation polymers (Chapter 9).
- Some pre-IB knowledge on organic chemistry (for example, homologous series, functional group, general formula, structural formula, isomer, alkanes, and alkenes)

Syllabus overview

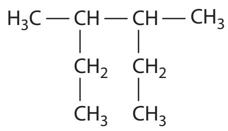
- Organic chemistry is the study of carbon-containing compounds. Carbon atoms can form long chains and ring structures with themselves, allowing a large range of compounds to be made. Originally, *organic* meant compounds produced by living organisms, but this has been broadened to include man-made pharmaceuticals, plastics and many others.
- This chapter starts by introducing the concept of a homologous series and the representation of its members using structural, skeletal and stereochemical formulas. The general physical properties of different homologous series are discussed, and this consolidates the knowledge of intermolecular forces and their effect on boiling / melting points, viscosity and solubility of the molecules, as introduced in Chapter 7. Their chemical properties are covered in Chapters 20–22.
- IUPAC nomenclature is applied to saturated and mono-unsaturated compounds. Students should relate the concept of drawing structural isomers to the naming system, to understand how to identify the longest continuous carbon chains as the basis for naming the compounds and numbering the branches. The use of molecular modelling is important for visualising and distinguishing between the 3D shapes of various isomers. At Higher Level, students continue further to stereoisomers, including *cis–trans* and optical isomerism.
- Three different analytical techniques are explored in this chapter. Mass spectrometry is mentioned in Chapter 2 for measuring relative atomic masses, and here it is expanded to simple molecules. IR is used to identify the types of bonds present. Whether a molecule is IR active depends on the change in its dipole moment – covered in Chapter 7. ^{1}H NMR provides the most information about the structure of a molecule, and both low- and high-resolution spectra are introduced. When using combined techniques, it is worth emphasising that the structure deduced must fit all the information provided.

11.1 The structures of organic molecules and 11.2 Homologous series and functional groups

LEARNING PLAN

Learning objectives	Success criteria
Understand how the structures of organic molecules can be represented by different types of formula	Students can write and convert between different types of formula for organic molecules.
Understand what a homologous series is	Students know how to explain what a homologous series is and its characteristics.
Recognise different homologous series	Students should be able to recognise different homologous series based on the functional groups of the molecules.
Understand the term functional group and how they influence properties	Students can explain the term functional group.
Recognise different functional groups	Students can identify functional groups by name and structure.
Understand the terms saturated and unsaturated	Students can explain the terms saturated and unsaturated based on the presence / absence of C=C and / or C≡C.

Common misconceptions

Misconceptions	How to identify not elicit	How to overcome
Students get confused on how to name organic compounds.	Ask students to name a compound, for example,  Some students will name this 2,3-diethylbutane rather than 3,4-dimethylhexane.	The teacher emphasises that, when naming an organic compound, one should look for the longest continuous carbon chain to base the name on, rather than the chain drawn horizontally.
Names of functional groups vs homologous series are different sometimes.	Ask students to name the functional groups in a few large molecules (for example, taxol, ascorbic acid, citric acid).	Students can draw a table to compare the names of the functional groups and the homologous series they are characteristic of, for example, hydroxyl vs alcohol, amido vs amide.

Starter ideas

1 Assess prior knowledge from pre-IB on organic compounds (10 minutes)

Resources: Pen and paper.

Description and purpose: Ask students to explain keywords, including homologous series, functional group, general formula, structural formula, isomer, alkanes, and alkenes. Students can describe these terms in words and draw examples to illustrate.

What to do next: Some students might need a reminder on what these terms mean. For consolidation, they can be provided with a textbook or BBC Bitesize pages for definitions and to find examples.

› **Language focus:** Application of keywords for definitions.

2 Identify organic compounds (20 minutes)

Resources: Search the internet for the UK Chemistry Olympiad 2012 past paper and use Question 3f.

Description and purpose: An activity to encourage students to link what they learn in a chemistry class to real life by finding out the structures of caffeine, paracetamol, sucrose and an artificial sweetener (aspartame).

What to do next: Ask students to use the internet and try to identify the functional groups in these chemicals and discuss the presence of the dashed lines in the structure of aspartame.

