Unit 11: Applications of Chemistry
The Chemistry of Life

Context
This unit should be taught at the end of the A2 course as it draws on important ideas and principles discussed earlier in the course. The aim is to illustrate how fundamental Chemistry is to understanding biological systems and processes, and to appreciating certain key advances and concerns in modern science and medicine.

Outline
This part of the unit looks at the nature of proteins, their structure and the genetic control of their synthesis; and at some of the diverse roles played by proteins in biological processes, most particularly as enzymes.

AO	Learning outcomes	Suggested Teaching activities	Learning resources
11.1 (a)	Recall that proteins are condensation polymers formed from amino monomers and describe the generalised structure of amino acids (link to core syllabus, sections 10.7 and 10.8)	Introduce the structure of α-amino acids as bi-functional molecules – revise the acid/base nature and structures of the amino group and carboxylic acid group. Revise the concept of condensation polymerisation and the formation of the peptide (amide) link. In order to link with 11.2(a) there will need to be some discussion of the ionisation of amino acids at different pH's. In this context a useful practical would be to produce titration curves for certain characteristic amino acids e.g. glycine or alanine, lysine and glutamic acid [these latter two link to part (b). This experiment can be carried out as a datalogging practical.	Links here to sections in the core syllabus – 10.7 and 10.8 www.accessexcellence.com has a very useful graphics section with diagrams in a format that can be downloaded.
11.1 (b)	Explain the importance of amino acid sequence (primary structure) in determining the properties of proteins	Outline the broad types of R-groups present in the 20 amino acids used to build proteins [link to the practical mentioned above and to 11.2 (a)]. Explain the idea of a protein 'backbone' – proteins as linear polymers having direction. Proteins as a sequence of amino acid residues where interactions between side-chains govern the structural folding of the protein.	Again www.accessexcellence.com has a very useful graphics section with diagrams in a format that can be downloaded.

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		One possible practical is the thin layer chromatography or electrophoresis of the hydrolysis products of aspartame	
11.1 (c)	Distinguish between the primary, secondary and tertiary structure of proteins and explain the stabilisation of secondary and tertiary structure using the chemistry learnt in the core syllabus, sections 3 and 10.7	Clearly define the hierarchy of structure involved in the folding of proteins – could mention different roles played by proteins and the general importance of the link between function and shape. Important to stress the involvement of the different regions of the protein chains in the different levels of structure – hence secondary structure involves interactions between the peptide link regions, whereas tertiary structure involves the side-chains. Revise the nature of hydrogen-bonding, van der Waals forces etc.	Again www.accessexcellence.com has a very useful graphics section with diagrams in a format that can be downloaded.
11.1 (d)	Describe and explain the characteristics of enzyme catalysis, including (i) specificity (using a simple lock and key model) and the idea of competitive inhibition) (ii) structural integrity in relation to denaturation and non-competitive inhibition	Introduce this section by first revising the concept of catalysis – emphasise the lowering of E_A [the activation energy] and its diagrammatic representation in an energy profile. Enzyme catalysis shows some of the characteristics of both heterogeneous and homogeneous catalysis. Explain enzymes as biological catalysts able to work with a great degree of specificity and high efficiency under mild conditions. Emphasise the importance of enzyme shape and the concepts of the 'active site' and substrate binding. Use the 'lock and key' model without going into the more advanced ideas of 'induced fit'. Illustrate the ideas with examples, e.g. lysozyme, and with the phenomenon of competitive inhibition. Here the inhibitor has a similar shape to the substrate but cannot accomplish the catalysed reaction. There are a range of practical possibilities here using different enzymes. Experiments with urease are possible as thiourea acts as a competitive inhibitor. However other enzymes can usefully	Link to section 8 (f) There are IT simulations of enzyme activity available for class use – see, for instance, www.newbyte.com There are also a wide range of practical protocols exploring enzyme activity – material can be downloaded from the NCBE website, www.ncbe.reading.ac.uk and there are a series of kits on a variety of enzymes, including proteases, marketed by Philip Harris Education.

