

1

Energy transfer

When you have finished revising this topic, you should:

- be able to explain the difference between catabolic and anabolic reactions
- be able to describe the part played by ATP in cell metabolism
- understand the relationship between photosynthesis and respiration in a leaf

1.1 Catabolism and anabolism

Metabolism is a term used to describe all the chemical reactions taking place in an organism. These reactions are divided into:

- **Catabolic reactions** in which larger molecules are broken down to smaller ones with the release of energy. Respiration involves a series of catabolic reactions.
- **Anabolic reactions** in which smaller molecules are built up into larger ones. This is energy requiring. Photosynthesis and protein synthesis are anabolic reactions.

There is a balance between catabolic and anabolic reactions. Catabolism provides the energy for the organism to synthesise larger molecules in its anabolic reactions.

1.2 ATP

Adenosine triphosphate, **ATP**, is a nucleotide. It consists of three components:

- a 5-carbon sugar — ribose
- an organic base — adenine
- three phosphate groups

Figure 5.1 shows how these components are arranged to form an ATP molecule.

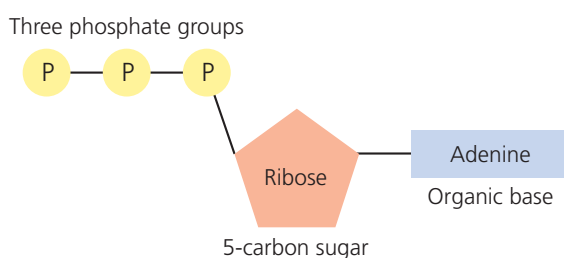


Figure 5.1 A molecule of ATP

ATP breaks down to form ADP and a phosphate group (written as P_i for inorganic phosphate). This breakdown involves hydrolysis of the ATP molecule, and releases energy that is used for energy-requiring reactions. Since more energy is always released than is required for the reaction, some is lost as heat.

To maintain the organism's anabolic reactions, ATP must be continually formed from ADP and phosphate. This reaction needs a source of energy. The formation and breakdown of ATP are summarised in Figure 5.2.

It is best to write about the transfer of energy, although it is sometimes more convenient for biologists to refer to energy being released. Never write about reactions making energy.



Energy transfer

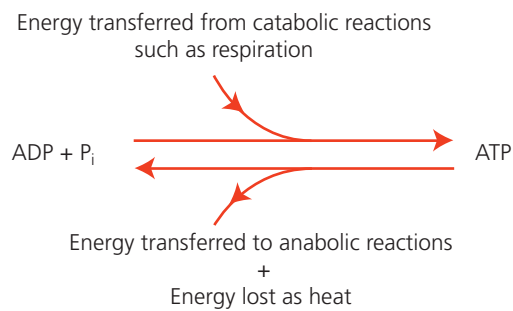


Figure 5.2 The formation and breakdown of ATP

ATP is more useful than glucose as an immediate source of energy because:

- The breakdown of ATP makes energy instantly available. It takes longer for energy to be made available from the series of reactions involved in the breakdown of glucose during respiration.
- The breakdown of a molecule of ATP releases a small amount of energy ideal for driving an anabolic reaction. The breakdown of a molecule of glucose would produce much more energy than would be required.

1.3 Photosynthesis and respiration

Plants produce sugars from carbon dioxide and water. This process is anabolic and requires light energy. The sugars are used as the starting point for other anabolic reactions, such as those producing proteins, lipids and nucleic acids. The energy required for these reactions comes from ATP synthesised during respiration.

Although very basic, the relationship between photosynthesis and respiration in a leaf is frequently misunderstood:

- In daylight, the cells of the leaf are photosynthesising and respiring. The rate of photosynthesis is greater than the rate of respiration. If it were not, the plant would not be able to accumulate organic molecules and grow. Therefore, in the light there is a net uptake of carbon dioxide.
- At night, no light is available so the leaf cannot photosynthesise. It still respire. In the dark, there is a loss of carbon dioxide.