Main teaching ideas

1 Make molecular or virtual models of alkanes (30 minutes)

Resources: Molecular modelling kits or virtual modelling software, for example, ChemSketch or CheMagic.

Description and purpose: Ask students to build models for the first six members of the alkane homologous series and identify the structural similarities and differences between the different alkanes. Show students how the physical properties (for example, boiling point) of alkanes change as the molecules get bigger in Figure **11.13**.

› **Differentiation ideas:**

Support: Divide students into mixed-ability groups, so they can help each other with building models. The teacher can support accordingly.

Stretch and challenge: Ask students to produce a definition of a homologous series and explain why the boiling points increase as the alkanes get bigger. Students can also start making branched isomers of larger members of the alkanes.

2 Research into other homologous series (60 minutes)

Resources: Sub-chapter 11.2 from the Coursebook and Chemguide.co.uk, poster paper and Post-it notes. Students can research using either the Coursebook or online, then present their information on a poster.

Description and purpose: Divide students into groups of twos or threes. Assign each group a homologous series (alkenes, alkynes, alcohols, halogenoalkanes, aldehydes, ketones, carboxylic acids, ethers, amines, amides and esters) and they need to research and find information on 1) functional group; 2) general formula; 3) names and structures of the first few members; 4) trend in physical properties, such as boiling points, melting points and solubility; 5) common chemical properties of the compounds and 6) make a model of a member of the homologous series. Students then rotate to other groups to take notes.

› **Assessment ideas:** In addition, students can make two stars and a wish on each poster.

› **Differentiation ideas:**

Support: The teacher can divide students into groups according to their abilities and help with students' research accordingly.

Stretch and challenge: Students can research and plot graphs to show the trend in physical properties shown by the members of a homologous series. They can also be encouraged to look at and explain the difference in boiling points and solubilities of different series of compounds, for example, alkanes, alcohols and carboxylic acids.

3 Introduce the structural, stereochemical and skeletal formulas of the organic compounds (60 minutes)

Resources: Molecular modelling kits and Test your understanding Questions 1–4 from the Coursebook.

Description and purpose: Introduce the various ways for representing organic compounds. The teacher can make a model of a molecule, then draw it out using full structural, condensed structural, and skeletal formulas. Students can practice with examples and interconvert the different types of formulas.

› **Differentiation ideas:**

Support: Provide students with full structural formulas, so they can condense them. Use modelling kits to help visualise the stereochemical formulas.

Stretch and challenge: Students can practice drawing stereochemical formulas and more complex skeletal formulas for larger molecules. In addition, they can write the molecular formulas for NanoPutians. Search the internet for images of NanoPutians.

Plenary ideas

1 Spot the functional groups / homologous series in large organic molecules (10 minutes)

Resources: Test your understanding Questions 5–6 from the Coursebook.

Description and purpose: Assess students' understanding on functional groups and homologous series and see if they know the difference between these two terms.

2 Compare and explain the boiling points between the following pairs of molecules (10 minutes)

Resources: A multiple choice question, for example:

What is the correct order of boiling points of the following organic compounds: C_3H_8, CH_3CH_2F and CH_3CH_2OH?

A $C_3H_8 < CH_3CH_2OH < CH_3CH_2F$

B $CH_3CH_2F < CH_3CH_2OH < C_3H_8$

C $CH_3CH_2OH < CH_3CH_2F < C_3H_8$

D $C_3H_8 < CH_3CH_2F < CH_3CH_2OH$

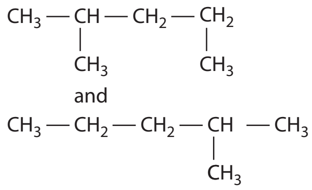
Description and purpose: This type of question assesses the students' understanding of the structural formulas of the compounds, the types of intermolecular forces present and the relative strength of the intermolecular forces. The correct answer is D. It is important to recognise that these molecules are all of similar molecular masses, so the London forces between the molecules are similar.

