

Topic 5 – Energy Flow, Ecosystems, and the Environment

1. Describe the reaction of photosynthesis with equation - as requiring energy from light to split apart the strong bonds in water molecules, storing the hydrogen in a fuel (glucose) by combining it with carbon dioxide and releasing oxygen into the atmosphere.

ANS: *carbon dioxide + water → glucose + oxygen*



- The energy from light is used to break the strong H-O bonds in the water molecules.
- The hydrogen which is released is combined with carbon dioxide to form a fuel for the cells (glucose).
- Oxygen is released into the atmosphere as a waste product of this process.

2. Explain the hydrolysis of ATP provides an immediate supply of energy for biological processes.

- The breakdown of ATP into ADP and phosphate is a reversible reaction.
- ATP can be synthesized (made) from ADP and a phosphate group.
- This synthesis reaction is also catalyzed by the enzyme ATPase.
- The energy needed to drive the synthesis of ATP usually comes from catabolic (breakdown) reactions or redox reactions.
- As a result, an ATP molecule provides an immediate supply of energy for your cells, ready for use when needed.

3. Explain the light-dependent reactions of photosynthesis - cyclic and non-cyclic photophosphorylation.

■ **CYCLIC PHOTOPHOSPHORYLATION:**

- Cyclic photophosphorylation involves only photosystem I (PSI) and drives the production of ATP.
- When light hits a chlorophyll molecule in PSI, a light-excited electron leaves the molecule.
- It is collected by an electron acceptor and transferred directly along an electron transport chain to produce ATP.
- When an electron returns to the chlorophyll molecule in PSI, it can then be excited in the same way again

■ **NON-CYCLIC PHOTOPHOSPHORYLATION:**

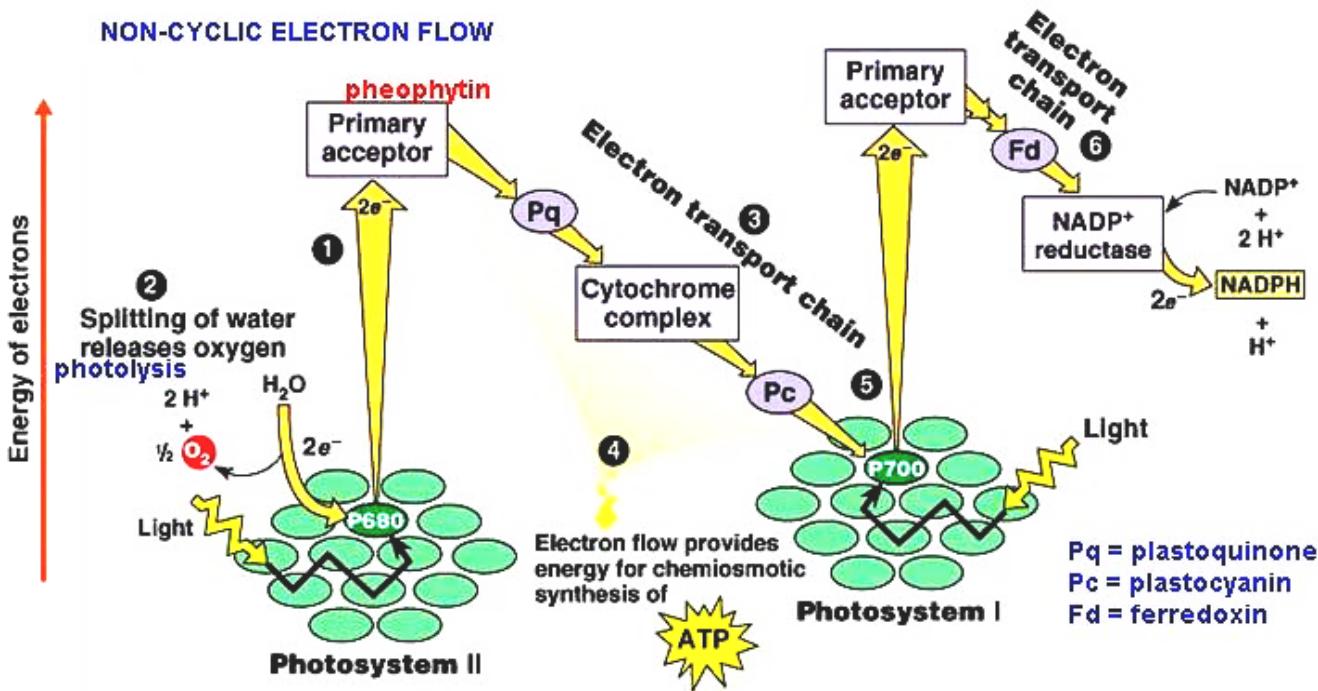
- Both **PS1** and **PS2** are involved,
- When photons hit **PS2**, electrons are excited to higher energy levels until they gain sufficient energy and leave the Photosystem,
- Electrons are accepted by an electron acceptor and transported along the electron transport chain
- This drives the production of one molecule of ATP
- This electron is then used to replenish the lost electron in PS1
- In **PS1** the electron that was excited by photons is accepted by NADP
- Meanwhile, Photolysis occurs, the breakdown of water molecules releases H⁺ ions and OH⁻ ions
- Electrons released from Photolysis are used to replenish the unstable PS2
- H⁺ ions then combine with NADP to form Reduced NADP
- Which is then transported to the Calvin Cycle.

4. Describe the role of sunlight/water in photosynthesis. (photolysis of water)

Electrons excited by photons, flow from chlorophyll to NADPH and are used to reduce CO₂ in the Calvin cycle producing monosaccharides.

In these light reactions, water is split (photolysis) to satisfy the electron debt in the chlorophyll molecules in photosystem II. These electrons flow through non-cyclic photophosphorylation to produce ATP and NADPH which drive the Calvin cycle.

Oxygen is produced in the photolysis of the light reactions and escapes to the atmosphere.



