The science of biology

Unit 1

Learning competencies for Unit 1

By the end of this unit students should be able to:

- Define science as a way of knowledge and explain it as a way of looking at and thinking about natural events.
- Describe and explain the main steps that scientists follow when they are investigating something.
- Demonstrate scientific methods by narrating how Louis Pasteur and Alexander Fleming used the scientific method to solve problems.
- Plan and conduct an experiment to investigate a particular observation.
- Write a report for a scientific experiment.
- Name and describe the function of the main pieces of apparatus that are used by biologists the world over.
- Describe how these pieces of apparatus work.
- Explain how, and under what circumstances, these pieces of apparatus would be used and demonstrate the use of some of them.
- Classify the apparatus as laboratory tools, field tools or both.
- Be aware of possible health and safety implications of using these tools.
- Explain how biological science is relevant to food production, health and disease, conservation, and control of the population.
- Explain the promise of biology in relation to genetic engineering and biotechnology.
- Explain how biologists are actively involved in the fight against AIDS.
- Describe how you can help community efforts to control AIDS.
- Describe the decisions you will need to take to help control AIDS.

This unit should fill approximately **29 periods** of teaching time.

1.1 The methods of science

This section should fill approximately **10 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Define science as a way of knowledge and explain it as a way of looking at and thinking about natural events.
- Describe and explain the main steps that scientists follow when they are investigating something.
- Demonstrate scientific methods by narrating how how Louis Pasteur and Alexander Fleming used the scientific method to solve problems.
- Plan and conduct an experiment to investigate a particular observation.
- Write a report for a scientific experiment.

The nature of biology as a science

Starting off

The first section will help to establish that biology is a science and that biology and other sciences constitute an objective and logical attempt to understand the natural universe, based on observation leading to suggestions, or hypotheses, that are testable by experiment. Students will also learn that good science is an ongoing process of testing, evaluation, re-testing and re-evaluation. One of the hoped-for benefits of students taking a biology course is that they will become more familiar with the process of science.

Teaching notes

In this short theme, students should be made aware of the scope of biology. Many students have only a hazy view of the work of biologists. The examples in the book are deliberately chosen to challenge this limited view. There are many other examples, of course, and students could be encouraged to research the topic and make a display of the scope of biology.

This library search can be backed up by reference to internet sources. Please see the Further Resources section.

SA = starter activity MA = main activity CA = concluding activity	
What is the science of biology? (Activity 1.1)	
SA	Students tackle activity 1.1 to work out what they understand science and the work of scientists to be: the teacher should read out the text of the activity and encourage responses from the class.
MA	Students discuss the scope of biology and make a display of the work of biologists, incorporating some fairly 'standard' occupations and other less well appreciated ones. They will need to research this, or discuss it first.
CA	Class to compare presentations to get an overall 'feel' for the work of biologists.
What is science?	
SA	Students describe the work of Gregor Mendel, Isaac Newton (and other well-known scientists if desired).
MA	Students find common elements in their very different work. Use this to introduce the concept of the 'scientific method'.
CA	Students could also make a display or write a short essay illustrating the common elements in scientific research.
What is the scientific method?	
SA	Students discuss with the teacher the key feature behind acceptance of conclusions of scientific research. Try to elucidate the concept that, if it is to be accepted, it must establish cause and effect.
MA	Students discuss with the teacher the problems associated with assuming cause and effect from simple observations; use examples in the textbook and others to illustrate this point. Students discuss with the teacher the main elements of the scientific method as shown in figure 1.1 and table 1.1.

CA	Students carry out extension work to show how they would use the scientific method to investigate one of the problems quoted later in this book. They should include a description of the pattern of results that would support their hypothesis.

Activities

There are a range of student activities that could be used as a follow-up to the research itself:

- Make a display of their research.
- Make a presentation to give to the rest of the class.
- Carry out a role-play interview in which one student takes the role of an interviewer and another takes the role of a particular biologist, whose work they have researched.
- Write an essay about the scope of biology.
- Present a short lesson to their classmates on the scope of biology.

The scientific method

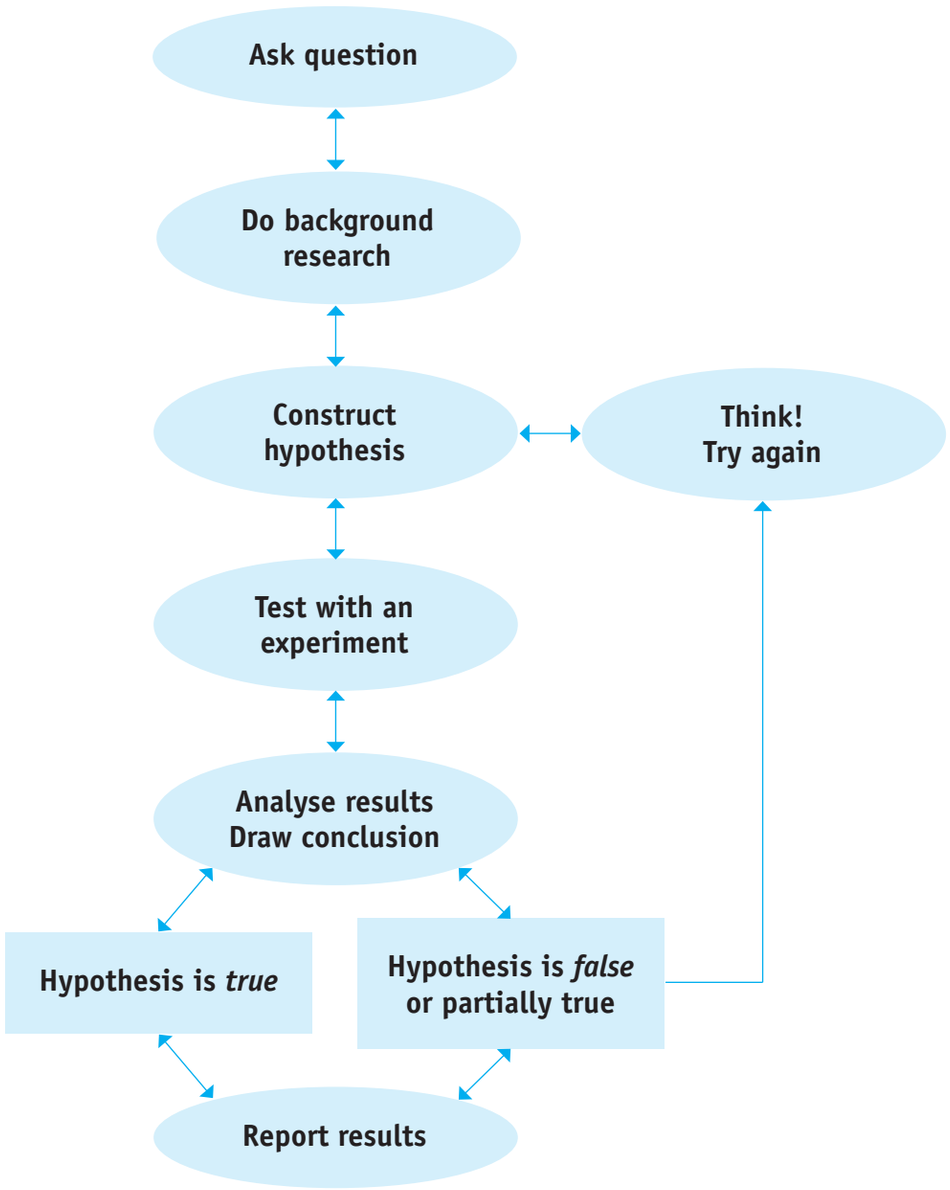
Starting off

This section sets out to help students appreciate that the 'scientific method' is a critical logical approach to problem-solving that yields evidence to prove or disprove a hypothesis. The concept of falsifiability, first proposed by Karl Popper, is a cornerstone of the scientific method and a key way in which science differs from other ways of looking at the world. Science can only accept ideas that are supported by evidence. If an idea is couched in such terms that it can never be proved wrong, science can never accept that it is correct either; this would require an act of faith, which is not part of the scientific way of thinking.

Teaching notes

In this theme students should be made aware of the way in which the scientific method takes an observation and an idea of how to explain the observation (a hypothesis) to the status of an accepted explanation, backed up by evidence that can be confirmed or challenged by further experimentation.

Some historical background is given showing how, before the scientific method, ideas that sought to explain naturally occurring phenomena were based on observation and interpretations unsupported by any real evidence. The 'theory' of spontaneous generation provides an excellent example as it shows how the original idea was eventually disproved by successively more sophisticated experiments, culminating in the landmark investigations by Louis Pasteur.



The flowchart given in the Students' Book illustrates the main steps of the process. Students should discuss the various steps to gain a clear understanding of why each step is core to the whole process.

The book takes students through the various stages using the concrete example of 'Why do tomato seeds not grow inside the tomatoes?'. This is an easy-to-understand problem and one that can be carried out by students using a minimum of equipment. It can also be extended to investigate whether or not this phenomenon is true of other fruits and, if so, is it the same chemical involved in all cases. If this is the case, tomato extract should inhibit the germination of melon seeds or oat seeds. Students can form their own hypotheses for these experiments before carrying them out.

Students can also be given examples of problems and be asked how they would investigate them using the scientific method.

<table>
<tr><td colspan="2">SA = starter activity MA = main activity CA = concluding activity</td></tr>
<tr><td colspan="2">The scientific method and spontaneous generation (Activity 1.2)</td></tr>
<tr><td>SA</td><td>Students revisit the belief that rotting meat produces flies.</td></tr>
<tr><td>MA</td><td>Students design an investigation to establish whether or not this belief is true.
Students compare their design with the work of Francesco Redi.
Students explain why Redi's experiment was accepted as proof that rotting meat did not produce flies.</td></tr>
<tr><td>CA</td><td>Students read the account of the work of Louis Pasteur on the souring of wine and complete activity 1.2 in class. This will reinforce their understanding of the scientific method.</td></tr>
<tr><td colspan="2">Cause and effect in science (Activity 1.3)</td></tr>
<tr><td>SA</td><td>Students examine what is meant by cause and effect and its importance in scientific investigations. Introduce the terms independent variable and dependent variable.</td></tr>
<tr><td>MA</td><td>Students discuss with the teacher the conditions under which an experiment could show that changes in the independent variable caused changes in the dependent variable.
Introduce the concepts of:
• controlled variables
• confounding variables.</td></tr>
<tr><td>CA</td><td>Students complete Activity 1.3: the teacher should ensure students know how to use a library and other resources to find information. Students research the work of Lazaro Spallanzani and describe those elements of his work that were:
• similar to Pasteur's work
• different from Pasteur's work.
Students explain the way in which Pasteur's investigation was an improvement on Spallanzani's investigation.</td></tr>
<tr><td colspan="2">Accuracy, reliability and validity (1) (activity 1.5)</td></tr>
<tr><td>SA</td><td>Students write down what they understand by each of the terms.</td></tr>
<tr><td>MA</td><td>Students discuss each concept in turn, using materials presented in the textbook and other examples. Students summarise the concepts in a table, such as the one shown.
<table>
<tr><th>Concept</th><th>Description</th><th>Example</th></tr>
<tr><td>Accuracy</td><td></td><td></td></tr>
<tr><td>Reliability</td><td></td><td></td></tr>
<tr><td>Validity</td><td></td><td></td></tr>
</table></td></tr>
<tr><td>CA</td><td>Students choose one example in activity 1.5 and plan an investigation that will establish cause and effect. The teacher should ensure that the students have read and understand the three scenarios and how to write up the investigation – it may help to draw up a sample structure on the board. Encourage the students to plan independently.</td></tr>
<tr><td colspan="2">Accuracy, reliability and validity (2) (Activities 1.4 and 1.6)</td></tr>
<tr><td>SA</td><td>Students complete activity 1.4 and discuss their answers.</td></tr>
<tr><td>MA</td><td>Students carry out activity 1.6 in pairs. Ask two or three of the pairs to explain their reasoning to the class and then discuss whether they are right or wrong.</td></tr>
<tr><td>CA</td><td>Students look back at the definitions they made at the beginning of the previous lesson and discuss whether they are still sufficient, and agree on any changes.</td></tr>
</table>

Activities

Suitable examples could include:

- *A home wine-maker finds that when she uses the sugar lactose to make wine, the result is not as good as when she uses ordinary sucrose.*

  (Students could investigate the rate of fermentation of yeast using different sugars.)
- *A baker uses different strains of yeast to bake his bread. Not all bakers make bread with a good texture; some is quite 'flat'.*

  (Students could investigate the rate of fermentation of yeast using different yeasts.)
- The distribution of [*plant or small invertebrate around your school*] seems to be influenced by [*appropriate environmental factor*].

  (Students could investigate the distribution of the species by either transect or random sampling techniques, as appropriate. In carrying out an ecological investigation, students should realise that they cannot control other factors in the same way as biologists can in the laboratory. However, they can *monitor* these variables so that they can either exclude them from factors influencing the outcome or recognise that they may be exerting some effect.)

In addition, students could research key scientific investigations (other than those given in the book) and show how the scientific method was used in each. They could research:

- Charles Darwin's experiments on phototropism.
- Gregor Mendel's experiments on inheritance in pea plants.

Students could use the pro forma in the appendices to record their plans.

Scientific experiments and writing reports

Starting off

This section sets out to show students that scientific experiments are carried out in such a way as to establish cause and effect between two variables. To do this, other variables must be controlled so that they have no influence on the experiment. If, then, changing one variable (the independent variable – IV) produces changes in the variable being measured (the dependent variable – DV), then cause and effect is established and the hypothesis is proved. Students also need to appreciate that to be accepted by other scientists, experiments must be shown to be: accurate, reliable, valid; students must be able to differentiate between these three concepts. They need to learn that a standard format for writing up experiments is important so that scientists across the world can appreciate the way in which the experiment was carried out and repeat them if need be.

Teaching notes

Students should appreciate that scientific experiments seek to establish cause and effect between two variables:

- the independent variable (IV)
- the dependent variable (DV).

They should also appreciate the need to control other variables that might exert an influence on the results. For example, enzyme-controlled reactions are influenced (in particular) by:

- temperature
- pH
- substrate concentration
- enzyme concentration.

Students should appreciate that, if they are to investigate (say) the effect of temperature (IV) on enzyme action (DV), then the other factors should be controlled (not allowed to vary in the different conditions of the IV) so that the comparison of the outcomes in different conditions of the IV is a *fair test* and likely to be due only to the variation in the IV. This is illustrated in the book by reference to the tomato seed investigation used throughout the unit.

Students should also appreciate that for the results of investigations to be accepted by other biologists, these biologists need to be convinced that the investigations were:

- accurate
- reliable
- valid

These concepts are often muddled and it is important that students appreciate the nature of each and that, although related, they are distinct.

Accuracy concerns the degree of precision with which data are measured and recorded. It is concerned with the extent of error in the investigations. One aspect of this is the error involved in measuring equipment, such as pipettes and balances. As the different instruments deal with different ways of measuring, the only way of comparing is by percentage error.

Students should appreciate that the real error of a piece of graduated equipment is taken to be 0.5 of the graduation. For example, in a 20 cm^3 pipette, the graduations may be 1 cm^3. In this case, the real error is 0.5 cm^3.

$$\frac{\text{real error} \times 100}{\text{volume measured}}$$

So, if a syringe was used to measure 15 cm^3, the percentage error would be:

$$\frac{0.5 \times 100}{15} = 3.33\%$$

If the syringe was used to measure 20 cm^3, the percentage error would be 2.5%.

This illustrates an important principle, that, given a certain accuracy of measurement, the percentage error is reduced by using larger volumes.

Students should be encouraged to calculate percentage errors for a given piece of apparatus, measuring different quantities to illustrate this principle.

Reliability is concerned with repeatability. If others were to try the same experiment under the same conditions, how likely is it that they would get similar results? One way of increasing the reliability of results is to repeat the investigation several times to generate mean data. Means are generally more reliable than data from individual investigations as the effects of any anomalous results are minimised in the mean.

Reliability will also be enhanced if procedures are standardised so that variation in the process of carrying out the investigation is kept to a minimum.

However, it should be emphasised that just because an experiment is reliable, doesn't mean that it is accurate. An experiment may well be repeatable but have a low level of accuracy and, if a control variable was consistently ignored, the experiment will not be valid.

Validity is about truth. It is concerned with whether an investigation is, in fact, measuring what it says it is measuring. When we report that changes in the activity of an enzyme are due to the changes in pH in our investigation, we must be sure that nothing else can be causing the changes. If we have failed to control variables adequately, then another variable could be producing the changes and our conclusions may not be valid.

Students could be encouraged to look at the key investigations cited in the book (Redi, Pasteur and Fleming) and assess how accurate, reliable and valid these investigations were.

Reporting scientific investigations needs to follow an agreed format so that biologists can instantly recognise the way in which the work of another biologist is reported. This has grown out of a need for research biologists across the world to be able to understand one another, but it is important that students realise that reporting scientific investigations is not an activity that can lend itself to freedom of expression.

SA = starter activity MA = main activity CA = concluding activity	
Writing reports on experiments (1) (Activity 1.7)	
SA	Students discuss with the teacher the purpose of a report on a scientific investigation. Try to elucidate the following: • a clear statement of the aims of the investigation (including an hypothesis) • an account of how the work was carried out • a clear summary of the results • conclusions drawn with explanations • an evaluation of the likely accuracy, reliability and validity of the procedures, results and conclusions
MA	Class to discuss the material in the textbook showing the components of a scientific report. Students examine the purpose of each component.
CA	Students draw up a rough outline of the report in activity 1.7.
Writing reports on experiments (2) (Activity 1.7)	
SA	Students plan in pairs an appropriate method for evaluating the success of the report they are about to write for activity 1.7.
MA	Students carry out activity 1.7.
CA	Students evaluate the success of their report in pairs – students take it in turns to test their reports on each other.
Developing and testing hypotheses (Activity 1.8)	
SA	Students briefly brainstorm activity 1.8 in pairs.
MA	Whole class brainstorms; write up the results at the front of the class. Students then split into pairs to complete the activity by drawing up flowcharts.
CA	each pair makes a brief presentation of their flowchart to the rest of the class.

Activity

Students could also evaluate actual scientific research in terms of the scientific method. The link below produces an interesting account of an investigation into the effect of pH on yeast activity:

sophia.smith.edu/~lrizzo/writing/lab6.ppt

The account includes results together with an analysis of the results and an evaluation of limitations of the procedure, and possible errors that may have limited the validity of the investigation.

Answers to review questions

1. C
2. D
3. C
4. B
5. C
6. A
7. D
8. D
9. B
10. C

1.2 The tools of a biologist

This section should fill approximately **7 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Name and describe the function of the main pieces of apparatus that are used by biologists the world over.
- Describe how these pieces of apparatus work.
- Explain how, and under what circumstances, these pieces of apparatus would be used and demonstrate the use of some of them.
- Classify the apparatus as laboratory tools, field tools or both.
- Be aware of possible health and safety implications of using these tools.

Starting off

This section sets out to help students learn about the range of equipment that biologists across the world would recognise as being the 'tools of the biologist'. These include laboratory equipment such as optical microscope, electron microscope, balance, pipette, Petri dish, dissecting instruments, centrifuge, as well as field equipment such as quadrat, insect net, trap, altimeter, plant press, CPS.

Teaching notes

It is recognised that students may well have used many of these pieces of equipment already in their biology course. However, this section seeks to formalise their knowledge and to make students aware of some of the different ways in which some pieces of apparatus can be used.

Students will already be familiar with many of the measuring devices listed (syringes, measuring cylinders, pipettes, balances, etc.) but they should now be made aware again of the ways in which these pieces of equipment should be used to gain readings that are as accurate and reliable as possible.

Techniques to be stressed include:

- reading the level of a liquid in such a way as to avoid parallax errors;
- always measuring the level of a liquid by reading the lowest level of the meniscus;
- not reading any digital equipment until the reading has stabilised.

SA = starter activity MA = main activity CA = concluding activity	
Equipment used to take measurements	
SA	Students discuss with the teacher the sorts of measurements that a biologist might wish to make, include measurements of: • length • volume • mass • time
MA	Students make a list of the different apparatus that could be used for each and the occasions when each might be used (relate the precision of the equipment used to that needed by the investigation).
CA	Students could carry out the experiment shown in figure 1.9. They could use the equipment shown, but also use a balance to measure the loss in mass (due to loss of oxygen produced) during the reaction. Write up briefly explaining the role of measuring equipment.
Equipment used to aid observation	
SA	Students examine the point that such equipment includes anything that will make observation easier.
MA	Students discuss the ways in which observation can be made easier. Include: • magnification (lenses and microscopes) • removing overlying structures (dissecting equipment) • Petri dishes containing culture media (allow growth/reproduction of micro-organisms and so observation of colonies formed).
CA	Students describe how each of the above contribute to making more meaningful observations.
Microscopes (1)	
SA	Students carry out a simple activity that involves making a temporary mount for an optical microscope (such as making a slide of onion epidermis). Students discuss with the teacher how an optical microscope produces a magnified image.
MA	Give students an electron micrograph of a plant cell to compare with their image of onion cells from their slide. Students examine that an electron microscope uses beams of electrons rather than light. Introduce the concept of resolution and describe the differing resolutions of optical and electron microscopes. Students examine how this has allowed details of cellular structure to be elucidated. Students could now carry out Activity 1.10: in this very brief activity the teacher should ask the question at the front of the class and then invite students to discuss their opinions.
CA	Students make notes on optical and electron microscopes.

Microscopes (2)	
SA	Students recap the differences between optical and electron microscopes as preparation for the visit.
MA	Visit a higher education institution and see the sophistication of optical microscopes used and electron microscopes in use, if possible. Students make notes on the way in which the microscopes are used.
CA	Students write up notes on the way the two different types of microscopes are used in education and research.
Field equipment (1)	
SA	Students discuss with the teacher the types of investigations that biologists carry out in the field.
MA	Students study the commonly used field apparatus. Students read through Activity 1.11 to assist their understanding: this could be done as homework later on. The teacher should explain – or demonstrate if possible – how a plant press works and how a simple one can be made.
CA	Students design investigations into: • what factors influence the distribution of an organism in the local environment • the abundance of one or more organisms in the local environment. Students examine that they should make clear: • the field equipment they will use • how they will use it • how they would interpret any results. The teacher will need to check these plans and comment on suitability and suggest revisions where necessary.
Field equipment (2)	
SA	Students discuss the revised investigations with the teacher.
MA	Get students to carry out their investigations (this may take more than one session).
CA	Students write up the results of their investigations explaining: • how they used the equipment to obtain the results • any conclusions they draw from their results. Students could also carry out Activity 1.12 if there is time, and complete for homework. The teacher should explain that this is a summary exercise, and check all the tables the students produce to ensure they have understood.

