



Unit 21: Applications of Organic Chemistry

Delivery guidance

In Unit 6, learners will have been introduced to organic chemistry and here they have the opportunity to build on the concepts and principles encountered there. From biology and other units, there will also be an awareness that organic substances comprise not only living cells and tissues but pharmaceutical products, synthetic fibres, soaps/detergents, dyes, flavourings, etc. Learners will thus recognise the importance of organic compounds in areas such as medicine, veterinary work, the environment and a wide range of industrial applications.

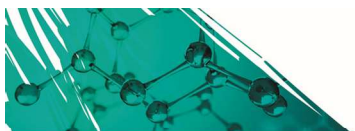
Learners will look at a number of key classes of organic compounds that are important, including their naming, reactions and properties. They will further explore how these compounds can be converted into one another to facilitate synthesis and develop their understanding of isomerism beyond that in Unit 6. Learners have the opportunity to further develop their practical technical skills through carrying out a number of reactions involving the preparation and testing of organic compounds, using wet techniques as well as a range of spectroscopic and instrumentation methods.

Learners should have access to laboratory facilities that enable them to carry out practical activities investigating chemical reactions, including those concerned with the preparation and testing of organic compounds. Visits to organisations involved in synthetic and analytical methods, e.g. manufacture of pharmaceuticals, production of synthetic materials and biomedical science, would be very useful.

Approaching the unit

Learners will bring knowledge of organic chemistry learned in Unit 6 into this qualification. You could give initial introductory input to your learners about how the aims of the unit fit into the overall study of chemistry, and how it relates to the study of biology and biochemistry. They will revisit structure and isomerism in organic compounds and further develop their knowledge of the reactions of functional group compounds: carbonyl compounds, carboxylic acids and their derivatives, and nitrogen-containing compounds. They will be introduced to aromatic compounds, using benzene and its monosubstituted compounds to explore the structure and reactions. Learners will have the opportunity to further develop practical skills acquired in relation to preparing organic compounds and testing identity, estimating purity and determining the yield. They will be introduced to instrumentation techniques that can be used to identify organic compounds and determine quantities. They will have encountered some aspects of mass spectrometry and chromatography in units 2 and 6 but will have the opportunity to explore applications to organic chemistry in greater depth. You could encourage learners to read about the applications of organic chemistry and any new developments that are reported in scientific magazines. Visits to a university or a science organisation that uses, manufactures or analyses organic chemicals would be of benefit, as would visiting/guest speakers from such an establishment.

Learning aim A builds on many of the concepts learned in Unit 6 regarding the properties of organic compounds in the light of structural and geometric isomerism. Learners will enhance their knowledge of these forms of isomerism and be introduced to optical isomerism. They will appreciate that this is widely occurring in nature and has ramifications regarding the therapeutic effects of optical isomers of drugs. The learning aim will focus on the properties and reactions of three types of compounds: carbonyl, carboxylic acids and derivatives, and nitrogen-containing compounds. For aldehydes and ketones, learners will investigate nucleophilic addition, addition-elimination, reduction and oxidation. They will understand that carboxylic acids are weak acids



but, like mineral acids, will react with bases, metals and metal carbonates. They will understand the importance of reaction with alcohols to form esters and explore the reactions of acyl chlorides and acid anhydrides. They will look at the structure and properties of nitrogen-containing organic compounds: the structural features of amines and the ability to partake in nucleophilic substitutions and condensation reactions; the structure of amines and amides and their hydrolysis by alkalis and acids; and the acid-base characteristics of amino acids and polypeptide/protein formation. This learning aim also looks at the ability of carboxylic acids and derivatives to form polymers. Finally, learners should be able to propose mechanisms for reactions and identify synthetic routes for the preparation of organic compounds.

