UNIT 1 Energy, respiration and photosynthesis

Timing This unit comprises approximately 24% of the learning material in A2 Biology, and about 12% of the learning material in a complete Biology A Level learning programme. Units 2 and 3 are each slightly smaller. Each contains about 22% of the A2 material, 11% of the whole A Level. The Option contributes 32% of the A2 assessment, 16% of the total, and thus should be given approximately 32% of the teaching and learning time – more than any of these A2 core units.

Recommended Prior Knowledge Students should be familiar with the concept of energy transfer, e.g. from light energy to chemical energy. They should have a sound understanding of what a molecule is, and understand chemical formulae and equations. It would be helpful if they understood the concept of oxidation and reduction, at least at a simple level.

Context This Unit considers energy transfers in living organisms. It builds on material covered at AS level, especially Section A, Cell Structure, Section B, Biological Molecules, Section G, Transport and Section H, Gas Exchange.

Outline This unit covers the need for energy in living organisms and the universal occurrence of ATP as energy 'currency'. Glycolysis, the Krebs cycle and the electron transport chain are described. Aerobic and anaerobic respiration, in mammals and in yeast, are dealt with. Students use respirometers to make quantitative studies of respiration. The light-dependent and light-independent stages of photosynthesis are described, and also the ways in which the structures of leaves, palisade cells and chloroplasts adapt them for their functions. There are good opportunities within this Unit for students to develop their skills in data analysis. This Unit provides many opportunities for practical work relating to Assessment Objectives in Group C (Experimental skills and investigations), particularly in using the microscope to make observations and record them as drawings. Try to ensure that each student works alone and under time pressure on some occasions, as this will help to prepare for the practical examination(s).

Reinforcement and formative assessment It is recommended that, towards the end of the time allocated to the unit, time be taken to permit reinforcement of the learning that has occurred. There are many ways in which this might be done, ranging from revision lessons, through overview homework, through research project and into preparation of essays, presentations, posters or other material.

- This topic, with so much attractive visual material, is very well suited to highly visual presentations. Small groups of two or three students should be encouraged to work together for an hour or two of lesson time, plus homework for a week or two. They should prepare a visual presentation of a topic to their peers. This could be in the form of a poster, a video, a PowerPoint presentation, an OHP illustrated talk, a short video clip or whatever seems appropriate. Some students will wish to draw their own diagrams, and others to download them from the net, and others to photocopy them from paper sources – all these approaches should be encouraged.
- Formative assessment could take the form of student self-marked minitests, taking just 10 or 15 minutes for students to do and then mark for themselves, perhaps using questions from the Learn CIE Test Centre – discussing the correct answers as a whole class.
- At the end of the unit, there should be a much larger formative assessment test, using appropriate past-examination and similar style questions, taking a lesson to do, and a lesson to provide feedback after marking by the teacher.

Sequence of teaching and learning There are two logical teaching / learning sequences for this unit – both of them work well.

- Some teachers will prefer to teach ATP (L(a), (b) and (c) below), and then go on to photosynthesis L(a), (b), (c), (e) and (f) (at the end of the unit) on the basis that it does not make sense to do respiration until students understand how the energy got into biochemicals in the first place, and the importance of input of energy into reduced molecules (that can then be oxidised with release of energy).
- Other teachers prefer to teach it in the order it is presented, on the basis that respiration is more familiar and of more interest to many candidates, and therefore easier to understand first.

- The other decision to make is whether to do the whole unit without interruption (which gets most of the A2 biochemistry done in one go, and allows students to understand one process in the light of the other), or to split the unit in half, and teach another, different unit, between photosynthesis and respiration (which gives students time to internalise the learning of one before they meet the other, which some teachers believe has the effect of reducing confusion between the two).