Activities

To check understanding of the nature of the equipment, students could be asked to give a brief outline and a sketch of the assembled equipment they would use to investigate a particular problem. Although only a brief account is needed, students should still list any variables they would need to control and describe any control experiments they would carry out.

Some examples could be:

- using a gas syringe to measure the rate of respiration in yeast
- using a digital balance to measure the effect of different concentrations of sucrose on water gain or loss by potato (or other root vegetable)
- using a gas syringe to measure the rate of photosynthesis of a water plant under different environmental conditions
- using a measuring cylinder to measure the rate of evolution of oxygen gas when yeast decomposes hydrogen peroxide.

Students could be made aware of how a simple piece of equipment such as a Petri dish can be used in many different ways. Its use requires little additional equipment and can be used in the following ways:

- to culture micro-organisms from different places using a basic nutrient agar in the Petri dishes
- by using a Petri dish with gridded lid (as shown on page 18 of the Students' Book), recording the percentage of the Petri dish covered in micro-organisms each day and plotting a graph to estimate growth rates
- by using different antibiotic discs, the effect of each on microbial growth can be observed
- by using starch agar with wells punched in it using cork-borers, the rate of digestion of starch by different concentrations of the enzyme amylase can be estimated.

There is no tool quite as synonymous with biologists as the microscope. Students should revisit the basic structure and functioning of a basic optical microscope, first met in grade 9, and try to improve their technique of:

- slide making
- using the microscope at different levels of magnification
- making drawings from microscope slides.

They should be reminded of the concepts of magnification and resolution and how it is resolution that is the real key to producing detailed images.

They should also be made aware that some optical microscopes are anything but simple and produce an image that is projected onto a screen after being computer-enhanced to improve resolution. If possible, a visit to a higher education or research institute would reinforce this.

They should also be reminded of the greater resolution produced by an electron microscope and the benefit this has been to biologists in elucidating the structure of cells.

Field investigations require a different set of equipment and a slightly different approach. Students should appreciate that, often, we want to establish an estimate of numbers of a particular organism in an area or the way in which the numbers of an organism change across an area. They should be reminded that to investigate numbers in an area we need to use a random sampling technique to avoid bias. To investigate changes across an area, a transect with a systematic sampling technique is required. This is not random and does have bias, but it makes it less likely that key areas in the transect will be omitted.

In their investigations in the field it is not possible to control variables in the same way as in the laboratory, so they must monitor them so that they can be taken into account when considering the results.

Activity

To check understanding of the nature of the equipment, students could be asked to give a brief outline of how they would investigate:

- the numbers of [*a small plant or small invertebrate common in your area*]
- the change in numbers of [*small plants or small invertebrates common in your area*].

Although only a brief account is needed, students should still list any variables they would need to monitor and how they would go about this.

Answers to review questions

1. C
2. B
3. B
4. D
5. C
6. B
7. C
8. C
9. B
10. C

1.3 The relevance and promise of biological science

This section should fill approximately **5 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Explain how biological science is relevant to food production, health and disease, conservation and control of the population
- Explain the promise of biology in relation to genetic engineering and biotechnology.

Starting off

This section sets out to help students appreciate that biology is relevant to our lives at many different levels. It offers answers to many 'deep' questions that students will all ask themselves at some time. It explains how our bodies work and how we depend on other organisms in all manner of different ways. It offers an answer to the questions: 'Where did we come from?' and 'How did we get here?'.

Teaching notes

The focus of this section is the students carrying out searches and finding information through interviews. It is a research section of the syllabus.

The Students' Book gives some examples of how biological science is relevant and something of the promise of biotechnology in particular, but this is intended to be indicative and in no way prescriptive. There is no reason for the students to confine themselves to this area in their searches.

<table>
<tr><th colspan="2">SA = starter activity MA = main activity CA = concluding activity</th></tr>
<tr><th colspan="2">Questions that biologists try to answer</th></tr>
<tr><td>SA</td><td>Students discuss with the teacher some areas of biological research. They need not all be large-scale examples, but some areas such as:
• how can we develop a vaccine against HIV?
• how can we improve the yields of crop plants?
• what causes migraine?
• How did modern humans evolve?
are useful examples.</td></tr>
<tr><td>MA</td><td>Students carry out activity 1.14. Give students credit for their own questions.</td></tr>
<tr><td>CA</td><td>Students summarise their research in a table such as the one shown below.
<table>
<tr><th>Biological question</th><th>Current research</th><th>My view on the research</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><th colspan="2">The promise of biology in agriculture, medicine, the environment and specifically in Ethiopia</th></tr>
<tr><td>SA</td><td>Assign students or groups of students a specific research project based on one of the areas above.</td></tr>
<tr><td>MA</td><td>Students carry out Activity 1.16. Again the teacher should ensure that students know how to use research resources, and suggest they use the library but also look for other sources of information. This is likely to take more than one session and may be partly done as homework.</td></tr>
<tr><td>CA</td><td>Students make a presentation or display of their research. This could easily take one full session.</td></tr>
</table>

Activity

They may wish to look at the promise offered by research into:

- stem cells
- transplant surgery
- vaccines for AIDS
- protection of the environment

Whatever they choose, it is important that their search has a focus from the outset and they do not just try to research 'the promise of biology'.

Answers to review questions

1. C
2. D
3. D
4. D
5. C

1.4 Biology and HIV/AIDS

This section should fill approximately **7 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Explain how biologists are actively involved in the fight against AIDS.
- Describe how you can help community efforts to control AIDS.
- Describe the decisions you will need to take to help control AIDS.

Starting off

This section sets out to help students appreciate the following:

- Biologists are actively involved in the fight against AIDS by:
  - carrying out research to develop a vaccine against HIV
  - developing new and better anti-retroviral drugs to combat HIV.
- People can help in the fight against AIDS by:
  - working to change attitudes
  - developing the life skills that will allow them to solve problems related to AIDS in the community and take difficult decisions regarding their social interactions
  - adopting responsible practices.

Teaching notes

It is worthwhile beginning this section with a brief outline of the nature of the human immuno deficiency virus and the disease AIDS. The Students' Book gives an account sufficient for this discussion, together with a description of the extent of AIDS. This will naturally be slightly out of date by the time this book is read and it is preferable to use up-to-date figures. The methods of transmission of AIDS are also restated.

At this point strongly emphasise the point that any way of breaking the transmission pathway will be effective in reducing the spread of AIDS. This should be thoroughly discussed – the main methods are listed in the book, but listing them is simple. The students must discuss ways of actually achieving them. This will entail a discussion of social attitudes and taboos that must change if the spread of AIDS is to be controlled.

The Students' Book then considers the role of anti-retroviral drugs in combating AIDS. These drugs combat the replication of HIV in the T-helper cells. Different drugs combat different stages of the cycle of replication.

HIV mutates and can acquire resistance to one or more drugs because its replication cycle becomes slightly altered. However, by using the drugs in combination (Highly Active Anti-Retroviral Treatment or HAART), it is much more likely that the virus will be controlled.

<table>
<tr><td colspan="2">SA = starter activity MA = main activity CA = concluding activity</td></tr>
<tr><td colspan="2">The nature of AIDS</td></tr>
<tr><td>SA</td><td>Students discuss with the teacher the distinction between AIDS and HIV.</td></tr>
<tr><td>MA</td><td>Students recap with the teacher:
• reasons for AIDS being a killer disease
• the life cycle of HIV.</td></tr>
<tr><td>CA</td><td>Students summarise AIDS in a table such as the one below.
<table>
<tr><th>Feature of AIDS</th><th>Description</th></tr>
<tr><td>What fraction of the world's AIDS cases are in Ethiopia?</td><td></td></tr>
<tr><td>What causes AIDS?</td><td></td></tr>
<tr><td>How is HIV transmitted?</td><td></td></tr>
<tr><td>Which cells does HIV infect?</td><td></td></tr>
<tr><td>What is the consequence of infecting these cells?</td><td></td></tr>
<tr><td>Why is AIDS nearly always fatal?</td><td></td></tr>
</table></td></tr>
<tr><td colspan="2">Breaking the transmission pathway</td></tr>
<tr><td>SA</td><td>Students recall the ways in which AIDS can be transmitted.</td></tr>
<tr><td>MA</td><td>Students carry out activity 1.18. Ensure the students respect each other's opinions as this could be a sensitive topic: some guidance on the topic is given in the teaching notes.</td></tr>
<tr><td>CA</td><td>Teacher and class review the posters produced by each of the groups.</td></tr>
<tr><td colspan="2">The basis of drug therapy</td></tr>
<tr><td>SA</td><td>Students discuss with the teacher the difference between drug therapy that is available and a true vaccine.</td></tr>
<tr><td>MA</td><td>Students examine the life cycle of a retrovirus such as HIV (use figure 1.35 as a basis for this). Students examine that any drug that prevents any stage of this cycle from taking place will effectively break the life cycle of the virus.
Students examine the basis of HAART (Highly Active Anti-Retroviral Therapy).</td></tr>
<tr><td>CA</td><td>Students include in their notes:
• a diagram to summarise the life cycle of HIV
• the basis of HAART.</td></tr>
<tr><td colspan="2">Our role in the fight against AIDS (1)</td></tr>
<tr><td>SA</td><td>Students discuss with the teacher where individuals can influence the transmission pathway and where this is not possible.</td></tr>
<tr><td>MA</td><td>Students discuss with the teacher how individuals can:
• show tolerance, support, compassion and understanding to sufferers
• change our social behaviour patterns to minimise the risk of infection.</td></tr>
<tr><td>CA</td><td>Students write a short 'essay' on 'My role in preventing the spread of AIDS'.</td></tr>
<tr><td colspan="2">Our role in the fight against AIDS (2)</td></tr>
<tr><td>SA</td><td>Students recap the social behaviour patterns they identified in the previous session.</td></tr>
<tr><td>MA</td><td>Students carry out activity 1.20. Ensure the students understand that this is a role-play exercise where they need to represent the allocated position, and that everyone understands this is not necessarily their own opinion: be sensitive when allocating the roles of 'good friend' and 'bad friend'. This could be an embarrassing exercise for some students so it will need to be monitored carefully.</td></tr>
<tr><td>CA</td><td>Teacher summarises the presentations.</td></tr>
<tr><td colspan="2">Our role in the fight against AIDS (3)</td></tr>
<tr><td>SA</td><td>Again, students review the social behaviour patterns that lead to AIDS transmission.</td></tr>
</table>

MA	Students carry out activity 1.19. Ensure that students know what a poem is, and suggest to any student who is unsure that a short story would suffice instead. The students will need peace and quiet to think and carry out this activity.
CA	Students read their poems to another member of the class, or the whole class if they are not too daunted by this. As mentioned, ensure the students respect each other's opinions. Other member/the class comments on the issues raised in the poem.
Our role in the fight against AIDS (4)	
SA	Students discuss with the teacher the possibilities of engaging with healthcare professionals or with PLWHA and decide on either a visit or inviting a speaker to the school.
MA	Students take the opportunity to question the speaker about issues that concern them.
CA	Students report on if/how the discussion has changed their views.

Activity

Finally, the focus of the section again cannot be dealt with adequately in a textbook as it involves students discussing the problems and challenging attitudes. Role-play work would be particularly useful here and it is often productive to get students to adopt a role whose views they would not normally agree with.

They should discuss the attitudes such as prejudice and stigma that are associated with AIDS and how these can be challenged.

Answers to review questions

1. D 2. D 3. C 4. B 5. D

Answers to end of unit questions

1.

Step	What is involved
Ask a question	From observations, identify a problem to be solved: identify what may be the independent variable (IV) and the dependent variable (DV).
Background research	Find out what is already known about the problem so that you do not have to start from scratch.
Hypothesis	Think of the way you expect the IV to influence the DV and frame this as a statement.
Experiment	Think of a suitable way of changing the IV and measuring the DV. Keep other variables that might influence the outcome controlled. Repeat the investigation for greater reliability.
Analyse results and draw conclusions	Look for trends and patterns in the results and try to explain these trends and patterns in terms of the influence of the IV on the DV.

Accept or reject hypothesis	If the results support the IV hypothesis, accept it. If they do not, it must be rejected. Sometimes results are inconclusive and, again, the hypothesis must be rejected. In both these cases, further experimentation may be necessary.
Report findings	A research biologist should then report their findings in a professional journal. Negative results can be just as important as positive ones and also need reporting.

2. a) i) IV is the variable that the experimenter changes.

   ii) DV is the variable that changes as a result of changes in the IV and is measured by the experimenter.

   b) If other variables are not controlled, then the experiment may not be valid as it will not be known if changes in the DV are a result of changes in the IV or because other variables had an influence.

   c) A control experiment is a standard against which to compare. If the IV is absent from the control experiment, any changes here are due to natural events and can be assumed to happen in the other experiments also.

3. *Accuracy* refers to how precisely you measure or count something.

   Reliability is a measure of how dependable the results are.

   Validity is about whether or not your experiment measures what it says it is measuring.

4. a) i) As temperature increases
   rate of reaction increases up to 40 °C
   then decreases rapidly to zero at 60 °C

   ii) Highest rate of reaction at pH 6
   Falls away above and below this

   b) Ideal conditions are pH 6 and 40 °C

   as these are the conditions that give highest rates individually

5.

a)	b)
• optical microscope	both – magnification/identification of specimens
• quadrat	field – estimating abundance of organisms
• altimeter	field – measuring height of objects
• electronic balance	lab. – measuring mass
• pipette	both – transferring liquids
• Petri dish	lab. – culturing micro-organisms/enzyme activity assay/antibiotic activity assay
• plant press	field – temporary preservation/storage of plant specimens

6. Limit number of sexual partners – restrict the transmission of HIV

   Male circumcision – reduces acquisition by males

   Use of condoms – restrict transmission of AIDS

7. a) Anti-retroviral drugs break the replication cycle of HIV in cells.

   Some block:

   - the entry phase
   - the reverse-transcription to DNA phase
   - incorporation into host cell DNA
   - viral protein synthesis stage

   b) i) Almost half the treatments are in Addis Ababa

   Most of the rest are in cities/towns

   Fewest in rural areas

   (ii) Greatest concentration of population in cities

   Problems with getting information to rural areas

   Problems with getting treatments to rural areas

Answers to end of unit crossword puzzle

Across

2 fair test
8 spontaneous generation
10 DV
13 HAART
14 AIDS
16 reliability
18 validity

Down

1 microscope
3 accuracy
4 hypothesis
5 Francesco Redi
6 Louis Pasteur
7 Petri dish
9 scientific method
11 experiment
12 prediction
15 HIV
17 IV

Further resources

www.the-aps.org/education/k-12misc/careers.htm – careers in biology'

http://www.sciencebuddies.org/science-fair-projects/project_scientific_method.Shtml – the scientific method

http://biotech.einnews.com/ – biotechnology resources

http://www.ibc-et.org/ – Ethiopian institute of Biodiversity

http://www.sciberbrain.org/ – genetic engineering activities

http://www.apositivelife.com/forasos/biology-of-hiv.html – information on HIV/AIDS

http://www.avert.org/ – information on HIV/AIDS prevention

http://www.unaids.org/en/ – UN HIV/AIDS campaign

Appendix: Pro forma for developing plans for investigations

Title	

Step of scientific method	Application to your plan	
Background research		
Hypothesis		
Experimental investigation	Independent variable	
	Dependent variable	
	Other variables to be controlled or monitored	
	List of apparatus	Procedure to be followed

Record your results in the space below

Step of scientific method	Application to plan	
Analysis of results	Trends	Explanation of trends using biological knowledge
Accept or reject hypothesis	Accept or reject	Reason(s)
Evaluation	Source of error	Possible improvement

Biochemical molecules

Unit 2

This unit should fill approximately **24 periods** of teaching time.

Learning competencies for Unit 2

By the end of this unit students should be able to:

- Group biochemical molecules as inorganic and organic.
- Explain which chemical elements are found most often in biological molecules.
- Describe the properties of water.
- Explain the importance of water to living organisms.
- List and describe the structures of organic molecules in living things and state their functions.
- Show the structures and functions of biological molecules using chemical formulae and examples.
- Identify biologically important compounds by conducting simple food tests.
- Appreciate how biological molecules are obtained from different foods.

This section should fill approximately **8 periods** of teaching time.

2.1 Inorganic and organic molecules

Learning competencies

By the end of this section students should be able to:

- Group biochemical molecules as organic and inorganic.
- Explain which chemical elements are found most often in biological molecules.
- Describe the properties of water.
- Explain the importance of water to living organisms.

Starting off

At the outset of this unit, there is some basic chemistry that will need revision. Students need to be aware of the following concepts:

- atom
- molecule
- element
- compound
- valency

They also need to be able to distinguish between inorganic and organic. The generally accepted distinction is that organic molecules contain carbon and hydrogen whereas inorganic molecules may contain one or the other, but not both.

Also worth stressing is the significance of carbon having a valency of 4; this means that it is able to form long chain molecules, which are important in biological structures.

It is interesting for the students to note the close grouping of the most commonly occurring elements of biological molecules in the periodic table of elements. This should indicate to them some similarity of properties and, particularly, the way in which they form bonds with atoms of other elements.

Teaching notes

The chemical formula for water is known to just about everybody, but the students will probably not be aware of:

- the shape of the molecule
- its polarity as a result of the charge distribution of the molecule.

Students need to appreciate that this is a crucial property of the water molecule as it results in hydrogen bonding between the water molecules on which so much, from surface tension to the transpiration stream, depends.

Students should be aware that biologists believe that life originated in water and that no life can survive and be active for long periods without water.

The various properties of water that are significant to life are covered in some detail in the Students' Book, grouped under major headings:

- Water as a place to live
  - transparency
  - high specific heat capacity
  - maximum density at 4 °C (ice less dense than liquid water)
  - high latent heat of vaporisation
  - water has a high surface tension
- Water as a transport medium
  - excellent solvent
  - ideal viscosity
- Water as a reactant
- Water as a medium for chemical reactions
  - excellent solvent
  - low viscosity

together with examples of the consequences of each property.

Students could make a display of the properties of water and their importance to living things using local examples, where possible.

SA = starter activity MA = main activity CA = concluding activity	
Classification of inorganic and organic molecules	
SA	Question and answer session to see if the students know the difference between inorganic and organic molecules. Students review their knowledge of atoms and molecules.
MA	Students analyse of substances in table 2.1 to find the common properties of organic and inorganic molecules. Activity 2.1 Using knowledge gained, students classify the molecules listed as organic or inorganic. This is a straightforward activity but ensure students understand the table before they copy it out.
CA	Students write a summary of the difference between inorganic and organic molecules and quote one or two *new* examples of each.

SA = starter activity MA = main activity CA = concluding activity	
Library search	
SA	Students review the periodic table in figure 2.1 and describe any elements they recognise. Students review the major features of the table with the teacher.
MA	Students go away and complete activity 2.2. Give them approximately 20 minutes to do this and ensure they have access to relevant resources.
CA	Students gather back in the classroom and present their findings to the class.
Valency and its consequences	
SA	Discussion/lecture on what is meant by valency (students should see it as 'combining power' of atoms.
MA	Analysis of large organic molecules and smaller inorganic ones to show that the valency of carbon is fundamental to the formation of large organic molecules.
CA	Students review the significance of the valency of carbon.
The structure of water (1)	
SA	Students write down the formula of water. They should understand that this represents one molecule of water.
MA	If possible distribute drinking straws and glasses of water. Students take turns to suck water through the straws, as a prelude to a class discussion on why it is possible to do so. Write their ideas on the board and draw from them the idea that molecules must somehow stick together.
CA	Students study figure 2.6.
The structure of water (2)	
SA	Following from the previous lesson, students discuss with the teacher the idea of bonds between water molecules; students make notes on the nature of these bonds.
MA	Students debate the shape of the molecules and how this contributes to hydrogen bond formation. Students write up the structure and shape of water molecules.
CA	Students draw the structure of a water molecule without reference to their text books.
The importance of water to living things (1)	
SA	Students read pages 46 to 50 in the textbook about why water is important to living things and make notes.
MA	Take students to look at a pond, or get them to imagine a pond, containing plants, animals and decomposers. Ask the students to list as many things as they can that the water provides for these organisms.
CA	Students make a class display about living things and water (this could take more than one lesson).
The importance of water to living things (2)	
SA	Students talk about the ways in which water is important to living things, based on their learning in previous lessons.
MA	Students complete activity 2.4.
CA	Students present their wallcharts to the class.

Answers to review questions

1. C
2. B
3. C
4. D
5. D
6. A
7. C
8. C
9. D
10. A

2.2 Organic molecules

This section should fill approximately **16 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- List and describe the structures of organic molecules in living things and state their functions.
- Show the structures and functions of biological molecules using chemical formulae and examples.
- Identify biologically important compounds by conducting simple food tests.
- Appreciate how biological molecules are obtained from different foods.

Starting off

Introduce the section by asking students what they know of organic molecules in living things. They should be able to name all four of them (although nucleic acids may need a little coaxing) from their studies in grades 9 and 10. They should also be able to give an outline description of their functions.

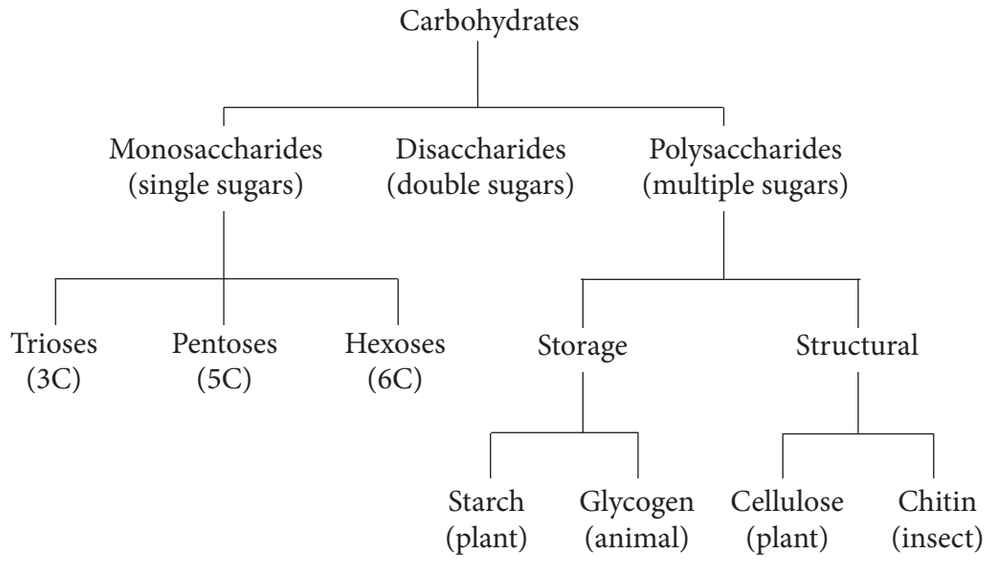
From this starting point, a more detailed description of the structures and properties of the various types can be built.