11.3 Naming organic molecules and 11.4 Isomers

LEARNING PLAN

Learning objectives	Success criteria
Understand how to name saturated or mono-unsaturated organic molecules containing up to six carbon atoms in the longest carbon chain	Students should be able to name saturated or mono-unsaturated organic molecules containing up to six carbon atoms in the longest carbon chain, including straight-chain and branched-chain isomers.
Understand the classification of groups as primary, secondary or tertiary	Students should be able to recognise primary, secondary and tertiary alcohols, halogenoalkanes and amines.
Understand what structural isomers are	Students can recognise isomers, including chain, position and functional group isomers.
Draw structural isomers of compounds	Students can draw structural isomers of compounds using full or condensed structural formulas.
Understand the term stereoisomer	Students can explain the term stereoisomer and understand its difference from structural isomer.
Understand *cis–trans* isomerism	Students should be able to explain *cis–trans* isomerism and recognise and draw *cis–trans* isomers.
Understand what chirality is	Students can identify chiral centres and explain the terms optical activity, enantiomer and racemic mixture. Students understand the different properties of enantiomers.
Draw enantiomers using stereochemical formulas	Students can recognise enantiomers from 3D modelling and know how to represent them on paper.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students get confused about how to draw structural isomers correctly.	Ask students to draw out all the structural isomers for C_6H_{14}. Some students think  are different isomers.	Use modelling kits to build these molecules and show that they are identical in 3D. Students should always identify the longest continuous carbon chain in the isomers before checking the positions of branches in molecules. They can also try to name the compounds: if the compounds have the same name, they are the same molecule.
Functional group isomers are also structural isomers.	Ask students to draw out all the structural isomers for C_3H_8O and some may forget to include the ethers.	Use modelling kits to make isomers of different functional groups. For example, alcohols and ethers, aldehydes and ketones, carboxylic acids and esters can often be structural isomers of each other.
Students are unsure of the difference between structural and stereoisomers.	Ask students to name the type of isomerism (*cis* vs *trans*, optical isomers vs structural isomers) in different pairs of molecules.	The teacher can point out the fact that structural isomers must have different connectivity of atoms. Visualise the molecules in 3D with modelling kits.

Starter ideas

1 Draw the first four members of the alkane and alkenes families using structural (and for extension, skeletal) formulas (10 minutes)

Resources: Mini-whiteboards and pens.

Description and purpose: Review knowledge from the previous sub-chapter on homologous series, functional groups and different types of formulas.

What to do next: If students are familiar with how to draw the formulas, they can start making or drawing isomers of branched alkanes and alkenes.

2 *cis–trans* isomerism (15 minutes)

Resources: Molecular modelling kits or virtual modelling software, for example, ChemSketch or CheMagic.

Description and purpose: Ask students to make models of but-2-ene and see if they can appreciate that the *cis* and *trans* isomers are not the same molecules.

What to do next: Discuss the importance of *cis–trans* isomerism, relating to, for example, *cis* and *trans* fats in food.

3 Optical isomerism (15 minutes)

Resources: Molecular modelling kits or virtual modelling software, for example, ChemSketch or CheMagic.

Description and purpose: Ask students to make models of butan-2-ol. Take one *R* and one *S* isomer and ask students to assess if they are identical.

What to do next: Introduce the idea of optical isomers, using left and right hands as examples.

Main teaching ideas

1 Isomers of alkanes, straight-chain and branched (30 minutes)

Resources: Pens and paper, molecular modelling kits or virtual drawing tools.

Description and purpose: Students should be able to recognise and draw straight-chain / branched isomers of alkanes.

› **Differentiation ideas:**

Support: Remind students to keep the longest continuous carbon chain horizontal when drawing. Practice with simpler molecules, including C_4H_{10} and C_5H_{12}, and use full displayed formulas.

Stretch and challenge: Draw all the isomers for larger alkanes, for example, C_7H_{16}. Students can attempt skeletal formulas and self-assess with modelling kits to see if there are any repetitions of molecules.

2 Name alkanes (30 minutes)

Resources: Test your understanding Question 8 from the Coursebook, mini-whiteboards and pens.

Description and purpose: The teacher goes through a few examples on naming straight-chain and branched alkanes first, using IUPAC nomenclature. Students apply their knowledge to unfamiliar molecules afterwards.

