8 METABOLISM, CELL RESPIRATION AND PHOTOSYNTHESIS (AHL)

Introduction

Life is sustained by a complex web of chemical reactions inside cells. These metabolic reactions are regulated in response to the needs of the cell and the organism. Energy is converted to a usable form in cell respiration. In photosynthesis light energy is converted into chemical energy and a huge diversity of carbon compounds is produced.

8.1 Metabolism

Understanding

- Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.
- Enzymes lower the activation energy of the chemical reactions that they catalyse.
- Enzyme inhibitors can be competitive or non-competitive.
- Metabolic pathways can be controlled by end-product inhibition.

Applications

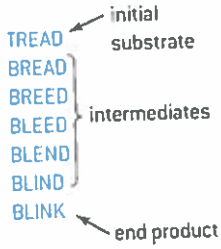
- End-product inhibition of the pathway that converts threonine to isoleucine.
- Use of databases to identify potential new anti-malarial drugs.

Skills

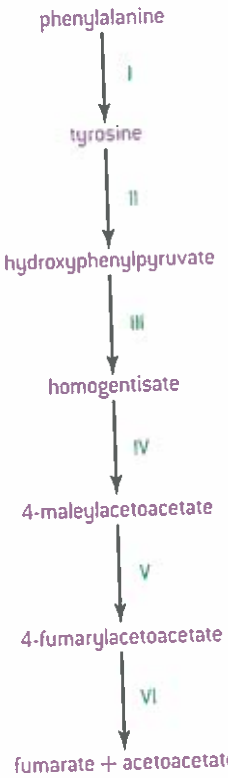
- Distinguishing different types of inhibition from graphs at specified substrate concentration.
- Calculating and plotting rates of reaction from raw experimental results.

Nature of science

- Developments in scientific research follow improvements in computing: developments in bioinformatics, such as the interrogation of databases, have facilitated research into metabolic pathways.



▲ Figure 1 Word game analogy for metabolic pathways



▲ Figure 2 Example of a metabolic pathway

Metabolic pathways

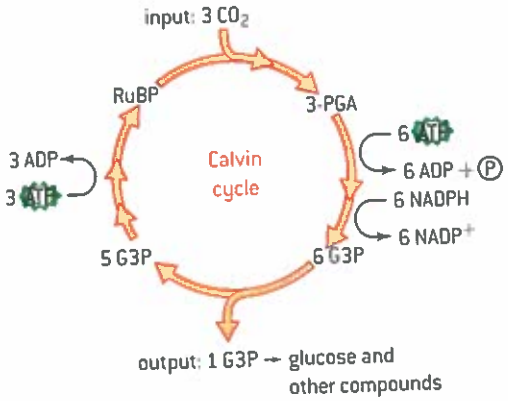
Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.

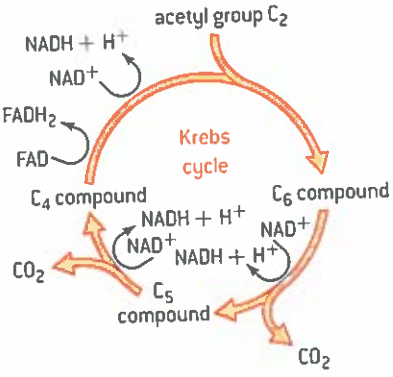
The word "metabolism" was introduced in the 19th century by the German cytologist and physiologist Theodor Schwann, to refer to the chemical changes that take place in living cells. It is now known that a huge range of chemical reactions occur in cells, catalysed by over 5,000 different types of enzyme. Although metabolism is very complex, there are some common patterns.

1 Most chemical changes happen not in one large jump, but in a sequence of small steps, together forming what is called a metabolic pathway. The word game in figure 1 is an analogy.

2 Most metabolic pathways involve a *chain* of reactions. Figure 2 shows a reaction chain that is used by cells to convert phenylalanine into fumarate and acetoacetate, which can be used as energy sources in respiration. Phenylalanine causes severe health problems if there is an excess of it in the blood.