5. Describe the light-independent reactions (carbon fixation in the Calvin cycle, the role of GP, GALP, RuBP, RUBISCO, the synthesis of new biological molecules such as polysaccharides, amino acids, proteins, lipids, and nucleic acids)

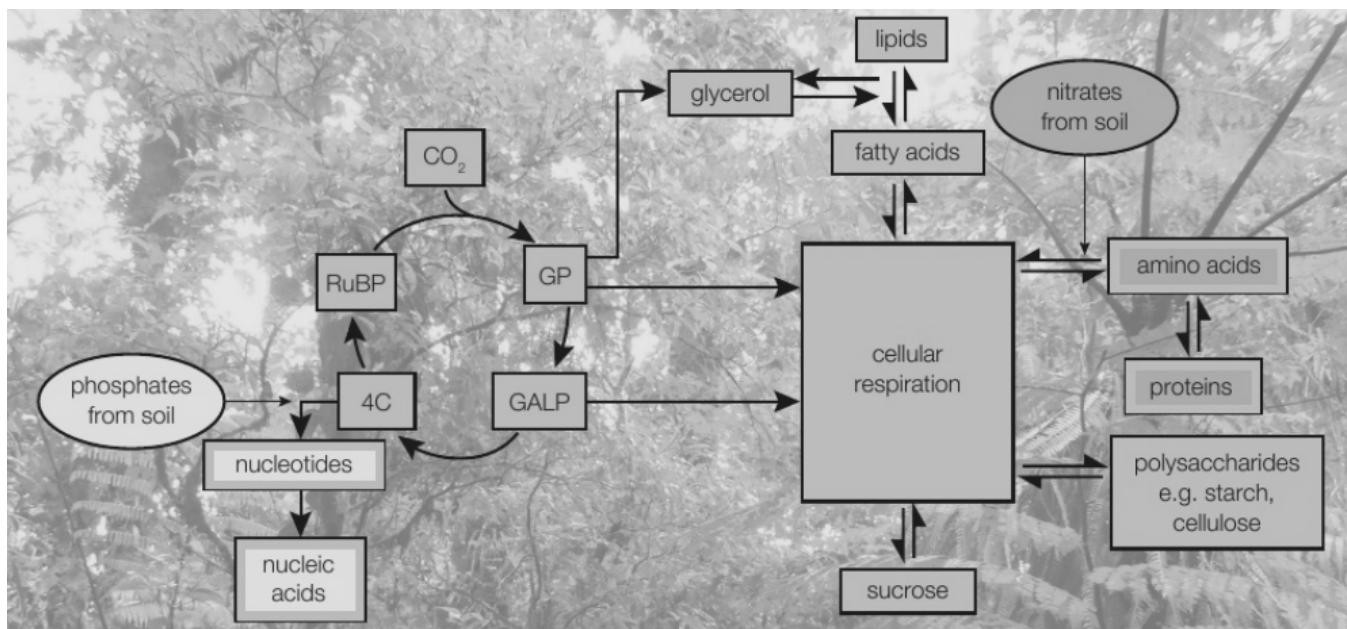
In the first step of the Calvin cycle, carbon dioxide from the air combines with the 5-carbon compound ribulose bisphosphate (RuBP) in the chloroplasts. The carbon dioxide is said to be fixed, so this process is known as carbon fixation.

Glucose is the end product of the Calvin Cycle. This glucose may be converted into disaccharides such as sucrose for transport around the plant; into polysaccharides such as starch for energy storage; and into cellulose, for structural support

The GALP that enters cellular respiration is used to provide energy in the form of ATP for the functions of the cell. Compounds from these pathways are also used as the building blocks of amino acids. The molecules combine with nitrates from the soil. GALP can also continue around the Calvin cycle and, in that case, it can combine with phosphates from the soil to produce nucleic acids.

Some of the GALP that enters the cellular respiration pathways is converted into a chemical called acetyl coenzyme A. This compound is then used to synthesize the fatty acids needed for the production of phospholipids for membranes, and lipids needed for storage and other functions within the plant.

GP is also part of this process, but GALP is regarded as the main molecule leading to the synthesis of all the other molecules needed by the plant



6. The structure of chloroplasts in relation to their role in photosynthesis.

Grana:

Thylakoids provide a large surface area for light absorption and light-dependent reactions

Chlorophyll molecules are grouped together to form the photosystems which are embedded in the membrane along with the electron carriers

Folds in the thylakoid membranes allow photosystems and electron carriers to be close together.

Thylakoid spaces:

Collect hydrogen ions for Chemiosmosis

The low volume enables the hydrogen ion gradient to be generated rapidly.

Hydrogen ions flow back to the Stroma down the electrochemical gradient through the ATP synthase channel.

The Stroma:

Contains rubisco for carboxylation of RUBP

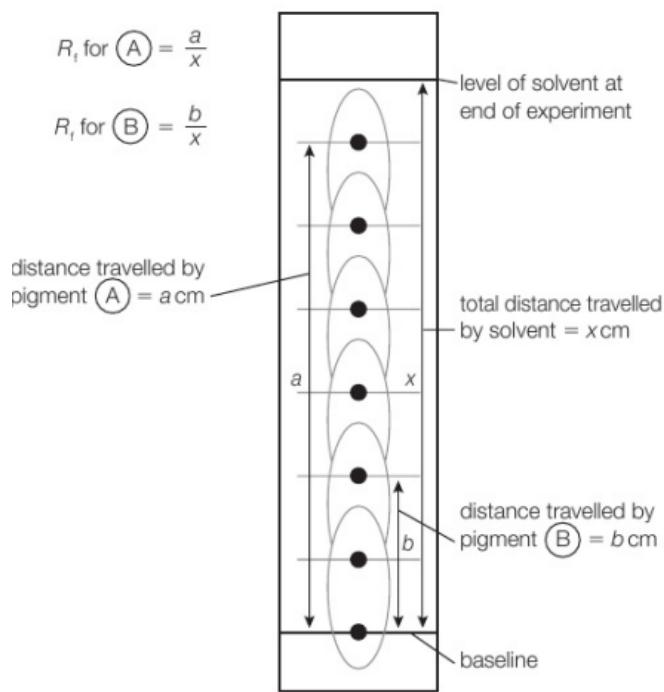
7. What is meant by the terms absorption spectrum and action spectrum?

absorption spectrum: a graph showing the amount of light absorbed by a pigment against the wavelength of the light

action spectrum: a graph demonstrating the rate of photosynthesis against the wavelength of light

8. Chloroplast pigments can be separated using chromatography and the pigments are identified using R_f values.

$$R_f \text{ value} = \frac{\text{distance travelled by solute (photosynthetic pigment)}}{\text{distance travelled by solvent}}$$



9. The relationship between gross primary productivity (GPP), net primary productivity (NPP), and plant respiration (calculate net primary productivity).