Please evaluate these various approaches, and choose the sequence of units that seems most appropriate for your students.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(a)	Outline the need for energy in living organisms, as illustrated by anabolic reactions, active transport, movement and the maintenance of body temperature. **Learning Activity** Pupils should participate in: whole class discussion / oral question and answer leading to bullet point list of uses of energy in organisms	Ask students: what do living organisms use energy for? Build up a list of examples and try to classify them into groups. (For example, breathing, running and talking could be classified under 'movement' or 'muscle contraction'.)	http://www.elmhurst.edu/~chm/vchembook/592energy.html contains a straightforward review of the uses of energy in cells. http://au.encarta.msn.com/encyclopedia_761569250/Metabolism.html Is an Encarta encyclopaedia article that includes anabolisms and use and transfer of energy	The need for energy to do work in living organisms is reviewed on pages 196-7 in *Biology*, Jones. Fosbery, Taylor and Gregory. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7 begins with a review of why organisms need energy, taken further in 9.2.2. *Understanding Biology for Advanced Level*, Toole and Toole, begins chapter 13 with an interesting placing of energy in context, likely to appeal to able students. *Advanced Biology*, Jones and Jones, starts chapter 8 and *Advanced Biology, Principles and Applications*, Clegg and Mackean, starts chapter 15.6 with appropriate material on the need for energy.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(b) and (c)	Describe the structure of ATP as a phosphorylated nucleotide; describe the universal role of ATP as the energy currency in all living organisms. **Learning Activity:** Pupils should participate in: – using diagrams and models to illustrate structure of ATP, release of energy when phosphate is removed and its origin / recycling from ADP and inorganic phosphate complete an interactive online quiz on ATP	Show pupils the structure of an ATP molecule; identify the components of the molecule and remind students what a nucleotide is. (This can be related to the nucleotides that make up RNA and DNA.) Explain that energy is released when a phosphate is removed. If muscle from a freshly-killed animal is available, it can be used to demonstrate the effect of ATP on muscle contraction.	http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/ATP.html good straightforward information including uses of energy released by hydrolysis of ATP. http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookATP.html starts off simple and goes into far more detail than needed by the average candidate, but great for interested students. http://www.biologyinmotion.com/atp/index.html Simple but effective animated page. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/energy/atpan.html http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/energy/adpan.html Animations of formation and hydrolysis of ATP http://www.teachnet.ie/foneill/atp.html Nice text and animation – click on the grey bar below the diagram. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/energy/atp_quiz.html An interactive quiz on ATP	The structure of ATP is shown on page 198 in *Biology*, Jones. Fosbery, Taylor and Gregory. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.2 is about the structure of ATP. *Advanced Biology*, Jones and Jones, starts chapter 8 with information about ATP and energy release. *Advanced Biology, Principles and Applications*, Clegg and Mackean, has appropriate and clear information on ATP production and use. *Understanding Biology for Advanced Level*, Toole and Toole, has a very clear section on production and use of ATP. A protocol for demonstrating the contraction of muscle fibres in the presence of ATP is described in *Practical Advanced Biology*, King et al. *Advanced Biology A2,* Biozone, page 27 explains the role of ATP in cells followed by a series of questions. Page 29 covers the role of the mitochondria in respiration. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(e)	Outline glycolysis as phosphorylation of glucose and the subsequent splitting of hexose phosphate (6C) into two triose phosphate molecules, which are then further oxidised with a small yield of ATP and reduced NAD. **Learning Activities** Pupils should participate in: – whole class discussion / verbal question and answer to establish a clear understanding of what respiration is for, and why (by analogy with electricity generation in power stations rather than in each person's house) aerobic respiration (needing 70 enzymes) is localised (in mitochondria) generating ATP, from which energy can be released by one ATPase enzyme – using bullet points and simple flow diagrams to describe glycolysis (do **not** include more detail than is listed in the syllabus) – whole class discussion / verbal question and answer leading to a brief written or diagrammatic explanation of how glycolysis uses 2 ATP, but produces 4 ATP in total, giving a net production of 2 ATP – whole class discussion / verbal question and answer to produce bullet point notes stating the fate of the reduced NAD formed, either entering the mitochondrion for ATP production in the electron transport system, or, during anaerobic respiration, being used to change pyruvate	Ask students; what is respiration? Where does it take place? Build up the idea that respiration is a series of metabolic reactions that take place in all living cells, in which energy contained in molecules such as glucose is used to make ATP molecules. With the class, gradually build up a flow diagram outlining glycolysis. Emphasise the need for phosphorylation of glucose to make subsequent stages easier; the removal of hydrogen and its acceptance by NAD; the production of a small amount of ATP; and the production of pyruvate. Students should know that this all takes place in the cytoplasm, and happens in virtually every living cell. Students should understand that, after the hexose is split into two identical triose molecules, each of these is processed in exactly the same way, and that most books show only what is happening to one of these two triose molecules. It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds should be introduced beyond those specified in the syllabus.	Most web sites give too much detail of glycolysis, which will confuse many students, so it is important to be very selective. www.science.smith.edu/departments/Biology/Bio231/glycolysis.html A nice simple animation showing the main events in glycolysis. http://www.jonmaber.demon.co.uk/glyintro/ This is a simple and easily understood document that includes some good animations, although they take quite a while to download over a dial up connection. http://www.gwu.edu/~mpb/glycolysis.htm A flow diagram showing displayed formulae of the molecules involved in glycolysis, also viewable in 3D; too complex for most students but those also studying Chemistry may find this interesting. www.accessexcellence.org/AB/GG/out_Glycol.html A simpler flow diagram. http://www.johnkyrk.com/glycolysis.html	Pages 202-3 and 205 in *Biology*, Jones. Fosbery, Taylor and Gregory cover glycolysis to a highly appropriate level of detail. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.3.4 gives an appropriately detailed account of glycolysis. *Advanced Biology*, Jones and Jones and *Understanding Biology for Advanced Level*, Toole and Toole, include glycolysis in detail, which may be of interest to students with a sound grasp of chemistry. *Advanced Biology, Principles and Applications*, Clegg and Mackean contains a very nice illustration emphasising the changes in the number of carbon and phosphate moieties during glycolysis. *Advanced Biology A2,* Biozone, page 30 covers details of glycolysis as phosphorylation of glucose. Model answers to questions are provided in a separate student book and on CD.

			A very detailed animation that will be very exciting for students who are interested and have a good grasp of chemistry. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/glycol_quiz.html Nice interactive quiz on glycolysis, almost all at an appropriate level.	