Teaching notes

The various functions of carbohydrates make an interesting introduction to this group. Many students will not get beyond suggesting that they are 'energy molecules' and perhaps that cellulose is used in plant cell walls.

There is quite a lot for the students to understand in the classification of carbohydrates and it needs to be introduced gently. Students sometimes find it useful to have the classification presented in a more visual format.

One possible presentation is shown below.



When discussing the structure of hexoses, the concept of isomerism is important and students should appreciate that the slightest rearrangement of the same atoms can result in a molecule with significantly different properties. To drive this point home, it is perhaps worth mentioning here that the difference in the arrangement of the atoms on carbon 1 of α-glucose and β-glucose leads to the formation of polysaccharides based on the two molecules that are very different in structure and in function – starch and cellulose.

The students will find an initial difficulty in appreciating that the formula of a disaccharide formed from two hexose monosaccharides is $C_{12}H_{22}O_{11}$, rather than the expected $C_{12}H_{24}O_{12}$.

They need to appreciate that:

- A chemical bond is necessary to hold the two monosaccharide molecules together.
- All the potential bonds in the individual monosaccharide molecule are already 'used' in holding together the atoms that make up the molecule.
- Some new 'free bonds' must therefore be created by breaking existing ones.
- The way in which this happens is by removing H and OH from carbon 4 of one glucose molecule and carbon 1 of the other.
- The 'free bonds' created then link up and hold the the two glucose units together.

This is shown in figure 2.21 in the Students' Book.

They need to appreciate that the process is called condensation. They can think of it as 'two molecules being condensed into one'.

Figure 2.1 shows the reverse process, with the disaccharide molecule being hydrolysed into two monosaccharide molecules with the addition of a molecule of water.

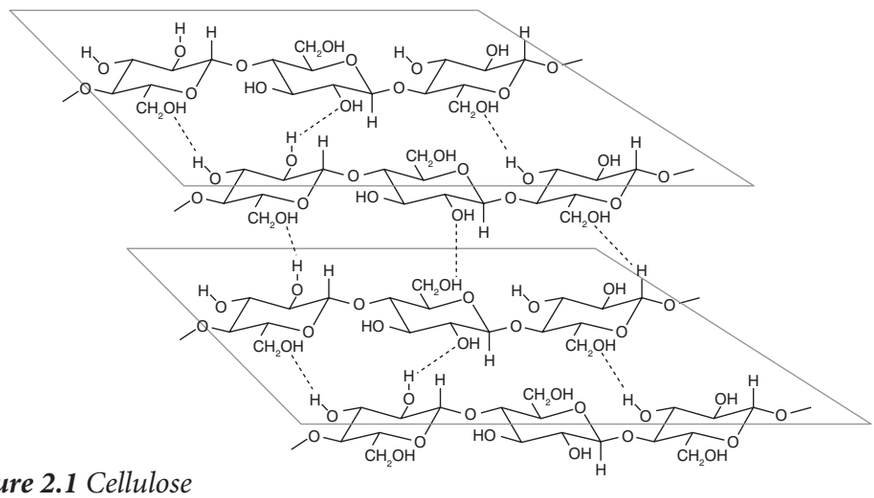


Figure 2.1 *Cellulose*

It is well worth spending some time ensuring that the students have understood the process of condensation, as it reappears several times in the unit.

The structure of the polysaccharides amylase, amylopectin and glycogen should be readily appreciated, once the formation of maltose has been understood.

The structure of cellulose requires a little more thought on their behalf. They need to appreciate that for two molecules of β-glucose to join, there has to be a

conformational change as the OH and H on carbons 1 and 4 do not align. But if one of the two molecules of β-glucose 'flips' through 180º, then they do align and bond formation is possible. So every other β-glucose molecule in the chain that makes up cellulose is 'upside down'.

The ability of cellulose molecules to form hydrogen bonds with adjacent molecules is something that the students must appreciate and understand that it leads to the formation of aggregates of molecules in microfibrils, which then can form larger fibrils.

The nature of lipids is discussed next and students will have some understanding of the nature of this group of compounds, if not their biochemical make-up. Central to this is their appreciation of the structure of glycerol and fatty acids. Once this is established, they should appreciate how glycerol can react with three fatty acids (by condensation reactions) to form a triglyceride.

With the structure of a triglyceride established, the structure of a phospholipid should be discussed. It is particularly important for work in the next unit that they appreciate that phospholipids have both hydrophilic and hydrophobic components to the molecule and that, as a consequence, one stable arrangement of phospholipid molecules in aqueous solutions is the phospholipid bilayer.

It may be worthwhile spending a little time showing students how the icon used to represent phospholipids in membrane structure is derived from the actual molecular structure of a phospholipid. The diagram below illustrates this.

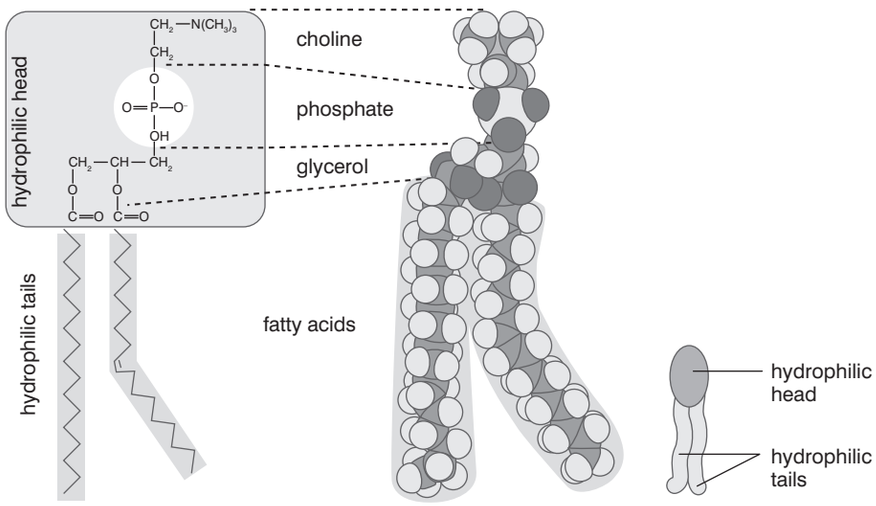


Figure 2.2 *Phospholipids*

Next we begin to study proteins and, at the outset, study the structure of amino acids. Students should be able to say, without clueing, from their studies of food and digestion, that protein molecules are built from amino acids.

The generalised structure of an amino acid is presented and students should appreciate why it can be called an 'amino acid'. The presence of an amino group clearly allows the 'amino' part of the name, but they may not realise where the acidic nature comes from. Explain that the hydrogen in the carboxyl group (COOH) can dissociate from the molecule as a hydrogen ion (H^+). They should be aware that an acid is defined as any substance that increases the concentration of hydrogen ions in a solution. Clearly then, an amino acid can do this.

By now, they should be comfortable with the concept of condensation linking two monomers together into a dimer and, from there, the addition of further monomers to form a polymer. This process is seen in the formation of dipeptides and then polypeptides.

Students then need to appreciate the subtle difference between a polypeptide and a protein. They should understand that the protein is the final 3-D configuration of the polypeptide chain, which only represents the primary structure of the protein. Secondary and tertiary structures should be explained and are illustrated in figure 2.36 in the Students' Book.

Stress the significance of the unique tertiary structure of each protein as being related to its function. Some examples are given in the Students' Book. Some others for discussion are listed below.

Type of protein	Function	Examples
Enzymatic proteins	Selective acceleration of chemical reactions	Digestive enzymes
Structural proteins	Support	Silk fibres; collagen and elastin in animal connective tissues; keratin in hair, horns, feathers, and other skin appendages
Storage proteins	Storage of amino acids	Ovalbumin in egg white; casein, the protein of milk; storage proteins in plant seeds
Transport proteins	Transport of other substances	Haemoglobin, transport proteins
Hormonal proteins	Co-ordination of an organism's activities	Insulin, a hormone secreted by the pancreas
Receptor proteins	Response of cell to chemical stimuli	Receptors in nerve cell membranes
Contractile and motor proteins	Movement	Actin and myosin in muscles, protein in cilia and flagella
Defensive proteins	Protection against disease	Antibodies combat bacteria and viruses

The concept of a quaternary structure is illustrated with the quaternary structure of two very different proteins – haemoglobin and collagen. Use these examples to explain the distinction between fibrous proteins and globular proteins.

Finally, we consider the structure of nucleic acids and begin with the generalised structure of a nucleotide. Stress its importance as it will be crucial to an appreciation of:

- DNA replication
- transcription
- the structure and function of ATP

Also stress the importance of distinguishing between a strand of DNA and a molecule of DNA. In RNA the two are synonymous.

The strands in both types of molecules can be described as polynucleotide strands, with the nucleotides (monomers) being joined, once again, by condensation. This is illustrated in the diagram below, which could be used to help any students who wish to know more.

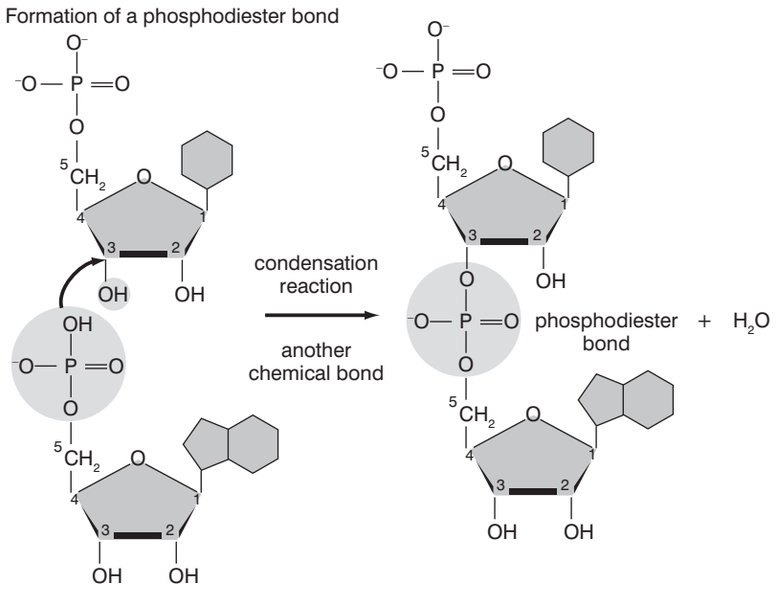


Figure 2.3

The basic biochemical tests for starch, reducing and non-reducing sugars, protein and lipids are all described in the Students' Book using 'test solutions' of lipid, sugar or whatever is on test. This is important so that students can see the expected result.

With the exception of the test for non-reducing sugars, this should, however, be no more than revision of work covered in grade 9, as should a more meaningful practical of testing local foods to see which of the major biological molecules they contain.

There are other options, however. If time and equipment permit, students could be given five solutions of different concentrations of either a reducing sugar (such as glucose) or of a protein (such as albumen), labelled only as A, B, C, D and E, and asked to determine by experiment the order of concentrations of the five solutions.

This is a useful exercise in that it tests the students' ability to plan and recognise that they need to control several variables:

- the volume of food substance used
- the volume of reagent used
- the length of time heated (if using Benedict's solution)
- the temperature at which they are heated

Then a comparison of the intensities of the colours formed should allow correct sequencing of the concentrations.

Also, the practical described in the end of unit question 8 (a) could be adapted for the students to carry out.

Give the students the information:

You are given four solutions, one containing glucose, one containing starch, one containing amylase (a starch-digesting enzyme) and one containing sucrose. They

have been labelled as solutions A, B, C and D. Carry out the following tests to identify the solutions.

1. Test all the solutions with Biuret solution. Record your results and your deductions in the table.
2. Test any solutions that remain blue with Benedict's reagent. Record your results and deductions in the table.
3. Incubate any solutions that remain blue with solution C (mix the solution with solution C and stand in warm water for 10 minutes).
4. Re-test these solutions with Benedict's solution. Record your results and deductions in the table.

A specimen table for recording together with idealised results and deductions is given below.

Note: this table assumes that the solutions made up were:

A – non-reducing sugar

B – starch

C – amylase

D – reducing sugar

Test	Result	Deduction
Biuret test	Solution C turns purple, remainder stay blue	Solution C is protein and so must be the enzyme amylase as no other proteins
Benedict's test	Solution D turns orange/ red, A & B remain blue	Solution D is reducing sugar
Benedict's re-test	Solution B turns red, solution A remains blue	Solution B must be starch as converted to reducing sugar by amylase Solution A must be sucrose (process of elimination)

SA = starter activity MA = main activity CA = concluding activity	
Organic molecules in living things	
SA	Students write down some examples of organic molecules in living things.
MA	Students use the examples to build a list of organic molecules. Students classify the organic molecules into proteins, lipids, carbohydrates and nucleic acids, with examples of each type together with their function.
CA	Students make notes on the different types of organic molecules, the functions of each type and giving at least one example of each.
The nature of carbohydrates – monosaccharides	
SA	Students name as many different carbohydrates as they can and to describe any differences between them.

MA	Students examine the idea of: • monosaccharide sugars • disaccharide sugars • polysaccharides. Students study that with different examples of monosaccharides (trioses, pentoses, hexoses) and appreciate the concept of functional groups (aldehyde and ketone groups).
CA	Students read pages 52 to 55.
Disaccharides	
SA	Question and answer - review what a disaccharide is and how it is made up. Students give some examples of disaccharides.
MA	Class discussion – how do two monosaccharides join? Question and answer to establish the ideas that: • all the atoms in the monosaccharides have all their bonds occupied • therefore 'spare bonds' must be created on each monosaccharide if they are to join. Students examine that this happens by removing –OH from one monosaccharide and –H from the other as a molecule of water. Students study the structure of common disaccharides (maltose, sucrose and lactose).
CA	Students read the section on disaccharides and make notes on: • general nature of a disaccharide • examples of disaccharides (including the monosaccharides they are made from) • condensation of two monosaccharides to form a disaccharide.
Polysaccharides	
SA	Students review the prefixes mono- and di- and use these to discuss the meaning of poly- and arrive at an idea of what polysaccharides are. Students study the difference between macromolecules and polymers.
MA	Students examine that condensation reactions create the large polysaccharide molecules and that in some cases the chains of molecules can form branches and that branching (or not) affects the properties of the molecule. Students read the section on polysaccharides and make notes on the structure of starch, glycogen and cellulose.
CA	Students make a table comparing the structure of starch and cellulose.
Lipids	
SA	Question and answer – elicit from the students as many different types of lipids as possible. From their examples, students appreciate the formal classification of lipids shown in the book and discuss the functions of the various types.
MA	Students appreciate the idea that triglycerides are made from fatty acids and glycerol. Students study the structure of a typical fatty acid and the glycerol molecule. Students examine the difference between saturated and unsaturated fatty acids. Students examine the role of condensation reactions in bonding glycerol with three fatty acids. Students study how phospholipids derived from triclycerides.
CA	Students read the section on lipids and make notes on: • the structure of glycerol • the structure of saturated and unsaturated fatty acids • how condensation reactions bond glycerol to three fatty acids • the structure of phospholipids.

Proteins – polypeptide chains	
SA	Students write down what they already know about proteins from earlier grades. They should be able to mention: • some uses of proteins • some sources of proteins • that proteins contain C, H, O and N • that proteins are made from amino acids.
MA	Students study the structure of an amino acid and explain how amino acids link together to form polypeptides.
CA	Students read pages 61–63 and make notes.
Proteins – levels of structure of a protein	
SA	Students review the structure of a polypeptide chain.
MA	Students examine the meaning of: • primary structure • secondary structure • tertiary structure • quaternary structure of a protein and describe the bonds holding the structure together. Students read the section in the textbook and make notes on levels of structure and give examples of fibrous and globular proteins.
CA	Students produce a table to describe the type of bonds holding the different levels of structure in place.
Carbohydrates, Lipids and Proteins: review	
SA	Students discuss and review the distinct features of carbohydrates, lipids and proteins.
MA	Students split into groups and choose to do either activity 2.5, 2.6 or 2.7.
CA	Students present and display their posters in the classroom.
Nucleic acids	
SA	Class discussion to review the students' understanding of DNA from earlier years.
MA	Students appreciate that DNA is just one type of nucleic acid. Students examine that all nucleic acids are built from nucleotides and show the structure of a nucleotide. Students examine how nucleotides can link by condensation reactions to form polynucleotide chains (compare the terminology with polypeptide chains). Students examine that a molecule of DNA is made from two polynucleotide strands whereas RNA has just one strand. Stress the difference between a molecule of DNA and a strand of DNA. Students revise complementary base pairing in DNA. Students read the section in the book and make notes.
CA	Students construct a table to show the differences between DNA and RNA.
Testing food substances to find which biological molecules they contain (1)	
SA	Students recall Benedict's test for reducing sugars. (Point out that the test is for all reducing sugar and not just for glucose.)
MA	Activity 2.9: students carry out Benedict's test for reducing sugars on: • pure solutions of the appropriate substance • local foodstuffs. More information on this test is given in the teaching notes section.
CA	Students write up their practical work.

Testing food substances to find which biological molecules they contain (2)	
SA	Students recall the Biuret test for protein.
MA	Activity 2.12: students carry out the Biuret test for protein on: • pure solutions of the appropriate substance • local foodstuffs. More information on this test is given in the teaching notes section.
CA	Students write up their practical work.
Testing food substances to find which biological molecules they contain (3)	
SA	Students recall the emulsion test for lipids.
MA	Activity 2.11: students carry out the emulsion test for lipids on: • pure solutions of the appropriate substance • local foodstuffs. More information on this test is given in the teaching notes section.
CA	Students write up their practical work.
Testing food substances to find which biological molecules they contain (4)	
SA	Students learn about and watch teacher's demonstration of the Benedict's test for non-reducing sugars.
MA	Activity 2.10: Give students solutions containing known mixtures of reducing sugar/non-reducing sugar/lipid/protein. Students test these solutions. More information on this test is given in the teaching notes section.
CA	Students write up the results of their tests and deduce which substances are present in which solutions.
Sequencing the concentration of protein solutions (1)	
SA	Students recall the Biuret test for proteins. Students examine that the intensity of the colour formed depends on a number of factors, including: • concentration of the protein solution used • volume of the protein solution used • volume of biuret solution used • time allowed for the reaction • temperature.
MA	Students design an experiment to find out the relative concentrations of four protein solutions.
CA	Students carry out their experiment if there is time; carry it over into the next lesson if necessary.
Sequencing the concentration of protein solutions (2)	
SA	Students discuss with the rest of the class the design and results of their experiment from the previous lesson.
MA	Students write up their experiment, including diagrams to show the experiment design if necessary.
CA	Students suggest and debate how the colorimeter could be used to improve the reliability of their experiments (they may have to revise the principle of the colorimeter first).
Debate	
SA	Students split into groups of four and assign a type of biological molecule to each member.
MA	Groups carry out activity 2.14 up until the recording of votes.
CA	Students complete activity 2.14 by setting up a tally chart and discussing the results.

Answers to review questions

1. C	6. A	11. C
2. A	7. B	12. A
3. D	8. C	13. B
4. B	9. D	14. D
5. A	10. D	15. B

Answers to end of unit questions

1. a) i) Amino group indicated

   Carboxyl group indicated

   ii) Peptide bond shown between CO and NH

   Molecule of water formed

   iii) Condensation

   Peptide bond

   b) Combination of two or more polypeptide chains in single molecule of protein

2. a) Mono-unsaturated

   One double carbon–carbon bond/one C=C bond

   b) *Three of*:

   Contains fewer oxygen atoms

   Contains more hydrogen atoms

   Contains carboxyl functional group

   Cannot assume ring form like glucose

   Contains C=C bonds

   c) i) *Three of*:

   Three fatty acids react with glycerol

   In condensation reactions

   Form ester bonds

   Three water molecules formed

   (accept these points from a labelled diagram)

   ii) Two fatty acids react with glycerol

   Third is replaced with phosphate group

3. a)

Organic substance	Solubility in water	Sub-units	Elements present
Glucose	High/soluble	(none)	C, H, O
Starch	Low/insoluble	α-Glucose	C, H, O
Triglcyeride	Low/insoluble	Fatty acids & glycerol	C, H, O
Protein	Variable	Amino acids	C, H, O, N (S & P)

b) i) Heat with Benedict's solution

Look for yellow/orange/red precipitate

ii) Add Biuret solution and allow to stand

Look for purple/mauve/lilac colouration

4.

Property	Importance to living things
High specific heat capacity	Water heats up and cools down slowly/water retains a stable temperature
Transparency	Light is transmitted – allows photosynthesis
High latent heat of vaporisation	Takes a lot of energy to turn it to a vapour – allows temperature regulation by sweating
High surface tension	Allows organisms to live at and just below the surface
Ice is less dense than liquid water	Water freezes from top down/ice insulates water below/life possible under the ice
Excellent solvent	Allows many substances to dissolve and allows many reactions to take place

5. a) *Three of*:

DNA is double-stranded

DNA has ribose sugar

DNA shows base pairing

DNA has thymine

Note: DNA is larger and this cannot be seen in the diagram, so ignore.

b) In the nucleus

In a chromosome

c) Huge size allows it to carry many genes/much information.

Stability ensures that the coded information remains the same from one generation to the next.

Double-stranded nature allows for replication that automatically produces an identical copy.

6. a) *Five of*:
   Made of two molecules – amylase and amylopectin
   Polymer of α-glucose
   Amylase helical
   Amylopectin branched
   (both) Compact so much can be stored in a small space
   (both) Insoluble so no osmotic effects
   Branching of amylopectin allows speedy hydrolysis

   b) i) *Three of*:
   Cellulose is unbranched
   Has β-1,4 links
   Is a polymer of β-glucose
   Can hydrogen-bond with other cellulose molecules
   Only made of one type of molecule

   ii) Glycogen is more highly branched
   Only made of one type of molecule

7. a) *Five of*:
   Atoms arranged differently
   Are isomers of each other
   Diagram of glucose
   Diagram of starch
   Difference I highlighted on diagram
   Difference II highlighted on diagram

   b) A functional group gives a molecule a specific property
   Suitable example
   Suitable example
   (examples could include:
   - *amino group confers basic property on amino acids*
   - *carboxyl group confers acidic properties on amino acids/fatty acids*
   - *aldehyde/ketone group confers reducing properties on sugars)*

   c) Link between carbon 1 of one molecule and carbon 4 of another α-glucose

8. a) C is amylase
   Biuret test proves it is a protein
   Amylase is the only protein/all enzymes are proteins
   D is a reducing sugar
   Positive result with Benedict's solution
   B is starch
   Converted to reducing sugar by amylase/amylase acts on starch
   A is a non-reducing sugar (process of elimination)

   b) i) Molecule of glycerol
   linked to three saturated fatty acids
   by ester bonds

ii) *Three of*:
Phospholipid molecule is polar
has hydrophobic and hydrophilic regions
has only two fatty acids
has phosphate group

c) *Three of*:
Plasma membranes
Insulation/adipose tissue
Insulation of nerve cell axons
Respiration/energy source
Waterproofing of exoskeletons and leaves

Answers to end of unit crossword puzzle

Across

2 RNA
6 compound
8 DNA
12 molecule
14 carbohydrate
15 peptide
17 phospholipid
19 functional group
20 disaccharide
21 carbon

Down

1 lipid
3 atom
4 nucleotide
5 fatty acid
7 element
9 amino acid
10 hydrogen bond
11 polysaccharide
13 glycosidic
16 hydrogen
18 water

Further resources

http://www.bio.cmu.edu/Courses/BiochemMols/BCMolecules.html – further information on molecules

http://www.elmhurst.edu/~chm/vchembook/547cellulose.html – research and diagrams on polysaccharides

http://www.ipn.uni-kiel.de/eibe/UNIT01EN.PDF – research and activities on microbes and molecules

http://www.biotopics.co.uk/JmolApplet/jcontentstable.html – 3-D structures of biological molecules

Enzymes

Unit 3

This unit should fill approximately **27 periods** of teaching time.