› **Differentiation ideas:**

Support: Give students a checklist of steps to go through when naming compounds. For example:

1. Find the longest continuous carbon chain in the molecule.
2. Use the prefix to represent the number of carbon atoms in the longest continuous carbon chain, and the ending -ane to show that it is an alkane.
3. Number the positions of the substituent groups using the combination that includes the lowest individual numbers (not the sum).
4. Count the number of each type of substituent and use prefixes to indicate the number and methyl, ethyl, etc. to show the substituents.
5. Arrange the names of the substituents in alphabetical order.

Stretch and challenge: Students can work independently on this task and explain their answers to others.

3 Draw isomers of alkenes, introduce position and functional group isomers in addition to straight-chain / branched isomers (50 minutes)

Resources: Pens and paper, molecular modelling kits or virtual drawing tools.

Description and purpose: Students should be able to recognise and draw straight-chain / branched, positional and functional group isomers of alkenes.

› **Differentiation ideas:**

Support: The teacher gives examples for each type of isomer, drawing on a board or making models.

Stretch and challenge: Ask students to make isomers of C_4H_8 using modelling kits; these should include examples for all three types of structural isomers. If there is time, students can start researching into *cis–trans* isomers.

› **Assessment ideas:** Students hold up their models and assess each other's to see whether they are correct.

4 Name alkenes (20 minutes)

Resources: Test your understanding Question 14 from the Coursebook.

Description and purpose: Recap students' prior knowledge on naming alkanes before applying it to isomers of alkenes.

› **Differentiation ideas:**

Support: The teacher can support students by working through examples on a board.

Stretch and challenge: Students can complete the task independently and help others. They can also name the functional group isomers (cycloalkanes).

5 Identify primary, secondary and tertiary compounds (60 minutes)

Resources: Pens and poster paper, molecular modelling kits or virtual drawing tools.

Description and purpose: Students can follow the previous examples on alkanes and alkenes and make models of alcohols, halogenoalkanes and amines. Divide students into three groups to focus on the three homologous series. Each group should include on their poster the following:

1. Introduce the naming of the compounds.
2. Draw structural isomers of each class of compounds.
3. Give examples of primary, secondary and tertiary molecules in each series.

They then need to present the information to the rest of the class.

› **Assessment ideas:** Peer review of each other's presentations. Making posters on drawing and naming isomers for other homologous series,including alcohols, halogenoalkanes and amines.

› **Differentiation ideas:**

Support: Students can work collaboratively and be allocated to mixed-ability groups, so they can learn from their peers. Group work encourages more discussions and allows the teacher to give verbal support accordingly.

Stretch and challenge: More confident students can familiarise themselves with chemical drawing tools and produce computer drawings of their isomers.

6 Draw and name aldehydes, ketones and carboxylic acids (45 minutes)

Resources: Test your understanding Questions 17 and 18 from the Coursebook.

Description and purpose: The teacher introduces the naming of aldehydes, ketones and carboxylic acids. Students practice with Test your understanding questions.

› **Differentiation ideas:**

Support: The teacher goes through a few examples on the board before students complete this task independently.

Stretch and challenge: Ask students to find functional group isomers for alcohols, aldehydes, carboxylic acids and alkenes. For example, alcohols with ethers, aldehydes with ketones, carboxylic acids with esters, alkenes with cycloalkanes or a mixture of functional groups (carboxylic acids with an alkene alcohol, etc.). Students can also research into how to name alkenes containing functional groups such as halogeno, hydroxyl, carbonyl and carboxyl.

7 Make models of alkenes and C_3 and C_4 cycloalkanes to look for *cis–trans* isomerism (45 minutes)

Resources: Molecular modelling kits or virtual modelling software. Test your understanding Question 29 from the Coursebook.

Description and purpose: The teacher shows a few examples of *cis–trans* isomerism in alkenes and cycloalkanes. Ask students to come up with their own criteria on why *cis–trans* isomerism arises.

› **Differentiation ideas:**

Support: Use molecular modelling kits to build more models to visualise the difference between the isomers.

Stretch and challenge: Students can investigate the *cis–trans* isomerism for the platin complex and the relevance of this in the application of cisplatin as an anti-cancer drug.

8 Identify and draw optical isomers (45 minutes)

Resources: Pens and paper, molecular modelling kits or virtual drawing tools. Test your understanding Question 30 from the Coursebook. Chemicals include caraway seeds, spearmint and images of carvone (*R* and *S* forms).