For **learning aim B**, learners will be introduced to benzene and its properties as an aromatic substance. They should understand the structure of benzene in terms of the resonance hybrid model, using sigma and pi bonding, and give evidence in support of this. Learners can refer to bond, thermochemical data, the smokiness of the flame of benzene or other aromatic compounds and compare this to the properties of cyclohexane and cyclohexene. It is important for learners to have an understanding of the main reactions and properties of benzene and other aromatic compounds. Learners will explore the electrophilic substitution reactions of benzene, to include nitration, sulphonation and chlorination. Learners should be aware of the importance of benzene in the manufacture of polymers, detergents and insecticides. Learners should be able to name a number of mono-substituted benzene compounds and understand how the mono-substituted atom or group affects the reactivity and the position of any further electrophilic substitutions on the benzene ring. Learners should appreciate that phenol is a weak acid that will react with strong bases but not weak ones. They should understand the bromination reaction of phenol and condensation reaction with carboxylic acids. Finally, learners should be able to show how azo dyes can be formed from phenol through coupling with benzenediazonium ions that were produced from phenylamine, which itself is produced from nitrobenzene. They should be aware of the commercial importance of phenol, alkylbenzenes and azo dyes.

Learning aim C will further develop skills learned in Unit 6 regarding preparing organic compounds and testing to confirm identity and determine purity. They should be aware of health and safety rules and regulations that apply to organic reactions in a laboratory, the use of fume cupboards and protective clothing and equipment. Learners should understand the importance of ensuring that equipment and apparatus is set up properly, and that they should seek permission before starting a reaction. It is good practice for them to write up their experiments in their laboratory report books, using the correct headings, in the past tense and using the correct terminology. They should refer back to the reactions that they have studied in theory in learning aims A and B to plan synthesis routes or detailed synthesis maps, involving two or more steps for each route. Learners should prepare at least one organic liquid and one organic solid from those listed in the unit content, using a range of techniques (see also the unit content). They should carry out the appropriate tests for functional groups and purity and calculate percentage yield, discussing physical and chemical factors that affect yield.

For **learning aim D**, spectroscopy techniques should be used for the joint structure elucidation of organic compounds. Learners may recall some understanding of mass spectroscopy from Unit 2 and they should understand the principles of it, along with those of infrared and nuclear magnetic resonance spectroscopy with regard to elucidating the structure of organic compounds. Learners should be able to identify an organic compound from the masses of the molecular ion peak and those for fragments in the mass spectrum of the compound. They should be able to identify an alkane, alkene, alcohol, ester, aldehyde, ketone and carboxylic acid from the key peaks at certain wavenumbers in infrared spectra and use the relative transmission values of peaks to determine quantities of compounds. Learners should understand that NMR spectra can be used to identify the number of protons or carbon atoms in chemically equivalent environments, and

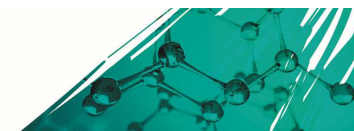


therefore be able to predict the number of unresolved peaks, their relative areas and approximate chemical shift. This will allow them to match simple spectra to displayed chemical formulae. They should also be able to explain simple splitting patterns. Learners should understand the principles of chromatography from Unit 6, but this should be extended to gas chromatography and high-performance liquid chromatography. It would be advisable to have links with an organisation that uses these techniques, but learners must be able to describe the techniques in terms of the general principles, operation and equipment, mobile phase and parameters that can be altered. They should be able to interpret examples of GC and HPLC chromatograms and appreciate that they can be used for qualitative and quantitative purposes.



Assessment model

Learning aim	Key content areas	Recommended assessment approach
A Understand the structures, isomerism and reactions of functional group compounds	A1 Isomerism A2 Carbonyl compounds A3 Carboxylic acids and derivatives A4 Nitrogen containing organic compounds	<p>A research report showing the different types of reactions for a range of functional groups and the significance of isomerism.</p> <p>Detailed understanding of the reactions using mechanisms will be shown. The effect of more than one functional group within an organic molecule will be considered.</p> <p>The report will propose detailed plans for the multi-step synthesis of organic molecules using this research.</p>
B Understand the properties and reactions of aromatic compounds	B1 Structure, properties and reactions of benzene B2 Monosubstituted aromatic compounds	<p>A research report of diagrams and explanations of how the structure of benzene was established. The typical reactions undergone by benzene and monosubstituted benzene rings will be explained.</p> <p>Detailed understanding of the reactions will be shown using mechanisms and diagrams to show the different effects of monosubstituents on reactivity.</p> <p>The report will propose detailed plans for the multi-step synthesis of organic molecules using this research.</p>
C Investigate organic chemistry reactions in order to gain skills in organic synthesis	C1 Practical organic synthesis C2 Practical techniques for synthesis C3 Testing identity, estimating purity and determining yield	<p>A portfolio of reactions that learners have carried out in the course of this unit, including observations of safe working and risk assessment.</p>



