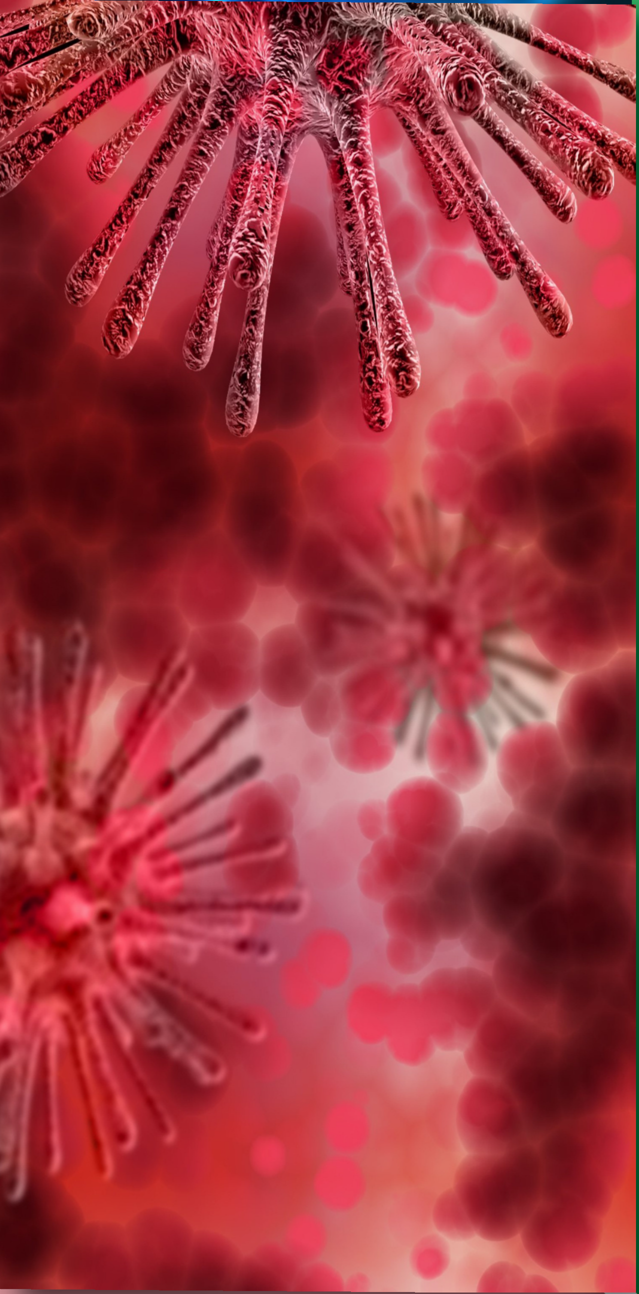

Biology Unravelled

Second edition

comprehensive summary notes and exam study plan

VCE Biology Units 3 and 4

Ariana Fabris

Biology Unravelled

Comprehensive summary notes and exam study plan

ARIANA FABRIS

Your seven-week exam study plan

Introduction

Biology Unravelled (second edition) is a set of comprehensive summary notes that has proven invaluable for students of VCE Biology, Units 3 and 4. Written in simple language making it easier to understand, it goes a long way towards helping to clarify some of the more difficult concepts and ideas in biology, and can greatly assist exam preparation.

The content in these pages thoroughly addresses the VCAA Biology Study Design, covering all the important information *without* being overwhelming. It also contains more than 100 diagrams, photos and charts to illustrate content and assist the visual learner.

Biology Unravelled is written by a VCE Biology teacher of more than 20 years' experience.

How to use this book

The following is a series of steps you can take to help you get the most out of this book and assist in your exam preparation. It is recommended that you begin this study program about seven weeks before the exam date.

1. Read each section thoroughly

Biology Unravelled is divided into 11 sections (plus vocabulary lists). Read each section *at least* three times (the more the better) and make your own hand-written notes. Why? Because while this book does provide ready-made summaries of course content, writing information by hand can help you retain it better. Also, pay particular attention to the diagrams; examine them carefully, including *all* labels and captions. Note that you should be aiming to revise around two sections per week.

2. Learn some things by heart

While there has definitely been a strong movement away from 'rote learning' (memorisation) as a learning technique, there are still certain facts and processes in biology that you'll need to learn almost by heart, such as the inputs and outputs of photosynthesis and cellular respiration, steps involved in transcription, translation and the trp operon, functions of the various types of immune cells and meanings of terms such as 'genetic drift', 'gene flow' and 'founder effect'. If you're unsure about the sorts of information or facts that need to be memorised, check with your teacher.

3. Make flash cards

At the end of each section you will find a list of suggested flash card questions. Flash cards are a great study tool and they're easy to make. Simply write the question on one side of a small card and the answer on the other side (you can purchase packets of 'study cards' from office supply stores such as Officeworks).

Note that there are no actual lists of answers to the flash card questions provided here; this is because it's important that you read the content in the preceeding pages in order to find the answers yourself. If you have any trouble at all, ask your teacher for help.

Make as many flash cards as you can, keep them handy and use them often; on the train or bus, while waiting in a cue, or even during the ad break on TV. Using flash cards not only helps you to retain information, but can also assist in identifying any areas of weakness that you need to focus on.

4. Complete as many VCAA sample exam questions as you can

At the end of each section is a table that lists useful multiple choice (**MC**) and short answer (**SA**) questions from VCAA sample exams dating back to 2013. The importance of completing as many of these as possible cannot be overemphasized; in fact, your exam preparation should be at least 50% exam practice (your teacher will probably also provide you with exams produced by other organisations, such as STAV, NEAP, Lisachem, QATs and Insight). VCAA sample exams can be downloaded from the VCAA website, along with the *examination reports*, which not only provide the answers but also useful feedback on how students performed and where common errors were made. Read these reports carefully so that you can analyse your results and correct any mistakes.

5. Check that you know your terminology

At the end of this book is a list of all the important terms from each section. Look through these and make sure you understand what each one means and - where appropriate - how to define it, explain it in your own words and importantly, how to *apply* it, which means being able to use the term in new, unfamiliar situations. Also, make sure you know how to spell it!