3 Some metabolic pathways form a *cycle* rather than a chain. In this type of pathway, the end product of one reaction is the reactant that starts the rest of the pathway.





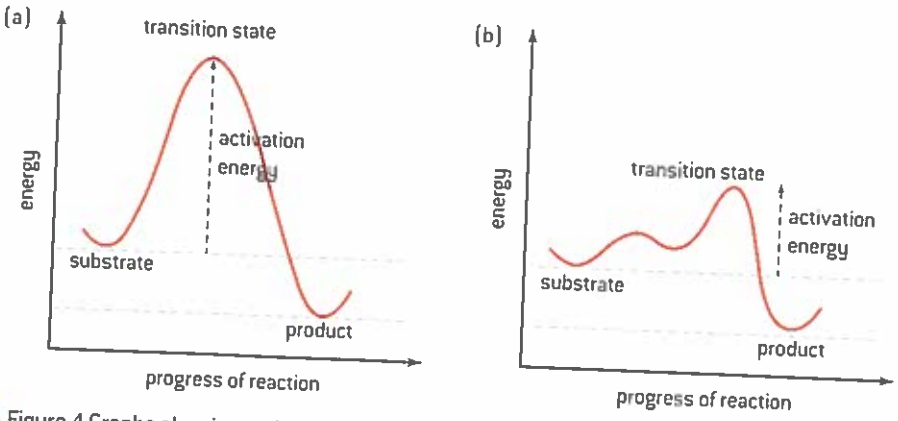
▲ Figure 3

Enzymes and activation energy

Enzymes lower the activation energy of the chemical reactions that they catalyse.

Chemical reactions are not single-step processes. Substrates have to pass through a transition state before they are converted into products. Energy is required to reach the transition state, and although energy is released in going from the transition state to the product, some energy must be put in to reach the transition state. This is called the activation energy. The activation energy is used to break or weaken bonds in the substrates. Figure 4 shows these energy

changes for an exergonic (energy releasing) reaction that is and is not catalysed by an enzyme.



▲ Figure 4 Graphs showing activation energy (a) without an enzyme and (b) with an enzyme

▲ Figure 5 A molecular model of the restriction enzyme EcoRV (purple and pink) bound to a DNA molecule (deoxyribonucleic acid, yellow and orange). Restriction enzymes, also known as restriction endonucleases, recognize specific nucleotide sequences and cut the DNA at these sites. They are found in bacteria and archaea and are thought to have evolved as a defence against viral infection

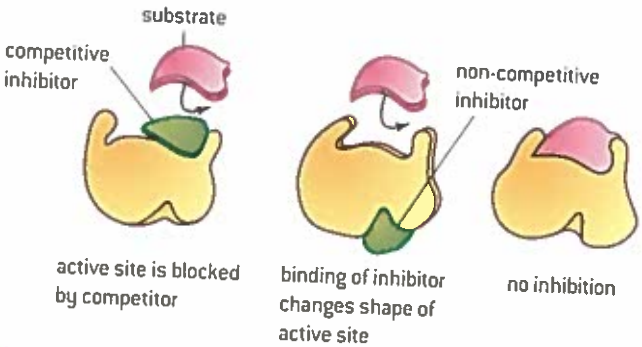
When an enzyme catalyses a reaction, the substrate binds to the active site and is altered to reach the transition state. It is then converted into the products, which separate from the active site. This binding lowers the overall energy level of the transition state. The activation energy of the reaction is therefore reduced. The net amount of energy released by the reaction is unchanged by the involvement of the enzyme. However as the activation energy is reduced, the rate of the reaction is greatly increased, typically by a factor of a million or more.

Types of enzyme inhibitors

Enzyme inhibitors can be competitive or non-competitive.

Some chemical substances bind to enzymes and reduce the activity of the enzyme. They are therefore known as inhibitors. The two main types are competitive and non-competitive inhibitors.

Competitive inhibitors interfere with the active site so that the substrate cannot bind. Non-competitive inhibitors bind at a location other than the active site. This results in a change of shape in the enzyme so that the enzyme cannot bind to the substrate. Table 1 shows examples of each type.