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(f)	Explain that, when oxygen is available, pyruvate is converted into acetyl (2C) coenzyme A, which then combines with oxaloacetate (4C) to form citrate (6C). **Learning Activities:** Pupils should participate in: – whole class discussion / verbal question and answer involving use of bullet points and simple flow diagrams to describe the link reaction (**not** including more detail than is listed in the syllabus) – examining electron micrographs of mitochondria, identifying the outer and inner membrane, cristae and matrix – looking at microscope slides prepared to show mitochondria, or photomicrographs from the web, or use methyl pyronin green to stain actively respiring mitochondria in living cells (they are about the same size as bacteria, and therefore clearly visible under a good light microscope at x 1000)	Talk through the link reaction, explaining that pyruvate is taken into the mitochondrion by active transport through its two membranes; during this reaction carbon dioxide is given off. (Mitochondrial structure could be revised at this point.) It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds should be introduced beyond those specified in the syllabus.	http://ghs.gresham.k12.or.us/science/ps/sci/soph/energy/resp/notes/krebs.htm Very appropriate diagrammatic representations of the link reaction and Kreb's cycle. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/transit.html Part of an excellent microbial biochemiustry site which covers what they call the transition reaction, including a highly appropriate interactive quiz at: http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/transit_quiz.html http://www.revision-notes.co.uk/revision/263.html A basic bullet points that some students will find useful, including the link reaction.	Pages 203 and 205 in *Biology*, Jones. Fosbery, Taylor and Gregory covers the link reaction in an accessible way that is suited to the level of detail required by the assessment. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.3.5 includes a very brief review of the link reaction (termed transition stage). *Advanced Biology*, Jones and Jones and *Understanding Biology for Advanced Level*, Toole and Toole, do not separate out the link reaction specifically, although the detail presented is appropriate. *Advanced Biology, Principles and Applications*, Clegg and Mackean, labels the link reaction of a diagram of Krebs cycle. *Advanced Biology A2,* Biozone, page 30 includes details of the role of acetyl co-enzyme A. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(g), (h)	Outline the Krebs cycle, explaining that citrate is reconverted to oxaloacetate in a series of small steps in the matrix of the mitochondrion (no further details are required); explain that these processes involve decarboxylation and dehydrogenation and describe the role of NAD. **Learning Activities:** Pupils should participate in: – whole class discussion / verbal question and answer leading to use of bullet points and simple flow diagrams to describe the Krebs cycle (**not** including more detail than is listed in the syllabus – there is **no** requirement to learn names of compounds beyond those listed in the syllabus) – annotating a simple diagram of Krebs cycle to illustrate the following: o series of small steps o decarboxylation (release of CO_2) o dehydrogenation (production of reduced NAD (or FAD) containing hydrogen atoms / protons and electrons from the respiratory substrate) – carrying out an investigation into the activity of dehydrogenase enzymes during respiration, using DCPIP	With the class, gradually build up a simple diagram showing the required steps in the Krebs cycle. Emphasise its cyclic nature, and that hydrogen is removed and accepted by NAD and FAD; carbon dioxide is given off. Practical work could be carried out using tetrazolium chloride (TTC) as an artificial hydrogen acceptor, to illustrate the activity of dehydrogenase enzymes during respiration. It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds should be introduced beyond those specified in the syllabus.	Like glycolysis, watch out for university websites with far more detail than is needed for this course, and avoid them. http://www-saps.plantsci.cam.ac.uk/osmoweb/ttc.htm A protocol for a simple investigation using TTC to show the location of sites of faster and slower respiration in slices of fruit http://scidiv.bcc.ctc.edu/rkr/Biology201/labs/pdfs/CellRespirationLab201.pdf A acrobat pdf that includes protocols that can be adapted for school use, for using for using DCPIP to investigate Krebs cycle. http://ghs.gresham.k12.or.us/science/ps/sci/soph/energy/resp/notes/krebs.htm Very appropriate diagrammatic representations of the link reaction and Kreb's cycle, including a link to a more detailed diagram which makes very clear the number of carbon atoms in each molecule. http://www.revision-notes.co.uk/revision/263.html A basic bullet points that some students will find useful http://www.wiley.com/legacy/	Pages 204 and 205 in *Biology*, Jones. Fosbery, Taylor and Gregory cover Krebs Cycle in the level of detail that is required for success in the examination, yet in an accessible and comprehensible way. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.3.5 includes a review of Krebs cycle that uses more names than are needed, and, whilst clear, does not really emphasise sufficiently the points required by the examination. Experiment 9.1 is a protocol for investigation of oxidation of a Krebs cycle intermediate using DCPIP, which could probably be adapted to use decanting / filtration rather than a centrifuge. *Advanced Biology*, Jones and Jones and *Understanding Biology for Advanced Level*, Toole and Toole, includes Krebs cycle with more names than are required, but draw attention to the key points. *Advanced Biology, Principles and Applications*, Clegg and Mackean and *Understanding Biology for Advanced Level*, Toole and Toole, very clearly