Tying it all together

Once you've completed steps 1-4 above for all 11 sections of the book, there should still be some time before the exam to continue reading, revising and using your flash cards, particularly for any areas that you've identified as needing extra attention. It will also be important for you to complete one or two recent sample exams *under exam conditions*, including the standard reading time of 15 minutes followed by the allotted two and a half hours to complete the paper. This will give you a good idea of how quickly you will need to work through the exam in order to finish it on time.

Best of luck with your studies.

During the year

The following is a list of things you can do throughout the year to help you achieve your very best in Biology:

1. Read, read, read

Read from your textbook, class notes/handouts or *Biology Unravelled* whenever you can. Go over what you learnt in class and if you have time, read the next section of your textbook as well to give you a bit of a heads-up on what's coming. It takes an enormous amount of discipline to keep this up, particularly when you have other homework and SACs to prepare for, but it can make studying for the exam a lot easier so the rewards are great.

2. Use visual aids

The benefits of using visual aids to enhance learning have been well documented. The Units 3 and 4 biology exam will most likely include lots of diagrams, graphs, charts and photos and you may even be asked to draw a simple diagram, so it follows that you should be getting plenty of practice. Try constructing flow charts, Venn diagrams, mind maps, concept maps and anything else that helps you to comprehend and/or reinforce important biological pathways and processes. Also, don't forget that other great visual resource, **YouTube**, where you can find lots of very useful programs and it can be a bit like having your own private tutor!

3. Complete sample exam questions regularly

While completing sample exam questions forms part of your seven-week study plan described above, this can really be started as soon as you finish the first topic in biology. Even if you can only manage a few questions per week, it's a good habit to get into.

4. Keep an eye on the media

From time to time articles appear in newspapers that relate to what you're learning in biology, such as recent developments in cancer treatment, the emergence of a particularly nasty new flu virus, the solving of a cold case crime using the latest DNA manipulation techniques, or an exciting new fossil discovery. These articles not only provide examples of how biological knowledge is used and applied in the real world, they can also help keep you interested and motivated.

5. Attend a lecture

There are a number of organisations that provide biology lectures, such as ACED, ATAR Notes, TSFX, Connect Education and TSSM. These lectures present information from a new perspective, which can help improve your understanding, while some of them also focus on developing useful examination strategies, such as helping you make the most effective use of the two and a half hours you're given to finish the paper. Visit the organisation's website to find out more about these lectures, including how to book a place.

Last-minute tips

Here are a few tips to help you during the exam:

1. Make good use of the reading time

Read each question carefully and don't let your mind wander; absorb as much of the information as you can. This is especially important for those questions that contain background information that may need to be included in the answers you give. Try not to panic if you come across a question that appears difficult, or a term you don't recognise; sometimes the most complex-looking questions turn out to be quite simple! Also, don't ignore the diagrams, graphs, tables and flow charts here; look at them carefully so you get a good idea of what they convey.

2. Think before you write

Many students make the mistake of rushing their answers, which can lead to careless errors. Take a little time to think about what you want to write before putting pen to paper. It's also a good idea to check how many marks a question is worth and how much space has been provided for you to write your answer; this gives you an idea about the amount of detail you need to include.

3. Answer the question asked

Read the question carefully and underline the key words. This can help you avoid including irrelevant information in your answer, for example, if you're asked to simply describe the *structure* of an RNA molecule, there's no need to relate the structure to its function, or to compare it with DNA.

4. Use the information provided

Data and background information provided in a question are there for a reason, so don't ignore any part. Even a single sentence, no matter how insignificant it might seem, *could* contain the answer to a question, or part of a question.

5. Use dot points where appropriate

Dot points are useful particularly when outlining the steps involved in a process, such as natural selection, or protein synthesis. They're also useful for those questions that are worth a lot of marks because if you allocate one dot point per mark, it helps ensure that you've included everything.

6. Use common abbreviations

It's okay to write 'DNA', 'RNA', 'NADPH' and 'ATP' rather than the complete name in words, plus they're a lot easier to spell!

7. Be aware of time

During the exam it's important to keep an eye on the clock (without becoming obsessed). A good plan would be to aim to spend around 40 to 45 minutes on the multiple choice section (part A) and about 90 minutes on the short answer section (part B), leaving 15 to 20 minutes at the end to check your answers. Don't panic if you find you're going a bit over; just step it up and try to make up the time later.

CONTENTS

4. Photosynthesis

Photosynthesis is the process by which plants, algae as well as certain protists and bacteria are able to use the sun's energy to convert simple substances like water and carbon dioxide into glucose, a type of sugar. They then use this sugar as a source of energy.

Photosynthesis is an example of a complex **biochemical pathway** involving numerous biochemical reactions. A 'biochemical' reaction is one which occurs in cells and involves the conversion of a *reactant* (the molecules you start with) into a *product* (the end result), using a specific enzyme. A biochemical pathway may involve many steps, and the product of one step/reaction becomes the reactant for the next:

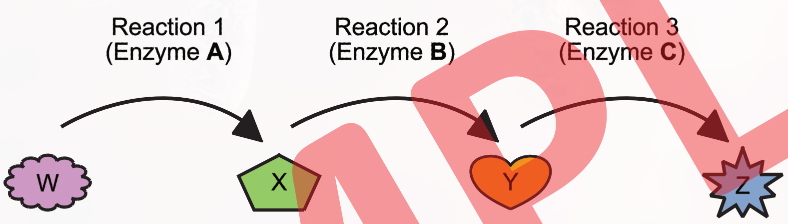

Figure 47: A biochemical pathway. In reaction 1, enzyme **A** converts reactant W into product X, which then becomes the reactant in reaction 2, and is acted on by enzyme **B**, and so on (Z is the final product of the pathway). Note that because the reactants are being acted on by enzymes, they can also be referred to as *substrates*.