Learning aim	Key content areas	Recommended assessment approach
<p>D Investigate spectroscopic and chromatographic techniques to identify organic compounds and determine quantities</p>	<p>D1 Spectroscopic techniques</p> <p>D2 Chromatographic techniques</p>	<p>A report which explains the principles and operation of MS, IR, NMR, GC and HPLC techniques.</p> <p>Completed exercises on matching percentage composition, mass spectra, infrared spectra, ^1H and ^{13}C NMR spectra to structural formulae of simple organic molecules.</p> <p>An account of how two unknown organic compounds have been identified from their percentage composition and combined spectroscopic techniques.</p> <p>A portfolio of qualitative and quantitative interpretation of chromatograms and peak area results for GC and HPLC.</p>

Assessment guidance

This unit is internally assessed via a number of independent tasks. Learners must produce individual evidence that is original and can be authenticated.

For **learning aim A**, learners are required to produce a research report showing the different types of reactions for a range of functional groups and the significance of isomerism. This should assess the importance of isomerism in biological (e.g. enzyme activity) and industrial (e.g. pharmaceutical) contexts. The reactions should focus on the chemistry of carbonyl compounds, carboxylic acids and derivatives, and nitrogen-containing compounds. Detailed understanding of the reactions using mechanisms will be shown in the report. The effect of more than one functional group within an organic molecule will be considered, especially in relation to the ability to undergo polymerisation reactions. The report will propose detailed plans for the multi-step synthesis of organic molecules, using learners' research.

For **learning aim B**, learners will produce a research report which includes diagrams and explanations of how the structure of benzene was established. There should be reference to the sigma and pi bonding, and a comparison with the properties of saturated and unsaturated counterparts to support evidence for the structure. The typical reactions undergone by benzene and monosubstituted benzene rings will be explained, with an emphasis on electrophilic substitution. The report should convey a detailed understanding of the reactions, using mechanisms and diagrams to show the different effects of monosubstituents on reactivity. It will also propose detailed plans for the multi-step synthesis of organic molecules using this research.

For **learning aim C**, learners must produce a portfolio of reactions that they have carried out in the course of this unit, including observations of safe working and risk assessment. This can focus on the preparation of an organic liquid and an organic solid, identifying it and determining the purity. Learners should demonstrate that they have carried out the required techniques in a safe and efficient manner. There should be an evaluation of the practical work in terms of the yield obtained and the extent to which various factors (e.g. competing side reactions, conditions, transfer loss, volatile reactants or product) have influenced this.



For **learning aim D**, learners are required to produce a report which explains the principles and operation of MS, IR, NMR, GC and HPLC techniques. If possible there could be recollection of visits to a laboratory where they have observed and/or used these techniques. The report should contain completed exercises on matching percentage composition, mass spectra, infrared spectra, ^1H and ^{13}C NMR spectra to structural formulae of simple organic molecules. It should also give an account of how two unknown organic compounds have been identified from their percentage composition and combined spectroscopic techniques. Also included should be a portfolio of qualitative and quantitative interpretation of chromatograms and peak area results for GC and HPLC.



Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 21: Applications of Organic Chemistry

Introduction

This unit gives learners the opportunity to develop their knowledge, skills and understanding of the basic principles of organic chemistry, beyond that which was dealt with in Unit 6. It covers further concepts related to organic chemistry and will extend learners' knowledge of analytical techniques. Most topics will involve practical work and learners will have the opportunity to develop their skills and techniques in organic synthesis, identification of functional groups and estimation of purity. They will use a range of spectroscopic and chromatographic techniques. This unit and the expertise gained will prove to be useful in laboratory careers and in higher education courses, and for those who progress to industrial laboratory work. Visits to a university or a science organisation that uses, manufactures or analyses organic chemicals would be of immense benefit.