Learning competencies for Unit 3

By the end of this unit students should be able to:

- Define enzymes and explain the properties of enzymes.
- Explain how enzymes are named and then classify them according to their structure.
- Conduct an experiment to show the specificity of an enzyme.
- Appreciate the importance of enzymes in industries and local products.
- Explain how enzymes lower activation energy.
- Explain the mechanism of enzyme action.
- Discuss the action of apo- and coenzymes.
- Give examples of vitamins and minerals in food that act as cofactors.
- Explain factors that affect enzyme activity.
- Investigate the destruction of an enzyme by heat.
- Show how temperature, pH, substrate concentration and enzyme concentration affect enzyme activity.
- Explain allosteric regulation and feedback control mechanism of enzyme activity.
- Appreciate the role of enzymes in controlling our metabolic activities.

This section should fill approximately **7 periods** of teaching time.

3.1 Nature of enzymes

Learning competencies

By the end of this section students should be able to:

- Define enzymes and explain the properties of enzymes.
- Explain how enzymes are named and then classify them according to their structure.
- Conduct an experiment to show the specificity of an enzyme.
- Appreciate the importance of enzymes in industries and local products.

Starting off

Introduce the topic by explaining to students that nearly all enzymes are proteins. There are a few RNA molecules that have catalytic properties but, effectively, all enzymes are proteins.

Discuss with them the structure of lipase (figure 3.1 in the Students' Book) and identify the regions suggested. Get them to appreciate that no other enzyme will have a tertiary structure quite the same as this.

From there, familiarise the students with the term and concept 'substrate' as it will be used a lot in this unit. Also, introduce the concept of an 'active site' within the enzyme molecule as the region of the enzyme that is chiefly responsible for the specificity of the enzyme.

Use figure 3.2 in the Students' Book as a model for the cycle of events that take place in an enzyme-controlled reaction and introduce the terms:

- enzyme–substrate complex (stage 2 in figure 3.2)
- enzyme–product complex (stage 3 in figure 3.2)

By the end of the introduction, the definition of an enzyme given in the Students' Book:

An enzyme is a globular protein with a uniquely shaped active site; it acts as a biological catalyst for a specific reaction, but remains unaltered by the reaction.

should be meaningful to the students.

Teaching notes

Revise briefly with the students the nature of enzymes. Stress again that (for all practical purposes) they are all proteins. Discuss with them the specificity of enzymes and the implication of this for control of all the different chemical reactions that take place in living cells.

Mention that they can be inactivated by extremes of pH and by high temperatures and that their activity is influenced by their concentration and the concentration of their substrate. However, this is only an introduction as these will be discussed in more detail later.

The nature of catalysis is an important concept for them to grasp. It should not be new as they will likely have encountered it before in studies in chemistry. Stress that catalysts only alter the pathway of the reaction, not the nature of the products or the overall energy change in the reaction. Stress also that the catalyst remains in its original form at the end of the reaction.

The naming of enzymes is a mystery to many students. They will probably have noticed that the names of many enzymes end in –ase. Start from here and ask them if they have noticed anything about the rest of the name. Ask them to name the enzymes that act on proteins (they should know protease) and lipids (lipase). Explain that another common way of naming enzymes is by the type of reaction they catalyse (polymerase, dehydrogenase, oxidase are examples). Discuss the varied ways of naming enzymes before moving towards the formal method of classifying enzymes approved by the Enzyme Commission.

The students should find the initial classification into six divisions/classes straightforward, even if some of the names are a little difficult to comprehend, but they will need help with the other levels of classification. Point out the benefits of such a classification; it is accessible to all biologists everywhere and is not really language dependent.

The uses of enzymes is a huge topic and lends itself to a display by the students. It is as well to start by giving the students a historical perspective on this, explaining that man was using enzymes before he ever knew what enzymes were! The

examples of brewing and baking illustrate this point. Further examples are best chosen to illustrate local use of enzymes.

Point out to the students that, because enzymes allow reactions to proceed at moderate temperatures, there are benefits beyond the cost-saving to the manufacturer. If less heat is required, then less fuel need be burned, which is of benefit to the environment by reducing the amount of CO_2 released into the atmosphere. Figure 3.7 in the Students' Book shows some of the savings in CO_2 emissions per ton of product in some industrial processes.

SA = starter activity MA = main activity CA = concluding activity	
The nature of enzymes	
SA	Students examine the idea that all enzymes are globular proteins.
MA	Students discuss the consequences of enzymes being globular proteins: • unique tertiary structure (and therefore shape) • regions with an α-helix and a β-pleated sheet • specificity of action. Students examine the concepts of active site, substrate and enzyme–substrate complex and discuss the properties of enzymes (including those of a catalyst).
CA	Students copy the definition of an enzyme in the text and make notes on the properties of enzymes, explaining why enzymes are specific and why they are affected by temperature.
Naming and classifying enzymes	
SA	Students give the names of some enzymes and to find the pattern in the names – that they frequently end in -ase.
MA	Students discuss with the teacher the origin of the first part of the name of an enzyme such as: • lipase • oxidase to establish different ways of naming enzymes. Class to discuss briefly the principles of the Enzyme Commission classification and the benefits of systematic naming of enzymes.
CA	Give the students examples of enzymes and ask them to deduce how they have been named (i.e. by the substrate they act on, by the type of reaction they catalyse, common naming, etc.). Students can do Activity 3.2 in class if there is time, or as homework. Review their answers quickly at the beginning of the next lesson.
Uses of enzymes (1)	
SA	Students learn the origin of the word 'enzyme' – point out that it means 'in yeast'. Students learn that yeast was the first source of enzymes to be used.
MA	Students discuss the role of yeast in brewing and baking. Point out that fermentation of sugars happens in both processes.
CA	Students make a display on brewing tella and baking injera.
Uses of enzymes (2)	
SA	Students give one or two examples of processes in which enzymes are used. Students discuss the benefits of using enzymes in these processes.
MA	Students use table 3.3 and their own sources to make a display of how enzymes are used in different processes.
CA	Class reviews some of the uses of enzymes.
Uses of enzymes (3)	
SA	Students begin discussion on when and where enzymes are used in local manufacturing – write their ideas on the board.

MA	Students conduct the debate as described in activity 3.3: you will need to chair it, and ensure that all students get a turn to speak and respect each other's opinions.
CA	Students conclude the debate; make notes of the main points in preparation for the next lesson.
Uses of enzymes (4)	
SA	Students recall the main ideas and opinions from the debate in the previous lesson and discuss whether they have changed their minds at all since – if so, why? You may have to prompt them using your notes.
MA	Students write a summary report of the discussion or present it as a diagram or poster.
CA	Students study figure 3.7.
Uses of enzymes (5)	
SA	Students recall that enzymes increase the rate of reactions of biological processes at moderate temperatures.
MA	Students discuss the benefits of using moderate temperatures, including saving on energy bills, reduced emissions of carbon dioxide from burning fossil fuels. Students can study the 'Did you know' box for ideas.
CA	Students make notes on the benefits of using enzymes in industrial processes, quoting examples.

Answers to review questions

1. B
2. C
3. A
4. D
5. A
6. D
7. D
8. C
9. B
10. D

3.2 Functions of enzymes

This section should fill approximately **9 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Explain how enzymes lower activation energy.
- Explain the mechanism of enzyme action.
- Discuss the action of apo- and coenzymes.
- Give examples of vitamins and minerals in food that act as cofactors.

Starting off

Begin by reminding the students of the nature of enzymes, that they are:

- proteins
- biological catalysts
- specific
- affected by pH and temperature

- affected by the concentration of their substrate and the presence of certain substances that act as inhibitors.

Recap also the nature of catalysts, remind them that catalysts:

- speed up a chemical reaction with no overall change to:
  - the nature of the products
  - the energy change that takes place during the reaction
  - the catalyst itself.

Teaching notes

Introduce the nature of catalysis by enzymes with a discussion of energy change during the reaction. Stress again that there is no overall change in the energy levels of reactants and products, but that the pattern of the reaction alters. Introduce the concept of activation energy as the energy required to initiate a reaction. Use figure 3.8 in the Students' Book to compare the activation energy of a catalysed and uncatalysed reaction.

Discuss the consequences of a lower activation energy being required in terms of molecules having the necessary kinetic energy. Explain that not all molecules have the same kinetic energy and that only those with sufficient kinetic energy will be able to 'climb the activation energy hill'. If this 'hill' is lower, a larger proportion of the molecules will have the necessary energy. The diagram below may be helpful when discussing this concept.

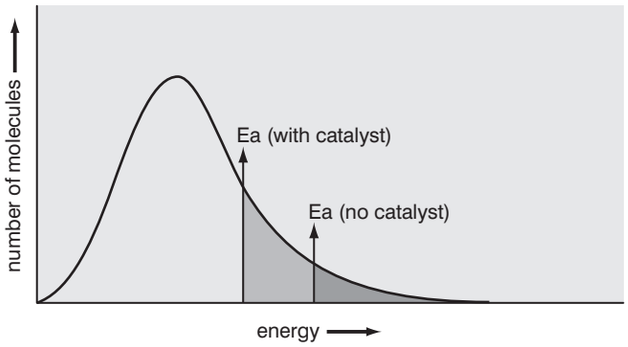


Figure 3.1 *Activation energy with and without catalyst*

The two models of enzyme action, lock-and-key and induced-fit models, are described in the Students' Book. Explain to the students reasons for preferring the induced-fit model, including:

- it explains how the transition state might lower activation energy (by putting bonds in the reactant under 'tension' so that they are more likely to break and re-combine; this is a rather simplistic and physical explanation, but it gives the students some idea of how activation energy might be lowered)
- it better explains the action of non-competitive inhibitors, whose action requires the re-shaping of the active site.

Table 3.4 gives some data on the effects of enzymes on increasing the rate of reaction. Some of the concepts in the table are not essential to understanding how enzymes work, but the turnover number is a useful idea for them to be able to carry around. Ask students to write out some of the rate enhancements longhand to give a better appreciation of the effect of the enzyme.

Finally, we look at the question of cofactors and how they are sometimes necessary for enzyme action. Figure 3.12 in the Students' Book illustrates why this might be. The apoenzyme provides the basic structure, but the active site is not truly complementary in shape to the substrate without the cofactor. This is not the only mode of action of cofactors, but it does give the students a physical model to build the concept around.

Table 3.5 gives some examples of cofactors together with the enzyme that they activate and the role of the active enzyme. Table 3.6 gives similar information about some mineral ions and their role in activating enzymes.

SA = starter activity MA = main activity CA = concluding activity	
How do enzymes act as catalysts?	
SA	Students discuss what a catalyst does.
MA	Students examine the concepts of: • energy levels of reactants and products • activation energy • exergonic (exothermic) reactions • endergonic (endothermic) reactions. Explain that by reducing the activation energy needed, the energy input to the system is reduced and so more product is formed for the same energy input – i.e. the reaction proceeds faster.
CA	Students make notes on these concepts.
Enzyme model	
SA	Students brainstorm the characteristics and function of an enzyme.
MA	Students complete activity 3.5, making their model if possible.
CA	Students present either their plan for a model or actual model to the class and explain their design.
How do enzymes lower activation energy (1) – the lock-and-key model	
SA	Students discuss the concept of complementary shapes and enzyme–substrate complex (ES complex).
MA	Students examine that forming an ES complex can lead to: • a transition state • an alternative pathway for the reaction with a lower energy demand. Explain also that a weakness of the model is that it does not explain how the transition state is formed, nor how it reduces the energy demand.
CA	Students make notes on this.
How do enzymes lower activation energy (2) – the induced-fit model	
SA	Students discuss the concept of complementary shapes and enzyme–substrate complex (ES complex).
MA	Students discuss the concepts of the induced-fit model paying particular attention to the conformational change that takes place as enzyme and substrate bind. Students discuss the concept of 'turnover rate' as a measure of rate of reaction of an enzyme-controlled reaction.
CA	Students summarise the similarities and differences between this model and the lock-and-key model.

Industrial visit (1)	
SA	Tell the students about the industrial location to which you have chosen to take them on a visit, for activity 3.4.
MA	Preparation for visit: students plan what they will need to find out, questions to ask, and do some personal library/Internet research into the industry.
CA	Students draft a structure for their eventual report on their visit.
Industrial visit (2)	
SA	Students complete industrial visit (will take whole lesson and perhaps longer).
MA	Students continue industrial visit.
CA	Students continue industrial visit and write up their report as homework.
Research project (1)	
SA	Students brainstorm different industrial uses of enzymes. Push them to think creatively about different situations where enzymes may be used.
MA	Students select one use of enzymes (not the one already covered in the industrial visit) to write a full research project on). Ensure that there is a good variety of topics across the class, and that each one chosen provides sufficient scope for a detailed report. Students plan the structure of their project and scope of work, and identify the information sources they will need, including independent research visits and interviews where possible and relevant.
CA	Students begin work on their projects and continue their research outside of the classroom as homework.
Research project (2)	
SA	Students show evidence of progress on their projects to you, and continue work.
MA	Students complete research projects.
CA	Students present a brief summary of their research projects to the rest of the class.
Cofactors	
SA	Students examine the idea that active enzymes may not be single entities.
MA	Students examine the distinction between cofactors as a generic group of substances that activate apoenzymes and the different types of cofactors. In particular, students examine coenzymes and NAD and FAD as examples of coenzymes in the respiratory pathway. Students be aware of some mineral ions that act as cofactors.
CA	Students describe the role of cofactors.

Answers to review questions

1. B
2. C
3. B
4. D
5. C
6. A
7. B
8. A
9. B
10. C

3.3 Factors affecting the functions of enzymes

This section should fill approximately **11 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Explain factors that affect enzyme activity.
- Investigate the destruction of an enzyme by heat.
- Show how temperature, pH, substrate concentration and enzyme concentration affect enzyme activity.
- Explain allosteric regulation and feedback control mechanism of enzyme activity.
- Appreciate the role of enzymes in controlling our metabolic activities.

Starting off

Begin by reminding the students of the basic pattern of an enzyme-controlled reaction described in figure 3.2 and reproduced again here for convenience. Discuss with the students how different factors might influence the pattern of this reaction. Get them to think about the influence of:

- more substrate molecules (substrate concentration)
- more kinetic energy (higher temperature)
- more enzyme molecules (enzyme concentration)

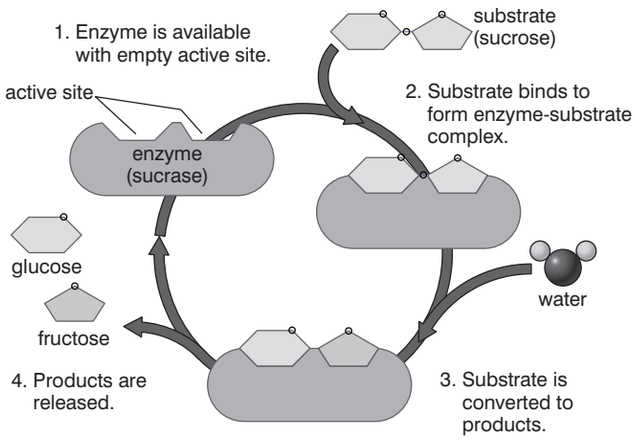


***Figure 3.2** The hydrolysis of sucrose by sucrase*

Teaching notes

Begin discussing the effect of temperature on enzyme action by establishing the fact that heat gives particles kinetic energy with the result that the particles will either:

- move around more quickly if they are free to do so (in this case they are more likely to meet other particles and react)
- vibrate more vigorously if they are held in place as part of a molecule (in this case the increased vibration will put extra strain on the bonds holding the particles in position).

Introduce the concept of denaturation by considering the second of the above effects in a little more detail. Stress to them that denaturation is normally non-reversible *in vitro* but can often be reversed *in vivo*, provided the temperatures haven't been too extreme. The concept of non-reversible denaturation can be

illustrated by thinking of boiling an egg. The liquid albumen protein becomes white and solid because it has been heat denatured. It does not revert to a translucent liquid on cooling. The effect is not reversible.

Stress to students that the activity of an enzyme at a given temperature is a 'trade-off' between the effect of increased collisions and the effect of denaturation, both of which increase with temperature. Get them to realise that there will be some denaturation at the optimum temperature, and to think of the optimum temperature as:

the highest temperature at which the effects of increased collisions still outweigh the effect of denaturation.

At temperatures higher than the optimum, denaturation occurs much more rapidly and activity soon reduces to zero. Ask the students to recognise this in the pattern of the activity/temperature graph. Also, get them to realise that not all enzymes have an optimum of 37 °C! Ectothermic animals living under the polar ice need enzymes to function efficiently at temperatures much lower than that.

With the effects of denaturation established, the effects of extreme pHs are straightforward to explain, although the mechanism of inactivation is different to that for temperature. Also, students must appreciate that some enzymes do have optimum pHs that are not neutral. This is easily demonstrated by reference to the enzymes from different regions of the human gut.

At one level, the effect of substrate concentration is straightforward for the students to understand; they readily appreciate that more substrate molecules means more enzyme–substrate complexes and, so, a faster rate of reaction. However, it requires an appreciation of 'turnover number' to fully explain the shape of the graph in figure 3.17 in the Students' Book, reproduced here again for reference. At high substrate concentrations, V^{max} is approached as nearly all the active sites are occupied at any given time.

Discussing the effect of enzyme concentration allows a distinction to be made between enzyme activity (the turnover rate of each individual molecule of enzyme) and reaction rate (the overall rate at which product is formed).

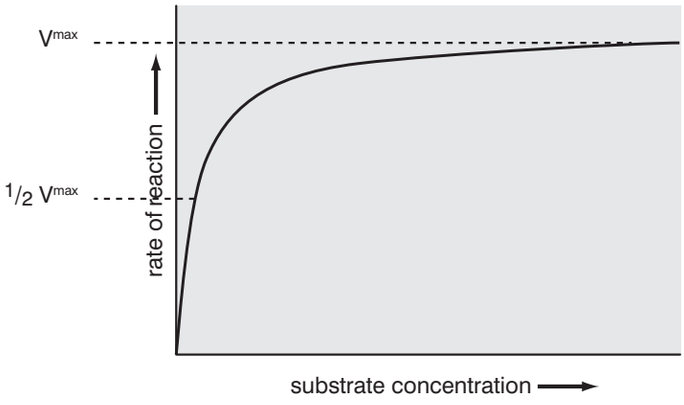


Figure 3.3 *The effect of substrate concentration on enzyme activity*

There are so many opportunities for practical work with enzymes that it is difficult to know which to suggest. However, a number are suggested in the Students' Book that are based on the decomposition of hydrogen peroxide by catalase; this is often a convenient practical as there are many sources of catalase. One method of measuring the volume of oxygen produced is suggested in the Students' Book, but there are clearly others.

At the most basic level, numbers of bubbles can be counted (students could then in their evaluations point out that the bubbles are unlikely to all be of the same volume).

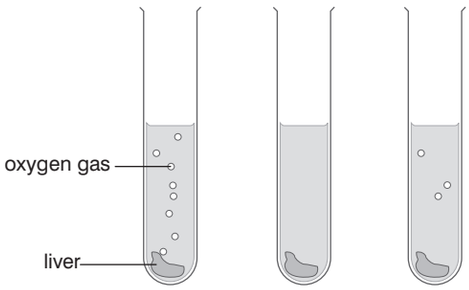


Figure 3.4

Alternatively, the volume of oxygen gas produced can be measured by collecting the gas in an inverted measuring cylinder.

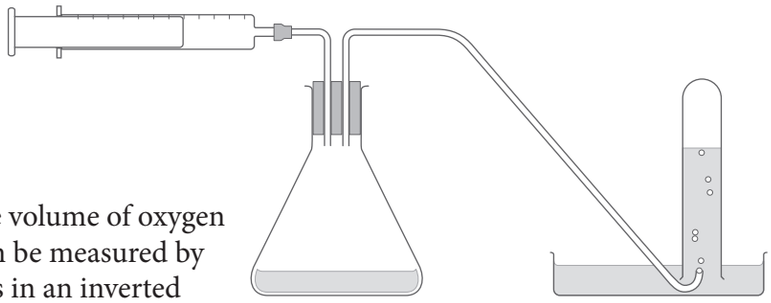


Figure 3.5

The Institute of Biology recommends that for graphs such as these:

- mean data are always plotted
- points are joined by ruled lines or, where appropriate, a line of best fit is drawn through the points.

Whatever method is chosen to measure the volume of gas produced, there is considerable scope to discuss with the students:

- issues relating to the validity of the experiment; these could include:
  - does the experiment really measure what is intended to be measured or could there be other factors that could be influencing the results?
  - is the range of values for the IV appropriate to draw valid conclusions?
- issues relating to the reliability of the experiment; these could include:
  - have repeats been carried out to ensure reproducibility of the results?
  - were changes in the DV (volume of gas produced) measured to an appropriate degree of accuracy?
  - have changes to the IV (temperature, pH) been maintained to an appropriate degree of accuracy?

If it is not practicable for some reason to carry out these, or other, investigations then sample results are provided for analysis.

In each case, students should:

- calculate mean values from the raw data supplied
- plot graphs of mean values of the DV against the IV
- describe any patterns evident in the graphs
- try to explain these patterns using biological knowledge of enzyme action
- suggest how the investigation might be improved to give more reliable and valid results.

The effect of competitive inhibitors on enzyme action is relatively easy for student to grasp; they can appreciate that if another substance has a similar shape to that of the substrate, then it could enter the active site and prevent substrate molecules from entering.