Photosynthesis can be summarised like this:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{(chlorophyll)}]{\text{(light)}} \text{glucose} + \text{oxygen} + \text{water}$$

or as a balanced chemical equation:

$$6CO_2 + 12H_2O \xrightarrow[\text{(chlorophyll)}]{\text{(light)}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

The chemical equation can also be simplified as follows:

$$6CO_2 + 6H_2O \xrightarrow[\text{(chlorophyll)}]{\text{(light)}} C_6H_{12}O_6 + 6O_2$$

*** Note the difference between the two chemical equations shown above. Although water is produced during photosynthesis as well as being used, it is not always shown because any water molecule made is immediately recycled back into the process.**

Photosynthesis can also be described as an *anabolic* pathway. In anabolic reactions, small molecules (in this case, carbon dioxide and water) are joined together to form larger molecules (glucose), a process that requires energy. Reactions that require an input of energy can also be termed *endergonic* reactions.

Photosynthesis occurs in two stages: the *light-dependent* stage and the *light-independent* stage.

The light-dependent stage (LD)

The first stage of photosynthesis requires the presence of light and occurs on the **thylakoid membranes** located within chloroplasts. These membranes contain the light-trapping pigment *chlorophyll* as well as enzymes that are needed for the process to occur.

The steps involved in the LD stage (see figure 48) are:

1. Light energy is used to split water ($6H_2O$) into hydrogen and oxygen. The oxygen ($6O_2$) is given off as a waste product. This step requires a water-oxidising enzyme.
2. As part of the oxidation, the hydrogen is also split, into hydrogen ions (H^+) and high-energy electrons (e^-).
3. A carrier molecule, the coenzyme $NADP^+$, picks up hydrogen ions *and* electrons to form NADPH.
4. Energy produced from the splitting of water is also used to create ATP by combining adenosine di-phosphate and inorganic phosphate. This step requires the enzyme *ATP synthase*.

Note that the inputs of the LD stage are **sunlight**, **water**, **$NADP^+$** and **ADP + Pi**. The outputs are **oxygen**, **NADPH** and **ATP**. While the oxygen produced takes no further part in the reaction, the NADPH and ATP will be required for the second stage of photosynthesis, the light-independent stage.

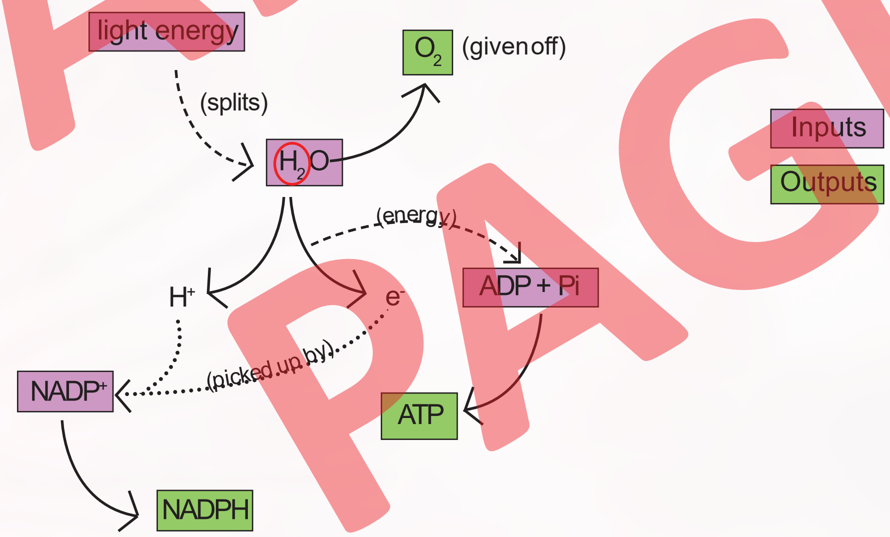

Figure 48. Simplified diagram of the light-dependent stage of photosynthesis, showing inputs and outputs. Note that the total numbers of atoms and molecules are not included.

The coenzyme NADP plays a vital role in photosynthesis. NADP comes in two forms: the 'loaded' **NADPH** and the 'unloaded' **$NADP^+$**. The unloaded form, as shown above, *accepts* hydrogen ions and electrons during the light-dependent stage of photosynthesis, while NADPH (loaded) *donates* hydrogen ions and electrons during the later, light-independent stage (see next section).

Loading of $NADP^+$: $NADP^+ + H^+ + 2e^- \longrightarrow NADPH$

Unloading of NADPH: $NADPH \longrightarrow NADP^+ + H^+ + 2e^-$

The light-independent stage (LI)

The second stage of photosynthesis does not require light and occurs in the **stroma** (fluid part) of chloroplasts. The stroma contains certain enzymes that are needed for this process to proceed.

The steps involved in the LI stage (see figure 49), are:

1. The loaded coenzyme NADPH, produced in the LD stage, gives up its hydrogen and donates its electrons to become $NADP^+$ again. This is a reaction that, importantly, releases energy.
2. The coenzyme ATP is converted back into ADP + Pi, also releasing energy.
3. The energy produced from the breakdown of NADPH and ATP is used to build a molecule of glucose ($C_6H_{12}O_6$), using a source of carbon dioxide ($6CO_2$) and the hydrogen from the NADPH.

Note that not all of the hydrogen carried by NADPH goes into making a glucose molecule; some of it goes into producing water when it is combined with some of the oxygen from the carbon dioxide.

