A2 Biology Syllabus 9700
Unit 1: Energy, respiration and photosynthesis

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, is 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.

L Energy and Respiration
- The need for energy in living organisms
- Respiration as an energy transfer process
- Aerobic respiration
- Anaerobic respiration
- The use of respirometers

M Photosynthesis
- Photosynthesis as an energy transfer process
- The investigation of limiting factors

There are two logical teaching / learning sequences for this unit – both of them work well. Some teachers will prefer to teach ATP in section L, learning outcomes (a), (b) and (c), and then go straight on to section M, photosynthesis, to show students how energy gets into biochemicals in the first place. This enables students to understand 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.

There is another consideration for this unit -

Complete the whole unit without interruption:

- gets most of the A2 biochemistry done in one go
- allows students to understand one process in the light of the other

or

Split the unit in half, and teach another, different unit, between photosynthesis and respiration:

- gives students time to internalise the learning of one before they meet the other
- 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.

Use the practical opportunities within this Unit to develop strategies to help prepare students for Paper 5. Students will need to develop their skills relating to Assessment Objectives in Group C (Experimental skills and investigations), including data analysis and the design and evaluation of their own investigations. Try to ensure that each student works alone and under time pressure on some occasions.

Text book resources

In addition to the text books mentioned in '**General Resources**' in the '**Overview of AS and A Level**', the following textbooks are useful for this topic:

Advanced Biology, Jones and Jones, pub.CUP
Advanced Biology: Principles and Applications (2nd edition) Clegg and Mackean, pub. John Murray *(and **Study Guide** available)*
Biological Science 1 and 2 (3rd edition), Taylor, Green, Stout & Soper, pub CUP
New Understanding Biology for Advanced Level (4th edition), Toole and Toole, pub. Nelson Thornes

AO	Learning outcomes	Suggested Teaching activities	Learning 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.	Carry out a brainstorming exercise. Why do living organisms need energy? What do living organisms use energy for? Ask students to provide examples. 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'). Encourage students to think of, and discuss, examples that are from all five kingdoms e.g. for movement: • prokaryotes: flagellar movement (student should be aware of the differences between prokaryotic and eukaryotic flagella) • protoctists: amoeboid movement, cilia synchronous rythmn and flagellar movement; • fungi: discharge of spores • animals: muscle contraction • plants: translocation of sugars **Class activities** 1. Students should participate in whole class discussion / oral question and answer. 2. Research and write definitions of metabolism, catabolism and anabolism. 3. Make a list of the main uses of energy in organisms: where relevant add bullet points e.g. for anabolic reactions students will be able to recall AS and give examples from Section B (Biological molecules).	http://www.elmhurst.edu/~chm/vchembook/592energy.html contains a straightforward review of the uses of energy in cells. http://www.rsc.org/education/teachers/learnnet/cfb/metabolism.htm explanation of anabolism and catabolism http://staff.jccc.net/pdecell/metabolism/entrans.html#atpadp summary of the ATP-ADP cycle The need for energy to do work in living organisms is reviewed in ***AS and A Level Biology*** (Chapter 15, pp.196-197). In ***Biological Science 1 and 2***, ***New Understanding Biology for Advanced Level*** and ***Advanced Biology: Principles and Applications,*** there is a review of why organisms need energy. ***Advanced Biology*** starts chapter 8 with appropriate material on the need for energy

AO	Learning outcomes	Suggested Teaching activities	Learning resources
L	(b) describe the structure of ATP as a phosphorylated nucleotide; (c) describe the universal role of ATP as the energy currency in all living organisms.	Show students 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, AS, section F). Explain that energy is released when a phosphate is removed. Students are likely to have come across the idea of *activated nucleotides* in DNA replication (AS, section F) **Class activities** 1. Use diagrams and models, and make notes, to illustrate the structure of ATP, release of energy when phosphate is removed and its origin / recycling from ADP and inorganic phosphate. 2. Make bullet-pointed notes on the features that make ATP the universal energy currency: this could begin with a brainstorming activity.	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 in a simple manner 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.teachnet.ie/foneill/atp.html nice text and animation – click on the grey bar below the diagram. The structure of ATP is shown in ***AS and A Level Biology*** (Chapter 15, p. 198) In ***Biological Science 1 and 2*** and ***New Understanding Biology for Advanced Level*** there is a section about ATP structure. ***Advanced Biology***, starts chapter 8 with information about ATP and energy release and ***Advanced Biology: Principles and Applications*** have appropriate and clear information on ATP production and use. ***Bio Factsheet 129:*** *ATP–what it is, what it does*