What is more difficult for them is to appreciate the proportionality of this effect. They need to appreciate that in a mix of 80% substrate and 20% inhibitor, 80% of the collisions with the enzyme will be substrate molecules and 20% will be inhibitor molecules. Put another way, each active site will be occupied with substrate for 80% of the time and with inhibitor for 20% of the time, reducing enzyme activity to 80%.

The effect of non-competitive inhibition is a very visual concept. Figure 3.22 in the Students' Book should help the students to understand how binding to the allosteric site can influence the active site. This will be easier to grasp if they have fully understood the induced-fit model of enzyme action.

The role of non-competitive inhibitors in feedback control of metabolic activity is the final concept in this unit. Students need to appreciate that some kind of control mechanism must exist in cells otherwise they would just continue making product that could not be used. This would be at least wasteful of resources and at worst lethal to the cell if the product were toxic in high concentrations.

The concept of feedback inhibition is usually quite readily appreciated if the idea of non-competitive inhibition is fully understood. Explain to the students not just the switching off of the pathway but also that, when concentrations of the end-product fall again, the inhibition of the key enzyme will be removed and the pathway will be reinstated.

SA = starter activity MA = main activity CA = concluding activity	
The effect of temperature on enzyme activity	
SA	Students examine the distinction between heat (a form of energy) and temperature (a measure of the heat content of a system).
MA	Students discuss how heat might affect: • the kinetic energy of the molecules involved in a reaction • the kinetic energy of the atoms making up each molecule. From these ideas develop the ideas that increasing temperature will lead to: • increased kinetic energy of enzyme and substrate molecules, making collision and binding more likely • increased rate of movement of atoms within a molecule – including the enzyme molecules. The increased rate of movement of atoms will lead to denaturation – leading, in turn, to a change in shape of the active site, making binding with the substrate less likely the activity of an enzyme will depend on a trade-off between the two effects.
CA	Students copy figure 3.14 and explain the shape of the graph.
The effect of pH on enzyme activity	
SA	Students revisit the idea that anything that makes binding between active site and substrate will reduce the activity of the enzyme.
MA	Students examine the dual effects of extreme pHs in: • changing the charge structure of the active site • breaking ionic bonds leading to denaturation of the enzyme molecule.
CA	Students copy and explain the shape of the graphs in figure 3.15 and figure 3.16.
The effect of substrate concentration	
SA	Students remember what happens in an enzyme-controlled reaction – in both models of enzyme action, the active site binds with the substrate.

<table>
<tr><td>MA</td><td>Students remember the concept of ‘turnover rate’. Go on to discuss the conditions for maximum rate of reaction – all the active sites must be operating at their maximum turnover rate.
Students sketch figure 3.17 and explain the shape of the graph.</td></tr>
<tr><td>CA</td><td>Students read and discuss the key idea of changing substrate concentration over the duration of a reaction and to sketch a graph for the rate of reaction as the reaction proceeds.</td></tr>
<tr><td colspan="2">Catalase practical to measure enzyme activity (1)</td></tr>
<tr><td>SA</td><td>Students discuss with the teacher the two generic ways of measuring the rate of an enzyme-controlled reaction:
• measuring the rate at which the substrate is used up
• measuring the rate at which (one of) the product(s) is formed.
Discuss the reasons for choosing the second of these in the case of the catalase reaction.</td></tr>
<tr><td>MA</td><td>Students carry out the experiment (activity 3.6). This is a good, basic experiment to show enzyme activity. Detailed information on this is given in the teaching notes.</td></tr>
<tr><td>CA</td><td>Students write up and plot a graph of their results.</td></tr>
<tr><td colspan="2">Catalase practical to measure enzyme activity (2) – improving the investigation</td></tr>
<tr><td>SA</td><td>Students discuss with the teacher reasons why the reliability and validity of the experiment in its original form are limited (lack of controls limit validity and lack of repeats limit reliability).</td></tr>
<tr><td>MA</td><td>Students discuss with the teacher realistic ways of improving the reliability and validity of the experiment.</td></tr>
<tr><td>CA</td><td>Students write up ways of improving the experiment, using table 3.7 as a basis.</td></tr>
<tr><td colspan="2">Catalase practical to measure enzyme activity (3) – planning further investigations</td></tr>
<tr><td>SA</td><td>The students are to design their own investigations. Students recall the importance of choosing:
• a suitable way of changing the independent variable
• a suitable range of values for the independent variable
• a suitable method of measuring the dependent variable
• suitable ways of controlling other variables.</td></tr>
<tr><td>MA</td><td>Students design experiments to investigate the effect of:
• temperature
• pH
• substrate concentration
• enzyme concentration
on the activity of catalase.
This could be in the form of a table such as:
<table>
<tr><th>IV</th><th>How varied</th><th>DV</th><th>How measured</th><th>Controlled variables</th><th>How controlled</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table></td></tr>
<tr><td>CA</td><td>Students write up their plans.</td></tr>
</table>

Catalase practical to measure enzyme activity (4) – optional – students carry out planned experiments	
SA	Students recall safety requirements and modify their plans if: • there are safety issues • there are issues of reliability or practicability.
MA	Students carry out their planned experiments (this may take several sessions).
CA	Students write up the results of their investigations.
Catalase practical to measure enzyme activity (5) – analysing the results	
SA	Discuss with the students the reasons for: • calculating and using mean values • plotting graphs of their results.
MA	Students calculate means and plot graphs of their results or of the data supplied in the textbook.
CA	Students write up conclusions from their graphs.
Types of enzyme inhibitors	
SA	Students discuss the concept of an inhibitor and suggest how another substance might reduce the turnover rate of an enzyme. Students focus on turnover rate.
MA	Students examine that there are different types of inhibitors: • irreversible • reversible • competitive • non-competitive and explain how they work. Students make notes on this.
CA	Students explain the action of the painkillers: • aspirin • ibuprofen in terms of enzyme inhibition.
Enzyme inhibitors in living cells	
SA	Students examine the concept of a metabolic pathway.
MA	Students discuss why metabolic pathways need to be 'switched on and off'. Students examine that the end-product of a metabolic pathway often inhibits one of the earlier reactions, thus limiting the rate of the production of the end-product.
CA	Students make notes on the importance of: • end-product inhibition • activators in controlling metabolic pathways.

Answers to review questions

1. D
2. B
3. B
4. C
5. C
6. D
7. A
8. D
9. D
10. D

Answers to end of unit questions

1. a) Non-protein substance that binds with apoenzyme to form active enzyme

   b)

Type of group	Organic	Protein	Binds tightly
Apoenzyme	✓	✓	✓
Coenzyme	✓	✗	✓
Ion	✗	✗	✗

   One mark per correct row

   If no correct rows, allow one mark per correct column

2.

Factor controlled	How controlled	Reason for controlling factor
Temperature	Water bath	Temperature increases/ decreases rate of reaction High temperature may denature enzyme
pH	pH buffer	Changes in pH can alter charge on amino acids in the active site
Substrate concentration	Equal strength solutions	Different concentrations influence rate of reaction by affecting number of active sites in use

3. a) Enzyme A 36–38 °C

   Enzyme B 76–78 °C

   These temperatures show peak enzyme activity.

   b) Enzyme B

   high optimum temperature

   thermophilic means 'heat-loving'

   c) Rate of reaction increases

   increased temperature gives more kinetic energy

   increased collisions between enzyme and substrate

   more enzyme–substrate complexes formed

4. a) i) Reaction velocity increases

   increased number of substrate molecules

   increased number of collisions with active sites

   ii) Reaction velocity levels off

   all active sites occupied at any time

   extra substrate molecules have no effect

b) Line increases to same maximum
but maximum reached at a lower concentration

5. a) Initial energy of reactants is the same
final energy of products is the same

b) *Three of*:
X and Y represent activation energies
higher for uncatalysed reaction
because catalyst/enzyme allows transition state
bonds in reactants put under strain

c) *Three of*:
Lower activation energy
so more reactant molecules have sufficient kinetic energy
to 'climb activation energy hill'/to achieve activation energy levels
so more reactions per second

6. a) Any three suitable examples such as:
washing powders, leather industry, brewing, baking

b) Reduce heating costs
reduce emissions

c) Lower temperatures due to lower energy requirements
reduce amount of fuel burned
reduce CO_2 emissions

7. a) i) 19 °C

ii) May have been quicker just lower or just higher than this
need more temperatures to be sure

b) Enzyme is a catalyst
only speeds up the reaction, does not cause it to happen

c) i) Increased temperature increases kinetic energy
more collisions
more enzyme–substrate complexes

ii) Increased temperature causes increased vibration of atoms in the enzyme molecule
begins to denature/active site changes shape
substrate molecules will no longer fit/bind with active site

8. a) *Four of*:
Inhibitor binds with allosteric site/site away from active site
enzyme undergoes conformational change
active site changes shape
substrate molecules cannot bind

extent of inhibition does not depend on amount of substrate/extent of inhibition only depends on amount of inhibitor

b) (i) Substance D is the end product
each reaction dependent on the one before it
if the chain of reactions is broken, end product will not be formed
end product inhibits E1
by non-competitive inhibition

(ii) End product can inhibit an enzyme in a pathway
so pathway is 'switched off'/cannot take place
so concentration of end product decreases
as it is used up by the cell
as concentration decreases, inhibition of enzyme decreases
enzyme becomes active and pathway active again

Answers to end of unit crossword puzzle

Across

6 specific
13 ASE
15 non-competitive inhibitor
16 induced fit
17 hydrolysis
18 temperature
20 cofactor

Down

1 biological catalysts
2 enzyme–subtrate complex
3 washing powder
4 optimum
5 activation energy
7 catalysts
8 lock and key
9 active site
10 competitive inhibitor
11 concentration
12 globular protein
14 apoenzyme
19 PH

Further resources

http://www.biochemistry.org/Portals/0/Education/Docs/BASC03_full.pdf – research and further activities related to enzymes

http://www.biology.arizona.edu/biochemistry/problem_sets/energy_enzymes_catalysis/energy_enzymes_catalysis.html – problems/exercises on enzymes

http://www.practicalbiology.org/areas/advanced/bio-molecules/enzyme-catalysed-reactions/ – example experiments

http://www.practicalbiology.org/areas/advanced/bio-molecules/quantitative-food-tests/ – example food test experiments

Cell biology

Unit 4

This unit should fill approximately **29 periods** of teaching time.

Learning competencies for Unit 4

By the end of this unit students should be able to:

- Tell the history of cell biology.
- Describe cell theory and investigate the size, structure and shape of cells.
- State the basic functions of cells.
- Appreciate that all life on Earth originates from cells.
- Appreciate that there are just two basic types of cells: prokaryotic and eukaryotic cells.
- Give examples and describe the basic structure of each type.
- Explain the difference between prokaryotic and eukaryotic cells.
- Discuss the importance of a cell membrane.
- Describe the composition and arrangement of lipids and proteins in the membrane.
- Compare the Davson–Danielli and fluid mosaic models.
- Construct and show the arrangement of the phospholipids and proteins in the fluid mosaic model.
- Explain the role of glycoprotein and other components in the cell membrane.
- Name the different parts of the cell and explain their functions.
- State and explain the mechanisms of substance transport across a cell membrane.
- Conduct an experiment to show movement of solvent through a semi-permeable membrane.
- Demonstrate osmosis at a semi-permeable membrane.
- Explain that the size of a cell changes by osmosis because of the inflow and outflow of water.
- Appreciate that osmosis is responsible for everyday life phenomena.

This section should fill approximately **8 periods** of teaching time.

4.1 Cell theory

Learning competencies

By the end of this section students should be able to:

- Tell the history of cell biology.
- Describe cell theory and investigate the size, structure and shape of cells.
- State the basic functions of cells.
- Appreciate that all life on Earth originates from cells.

Starting off

Introduce the unit by asking students to name as many different types of cells as they can think of. Inevitably, this will start with them naming human cells, but with a little prompting, they can easily widen this to include cells from all kinds of other organisms.

It could even be worth making a display, which could highlight:

- features that cells have in common
- the range of size of the different cells
- the range of functions of different cells
- the way in which some different cells are adapted to their functions

Students should appreciate that any serious study of cells, even their discovery, had to wait for the invention of reliable microscopy.

Teaching notes

The Students' Book provides a description of the major events in the history of the development of the modern cell theory and a slightly more inclusive one in tabular form. These could form the basis for students to construct a time line of their own using the diagram below as a format.

They could add more detail to the timeline, such as:

- photographs/drawings of the scientists involved
- illustrations of what they found (where relevant)
- descriptions of any theories they put forward
- any limitations of their work

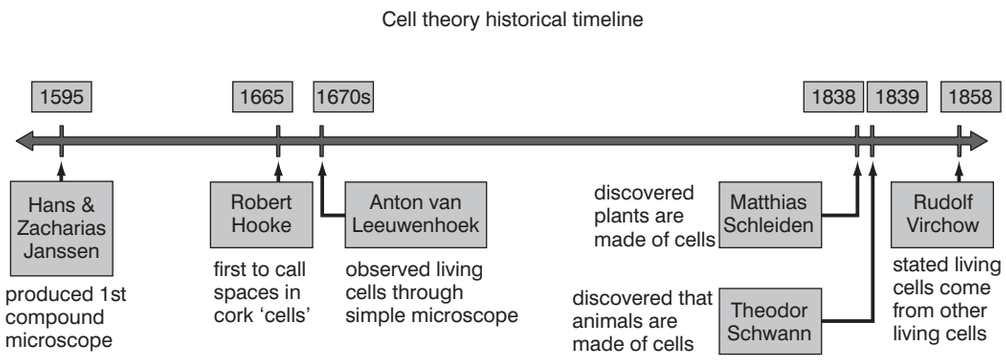


Figure 4.1

Ask students how big cells are and you will likely get the answer 'microscopic'. Whereas this is a true statement for most cells, it does not really answer the question, and, often, students do not really have an idea as to the size of cells. Nor do they really understand what units cell size is measured in.

Introduce students to the problems of measuring very small objects in everyday units – the number of decimal places involved is bewildering and not easily comprehensible. Introduce them to:

- micrometres (μm, 0.000 001 m) and
- nanometres (nm, 0.000 000 001 m)

and the way to convert them to everyday units such as millimetres.

To measure the size of cells accurately, a stage micrometer and eyepiece graticule are essential. Students find the theory behind using these a little confusing and so it must be presented in bite-sized chunks!

You could try the following approach.

- If there was a 'built-in' ruler on the slide of the cells we were looking at, we could measure the cells against that.
- However, it is not practical to try to have a scale on the slide and cells at the same time – there just isn't room.
- We could place a 'ruler' inside the eyepiece and as we look at the cells we could see this ruler at the same time.
- But when we changed magnification the ruler in the eyepiece would not take account of this and measure the same part of the field of view as the same size!
- So we place a ruler on the slide (the stage micrometer) without cells and in the eyepiece (the graticule) at the same time.
- For each magnification, we work out how the scale on the graticule relates to the scale in the eyepiece – this is called calibrating the eyepiece graticule.
- Now we can just use the eyepiece graticule, because we know (from the calibration exercise) exactly what the divisions on the graticule are measuring.

A practical exercise in calibrating an eyepiece graticule and using it to measure onion epidermis cells can be found at:

http://www.cambridge.org/uk/education/secondary/science/alevel/coas/downloads/biology_practical.pdf

If it is not possible to use a graticule and a stage micrometer, an alternative method is described that will give much less accurate results, but results that are, none-the-less, of the right order of magnitude. All that is needed is a transparent ruler with millimetre divisions.

From the concept of linear dimensions of a cell, we move on to surface area and volume and the relationship between the two in different sized cells. If students carry out the exercise in the Students' Book, they will see that as the linear dimensions increase, then the surface-area-to-volume ratio decreases.

The consequences of this are best explained in terms of 'supply' (of oxygen is the easiest to understand) and 'demand'. If they appreciate that the volume creates the demand (the more cell there actually is, the more oxygen it will require) and that the cell surface (and so the surface area) determines the supply, then if the volume increases faster than the surface area, demand will outstrip supply.

The section ends with a question about the consequences of the change in surface-area-to-volume ratio. If the supply of oxygen is inadequate, the cell will not be able to respire effectively and release the energy needed.

Explain to the students that all the same arguments just applied to cells can also be applied to organisms. During evolution, further increase in size of organisms has occurred because either:

- organisms developed gas exchange surfaces with large surface areas to restore the surface-area-to-volume ratio
- organisms evolved shapes with a high surface-area-to-volume ratio.

SA = starter activity MA = main activity CA = concluding activity	
The origins of modern cell theory (1)	
SA	Students discuss the nature of cells and the idea of cell theory.
MA	Students write down as many types of cells as they can think of - note they should not all be human cells. Students then put their lists together and discuss.
CA	Students read and review the timeline of discoveries described in the textbook - they can continue as homework if necessary.
The origins of modern cell theory (2)	
SA	Students create tables to summarise what they have learnt about the development of cell theory.
MA	Students split into groups and begin to research their presentations for activity 4.1, using libraries, the Internet, and other sources of information where possible.
CA	Students continue their presentation planning.
Presentations: cell theory	
SA	Students make final preparations in their groups for their presentations.
MA	Students make their presentations for activity 4.1 to the rest of the class.
CA	Students discuss and rate the presentations.
Measuring the size of cells (1)	
SA	Students discuss the range of sizes of cells, giving examples.
MA	Students describe the metre as the SI unit of length and relate derived units to the metre, explaining how conversion between derived units can be calculated and working in groups on example calculations.
CA	Students prepare for activity 4.2 by reading through the text and assembling the equipment required.
Measuring the size of cells (2)	
SA	Students complete activity 4.2. Guidance on this and similar activities is given in the teaching notes section.
MA	Students discuss results of activity 4.2 and complete the 'How you make a rough estimate of cell size' activity from page 117.
CA	Students write up their practicals and calculate cell size.
Size and surface-area-to-volume ratio (1)	
SA	Students discuss what is meant by: • linear dimensions • surface area • volume in relation to a cube.
MA	Students carry out activity 4.3. Help students design a table for their results and refresh their understanding of how to plot a graph before letting them begin.
CA	Students plot graph of results of activity 4.3.

Size and surface-area-to-volume ratio (2)	
SA	Students review and discuss the graphs they made in the previous lesson.
MA	Students explain how different surface-area-to-volume ratios of a cell wall affect how well exchange occurs at a cell surface.
CA	Students divide into three groups ready for preparing activity 4.4 in the next lesson, and familiarise themselves with the idea and structure of the debate.
Size and surface-area-to-volume ratio (3)	
SA	Students break into their groups, assign roles within the groups and discuss their approach to the activity 4.4 debate
MA	Students complete the debate in activity 4.4.
CA	Students vote on the outcome of the debate and write up the results.

Answers to review questions

1. C
2. B
3. D
4. B
5. D
6. B
7. D
8. B
9. C
10. C

This section should fill approximately **4 periods** of teaching time.

4.2 Types of cells

Learning competencies

By the end of this section students should be able to:

- Appreciate that there are just two basic types of cells: prokaryotic and eukaryotic cells.
- Give examples and describe the basic structure of each type.
- Explain the difference between prokaryotic and eukaryotic cells.

Starting off

If you ask the students for the two main types of cells, they will almost certainly answer plant and animal cells. It must be explained that, although there are differences between these two types of cells, they are essentially built to the same basic plan; there are a distinct nucleus, membrane-bound organelles and a plasma membrane to control entry and exit. Plant cells have some extra structures, but the core divisions are the same. Explain that these are called eukaryotic cells, they have a true, membrane-bound nucleus. Introduce the prokaryotic cells that do not contain a membrane-bound nucleus.

Teaching notes

The nature of prokaryotic and eukaryotic cells is dealt with in sufficient detail in the Students' Book, with a summative table at the end of the section.

Further information on the structure of prokaryotic and eukaryotic cells can be found at the websites listed in the Further Resources section.

SA = starter activity MA = main activity CA = concluding activity	
Prokaryotic and eukaryotic cells	
SA	Students examine that, although there are many hundreds of different cells, they can all be classified into just two main types called prokaryotic and eukaryotic.
MA	Students study the structure of a bacterial cell (prokaryotic), a 'typical' plant cell (eukaryotic) and a 'typical' animal cell. Students discuss the features that plant and animal cells (as eukaryotic cells) share and the differences between these cells and bacterial cells (prokaryotic cells).
CA	Students produce a table showing which structures are present in which cells.
The origin of eukaryotic cells (the endosymbiont theory)	
SA	Students study the features of mitochondria and chloroplasts that make them similar to some ancient bacteria.
MA	Students examine the way in which the eukaryotic cell is thought to have originated from prokaryotes, according to the endosymbiont theory.
CA	Students list the types of organisms that have eukaryotic cells and those that have prokaryotic cells. Figure 4.18 can be used as a basis.
The differences between eukaryotic cells and prokaryotic cells	
SA	Students revise the features found in the different types of cells.
MA	Students list the differences between eukaryotic and prokaryotic cells and discuss the consequences of these differences between the cells.
CA	Students copy table 4.2 into their notes.

Answers to review questions

1. D
2. C
3. B
4. C
5. A

This section should fill approximately **17 periods** of teaching time.

4.3 Parts of the cell and their functions

Learning competencies

By the end of this section students should be able to:

- Discuss the importance of a cell membrane.
- Describe the composition and arrangement of lipids and proteins in the membrane.
- Compare the Davson–Danielli and fluid mosaic models.
- Construct and show the arrangement of the phospholipids and proteins in the fluid mosaic model.
- Explain the role of glycoprotein and other components in the cell membrane.
- Name the different parts of the cell and explain their functions.
- State and explain the mechanisms of substance transport across a cell membrane.
- Conduct an experiment to show movement of solvent through a semi-permeable membrane.
- Demonstrate osmosis at a semi-permeable membrane.
- Explain that the size of a cell changes by osmosis because of the inflow and outflow of water.
- Appreciate that osmosis is responsible for everyday life phenomena.

Starting off

Recap the structure of a eukaryotic cell, mentioning the major organelles once more. Direct the students' attention to the problem of controlling what enters and leaves the cell. Get them to realise that it must be the cell surface membrane (plasma membrane) that carries out this function (rather than the cell wall, which some believe also regulates movement into and out of cells) as animal cells have no cell wall.

Teaching notes

Introduce the topic of the cell membrane by discussing its various functions in:

- controlling what enters and leaves the cell
- cell signalling and cell recognition.

Then discuss with the students the history of the development of our understanding of the structure of the plasma membrane. A timeline of the important developments is provided in the Students' Book.

Another, slightly more detailed account of this timeline can be seen at:

http://www.nature.com/nrm/journal/v4/n5/images/nrm1102-i1.jpg

It is then necessary to focus on the Davson–Danielli model to show how it was initially thought to be a plausible model based on the available evidence. Students should realise that, although the model was developed without the aid of electron micrographs, as these became available they were initially taken as evidence confirming the Davson–Danielli model. The three layers apparent in the micrographs were taken as being the two outer protein layers and a middle lipid layer.