Gross primary productivity (GPP) in plants, is the rate at which light from the Sun catalyzes the production of new plant material,

Net primary productivity (NPP) is the material produced by photosynthesis and stored as new plant body tissues; that is,

NPP GPP-R (where R = losses due to respiration)

10. How to calculate the efficiency of biomass and energy transfers between trophic levels.

We divide the amount from the higher trophic level by the amount from the lower trophic level and multiply by one hundred.

11. What is meant by the terms population, community, habitat, ecosystem, and niche (How does the concept of niche account for the distribution and abundance of organisms in a habitat)?

- A **habitat** is a place where an organism lives
- A **population** is a group of organisms of the same species, living and breeding together in a habitat.
- A **community** is all the populations of all the different species of organisms living in a habitat at any one time.
- The **niche** of an organism can be described as the role of the organism in the community, or its way of life.

No two species can occupy the same niche; interspecific competition excludes one species or the niche is divided according to adaptations.

12. The numbers and distribution of organisms in a habitat are controlled by biotic and abiotic factors.

The biodiversity and distribution of organisms within an ecosystem are due to both abiotic (non-living) and biotic (living) factors.

Abiotic factors are non-living variables that can influence where organisms can live.

The values of the **abiotic factors** in an ecosystem affect the range of species that are found. This is because the individuals in each species are adapted to occupy particular niches.

Examples of abiotic factors include

- light intensity
- temperature
- soil pH
- soil moisture

Biotic factors are interactions associated with living organisms. They can also influence the distribution of organisms in an ecosystem.

- competition for environmental resources
- grazing - too little leads to dominant plants outcompeting other species, too much reduces species numbers overall. Both decrease biodiversity
- predation - a reduction in predators can lead to an increase in prey. High numbers of prey can lead to overgrazing, which can reduce biodiversity
- disease
- food availability

13. The stages of succession from colonization to the formation of a climax community.

Stage of Primary succession

Stage 1: bare rock is exposed due to some type of disturbance such as a retreating glacier or volcano eruption

Stage 2: Pioneer species like lichens and mosses, establish themselves on the rock substrate

Stage 3: Pioneer species die and decay providing soil and nutrients for other plant species like shrubs and small trees

Stage 4: Small and large trees begin to grow and the community reaches equilibrium, this results in a climax community.

Stage of Secondary succession

Stage 1: organisms are driven away or killed by some type of disturbance, like a forest fire, leaving behind only the soil

Stage 2: Pioneer species like grass and weeds begin to grow from the soil roots and seeds left over may also begin to grow again

Stage 3: Some Pioneer species die and are replaced or out-competed by other species like shrubs and trees

Stage 4: Small and large trees begin to grow and the community reaches equilibrium or balance, this results in the climax community.

14. Different types of evidence for climate change and its causes, including records of carbon dioxide levels, temperature records, pollen in peat bogs, and dendrochronology, recognizing correlations and causal relationships.

Temperature records:

Antarctic and Greenland ice cores are often used as a source of temperature proxies, scientists drill deep down into the ice and then analyze the air trapped in different layers, this provides us with records that go back thousands of years. The oxygen isotope in melted ice (the proportion of oxygen-18 to oxygen-16) reflects the air temperature at the time the ice layer was formed we can use cores to measure the atmospheric carbon dioxide levels.

Dendrochronology:

Another temperature proxy is dendrochronology

Dendrochronology is the dating of past events using tree-ring growth, it's the method of figuring out how old a tree is using tree rings. The thickness of the tree rings depends on the climate when the ring is formed.

When the climate is warmer, the tree ring is thicker, by working out the thickness of the tree rings scientists can easily identify the climate change, most trees produce one ring every year. Every year trees produce a new layer of xylem vessels by the division of cells underneath the bark. The diameter of the new xylem vessels varies according to the seasons when they produce different widths of the vessels creating a pattern that can be seen when the trees are cut down. Instead of cutting, a core sample can be taken.

The ring cannot give any precise dates, but strong clue about past climates.

However, growth is dependent on many factors including the amount of sunshine, temperature, carbon dioxide levels, and amount of rainfall
So evidence for dendrochronology may not be accurate. One way to check the reliability is by comparing the results from different places. If the rings are similar then the climate was generally similar, not just in that area.

Pollen in peat bogs

Pollen is often preserved in peat bogs, (acidic Wetland areas) it is very acidic and anaerobic. which prevents bacteria from decomposing organic material, so pollen grain mass spores, and even plant tissue are preserved in peat. Scientists know the climate of the different plant species when they find preserved from similar plants. This indicates that the climate is similar when pollen is produced.

Scientists can take cores from Peat bogs and extract pollen grains from the different age layers and identify the species, plant species vary with the climate so the preserved pollen will vary as the climate varies.

Plant growth rate depends on the prevailing conditions and varies widely, so evidence from undisturbed peat bogs can give us a clear and unbroken record of the climate

Correlation is simply a relationship where action A relates to Action B but one event does not necessarily cause the other event to happen

Causation is when one thing causes another

15. The causes of anthropogenic climate change, include the role of greenhouse gases in the greenhouse effect.

The causes of anthropogenic climate changes are:

1. Increased levels of greenhouse gases added to the atmosphere and
2. Destruction of carbon sinks such as rainforests.

Role of greenhouse gasses in the greenhouse effect: when radiation from the sun such as infrared reaches the earth, some are reflected back into space by the atmosphere, and some are absorbed by the atmosphere. Infrared reaches earth in short wavelengths but is reflected in longer wavelengths. This radiation is absorbed and radiated back by greenhouse gases such as carbon dioxide. Increasing levels of carbon dioxide increase the amount of heat retained, causing the atmosphere and earth's surface to heat up. This is called the greenhouse effect.

16. How the carbon cycle can be applied to methods to reduce atmospheric levels of carbon dioxide.

- Use of carbon sinks-carbon removed from the atmosphere and is locked there
- can be bodies of living organisms or rocks
- use of carbon neutral material
- use of biofuels
- use of renewable energy resources
- reforestation

17. Data can be extrapolated to make predictions and these are used in models of future climate change (models for climate change have limitations).