AO	Learning outcomes	Suggested Teaching activities	Learning 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;	Ask students; what is respiration? Where does it take place? Build up the idea that respiration is a series of enzyme-controlled metabolic reactions that take place in all living cells, in which energy contained in molecules such as glucose is used to make ATP molecules. Students should know that glycolysis occurs in the cytoplasm (in virtually every organism) and occurs in both anaerobic and aerobic respiration. Emphasise the need for supplies of NAD to allow glycolysis to proceed. It is worth telling students that NAD is a coenzyme. If students have not come across this at AS, explain that coenzymes are compounds that are required in many enzyme reactions. Here, NAD is a hydrogen carrier). Students need to appreciate the principles rather than the detail of the steps involved – see learning outcome (e) and activity 1. No intermediate steps or additional compounds need to be introduced. **Class activities** 1. Participate in whole class discussion / verbal question and answer to build up a simple flow diagram to describe glycolysis, annotated with points: • phosphorylation of glucose to make subsequent stages easier (link back to uses of ATP covered in (b) and (c)) • after the hexose is split into two identical triose molecules, each of these is processed in exactly the same way to produce pyruvate (i.e two pyruvate molecules per glucose) • the need for hydrogen removal and its acceptance by NAD • 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 • the production of a small amount of ATP • uses 2 ATP, but produces 4 ATP in total, giving a net production of 2 ATP • glycolysis can be described as the oxidation of glucose to pyruvate	Most web sites give too much detail, which w confuse many students, so it is important to be very selective.(http://glycolysis.co.uk/ is a resource to remind teachers of the details) www.science.smith.edu/departments/Biology/Bio231/glycolysis.html a nice animation showing the main events http://www.terravivida.com/vivida/glyintro/ this is a simple and easily understood document that includes some good animations http://www.johnkyrk.com/glycolysis.html a very detailed animation that will be very exciting for knowledgeable, interested students http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation__how_glycolysis_works.html another good animation of glycolysis (uses the term 'diphosphate' rather than bisphosphate), finishing with a mention of the fate of pyruvate in anaerobic or aerobic respiration. ***AS and A Level Biology*** cover glycolysis at an appropriate level (Chapter 15, pp.201-202 and p. 205). The other text books noted in the Unit introduction include glycolysis, all with a slightly different style and some in more detail.

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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);	The various stages of respiration can be covered in class activity 1, as an introduction for later learning outcomes. Mitochondrial structure could also be revised at this point. By analogy with electricity generation in power stations, rather than in each person's house, students should understand why aerobic respiration (needing 70 enzymes) is localised in mitochondria, generating ATP. Talk through the link reaction, explaining that pyruvate is taken into the mitochondrion by active transport through its two membranes and is then converted to the smaller acetyl coenzyme A to allow this molecule to enter the Krebs cycle. During this reaction carbon dioxide is given off and NAD acts as a hydrogen carrier (hence the terms *dehydrogenation* and *decarboxylation*). Combination of acetyl coenzyme A with oxaloacetate to form citrate can be discussed with the next learning outcome (g), if preferred. **Class activities** 1. Produce a diagram of an overview of the location of the stages of respiration. Draw a large cell (take a whole page for this) and include a large mitochondrion within (remind of AS, section A). Label the cytoplasm, mitochondrion, inner membrane / crista(e) and matrix. Show glycolysis as glucose → pyruvate in the cytoplasm, the link reaction and Krebs cycle (pyruvate into the mitochondrial matrix and acetyl coenzyme A entering the cycle), NADH and FADH leaving the cycle to the crista, (label oxidative phosphorylation). This can be added to as each learning outcome is covered and eventually used as a summary. 2. Examine (e.g. images from text books and the internet) light micrographs and electron micrographs of mitochondria, identifying the outer and inner membrane, cristae and matrix. 3. Participate in whole class discussion / verbal question and answer to make bullet pointed notes and construct a simple flow diagram to describe the link reaction. Notes should include that 2 pyruvates are involved for each glucose molecule.	http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation__how_the_krebs_cycle_works__quiz_1_.html a simple introduction to the link reaction, following through to the Krebs cycle The link reaction is also covered in the websites listed in the section on learning outcome (g), the Krebs cycle. ***AS and A Level Biology*** cover the link reaction and mitochondrial structure and function in an accessible way that is suited to the level of detail required (Chapter 15, pp. 203, 205 and 206). The other text books noted in the Unit introduction include the link reaction in appropriate detail, some as part of the Kreb's cycle and not denoted specifically as the link reaction. ***Biology - A Functional Approach: Student's Manual 2nd edition***, Roberts and King, pub. Nelson Thornes, has a protocol for studying active mitochondria under the light microscope, using Janus green indicator. ***Bio Factsheet 61****: Chloroplasts and mitochondria*