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		be used to illustrate the sensitivity of enzyme activity to temperature and pH. A comparison of the proteases trypsin and pepsin illustrates the link between pH optima and site of function in the body. A datalogging experiment on urease following the increased conductivity following enzyme action can be used to illustrate the action of heavy metal ions in inhibiting enzyme activity.	
11.1 (e)	Given information, use core chemistry to explain how small molecules interact with proteins, and how they can modify the structure and function of biological systems (for example, as enzyme inhibitors or cofactors, disrupting protein-protein interactions, blocking ion channels) (link to 11.3(a)).	Introduce the idea that many enzymes involve non-protein co-factors or prosthetic groups in their activity. Distinguish between metal ions, e.g. zinc in carbonic anhydrase, prosthetic groups, such as the haem group, which become integral parts of the functioning enzyme, and cofactors, such as NADH, which provide essential reactants not readily available from the protein itself.	Again www.accessexcellence.com has a very useful graphics section with diagrams in a format that can be downloaded.
11.1 (f)	Describe the double helical structure of DNA in terms of a sugar-phosphate backbone and attached bases	Illustrate the general overall structure of DNA concentrating on the structure being made up of two anti-parallel strands. The strands are made up of a sugar-phosphate backbone with nitrogen-containing bases attached. Show the structures of the bases but stress that these are not meant to be learnt. The sense that the strands have direction is difficult to avoid as the concept is central to the fact that the strands contain a readable 'message' contained within the sequence of the bases. Consider how the DNA 'ladder' coils into a double helix. A useful practical may be to extract some DNA from a readily available source – frozen peas, for instance. A simpler experiment would be to carry out DNA 'spooling' for which Sigma market a simple kit.	Again www.accessexcellence.com has a very useful graphics section with diagrams in a format that can be downloaded. There are also very useful model kits that can be obtained commercially – see www.molymod.com Protocols for DNA extraction are available at www.ncbe.reading.ac.uk see also the EMBO/EMBL teachers websites for protocols and information: www.embo.org
11.1 (g)	Explain the significance of hydrogen-bonding in the pairing of bases in DNA	Consider the structures of the bases – single ring and two-ring structures and how they fit together in the central 'space'	Useful information and historical material is available from the DNA Learning Centre and

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	in relation to the replication of genetic information	between the backbone strands. The complementary pairing of the bases is emphasised by the levels of hydrogen bonding between the two combinations [A to T; and G to C]. This complementary base-pairing is crucial to the ideas of replication and gene expression. Illustrate how the replication of DNA is semi-conservative.	NCBE websites: www.ncbe.reading.ac.uk The BBC drama documentary 'Life Story' is very useful at conveying the significance of the discovery of the DNA structure and the key concepts – also shows the importance of X-ray crystallography [section 11.2(e)].
11.1 (h)	Explain, in outline, how DNA encodes for the amino acid sequence of proteins with reference to mRNA, tRNA, and the ribosome in translation and transcription	Introduce the various forms of RNA and how these molecules differ from DNA. Stress the different types of RNA and their different roles. Illustrate how the concept of complementary base-pairing is central to the transcription and translation of the message. Build from the summary of the 'central dogma' to illustrate some of the processes involved in transcription and translation. Introduce the idea of the triplet genetic code, emphasising certain key codings e.g. START and STOP	The programme suite eDNA 2.0 contains documentation on the structure of DNA and the processes of transcription and translation – see www.newbyte.com This CD-ROM also provides useful simulations of the various applications of DNA fingerprinting techniques – link to section 11.2(b).
11.1 (i)	Explain the chemistry of DNA mutation from provided data	Illustrate the different types of mutation and carry out exercises using defined sequences to illustrate the consequences.	
11.1 (j)	Discuss the genetic basis of disease (for example, sickle cell anaemia) in terms of altered protein structure and function	Discuss a range of genetically-inherited diseases – but focus on sickle cell anaemia [which affects the structure of haemoglobin and hence the shape of red blood cells] and cystic fibrosis [which affects a specific ion channel]. These examples link to proteins covered elsewhere in this section.	
11.1 (k)	Explain how modification to protein/enzyme primary structure can result in new structure and/or function	Link to earlier examples of defective function in disease – but also to modern research on improving the efficiency of enzymes by genetic modification.	
11.1 (l)	Outline in terms of the hydrolysis of ATP to ADP + Pi, the provision of energy for the cell	Introduce one of the key ideas in cell metabolism, namely that desired reactions are broken down into sequences of energetically 'manageable' steps that are enzyme controlled. Energy for these steps is drawn from the hydrolysis of ATP. Discuss the structure of ATP, the importance of the reversible	