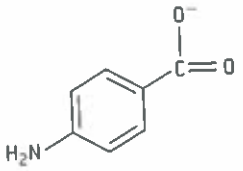
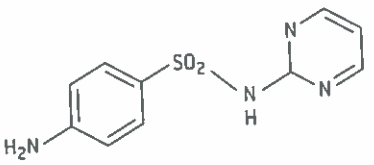
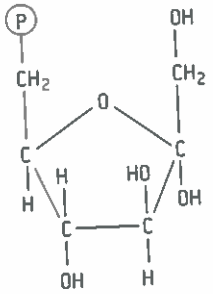
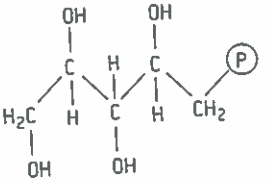
▲ Figure 6

TOK

To what extent should ethics constrain the development of knowledge in science?

Sarin was a chemical developed as an insectide before being applied is a chemical weapon. It is a competitive inhibitor of the neurotransmitter acetylcholinesterase. Chemical weapons would not exist without the activities of scientists. In fact, the name Sarin is an acronym of the surnames of the scientists who first synthesized it.

Fritz Haber received the 1918 Nobel Prize for Chemistry for his work in developing the chemistry behind the industrial production of ammonia fertilizer. Some scientists boycotted the award ceremony because Haber had been instrumental in encouraging and developing the use of chlorine gas in the First World War. Haber is quoted as saying: "During peace time a scientist belongs to the World, but during war time he belongs to his country."

Enzyme	Substrate	Inhibitor	Binding
dihydropteroate synthetase	para-aminobenzoate 	sulfadiazine 	The inhibitor binds reversibly to the enzyme's active site. While it remains bound, substrates cannot bind. This is competitive inhibition.
phosphofructokinase	fructose-6-phosphate 	xylitol-5-phosphate 	The inhibitor binds reversibly to a site away from the active site. While it remains bound, the active site is distorted and substrate cannot bind. This is non-competitive inhibition.

▲ Table 1 Examples of each type of inhibitor

Effects of enzyme inhibitors

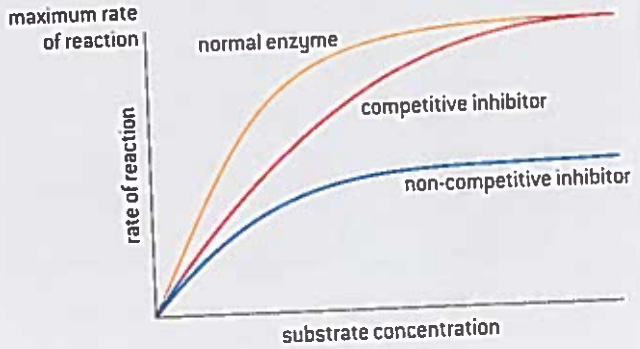
Distinguishing different types of inhibition from graphs at specified substrate concentration.

Figure 7 represents the effect of substrate concentration on the rate of an enzyme controlled reaction.

The orange line represents the effect of substrate concentration on enzyme activity in the absence of an inhibitor.

The red line shows the effect of substrate concentration on the rate of reaction when a competitive inhibitor is present. When the concentration of substrate begins to exceed the amount of inhibitor, the maximum rate of the uninhibited enzyme can be achieved; however, it takes a much higher concentration of substrate to achieve this maximum rate.

The blue line shows the effect of substrate concentration on the rate of reaction when a non-competitive inhibitor is present. In the presence of a non-competitive inhibitor, the enzyme does not reach the same maximum rate because the binding of the non-competitive inhibitor prevents some of the enzymes from being able to react regardless of substrate concentration. Those enzymes that do not bind inhibitors follow the same pattern as the normal enzyme. It takes approximately the same concentration of enzyme to reach the maximum rate, but the maximum rate is lower than the uninhibited enzyme.



▲ Figure 7

Despite the differences in the amino acid sequence between animal and human insulin, they all bind to the human insulin receptor and cause lowering of blood glucose concentration. However, some diabetics develop an allergy to animal insulins, so it is preferable to use human insulin. In 1982 human insulin became commercially available for the first time. It was produced using genetically modified *E. coli* bacteria. Since then methods of production have been developed using yeast cells and more recently safflower plants.