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L	(g) 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); (h) explain that these processes involve decarboxylation and dehydrogenation and describe the role of NAD;	With the class, gradually build up a simple diagram showing the required steps in the Krebs cycle. Emphasise: • its cyclic nature, with a series of small steps • enzyme-controlled reactions • dehydrogenation occurs so that hydrogen is removed and accepted by NAD and FAD • decarboxylation occurs so carbon dioxide is given off. Extra detail is not required for the examination and students who may easily become confused should be encouraged to avoid websites that have far more detail than the recommended text books. **Class activities** 1. Participate in whole class discussion and verbal question and answer, leading to use of bullet points and simple annotated flow diagrams to describe the Krebs cycle. Notes / the cycle should show: • decarboxylation of intermediates (release of carbon dioxide) • changes to number of carbon atoms in intermediates (overall : 4C+ 2C → 6C; 6C → 4C + 2CO_2) • dehydrogenation of intermediates coupled with reduction of NAD and FAD • so NADH and FADH contain hydrogen atoms / protons and electrons from the respiratory substrate • substrate-linked phosphorylation of ADP to give ATP • oxaloacetate (4C) as the acceptor of acetyl coenzyme A (2C) • the formation of citrate (6C) 2. State and explain how many turns of the cycle occur for each molecule of glucose. 3. Carry out an investigation into the activity of dehydrogenase enzymes during respiration, using tetrazolium chloride (TTC) as an artificial hydrogen acceptor.	http://www-saps.plantsci.cam.ac.uk/osmoweb/ttc.htm a protocol to locate sites of faster and slower respiration in slices of fruit (uses TTC) http://www.wiley.com/legacy/college/boyer/0470003790/animations/tca/tca.htm a very nice animated, interactive website: the Intro and carbon parts are appropriate in level http://www.science.smith.edu/departments/Biology/Bio231/krebs.html an animation showing the Krebs cycle for students with a good grasp of the topic: http://www.johnkyrk.com/krebs.html a very detailed, interesting animation http://bcs.whfreeman.com/thelifewire/ click on chapter 7, activities index, and then chapter 7.3 for a nice interactive tutorial ***AS and A Level Biology*** give a clear and accessible account of the Krebs cycle (Chapter 15, pp. 203 and 205). ***Advanced Biology: Principles and Applications*** clearly explains oxidation and reduction. ***Biological Science 1 and 2*** has a protocol for investigation of oxidation of a Krebs cycle intermediate using DCPIP, which could probably be adapted by using decanting / filtration rather than a centrifuge.