Description and purpose: Use real-life examples to introduce optical isomers, for example, caraway seeds vs spearmint. Show students pictures of the structures of *R*- and *S*-carvones present in these chemicals, and how they can be distinguished easily by smelling. Ask students to make their own models of chiral molecules (butan-2-ol or just a made-up molecule with carbon attached to four different coloured atoms, and their mirror images) and try to superimpose. Show how optical isomers can be represented on paper using the wedge-dash lines.

Differentiation ideas:

Support: Help students identify the chiral centre and show examples of 3D drawing. Students can work through Test your understanding Question 30 with the teacher's support.

Stretch and challenge: Students complete Question 30 independently. In addition, they can look into optical isomerism in transition element complex ions with polydentate ligands. For example, $[Co(NH_2CH_2CH_2NH_2)_2Cl_2]^+$ has *cis* and *trans* stereoisomers and one of these also has an optical isomer.

9 Research on measuring chirality (50 minutes)

Resources: Search for 'polarimeter' on the internet.

Description and purpose: Students research in groups on how optical activity can be measured. They need to present their findings in slides, including an explanation for the following terms: chirality, chiral centre, enantiomer, plane-polarised light, optically active and racemic mixture. Students should also address the similarities / differences in physical and chemical properties of enantiomers.

Differentiation ideas:

Support: Help students with research and give them explicit examples on how to define some of the terms. The teacher can also help to structure the presentation with sub-sections.

Stretch and challenge: Students can carry out the task independently in groups. Once they are done, they can design filling the gap exercises with the definitions of the key terms above.

Plenary ideas

1 Spot the mistakes in naming (10 minutes)

Resources: Test your understanding Question 12 from the Coursebook.

Description and purpose: To see if students can apply their knowledge to spot mistakes and produce the correct names of alkanes.

Assessment ideas: Students can self-assess the answers.

2 Draw formulas for various compounds (15 minutes)

Resources: Pen and paper.

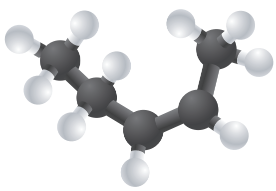
Description and purpose: Students can draw a molecule and ask a partner to name it. Or, they can think of a structure and name it, then ask a partner to draw a structure.

Assessment ideas: This allows students to peer-assess if the structures / names they think of independently are correct.

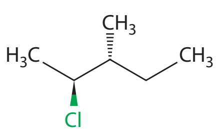
3 Name organic compounds (10 minutes)

Resources: Students can search images of organic compounds online.

For example,



and



Description and purpose: Ask students to name compounds based on the model or stereochemical formulas. Here, students need to combine and apply their knowledge of 3D representations of molecules with IUPAC nomenclature.

4 True or false (10 minutes)

Resources: Students mark the following statements as true or false:

- **i** A racemic mixture of enantiomers is optically active.
- **ii** Enantiomers rotate the plane of plane-polarised light in opposite directions.
- **iii** Plane-polarised light travels in a single line.
- **iv** Enantiomers have the same melting points.
- **v** Enantiomers always have the same chemical properties.
- **vi** There is a chiral centre in but-2-ene.
- **vii** The reflection of plane-polarised light is measured in a polarimeter.

Description and purpose: Ask students to write down their answers on mini-whiteboards and correct the statements that they think are incorrect. This activity allows the teacher to assess the students' understanding of the specific terminologies used in describing optical isomerism.

5 Spot the type of isomers (10 minutes)

Resources: Test your understanding Question 33 from the Coursebook.

Description and purpose: Students need to assign pairs of molecules to different types of isomerism (or none). This requires a clear understanding of the 3D representation in stereochemical formulas and the difference between stereo- and structural isomerism.