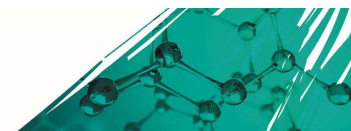
Learning aim A – Understand the structures, isomerism and reactions of functional group compounds

- Learning aim A is concerned with the structures, isomerism and reactions of organic functional groups. Learners will have been taught structure and isomerism in Unit 6 and should be able to draw the structures and possible chain, positional and geometric isomers for a range of organic compounds. It would be useful to give learners an exercise such as a quiz, which will enable them to revisit this and test their understanding to date. They will be introduced to optical isomerism and explore in more detail the structure and properties of carbonyl compounds, carboxylic acids and derivatives, as well as nitrogen-containing compounds.
- Begin by giving learners the molecular formulae of alkanes and alkenes that have isomers. Ask them to draw structural formulae and produce molecular models of possible structural and geometric isomers. This could be followed by introducing other types of isomerism, such as functional group and optical, and then asking learners to produce a scientific poster or leaflet about different types of isomers.
- Then ask learners to research how they would be able to test the differences between isomers and differences in the physical properties of isomers. Learners should be aware that isomers exist in nature, and how important it is to use the correct isomer in medicine (re. case study of d and l-thalidomide). Ask learners to investigate the use of different isomers in medicine and the difference between starch and cellulose (in terms of alpha- and beta-glucose). Discuss with the learners their findings and the industrial importance of isomers. For assessment, learners should produce a research report showing 2D and 3D structural diagrams of the different types of isomers.
- Give learners a worksheet which includes a list of molecular formulae. Ask them to draw the structures of all the possible carbonyl compounds (aldehydes and ketones) and name them. Explain that, because of the electron-deficient carbon atom, the carbonyl compounds can undergo nucleophilic addition. Use the reaction with HCN as an example.
- Ask the learners to draw the mechanism for several aldehydes and ketones, and identify where different isomers result. Learners should understand that carbonyl compounds can (like alkenes) add hydrogen and be reduced. Again you could ask learners to write the



equation for the reduction of several aldehydes and ketone, using lithium aluminium hydride, and identify the compounds formed. Learners may recall from Unit 6 the oxidation of alcohols and that, while aldehydes from the oxidation to primary alcohols can be further oxidised to acids, ketones cannot be oxidised further. There is perhaps some opportunity for practical work as learners can investigate the oxidations by acidified dichromate and/or Benedict's/Fehling's solution. Learners should understand that carbonyl compounds can undergo addition-elimination (condensation) reactions and write mechanisms for the reaction with 2,4-Dinitrophenylhydrazine, hydrazine and oxime. They should be aware that the product for the reaction with 2,4-Dinitrophenylhydrazine (Brady's reagent) can be used to identify the original carbonyl compound from its melting point, etc.