AO	Learning outcomes	Suggested Teaching activities	Learning resources
L	(i) outline the process of oxidative phosphorylation, including the role of oxygen (no details of the carriers are required); (d) explain that the synthesis of ATP is associated with the electron transport chain on the membranes of the mitochondrion;	See advice given for learning outcomes (g) and (h) regarding level of detail required. Using class discussion and question and answer, build up a flow diagram to illustrate oxidative phosphorylation. *electron transport chain should include:* • regeneration of NAD from reduced NAD • hydrogen from NAD split into protons and electrons • transport of electrons (from hydrogen atoms) down a chain of carriers (i.e. to lower energy levels) • use of oxygen as the final electron acceptor • oxygen + electrons + protons produce water as a waste product *chemiosmosis should include:* • transfer of electrons from one carrier to the next provides energy • the energy is used to pump hydrogen ions from the mitochondrial matrix into the intermembrane space (explain the membrane is relatively impermeable to hydrogen ions) • as the hydrogen ions move back down their concentration (and electrical) gradient, they pass through ATPsynthases/ synthetases (an example of facilitated diffusion) • and ATP is synthesised from ADP and Pi Explain why the estimate of '1NADH = 3ATP' is now seen as approximately 1NADH = 2.5ATP (1FADH = 1.5ATP). **Class activities** 1. Summarise oxidative phosphorylation with flow diagrams and bullet point notes, as worked out in the class discussion. 2. Sort a set of statements into a correct sequence to outline oxidative phosphorylation. 3. For interest only, and to revise each stage, construct an ATP use and synthesis balance sheet for one molecule of glucose. 4. Write out the overall equation for aerobic respiration. 5. To consolidate understanding of aerobic respiration, explain how the structure of a mitochondrion is adapted for its functions.	animations showing oxidative phosphorylation http://www.science.smith.edu/departments/Biology/Bio231/etc.html and http://www.stolaf.edu/people/giannini/flashanimat/metabolism/mido%20e%20transport.swf 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 – for interested students ***AS and A Level Biology*** and ***Advanced Biology*** (nice diagram of ATP synthase) cover oxidative phosphorylation and the ETC in a comprehensible way, and with a level of detail suitable to the needs of the question papers (Chapter 15, pp. 204-205). ATP synthesis by the chemiosmosis process is also described (p.199). This can also be used for photosynthesis. ***Biological Nomenclature (4th Edition)***, pub. Society of Biology, is also a useful reference for respiration. ***Bio Factsheet 12***: *Respiration*

AO	Learning outcomes	Suggested Teaching activities	Learning 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;	Use flow diagrams to explain the lactate pathway in mammals and the ethanol pathway in yeast. Ensure students understand that anaerobic respiration occurs in the cytoplasm when oxygen is not available and explain that, although ATP is synthesised in glycolysis, pyruvate needs to be further converted to regenerate NAD to allow glycolysis to continue. Explain that there is a very limited quantity of NAD per cell so it needs to be regenerated. Mention to students that anaerobic respiration in yeast is also known as alcoholic fermentation. **Class activities** 1. Draw out an outline of glycolysis, showing the oxidation of glucose to pyruvate, with NAD acting as the hydrogen carrier. Following class discussion, show how NAD is regenerated by production of lactate from pyruvate. 2. Research the concept of oxygen debt in textbooks or on the web. Add to the lactate pathway to show how, when oxygen becomes available, lactate can be converted back to pyruvate that can then be converted to glucose and glycogen for storage, or enter the Krebs cycle. 3. Repeat activity 1, showing the two-step reaction from pyruvate to produce ethanol, carbon dioxide production and regeneration of NAD from reduced NAD in yeast (plus other fungi and many plant cells). 4. Investigate factors affecting anaerobic respiration in yeast.	http://www.dentistry.leeds.ac.uk/biochem/lec e/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.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. ***AS and A Level Biology*** covers anaerobic respiration, briefly, but in sufficient detail to serve the needs of the course (Chapter 15, p.207). ***Advanced Biology***, includes a suitable review of anaerobic respiration. ***Advanced Biology: Principles and Applications***, ***Biological Science 1 and 2*** and ***New Understanding Biology for Advanced Level*** cover anaerobic respiration and the concept of oxygen debt. ***Practical Advanced Biology*** 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.