We can extrapolate the data on greenhouse gasses and use them in models to make predictions about what will happen to temperature and other aspects of global warming in the future. However, there are some limitations to such models:

- 1) limited data
- 2) limited knowledge of how the climate system works.
- 3) limitation in computing resources
- 4) failure to include all factors affecting climate.

18. The effects of climate change on plants and animals (changing rainfall patterns and changes in seasonal cycles, distribution of species, development, and lifecycles).

Changes in climate act as a selection pressure for plants and animals. The changes also result in extinction as plants and animals cannot quickly adapt to the changes around them.

Changes in rainfall pattern:

Rainfall patterns change across the globe as monsoon rain becomes heavier in some countries. This results in devastating floods and also severe repeated droughts all across the country.

Distribution of species, development, and life cycles:

A change in climate could affect the area in which many organisms live. Most animals extend to the southern while becoming extinct in northern areas.

The spread of diseases becomes more vulnerable as animals move from place to place.

Climate change also leads to

1. **Allopatric speciation** (population becomes physically or geographically isolated due to global warming such as a rise in sea level)

AND,

2. **Sympatric speciation** (organisms become reproductively isolated due to mechanical, behavioral, or seasonal changes).

When a population becomes separated, gene flow between them ceases. Since the two groups are in their unique ecosystem and experience different selection pressure, they adapt to their environment over time and can eventually become different from each other.

19. Describe the effect of temperature on the rate of enzyme activity and its impact on plants, animals, and microorganisms, to include Q 10.

The temperature has an effect on enzyme activity which in turn affects the whole organism. There is an optimum temperature for many enzyme-catalyzed reactions. Increasing temperature affects different processes including growth and reproduction. Increasing temperature beyond the optimum temperature causes enzymes to denature so the reaction rate falls. The effect of temperature on the rate of any reaction can be expressed as the **temperature coefficient (Q 10)**. Q 10 for any reaction between 0 degrees and 40 degrees is 2.

20. How evolution (a change in allele frequency) can come about through gene mutation and natural selection.

- Evolution is the process by which populations of organisms change over generations.
- Genetic variations underlie these changes.
- Genetic variations can arise from gene mutation or gene recombination.
- These variations often alter gene activity or protein function, which can introduce different traits in an organism.
- Due to **selection pressure**, only advantageous alleles will survive and reproduce, the genetic variation is more likely to be passed to the next generation (a process known as natural selection).
- Over time, as generations of individuals with traits continue to reproduce, the advantageous trait becomes increasingly common in a population.

21. how isolation reduces gene flow between populations, leading to allopatric and sympatric speciation.

When a population is separated because of a geographic feature, like distance, a canyon, a river, or a mountain range, those two subgroups of the population are no longer able to reproduce together.

When populations become separated, gene flow between them **ceases**. Over time, the populations may become *genetically different* in response to the natural selection imposed by their different environments.

Since the two groups are in their own unique ecosystems and each experiences unique selection pressures, they will adapt to their environment over time and can eventually become very different from each other.

Once the two populations are unable to breed and produce **fertile offspring**, they are considered to belong to different species and there is reproductive isolation between them. ***The longer the two groups are geographically isolated, the more likely speciation such as allopatric and sympatric will occur.***

22. Scientific conclusions about controversial issues, such as what actions should be taken to reduce climate change or the degree to which humans are affecting climate change.

Actions that should be taken include

- Controlling the use of fossil fuels (because this will reduce the carbon dioxide released into the atmosphere)
- Making industrial processes and car engines cleaner
- Less polluting
- Increasing awareness to use sustainable resources
- Using biofuels
- Reforestation (because more plants will absorb more carbon dioxide for photosynthesis)
- Reduce the number of cattle being farmed (as this will reduce the methane being released into the atmosphere)

23. Describe reforestation and the use of sustainable resources, including biofuels

Reforestation is the replanting of trees in an area where trees have been lost. Sustainable resources are resources that can be grown and used in a sustainable way. Biofuels are sustainable and can replace fossil fuels. Some biofuels include biodiesel, hydrogen, ethanol, and methane.

BIODIESEL: can be obtained from crops such as soybeans and palm seeds. Products of biodiesel are carbon dioxide and water.

HYDROGEN: can be obtained from the catalysis of methane from fossil deposits. The product is water vapor

ETHANOL: which can be obtained from fermented sugars from crops such as sugarcane. Products of ethanol are carbon dioxide and water vapor.

METHANOL: can be extracted from fossil fuels deposits. Products are carbon dioxide and water vapor.

Topic 6 – Microbiology, Immunity, and Forensics

1. The principles and techniques involved in culturing microorganisms, using an aseptic technique.

Culturing microorganisms involves a number of steps.

First, we need to decide which microorganisms we want to culture and obtain a culture of them. Then we need to provide the microorganisms with the right nutrients in order to grow. Most microorganisms require a good source of carbon and nitrogen as well as specific minerals.

We can use a nutrient medium in the form of nutrient broth, where the nutrients are in liquid form for a liquid culture in a flask or test tube, or in a solid form, usually nutrient agar. Agar is a jelly extracted from seaweed. It is very useful because, although it solidifies as jelly at 50°C, it does not melt again until it is heated to 90°C. Both solid and liquid media must be kept sterile until ready for use.

The majority of microorganisms grow on or in a medium enriched with good protein sources such as blood, yeast extract, or meat extract. Producing a nutrient medium with very specific ingredients provides a selective medium. A selective medium is a growth medium for microorganisms containing a very specific mixture of nutrients so only a particular type of microorganism will grow on it.

Selective media are important in identifying particular mutant strains of microorganisms and antibiotic resistance. Selective media are also useful for identifying microorganisms that have been genetically modified.

One way in which bacteria can be grown in the laboratory:

- An agar medium containing glucose medium must be prepared.
- Inoculate a strain of bacteria using a cotton swab dipped in a sample and swiped across the agar.
- Cover the petri dish and use tape to secure the lid.
- Ensure to leave gaps in the tape to allow oxygen to pass through and prevent the growth of other strains of anaerobic bacteria.
- Incubate the petri dish at 30 degrees centigrade for 24 hours after which, a culture of bacteria will be produced

2. The different methods of measuring the growth of microorganisms, such as cell counts, dilution plating, and optical methods (turbidity)

CELL COUNT BY HAEMOCYTOMETER:

A hemocytometer is a specialized thick microscope slide with a rectangular chamber that holds a standard volume of liquid of 0.1 mm^3 . The chamber is engraved (marked) with a grid of lines. It was originally designed for counting blood cells.