- Give learners a worksheet which includes a list of molecular formulae. Ask them to draw the structures of the carboxylic acids and name them. Explain (e.g. with reference to the Bronsted-Lowry theory) that the carboxylic acids are weak acids. There is perhaps some scope for practical activity, as learners could investigate the pH of ethanoic acid and its reactions with bases, metals and metal carbonates. This could also extend to the reaction with alcohols to form esters. Learners should be aware of the industrial importance of esterification and could be asked to investigate the use of a wide range of esters. Explain that esters can be hydrolysed back to the corresponding carboxylic acid and alcohol by acid or alkaline hydrolysis. Learners can be asked to write the equations for the hydrolysis of several esters, stating the conditions and illustrating the mechanism.
- Explain how acyl chlorides and acid anhydrides are derivatives of carboxylic acids, illustrating structure and properties. Ask learners to investigate their reaction with water, alcohols, ammonia, amines and carboxylic acids. Then give them a worksheet and ask them to write equations for several reactions, naming the compounds formed. Ask learners to research the industrial applications of the reactions of difunctional carboxylic acids and acyl chlorides to form polyesters.
- Briefly outline the structure of the amine and amide functional groups and ask learners to draw the structure of several examples. Explain the properties of amines and amides and that the latter can be classed as carboxylic acid derivatives. Ask learners to draw the structure of amines in terms of primary, secondary and tertiary. Learners should understand that, as amines are derivatives of ammonia, they can act as weak bases by adding H^+ ions and also as nucleophiles through the non-bonding electrons on the nitrogen atom. Ask learners to write equations for reactions and illustrate the ability to act as a base (e.g. with HCl) and as nucleophile, e.g. with halogenoalkanes. Learners should understand that they can react with carboxylic acids and acyl chlorides in a reaction analogous to esterification to form amides – a condensation reaction involving the removal of a water molecule.
- As with esters, learners should appreciate that amides can undergo acid or alkaline hydrolysis. Ask learners to write equations and illustrate the mechanism of hydrolysis for several amides. Learners will likely be familiar with amino acids from biology-related units and will appreciate that they contain both the carboxylic acid and amino group. They can also undergo condensation reaction, resulting in the formation of polypeptides and proteins through the peptide link. This may need a recap – ask learners to write equations for the formation of di- and tripeptides from different combinations of amino acids. Then ask learners to research the industrial applications of the reaction of difunctional amines with acyl chlorides to form polyamides.



Learning aim B - Understand the properties and reactions of aromatic compounds

- Learning aim B focuses on the structure and properties of aromatic compounds, with reference to benzene and its derivatives. From Unit 6, learners will understand that double and triple bonds involve both sigma and pi bonds. Here they will understand that this can also lead to situations where the bonding is intermediate between single and double, giving rise to aromatic character. Learners will investigate the structure and properties of benzene and its monosubstituted compounds, and recognise that aromaticity results in chemical reactivity, which differs somewhat from that of saturated and unsaturated compounds. While there is some scope for practical activity, benzene itself is highly carcinogenic; any experimental investigation should involve derivatives which have a lower risk.
- Introduce learners to benzene and ask them what they know about it. Ask them to investigate the structure of benzene and the evidence to support its structure. Discuss with learners its formulae and hybridisation model. Introduce the combustion of benzene and ask learners about the smokiness of its flame compared to alkanes. Explain the electrophilic substitution reactions of benzene and the substitution mechanism: nitration involving a mixture of concentrated sulphuric acid and nitric acid to form the nitronium ion, which acts as the electrophile; chlorination involving a halogen carrier such as AlCl_3 to form the electrophilic Cl^+ ion; and sulfonation involving the reaction of benzene with concentrated sulphuric acid. Ask learners to complete the reaction mechanisms of some similar reactions. Ask them to carry out independent research into the applications of benzene.
- Introduce monosubstituted compounds of benzene and their nomenclature with reference to the 1,2, 1,3 and 1,4 (ortho, meta and para) positions. Ask them to draw structures for named aromatic compounds and vice versa. Explain to learners that, like benzene, the monosubstituted aromatic compounds will undergo electrophilic substitution but the product formed will depend on whether the substituent is activating or deactivating. Use the reactions involving nitration, chlorination and alkylation to demonstrate this, and get learners to predict further substitution on the ring giving them similar compounds to the ones covered. Then discuss with the learners their predictions. They should be able to compare these reactions with those involving benzene, in terms of the conditions used.
- Learners should understand that phenol is an aromatic alcohol, being a monosubstituent of benzene with the OH group. Explain that, because of the ability of the ring to draw electron density away from the OH group, phenol is mildly acidic, but emphasise that it will only react with strong bases. Compare the pH value with that of aliphatic alcohols. Explain that phenol can be formed from benzene sulfonic acid or benzenediazonium salt, as well as the reactions of phenol with bromine and with carboxylic acids such as ethanoic acid. Ask learners to write equations for these reactions, naming the products formed, and show how phenol could be prepared, starting with benzene itself.
- Explain the reaction of nitrobenzene with concentrated hydrochloric acid and tin to form phenylamine, and that this can then be reacted with sodium nitrite and hydrochloric acid at low temperature to produce a benzenediazonium salt. The benzenediazonium salt can be coupled with phenol and other activated rings to produce azo dyes. Ask learners to produce a poster which shows how a particular azo dye could be produced, starting with benzene. Ask them to research the applications of typical aromatic compounds, including phenol, alkylbenzenes and azo dyes.