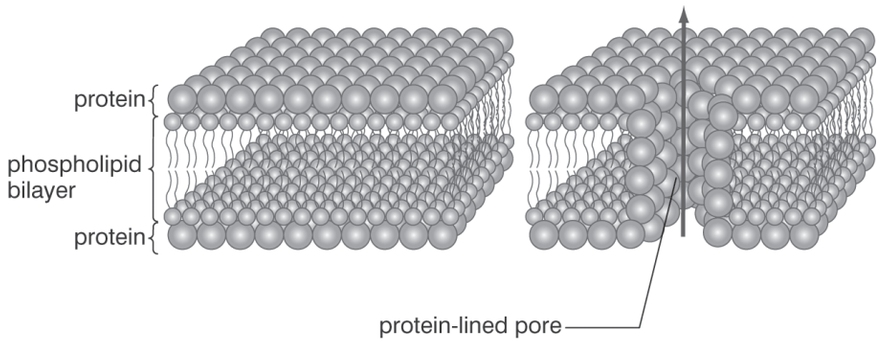


Figure 4.2

Discuss then with the students the evidence that began to accumulate that was incompatible with the Davson–Danielli model.

1. Biologists knew that membranes had some properties of fluids. The Davson–Danielli model did not make it clear how such fluidity could occur without tearing or breaking of bonds.
2. Microsurgical methods reinforced the idea that the membrane was a fluid. If a cell membrane is pushed with a probe, it bends like the surface of a balloon, and springs back when released. If it is penetrated, however, the membrane simply conforms around the probe. When the probe is withdrawn, the membrane reseals as if it were a liquid flowing into itself.
3. New chemical methods revealed that the proteins of membranes were highly variable in both quantity and type.
4. The new methods also showed that the proteins in membranes, rather than being hydrophilic (as the Davson–Danielli model required), were largely lipophilic and hydrophobic.
5. Using 'freeze-fracture' techniques, biologists were able to split cell membranes along the lipid layer. This revealed a smooth surface with bumps sticking out. The bumps turned out to be proteins – in the middle of the membrane. They could not merely be a layer coating the central lipids.

For these reasons the Davson–Danielli model was rejected in 1972 in favour of the fluid mosaic model devised by Singer and Nicholson.

Discuss with the students the structure of the membrane as shown in the fluid mosaic model shown in figure 4.22 in the Students' Book.

Students should understand that the structure of the membrane is highly complex, but need a diagram that they can reproduce, if necessary, that shows the essence of the membrane without showing every detail. Something like the diagram below would be appropriate.

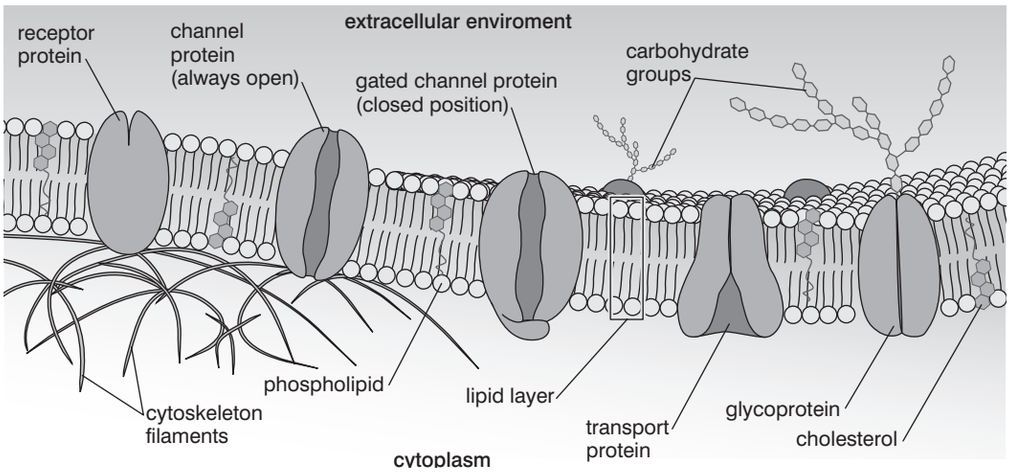


Figure 4.3

Discuss with the students the role of the various proteins in the membrane together with the role of cholesterol in maintaining membrane stability.

Next introduce the different ways in which substances cross the membrane. The students may well have heard of some of these before, but will not be aware of the way in which the process is related to cell membrane structure. Discuss the division of processes into passive processes that require no input of metabolic energy and active processes that require metabolic energy to take place. These are summarised in table 4.4 in the Students' Book.

After a general discussion, it is best to introduce simple diffusion as the first transport process. Ensure that students understand that the ability of particles to cross the membrane by simple diffusion depends on their ability to pass between adjacent phospholipid molecules. For particles to do this they must be:

- small
- lipid soluble
- non-polar

The only particle that can cross membranes by diffusion and does not quite conform to all of these criteria is the water molecule. It is able to pass the membrane because of its extremely small size. Following the discussion of the process itself, the factors affecting the rate of diffusion are discussed and summarised mathematically in Fick's law.

If it was established in the students' mind that only certain particles could pass the membrane by simple diffusion, the need for a process such as facilitated diffusion will be readily appreciated. Discuss with students the distinction between a protein pore and a carrier protein. This is illustrated in figure 4.26 in the Students' Book. Explain that the dependence of the process on carrier proteins or protein pores sets a finite limit on the rate of the process. When all the protein carriers/ pores are occupied all the time, the process cannot proceed any faster, despite any changes in the concentration gradient.

We then come to the third passive process – osmosis. The concept of water potential, central to an understanding of osmosis, does not come naturally to the students. The idea of assigning a maximum value of zero and making all other values negative is counterintuitive and needs careful explaining. The explanation of water potential (in terms of hydration shells reducing the number of 'free water molecules' in a system) given in the Students' Book is reasonably accurate at this

level, where discussions of free energy are not really appropriate. The diagram below can be used to illustrate the process, showing:

- the partial permeability of the membrane
- the 'free' and 'attached' water molecules in the solution
- the concept of net movement of water molecules.

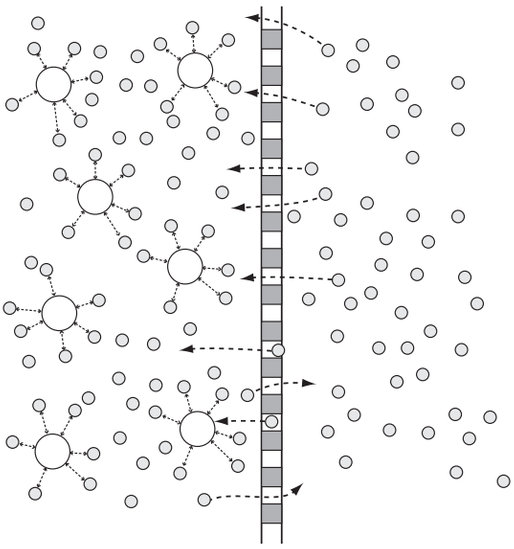


Figure 4.4

With the concept of water potential established, the definition of osmosis then resembles the definition of diffusion, except that, in the case of osmosis, the process can *only* take place across a membrane. The term partially permeable is now the Institute of Biology's preferred description of such membranes (rather than semi-permeable).

The influence of solutions with different water potentials on plant and animal cells is described and illustrated in the Students' Book. The importance of turgor in plant cells should be discussed with the students.

There are many different practical opportunities that are based on the process of osmosis. Two are described in the Students' Book. One is based on a non-living system and the other on living plasma membranes.

Next we encounter the first of the active processes – active transport. The need for an energy input to move substances against a concentration gradient can be likened to moving a boulder against a physical gradient. You have to push it uphill, whereas it will roll downhill (move down the gradient) freely.

The mechanism of the sodium–potassium pump is used to illustrate how ATP binds to the transport protein and is hydrolysed to ADP and P_i during the process, setting in motion the series of events that then move sodium ions and potassium ions in opposite directions across the membrane. The critical point for the students to appreciate is not particularly *how* ATP binds, but the fact that it does bind and release energy for the process to take place.

Endocytosis and exocytosis are readily appreciated as active processes by most students. Both processes are illustrated to an appropriate level of detail in the Students' Book.

Table 4.5 provides a useful summary of the main features of the processes that transport substances across plasma membranes.

The practical opportunity of investigating the effect of temperature on beetroot cell membranes is best carried out using a colorimeter, but qualitative or semi-quantitative data can be obtained without a colorimeter by:

- preparing in advance extracts from beetroot cells that have been in water of different temperatures for different lengths of time to give a range of coloration
- placing these in order from most intense to least intense and numbering them (1 is least intense)
- students carry out the practical and, at the end, match their extracts to one of the numbered reference tubes (or assign a value between two of the reference tubes).

The table below gives some data that can be used for analysis if it is not possible to carry out the practical. Note that these readings are for transmission, not absorbance, as described in the experiment; decreasing transmission will indicate more pigment escaping from the cells into the water during the experiment.

Temperature (°C)	Observation	Colorimeter reading (% transmission of light)			
		Sample A	Sample B	Sample C	Mean
0	clear	100	98.5	99.0	99.2
22	very pale pink	93.9	95.0	96.0	95.0
42	very pale pink	80.1	77.0	76.9	78.0
63.5	pink	26.3	29.9	31.0	29.1
87	dark pink	0.7	0.7	1.0	0.8
93	red	0.0	0.1	0.0	0.0

Students should be able to explain the changes using their knowledge of the fluid mosaic model and their knowledge of lipids and proteins. There are two influences on the permeability of the membrane:

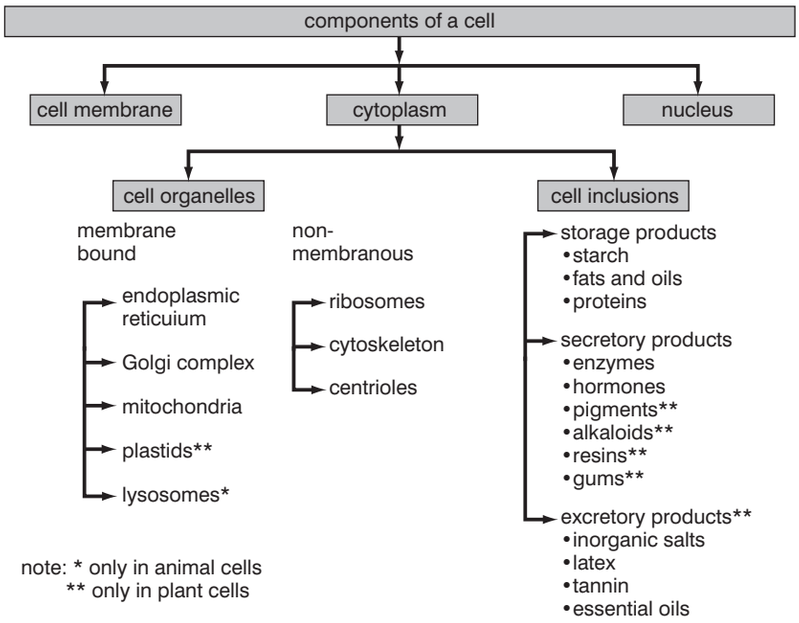
- the increase in the fluidity of the membrane (causing temporary 'gaps' to appear and disappear) due to the increased mobility of the lipids as temperature increases
- the denaturing of the proteins causing large permanent gaps to appear.

The first is a gradual trend, whereas the second is more sudden. Students should be asked to deduce from these results when they think that this happened and how they could modify the experiment to give a more accurate answer.

Having discussed at some length the structure and properties of the cell membrane, we now address the other cell organelles. The descriptions in the Students' Book are accompanied by electron micrographs of the organelles to help students to visualise the nature of each.

Students often find the detailed structure of a cell a little bewildering as it seems to be just a list of various 'bits' with no obvious relation to each other. The classifications below of the structures in a cell may help in introducing some sort of order into the nature of the components of a cell.

Classification by nature of the component:



Classification of component by location:

Cell

Nucleus	Cytoplasm	Surface
nuclear membrane	mitochondria	cell membrane
nucleolus	chloroplasts**	cell wall**
chromosomes	lysosomes*	
	rough endoplasmic reticulum	
	smooth endoplasmic reticulum	
	ribosomes	
	centrioles	
	Golgi apparatus	

It is recommended that some method of grouping the organelles is adopted so that there is structure and focus to the lessons.

Finally, the technique of cell fractionation is discussed to explain to students how biologists have been able to isolate individual organelles so that they could carry out experiments with them to find out how they carry out their functions.

The principle of larger, heavier organelles settling out at lower centrifugation speeds is usually quite readily accepted by most.

One point worthy of stressing is that storing the sample in an isotonic solution is to protect the organelles from osmotic damage, not the cell. The cell will soon be processed in a blender!

SA = starter activity MA = main activity CA = concluding activity	
The importance of the cell membrane	
SA	Students examine the distinction between a cell membrane and a cell wall that may be present in some cells. Students examine that: • the cell wall is largely inert, provides support, but is freely permeable to all substances • the cell membrane is an active structure, provides no support, but is selectively permeable and therefore controls what enters and leaves the cell.
MA	Students discuss the different ways in which substances can enter and leave a cell and the membrane's role in cell signalling.
CA	Students make a table giving functions of the cell membrane with examples.
The structure of the cell membrane (1)	
SA	Students review with the teacher the evidence that eventually led to the development of the fluid mosaic model of the cell membrane.
MA	Students examine how advances in technology provided ever more information and allowed an increasingly sophisticated model of the structure of the membrane to develop. Students be aware of the following models of membrane structure: • Davson–Danielli 1935 • Davson–Danielli 1954 • Singer and Nicholson (fluid mosaic) 1972
CA	Students label photocopied diagrams of each model.
The structure of the cell membrane (2)	
SA	Students go back to their labelled diagrams and produce a table showing the similarities and differences between the models.
MA	Students list the key structures in the fluid-mosaic model and describe their functions. Make sure they include a description of the different types of proteins.
CA	Students make notes on why the fluid-mosaic model is so called.
Crossing the cell membrane	
SA	Students review the nature of the membrane and relate this to the molecules that could physically pass through the bilayer.
MA	Students examine the distinction between active and passive processes that are involved in moving particles across the membrane.
CA	Students write up notes on the substances that can cross the membrane unaided, explaining why.
Passive processes – simple diffusion	
SA	Students review the idea that although no energy from metabolism is required for these processes, the idea that they don't need energy is erroneous. The processes are dependent on the kinetic energy of the particles.
MA	Students discuss and revise their ideas on simple diffusion. Students discuss the concepts of: • concentration gradient • surface area • diffusion distance as they relate to the process of simple diffusion across a cell membrane and from them explain the derivation of Fick's law.
CA	Students make notes on the process of simple diffusion, stating and explaining Fick's law.

Passive processes - facilitated diffusion	
SA	Students recall the factors that affect simple diffusion and discuss that all of them also affect facilitated diffusion, plus one extra (the number of carrier pores or ion pores that are present in the membrane).
MA	Students study figure 4.26 and use it to help them make notes on facilitated diffusion. They can then make a table comparing simple and facilitated diffusion.
CA	Students discuss their tables in pairs and read the section on osmosis to prepare for the next lesson.
Passive processes – osmosis (1)	
SA	Students state the definition of osmosis that they know from earlier studies; this will probably involve some difference in 'concentration of solutions'. Students examine the idea that osmosis relies on a gradient in a similar way to diffusion, but this cannot be described as a concentration gradient as concentration is usually a measure of one substance dissolved in another.
MA	Students explain the concept of water potential as a measure of the free water particles in an aqueous system. Students must understand that all water potential values are relative values as the water potential of pure water is arbitrarily set at zero. From this, students copy and then explain a definition of osmosis based on water potential. Students then discuss the terms isotonic, hyptonic and hypertonic and make notes on the same.
CA	Students set up activity 4.8. The experiment will be completed in the next lesson. Detailed guidance on facilitating students' understanding of osmosis is given in the teaching notes.
Passive processes – osmosis (2)	
SA	Students discuss the direction of water movement when cells are placed in each of the above solutions, and discuss why the consequences of being placed in such solutions are different for plant and animal cells.
MA	Students complete activity 4.8 with the equipment set up in the last lesson.
CA	Students draw their graphs and write up their results.
Passive processes – osmosis (3)	
SA	Students set up activity 4.9 and prepare the table for their results. Ensure they read the instructions carefully and understand the aim of the experiment before they begin. As before, split the students into pairs or groups according to how much equipment is available.
MA	Students complete activity 4.9.
CA	Students write up activity 4.9. Show them how to construct the graph, which will have to show both positive and negative percentage changes in mass. The concentration of the solution producing zero change in mass has a water potential equivalent to that of the potato cells.
Osmosis in an Egg	
SA	Students read through the instructions for activity 4.7 and collect the necessary equipment. Explain in detail the process and the aim of the experiment, using the steps in the textbook as a guide. Ensure that there is sufficient time and space in the room for students carry out the experiment and divide them into pairs or groups according to availability of space and equipment.
MA	Students complete activity 4.7.
CA	Students write up the results of their practical and discuss.

Active processes (1)	
SA	Students examine the concept by comparing this with movement of a rock up and down a slope. The stone will roll down the slope – comparable to movement down a concentration gradient, but energy must be put in to move it up the slope – comparable to moving against a concentration gradient.
MA	Students use figures 4.32, 4.33 and 4.34 as a basis for discussion and understanding the idea of active processes. They then make notes on the different types of active processes.
CA	Students discuss the role of ATP in active processes.
Active processes (2)	
SA	Students brainstorm the differences between the active and passive processes they have studied.
MA	Students design and complete a table similar to table 4.4 to record their comparison of active and passive processes.
CA	Students define different active and passive processes without reference to notes in response to direct questions from you during a general discussion.
The effect of temperature on the permeability of a cell membrane (1)	
SA	Students revise the structure of a membrane. Students suggest how heat may affect: • proteins in the membrane • the phospholipids in the membrane.
MA	Students discuss the idea that any factor that disrupts membrane structure will affect permeability. Students work in pairs to discuss the likely effects of alcohol and changes in pH, and then come together for a class discussion on this.
CA	Students design a table in which to record the results of activity 4.10, which they will complete in the next lesson.
The effect of temperature on the permeability of a cell membrane (2)	
SA	Students set up activity 4.10. Ensure students are aware of safety issues when working with water baths and talk them through the set up by demonstrating at the front of the class. Again, divide students into pairs or groups according to availability of equipment.
MA	Students complete activity 4.10: this will take until the end of the lesson, given the waiting times involved.
CA	Students complete activity 4.10, noting their results in the tables they prepared in the last lesson.
The other cell organelles (1)	
SA	Students discuss and list the organelles found in plant and animal cells.
MA	Students discuss and make notes on the structure and function of the major organelles.
CA	Students make a table to summarise the above. A suggested format is given below.

Organelle	**Structure (include diagram and description)**	**Functions**

The other cell organelles (2)	
SA	Students review (and complete if necessary) the tables they made in the last lesson.
MA	Students complete activity 4.11.
CA	Students give their presentations to the rest of the class, briefly.

How do biologists study the organelles?	
SA	Students discuss the need to isolate organelles to be able to study individual functions. Get the students suggest the basis for a separation technique.
MA	Students study a centrifuge if possible and either an explanation of how it works or a demonstration of a separation of a suspension (e.g. chalk and water). Students examine the ultracentrifuge works on the same principle but spins at much higher speeds, creating much higher sedimentation forces. Students examine the importance of the preparation of the cell sample prior to centrifuging.
CA	Students answer multiple choice questions.

Answers to review questions

1. A
2. A
3. C
4. C
5. D
6. A
7. C
8. C
9. D
10. D

Answers to end of unit questions

1. a) i) The cell is the unit of structure, physiology, and organisation in living things.

   The cell retains a dual existence as:
   - a distinct entity, and
   - a 'building block' in the formation of organisms.

   ii) Cells arise by spontaneous generation

   iii) Virchov

   b) The cell is the unit of structure, physiology and organisation in living things.

   Cells contains hereditary information that is passed from cell to cell during cell division.

   All cells have basically the same chemical composition.

   All energy flow (metabolism & biochemistry) occurs within cells.

2. a) Hooke developed one of the first microscopes and saw dead cells in cork.

   b) van Leeuwenhoek saw living protoctista and living bacteria.

   c) Dutrochet proposed that all living things are made of cells and that growth occurs because of the addition of cells.

3.

Feature	Prokaryotic cells	Eukaryotic cells
Size	1–10 µm	10–100 µm
Nucleus	absent	present
DNA	• in a continuous loop	• linear • associated with protein
Mitochondria	absent	present
Ribosomes	70S ribosomes	80S ribosomes

4. a) Increase surface area
more transport proteins
for facilitated diffusion

b) Mitochondria
release energy/produce ATP
during respiration
needed for active transport

c) A – facilitated diffusion as transport protein but no ATP
B – osmosis as water only moves by osmosis
C – active transport as transport protein and ATP
D – simple diffusion as no transport protein

5. a) i) $\frac{79 + 49 + 44 + 24}{18 + 51 + 52 + 76}$

= 1.005:1

ii) *Two of*:
Transport protein
ion pore
glycoprotein/cell recognition

iii) Formation of glycoproteins/antigens

iv) Proteins usually associated with transport
cell D more actively involved in transport than A

b) i) Move around more
temporary gaps appear
so increase permeability of membrane

ii) 30–50 °C

iii) Wider range
20–60 °C

iv) Stabilise phospholipids
reduce fluidity of membrane

6. a)

Organelle	**Function**
Nucleus	Contains DNA, regulates cell metabolism
Ribosome	Protein synthesis
Mitochondrion	Site of aerobic respiration, produces most of the ATP in a cell
Golgi body	Modifies structure of protein molecules
Lysosome	Contains hydrolytic enzymes; digests worn-out organelles
Chloroplast	Photosynthesis
Plasma membrane	Controls entry and exit of substances from cell
Cell wall	Gives cell support and rigidity

b) Cells stored in cool, isotonic and buffered solution
prevent damage to organelles
processed in blender
release organelles
spun at low speeds
nucleus settles out
spun at higher speeds
other organelles settle out according to density/mass

7. a) 1 – phospholipid bilayer
2 – glycoprotein
3 – cholesterol
4 – ion pore/channel

b) Transport protein
moves ions across membrane
by facilitated diffusion

c) Membrane has fluid properties
due to phospholipids/proteins moving around
proteins studded in phospholipids like a mosaic

8. Award marks in the following categories:

Category	Marks	Descriptors
Breadth	0–2	Student involves all the main aspects of the topic in reasonable detail
Relevance	0–2	Student does not bring in irrelevant material, although some extra, related biology is acceptable
Communication	0–2	Essay is well written and logically presented, making good use of scientific vocabulary
Biological accuracy	0–5	Biological content is not at the required level and may contain significant misconceptions
	6–10	Biological content is essentially correct and of an acceptable standard although there may be an occasional slight error
	11–15	Essay is of a high standard with no significant errors.