AO	Learning outcomes	Suggested Teaching activities	Learning resources
L	(k) explain the relative energy values of carbohydrate, lipid and protein as respiratory substrates;	Students should understand that many cells can use other respiratory substrates in addition to glucose and that different substrates have different energy values per unit mass. It may help to discuss the general equation: organic compounds + oxygen ⟶ (ATP + heat energy) + water + carbon dioxide This is a good opportunity, by verbal question and answer, to remind students of their AS work on Biological molecules. Also, revisit oxidative phosphorylation and show students the importance of supplying hydrogen, carried by NADH and FADH, to the crista and ETC for electron flow and the release of energy. This will lead students to understand that, as proteins and carbohydrates contain similar ratios of C, H and O, but lipids contains less O than C and H, lipids will yield more energy as they have proportionately more hydrogen per g of substrate. Students do not have to describe how the energy values are obtained.	for student background interest: http://mutuslab.cs.uwindsor.ca/schurko/animations/bombcal/animation4.htm short animation showing the operation of an oxygen bomb calorimeter and http://www.tutorvista.com/content/chemistry/chemistry-iv/thermodynamics/bomb-calorimeter.php narrated animation of a bomb calorimeter In ***AS and A Level Biology*** (Chapter 15, pp. 207-208) there is a short section discussing this learning outcome. There is also a table that students can copy out to show typical energy values and a diagram of a simple calorimeter.
	(l) define the term *respiratory quotient* (RQ); (m) carry out investigations, using simple respirometers, to measure RQ and the effect of temperature on respiration rate;	Following class activity 3, use simple balanced chemical equations to illustrate why different respiratory substrates have different RQs. Explain to students how to use a simple respirometer and, using these, ask them to carry out an investigation to measure RQ, and another to compare rates of respiration at different temperatures. Engage students in discussion to build understanding of how, within a respirometer, soda lime can be used to absorb carbon dioxide to allow rate of oxygen uptake to be measured, and how, by leaving out the soda lime, the rate of carbon dioxide production can then be calculated. 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	http://www.biologymad.com/master.html?http://www.biologymad.com/PhotosynResp/PhotosynResp.htm the section about RQ shows a temperature-compensated respirometer http://www.phschool.com/science/biology_place/labbench/lab5/features.html a series of pages showing how to make and use simple respirometers ***AS and A Level Biology*** covers respiratory substrates, RQ and respirometers (Chapter 15, pp. 207-209). ***Advanced Biology: Principles and Applications***, has an interesting graph of RQ changes in germinating wheat and flax seeds.

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 tubing 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.

Class activities

1. List, from memory of previous studies and from text research, respiratory substrates from which energy can be obtained.
2. State the relative energy values of carbohydrates, proteins and lipids and make brief notes explaining why have they have different relative energy values.
3. Whole class discussion/verbal question and answer leading to definition of RQ in terms of volumes of carbon dioxide produced and oxygen used, considering theoretical values from the equation for respiration of glucose.
4. Do SAQ 15.8, in ***AS and A Level Biology***, to calculate an RQ for a fatty acid.
5. Use a simple respirometer to measure carbon dioxide production and oxygen absorption by germinating seeds, and calculate RQ.
6. Use a temperature-compensated respirometer to investigate the effect of temperature on rate of respiration (such respirometers can be made from ordinary laboratory equipment).

New Understanding Biology for Adva ***Level*** has a clear section on theoretical R carbohydrate and lipid.

Practical Advanced Biology 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. ***Comprehensive Practical Biology for A Level*** also has detailed protocols for these two investigations.
New Perspectives in Advanced Biology, Hansen, pub. Hodder and Stoughton, has a simple syringe-based respirometer.