Learning aim C – Investigate organic chemistry reactions in order to gain skills in organic synthesis

- Learning aim C builds on the knowledge and understanding from Unit 6 and the previous learning aims in this unit. Learners will further develop their knowledge of the chemical behaviour of organic functional groups in the context of preparation of organic compounds, identification and testing for purity. There will be a large practical focus and learners should be aware of health and safety rules and regulations that apply to organic reactions in a laboratory. They should set up apparatus and equipment properly with regard to organic preparations, understanding the importance of following given procedures in a step-by-step fashion and the use of the fume cupboard for many reactions. Discuss with the learners some of the reactions they will be carrying out, and where they have covered them in theory in Unit 6 and learning aims A and B. Encourage learners to produce a plan before embarking on their practical activity.
- Go through with learners the examples of preparations for organic liquids and solids listed in the unit content. Ask the learners, working in pairs or groups, to prepare at least one liquid and solid as a class-based activity, and to select another from each category for their assessment activity. Encourage learners to write up their practical preparation as a scientific report with an introduction, objective, methods, observations and recording of yield (the working out of percentage yield should be clearly shown).
- Learners should have the opportunity to use, or at least practice using, the techniques for synthesis listed in the unit content: refluxing, distillation, solvent extraction, crystallisation/recrystallisation, filtration (gravity and vacuum), and removal of impurities and moisture followed by evaporation and drying.
- Learners should use tests that are appropriate for the functional group of the organic compound prepared. If unsaturated using bromine water; halogenoalkane using silver nitrate; ketone, using 2,4-Dinitrophenylhydrazine to form an orange precipitate followed by determination of the melting point of the latter; aldehyde using Tollen's or Benedict's reagent; carboxylic acid using sodium carbonate; phenol using iron(III) chloride. Purity can be tested for by melting/boiling point, thin layer or paper chromatography. Learners could use GC, HPLC and IR if these facilities are available internally or externally (see also learning aim D). After the organic compounds have been purified, dried etc., they should be accurately weighed and the percentage yield calculated. Follow up with a discussion which reviews all of the preparations in terms of the yields obtained and how various factors (e.g. competing side reactions, conditions, transfer loss, volatile reactants or product) can influence this.

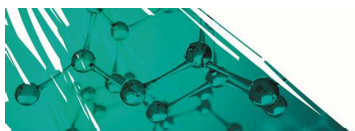
Learning aim D – Investigate spectroscopic and chromatographic techniques to identify organic compounds and determine quantities

- Learning aim D is concerned with instrumentation techniques that can be used for the joint structure elucidation of organic compounds: namely spectroscopy and chromatography. Learners may understand the principles of mass spectroscopy from Unit 2 in relation to the determination of isotopic masses but here they will have the opportunity to understand its application in the elucidation of organic compounds. They will also be introduced to the principles and techniques of nuclear magnetic resonance (proton and carbon 13 NMR) and infrared spectroscopy. Learners may also understand the principles of chromatography as applied to thin layer and paper chromatography, but in this learning aim they will be introduced to gas chromatography (GC) and high-performance liquid chromatography (HPLC). Learners will appreciate how all or some of these techniques together can be used in the



identification of organic compounds. It would be highly beneficial to have links with a university or industrial laboratory that uses these techniques and which you and learners could access.

