Higher Biology Unit 2 Metabolism and Survival

Learning Outcomes

Key Area 1: Metabolic Pathways

- Metabolic pathways are integrated and controlled pathways of enzyme-catalysed reactions within a cell
- Reactions within metabolic pathways can be anabolic or catabolic
- Anabolic reactions build up large molecules from small molecules and require energy
- Catabolic reactions break down large molecules into smaller molecules and release energy
- Metabolic pathways can have reversible and irreversible steps and alternative routes may exist that can bypass steps in a pathway
- Proteins embedded in phospholipid membranes have functions such as forming pores, pumps or enzymes
- Metabolic pathways are controlled by the presence or absence of particular enzymes
- Metabolic pathways can be controlled through the regulation of the rate of reaction of key enzymes within the pathway
- Substrate molecules have a high affinity for the active site of an enzyme
- The active site is flexible and the substrate can induce the active site to change shape. This is known as induced fit
- Induced fit occurs when the active site changes shape to better fit the substrate after the substrate binds
- Products have a low affinity for the active site allowing them the leave the active site
- The energy required to initiate a chemical reaction is called the activation energy
- Enzymes lower the activation energy
- Most metabolic reactions are reversible and the presence of substrate or removal of product drives a sequence of reactions in a particular direction
- Competitive inhibitors bind at the active site of the enzyme preventing the substrate from binding
- Competitive inhibition can be reversed by increasing substrate concentration
- Non-competitive inhibitors bind at a site away from the active site but

change the shape of the active site preventing the substrate from binding

- Non-competitive inhibition cannot be reversed by increasing substrate concentration
- Feedback inhibition occurs when the end-product in the metabolic pathway reaches a critical concentration. The end product then inhibits and enzyme earlier in the pathway, blocking the pathway and so prevents further synthesis of the end product.

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Learning Outcomes

Key Area 2: Cellular Respiration

- Cellular respiration pathways are present in cells from all three domains of life
- The metabolic pathways of cellular respiration yield energy and are connected to many other pathways
- In respiration, glucose is broken down in a series of enzyme-controlled steps
- ATP from cellular respiration is used to transfer the energy to cellular processes which require energy
- The breakdown of ATP to ADP and phosphate (Pi) releases energy
- The regeneration of ATP from ADP and phosphate (Pi) uses the energy released from cellular respiration
- Phosphorylation is the addition of a phosphate group to a molecule
- Glycolysis is the first stage of respiration and involves the breakdown of glucose to pyruvate in the cytoplasm
- In glycolysis, ATP (2) is required to phosphorylate glucose and intermediates in an energy investment phase. This leads to the generation of more ATP (4) in an energy pay-off stage resulting in a net gain of ATP (2)
- In aerobic conditions, pyruvate is broken down to an acetyl group that combines with coenzyme A forming acetyl coenzyme A
- In the citric acid cycle the acetyl group from acetyl coenzyme A combines with oxaloacetate to form citrate.
- The citrate formed is gradually converted back to oxaloacetate during a series of enzyme controlled steps resulting in the generation of ATP and the release of carbon dioxide
- The citric acid cycle occurs in the matrix of the mitochondria
- At certain steps in glycolysis and the citric acid cycle, dehydrogenase enzymes remove hydrogen ions and electrons
- The hydrogen ions and electrons are passed to the coenzyme NAD forming NADH
- The electron transport chain is a collection of carrier proteins attached to the inner membrane of the mitochondria
- The hydrogen ions and electrons from NADH are passed to the electron

transport chain

- The electrons are passed along the electron transport chain releasing energy
- This energy is used to pump hydrogen ions across the inner mitochondrial membrane
- The return flow of hydrogen ions back through the membrane protein ATP synthase results in the production of ATP
- The final electron acceptor is oxygen, which combines with hydrogen ions and electrons to form water
- In the absence of oxygen, fermentation takes place in the cytoplasm
- In animal cells, pyruvate is converted to lactate in a reversible reaction
- In plants and yeast, ethanol and CO_2 are produced in an irreversible reaction
- Fermentation results in much less ATP being produced than in aerobic respiration