We dilute the sample of nutrient broth by half with an equal volume of trypan blue, a dye that stains dead cells blue so we can identify and count only the living cells.

Then we can view and count the cells using a microscope. Each corner of the hemocytometer grid has a square divided into 16 smaller squares. The number of cells in each of these four sets of 16 squares is usually counted and the mean is calculated. The hemocytometer is calibrated so that the number of bacterial or fungal cells in one set of 16 squares is equal to the number of cells 10^4 per cm^3 of broth.

In this way, we can calculate the number of microorganisms in a standard volume of broth.

OPTICAL METHOD (TURBIDITY):

An alternative way of measuring the number of cells in a culture is turbidimetry, a specialized form of colorimetry. As the number of bacterial cells in a culture increases, it becomes increasingly turbid (cloudy). As a solution becomes more turbid, it absorbs more light, so less light can pass through it. A colorimeter measures how much light passes through a sample and thus shows how much light is absorbed. This indirectly indicates how many microorganisms are present.

We can produce a calibration curve by growing a control culture and taking samples at regular time intervals. We can measure each sample's turbidity and count the cells using a hemocytometer for each sample. This gives us a relationship between the turbidity of the culture and the number of bacterial cells present. We can then use this calibration curve to measure the number of microorganisms simply using turbidimetry. For example, we might want to investigate the effect of different conditions on the growth rate of the microorganism.

DILUTION PLATING:

Dilution plating is a method used to obtain a culture plate with a countable number of bacterial colonies. Total viable cell counts are a measure of the number of cells that are alive in a specific volume of culture.

This technique is based on the idea that each of the colonies on the agar plate has grown from a single, viable microorganism on the plate. So, if we have two bacterial colonies after culturing, we can presume that there are two initial living bacteria on the plate.

However, a solid mass of microbial growth is often present after culturing and it is not possible to identify the individual colonies. We can solve this problem by diluting the original culture in stages until we reach a point when we can count the colonies. We can calculate the total viable cell count for the original sample by multiplying the number of colonies by the dilution factor.

3. The different phases of a bacterial growth curve (lag phase, exponential phase, stationary phase, and death phase) and calculate exponential growth rate constants.

Bacteria growth cycles in a growth curve consist of four phases: lag, exponential(log), stationary, and death.

Lag Phase: The lag phase is when bacteria are adapting to their new environment and are not reproducing at their maximum rate. The bacterial cells increase in size, but no cell division occurs in this phase.

Exponential (log) phase: The log phase is when the rate of reproduction is close to or at its theoretical maximum, repeatedly doubling in a given time period. When cells divide by binary fission, they double in numbers after each generation. The metabolic activity of bacteria is high in this phase. In this growth phase, antibiotics and disinfectants are most effective as they target bacterial cell walls.

Stationary Phase: The stationary phase is when the total growth rate is zero as the number of new cells formed by binary fission equals the number of cells dying. Eventually, the growth rate decreases as nutrients become depleted and waste products accumulate. This results in no overall population. Under unfavorable conditions, competition for nutrients increases, and cells become less metabolically active.

Death Phase: The death phase is when reproduction has almost stopped and the death rate of cells increases as nutrients become less available and waste products increase, the number of cells dying continues to rise. In the death phase, the number of living cells decreases exponentially and population growth experiences a sharp decline.

Exponential Growth Rate Constants:

You can calculate the number of bacteria in a population using the following formula:

$$N_t = N_0 \times 2^{kt} \text{ where:}$$

N_t = the number of organisms at time t

N_0 = the number of organisms at time 0 (the beginning of the experiment)

k = the exponential growth rate constant

t = the time the colony has been growing

$$k = \frac{\log_{10} N_t - \log_{10} N_0}{\log_{10} 2 \times t}$$

4. Compare the structure of bacteria and viruses (nucleic acid, capsid structure, and envelope) with reference to the Ebola virus, tobacco mosaic virus (TMV), human immunodeficiency virus (HIV), and lambda phage (λ phage).

Comparison between the structure of bacteria and viruses:

Bacteria:

1. A bacteria has a cell wall containing peptidoglycan
2. Cell surface membrane similar to eukaryotic cells
3. A nucleoid
4. 70s ribosomes which are the site of photosynthesis
5. Some bacteria have a capsule or slime layer
6. Some bacteria have pili which are threadlike projections
7. Some bacteria have mesosomes which are internal extensions of membranes and may be the site of cellular respiration
8. Some bacteria have additional rings of DNA called plasmids

Viruses:

1. Viruses have a protein coat or capsid which has simple repeating units of protein known as capsomeres
2. Nucleic acid acts as genetic material and this can be DNA or RNA.
3. Specific proteins (antigens) known as virus attachment particles (VAPs)
4. Some viruses have a lipid envelope_produced from the host cells and it makes it easier for them to pass from cell to cell.

5. Viruses are of 3 types-

- a) **DNA VIRUSES** have DNA as their genetic material which acts directly as a template for both the new DNA and for mRNA needed to induce the synthesis of viral proteins. Examples are the smallpox virus and lambda phage virus.
- b) **RNA VIRUSES** have RNA as their genetic material and they are much more likely to mutate than DNA viruses. Examples include the tobacco mosaic virus(TMV) and the Ebola virus.
- c) **RETROVIRUSES** are a special type of RNA virus. They are responsible for making DNA molecules corresponding to the viral genome. An example is Human Immunodeficiency Virus (HIV).

5. What is meant by the terms lytic and latency?

LYTIC: The lytic cycle involves the virus taking control of the host cell and using it to produce more virus cells killing the host cell in the process

LATENCY: The ability of a pathogenic virus to lie dormant within the cell

6. Details of *Mycobacterium tuberculosis*, human immunodeficiency virus (HIV), and Ebola virus.

HOW TB IS DEVELOPED? WHAT ARE THE DIAGNOSIS, SYMPTOMS, AND TREATMENT

TB is commonly caused by the bacterium ***Mycobacterium Tuberculosis***, which is spread by droplet infection.

In the **primary infection**, the bacteria which have been inhaled into the lungs multiply slowly often causing no symptoms.

People who have a healthy immune system allow inflammatory response to work forming a tubercle that contains dead bacteria and macrophages.