Answers to end of unit crossword puzzle

Across

1 Golgi body
6 active transport
9 osmosis
11 chloroplast
12 fluid mosaic
15 Schleiden and Schwann
18 micrometre
20 plasma membrane
21 mitochondrion
22 Robert Hooke
23 eukaryotic

Down

2 Davson and Danielli
3 nucleus
4 prokaryotic
5 simple diffusion
7 Rudolf Virchow
8 ribosome
10 water potential
11 cell fractionation
13 carrier protein
14 van Leeuwenhoek
16 amoeba
17 channel protein
19 membrane

Further resources

http://www.biologyreference.com/Gr-Hi/History-of-Biology-Cell-Theory-and-Cell-Structure.html – cell theory and cell structure

http://kentsimmons.uwinnipeg.ca/cm1504/celltheory.htm – cell theory

http://www.bio.miami.edu/~cmallery/150/unity/cell.text.htm – more cell theory

http://library.thinkquest.org/12413/structures.html – structure of prokaryotic and eukaryotic cells

http://www.tvdsb.on.ca/westmin/science/Sbi3a1/cells/cellquiz.htm – cell structure quiz

http://library.thinkquest.org/12413/structures.html – organelles

http://learn.genetics.utah.edu/content/begin/cells/insideacell/ – interactive resource

http://www.johnkyrk.com/ – cell biology animations

http://www.cellsalive.com/index.htm – cell biology activities and resources

Energy transformation

Learning competencies for Unit 5

By the end of this unit students should be able to:

- Describe the structure of ATP and its role in cellular metabolism.
- Explain how ATP is adapted to its role as an energy transfer molecule within a cell.
- Describe how ATP is produced in a cell.
- Locate where the different processes of cellular respiration occur in the cell.
- Explain the role of electron donors and acceptors.
- Describe in detail each stage of aerobic respiration.
- Draw and label the structure of a mitochondrion.
- Explain the processes of alcoholic fermentation and lactate production.
- Appreciate the importance of lactate production during running and other sports.
- Summarise the metabolism of proteins, polysaccharides and lipids.
- Draw, label and describe a chloroplast.
- Locate where light-dependent and -independent processes occur in the chloroplast.
- Name the products of the light-dependent and –independent processes.
- Explain how the structure of a photosystem is related to its function.
- Explain what is meant by a photosynthetic unit.
- Describe how glucose is synthesised in the light-independent reactions of photosynthesis.
- Describe the factors that affect the rate of photosynthesis and explain why they affect the rate.
- Separate photosynthetic pigments by paper chromatography.
- Explain photorespiration and how it is related to higher temperatures.
- Distinguish between C3 and C4 plants and give at least three examples of each.
- Appreciate the importance of C4 plants in Ethiopia.
- Describe the CAM photosynthetic pathway and explain why this brings added benefits to plants living in desert conditions.

This unit should fill approximately **27 periods** of teaching time.

5.1 Respiration

This section should fill approximately **14 periods** of teaching time.

Learning competencies

By the end of this section students should be able to:

- Describe the structure of ATP and its role in cellular metabolism.
- Explain how ATP is adapted to its role as an energy transfer molecule within a cell.

- Describe how ATP is produced in a cell.
- Locate where the different processes of cellular respiration occur in the cell.
- Explain the role of electron donors and acceptors.
- Describe in detail each stage of aerobic respiration.
- Draw and label the structure of a mitochondrion.
- Explain the processes of alcoholic fermentation and lactate production.
- Appreciate the importance of lactate production during running and other sports.
- Summarise the metabolism of proteins, polysaccharides and lipids.

Starting off

Begin by discussing the diagram below, which shows the relationship between photosynthesis and respiration. Students need to appreciate just what is represented in this diagram. They should note that the terms 'plant' and 'animal' do not appear anywhere on the diagram. This is clearly deliberate and students should appreciate why. They should know that photosynthesis does not only occur in plants and respiration occurs in all living things. Hence the diagram shows the sites of respiration and photosynthesis within cells.

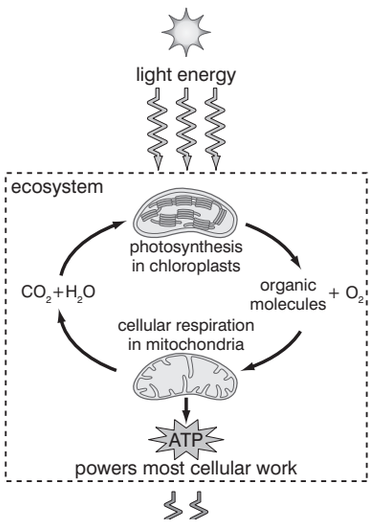


Figure 5.1
Photosynthesis and cellular respiration

Students should also note the overall transformation of energy. Energy enters an ecosystem as light and, after performing useful work in cells, leaves as heat, never to be used again by living things. Finally, they should note that photosynthesis is represented as producing 'organic molecules' rather than 'glucose' and respiration as using 'organic molecules'. This, again, is deliberate to reinforce the point that photosynthesis is the starting point for the synthesis of all organic molecules and respiratory substrates include lipids and proteins as well as carbohydrates.

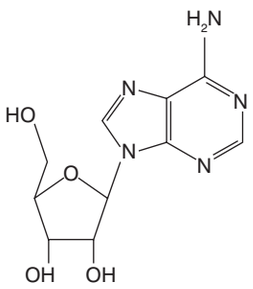


Figure 5.2

Teaching notes

Introduce the topic by revising their knowledge of respiration as a means of releasing chemical potential energy stored in organic molecules. The released energy is held, temporarily, in the ATP (Adenosine Tri-Phosphate) molecule.

Students should realise that the adenosine part of the molecule is derived from the base adenine (one of the nitrogenous bases found in DNA and RNA). Explain that adenosine is a nucleoside, comprising the base adenine and the pentose sugar ribose. As such it is an RNA nucleoside, rather than a DNA nucleoside, as the sugar present is ribose rather than deoxyribose. Adding one phosphate group to this would make a nucleotide containing adenine (also known as AMP). Adding two phosphate groups produces ADP, and adding three phosphate groups produces ATP. Figure 5.3 below may help students to appreciate this and why ATP is referred to as a phosphorylated nucleotide.

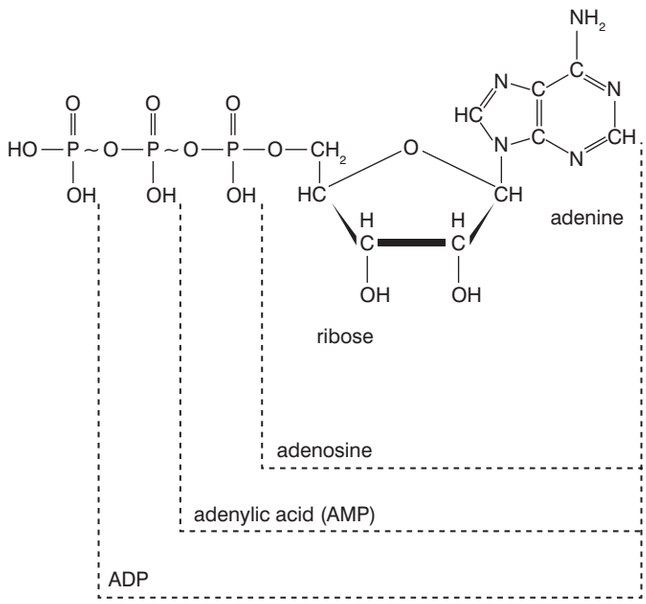


Figure 5.3

Figure 5.3 in the Students' Book shows the relationship between ATP, ADP, P_i and energy flow. Discuss with the students the quote concerning the whole world turning on the coupling and uncoupling of the third phosphate. Follow this with examples of the way in which ATP is used to drive biological processes.

The way in which ATP is produced can be quite difficult for many students to comprehend. To overcome this, it is presented as analogous to a 'water wheel' turned by hydrogen ions rather than by water. This then sets the context for explaining the importance of hydrogen ion carriers in respiration. These molecules will carry the hydrogen ions that will pass through the ATP synthase, spinning it and causing it to synthesise ATP from ADP and P_i.

SA = starter activity MA = main activity CA = concluding activity	
ATP and energy transfer	
SA	Students discuss briefly the relationship between photosynthesis and respiration. Students examine that to do useful biological work, energy is stored in the ATP molecule.
MA	Students recap the structure of a nucleotide and the structure of the ATP molecule. Students suggest why ATP is sometimes described as a phosphorylated nucleotide. Students examine the relationship between energy, ADP & P_i and ATP and how this relates to cellular work.
CA	Students write up examples of how ATP is used by cells.
The formation of ATP in cells	
SA	Students examine the difference between showing the reactants and product in the form of an equation and providing a mechanism for a process.
MA	Students examine that: • the formation of most ATP from ADP and P_i is controlled by an enzyme called ATP synthase • ATP synthase is always embedded in a membrane • it forms ATP when protons pass through it, making part of the molecule spin. Students should make their own notes on this.
CA	Class to review the nature and function of ATP and get students to answer multiple choice questions 1–5.
The structure of ATP	
SA	Students plan activity 5.1 and gather any materials they will need.
MA	Students complete activity 5.1.
CA	Students demonstrate their models to the rest of the class.

How is ATP produced in respiration?

Starting off

It is worth spending some time on the two sections below to ensure that the ideas in these are fully understood, as they set the scene for a thorough understanding of the process of aerobic respiration.

1. Introduce the idea of two energy-releasing metabolic pathways:
   - the aerobic pathway – aerobic respiration
   - the anaerobic pathway – alcoholic and lactate fermentations.

   Also mention the two ways in which ATP is actually formed in respiration:
   - ATP synthase (as already described in the text)
   - substrate level phosphorylation.
2. Now start to make the link between the hydrogen atoms in a glucose molecule and the hydrogen ions that are used by ATP synthase to produce ATP. They are transferred from one to the other by hydrogen acceptors (carriers) such as NAD and FAD. It is worth making sure that students understand the concepts of oxidation and reduction to appreciate that the NAD and FAD become reduced by accepting the hydrogen ions.

Teaching notes

Now the scene is set and you can begin to take the students through the stages of aerobic respiration. Use figure 5.8 in the Students' Book to:

- state the names of the stages
- state the locations of the different stages
- identify the net ATP productions of the different stages.

Discuss with the students the naming of the first stage of aerobic respiration (glycolysis) and get them to suggest why it takes place in the cytoplasm, rather than inside the mitochondrion like all the other stages.

It is as well then to give an overview of the whole process, showing where hydrogen ions are transferred to NAD and FAD (for later use in the synthesis of ATP), before commencing discussion of any stage in detail.

When discussing glycolysis it is important to draw students' attention to:

- the initial use of two ATP molecules
- the generation of four ATP molecules
- a net yield of two ATP molecules.

Students must be able to distinguish between the amount of ATP produced and the net yield.

The link reaction is quite a complex reaction for the students to understand, but, the essence of it is that both dehydrogenation and decarboxylation take place to generate reduced NAD and a two-carbon compound that is part of acetyl coenzyme A. figure 5.10 in the Students' Book illustrates this.

Figure 5.11 in the Students' Book then illustrates the first reaction of the Krebs cycle, in which acetyl coenzyme A reacts with oxaloacetate. It is probably not necessary for students to memorise the detail of this, but it does show clearly how the two-carbon portion of acetyl coenzyme A reacts with the four-carbon molecule oxaloacetate to form the six-carbon compound citrate.

Figure 5.12 in the Students' Book illustrates the main stages of the Krebs cycle, but the key elements that the students must appreciate are that:

- the four-carbon oxaloacetate is regenerated
- dehydrogenation takes place during several reactions of the cycle forming:
  - three molecules of reduced NAD
  - one molecule of reduced FAD
  - one molecule of ATP from substrate level phosphorylation.

Students should also appreciate that as each molecule of glucose produces two molecules of pyruvate and, from them, two molecules of acetyl coenzyme A, there will be two 'turns' of Krebs cycle per molecule of glucose, so the above amounts will be doubled when discussing the yield per molecule of glucose.

The reactions of the electron transport chain are complex and the students will need considerable guidance in understanding these. Although all the major components of the electron transport chain are named and described in the Students' Book, the key features of the process that students should appreciate are:

- Hydrogen atoms dissociate from reduced NAD and reduced FAD and then ionise forming hydrogen ions (protons/H^+) and electrons (e^-).

- The electrons are passed along a series of molecules making up the electron transport chain.
- The molecules of the electron transport chain are 'built into' the inner mitochondrial membrane.
- Three of these molecules pump hydrogen ions/protons into the inter-membrane space.
- This causes an accumulation of hydrogen ions/protons in the inter-membrane space.
- They diffuse back down their concentration gradient into the matrix; the only route for this to happen is through ATP synthase molecules.
- As they pass through the ATP synthase molecules, ATP is synthesised.
- The energy loss from the electrons from one molecule of reduced NAD allows sufficient hydrogen ions to be pumped into the inter-membrane space to generate three molecules of ATP when they diffuse back.
- The energy loss from the electrons from one molecule of reduced FAD allows sufficient hydrogen ions to be pumped into the inter-membrane space to generate two molecules of ATP when they diffuse back.

This is still quite a lot to take in, and it will need explaining carefully.

At the end of this, it is worth considering again an overview of the whole process, such as the one provided in figure 5.14 in the Students' Book. It might also be worth considering the way in which the structure of a mitochondrion is adapted to its function. Some of the main adaptations are given below:

1. **Outer mitochondrial membrane**

   – barrier to large molecules (molecular mass greater than 10 000)

2. **Inter-membrane space**

   – houses enzymes specific to mitochondria, allows accumulation of protons

3. **Inner mitochondrial membrane**

   a) allows diffusion only of small (<100 molecular mass) uncharged molecules

   b) allows for very specific control of the flow of biomolecules into (ADP) and out of (ATP) the mitochondrion

   c) has cristae – indentations that increase the surface area of the membrane

   d) contains the components of electron transport.

4. **Matrix**

   Contains enzymes for:

   a) pyruvate decarboxylation

   b) citric acid cycle

   c) fatty acid β-oxidation

   d) some amino acid metabolism

The practical opportunities discussed involve the use of some type of respirometer. If time does not permit carrying out the experiments, sample results for students to analyse are provided below.

Temp./ °C	Time / minutes	Germinating peas		Dry peas	
		Reading/ mm^3	Overall change/ mm^3	Reading/ mm^3	Overall change/ mm^3
25°	0	0.91		0.92	
	5	0.84		0.89	
	10	0.77		0.87	
	15	0.71		0.87	
	20	0.64		0.85	
10°	0	0.92		0.91	
	5	0.88		0,90	
	10	0.85		0.87	
	15	0.83		0.86	
	20	0.80		0.85	

Only raw data are included. Students should be reminded that the changes in volume in the respirometer are equivalent to the amount of oxygen being taken in. They should either copy the table from the board or be given a pre-prepared copy and asked to:

- calculate the cumulative (overall) changes in volume in each five-minute period
- plot these changes as four line graphs on a single set of axes
- comment on the differences between the sets of data.

They can also calculate the rate of oxygen consumption for each experiment from the slope of their graph where:

$$\text{rate} = \frac{\Delta y}{\Delta x}$$

Under anaerobic conditions, students easily accept that, if there is no oxygen to accept the hydrogen ions and electrons at the end of the electron transport chain, then there will be a sort of 'traffic jam' on the transport chain, which will effectively stop functioning. But they will need guiding into the knock-on effects of this:

- reduced NAD and reduced FAD arriving at the sites of electron transport will be unable to 'unload' their hydrogen atoms as there is 'nowhere for them to go'
- if NAD and FAD are not regenerated then Krebs cycle and the link reactions, both of which need either or both of these, will cease
- potentially glycolysis should also cease, as it too needs a supply of NAD.

You can then pose the question that, as glycolysis doesn't cease – what can we deduce?

Clearly, there must be another way of regenerating the NAD. Discuss with them figure 5.21 in the Students' Book as a general scheme for regenerating the NAD, before discussing the specific pathway in animal cells and that in plant and fungal cells.

Point out to the students that both processes are fermentations – they are not forms of anaerobic respiration. In fermentation, there is no overall change in the oxidation state of the substances. The hydrogen ions and electrons that were given to NAD at one stage of the reaction are taken back again by another substance

later in the reaction sequence. In anaerobic respiration, this is not the case. Glucose (or some other organic molecule) is oxidised completely; it is just that free oxygen is not the terminal electron acceptor. Nitrate may be used. However, none of these processes is able to release as much energy from the organic molecules as is aerobic respiration.

The process of fermentation in yeast is easily investigated by experiment as the Students' Book shows. It is useful, therefore, to ask the students to plan their own investigations into the various factors that might influence the rate of fermentation.

The significance of lactate fermentation in running is discussed in some detail in the Students' Book. An internet search for 'lactate and exercise' will yield much data for analysis, if more is required. An interesting animation of the Cori cycle can be found at:

http://images.google.com/imgres?imgurl=http://www.performance-edu.com/

It is then essential that students appreciate that lactate and alcohol are just two of the many fermentation products produced by different organisms. Figure 5.24 in the Students' Book illustrates a few of these.

Figure 5.28 in the Students' Book illustrates some of the metabolic pathways that are involved in the utilisation of substrates other than glucose and other carbohydrates. The diagram below is less detailed, but perhaps is a more easily understood version and could be used to supplement the diagram in the Students' Book.

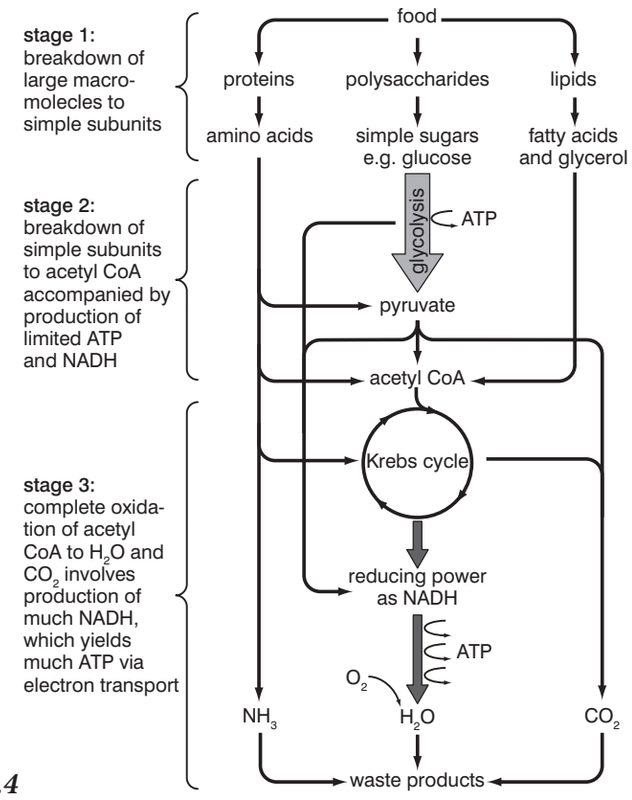


Figure 5.4

<table>
<tr><td colspan="2">SA = starter activity MA = main activity CA = concluding activity</td></tr>
<tr><td colspan="2">Different ways of producing ATP</td></tr>
<tr><td>SA</td><td>Students review the production of ATP by ATP synthase and understand that almost all the ATP produced in respiration is produced this way.</td></tr>
<tr><td>MA</td><td>Students explain as much as they can about aerobic and anaerobic respiration. Students examine that in both these processes some ATP is produced by another method – substrate level phosphorylation.
Students write notes on this.</td></tr>
<tr><td>CA</td><td>Students examine that:
• as only 10% of the ATP produced in aerobic respiration is produced by substrate level phosphorylation, 90% is produced by ATP synthase
• this requires protons to move through it to generate the ATP
• therefore, many of the reactions of aerobic respiration are geared to produce protons.
Students explain the role of reduced coenzymes in transferring protons to ATP synthase.</td></tr>
<tr><td colspan="2">The stages of aerobic respiration</td></tr>
<tr><td>SA</td><td>Students study the traditional equation for respiration:
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ energy released
Students examine that this is only a summary and does not give a mechanism for how it takes place.</td></tr>
<tr><td>MA</td><td>Students study the four stages of aerobic respiration (glycolysis, the link reaction, Krebs cycle and electron transport & chemiosmosis) and understand:
• where each stage takes place
• briefly, what happens in each stage
• the yield of coenzyme molecules and ATP molecules from each.</td></tr>
<tr><td>CA</td><td>Students produce a table to summarise the information in the text and in figure 5.8.
<table>
<tr><th>Stage</th><th>Location</th><th>Outline of stage</th><th>Yield of ATP</th><th>Yield of NADH/ FADH</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td colspan="2">Stages in aerobic respiration - glycolysis (1)</td></tr>
<tr><td>SA</td><td>Students examine the meaning of the term glycolysis as ‘sugar splitting’.
This could be a useful opportunity for students to revise some basic biological language:
• glyco- a prefix suggesting ‘sugar’ or ‘carbohydrate’
• lysis – a process involving splitting (remind them of hydrolysis).</td></tr>
<tr><td>MA</td><td>Students discuss with the teacher why all the reactions of aerobic respiration don’t take place in mitochondria. Expect them to suggest:
• the glucose molecule is too large to enter
• there are no transport proteins in the membranes of the mitochondria.
From this, students discuss with the teacher what must happen in glycolysis. Expect them to understand that the glucose molecule is split with the result that the smaller molecules formed can enter the mitochondria.
Students study the overview of glycolysis given in the text. This is ample detail for them to understand the principles of the process. Students familiarise themselves with the terms dehydrogenation and decarboxylation as they will meet these again in this chapter.</td></tr>
<tr><td>CA</td><td>Students explain the difference between the total ATP production of glycosis and the net gain of ATP in glycosis.</td></tr>
</table>

Stages in aerobic respiration - glycolysis (2)	
SA	Students write quick notes on glycosis based on what they remember from the last lesson.
MA	Students complete activity 5.2.
CA	Students present and explain their diagrams to the rest of the class.
Stages in aerobic respiration – the link reaction and Krebs cycle (1)	
SA	Students examine that the link reaction is so-named because it links the process of glycolysis to Krebs cycle.
MA	Students study figures 5.10 and 5.11 and read the accompanying text and then divide into pairs to come up with a concise explanation of the importance of the link reaction. They then write notes on the link reaction, explaining the biochemical transformations in terms of decarboxylation and dehydrogenation.
CA	Students describe: • the cyclical nature of this stage of aerobic respiration • the input of acetyl coA to start each 'turn' of the cycle • progressive decarboxylation and dehydrogenation regenerate the four-carbon compound that reacts with acetyl coA.
Stages in aerobic respiration – the link reaction and Krebs cycle (2)	
SA	Students brainstorm the major principles of the Krebs cycle; write up their points at the front of the classroom and prompt for any they have forgotten.
MA	Students complete activity 5.3 in groups.
CA	Groups present their wallcharts to the rest of the class
Stages of aerobic respiration – electron transport and chemiosmosis	
SA	These are really difficult conceptual ideas. Students must understand that: • the whole system is arranged to use the hydrogen atoms carried by NAD and FAD to generate a proton gradient • the hydrogen atoms split into protons and electrons to drive the electron transport system and chemiosmosis.
MA	Students study the structure of the electron transport chain and the proton pumps that create the proton gradient. Figure 5.14 could form a basis for this. The students must understand that: • as the electrons pass along the transport chain they lose energy • at certain points, this loss of energy drives proton pumps • these proton pumps move protons into the inter-membrane space • this creates the proton gradient that drives the formation of ATP by ATP synthase. It is less important that students learn each stage than they understand the above principles. Students examine the difference in ATP yields from NADH and FADH in terms of entry into the electron transport chain. Students examine the role of oxygen as the terminal electron acceptor.
CA	Students make notes on electron transport and chemiosmosis and summarise the yield of ATP from one molecule of glucose.
Investigating the rate of respiration – using respirometers	
SA	Students examine the principles involved: • the rate of carbon dioxide production is a measure of the rate of production of a product of respiration • the changes in volume of gas inside a respirometer is a measure of the volume of carbon dioxide produced.