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Learning Outcomes

Key Area 3: Metabolic Rate

- The metabolic rate of an organism is the amount of energy used in a given period of time
- The metabolic rates of different organisms can be compared through the measurement of oxygen consumption, carbon dioxide production and heat production
- Metabolic rates can be measured using respirometers, oxygen probes, carbon dioxide probes and calorimeters
- Organisms with high metabolic rates require more efficient delivery of oxygen to cells
- Birds and mammals have higher metabolic rates than reptiles and amphibians, which in turn have higher metabolic rates than fish
- Fish have a single circulatory system, which has a heart with two chambers – an atrium and a ventricle
- Amphibians and most reptiles have an incomplete double circulatory system, with a three-chambered heart made up of a right and left atrium and one ventricle in which oxygenated and deoxygenated blood mix
- Birds and mammals have a complete double circulatory system, with a four-chambered heart made up of two atria and two ventricles in which oxygenated and deoxygenated blood do not mix
- Complete double circulatory systems enable higher metabolic rates to be maintained because
    - there is no mixing of oxygenated and deoxygenated blood
    - the oxygenated blood can be pumped at higher pressure

  This enables more efficient delivery of oxygen to cells

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Learning Outcomes

Key Area 4: Metabolism in Conformers and Regulators

- The ability of an organism to maintain its metabolic rate is affected by external abiotic factors such as temperature, salinity and pH
- The internal environment of a conformer is dependent upon the external environment
- Conformers cannot alter their metabolic rate using physiological means, and as a result their metabolic costs can be low
- Conformers can have a narrow ecological niche unless they can tolerate or resist variation in their external environment
- Conformers use behavioural responses can help to maintain optimum metabolic rate
- Regulators maintain their internal environment regardless of external environment
- Regulators use metabolism to control their internal environment, which increases the range of possible ecological niches
- Homeostasis is the maintenance of steady conditions within an organism
- Regulators require energy to achieve homeostasis and as a result have high metabolic costs
- Negative feedback is the control mechanism by which homeostasis is achieved
- Negative feedback systems have monitoring centres with receptor cells, a system for sending messages and effectors, which carry out a response
- Thermoregulation (regulating body temperature) happens through negative feedback
- Thermoregulation is important for optimal enzyme activity and high diffusion rates to maintenance metabolism
- The hypothalamus is the temperature-monitoring centre of the mammalian brain and contains thermoreceptors, which detect changes in blood temperature
- Changes to body temperature is communicated from the hypothalamus by electrical impulses through nerves to effectors in skin and body muscles which bring about corrective responses to return the temperature to normal

- Responses to an increase in body temperature include sweating, vasodilation of blood vessels and decreased metabolic rate
- Sweating uses heat from the body to evaporate water in the sweat thereby cooling the skin
- Vasodilation increases the blood flow to the skin increasing heat loss by radiation
- A decreased metabolic rate reduces the amount of heat produced
- Responses to a decrease in body temperature include shivering, vasoconstriction of blood vessels, contraction of hair erector muscles and increased metabolic rate.
- Shivering generates heat through muscle contraction
- Vasoconstriction decreases blood flow to the skin and thereby decreases heat lost by radiation
- Contracting hair erector muscles raises hairs on the skin and trap a layer of insulating air
- Increase metabolic rate increases the amount of heat produced

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Learning Outcomes

Key Area 5: Metabolism and Adverse Conditions

- Many environments vary beyond the tolerable limits for the normal metabolic activity of an organism
- To cope with these fluctuations, organisms must have adaptations to survive or to avoid adverse conditions
- To allow survival during a period when the costs of continued normal metabolic activity would be too high, the metabolic rate can be reduced
- Dormancy is part of some organisms' life cycle and allows survival during a period when the costs of continued normal metabolic activity would be too high.
- During dormancy there is a decrease in metabolic rate, heart rate, breathing rate and body temperature.
- The metabolic rate is reduced during dormancy to save energy.
- Dormancy can be predictive or consequential.
- Predictive dormancy occurs before the onset of adverse conditions
- Consequential dormancy occurs after the onset of adverse conditions
- Examples of dormancy include hibernation and aestivation
- Hibernation is often defined in terms of mammals (e.g. hedgehog, dormouse) and is a common strategy for surviving low temperatures
- Aestivation allows survival in periods of high temperature or drought
- Daily torpor is a daily period of reduced activity in organisms with high metabolic rates (e.g. hummingbirds)
- Migration avoids metabolic adversity by expending energy to relocate to a more suitable environment
- Specialised techniques are used in studies of long-distance migration. For example leg rings and satellite tracking
- Experiments have been designed to investigate the innate and learned influences on migratory behavior