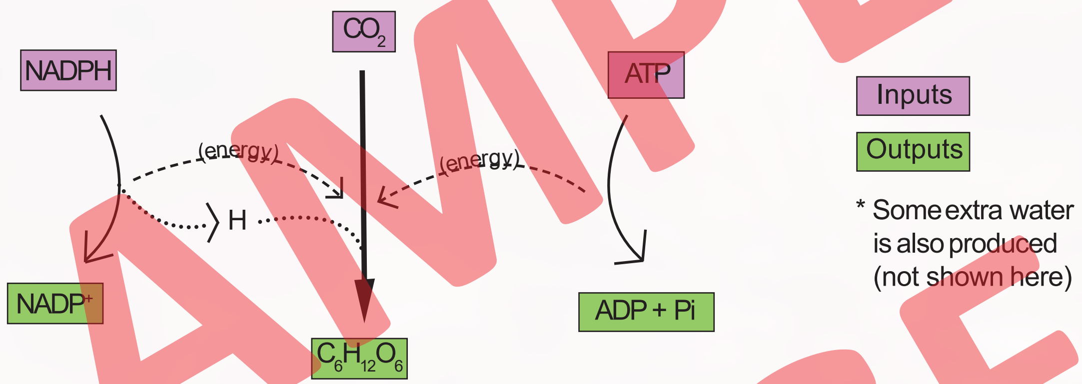

Figure 49. Simplified diagram of the light-independent stage of photosynthesis, showing inputs and outputs (total numbers of atoms and molecules not included).

Photosynthesis in C_3 and C_4 plants

Some plants differ in the way they carry out photosynthesis. In so-called '**C_3**' plants, for example, the production of glucose in the light-independent stage is a one-stage process (the *Calvin cycle*) that occurs in *mesophyll* cells, while in '**C_4**' plants, production of glucose involves *two* stages, the second of which is the Calvin cycle. In C_4 plants, the Calvin cycle occurs in *bundle sheath* cells (see figure 50).

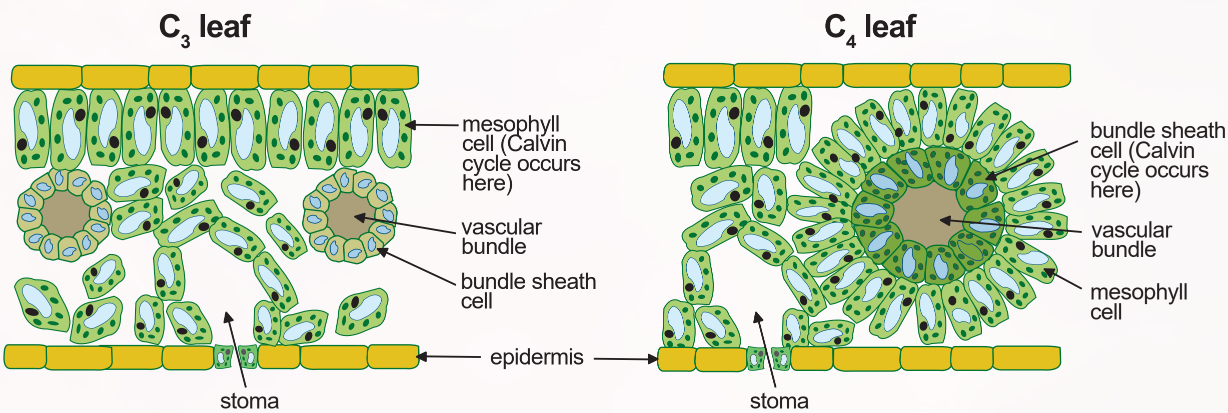

Figure 50. Sructure of leaf in C_3 and C_4 plants

C_3 plants

'C_3' plants make up the majority of terrestrial plants on Earth and tend to thrive in cool, wet climates. They include important crops such as wheat, rice, barley, oats and rye.

While C_3 plants carry out photosynthesis very efficiently in their usual cool, wet environment, they become less efficient if temperatures rise, or if it becomes too dry. This is because an important enzyme involved in the Calvin cycle, **Rubisco**, starts to bind *not* with its usual substrate carbon dioxide, but with oxygen instead. Remember that in C_3 plants, the Calvin cycle occurs in the mesophyll cells.

Why would Rubisco bind with the wrong substrate? Apparently the enzyme has an active site that can actually accommodate both molecules, so in effect, carbon dioxide and oxygen are competing with each other for the active site (a clear case of competitive inhibition).

When the temperature rises, the solubility of carbon dioxide decreases at a faster rate than that of oxygen, meaning that more oxygen becomes available in the fluid cytosol of plant cells carrying out photosynthesis.

When conditions become too dry, C_3 plants tend to close their stomata (pores) to prevent water loss, meaning that carbon dioxide can no longer enter the leaf from the air. Any oxygen produced during the light-dependent stage of photosynthesis cannot leave the plant, and so builds up inside the cells. This makes it more likely that Rubisco will bind with oxygen instead of carbon dioxide.

When Rubisco binds with oxygen instead of carbon dioxide, a process known as **photorespiration** occurs. Photorespiration is a wasteful process and results in less glucose being produced for the plant; instead, energy from the ATP produced during the light-dependent stage of photosynthesis goes into producing carbon dioxide.

The following diagram compares photorespiration (on the left) to the Calvin cycle (right):