			college/boyer/0470003790/animations/tca/tca.htm A very nice animated website that runs well over a dial-up connection. The Introduction and Carbon parts are appropriate in level, and involve interactive learning. www.science.smith.edu/departments/Biology/Bio231/krebs.html An animation showing what happens during the Krebs cycle. http://www.johnkyrk.com/krebs.html A very detailed animation that will be very exciting for students who are interested and have a good grasp of chemistry. http://bcs.whfreeman.com/thelifewire/ Click on chapter 7, activities index, and then chapter 7.3 for a nice interactive tutorial that leads candidates with a sound grasp of chemistry through krebs cycle. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/cac_quiz.html Useful interactive quiz on Kreb's cycle (which they term citric acid cycle).	explain oxidation and reduction. *Advanced Biology A2,* Biozone, pages 30 and 31 includes details of the role of the Krebs cycle and the role of NAD. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(i), (d)	Outline the process of oxidative phosphorylation, including the role of oxygen (no details of the carriers are required); explain that the synthesis of ATP is associated with the electron transport chain on the membranes of the mitochondrion. **Learning Activities:** Pupils should participate in: – whole class discussion / verbal question and answer leading to use of bullet points and simple flow diagrams to describe the process of oxidative phosphorylation by the electron transport chain (do **not** include more detail than is listed in the syllabus – there is **no** requirement to learn names of electron carriers beyond those listed in the syllabus) – annotating a simple diagram of the electron transport system to illustrate the following: o regeneration of NAD from reduced NAD o production of 3 ATP from 3 ADP + 3 inorganic phosphates o transport of electrons (from hydrogen atoms) down a chain of carriers o use of oxygen as a hydrogen acceptor at the end of the process, producing water as a waste product – complete an interactive online quiz on aerobic respiration	With the class, gradually build up a diagram such as the one in *Biology*, Jones. Fosbery, Taylor and Gregory, illustrating how the transfer of electrons from one carrier to the next provides energy which is used to pump hydrogen ions from the mitochondrial matrix into the intermembranal space; as these ions move back down their concentration (and electrical) gradient, they pass through ATPases and ATP is synthesised from ADP and Pi; oxygen is the final electron acceptor. To help them to consolidate their understanding of aerobic respiration, students could be asked to explain how the structure of a mitochondrion is adapted for its functions in respiration. It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds / specific electron carriers should be introduced beyond those specified in the syllabus.	www.science.smith.edu/departments/Biology/Bio231/etc.html http://www.stolaf.edu/people/giannini/flashanimat/metabolism/mido%20e%20transport.swf Animations showing oxidative phosphorylation. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/etsar.html Animation showing the principle of energy release from the electron transport system. http://www.woodrow.org/teachers/bi/1998/presentations/huffman/ Web page on how to use classroom simulation and activity to teach electron transport system in a way that will promote learning. http://sp.uconn.edu/~terry/images/anim/ETS.html Animation of electron transport chain, with link to animation showing role of ATP synthase enzyme – likely to be of interest to those with a good grasp of chemistry.	Pages 204-5 in *Biology*, Jones. Fosbery, Taylor and Gregory cover oxidative phosphorylation and the electron transport system in a comprehensible way, and with a level of detail suitable to the needs of the question papers. In *Biological Science* 1, Taylor, Green and Stout, Chapter 9.3.5 continues with a section on oxidative phosphorylation and the electron transport system (inadequately termed the respiratory chain). *Advanced Biology*, Jones and Jones, includes oxidative phosphorylation at an appropriate level of detail, with nice diagram showing ATP synthase. *Advanced Biology, Principles and Applications*, Clegg and Mackean, has a brief review of the electron transport system. *Understanding Biology for Advanced Level*, Toole and Toole contains more steps than is necessary, which may appeal to able students as background reading. *Biofactsheet 12: Respiration*

			http://scidiv.bcc.ctc.edu/rkr/Biology201/labs/pdfs/CellRespirationLab201.pdf A acrobat pdf that includes protocols that can be adapted for school use, for using TTC to investigate the electron transport system http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/etsch_quiz.html An interactive quiz. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/cellresp/yield.html A nice analysis of the theoretical yield of ATP from aerobic respiration with a link to an interactive quiz.	*Advanced Biology A2*, Biozone, pages 29 and 3 cover details of the role of the mitochondrion and outline oxidative phosphorylation. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(j)	Explain the production of a small yield of ATP from anaerobic respiration and the formation of ethanol in yeast and lactate in mammals, including the concept of oxygen debt. **Learning Activities:** Pupils should participate in: – describing, from research in textbooks or on the web, glycolysis, lactate production and regeneration of NAD from reduced NAD in animal cells and concept of oxygen debt in anaerobic conditions and glycolysis, ethanol & CO_2 production and regeneration of NAD from reduced NAD in plant and fungal cells in anaerobic conditions, using bullet points or annotated diagrams – investigating factors affecting anaerobic respiration in yeast, including potentially, temperature, glucose concentration, ethanol concentration	Use flow diagrams to explain the lactate pathway and the ethanol pathway. Ensure pupils understand their importance in regenerating NAD. Students could carry out practical work relating to anaerobic respiration in yeast.	http://www.dentistry.leeds.ac.uk/biochem/lecture/glycol/pyruvate.htm Provides clear information in a text format. http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookGlyc.html#Anaerobic Very clear information and nice graphics of both lactate and ethanol pathways. http://www.accessexcellence.org/RC/VL/GG/ana_Pyruvate.html A pair of detailed diagrams. http://instruct1.cit.cornell.edu/Courses/biomi290/MOVIES/GLYCOLYSIS.HTML Nice but very detailed animation that makes very clear (to students with a good grounding in chemistry) the idea of regenerating NAD by creating lactate (need shockwave software from http://sdc.shockwave.com/shockwave/download/download.cgi). http://www.brianmac.demon.co.uk/oxdebit.htm Sport-related text file which gives a reasonably simple view of oxygen debt. Most websites go too deeply into oxygen debt.	Page 207 in *Biology*, J[illegible] Fosbery, Taylor and Greg[illegible] cover anaerobic respiration, briefly, but in sufficient detail to serve the needs of the course. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.3.6 is about anaerobic respiration (but watch out – the diagram on the same page is aerobic respiration!), as well as oxygen debt. *Advanced Biology*, Jones and Jones, includes a very suitable review of anaerobic respiration. *Advanced Biology, Principles and Applications*, Clegg and Mackean and *Understanding Biology for Advanced Level*, Toole and Toole, cover anaerobic respiration. *Practical Advanced Biology,* King et al includes several possible practicals, including one investigating the effect of temperature on anaerobic respiration in yeast. Students may also investigate the effect of different concentrations of ethanol on rates of respiration in yeast. *Advanced Biology A2,* Biozone, has a brief review of different anaerobic pathways on page 32. Model answers to questions are