Each of these species has been genetically modified by transferring the gene for making human insulin to it. This is done in such a way that the gene is transcribed to produce mRNA and the mRNA is translated to produce harvestable quantities of insulin. The insulin produced has exactly the same amino acid sequence as if the gene was being transcribed and translated in human cells.

This may seem obvious, but it depends on each tRNA with a particular anticodon having the same amino acid attached to it as in humans. In other words, *E. coli*, yeast and safflower (a prokaryote, a fungus and a plant) all use the same genetic code as humans (an animal). It is fortunate for genetic engineers that all organisms, with very few exceptions, use the same genetic code as it makes gene transfer possible between widely differing species.

▲ Figure 12

2.8 Cell respiration

Understanding

- Cell respiration is the controlled release of energy from organic compounds to produce ATP.
- ATP from cell respiration is immediately available as a source of energy in the cell.
- Anaerobic cell respiration gives a small yield of ATP from glucose.
- Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.

Applications

- Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking.
- Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions.

Nature of science

- Assessing the ethics of scientific research: the use of invertebrates in respirometer experiments has ethical implications.

Skills

- Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer.

A summary of the main events of translation follows:

1 An mRNA binds to the small subunit of the ribosome.

2 A molecule of tRNA with an anticodon complementary to the first codon to be translated on the mRNA binds to the ribosome.

3 A second tRNA with an anticodon complementary to the second codon on the mRNA then binds. A maximum of two tRNAs can be bound at the same time.

4 The ribosome transfers the amino acid carried by the first tRNA to the amino acid on the second tRNA, by making a new peptide bond. The second tRNA is then carrying a chain of two amino acids – a dipeptide.

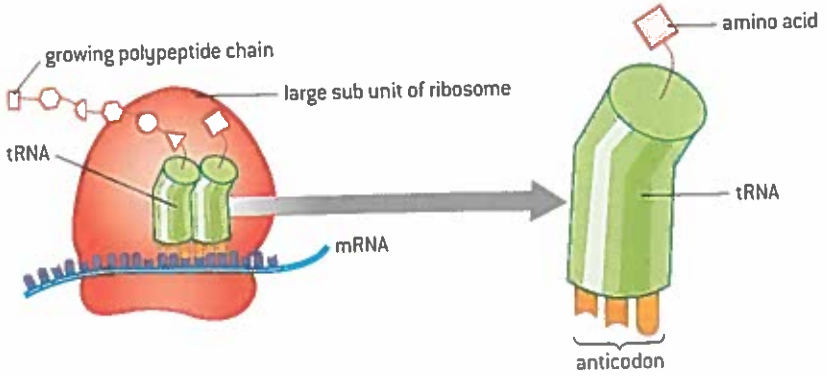
5 The ribosome moves along the mRNA so the first tRNA is released, the second becomes the first.

6 Another tRNA binds with an anticodon complementary to the next codon on the mRNA.

7 The ribosome transfers the chain of amino acids carried by the first tRNA to the amino acid on the second tRNA, by making a new peptide bond.

Stages 4, 5 and 6 are repeated again and again, with one amino acid added to the chain each time the cycle is repeated. The process continues along the mRNA until a stop codon is reached, when the completed polypeptide is released.

The accuracy of translation depends on complementary base pairing between the anticodon on each tRNA and the codon on mRNA. Mistakes are very rare, so polypeptides with a sequence of hundreds of amino acids are regularly made with every amino acid correct.



▲ Figure 11

Production of human insulin in bacteria

Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.

Diabetes in some individuals is due to destruction of cells in the pancreas that secrete the hormone insulin. It can be treated by injecting insulin into the blood. Porcine and bovine insulin, extracted from the pancreases of pigs and cattle, have both been widely used. Porcine insulin has only one difference in amino acid sequence from human insulin and bovine insulin has three differences. Shark insulin, which has been used for treating diabetics in Japan, has seventeen differences.