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		transformation of ATP to ADP, and the synthesis of ATP in the mitochondria of cells.	
11.1 (m)	Understand why some metals are essential to life and, given information and with reference to the chemistry of the core syllabus, be able to explain the chemistry involved (for example, iron in haemoglobin (section 9.5 (g) and 11.1 (e) and (j)), sodium and potassium in transmission of nerve impulses (section 3, ion solvation and section 5, energetics), zinc as an enzyme co-factor (section 10.1, nucleophilic attack, 11.1(e))).	Take each example in turn and emphasise the basic chemistry principles illustrated in each case – complex ion formation, variable oxidation state, hydration shells, charge density and polarising power, and nucleophilic attack.	Detail of protein structures and background information on particular enzymes and other proteins can be found from the Protein Data Bank: www.rcsb.org/pdb Discussion of the structure of ion channels can usefully be found at the following sites: http://nobelprize.org/chemistry/laureates [1997 & 2003] www.chemistry.org [this is the American Chemical Society website and it has a section for educators and students] Discussion [and simulations] of the sodium-potassium pump and ion channels can be found at www.biologymad.com/NervousSystem/ and www.chemsoc.org/exemplarchem/

Unit 11: Applications of Chemistry
Applications Of Analytical Chemistry

Context
This section can be studied on its own, or in conjunction with sections 11.1 and 11.3.

Outline
This covers the **Applications of Analytical Chemistry** section of syllabus section 11, **Applications of Chemistry**

AO	Learning outcomes	Suggested Teaching activities	Learning resources
11.2h	Explain the concept of mass spectroscopy, deduce the number of carbon atoms in a compound using the M+1 peak and the presence of bromine and chlorine atoms using the M+2 peak and suggest the identity of molecules formed by simple fragmentation in a given mass spectrum.	Students should copy out the diagram of the mass spectrometer, and be encouraged to talk through the processes that occur within it. Further practice on calculations involving M+1 abundances and determining molecular formulae by summing accurate atomic masses. Explain the ways in which molecular ions can fragment, and work through some examples.	http://www.rjclarkson.demon.co.uk/candrands/spectroscopy.htm#ms http://www.rod.beavon.clara.net/spectra.htm
11.2d 11.2e (part)	Outline in simple terms the principles of nuclear magnetic resonance in ^{1}H and be able to interpret simple NMR spectra. Show awareness of the use of NMR in determining the structure of macromolecules and in understanding their reactions.	Some time may need to be spent on the concept of nuclear magnetic moments, and the idea that they can take up only two orientations in a field. The concept of deshielding also needs to be explained – possibly best through the use of examples of spectra. Splitting patterns also cause some confusion: make sure the students understand that the number of peaks into which an absorption is split depends on the number of *adjacent* protons, and not the number of protons associated with the absorption. Going through the complete analysis of several spectra would prove useful.	http://www.rjclarkson.demon.co.uk/candrands/spectroscopy.htm#ms http://www.rod.beavon.clara.net/spectra.htm
11.2e (part)	Show awareness of the use of X-ray crystallography in determining the structure of macromolecules and in understanding their function.	This needs to be covered only very briefly, to allow students to understand the principles behind the elucidation of the structures of DNA, myoglobin and other biomacromolecules. No detailed explanation will be needed in the examination.	http://www.stolaf.edu/people/hansonr/mo/x-ray.html http://news.uns.purdue.edu/html4ever/9804.Crystallography.html
11.2f	State what is meant by partition coefficient and calculate a partition	Revise equilibria and K_c from the core syllabus. Simple experiments with iodine partitioned between aqueous KI and organic solvent can be	http://toxics.usgs.gov/definitions/kow.html