				provided in a separ[…] student book and on C[…]

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
L(k), (l), (m)	Explain the relative energy values of carbohydrate, lipid and protein as respiratory substrates; define the term *respiratory quotient* (RQ); carry out investigations, using simple respirometers, to measure RQ and the effect of temperature on respiration rate. **Learning Activities:** Pupils should participate in: – listing, from their memory of previous studies, and from text research, respiratory substrates from which energy can be obtained. – Whole class discussion/verbal question and answer leading to definition of RQ in terms of volumes of CO_2 produced and O_2 used, considering theoretical values from equations for respiration of carbohydrate and of a specific lipid. – Calculate RQ values from balanced chemical equations for the aerobic respiration of carbohydrates and lipids, using a teacher-prepared worksheet. – Whole class discussion/verbal question and answer to build understanding of how, within a respirometer, soda lime can be used to absorb CO_2, allowing rate of oxygen uptake to be measured, and how, by leaving out the soda lime, the rate of CO_2 production can then be calculated. – Using a simple respirometer to measure CO_2 use and O_2 production of germinating seeds, and calculate	Use simple balanced chemical equations to illustrate why different respiratory substrates have different RQs. Explain to students how to use a simple respirometer and ask them to carry out an investigation to measure RQ, and another to compare rates of respiration at different temperatures, using these. Once they have been shown the technique, this is a good opportunity to develop their abilities relating to Assessment Objectives in Group C (Experimental skills and investigations) including the design and evaluation of their own investigation. There are two schools of thought about respirometers for student use. Temperature compensation by having two tubes linked by a manometer results in well controlled experiments, but introduces many potentially leaky joints, so that students often fail to get results. Much simpler designs, using a single syringe and capillary tube are far more sensitive to temperature, but far more reliable in yielding results, provided that students leave them alone as far as possible. It is desirable for students to experience both types.	http://sps.k12.ar.us/massengale/lab_5_cellular_respiration_by_kr.htm A description of an investigation using respirometers, and a set of results which students could analyse. http://www.lampstras.k12.pa.us/hschool/teachers/pitts/apbio/cell_energy/respiration_lab.htm respirometer protocol using crickets http://www.science-projects.com/CC101L8.htm Two simple protocols at the bottom of the page. http://www.biologymad.com/master.html?http://www.biologymad.com/PhotosynResp/PhotosynResp.htm In RQ section shows temperature compensated respirometer http://www.ns.purchase.edu/biology/bio1550lab/aerobic.htm http://personal.nbnet.nb.ca/trevgall/biology/resplab.html	Pages 207-9 in *Biology*, Jones. Fosbery, Taylor and Gregory cover respiratory substrates and RQ. On page 209 there is a diagram and description of a respirometer and how to use it. In *Biological Science 1*, Taylor, Green and Stout, Chapter 9.3 includes different respiratory substrates, 9.5.9 an outline of RQ and experiment 9.2 is a rather complex protocol for using temperature compensated respirometers. *Advanced Biology, Principles and Applications*, Clegg and Mackean, has an interesting graph of RQ changes in germinating wheat and flax seeds. *Understanding Biology for Advanced Level*, Toole and Toole, has a clear section on theoretical RQ of carbohydrate and lipid. *Practical Advanced Biology,* King et al, has a protocol for investigating the effect of temperature on oxygen consumption of organisms, and another for determining respiratory quotient, which include detailed explanations of how to use respirometers.