This relationship is summarised in Figure 5.3.

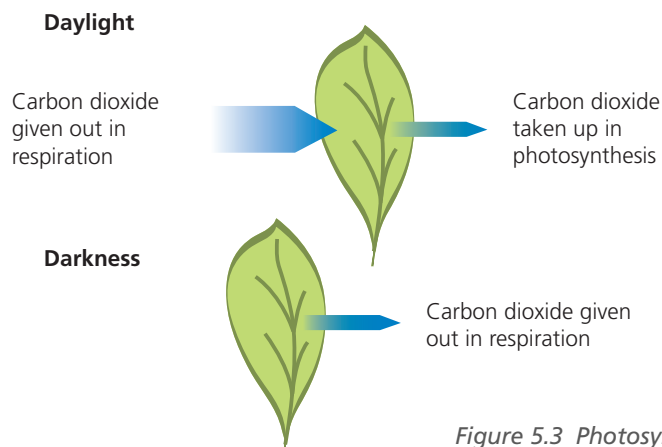


Figure 5.3 Photosynthesis and respiration in a leaf

During the day the concentration of carbon dioxide in the intercellular spaces of a leaf decreases because it is used in photosynthesis. It does not increase because it is needed for photosynthesis.

2

Respiration

When you have finished revising this topic, you should:

- understand that respiration involves the release of energy from organic molecules
- be able to explain how a molecule of glucose is oxidised to pyruvate with a net gain of ATP and reduced NAD
- know that pyruvate combines with coenzyme A to produce acetyl-coenzyme A
- be able to explain the role of the Krebs cycle in producing ATP and reduced coenzyme
- be able to explain how ATP is produced via a chain of electron carriers in the process of oxidative phosphorylation
- be able to describe the biochemical pathways of anaerobic respiration
- be able to calculate and interpret respiratory quotients

2.1 Introduction

Respiration is often represented by the equation:



This equation can be misleading. $\text{C}_6\text{H}_{12}\text{O}_6$ represents glucose, but glucose is not the only substance which can be used as a respiratory substrate. Similarly, under some circumstances, oxygen is not necessary for respiration, and water and carbon dioxide are only produced in the proportions shown in the equation when glucose is respired in the presence of oxygen. The only constant feature is the release of energy, and it is best to think of respiration as the biochemical pathway which takes place in cells and results in the release of energy from organic molecules.

At A2, we look in detail at only one of the many respiratory pathways. This is summarised by the equation above and represented in Figure 5.4.

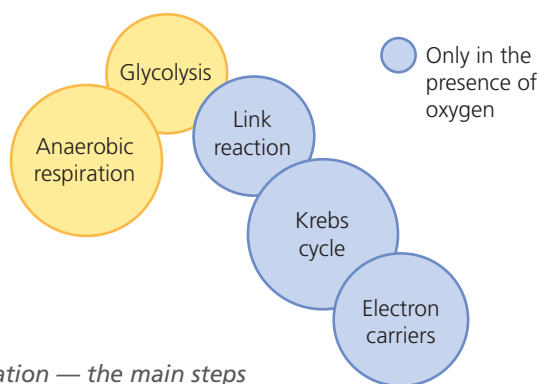


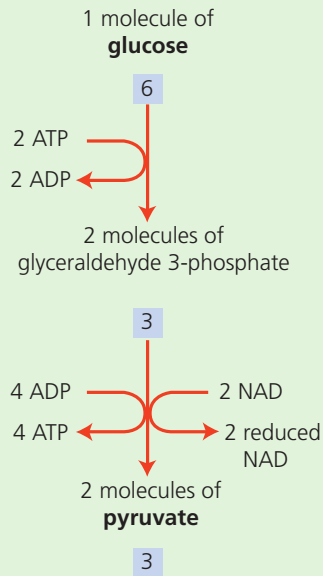
Figure 5.4 Respiration — the main steps

If you are not a chemist, the detail in the biochemical pathway of respiration may seem daunting. What you need to do is make sure that you have a sound understanding of the overall process. Once you have the general picture you can look in more detail at the individual steps in the process.