MA	Students carry out activity 5.4. They may need splitting into groups to carry out the investigation at the three temperatures.
CA	Students write up the experiment and explain their results.
The anaerobic pathway	
SA	Students review the concept of oxygen as the terminal electron acceptor; if oxygen is absent, electrons cannot move off the transport chain.
MA	Students examine the 'knock on' effect of the lack of oxygen on Krebs cycle and the link reaction. Students revise the formation of NADH from NAD in glycolysis and show how fermentation replaces the NAD so that glycolysis can continue. Students make notes on the anaerobic pathway.
CA	Students study other fermentation products made by different organisms under anaerobic conditions.
Investigating the rate of fermentation in yeast	
SA	Students discuss with the teacher the basis of measuring the rate of fermentation. Discuss the possible ways of carrying out the investigation, as shown in figures 5.25 and 5.26.
MA	Students carry out activity 5.5 to plan investigations into the effect of environmental factors on the rate of fermentation of yeast. If possible, they carry out the investigations they have planned – if this is not possible due to lack of equipment try and demonstrate a similar experiment at the front of the class.
CA	Students write up their plans.
Other metabolic pathways	
SA	Students review the idea that respiration is a process that releases energy from organic molecules – these need not necessarily be glucose.
MA	Students examine that: • carbohydrates, lipids and proteins may all be used as respiratory substrates • glycolysis can only occur with carbohydrates as the substrate • therefore the respiration of lipids and proteins must be aerobic • the common link to all substrates is the Krebs cycle (and from that electron transport and chemiosmosis). Students make notes on other pathways, using figure 5.27 as a basis.
CA	Students answer multiple choice questions 6–15.

Answers to review questions

1. B
2. C
3. D
4. D
5. D
6. A
7. D
8. C
9. D
10. A
11. B
12. A
13. D
14. C
15. A

This section should fill approximately **13 periods** of teaching time.

5.2 How do plants harness light energy in photosynthesis?

Learning competencies

By the end of this section, students should be able to:

- Draw, label and describe a chloroplast.
- Locate where light-dependent and -independent processes occur in the chloroplast.
- Name the products of the light-dependent and -independent processes.
- Explain how the structure of a photosystem is related to its function.
- Explain what is meant by a photosynthetic unit.
- Describe how glucose is synthesised in the light-independent reactions of photosynthesis.
- Describe the factors that affect the rate of photosynthesis and explain why they affect the rate.
- Separate photosynthetic pigments by paper chromatography.
- Explain photorespiration and how it is related to higher temperatures.
- Distinguish between C3 and C4 plants and give at least three examples of each.
- Appreciate the importance of C4 plants in Ethiopia.
- Describe the CAM photosynthetic pathway and explain why this brings added benefits to plants living in desert conditions.

Starting off

Begin with an overview of the process. Remind them of their work in grade 10 when they will already have learned of the light-dependent reactions and light-independent reactions. It may be useful to link this to a diagram of chloroplast structure. Figure 5.29 in the Students' Book does this, but the diagram included here gives a little more information and could usefully be used as an adjunct.

Point out to the students that the molecule carrying hydrogen atoms in photosynthesis is NADPH – not NADH as in respiration.

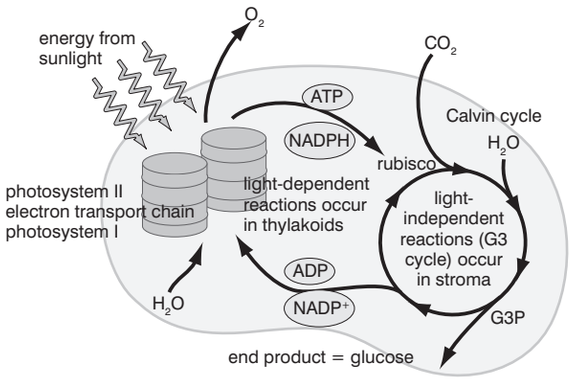


Figure 5.5

Teaching notes

It is well worthwhile at the outset considering how the structure of a chloroplast is related to its functions in the various stages of photosynthesis. The main features to point out are:

- the separation of the interior into grana and stroma linked to the light-dependent reactions and the light-independent reactions, respectively
- the presence of a double membrane around the chloroplast to isolate reactions from those taking place in the cytoplasm and to control what passes in and out of the chloroplast
- the organisation of pigment molecules into photosystems in the grana to maximise the absorption of light.

In addition to these points, you could link the structure back to unit 4 and the structure of cells and the origin of eukaryotic cells in particular and discuss the fact that chloroplasts also contain their own DNA, which controls the synthesis of proteins (mainly enzymes for the light-independent reactions) in the ribosomes that are also found in chloroplasts.

The role of the different pigments in the photosystems should be discussed in terms of:

- the absorption spectrum of the individual pigment molecules in the antenna complex
- the action spectrum of whole complex.

Make sure that the students appreciate the difference between the two terms.

In introducing the light-dependent reactions explain that although this phase is called the light-dependent phase, the molecules synthesised here (ATP and reduced NADP) drive the reactions of the light-independent reactions. So, in a sense, these reactions are also light-dependent.

The 'Z-scheme' model of the light-dependent reactions is summarised in figure 5.32 in the Students' Book, together with an account in the body of the text. The nature of the Z-scheme needs a little explaining to the students.

A simplified version might help in explaining this. The students should appreciate:

- the 'vertical axis' of the diagram shows the energy levels, so moving 'upwards' represents a gain in energy and falling downwards represents losing energy
- the horizontal axis represents time.

Having explained the events of the light-dependent reactions in terms of energy changes, it is necessary to look at the spatial arrangement of the various components on the thylakoid membrane. Introduce the concept of the photosynthetic unit as a collection of molecules that can carry out all the reactions of the light-dependent stage of photosynthesis.

The practical opportunity to separate the photosynthetic pigments is a straightforward exercise, but students should be made aware of the importance of:

- keeping the initial spot as small as possible
- not allowing the spot to dip into the solvent
- stopping the chromatogram before the solvent front reaches the top of the chromatography paper.

The important stages of the light-independent reactions can be explained quite briefly. In essence, students should realise that:

- CO_2 reacts with a 5C molecule (RuBP) that already exists in the stroma
- this reaction needs no input of ATP or reduced NADP and forms two molecules of GP
- the GP is converted to TP using ATP and reduced NADP from the light-dependent reactions
- some of the TP is used to form hexose sugars
- the rest is recycled to RuBP.

These stages are summarised in figure 5.37 in the Students' Book.

Having covered the two stages of the process, students should appreciate that, as photosynthesis is split into the two phases, any factor that influences the effectiveness of either stage will influence the overall efficiency of the process. These factors include:

- light intensity
- temperature
- concentration of carbon dioxide

Their effects are summarised in the table in the Students' Book. A discussion of which factor limits photosynthesis on different occasions can lead to a discussion of the principle of limiting factors.

The way in which each factor can limit the rate independently is shown, followed by an account of how the factors can interact to influence the rate. An important concept for the students to grasp when interpreting such graphs is that, if a factor is limiting the rate of photosynthesis, then increasing the factor will increase the rate. So, turning the logic around, if increasing light intensity produces an increase in the rate of photosynthesis, light must have been the limiting factor. If an increase in light intensity produces no increase in the rate of photosynthesis, some other factor is limiting the rate. This will need careful explanation, but relating this to practical applications, such as growing crops in the controlled environment in a polytunnel or greenhouse, may help.

The practical opportunity to investigate the effect of environmental factors on the rate of photosynthesis makes use of a straightforward practical using easy to obtain equipment. As with the investigations into fermentation in yeast, students are asked to plan their own investigations around a basic experiment.

If it is not possible to carry out the investigation, some results are given below for analysis by the students. Explain to them that, in this investigation, the factors varied were:

- light intensity; the plant was illuminated by a lamp, placing the lamp at different distances changes the light intensity according to the inverse square law
- concentration of carbon dioxide, varied by varying the molarity of the sodium hydrogen carbonate solution in which the *Elodea* was immersed.

Light intensity $1/d^2$ (m)	Time taken to collect gas/seconds					
	Molarity of $NaHCO_3$					
	0.00	0.01	0.02	0.05	0.07	0.1
400	3571	1666	1099	523	200	243
278	1670	5183	988	600	375	262
204	4998	4485	1175	1005	473	351
156	5590	2300	1770	1445	621	550
100	9990	3150	2900	2552	1224	645
25		4762	3984	2850	1640	1408
11		5945	4348	3780	2830	2564
4		16480	11904	5196	6578	3226

There are a number of activities the students can undertake with the data, including:

- change the volumes to a rate of reaction using the equation:

$$R = \frac{1000}{\text{Volume}}$$

- graph the results
- discuss the trends shown in the graphs in terms of the principle of limiting factors

SA = starter activity MA = main activity CA = concluding activity	
How do plants harness light energy in photosynthesis?	
SA	Students revise the idea of light-dependent reactions and light-independent reactions. Students revise the structure of chloroplasts to remind themselves of membranes (thylakoids) and stroma. Students remember the presence of photosensitive pigments in the thylakoid membranes.
MA	Students explain as much as they can about aerobic and anaerobic respiration. Students study the concept of a photosystem and its likely structure. Students study how the pigments in a photosystem increase the spectrum of absorption (use figures 5.31 (A) and (B) for this) of light and, as a consequence, the efficiency of photosynthesis. Students explain why the leaves of plants are usually green.
CA	Students recall that light is a form of energy. Students say what will happen to the total energy contained in a chlorophyll molecule when it absorbs light. Students explain that if enough energy is gained, electrons become 'excited' and may leave the chlorophyll molecule.
The light-dependent reactions of photosynthesis	
SA	Students study the idea that energised electrons from chlorophyll can behave in a similar way to the electrons from NADH in respiration. As electrons pass along an electron transfer chain the energy they lose can: • drive proton pumps that power the synthesis of ATP • drive the synthesis of reduced NADP (explain that NADP is similar to NAD). Students examine that the protons for both these reactions come from the splitting of water molecules (hydrolysis). Students appreciate that understanding these ideas is more important than knowing the fine detail of the processes.

MA	Students study the Z-scheme of the light-dependent reactions shown in figure 5.32. Explain that it is a kind of 'time-energy' diagram, with the vertical axis representing energy levels and the horizontal axis representing time. Use the ideas gained in SA to explain the different stages of the light-dependent reactions. Students study the structure of a photosynthetic unit, which shows the relative position of the components in the thylakoid membrane.
CA	If possible, present the students with a blank diagram of the Z-scheme and get them to label it. As an extension, students make notes on cyclic photophosphorylation and to list differences between this and non-cyclic photophosphorylation.
Investigating the different pigments in leaves	
SA	Students recap the structure of a photosystem and the pigments they contain.
MA	Students carry out activity 5.10 (with leaves from several different species, if possible, to allow comparison). More guidance and notes on this experiment can be found in the teaching notes.
CA	Students write up their findings.
The light-independent reactions of photosynthesis	
SA	Students recall that ATP and reduced NADP are synthesised in the light-dependent reactions. Students examine that these molecules will 'drive' the light-independent reactions.
MA	Students recall the cyclical nature of Krebs cycle, in which the starting product is regenerated. Students examine that the light-independent reactions are also cyclical and sometimes known as the Calvin cycle. Students study figure 5.37 and discuss the three stages of the cycle: • fixation of carbon dioxide into an organic molecule, by reacting with RuBP to form molecules of GP (a 3-carbon compound) • reduction of GP to TP (triose phosphate) using ATP and reduced NADP from the light-dependent reactions • regeneration of RuBP.
CA	Students examine that for three 'turns of the cycle' one molecule of TP is produced as 'profit' (i.e. not used in recycling of RuBP). Two of these can combine to form a hexose (such as glucose).
Factors that influence the rate of photosynthesis	
SA	Students use figure 5.38 to revise the relationship between: • light-dependent and light-independent reactions • inputs and outputs of photosynthesis. Students examine that, as all the 'inputs' are necessary for photosynthesis, if one is absent the process will stop. If one is reduced, the process will slow down. Students examine the concept of limiting factors.
MA	Students discuss the influence of light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis. Use figures 5.39–5.42 to illustrate this.
CA	Students make notes on the effect of these factors on photosynthesis.
Investigating factors that influence the rate of photosynthesis (1)	
SA	Students discuss with the teacher the basic experiment shown in figure 5.11. Get them to suggest why: • collecting the gas produced might be a reasonable way of measuring the rate of photosynthesis (the process produces gaseous oxygen) • there may be limitations to this (the gas collected may not just be oxygen).

MA	Students design experiments to investigate the factors that influence photosynthesis.
CA	Students research a more sophisticated method of investigating the rate of photosynthesis (such as using gas pressure sensors to measure the amount of dissolved oxygen in the water after specific time intervals).
Investigating factors that influence the rate of photosynthesis (2)	
SA	Go through the features of the students' designs and modify procedures as necessary.
MA	Students carry out their experiments.
CA	Students analyse their results, or results provided later in this guide, and draw their conclusions.
Other methods of photosynthesising	
SA	Students study the term C3 photosynthesis and understand the origin of the term. Students discuss the structure of the leaf of a C3 plant.
MA	Students examine why C3 photosynthesis is not efficient in the tropics and to appreciate that in these conditions: • stomata often close during the day to prevent excessive water loss • the carbon dioxide concentration in the air spaces falls as it is used and is not replaced. Students link this to abnormal behaviour of Rubisco and understand the two main stages of photorespiration. Students examine why photorespiration reduces the efficiency of photosynthesis. Students study the structure of the leaf from a C4 plant and describe the C4 pathway.
CA	Students make notes on the C4 pathway. As an extension, they could include the CAM pathway shown by cacti.
The main aspects of photosynthesis	
SA	Students appreciate that the aim of this session is to produce a summary of the main aspects of photosynthesis.
MA	Students divide into groups to carry out activity 5.13. They should follow the four given guidelines
CA	Students deliver their presentations.

Are there any other ways of photosynthesising?

Starting off

Begin this section by posing the problem faced by plants in the tropics of minimising water loss during the day whilst at the same time being able to obtain sufficient carbon dioxide for photosynthesis. Clearly, the stomata cannot behave in such a way as to do both – at least not using the type of photosynthesis already described.

Teaching notes

Explain the problem of low levels of carbon dioxide as a result of stomatal closure leading to photorespiration in which Rubiso binds with oxygen preferentially to carbon dioxide. The students will probably wonder where the 'respiration' element comes in. They will need an explanation that this term is used because the process involves light (hence 'photo') and oxidation (because carbon atoms are oxidised as they are in respiration).

Although all the principal reactions of photorespiration are described in the Students' Book, try to get the students to understand that photorespiration reduces the efficiency of photosynthesis because only one molecule of GP is formed as a result of the initial reaction with RuBP rather than two in the normal reaction. Also, the regeneration of RuBP uses more ATP than the normal reactions of the Calvin cycle.

Explain then how C4 plants have 'solved' this problem by:

- spatially separating the light-dependent and light-independent phases of the process so that high concentrations of oxygen do not induce photorespiration in the (bundle sheath) cells that carry out the reactions of the Calvin cycle
- evolving an additional set of reactions that:
  - fix carbon dioxide into an organic molecule (oxaloacetate, 4C) even when its concentration is low
  - release the carbon dioxide in the bundle sheath cells for use in the reactions of the Calvin cycle.

Then discuss with them the reactions of C4 photosynthesis using figure 5.48 in the Students' Book as a basis for the discussion. This should lead on to a discussion of the relative efficiencies of C3 and C4 photosynthesis at different temperatures, light intensities and carbon dioxide concentrations. Figure 5.49 in the Students' Book shows the effect of different carbon dioxide concentrations.

The CAM pathway for photosynthesis is included briefly for the sake of completeness. Discuss with the students the similarities and differences between this process and the C4 pathway. Students could be given the task of comparing the three pathways. The table below gives one possible format for this.

Feature of pathway	C3	C4	CAM
Initial carboxylating enzyme			
Special features of leaf/ cells			
Effect of high light intensity			
Is photosynthesis inhibited by oxygen?			
Does photorespiration occur easily?			
Temperature optimum for photosynthesis			
CO_2 concentration for maximum efficiency			

Answers to review questions

1. A
2. A
3. A
4. C
5. B
6. A
7. D
8. D
9. D
10. B
11. C
12. C
13. C
14. B
15. A

Answers to end of unit questions

1. a) *Four of*:

   Thylakoids for light-independent stage

   have pigments organised into photosystems

   to maximise absorption of light

   stroma is fluid for chemical reactions to occur

   rich in enzymes of Calvin cycle

   double membrane isolates from reactions in cytoplasm/controls what enters and leaves chloroplast

   b) i) *Two of*:

   Both surrounded by double membrane

   are fluid filled

   have internal membranous structures

   ii) *Two of*:

   Chloroplasts have stacks of membranes/thylakoids

   contain chlorophyll

   do not have cristae

2. a) Releases energy in small amounts

   releases energy in a one step reaction

   can move around cell easily but cannot escape cell

   b) i) *Three of*:

   Phosphorylated substrate binds to enzyme

   with ADP

   phosphate transferred to ADP

   ATP leaves enzyme

   ii) *Four of*:

   Hydrogen ions/protons

move through ATP synthase molecule
down concentration gradient
cause rotor to turn
activates enzymes/catalytic knob to synthesise ATP

3. a) A – stroma
B – thylakoid
C – granum
D – inter-membrane space

b) Would have no thylakoids/no grana
cannot carry out reactions of light-dependent stage
keeps oxygen concentrations low
helps prevent photorespiration

4. a) Suitable container for yeast/glucose
suitable delivery tube for carbon dioxide produced
method of ensuring anaerobic conditions (e.g. layer of oil)
quality of diagram

b) Use of water bath
indication of suitable range of temperatures
measurement of volume of CO_2 produced/rate of bubbling
repeats for reliability
Controls:
volume of glucose solution
concentration of glucose solution
volume of yeast suspension
concentration of yeast suspension
time
pH

5. 1 Light energy excites electrons in photosystem II
escape chlorophyll molecule

2 Photolysis/water molecule dissociates
producing hydrogen ions and oxygen

3 Electrons pass along electron transport chain
losing energy as they do so

4 Energy from electrons used to create proton/hydrogen ion gradient
for synthesis of ATP by ATP synthase

5 Light energy excites electrons in photosystem I
escape chlorophyll molecule

6 Pass along a different electron transport chain

combine with H^+ and NADP to form reduced NADP

6. a) i) X – first step of Krebs cycle (accept link reaction)
acetyl CoA reacts with oxaloacetate to form citrate

Y – substrate level phosphorylation
phosphorylated substrate transfers phosphate to ADP

ii) Occurs in glycolysis

in conversion of GP to pyruvate

b) *Four of*:

Oxygen is terminal electron acceptor

if not present, electrons cannot move off ETC

reduced NAD cannot dissociate/lose hydrogen atoms/ions

NAD not regenerated

NAD needed for reactions of Krebs cycle

c) i) *Two of*:

(At cristae) dissociates/loses hydrogen atoms/ions

and electrons

electrons pass along ETC

ii) Donates hydrogen ions

to pyruvate

converts pyruvate to lactate

7. a) Light is limiting in all three regions

increase in light intensity produces an increase in photosynthesis

not possible if some other factor were limiting

b) *Twelve of*:

Bottom line:

Low temperature

limits rate of reactions because little kinetic energy

few collisions between enzymes and substrates/between reactants

low carbon dioxide concentration

limits rate of initial reaction of Calvin cycle

so all reactions of Calvin cycle slowed

maximum rate at relatively low light intensity

Middle line:

One factor is increased

but still one factor present in low quantity

increase in maximum rate of photosynthesis

at higher light intensity

Upper line:
Both factors increased
larger increase in maximum rate of photosynthesis
at still higher light intensity
however, still levels off with increasing light
so something other than light is limiting the process

8. a) Converted to glucose
by two molecules combining
recycled to RuBP
to replace all molecules of RuBP used in Calvin cycle
converted to compounds other than carbohydrates, such as:
lipids/fatty acids/protein/amino acids/DNA/RNA/nucleotides

b) P – carboxylation
reaction of CO_2 with RuBP
Q – reduction
hydrogen ions donated from reduced NADP/hydrogen ions
donated to GP

c) *Five of*:
ATP and reduced NADP produced in the light-independent reactions
so neither produced in the dark/when light source removed
both needed to convert GP to TP
ATP needed to convert TP to RuBP
neither of these reactions can continue in the dark
RuBP can still be converted into GP
as neither ATP nor reduced NADP needed
so GP builds up and RuBP falls

Answers to end of unit corssword puzzle

Across

3 Krebs cycle
6 glycolysis
9 fermentation
10 Rubisco
11 ATP
18 photosynthetic unit
20 ATP synthase
21 ADP
22 NAD

Down

1 electron transport chain
2 light independent
4 respiration
5 C4
7 link reaction
8 grana
12 photosynthesis
13 photorespiration
14 light dependent
15 substrate level
16 oxidative
17 photosystem
19 pyruvate

Further resources

http://www.biotopics.co.uk/a2/TCAcycle.html – Krebs cycle

http://www.biochemistry.org/Portals/0/Education/Docs/BASC06_full.pdf – photosynthesis research and activities

Photosynthesis tests

http://www.biology.arizona.edu/biochemistry/problem_sets/photosynthesis_1/photosynthesis_1.html – exercises on photosynthesis