11.5 Spectroscopic identification of organic compounds

LEARNING PLAN

Learning objectives	Success criteria
Understand how mass spectrometry can be used to provide information about the structure of an organic compound Understand how IR spectroscopy can be used to provide information about the structure of an organic compound Understand what greenhouse gases are Understand how ^{1}H NMR can be used to provide information about the structure of an organic compound Use spectroscopic data to deduce the structure of an organic compound	Students can work out the relative molecular mass from a compound's molecular ion and further deduce the structures of the compound from its mass spectrum fragmentation patterns. Students know how to identify characteristic bonds in compounds from their IR spectra by referencing the data booklet. Students can explain why greenhouse gases absorb IR radiation. Students can interpret ^{1}H NMR spectra to deduce the number of H environments, relative number of Hs in each environment, the nature of the chemical environment and the number of adjacent Hs. Students can combine data from different analytical techniques to determine the structure.

Starter ideas

1 Recap students' knowledge on a mass spectrometer from Chapter 2 (15 minutes)

Resources: A mass spectrum for measuring isotopic abundances of an element, for example, Figure **2.8** from the Coursebook.

Description and purpose: Ask students to explain the concept of mass to charge ratio.

What to do next: Provide students with a mass spectrum of a simple organic molecule (for example, Figure **11.59** of propane in the Coursebook) and ask them to brainstorm on what the peaks in the spectrum could represent.

2 Polarity of molecules (10 minutes)

Resources: Pens and paper.

Description and purpose: Ask students to draw 3D shapes for gases in the air, for example, O_2, N_2, CO_2, CH_4, H_2O and label them as polar / non-polar molecules.

What to do next: Show students animations of CO_2 molecules vibrating and stretching (search the internet for 'CO2 vibrational modes, animation'), and ask them to think about the change in the dipole moment of the molecule in each mode.

Main teaching ideas

1 Introduce mass spectrometry of organic compounds (60 minutes)

Resources: Hard copies of mass spectra of organic molecules, for students to annotate, and IB Chemistry data booklet. Some spectra can be found in the Coursebook, for example, Figures **11.59–11.61**. More can be found by searching spectral databases on the internet.

Description and purpose: Introduce the concept of molecular ions and fragmentation patterns and practice annotating the spectra together. Students can continue to practice with identifying fragmented ions or fragments lost in other spectra.

› **Differentiation ideas:**

Support: Group students by ability and show a list of common fragmentation or fragments lost. Start with easier spectra and provide a framework for the students to work with. For example, find relative molecular mass → work out the masses of fragmented ions or lost fragments → check in the data booklet for possible identity of the lost fragment → suggest possible identity of the molecules.

Stretch and challenge: Students can present their working process in front of the class.

2 Introduce IR and how it can be used to identify the type of bond (60 minutes)

Resources: Test your understanding Questions 34 and 35 from the Coursebook. Some IR spectra, for example, Figures **11.54**, **11.55** and **11.56**.

Description and purpose: The teacher introduces what IR spectra show and how characteristic IR absorptions can be used to deduce the type of chemical bonds present. Students can then apply this knowledge to solve the Test your understanding questions.

› **Differentiation ideas:**

Support: Provide students with a glossary of the following keywords: absorbance, bond, vibrate, wavenumber, fingerprint region, broad / intense (sharp).

Stretch and challenge: Students can work independently on this task and research further into how the different vibrational modes of molecules absorb IR at different frequencies (search 'IR spectroscopy' on the Royal Society of Chemistry website).

3 The theory behind the greenhouse effect (50 minutes)

Resources: The Coursebook or the internet for research.

Description and purpose: Students should understand that, to be IR active, a molecule must have a changing dipole moment during its vibration. Students can fill in the following summary table of greenhouse gases with information on 1) the source of greenhouse gases, 2) the relative quantity of each gas present in the atmosphere and 3) why they absorb IR. See the following table for examples.

Greenhouse gas	Source	Relative quantity	Explanation
Water vapour	Evaporation from oceans and lakes, burning of fuels	Largest amount	All vibrational modes (symmetric / asymmetric stretching and bending) cause changes in the molecular dipole moment, so water is IR active; poor absorber but largest quantity present
Carbon dioxide	Burning of fossil fuels, deforestation	Less than water but more than methane, mainly due to anthropogenic activities	The asymmetric stretching and bending modes are IR active; poor absorber of IR but large quantity present
Methane	Energy production, anaerobic decomposition of vegetation, animals in agriculture, waste management	Less than carbon dioxide	Some of its vibrational modes are IR active; good absorber of IR, however, small amount present so far

› **Language focus:** Successful completion of the summary table with the correct information, well written and easy to understand.