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	coefficient for a system in which the solute is in the same molecular state in the two solvents.	devised, using thiosulphate to titrate the two layers. A few calculations involving K_{pc} values will help to reinforce the maths.	
11.2g	Understand qualitatively paper, high performance liquid, thin layer and gas/liquid chromatography in terms of adsorption and/or partition and be able to interpret data from these techniques.	The concept of the R_f values of components in PC and TLC can be illustrated practically in two ways: (i) Run a simple two-component mixture twice in the same solvent on the same TLC substrate (e.g. silica), but stop the running of one plate before the solvent has travelled fully up the plate. Measure the R_f values of each spot on each plate and compare the two runs. (ii) Run the same mixture up the same substrate, but increase the polarity of the solvent (e.g. by adding 10% methanol). See how the R_f values increase. Outline the principles of GLC and HPLC, and discuss the ways in which components can be detected coming off the columns. Give practice in interpreting retention times in terms of polarities and/or volatilities.	http://www.rpi.edu/dept/chem-eng/Biotech-Environ/CHROMO/chromintro.html
11.2a, 11.2c	Describe simply the process of electrophoresis and the effect of pH, using peptides and amino acids as examples. Describe the importance to modern medicine, and the challenges, of separating and characterising the proteins in cells.	A simple electrophoresis demonstration can be set up using a strip of filter paper soaked in pH 7 buffer, with a dilute solution of various amino acids (e.g. lysine, glycine and glutamic acid) spotted in the middle. Attaching two crocodile clips and applying a voltage of 100 V DC for half an hour should produce some movement. Develop the spots with ninhydrin. Give practice in predicting the electrophoretic mobilities of various simple di- and tripeptides at various pH values for the buffer. The teaching of section 11.2c could usefully be supplemented by students carrying out their own Internet searches.	http://www.bergen.org/AAST/Projects/Gel/
11.2b	Explain, in simple terms, the technique of DNA fingerprinting and its applications in forensic science, archaeology and medicine.	Teach/revise the structure of DNA if needed, emphasising that at normal pH it exists as a polyvalent anion. Explain that before analysis the DNA is split up, and often multiplied using PCR. Explain how different patterns of STRs and VNTRs are inherited from each parent. Student should be encouraged to find other examples through Internet searches.	http://www.people.virginia.edu/~rjh9u/twindna.html http://www.le.ac.uk/genetics/maj4/JoblingGill04.NRG.Forensics.pdf
11.2i	Draw conclusions given appropriate information and data from	Use the examples given in the booklet as starting points for discussion (none of these examples has to be recalled in the examination).	http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat.ht

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	environmental monitoring (for example, PCBs in the atmosphere, isotopic ratios in ice cores).	Students should be encouraged to use the Internet to root out their own examples of the use of these techniques in environmental monitoring, and present the results of their research either orally to the class or by means of a short report.	ml