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Learning Outcomes

Key Area 6: Environmental control of metabolism

- Microorganisms include archaea, bacteria and some species of eukaryote such as yeasts
- Microorganisms include species that use a wide range of substrates for metabolism and produce a wide range of products from their metabolic pathways
- Microorganisms can be used for a variety of research and industrial uses because of ease of cultivation and their speed of growth
- The growth of microorganisms is influenced by the composition of their growth medium and by environmental conditions
- Microorganisms require an energy source and raw materials for biosynthesis (e.g. amino acids to make proteins)
- Energy is derived from either chemical substrates or from light in photosynthetic microorganisms
- Many microorganisms can produce all the complex molecules required for biosynthesis, including all the amino acids required for protein synthesis, from simple chemical compounds in growth media
- Some microorganisms require complex compounds such as vitamins or fatty acids in their growth medium
- Culture conditions include sterility to eliminate competition from contaminating microorganisms, control of temperature by use of an incubator, control of oxygen levels by aeration and control of pH by buffers or the addition of acid or alkali
- The growth of unicellular organisms such as bacteria and yeast is recorded by measuring the increase in cell number in a given period of time
- The time it takes for a unicellular organism to divide into two is called the doubling or generation time
- There are 4 phases in microbial growth in culture; lag, log/exponential, stationary and death
- The lag phase of growth is when microorganisms adjust to the conditions of the culture by inducing enzymes that allow them to metabolise the

available substrates

- The log (exponential) phase of growth is when microorganism growth is most rapid due to the abundance of nutrients
- The stationary phase of growth is when nutrients in the culture medium are becoming depleted and toxic metabolites are being produced. Secondary metabolites such as antibiotics are also produced
- Secondary metabolism can confer an ecological advantage to microorganisms by producing substances not associated with growth, such as antibiotics
- The death phase is when lack of nutrients and the accumulation of toxic metabolites cause the death of cells
- Populations of microorganisms can be estimated by making total cell counts and viable cell counts
- Total cell counts involve counting both viable (live) and dead cells
- Viable cell counts involve counting only the living cells
- Only viable cell counts show a death phase where cell numbers are decreasing
- Exponential growth can be illustrated on semi-logarithmic graph paper

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Learning Outcomes

Key Area 7: Genetic control of metabolism

- Wild strains of microorganisms can be improved by mutagenesis or recombinant DNA technology
- Mutagenesis is the process of inducing mutations
- Exposure to ultraviolet (UV) light, other forms of radiation or mutagenic chemicals results in random mutations, some of which might produce an improved strain with desirable qualities
- Recombinant DNA technology involves the joining together of DNA molecules from two different species
- Plant or animal gene sequences can be transferred to microorganisms to produce plant or animal proteins
- As a safety mechanism, genes are often introduced that prevent the survival of a modified microorganism in an external environment
- Plant or animal genes can be transferred to microorganisms by recombinant plasmids or artificial chromosomes
- Recombinant plasmids and artificial chromosomes act as genetic vectors
- A vector carries the DNA from the donor organism into the host cell
- The vectors must contain restriction sites and marker genes in addition to an origin of replication and regulatory sequences to allow control of gene expression
- Selectable marker genes (e.g. antibiotic resistance genes) present in the vector ensure that only microorganisms that have taken up the vector are able to grow in the presence of the selective agent (antibiotic)
- Restriction endonucleases cut target sequences of DNA from chromosomes, leaving sticky ends
- Treatment of vectors with the same restriction endonuclease forms complementary sticky ends that are then combined using DNA ligase to form recombinant DNA
- Plant or animal recombinant DNA in bacteria can result in polypeptides that are folded incorrectly
- These polypeptides can be produced more successfully in a recombinant yeast cell