	RQ. – Using a temperature compensated respirometer to investigate the effect of temperature on rate of respiration (such respirometers can be made from ordinary laboratory equipment). – Brief whole class discussion/verbal question and answer to lead students to understand that proteins and carbohydrates contain similar ratios of C, H and O, but lipid contains less O than C and H, so lipid yields more energy.		http://central.saisd.org/dpts/science/biologyap/student/unit2/Unit%202%20Labs/Cell%20Respiration%20Lab.htm A simple respirometer protocols involving seeds http://www.phschool.com/science/biology_place/labbench/lab5/features.html A series of pages showing how to make and use simple respirometers	*Comprehensive Practi Biology*, Siddiqui, also ha detailed protocols for these two investigations. *New Perspectives in Advanced Biology*, Hansen, 1999, pub Hodder and Stoughton, has, on page 78, a simple syringe-based respirometer. *Advanced Biology A2,* Biozone, shows the determination of RQ for a variety of substrates on page 28. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
M(a)	Explain that energy transferred as light is used during photosynthesis to produce complex organic molecules and that the process of respiration allows this energy to be transferred through chemical reactions so that it can be used by living organisms. **Learning Activities:** Pupils should participate in: – whole class discussion / verbal question and answer leading to bullet pointed statements to build understanding of purpose of photosynthesis o Transfer of energy from light to complex organic molecules from which the energy can later be released to do work o Reduction of CO_2 by the addition of hydrogen / electrons / energy and removal of oxygen – researching information leading to drawing up an annotated diagram showing, in **outline**, that photosynthesis consists of a light dependent stage in which light energy is transferred to ATP and reduced NADP, and a light independent stage that uses the energy from the ATP and reduced NADP to reduce CO_2 to carbohydrate – organising cards with information about photosynthesis (made by the teacher) into a logical order, asking about areas not understood, in order to build understanding	Ask students: what is the purpose of photosynthesis? Where does it happen? Help them to understand that photosynthesis transfers energy from light to complex organic molecules. Introduce photosynthesis as a series of reactions in which energy is transferred from sunlight to molecules such as glucose.	www.accessexcellence.org/AB/GG/photo_Resp.html A diagram and short text explaining the interrelationship of respiration and photosynthesis. http://www.biologymad.com/ Follow the links to A2 Biology and then photosynthesis and respiration – links to relevant sites and materials for both processes http://www.wcsscience.com/photosynthesis/page.html Good reminder of basics. http://iusd.k12.ca.us/uhs/cs2/photosynsummary.htm Good summary of biochemical outline of photosynthesis. http://35.9.122.184/images/10-Photosynthesis/HTML/source/55.html Detailed summary of biochemistry of photosynthesis – next slide is same picture without labels. http://staff.jccc.net/pdecell/photosyn/photoframe.html Nice text, photo and diagrams including relationship between light dependent and light	Pages 212-3 in *Biology*, Jones. Fosbery, Taylor and Gregory cover the fundamentals of photosynthesis and the trapping of light energy. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7.12 looks at the relationship between photosynthesis and respiration, including a practical protocol to investigate compensation point in leaves. The beginning of Chapter 9 considers this further. *Advanced Biology*, Jones and Jones, includes a nice diagram, Fig. 8.4, showing the inputs and outputs from the stages of photosynthesis. *Advanced Biology, Principles and Applications*, Clegg and Mackean, starts chapter 12 with an extensive review that is good background reading for able students. *Advanced Biology A2,* Biozone, Although not covered explicitly, this section is implicitly covered in the unit detailing photosynthesis. Model answers to questions are provided in a separate

	– Complete an interactive online quiz on fundamentals of photosynthesis.		independent stages. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/photosyn/photo.html Nice basic introduction to photosynthesis with links to animation, diagram and interactive quiz. http://faculty.fmcc.suny.edu/mcdarby/Animals&PlantsBook/Plants/01-Photosynthesis.htm Another good basic introduction to photosynthesis leading on to the existence of light dependent and light independent stages. http://www.teachnet.ie/foneill/photo.html Text material with links to more detailed material relevant to the next two Scheme of Work units.	student book and o

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
M (b)	Describe the photoactivation of chlorophyll resulting in the photolysis of water and in the transfer of energy to ATP and reduced NADP (cyclic and non-cyclic photophosphorylation should be described in outline only). **Learning Activities:** Pupils should participate in: – whole class discussion / verbal question and answer leading to production of bullet points and annotated diagrams to build understanding of photolysis, photosystems, chain of electron carriers / ATP production and reduction of NADP, plus a brief outline of photosynthetic pigments – investigating the effect of light intensity and light wavelength on the Hill reaction, using a very simple protocol – investigating the pigments present in chloroplasts using paper or thin layer chromatography	Use flow diagrams (including the Z scheme) to explain the light-dependent stage to students. Avoid covering more detail than students need, as they frequently find this topic difficult. They should know about photosystem I and II, chloroplast pigments and their absorption spectra and roles, photolysis and the Hill reaction. Help students to see the similarities between the way in which ATP is produced in photosynthesis and in respiration. Practical work on the Hill reaction could be carried out, using DCPIP as an electron acceptor. Practical work could also involve chromatography of chloroplast pigments. It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds should be introduced beyond those specified in the syllabus.	http://www.biology4all.com/resources_library/details.asp?ResourceID=43 An animation showing the events taking place in the light-dependent stage – download the first flash animation. http://stolaf.edu/people/giannini/flashanimat/metabolism/photosynthesis.swf A good animation of photophosphorylation http://www.teachnet.ie/foneill/nadph.html Nice text and animation about making reduced NADP from NADP – click on the grey bar below the diagram. http://www.teachnet.ie/foneill/cyclic.html http://www.teachnet.ie/foneill/noncyclic.html Nice animations and text of cyclic and non-cyclic photophosphorylation. http://www-saps.plantsci.cam.ac.uk/worksheets/ssheets/ssheet10.htm A protocol for carrying out thin layer chromatography of plant pigments.	The depth of treatment topic on pages 213-5 in *Biology*, Jones. Fosbery, Taylor and Gregory, is a good guide to the level of detail required. *Biology*, Jones. Fosbery, Taylor and Gregory, contains a set of results on page 215, from an investigation into the Hill reaction using DCPIP. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7.5 includes absorption of light and 7.6 light dependent reactions, in detail. 7.11 includes a protocol for the Hill reaction that works well. By adapting it to use decanting and filtration rather than centrifuging, and melting point tubes rather than test tubes as reaction vessels, this can be done without expensive equipment. *Advanced Biology*, Jones and Jones, and *Advanced Biology, Principles and Applications*, Clegg and Mackean, include detailed and superbly illustrated accounts of the light dependent reactions likely to appeal to students with an interest in biochemistry.