Distinguish between respiration and gas exchange. Respiration is a biochemical pathway. Gas exchange involves exchange of respiratory gases with the environment.

Glycolysis

The part of the biochemical pathway of respiration in which a molecule of glucose is broken down into two 3-carbon pyruvate groups. The boxes represent the number of carbon atoms present in the molecules and ions shown.

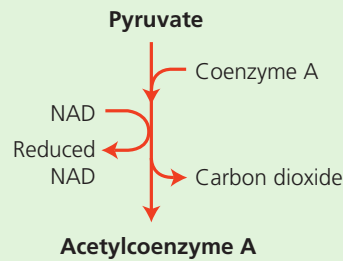


Phosphate groups are added to the glucose molecule. These phosphate groups are supplied by ATP.

The resulting phosphorylated sugar is then broken down to give 2 molecules of pyruvate. The process produces 4 ATP molecules so there is a net gain of 2 ATP for each molecule of glucose. The complete reaction is an oxidation reaction and releases hydrogen. This is removed and used to reduce a coenzyme known as NAD.

The link reaction

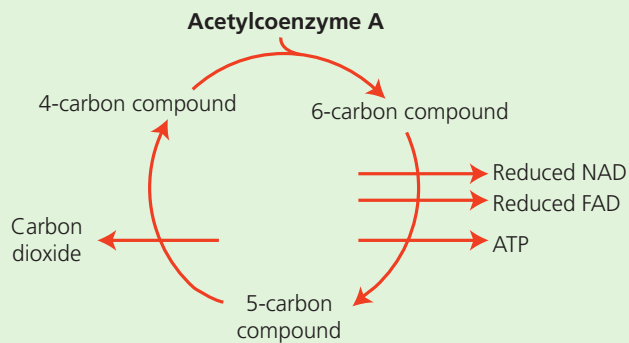
A name given to describe the reaction linking glycolysis to the Krebs cycle.



In the link reaction, pyruvate combines with coenzyme A to produce acetyl-coenzyme A. This reaction involves the loss of one molecule of carbon dioxide. It is also an oxidation reaction and the hydrogen that is lost is used to reduce NAD.

Krebs cycle

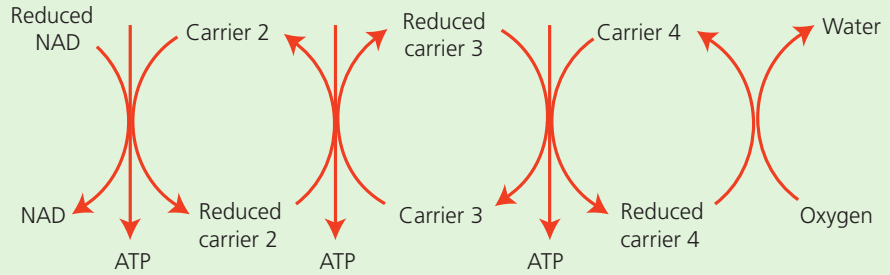
A series of oxidation reactions involving the release of carbon dioxide which leads to the production of ATP and reduced coenzyme.



Acetylcoenzyme A can be thought of as a 2-carbon compound. It is fed into Krebs cycle where it combines with a 4-carbon compound to produce a 6-carbon compound. The 6-carbon compound is broken down in a series of oxidation reactions to produce the 4-carbon compound again. Krebs cycle involves the loss of carbon dioxide and the production of ATP and reduced coenzymes.

Electron carrier systems

A chain of molecules in which the energy released in the passage of electrons from one molecule to the next is used to produce ATP.