› **Differentiation ideas:**

Support: Provide students with pictures (Figure **11.58**) or animations of the different vibrational modes of CO_2 (stretching and bending) to allow visualisation of the movement of atoms and how a changing dipole moment is produced in an overall non-polar molecule.

Stretch and challenge: Students can summarise and present their information in front of the class and further research into the different vibrational modes of the greenhouse gas molecules and correlate them with their IR absorption spectra.

4 Combine mass spectrometry and IR spectroscopy (30 minutes)

Resources: Questions such as the following:

The IR spectrum of an unknown compound A has a sharp absorbance at 1720 cm^{-1} and a broad absorbance in the region of 2500–3000 cm^{-1}. The compound contains 48.6% C, 43.2% O, and the rest is H. Its mass spectrum shows a molecular ion with a mass to charge ratio of 74.1. The answer is propanoic acid.

The IR spectrum of an unknown compound B has sharp absorbances in the region of 3300–3500 cm^{-1} and 2800–3000 cm^{-1}. The compound contains 48.6% C, 37.8% N, and the rest is H. Its molecular mass is 74.0 and its mass spectrum shows fragmentation peaks at 30.0 and 44.0. The answer is diaminopropane.

Description and purpose: Students need to combine knowledge of both mass and IR spectra and apply it to unfamiliar situations.

Differentiation ideas:

Support: The teacher can lay out the steps for working out a structure, for example, start by working out the empirical formula → then the molecular formula → use IR to identify the bonds → draw possible isomers with the bonds / functional groups.

Stretch and challenge: Give students time to try out the questions themselves and explain their reasoning to the rest of the class.

5 Introduce ^{1}H NMR of organic compounds (60 minutes)

Resources: Test your understanding questions 39, 40 and 42. Molecular modelling kits or virtual drawing tools.

Description and purpose: The teacher shows, with examples, how information from a ^{1}H NMR spectrum can be interpreted, with emphasis on the number of signals, relative areas under peaks (integration traces), chemical shift (encourage students to find the best match possible and emphasise that the chemical shifts in the data booklet are only approximations) and splitting patterns. Students then practice with Test your understanding questions to consolidate.

Differentiation ideas:

Support: Divide students into groups based on ability. Use molecular models to help identify different types of chemical environment, and the teacher can provide support accordingly.

Stretch and challenge: Students attempt the questions independently and can explain answers to others for peer assessment.

6 More practice on ^{1}H NMR analysis (30 minutes)

Resources: Test your understanding Question 43 from the Coursebook.

Description and purpose: Students practise synthesising information obtained from ^{1}H NMR and deduce overall structures of organic compounds.

Differentiation ideas:

Support: Provide a framework such as the following:

What to look for in the NMR spectrum	Information on the compound
Number of different H environments (= number of peaks)	
Types of H environments (using the chemical shift of each peak and check with the data booklet; remember some of the ranges are broad and the value of the chemical shift can change sometimes, depending on the adjacent chemical environments)	
Relative numbers of H in each environment (using the integration traces). Note: if you know the total number of H in the molecule, then you can work out the actual number of H in each environment	
Number of H atoms on adjacent C atoms (look at the splitting pattern, number of peaks = number of adjacent H + 1)	

Stretch and challenge: Students can work on this independently and help others in the class. They can also research the application of ^{13}C NMR, by searching 'C-13 NMR' on the internet.

7 Practice combining analytical techniques (60 minutes)

Resources: Hard copies of mass, IR and ^{1}H NMR spectra of simple organic compounds (for example, butanone, 2,3-dimethylpentane and ethyl methanoate) for students to annotate. Search for spectra of organic compounds on the internet.

Description and purpose: Students interpret a variety of data to determine the structures of organic compounds.

Differentiation ideas:

Support: Provide a framework of the working process:

1. Mass spectrum: M_r? Is it possible to work out empirical and molecular formulas? What about the fragmentation pattern, any notable ions or fragments lost?
2. IR: Any characteristic bonds or functional groups present? Can these be confirmed by the fragmentation pattern in the mass spectrum?
3. ^{1}H NMR: Repeat the process from activity 6 above.