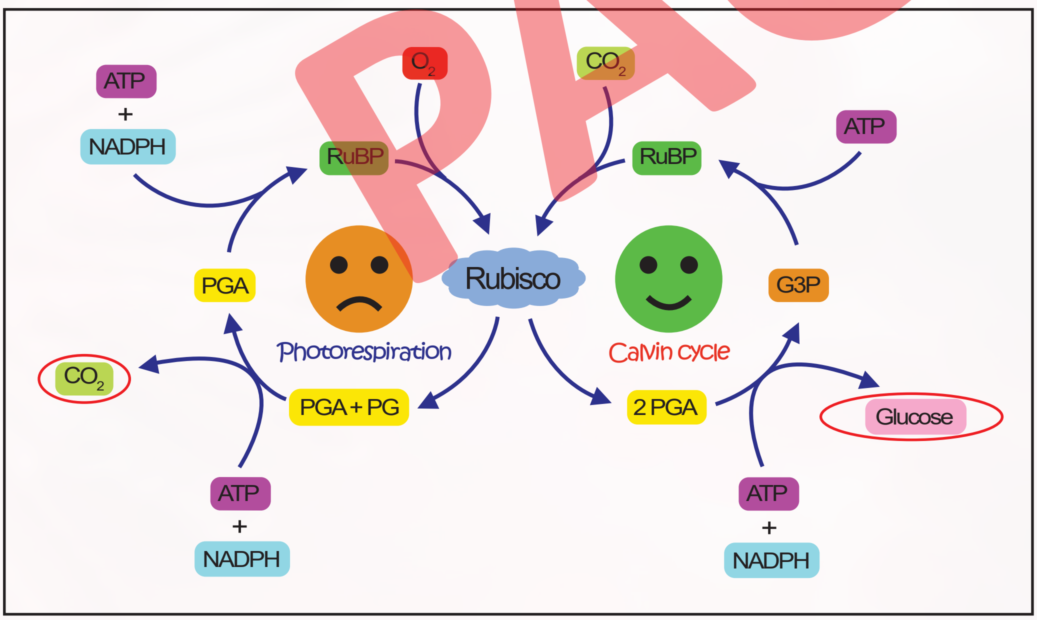

Figure 51. Simplified diagram comparing photorespiration and the Calvin cycle. Note the product for each reaction (circled): CO_2 for photorespiration and glucose for the Calvin cycle.

Steps involved in the Calvin cycle of C_3 plants (see figure 51):

1. CO_2 from the air is picked up by an acceptor molecule, **RuBP** (ribulose biphosphate). This reaction is catalysed by the Rubisco enzyme.

2. As a result of the reaction, two molecules of the substance **PGA** (phosphoglyceric acid) are produced. PGA is a three-carbon compound.

3. The PGA accepts hydrogens from the loaded NADPH coenzyme, converting it into **G3P** (glyceraldehyde phosphate), another three-carbon molecule. Energy to drive this reaction comes from ATP.

4. G3P is used to produce **glucose**, with *two* molecules needed to make a six-carbon glucose.

5. *Some G3P is also used to regenerate RuBP, a process that requires ATP energy. This is a necessary step to keep the Calvin cycle going, as RuBP is needed to bind with CO_2.

* Note that figure 51 does not provide actual numbers of G3P (and CO_2) molecules involved in the Calvin cycle. This is because the cycle is much more complex than is shown here, and in fact requires six 'turns' to create one molecule of glucose.

Steps involved in photorespiration (see figure 51):

1. O_2 (instead of CO_2) is picked up by the acceptor molecule, **RuBP**. This reaction is catalysed by the Rubisco enzyme.

2. As a result of the reaction, one molecule of **PGA** is produced, along with one molecule of **PG** (phosphoglycolate), a two-carbon compound.

3. Being a toxic substance capable of inhibiting photosynthesis, PG must be removed. This is achieved by converting it back into PGA through a series of energy-requiring reactions involving ATP and NADPH. These reactions release CO_2.

4. PGA molecules re-enter the C_3 cycle.

C_4 plants

'C_4' plants make up only around 3 per cent of terrestrial plant species and tend to live in warm, tropical regions. They include crops such as sugar cane, maize and sorghum.

We have seen that the production of glucose in C_4 plants involves a two-stage process, the second of which is the Calvin cycle that occurs in bundle sheath cells. In C_4 plants, the Calvin cycle is preceded by a series of reactions that occur in the mesophyll cells, and these reactions make up the first stage of glucose production.

Why is it that C_4 plants carry out glucose production in two stages rather than one? The reason is that this system has enabled C_4 plants to minimize the wasteful process of photorespiration and hence maximise the efficiency of photosynthesis.

The first stage in the C_4 pathway from carbon dioxide to glucose involves the *fixation* of carbon. This is a process in which living organisms convert inorganic carbon (particularly in the form of CO_2) into organic compounds. In this case, the carbon dioxide is converted into **malic acid**.

The first stage in the C_4 pathway involves the enzyme **PEP carboxylase** (mesophyll cells of C_4 plants do not contain Rubisco), which catalyses the binding of carbon dioxide to the acceptor molecule PEP (phosphoenolpyruvate). Importantly, PEP carboxylase, unlike Rubisco, cannot bind to oxygen, only to carbon dioxide. This means that photorespiration cannot occur.

The following diagram shows the light-independent stage of C_4 plants:

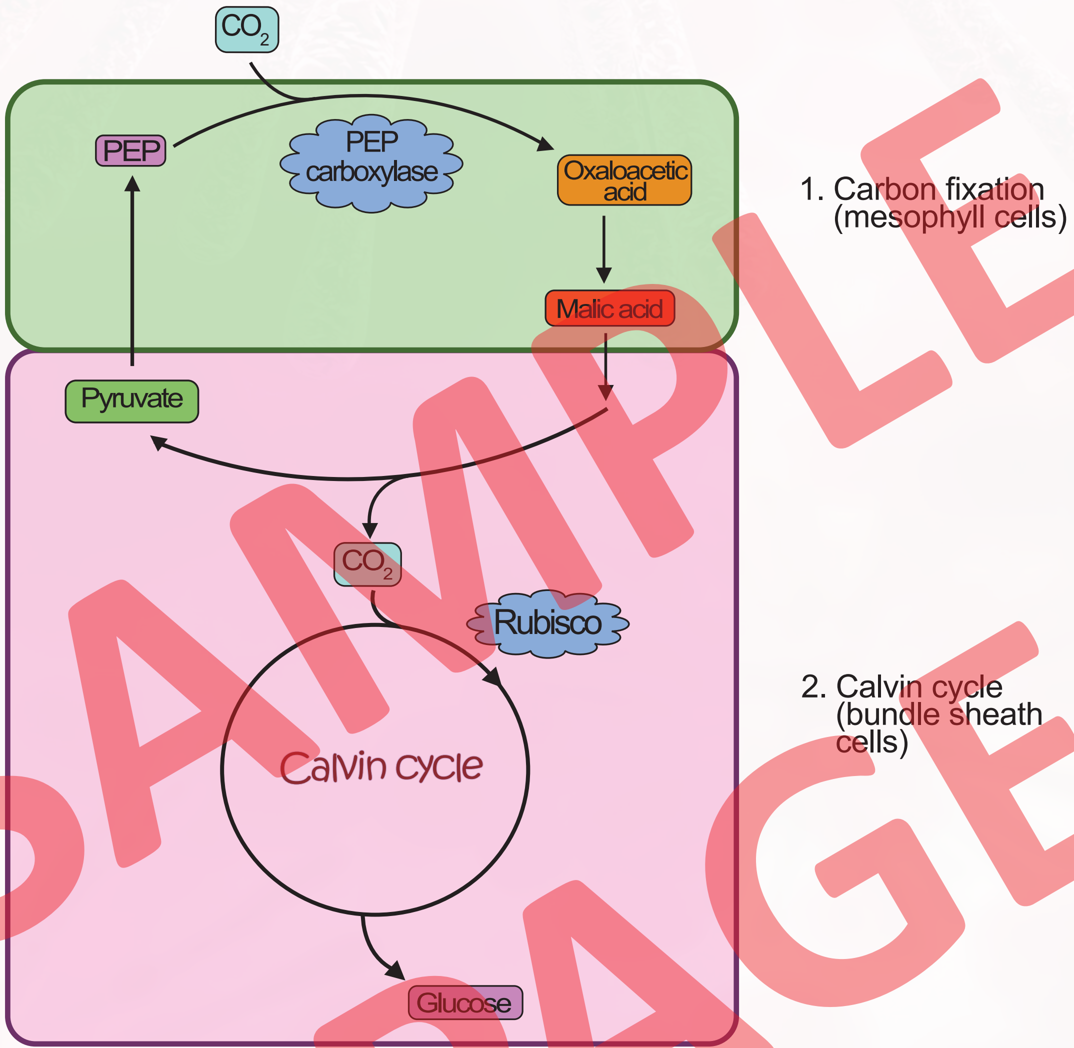

Figure 52. Light-independent stage in C_4 plants. This occurs in two stages: carbon fixation and the Calvin cycle.

Steps involved in carbon fixation of C_4 plants (see figure 52):

1. CO_2 from the air is picked up by an acceptor molecule, **PEP** (phosphoenolpyruvate). This reaction is catalysed by the enzyme PEP carboxylase.

2. As a result of the reaction, one molecule of the four-carbon compound **oxaloacetic acid** is produced.

3. Oxaloacetic acid is converted into **malic acid**, another four-carbon compound.

4. Malic acid is then transported from the mesophyll cells to the bundle sheath cells.

Steps involved in the Calvin cycle of C_4 plants (see figure 52):

1. In the bundle sheath cells, malic acid is converted into **pyruvate** and carbon dioxide.
2. The Rubisco enzyme binds the carbon dioxide to the acceptor molecule RuBP.
3. The rest of the Calvin cycle proceeds as normal, while the pyruvate is transferred back to the mesophyll cells for the regeneration of PEP.

Photosynthesis in CAM plants

'CAM' plants make up about eight per cent of terrestrial plants and live in hot, dry conditions. They include cacti, orchids, jade, sedum and agave.

As in C_4 plants, the production of glucose in CAM plants involves a two-stage process. The first stage, carbon fixation, occurs only at night when stomata are open, while the second stage, the Calvin cycle, occurs during the day when stomata are closed. Both stages take place in the mesophyll cells.

Like C_4 plants, CAM plants are able to avoid the problem of photorespiration because the carbon fixation stage involves the PEP carboxylase enzyme, which we have seen can bind only to carbon dioxide, and *not* to oxygen.

The following diagram shows the light-independent stage of CAM plants:

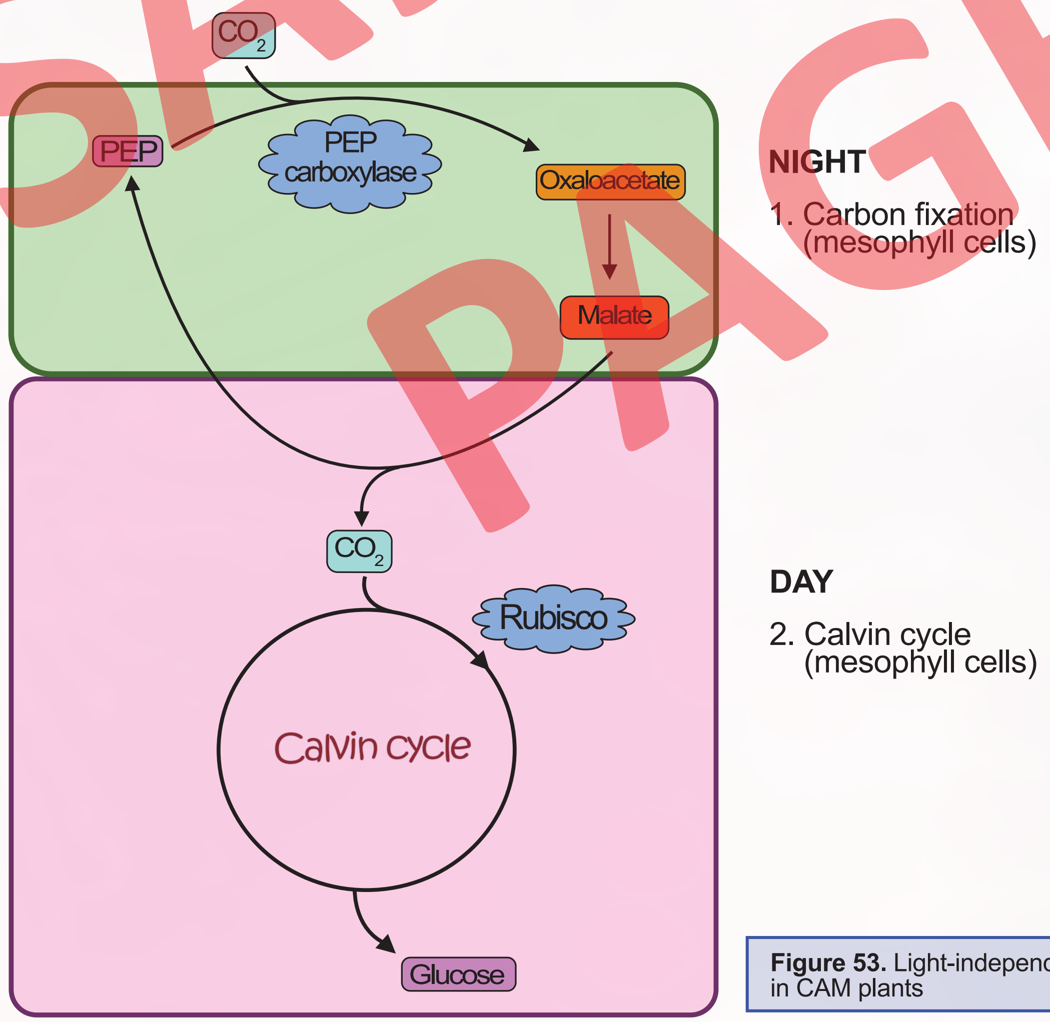

Figure 53. Light-independent stage in CAM plants

Steps involved in carbon fixation of CAM plants (see figure 53):

1. CO_2 from the air is picked up by an acceptor molecule, **PEP** (phosphoenolpyruvate). This reaction is catalysed by the enzyme PEP carboxylase (stomata are open, allowing CO_2 to enter the leaf).

2. As a result of the reaction, one molecule of the four-carbon compound **oxaloacetate** is produced.

3. Oxaloacetate is converted into **malate**, another four-carbon compound. Apart from malate, other types of organic acids may also be formed.

4. Malate and other organic acids are stored in the vacuoles of the mesophyll cells until the sun rises.

Steps involved in the Calvin cycle of CAM plants (see figure 53):

1. Once daylight begins, the stomata close. The stored malate and other organic acids are transported from the vacuoles to the stroma of chloroplasts.

2. Organic acids are broken down to steadily release carbon dioxide.

3. The concentration of carbon dioxide in the leaf increases.

4. Rubisco enzyme binds the carbon dioxide to the acceptor molecule RuBP.

5. The rest of the Calvin cycle proceeds as normal.

Factors affecting the rate of photosynthesis

A number of factors can affect the rate of photosynthesis, including:

1. Light intensity

Because light is needed for photosynthesis to occur, a lack of it can obviously reduce the rate of the process. In other words, it is a *limiting factor*. Increasing light intensity leads to an increase in photosynthesis, but only up to a certain point, the so-called *light saturation point*, at which the rate steadies (see figure 54a). This may be because of some other limiting factor, such as the amount of carbon dioxide or water, or it may be because the enzymes involved are already working to capacity and cannot go any faster.

2. Carbon dioxide concentration

Carbon dioxide is also a requirement of photosynthesis, and can therefore act as a limiting factor. A lack of carbon dioxide slows the process, while increasing it will speed it up (again, up to a certain point) (see figure 54b).

3. Amount of water

Water is also needed for photosynthesis to occur, and can therefore act as a limiting factor in the same way as light and carbon dioxide (see figure 54c).

4. Temperature

In general, increasing the temperature at which a reaction is occurring will also increase its rate. This does not only apply to photosynthesis, but to many chemical reactions. The reason for this is because the molecules involved tend to move faster when heated, colliding more often and therefore reacting together more often. Remember, however, that high temperatures can also denature enzymes, including those involved in photosynthesis, such as Rubisco. When this happens, the reaction starts to slow and can even stop altogether (see figure 54d).

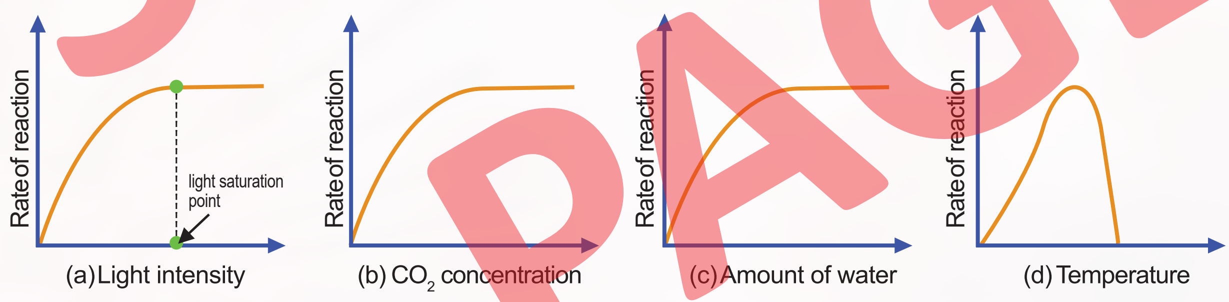

Figure 54. Effects of (a) light intensity (b) CO_2 concentration (c) amount of water and (d) temperature on the rate of photosynthesis

Other factors

Any substance that is needed for photosynthesis to occur can potentially become a limiting factor. This includes $NADP^+$ and ADP + Pi, which are needed for the light-dependent stage, as well as NADPH and ATP, needed for the light-independent stage. Amount of chlorophyll and availability of certain nutrients can also act as limiting factors.

A closer look at the structure of chloroplasts

Chloroplasts consist of an outer membrane and an inner membrane (see figure 55), as well as numerous flattened sac-like compartments called thylakoids which, as we have seen, are the sites of the LD stage of photosynthesis, and which contain the light-trapping pigment chlorophyll. Sometimes, groups of thylakoids stack together to form a *granum* (plural: *grana*), rather like a stack of coins.

The colourless liquid part of the chloroplast is called the *stroma*, which surrounds the grana. This is where the chloroplast's DNA and ribosomes are found, and is also the site of the LI stage of photosynthesis.