Hydrogen released during Krebs cycle acts as a source of electrons and protons. The electrons are passed from molecule to molecule along the electron transport chain. At each transfer a small amount of energy is released. This is used to pump protons through the inner mitochondrial membrane on which the carriers are situated. When the protons return through the membrane they release energy which is used to produce ATP.

2.2 Anaerobic respiration

In some circumstances, there is too little oxygen available to enable a cell to respire by the pathway described above. In order to produce ATP under these conditions, it must respire anaerobically. Anaerobic respiration relies on glycolysis to produce ATP, so it is far less efficient than aerobic respiration. A single molecule of glucose can produce 38 molecules of ATP in aerobic respiration; it only produces 2 molecules of ATP in anaerobic respiration.

During glycolysis, NAD is reduced. This reduced NAD is normally reconverted to NAD by the reactions of the aerobic pathway. If the cell is unable to respire aerobically, there would come a time when all the NAD would be reduced and glycolysis would be unable to continue. In anaerobic respiration, pyruvate is converted either to lactate in animals, or to ethanol and carbon dioxide in plants and in microorganisms such as yeast. This allows NAD to be reformed from reduced NAD. These pathways are summarised in Figure 5.5.

Remember the end product of anaerobic respiration in animals is lactate, not ethanol. Marathon runners don't fall down drunk!

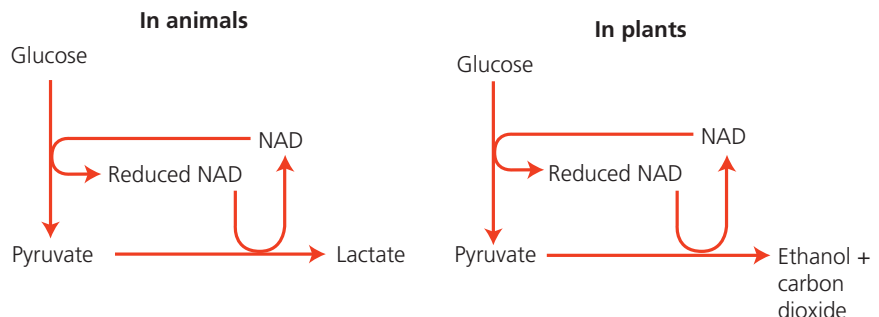


Figure 5.5 The biochemical pathways of anaerobic respiration

The respiratory substrate is the organic substance which is required. Oxygen is not a respiratory substrate.

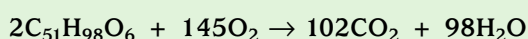
RQ is easy to calculate providing that you remember which way up the equation is.

2.3 Using different respiratory substrates

The organic substance which forms the starting-point for respiration is called a **respiratory substrate**. One way in which it is possible to find out which substrate is being respired is by calculating the **respiratory quotient** or **RQ**. The respiratory quotient is the amount of carbon dioxide produced in a given time divided by the amount of oxygen consumed in the same time.

Calculating the respiratory quotient

The equation below represents the respiration of a triglyceride (a fat):



$$\text{RQ} = \frac{\text{amount of carbon dioxide produced}}{\text{amount of oxygen consumed}}$$

Using the equation representing the respiration of the triglyceride,

$$\begin{aligned}\text{RQ} &= \frac{102}{145} \\ &= 0.7\end{aligned}$$

Table 5.1 shows RQs for some important respiratory substrates.

RQ	Respiratory substrate
0.7	Triglyceride
0.9	Protein
1.0	Carbohydrate

Table 5.1

We have to be careful about interpreting RQ. An RQ of 0.9, for example, may mean that the respiratory substrate is protein, but a mixture of triglyceride and carbohydrate could also give the same value.

3 Photosynthesis

When you have finished revising this topic, you should be able to explain that:

- photosynthesis involves light-dependent reactions in which light energy is captured by chlorophyll and used to produce ATP and reduced NADP
- the light-dependent reactions also involve photolysis, in which water molecules break down to produce electrons, hydrogen ions and oxygen
- carbon dioxide is reduced to carbohydrates in the light-independent reactions

The coenzyme involved in photosynthesis is NADP; that involved in respiration is NAD (P for photosynthesis).