After about 8 weeks, the immune system controls the bacteria, the inflammation disappears and lung tissue heals.

However, the bacteria which survive produce a thick waxy outer layer which protects them from the enzymes of macrophages. Bacteria with an effective coating remain deep in the tubercle in the lung, dormant or growing slowly weakening the person. This bacteria then cause active TB.

TB can be diagnosed by X-ray which shows opaque areas and thick-walled cavities in the lung

Typical symptoms of TB include fever, night sweats, weight loss, and loss of appetite.

The main treatment of TB is to use antibiotics for months.

For the first 2 months, a mixture of different antibiotics is used which destroys rapidly reproducing bacteria. For the next four to seven months, a mixture of two more antibiotics is used.

Extra- people living or working in crowded conditions, people who are ill or malnourished, and people living with HIV are more vulnerable to TB.

HOW HIV CAUSES AIDS? WHAT IS THE TREATMENT?

HIV is a retrovirus and attaches itself to the T helper cells. Once it enters the T helper cells, it controls the host DNA and replicates. The host T helper cell is destroyed when a new virus leaves the cell. At the same time, other cells of the immune system called T killer cells recognize and destroy some of the heavily infected T helper cells. These processes cause a large decrease in the number of T helper cells. As a result, the immune system cannot fight over other pathogens.

THE STAGES OF HIV:

STAGE 1: ACUTE HIV SYNDROME- In the first few weeks after infection, some people feel unwell. Symptoms include fever, headaches, tiredness, and swollen glands. Some people infected with HIV have no symptoms. Between 3 and 12 weeks after infection, HIV antibodies appear in the blood, making the person test HIV positive. This will happen even if they have not felt ill.

STAGE 2: THE ASYMPTOMATIC OR CHRONIC STAGE- Once the infection is established all symptoms disappear. During the asymptomatic stage, the virus replicates, infecting the T helper cells, but it is kept under control by the T killer cells. As this stage progresses, secondary infections develop because the immune system is unable to deal with the situation.

STAGE 3: SYMPTOMATIC DISEASE- Eventually the number of viruses attacking the immune system becomes so great that the whole immune system starts to fail. The normal T helper cell count falls from 500 to 200 per mm³ of blood. Patients begin to suffer HIV-related symptoms, including weight loss. This rapidly progresses to the final stage.

STAGE 4: ADVANCED AIDS- As T helper cell numbers fall, severe symptoms such as dementia as brain cells become infected and serious infections such as TB occur. The final stage of AIDS is always death.

AIDS is an incurable disease but various control methods are being investigated. Such as

- 1) celibacy
- 2) only having one sexual partner
- 3) using condoms to prevent the spread of the virus
- 4) using clean needles if injecting drugs
- 5) spreading awareness
- 6) using drug therapy.

EBOLA: Ebola virus is a disease caused by infection with the Ebola virus.

It is a serious often fatal disease. It is mainly spread through contact with the body fluids of an infected person. The Ebola virus lays dormant in victims for up to three weeks. Patients are given fluid salts to keep their bodies hydrated. Symptoms of this virus include high fever, headaches, aching joints and muscles, vomiting, and sore throat.

7. The role of barriers in protecting the body from infection, including skin, stomach acid, and gut and skin flora (the major routes pathogens may take when entering the body).

THE SKIN AND SKIN FLORA: Our skin is an impenetrable layer strengthened by keratin. It forms a physical barrier between many pathogens in the environment.

An oily substance produced by the skin is called sebum which contains chemicals that inhibit the growth of microorganisms. This forms the second layer of skin defense and does not harm the natural skin flora but plays a role in preventing disease. Our natural skin flora competes successfully for a position on the skin and also produces substances that inhibit the growth of other microorganisms.

THE GUT AND STOMACH ACID: The gut is also important in the natural defenses of the body against disease. The saliva in our mouth has bactericidal properties. Some polypeptides produced in the salivary glands destroy bacteria and others slow down bacterial growth. Our stomach produces hydrochloric acid with a pH of approximately 2 and this effectively destroys the majority of microorganisms that are absorbed through the mouth. The natural flora in the gut usually competes successfully for both nutrients and space with any microorganisms which manage to pass through the stomach. Like the skin flora, the gut flora produces antimicrobial compounds.

Another way in which the stomach helps protect against disease is vomiting. Vomiting can be caused by many things, including absorbing toxins, bad smells, tumors, etc. If the stomach is infected with bacteria or viruses, vomiting effectively physically removes many of the organisms from the system.

THE MAJOR ROUTES BACTERIA MAY TAKE WHEN ENTERING THE BODY are the eyes, nose, mouth, ears, anus, and urogenital opening. Another way in which bacteria may enter is directly into the blood through the skin.

8. Non-specific responses of the body to infection, including inflammation, lysozyme action, interferon, and phagocytosis.

Non-specific responses to infection are initiated by body cells breaking down and releasing chemicals.

INFLAMMATION: The inflammation involves a number of stages. Special cells called mast cells release chemicals called histamines. Histamines cause blood vessels to dilate and this leads to a rise in temperature which reduces bacteria reproduction. The histamines also make the cells forming the walls of the capillaries more permeable. As a result, plasma containing leukocytes and antibodies is forced out. The antibodies disable the pathogens and the macrophages and neutrophils destroy them by phagocytosis.

PHAGOCYTOSIS: phagocytosis is a process by which a cell engulfs another cell and encloses it in a vesicle to digest it. The process of digestion uses lysozymes. There are two main types of phagocytes:

Neutrophils: which are granulocytes and they engulf and digest pathogens by phagocytosis.

Macrophages: have the enormous capacity to ingest pathogens and unlike neutrophils, they can renew their lysosomes so they last much longer.

When phagocytes engulf a pathogen, it is enclosed in a vesicle called a phagosome. The phagosome then fuses with the lysosome. The lysozymes break down the pathogen.

INTERFERONS:

- Interferons prevent viral replication.
- It results in the synthesis of proteins such as ribonuclease which breaks down viral RNA of an RNA virus and protein kinases which inhibit translation.
- This in turn prevents the protein coat of the virus to not get produced.
- It also increases recognition of virus-infected cells by T-killer cells so that they can be destroyed faster and less time is available for new virus particles to get produced. Interferons also cause apoptosis (self-destruction) which releases incomplete virus particles that are engulfed by phagocytes during phagocytosis.