Stretch and challenge: UK Chemistry Olympiad past paper questions on functional group isomers (Question 4 2011 Round1) and on substituted benzene molecules (Question 4 2014 Round 1).

Plenary ideas

1 Identify functional groups using IR (10 minutes)

Resources: Ask students to suggest how the alcohol level can be detected using IR spectroscopy in a breathalyser.

Description and purpose: Students should suggest the presence of the O-H bond and its IR absorbance. This question also allows them to link theoretical knowledge to a real-world problem.

2 Predict the splitting pattern of molecules (10 minutes)

Resources: Test your understanding Question 41 from the Coursebook.

Description and purpose: This question requires students to deduce structures from their names and then identify different H environments and work out the splitting pattern based on the number of equivalent adjacent Hs.

Assessment ideas

- Test your understanding questions from the Coursebook.
- Practise on drawing isomers (structural and stereo) and making molecular models.
- Students draw structures and ask a partner to name and find isomers for peer assessment.
- Explain how methane molecules can be released into the atmosphere and contribute to global warming. Peer assessment of key phrases.
- Quiz on suggesting structures for fragments in mass spectra and on identifying bonds responsible for IR absorptions (search 'organic compounds spectral database' on the internet).
- Quiz on predicting 1) the number of peaks, 2) the ratio of heights in the integration trace and 3) the splitting pattern for various organic molecules in ^{1}H NMR spectra.

Homework ideas

- Give students the keywords from the chapter (for example, homologous series, functional groups, hydrocarbons, saturated, unsaturated, structural isomers, stereoisomers, chiral centre, enantiomer, racemic mixture, molecular ion, wavenumber) 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.
- Exercises 11.1–11.5 from the Workbook.
- Exam-style questions from the Coursework.
- Draw a mind map to summarise the formulas, functional groups, physical properties, naming and structural isomers of the following homologous series: alkanes, alkenes, alkynes, alcohols, halogenoalkanes, amines, aldehydes, ketones and carboxylic acids.

- Draw a mind map for analytical techniques, including the use of and information provided by mass spectrometry, IR spectroscopy and ^{1}H NMR spectroscopy.
- Past paper questions: search the internet for IB past paper questions on 'analytical techniques'.
- Further reading on ^{1}H NMR spectroscopy and mass spectrometry by searching 'proton NMR' and 'mass spectrometry' on the Royal Society of Chemistry website.
- Extension: question on labelling *R* and *S* optical isomers, for example, UK Chemistry Olympiad 2012 Round 1 Question 5.
- Students summarise the steps in naming an organic compound using IUPAC nomenclature.
- Students can self-assess their drawings of enantiomers in 3D.
- Students reflect on how analytical techniques can be combined to deduce structures.

Links to digital resources

- Search for UK Chemistry Olympiad past paper questions
- Virtual drawing tools for modelling organic molecules. Search the internet for 'ChemSketch' or 'CheMagic'
- Skeletal formulas for NanoPutians. Search the internet for 'images of NanoPutians'
- Images and naming of organic compounds, for example, search on ChemSpider
- Explanation on chirality and how a polarimeter works. Search the internet for 'polarimeter'
- Mass, IR and ^{1}H NMR spectra for organic compounds. Search the internet for 'spectral database'
- Reading on how different vibrational modes of molecules absorb IR at different frequencies. Search for the keywords 'IR spectroscopy' on the Royal Society of Chemistry website
- Reading on the application of ^{13}C NMR, by searching for 'C-13 NMR' on the internet
- Further reading on ^{1}H NMR and mass spectrometry by searching for 'proton NMR' and 'mass spectrometry' on the Royal Society of Chemistry website

CROSS-CURRICULAR LINKS

- Maths: Basic algebraic calculations and solving problems in unfamiliar situations. Recognising and representing 3D shapes with drawing and models.
- Physics: Plane-polarised light and optical activity.
- TOK: How does scientific knowledge progress? The term *organic* has different meanings beyond the chemistry of carbon-containing compounds. The development of analytical techniques allows us to gain information beyond our sense of perception. The role of imagination and intuition in the sciences, for example, how Kekulé proposed the structure of benzene.