3.1 Introduction

Photosynthesis is similar to respiration in that it is also a complex process involving a number of separate stages. It is useful to look at the overall process shown in Figure 5.6 before considering the detailed biochemistry.

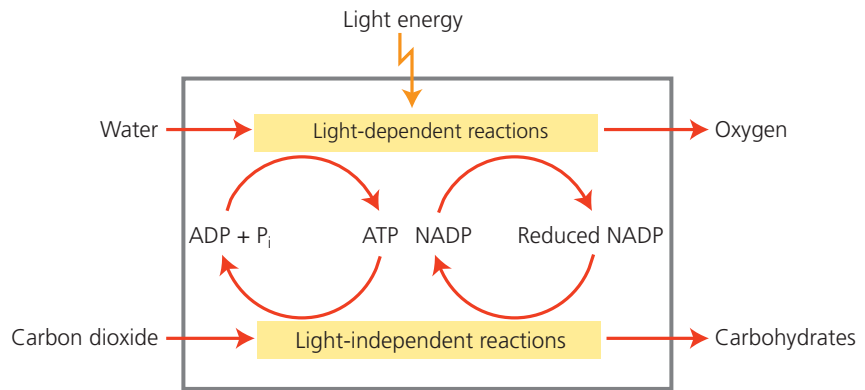


Figure 5.6 Photosynthesis, the main steps

There are two basic steps:

- 1** The **light-dependent** reactions in which light energy is captured by chlorophyll and is used to produce ATP and reduced NADP.
- 2** The **light-independent** reactions in which the ATP and reduced NADP are used in the conversion of carbon dioxide to carbohydrate.

It is convenient to consider these reactions separately.

3.2 The light-dependent reactions

Figure 5.7 summarises the light-dependent reactions.

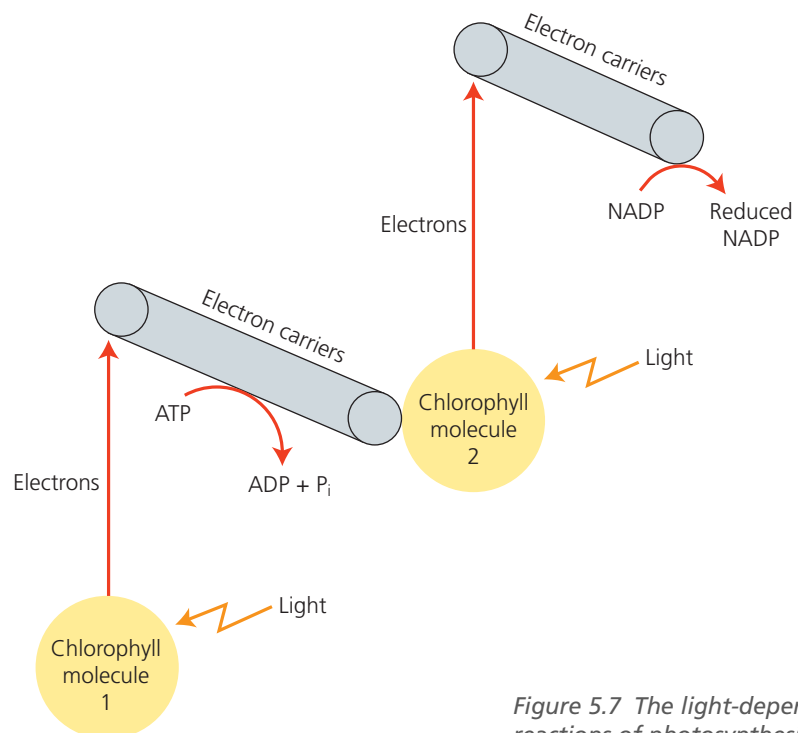
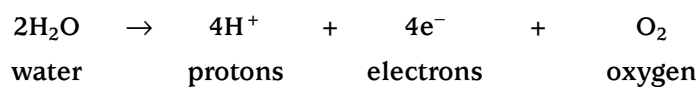