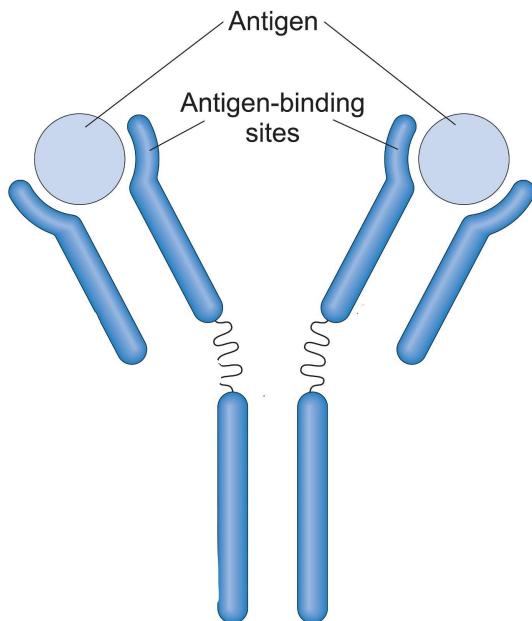
9. The roles of antigens and antibodies in the body's immune response include the involvement of plasma cells, macrophages, and antigen-presenting cells.

Antigens:

- Every cell in the human body has markers on its cell surface membrane that identify it.
- Microorganisms such as bacteria and viruses also have their own unique markers
- These markers are called antigens and they allow cell-to-cell recognition
 1. Antigens are found on cell surface membranes, bacterial cell walls, or the surfaces of viruses
 2. Some glycolipids and glycoproteins on the outside of cell surface membranes act as antigens
- Antigens can be either self-antigens or non-self antigens
 - Antigens produced by the organism's own body cells are known as **self-antigens**
 - Self-antigens do not stimulate an immune response
 - Antigens not produced by the organism's own body cells are known as **non-self** antigens
 - Non-self antigens stimulate an immune response
 - E.g. the antigens found on pathogenic bacteria and viruses, or on the surface of a transplanted organ
- After pathogens are engulfed by phagocytosis, phagocytes transfer the antigens of the digested pathogen to their cell surface membrane, becoming antigen-presenting cells
 - Antigen-presenting cells such as macrophages activate the specific immune response
 - This occurs when the white blood cells of the specific immune response, known as lymphocytes, bind to the presented antigens with specific receptors on their cell surface membranes
 - Note that macrophages are a type of phagocytic white blood cell

Antibody structure:

- Antibodies are Y-shaped molecules sometimes known as immunoglobulins
- They have two antigen-binding sites



Antibody function:

- Antibodies bind to specific antigens that trigger the specific immune response
- Antibodies function to disable pathogens in several ways:

Agglutination: is when antibodies bind to the antigens on pathogens so the microorganism agglutinates or sticks together. This helps to prevent them from spreading through the body and also makes it easier for phagocytes to engulf them.

Opsonization is when an antibody acts as an opsonin, a chemical that makes an antigen or pathogen more easily recognized by phagocytes.

Neutralization is when antibodies neutralize the effects of bacterial toxins by binding to them.

Plasma cells have extensive endoplasmic reticulum and many ribosomes which are adaptations for producing large quantities of protein antibodies. The antibodies remain in the blood for a long time. Memory cells may stay in the blood for years or even for a lifetime.

Macrophages are specialized white blood cells that are involved in the detection, phagocytosis, and destruction of bacteria and other pathogens. Once bacteria is inside a macrophage, it is trapped inside the phagosome which fuses with the lysosome. The lysosome contains enzymes that are able to digest the pathogen.

Antigen-presenting cells (APCs):

- **Macrophage** displays antigen from the pathogen on their surface (after hydrolysis in phagocytosis).
- Enhances recognition by T helper cells, which cannot directly interface with pathogens/antigens in body fluid.
- B cell APC divides to produce B memory cells. The B memory cells recognize the antigens on the surface and help to produce antibodies against it so rapidly that the pathogen is destroyed before symptoms of the disease develop.

10. The differences between the roles of B cells (B memory and B effector cells), and T cells (T helper, T killer, and T memory cells) in the host's immune response.

B Cell Response

- B cells, also known as B lymphocytes, are the second type of white blood cell in the specific immune response
 - B cells remain in the bone marrow as they mature, hence the B in their name
- B cells have many specific receptors on their cell surface membrane
 - The receptors are in fact antibodies, and are known as antibody receptors
 - Each B cell has a different type of antibody receptor, meaning that each B cell can bind to a different type of antigen
- If the corresponding antigen enters the body, B cells with the correct cell surface antibodies will be able to recognise it and bind to it
 - When the B cell binds to an antigen it forms an antigen-antibody complex
- The binding of the B cell to its specific antigen, along with the cell signalling molecules produced by T helper cells, activates the B cell
- Once activated the B cells divide repeatedly by mitosis, producing many clones of the original activated B cell
- The daughter cells differentiate into two main types of cells
 - **Effector cells**, which go on to form plasma cells
 - Plasma cells produce specific antibodies to combat non-self antigens
 - **Memory cells**
 - Remain in the blood to allow a faster immune response to the same pathogen in the future

T Cell Response

- T cells, sometimes known as T lymphocytes, are a type of white blood cell involved with the specific immune response
 - They are produced in the bone marrow and finish maturing in the thymus, which is where the T in their name comes from
- Mature T cells have specific cell surface receptors called T cell receptors
- These receptors have a similar structure to antibodies and are each specific to a particular type of antigen
- T cells are activated when they encounter and bind to their specific antigen on the surface of an antigen presenting cell
 - This antigen-presenting cell might be a macrophage, an infected body cell, or the pathogen itself
- These activated T cells divide by mitosis to increase in number
 - Dividing by mitosis produces genetically identical cells, or clones, so all of the daughter cells will have the same type of T cell receptor on their surface
- As they divide by mitosis the T cells differentiate into three main types of T cell
 - **T helper cells**
 - Release chemical signalling molecules that help to activate B cells
 - **T killer cells**
 - Bind to and destroy infected cells displaying the relevant specific antigen
 - **T memory cells**
 - Remain in the blood and enable a faster specific immune response if the same pathogen is encountered again in the future

11. Immunity (natural, artificial, active, and passive).

Naturally Acquired Active Immunity:

Antigens enter the body naturally, and the body induces antibodies and associated lymphocytes
(few years = lifelong)

Naturally Acquired Passive Immunity:

Antibodies pass [from the mother to fetus via placenta or to infant via the mother's milk
(weeks = months)

Artificially Acquired Active Immunity:

Antigens are introduced in vaccines body produces antibodies and special localized lymphocytes
(few years = life-long)

Artificially Acquired Passive Immunity:

Preformed antibodies in immune serum are introduced by injection
(= 3 weeks)

- **Active immune responses:** antibodies production and T-cell activation
- **Passive immune responses:** delivery of preformed antibodies, limited, not long term immunity, no development of an immune response.