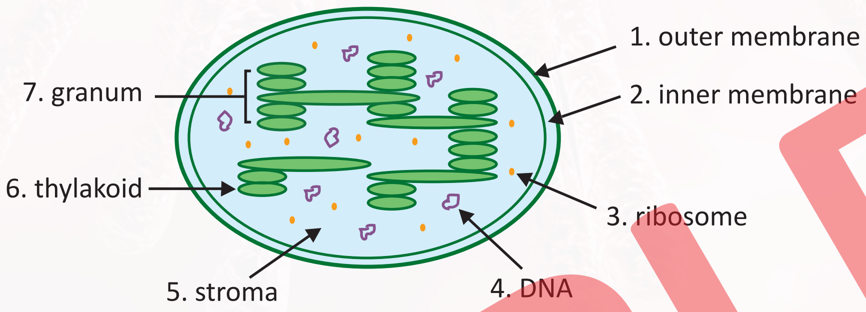

Figure 55. Structure of the chloroplast

Origin of the chloroplast

The chloroplasts found in eukaryotic organisms today - such as plants - are thought to have once existed as organisms in their own right, and that they are actually the descendants of a type of photosynthetic bacteria known as *cyanobacteria*. Scientists believe that these ancient, photosynthetic, free-living microbes were at some stage engulfed by another type of microbial cell in a process known as **endosymbiosis** (see figure 56). This endosymbiotic event was of benefit to both the engulfed cell, which gained protection, as well as the 'host cell', which now had a means of producing its own sugar.

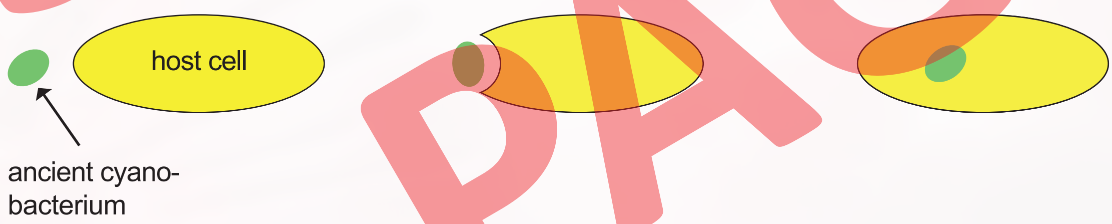

Figure 56. The process of endosymbiosis, showing an ancient cyanobacterium being engulfed by another type of microbe (the host cell). Engulfed microbes would eventually evolve to become chloroplasts in eukaryotic cells.

What evidence is there that supports the theory of endosymbiotic origin of chloroplasts? Scientists have made the following observations:

* Chloroplasts contain circular molecules of DNA similar to those found in bacteria.
* Chloroplasts also contain ribosomes, meaning that they can make their own proteins (being able to make proteins would have been necessary for their once-independent existence).
* The ribosomes found in chloroplasts are similar to those found in bacteria.
* Chloroplasts have their own method of reproduction, which is by binary fission. The eukaryotic cells they are found in however, divide by mitosis. Bacteria also divide by binary fission.
* Chloroplasts are similar in size to bacteria.

Using CRISPR-Cas9 to improve photosynthetic efficiency and crop yield

We have seen that CRISPR-Cas9 technology can potentially be used to edit faulty or harmful genes, such as those that cause serious disease in humans.

Another potential use of this technology is in agriculture. For example, CRISPR-Cas9 can be used to increase the efficiency of plant photosynthesis, leading to greater crop yields. This would in turn result in increased food production for a continuously growing world population.

How might CRISPR-Cas9 be used to increase yields in crops such as wheat, rice and other staples? We have seen that the Rubisco enzyme in C_3 plants is not very good at distinguishing oxygen from carbon dioxide, sometimes leading to the wasteful process of photorespiration and therefore a decrease in photosynthetic efficiency.

CRISPR-Cas9 can potentially be used to target those genes that code for the production of Rubisco, making small changes that reduce the enzyme's ability to bind to oxygen, and/or *improve* its ability to bind to carbon dioxide. This would result in less photorespiration occurring, more efficient photosynthesis, and potentially an increase in crop yields.

CRISPR-Cas9 has already been used to improve crop quality, which can then lead to increased crop yields. Examples of this include (i) making rice more drought tolerant (ii) making citrus plants resistant to *citrus canker*, a disease caused by the bacterium *Xanthomonas axonopodis* (iii) conferring herbicide resistance to potatoes (iv) increasing iron content in wheat and (v) improving pathogen resistance in the tomato.

Suggested flash card questions: photosynthesis

1. What is *photosynthesis*?
2. Photosynthesis is an example of a *biochemical pathway*. What does this mean?
3. What is meant by 'biochemical' reaction?
4. What are the two stages of photosynthesis?
5. Where does the LD stage of photosynthesis occur?
6. Name four inputs of the LD stage.
7. What waste product is produced during the LD stage?
8. What is the role of the unloaded carrier molecule $NADP^+$ in photosynthesis?
9. Where does the LI stage of photosynthesis occur?
10. Name three *inputs* and three *outputs* of the LI stage.
11. What is the role of the loaded coenzyme NADPH in the LI stage?
12. Why is ATP required during the LI stage?
13. Where does the Calvin cycle occur in (i) C_3 plants (ii) C_4 plants (iii) CAM plants?
14. What is the role of the Rubisco enzyme in photosynthesis?
15. What is 'photorespiration' and why is it considered to be a 'wasteful' process?
16. How are C_4 plants able to avoid carrying out photorespiration?
17. What is the name of the process that proceeds the Calvin cycle in C_4 plants and CAM plants?
18. What effect does (i) light intensity and (ii) CO_2 concentration have on photosynthesis?
19. Why does increasing temperature tend to speed up chemical reactions?
20. What are two features of chloroplasts that suggest they were once free-living microbes?
21. Give two examples of how CRISPR-Cas9 technology has been used to improve crop quality.

Useful VCAA sample exam questions

Photosynthesis

Year	Questions
2020	**MC** 10, 12, **SA** 3
2019	**MC** 15, **SA** 2
2018	**MC** 13 - 15
2017	**MC** 13 - 16
2016	**MC** 10, 11
2015	**SA** 3
2014	**MC** 7, 8,
2013	**SA** 1c