4.4 Bioenergetics

In this section we will explore how plants harness the Sun's energy in photosynthesis in order to make food. This process liberates oxygen which has built up over millions of years in the Earth's atmosphere. Both animals and plants use this oxygen to oxidise food in a process called aerobic respiration which transfers the energy that the organism needs to perform its functions. Conversely, anaerobic respiration does not require oxygen to transfer energy. During vigorous exercise the human body is unable to supply the cells with sufficient oxygen and it switches to anaerobic respiration. This process will supply energy but also causes the build-up of lactic acid in muscles which causes fatigue.

4.4.1 Photosynthesis

4.4.1.1 Photosynthetic reaction

Photosynthesis is represented by the equation:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$

Students should recognise the chemical symbols:

CO_2, H_2O, O_2 and $C_6H_{12}O_6$.

Students should be able to describe photosynthesis as an endothermic reaction in which energy is transferred from the environment to the chloroplasts by light.

4.4.1.2 Rate of photosynthesis

Students should be able to explain the effects of temperature, light intensity, carbon dioxide concentration, and the amount of chlorophyll on the rate of photosynthesis.

Students should be able to:

- measure and calculate rates of photosynthesis
- extract and interpret graphs of photosynthesis rate involving one limiting factor
- plot and draw appropriate graphs selecting appropriate scale for axes
- translate information between graphical and numeric form.

(HT only) These factors interact and any one of them may be the factor that limits photosynthesis.

(HT only) Students should be able to explain graphs of photosynthesis rate involving two or three factors and decide which is the limiting factor.

(HT only) Students should understand and use inverse proportion – the inverse square law and light intensity in the context of photosynthesis.

(HT only) Limiting factors are important in the economics of enhancing the conditions in greenhouses to gain the maximum rate of photosynthesis while still maintaining profit

Required practical activity 6: investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pondweed.

4.4.1.3 Uses of glucose from photosynthesis

The glucose produced in photosynthesis may be:

- used for respiration
- converted into insoluble starch for storage
- used to produce fat or oil for storage
- used to produce cellulose, which strengthens the cell wall
- used to produce amino acids for protein synthesis.

To produce proteins, plants also use nitrate ions that are absorbed from the soil.

4.4.2 Respiration

4.4.2.1 Aerobic and anaerobic respiration

Students should be able to describe cellular respiration as an exothermic reaction which is continuously occurring in living cells.

The energy transferred supplies all the energy needed for living processes.

Respiration in cells can take place aerobically (using oxygen) or anaerobically (without oxygen), to transfer energy.

Students should be able to compare the processes of aerobic and anaerobic respiration with regard to the need for oxygen, the differing products and the relative amounts of energy transferred.

Organisms need energy for:

- chemical reactions to build larger molecules
- movement
- keeping warm.

Aerobic respiration is represented by the equation:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

Students should recognise the chemical symbols:

$C_6H_{12}O_6$, O_2, CO_2 and H_2O.

Anaerobic respiration in muscles is represented by the equation:

$$\text{glucose} \rightarrow \text{lactic acid}$$

As the oxidation of glucose is incomplete in anaerobic respiration much less energy is transferred than in aerobic respiration.

Anaerobic respiration in plant and yeast cells is represented by the equation:

glucose → ethanol + carbon dioxide

Anaerobic respiration in yeast cells is called fermentation and has economic importance in the manufacture of bread and alcoholic drinks.

4.4.2.2 Response to exercise

During exercise the human body reacts to the increased demand for energy.

The heart rate, breathing rate and breath volume increase during exercise to supply the muscles with more oxygenated blood.

If insufficient oxygen is supplied anaerobic respiration takes place in muscles. The incomplete oxidation of glucose causes a build up of lactic acid and creates an oxygen debt. During long periods of vigorous activity muscles become fatigued and stop contracting efficiently.

(HT only) Blood flowing through the muscles transports the lactic acid to the liver where it is converted back into glucose. Oxygen debt is the amount of extra oxygen the body needs after exercise to react with the accumulated lactic acid and remove it from the cells.

4.4.2.3 Metabolism

Students should be able to explain the importance of sugars, amino acids, fatty acids and glycerol in the synthesis and breakdown of carbohydrates, proteins and lipids.

Metabolism is the sum of all the reactions in a cell or the body.

The energy transferred by respiration in cells is used by the organism for the continual enzyme controlled processes of metabolism that synthesise new molecules.

Metabolism includes:

• conversion of glucose to starch, glycogen and cellulose

• the formation of lipid molecules from a molecule of glycerol and three molecules of fatty acids

• the use of glucose and nitrate ions to form amino acids which in turn are used to synthesise proteins

• respiration

• breakdown of excess proteins to form urea for excretion.

All of these aspects are covered in more detail in the relevant specification section but are linked together here.