Figure 5.7 The light-dependent reactions of photosynthesis



3 Photosynthesis

- 1 Light strikes the first chlorophyll molecule (called chlorophyll molecule 1 for convenience). It excites some of the electrons in the molecule. These are raised to a higher energy level and pass to a molecule which acts as an electron acceptor.
- 2 These electrons are transferred along the series of molecules which form an electron carrier system. Energy is released and used to produce ATP.
- 3 The electrons are eventually accepted by chlorophyll molecule 2.
- 4 Light strikes chlorophyll molecule 2 and some of its excited electrons also pass down an electron carrier system.
- 5 Eventually these electrons are used to convert NADP to reduced NADP.
- 6 Another reaction is also involved. This is photolysis. Water is broken down to produce protons, electrons and oxygen. This is summarised by the equation:



- The protons help to reduce the NADP to reduced NADP.
- The electrons are accepted by chlorophyll molecule 1.
- The oxygen is given off as a waste product.

3.3 The light-independent reactions

This is the process in which carbon dioxide is reduced to form carbohydrates. It is summarised in Figure 5.8.

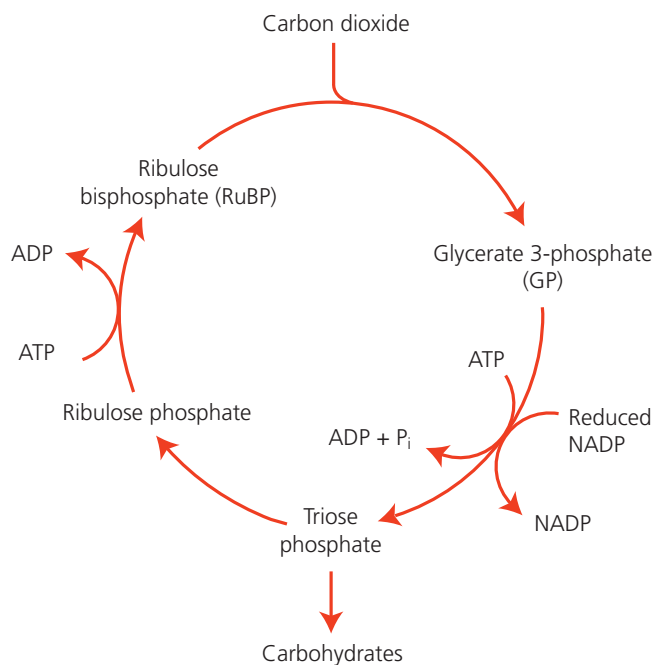


Figure 5.8 The light-independent reactions of photosynthesis

Light-independent reactions are so called because they are independent of light. However, they cannot take place without the ATP and reduced NADP produced in the light. Because of this, the light-independent reactions cannot continue for long in the dark.

Remember, the Calvin cycle is part of photosynthesis; the Krebs cycle is part of respiration.

- 1** Ribulose biphosphate (RuBP) is a 5-carbon compound. It combines with a molecule of carbon dioxide to form two molecules of the 3-carbon compound, glycerate 3-phosphate (GP).
- 2** GP is reduced to triose phosphate (also known as glyceraldehyde 3-phosphate, GALP). This requires reduced NADP and energy from ATP.
- 3** Some of the triose phosphate is converted into carbohydrates such as glucose and starch.
- 4** The rest of the triose phosphate is used to make more RuBP in a cycle of reactions known as the Calvin cycle. ATP is also required for the regeneration of RuBP. It supplies the phosphate necessary to convert ribulose phosphate to ribulose biphosphate.