AO	Learning outcomes	Suggested Teaching activities	Learning resources
M	(a) explain that energy transferred as light is used during the light-dependent stage of photosynthesis to produce complex organic molecules;	Ask students: what is the purpose of photosynthesis? Where does it happen? Help them to understand that photosynthesis is transfer of 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 sugars and starch. Be consistent in using the term *light-dependent stage* and avoid using the term 'light reaction'. **Class activities** 1. Students should participate in whole class discussion / verbal question and answer leading to bullet pointed statements to build understanding of purpose of photosynthesis: • transfer of energy from light to complex organic molecules • the requirement by plant for energy to be released later from organic molecules in order to do work • reduction of carbon dioxide by the addition of hydrogen / electrons / energy • photolysis of water to produce protons, electrons and oxygen • oxygen, a waste product, can be used for plant respiration or released into the atmosphere). 2. Research 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 carbon dioxide to carbohydrate. 3. Write out the overall equation for photosynthesis. 4. Define autotroph, photoautotroph and recall AS learning of producers and their role within the ecosystem.	http://photoscience.la.asu.edu/photosyn/stud tml why study photosynthesis? http://www.biologymad.com/ site map, photosynthesis– links to relevant sites and materials (also for respiration) http://staff.jccc.net/pdecell/photosyn/photoframe.html nice text, photo and diagrams including relationship between light dependent and light independent stages 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 ***AS and A Level Biology*** (Chapter 16, pp. 207-208) covers the fundamentals of photosynthesis and the trapping of light energy. ***Advanced Biology*** includes a nice diagram, Fig. 8.4, showing the inputs and outputs from the stages of photosynthesis. ***Biological Science 1 and 2*** looks at the relationship between photosynthesis and respiration, including a practical protocol to investigate compensation point in leaves.

AO	Learning outcomes	Suggested Teaching activities	Learning 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; *Note:* This learning outcome could be moved towards the end of the photosynthesis topic but it is also appropriate to teach it at this stage (i) to give students a time gap between the biochemical details of respiration and photosynthesis and (ii) to enable them to visualise the location of the various processes occurring within the chloroplast.	A question and answer session (of AS knowledge) will identify: • the photosynthetic organism - plant • the organ of photosynthesis - leaf • the tissue and cells of photosynthesis – palisade mesophyll and palisade cells • the organelle of photosynthesis - chloroplast A class discussion will enable students to link the structures with their functions in photosynthesis. At this stage a discussion of the location of chlorophyll and other light absorbing pigments in the thylakoid membranes of chloroplasts will encourage students to consider similarities with mitochondrial structure and recall the requirement for membranes and intermembrane spaces to generate ATP as electrons pass along a chain of electron carriers. There is **no** requirement to teach the mechanism of functioning of stomata in this part of the course, but this could be done now if it is felt to be appropriate (see Unit 2, learning outcome (r)) **Class activities** 1. Draw a labelled diagram of a palisade cell and a chloroplast and write a summary of how they are adapted for photosynthesis. 2. Interpret photomicrographs and electron micrographs of palisade cells and chloroplasts, drawing labelled diagrams. 3. Practise microscope work (can use Bioscope), observing and recording the structure of leaves in transverse section and also using a graticule and stage micrometer for measurement. Use prepared slides and fresh plant materials (e.g. *Elodea* entire leaf, freshly cut sections (in water) through a locally available dicotyledonous mesophyte). 4. Make temporary slides of epidermal strips from leaves of different species (perhaps using nail varnish and peeling off when dry), making quantitative comparisons by calculating the number of stomata per unit area on mesophytic and xerophytic leaves (again linking structure to function). Use the t-test to see if differences are significant.	images: http://images.botany.org micrographs of leaves 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 The CD-ROM: ***Images of Biology for Advanced* Level**, pub. Nelson Thornes has suitable images that are useful here. ***AS and A Level Biology*** (Chapter 16, pp. 216-219, also revisit Chapter 1) covers the learning outcome to an appropriate level. ***Advanced Biology*** includes some very appropriate and motivating material. ***Advanced Biology: Principles and Applications*** has clear illustrations of leaf, palisade cell and chloroplast structure. Bioscope: superb slides and learning tasks, including chloroplasts in *Elodea*, a variety of leaf sections, including sun and shade leaves. ***Practical Advanced Biology*** has a relatively simple practical looking at leaf structure, while ***Comprehensive Practical Biology for A Level*** has a more detailed practical. ***Bio Factsheet 198****: Chloroplasts – structure and function* (see also ***Bio Factsheet 61****: Chloroplasts and mitochondria*)