			http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/photosyn/ldr_quiz.html An appropriate interactive quiz on light dependent reactions. Follow links back to text page and animations of chemiosmosis of interest to the most able students	*Understanding Biol* *Advanced Level*, Tool Toole, includes the light dependent stage. *Comprehensive Practical Biology*, Siddiqui, has a protocol for investigating the Hill reaction, involving, like most others, the use of a centrifuge. Chromatography of photosynthetic pigments is described in *Practical Advanced Biology,* King et al and also in Siddiqui. *Advanced Biology A2,* Biozone, provides an outline of photosynthesis and then details of the photolysis of water during the light dependant phase. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
M(c) and (d)	Describe the uses of ATP and reduced NADP in the light-independent stage of photosynthesis; describe in outline the Calvin cycle involving the light-independent fixation of carbon dioxide by combination with a 5C compound (RuBP), and the conversion of GP into carbohydrates, lipids and amino acids (the regeneration of RuBP should be understood in outline only, and a knowledge of C4 and CAM plants is not required) **Learning Activities:** Pupils should participate in: - whole class discussion / verbal question and answer leading to white-board / black-board bullet points, annotated diagrams and written questions to build understanding of the light independent stage (in **no** more detail than is given in the syllabus), emphasising: o RuBP in CO_2 fixation to form GP o the use of ATP for energy to reduce GP to TP and as a source of phosphate and energy to regenerate RuBP from TP (individual steps in RuBP regeneration are **not** required) o the use of reduced NADP in reduction of GP to TP, regenerating NADP o GP as a raw material for producing carbohydrates, lipids and amino acids (**no**	With the class, gradually build up a simple diagram showing the Calvin cycle. Emphasise the source and roles of reduced NADP and ATP. Note: avoid the term 'dark reaction', as this wrongly implies that it only takes place in the dark. Note: look out for different names for some of the compounds involved. GP (glycerate 3-phosphate) is sometimes known as PGA (3-phosphoglycerate). Triose phosphate is sometimes known as GALP (glyceraldyhyde 3-phosphate) In the interests of 'error-free learning', use only the syllabus names and abbreviations at all times. The alternatives should be given to students **once** only, on paper, so that they can access textbooks designed for other syllabuses. It is very easy to teach this section in more detail than is required. **No** intermediate steps or additional compounds need to be introduced beyond those specified in the syllabus.	www.science.smith.edu/departments/Biology/Bio231/calvin.html An animation of the Calvin cycle. http://www.teachnet.ie/foneill/calvin.html A very nice animation of the Calvin cycle. http://www.cat.cc.md.us/courses/bio141/lecguide/unit4/metabolism/photosyn/lindr_quiz.html A nice interactive quiz on light independent reactions. http://www.teachnet.ie/foneill/workphoto.html Nice quiz about all aspects of photosynthesis – smiley face for correct answers, cross for incorrect! http://www.msu.edu/~smithe44/calvin_cycle_process.htm A step by step through the process in enough detail to satisfy the student with a solid understanding of Chemistry – some nice models of the molecules involved.	The depth of treatment topic on pages 215-6 in *Biology*, Jones. Fosbery, Taylor and Gregory, is a good guide to the level of detail required. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7.6 ends with a detailed review of light independent reactions. *Advanced Biology*, Jones and Jones and *Advanced Biology, Principles and Applications*, Clegg and Mackean, include clear explanations of the light independent reactions. *Understanding Biology for Advanced Level*, Toole and Toole, outlines the light dependent stage with a slightly unusual diagram, which may help some students. *Advanced Biology A2,* Biozone, gives details of the light dependant stage and an outline of the light independent Calvin cycle on page 38. Model answers to questions are provided in a separate student book and on CD.

	details of pathways required) Complete an interactive online quiz on the light independent reactions.			