- Recap the principles of mass spectroscopy and give learners a quiz to test prior knowledge and understanding on the relevance of concepts such as mass to charge ratio and relative abundance. Give learners a mass spectrum of an organic compound and ask them to identify the fragments formed from the masses and abundance of the peaks. Learners should understand that the molecular ion peak, while it may not be the most abundant, represents the relative molecular mass of the compound. Give learners the mass spectra for several compounds and ask them to identify the compound from the masses of the fragments and molecular ions.
- Explain infrared spectroscopy in terms of the radiation causing bends and stretches of bonds at characteristic frequencies/wavenumbers. Describe the instrumentation (including FTIR having replaced grating instruments), sample preparation and the need to exclude moisture. Explain the format of an infrared spectrum. Ensure that learners have a good correlation chart to use to help them identify peaks corresponding to C-H, C=O, O-H, N-H, C-O, C=C. If possible, visit an organisation which uses infrared spectroscopy and give learners the opportunity to run spectra for themselves or see them run. Learners should label the main peaks (e.g. O-H stretch) of known examples of the infrared spectra of the compound types so that they become familiar with their appearance.
- Explain NMR as being a technique using radiofrequency radiation in the presence of a strong magnetic field. Instead of varying frequency (as with ultraviolet-visible and infrared), the magnetic field is changed to make protons in different environments flip their spin (resonate). Explain the concept of shielding in terms of shielded protons having a very good share of the electrons in covalent bonds. Tetramethylsilane (TMS) is set to have a chemical shift of 0, while the deshielded aldehyde proton has a chemical shift of about 10. Ensure that the learners have a good correlation chart to use.
- Ask learners to complete a worksheet on the number of main peaks expected in a low-resolution spectrum (without resolution of splitting patterns). Learners should base their judgements on the proximity to electronegative atoms and on molecular symmetry. Benzene rings may be included. Learners should match simple spectra to displayed formulae. Explain simple splitting patterns for the more able learners.
- Explain that about 1% of natural carbon is carbon-13 and that it is also possible to run ¹³C NMR spectra (due to the development of modern pulse FTIR instruments). Explain that the principles are similar and that different carbons in molecules have different shares of bonding electrons. Chemical shifts are high for carbons bonded to electronegative atoms and low for those with a good share of bonding electrons. The value of chemical shift is higher for carbon-13. Ensure that learners have a good correlation chart to use and ask them to identify the number of chemically equivalent carbons and hence the number of low-resolution peaks in a molecule. Explain the n+1 rule for the multiplicity of peaks, split by bonded protons. Learners should match extended structural formulae to carbon-13 NMR spectra.
- Recap the principles of chromatography and extend this to explain those underlying the techniques of GC and HPLC. Give learners a framework for further researching the principles, instrumentation and operation of the techniques, as well as industrial and other applications. It would be useful to visit an organisation to use GC and HPLC instrumentation or to see the instrumentation in operation. Learners should see for themselves how chromatograms are produced following sample injection. Ideally, they should have the opportunity to inject samples for themselves. Learners should understand what the instrumentation is used for and explain the techniques in terms of the mobile and stationary phases, columns, modes of



injection, detectors, how to alter the temperature (GC) or the composition of the mobile phase (HPLC) and why that might be done. The host should explain the use of internet methods and why an alternative column may be used.

- With the help of an organisation that uses GC routinely, learners could prepare a bank of chromatograms that will allow them to identify components of a mixture from the retention time and 'spiking' (co-injection). Ideally, there should be chromatograms run at different temperatures to allow learners to see the effect of increasing/ decreasing temperature on retention time and separation of the peaks. Prepare chromatograms or collate data that allow learners to use peak area to determine the amount of a substance present. This may include use of a standard.
- Ask learners to work through a differentiated worksheet to identify components of a mixture and to draw conclusions about the effect of temperature. They should also work out the amount of a substance present in a mixture from its peak area in relation to a standard. They could carry out a similar exercise for HPLC.
- Learners should work through a differentiated worksheet which allows them to appreciate how a GC and HPLC method could be developed and optimised (e.g. initial research to identify a suitable column and solvent mixture and detector setting, trying out the method, altering the solvent mixture to get a better – more timely or greater – separation, reducing background noise etc.). Explain that GC can be coupled with mass spectroscopy to confirm that a compound identified from its retention time can be confirmed from the mass of the fragments and molecular ion peak.



Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This unit links to:

- Unit 2: Principles and Applications of Chemistry I
- Unit 6: Principles and Applications of Chemistry II
- Unit 16: Applications of Inorganic Chemistry
- Unit 20: Applications of Physical Chemistry.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC International L3 Qualifications in Applied Science. Check the Pearson website (<http://qualifications.pearson.com/endorsed-resources>) for more information as titles achieve endorsement.