AO	Learning outcomes	Suggested Teaching activities	Learning 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); (g) discuss the role of chloroplast pigments in absorption and action spectra, and separate them using 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. Students should also carry out a practical on the chromatography of chloroplast pigments. Students will have come across chlorophyll and the importance of magnesium ions during the AS course. Build on this to explain that there are different photosynthetic pigments with different roles and absorption spectra. **Class activities** 1. Produce an annotated diagram of the light-dependent stage. Add bullet points to build understanding of photolysis, photosystems, chain of electron carriers / ATP production and reduction of NADP. 2. Investigate the effect of light intensity and light wavelength on the Hill reaction, using a very simple protocol. 3. Investigate the pigments present in chloroplasts using paper or thin layer chromatography. 4. Give a brief outline of the main types of photosynthetic pigments, distinguishing between primary and accessory pigments. 5. Sketch out absorption and action spectra, explaining the similarities and differences between the two.	http://www.biology4all.com/resources_library/details.asp?ResourceID=43 the first animation shows the events taking place in the light-dependent stage 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 http://www.teachnet.ie/foneill/cyclic.html and 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 thin layer chromatography of plant pigments. The depth of treatment of this topic in ***AS and A Level Biology*** (Chapter 16, pp. 213-215) is a good guide to the level of detail required. Results from an investigation into the Hill reaction using DCPIP are included. ***Advanced Biology*** and ***Advanced Biology: Principles and Applications*** include detailed and superbly illustrated accounts of the light-dependent reactions likely to appeal to students with an interest in biochemistry. ***Biological***

Science 1 and 2, also includes a proto the Hill reaction that works well.

Protocols for the Hill reaction can often be adapted by using decanting and filtration rather than centrifuging, and melting point tubes rather than test tubes as reaction vessels.

Comprehensive Practical Biology for A Level 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*** and also in ***Comprehensive Practical Biology for A Level***. There is a protocol for the separation of photosynthetic pigments by paper chromatography in ***Biology - A Functional Approach: Student's Manual 2nd edition***, Roberts and King, pub. Nelson Thornes,

Teaching AS/A2 Biology Practical Skills – practical: 1 Hill reaction

Bio Factsheet 63*: Pigments in plants*

Bio Factsheet 153*: The light-dependent stage of photosynthesis*

AO	Learning outcomes	Suggested Teaching activities	Learning resources
M	(c) describe the uses of ATP and reduced NADP in the light-independent stage of photosynthesis; (d) describe, in outline, the Calvin cycle involving the light-independent fixation of carbon dioxide by combination with a 5C compound (RuBP) to yield two molecules of a 3C compound GP (PGA), 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 CAM plants or the biochemistry of C4 plants is not required);	With the class, build up a simple diagram (no more detail than the syllabus requires) showing the Calvin cycle. Emphasise the source and roles of reduced NADP and ATP. Once students have grasped the outline of the cycle, discuss how 6 carbon dioxide molecules are required to produce 1 glucose molecule (i.e. 12 x TP molecules, 10 used in regeneration of RuBP and 2 for glucose production) and remind students of the overall equation for photosynthesis. Note: avoid the term 'dark reaction', as this wrongly implies that it only takes place in the dark. Although there are different names for some of the compounds involved, it is sufficient for students to only learn: • GP (glycerate 3-phosphate) • TP (triose phosphate) • RuBp (ribulose bisphosphate) For 'error-free learning', use only the syllabus names and abbreviations at all times. If necessary, the alternatives should be given to students **once** only, on paper, so that they can access textbooks that use other names: GP = PGA (3PG / 3-phosphoglycerate / 3-Phosphoglyceric acid) TP = PGAL (GALP / glyceraldehyde 3-phosphate / G3P / 3-phosphoglyceraldehyde) **Class activities** 1. Participate in whole class discussion / verbal question and answer of the light-independent stage, leading to an outline of the Calvin cycle. This should be annotated: • carbon dioxide fixation by combination with RuBP in to form GP and catalysis by rubisco • the cleavage of an unstable 6C compound into 2 x GP • the use of ATP for energy to reduce GP to TP	http://www.science.smith.edu/departments/B[illegible]ogy/Bio231/calvin.html animation of the Calvin cycle http://www.teachnet.ie/foneill/calvin.html a simple animation, but using alternative names http://www.teachnet.ie/foneill/workphoto.html a quiz about all aspects of photosynthesis – smiley face for correct answers, cross for incorrect – note that 'dark phase' is used. http://www.msu.edu/~smithe44/calvin_cycle_process.htm a detailed step by step account – for students who have a good grasp of the process (some nice models of the molecules involved) http://www.wiley.com/college/boyer/0470003790/animations/photosynthesis/photosynthesis.htm this interactive animation summarising all of photosynthesis has many good sections at the level required, interspersed with more detail than is necessary, so better as a class exercise, highlighting the areas that link well to the syllabus learning outcomes http://nobelprize.org/nobel_prizes/chemistry/laureates/1961/calvin-lecture.pdf Calvin's Nobel lecture notes (1961), with a photograph of the apparatus set up for the 'lollipop experiment' – for interested students