Unit 11: Applications of Chemistry
Design and Materials

AO	Learning outcomes	Suggested Teaching activities	Learning resources
11.3(a)	Discuss the challenges of drug targeting and explain in simple terms how molecules may be identified, designed and developed to overcome these problems;	Designer drugs, a study of the targeting of a drug molecule to achieve its synthesis. Class discussion based around the synthesis of taxol. Revise chirality and the reasons why it is better to identify and use the active isomer. The need to deal with problems with drugs such as thalidomide.	Read p284-286 of CUP text for course, if available.
11.3(b)	Discuss the challenges of drug delivery and explain in simple terms how materials may be identified, designed and developed to overcome these problems;	Goldfish in a plastic bag! Discussion of new techniques using Liposomes to convey vaccines, drugs, enzymes, or other substances to target diseased cells or organs in the body. SAQ: Using the glossary definition of a liposome, make a drawing of how you think a liposome would look. (Interested students may like to explore virosomes as an alternative route to convey drugs.	http://www.answers.com/ http://www.ingentaconnect.com/content/ben/cpd/ www.bernabiotech.com/rd/platforms/virosomes/
11.3(c)	Discuss the properties and structures of polymers based on their methods of formation (addition or condensation);	Revision of addition and condensation polymerisation. SAQ to check understanding of addition polymerisation based on polyphenyl(ethene).	Syllabus section 10.8 If you are using the CUP textbook, you may wish to refer to pages 304-6, where you first met these types of polymer and to pages 380-381.
11.3(d)	Discuss how the presence of side-chains and intermolecular forces affect the properties of polymeric materials (for example spider silk);	Conducting and light emitting polymers. Practical: making polypyrrole. Polymeric OLEDs used for traffic lights and display screens. Use of internet links by students. Use of polymerisation to form polyester to check understanding of condensation polymerisation. Kevlar and its uses. SAQ on Kevlar. A look at spider silk compared to silk moth silk. Kevlar reinforced with spider silk.	http://www.dupont.com/afs/ http://www.lbl.gov/MicroWorlds/Kevlar/index.html Conducting polymers http://www-oe.phy.cam.ac.uk/links.htm http://www.xs4all.nl/~ednieuw/Spiders/spidhome.htm

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			http://www.xs4all.nl/~ednieuw/Spiders/Info/spindraad.htm A study of spider silk : http://www.chm.bris.ac.uk/motm/motm.htm
11.3(e)	Show awareness of nanotechnology and, given information and data, be able to discuss the chemistry involved with reference to the core syllabus;	The science of the very small with the big potential. Nanotechnology encompasses biology, chemistry, physics and materials science. SAQ on allotropy of carbon. Properties of buckyballs, Solubility, colours practical to determine concentration of buckyball using colorimetry Tigers in cages, enclosing an atom inside a buckyball cage. Other forms of fullerenes. Uses of carbon nanotubes. Graphene and SWNT. Use of internet: share out links amongst students.	http://cnanotech.com/ http://www.nanotech-now.com/nanotube-buckyball-sites.htm http://www.lbl.gov/Science-Articles/Archive/fullerenes.html http://www.nanotech-now.com/nanotube-buckyball-sites.htm http://www.azom.com/default.asp **http://** www.vega.org.uk/schools/download/index.php http://www.lps.u-psud.fr/Collectif/gr_23/themes/fullnano/en_AC60.htm For the Scanning Tunnelling Microscope: http://www.physicstoday.org/ http://www.che.utoledo.edu/nadarajah/webpages/whatsafm.html

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			http://www.cnanotech.com/pages/resources_and_news/gallery/3-2_buckytube_gallery.html http://www.kodak.com/eknec/
11.3 (f)	Discuss how a knowledge of chemistry can be used to extend the life of existing resources and to improve the efficiency of energy production	Exercise on the twelve green principles of chemistry. Use of supercritical CO_2 to make Thymol exercise. Ionic liquids, class exercise. Discussion over oil pollution from ships and a new method for cleaning up spilt oil. Bacterial leaching of gold or copper. Class discussion of the redox chemistry involved. Discussion - Is bioethanol or biodiesel really green? Visit websites featuring fuel cells. Watch fuel cell video on: http://www.utcfuelcells.com/video/fc_video_1.avi Copy diagrams and make notes.	http//:www.remediation.com/product_recovery.html http://home.cwru.edu/%7Eeay3/ESR/soil.htm http://www.groundwatercentral.info/ http://www.mining-technology.com/projects/bingham/bingham1.html http://www.ias.ac.in/resonance/Aug2004/Aug2004p27-34.htm http://www.utcfuelcells.com/video/fc_video_1.avi http://www.utcfuelcells.com/transportation/index.shtm
11.3(g)	Discuss how knowledge of chemistry can be used to extend the life of existing resources and to improve the efficiency of energy production and use.	Alternative fuels for transport - bioethanol and biodiesel. Is biogas an option? Looking for a future in hydrogen gas. The role of the fuel cell. For electricity, is nuclear the best option? Class discussion after reading the material.	