Textbooks

Christian, GD, Dasgupta, P and Schug, K – *Analytical Chemistry*, 7th edition (Wiley Global Education, 2013) ISBN 9780470887578. This advanced textbook includes chapters on titration, spectroscopy and chromatography, as well as information on good practice in industry.

Foal, S, Hocking, S, Llewellyn, R, Musa, I, Patrick, E, Rhodes, P and Sorensen, J – *BTEC Level 3 Applied Science Student Book* (Pearson, 2010) ISBN 9781846706800. This book covers *Unit 28: Industrial Applications of Organic Chemistry* (2010 specification).

Hudson, M and Fullick, A – *Edexcel A Level Science: AS Chemistry Students' Book* (Longman, 2009) ISBN 9781405896351. Comprehensive cover of halogenoalkanes, alcohols and isomerism with regard to alkanes and alkenes.

McDuell, B and Fullick, A – *Edexcel A Level Science: A2 Chemistry Students' Book* (Longman, 2009) ISBN 9781408206058. Comprehensive cover of carbonyl compounds, carboxylic acids, aromatic compounds, isomerism and organic synthesis.

Skoog, DA, West, DM, Holler, FJ and Crouch, SR – *Fundamentals of Analytical Chemistry*, 9th edition (Brooks/Cole, 2014) ISBN 9780495558286. Advanced textbook with chapters on titration, spectroscopy and chromatography.

Vollhardt, P and Schore, N – *Organic Chemistry Structure and Function*, 8th edition (Macmillan Learning, 2018) ISBN 9781319079451. This gives a more in-depth treatment of relevant topics in organic chemistry.

Journals

Journal of Analytical Chemistry – covers theoretical and applied aspects of analytical chemistry.

Nature – an international journal covering research spanning all areas of science.

New Scientist – covering the latest news and articles about science and technology.

Scientific American – latest science stories, articles and news.

Chemistry World – articles about developments in chemistry.

RSC News (Royal Society of Chemistry) – latest news in chemistry.



Videos

Search YouTube for the following videos:

'AQA A-Level Chemistry – Aldehydes and Ketones (inc. nucleophilic addition)' - reactions of carbonyl compounds

'Carboxylic Acid Derivatives Overview and Reaction Map' – reactions of carboxylic acids and their derivatives

'Best Trick For All Name Reaction of AMINES | Nitrogen Containing Compounds' – reactions of amines

'AQA A-Level Chemistry – Aromatic Chemistry 1 (Benzene Structure)' - aromatic compounds

'AQA A-Level Chemistry – Organic Analysis' – spectroscopy

'Gas chromatography | Chemical processes | MCAT | Khan Academy' – gas chromatography

'High Performance Liquid Chromatography HPLC' – HPLC

Websites

Visit aazea.com and search 'Analytical Chemistry, 6th edition, Christian, G.D.0' for an online textbook with chapters on titration, spectroscopy and chromatography.

Visit the Chemistry LibreTexts website (<https://chem.libretexts.org/>). This Open Access textbook environment supplants conventional paper-based books and has a wide-ranging collection of articles on most topics.

Visit the Royal Society of Chemistry website and search 'Organic spectroscopy and chromatography'. This explains the information to be gained from spectroscopic techniques and gives practice exercises. It also contains an introduction to GC and HPLC with videos and animations.

Visit the Spectral Database for Organic Compounds website. This is an extensive database of spectra (mass, infrared, ^1H NMR, ^{13}C NMR) which may be used to construct worksheets and assignments for learning aim B.

Visit the Virtual Textbook of Organic Chemistry website:

<https://www2.chemistry.msu.edu/faculty/reusch/VirtTxtjml/intro1.htm>

This contains useful information on a wide range of topics related to organic chemistry.

Pearson is not responsible for the content of any external internet sites. It is essential for tutors to preview each website before using it in class so as to ensure that the URL is still accurate, relevant and appropriate. We suggest that tutors bookmark useful websites and consider enabling students to access them through the school/college intranet.