		• ….and as a source of phosphate and energy to regenerate RuBP from TP (with ADP and P_i produced to be used in the light-dependent stage) • the use of reduced NADP in reduction of GP to TP, regenerating NADP (for the light-dependent stage) • GP as a raw material for producing carbohydrates, lipids and amino acids (**no** details of pathways required). 2. Complete an interactive on-line quiz on photosynthesis. 3. For background interest, investigate the 'lollipop' experiment, carried out by Calvin and his colleagues.	***AS and A Level Biology*** (Chapter 16, p 216) has a clear diagram of the Calvin cycle with accompanying text description. In ***Biological Science 1 and 2*** there is a detailed review of the light independent stage. ***Advanced Biology*** and ***Advanced Biology: Principles and Applications*** include clear explanations of the light independent stage. ***Bio Factsheet 02****: The essential guide to photosynthesis*

AO	**Learning outcomes**	**Suggested Teaching activities**	**Learning resources**
M	(f) discuss limiting factors in photosynthesis and carry out investigations on the effects of light intensity and wavelength, carbon dioxide and temperature on the rate of photosynthesis;	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 concentration 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 because enzymes are involved, temperature affects the rate of photosynthesis: the bulk of enzyme catalysed reactions occurring in the Calvin cycle of the light-independent stage; and the photolysis of water and the transfer of electrons to NADP for reduction requiring enzymes in the light-dependent stage. **Class activities** 1. Interpret graphs showing the effects of limiting factors. 2. Carry out an investigation into the effect of carbon dioxide	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. Easily 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 rates 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.teachnet.ie/foneill/exper.htm nice simple simulations of the effect of light intensity and carbon dioxide concentration on

concentration (by changing sodium hydrogen carbonate concentration) on rate of photosynthesis of an aquatic plant .

3. Plan and implement an investigation into the effect of light intensity on the rate of photosynthesis of an aquatic plant.
4. Explain how the plan can be modified to investigate the effect of limiting factors.
5. Research the effect of temperature on photosynthesis, using the internet and text book sources, finding clear graphical representations and making notes to explain the shape of the curve.
6. Carry out simulations of simple experiments on effect of light intensity, light wavelength, carbon dioxide concentration and temperature on the rate of photosynthesis (using website or CIE simulations).

rate of photosynthesis – can be used to generate data by counting bubbles per unit time.

http://www.assessnet.org.uk/e-learning/
create an account, then 'E-learning' - 'courses'- in 'course categories' choose 'resources' then 'science simulations' . A really good simulation with water weed – carbon dioxide concentration, light intensity and light colour can be adjusted.

http://www.biology4all.com/resources_library/details.asp?ResourceID=43
photosynthometer animation

AS and A Level Biology (Chapter 16, pp. 219-220) and the other text books (some in great detail) cover limiting factors. ***Advanced Biology*** covers the effect of limiting factors in a visual and clear way. ***Biological Science 1 and 2*** includes a quantitative protocol for investigating effect of light intensity on photosynthetic rate.
A range of possible practicals is described in ***Comprehensive Practical Biology for A Level*** and ***Practical Advanced Biology*** .

Bio Factsheet 136*: Practical Investigations for Photosynthesis*
Bio Factsheet 25*: Tackling data interpretation questions II: photosynthesis* (limiting factors)