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
M(e)	Describe the structure of a dicotyledonous leaf, a palisade cell and a chloroplast and relate their structures to their roles in photosynthesis. **Learning Activities:** Pupils should participate in: – interpretation, drawing and annotation of diagrams from photomicrographs and electron micrographs (from books and the web), diagrams, microscope slides, fresh plant materials (e.g. *Elodea* entire leaf, freshly cut sections (in water) through a locally available dicotyledonous mesophyte) and the Cambridge Hitachi Bioscope – making a brief written summary of the adaptations of palisade cells and chloroplasts to their functions – practising measuring skills with microscope / Cambridge Hitachi Bioscope and calculate size of objects and magnification of images – making epidermal strips from various leaves (perhaps using nail varnish and peeling off when dry), making quantitative comparisons	Students will have dealt with these structures during their AS course. Now they can link them with their functions in photosynthesis. Students should see and interpret electron micrographs of palisade cells and chloroplasts. Ask them to write a brief summary of how palisade cells and chloroplasts are adapted for photosynthesis. This is a good opportunity to practise microscope work, observing and recording the structure of leaves in transverse section and also using a graticule and stage micrometer for measurement. Students could prepare epidermal strips from leaves of different species, make their own temporary slides and record and interpret their observations. This can be done quantitatively, involving a calculation of the number of stomata per unit area on a mesophytic and a xerophytic leaf, again linking structure to function. (There is **no** requirement to teach the mechanism of functioning of stomata in this part of the course.) Students could be encouraged to consider similarities in the structure of mitochondria and chloroplasts, relating these to their common function of generating ATP as electrons pass along a chain of electron carriers	http://images.botany.org Micrographs of leaves. http://www.biu.soton.ac.uk/galleryindex.htm Includes a nice poplar leaf section. http://www.biologie.uni-hamburg.de/b-online/e05/r21.htm SEM of leaf section. http://faculty.uca.edu/~johnc/Chloroplast_and_microbodies.jpg TEM chloroplast. http://www.bio.ic.ac.uk/research/nield/gallery.html Images including TEM chloroplast.	There are many superb slides and associated learning tasks on the Cambridge Hitachi Bioscope, including very nice chloroplasts in *Elodea*, a variety of leaf sections, including sun and shade leaves. The Cambridge Hitachi Bioscope is a superb teaching and learning tool for the skills required to use a graticule and stage micrometer successfully. Pages 216-9 in *Biology*, Jones. Fosbery, Taylor and Gregory cover leaf, palisade cell and chloroplast structure to an appropriate level. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7.4 reviews leaf and chloroplast structure. *Advanced Biology*, Jones and Jones, includes some very appropriate and motivating material on leaf and chloroplast structure. *Advanced Biology, Principles and Applications*, Clegg and Mackean, has nice clear illustrations of leaf, palisade call and chloroplast structure. A relatively simple practical looking at leaf structure is

				described in *Practic* *Advanced Biology*, Ki and a more detailed one *Comprehensive Practical Biology* by Siddiqui. *Biofactsheet 61: chloroplasts and mitochondria* The CD-ROM: *Images of Biology for Advanced Level* published by Stanley Thornes has suitable images that are useful here. *Advanced Biology A2,* Biozone, gives basic details of leaf structure on page 33 and an explanation of the role and structure of a chloroplast on page 36. Model answers to questions are provided in a separate student book and on CD.

	Learning Outcomes	Suggested Teaching Activities	Online Resources	Other resources
M(f)	Discuss limiting factors in photosynthesis and carry out investigations on the effects of light, carbon dioxide and temperature on the rate of photosynthesis. Learning Activities: Pupils should participate in: - simulate simple experiments on effect of light and carbon dioxide on rate of photosynthesis using website or CIE simulations - carrying out an investigation into the effect of CO_2 concentration (by changing sodium hydrogen carbonate concentration) on rate of photosynthesis of an aquatic plant - planning and carrying out an investigation into the effect of light intensity on rate of photosynthesis in an aquatic plant - researching the effect of temperature on photosynthesis, using the internet and text book sources, finding clear graphical representations, and putting copies of these up on a wall in the laboratory answer questions based on graphical and tabular information (written by the teacher) to reinforce understanding and practice skills.	Practical work should be carried out to investigate the effect of light intensity, light colour (wavelength), carbon dioxide concentration and temperature on the rate of photosynthesis. Students could be expected to design and carry out at least one investigation of their own, once a technique has been shown to them. Carbon dioxide can be varied by using a water plant (such as *Elodea* or *Hydrilla*) and adding sodium hydrogen carbonate (sodium bicarbonate) to the water. Students should understand that temperature affects the rate of the light-independent stage as this is controlled by enzymes, whilst the light-dependent stage is *not* directly affected by temperature changes as these are photochemical reactions.	http://www-saps.plantsci.cam.ac.uk/worksheets/activ/prac5.htm A protocol using leaf discs to investigate the effect of light intensity on the rate of photosynthesis. This could easily be modified to investigate the effects of wavelength and/or temperature. http://www-saps.plantsci.cam.ac.uk/worksheets/ssheets/ssheet23.htm Using immobilised algae to investigate the rate of photosynthesis. http://www-saps.plantsci.cam.ac.uk/worksheets/ssheets/ssheet20.htm A protocol entitled 'Can leaf discs make starch in the dark? http://www-saps.plantsci.cam.ac.uk/worksheets/ssheets/ssheet20.htm http://www.teachnet.ie/foneill/workphoto.html Nice simple simulations of the effect of light intensity and carbon dioxide concentration on rate of photosynthesis – can be used to generate data by counting bubbles per unit time.	Pages 219-220 in *Biolo* Jones. Fosbery, Taylor a Gregory cover the limiting effects of light intensity, carbon dioxide concentration and temperature on photosynthesis. In *Biological Science 1*, Taylor, Green and Stout, Chapter 7.8 is a detailed review of limiting factors on photosynthesis. 7.11 includes a quantitative protocol for investigating the effect of light intensity on rate of photosynthesis. *Advanced Biology*, Jones and Jones, covers the effect of limiting factors in a visual and very clear way. *Advanced Biology, Principles and Applications*, Clegg and Mackean, has an extensive review of limiting factors that is good background reading for able students A range of possible practicals is described in both *Practical Advanced Biology*, King et al, and in *Comprehensive Practical Biology* Siddiqui *Advanced Biology A2,* Biozone, gives a brief outline of limiting factors and a series of questions on page 40. Model answers to questions are provided in a separate student book and on CD.