12. How the theory of an 'evolutionary race' between pathogens and their hosts is supported by evasion mechanisms shown by pathogens.

The battle between host and pathogen is known as an evolutionary race; each organism develops new ways in which to have an advantage over the other

HIV evasion mechanisms:

- The virus kills helper T cells after it infects them which reduces the number of cells that could detect the presence of the virus and activate the production of antibodies
- The virus prevents infected cells from presenting their antigens on the cell surface membrane, making it very difficult for the relevant white blood cells to recognize and destroy the infected cells

Mycobacterium tuberculosis evasion mechanisms:

- Once engulfed by phagocytes in the lungs the bacteria produce substances that will prevent a lysosome from fusing with the phagocytic vacuole
- This prevents the bacteria from being broken down by digestive enzymes, leaving them to multiply within the phagocyte
- As with HIV the bacteria can disrupt antigen presentation in infected phagocytes, making it difficult for the immune system to recognise and destroy these cells

13. The difference between bacteriostatic and bactericidal antibiotics.

Antibiotics are either:

- **Bactericidal;** they kill bacterial cells
- **Bacteriostatic;** they inhibit bacterial growth processes

Extra:

- Since mammalian cells are eukaryotic, they will not be damaged by antibiotics
 - They do not have cell walls
 - They have different enzymes
 - They have different ribosomes
- Viruses do not have cellular structures such as enzymes, ribosomes, and cell walls so they are not affected by antibiotics

14. Hospital-acquired infections - MRSA (infection prevention and control).

Methicillin-resistant Staphylococcus aureus (MRSA):

- In the absence of an effective antibiotic, these resistant bacteria are quite capable of causing death.
- To prevent this from continuing, we must reduce the selection pressure for antibiotic resistance.
- We can do this in a number of ways: by using antibiotics only when they are strictly necessary by making sure people understand that they must complete each course of antibiotics by using as few different antibiotics as possible, keeping some in reserve for use only if everything else fails.

15. The role of microorganisms in the decomposition of organic matter and the recycling of carbon.

- microorganisms secrete (enzymes / named enzyme}
- credit correct details of decomposition;
- e.g carbohydrase breaks down glycogen, protein broken down into amino acids,
- idea that products of decomposition are (taken up into / used by) microorganisms; (glucose/ hexose) used in respiration (by the microorganisms);
- releasing (carbon dioxide/methane/eq) (into the atmosphere);
- idea that other breakdown products return to the soil;

16. How DNA can be amplified using the polymerase chain reaction (PCR).

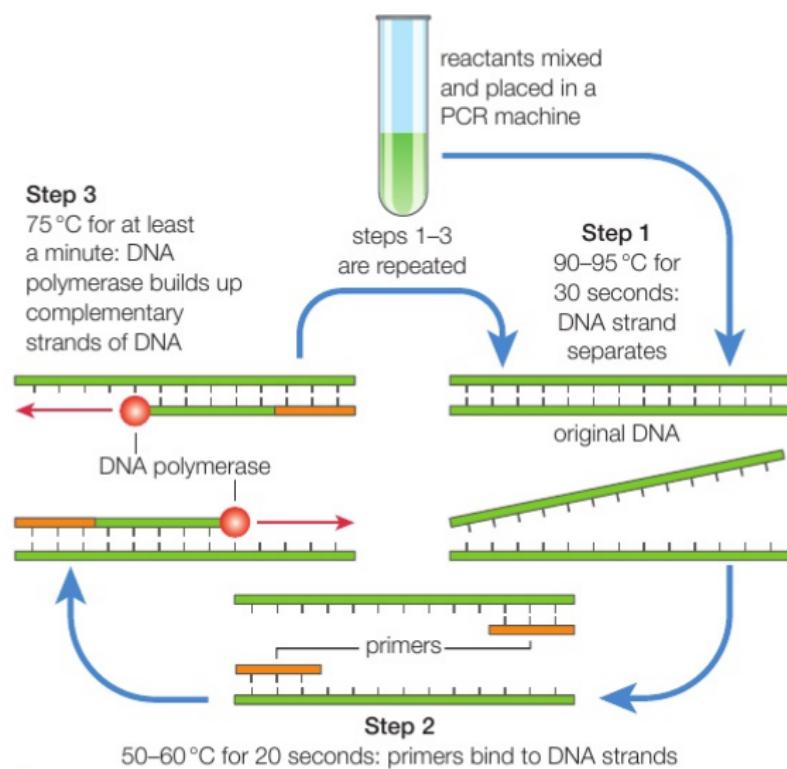
Each PCR reaction requires

- **DNA or RNA to be amplified**
- **Primers:**
 - These are short sequences of single-stranded DNA that have base sequences complementary to the 3' end of the DNA or RNA being copied; they define the region that is to be amplified, identifying where the DNA polymerase enzyme needs to bind
- **DNA polymerase:**
 - The enzyme used to build the new DNA or RNA strand.
 - The most commonly used polymerase is Taq polymerase, which comes from the thermophilic bacterium *Thermus aquaticus*
 - Taq polymerase does not denature at the high temperature required during the first stage of the PCR reaction
 - The optimum temperature of Taq polymerase is high enough to prevent annealing of the DNA strands that have not been copied yet
- **Free nucleotides**
 - Enable the construction of new DNA or RNA strands
- **Buffer solution**
 - Ensures the optimum pH for the reactions to occur in

The DNA sample that is to be amplified is mixed with the enzyme Taq (*Thermus aquaticus*)

DNA polymerase, primers (small sequences of DNA that must join to the beginning of the separated DNA strands before the copying can begin), a good supply of the four different nucleotides, and a suitable buffer for the reaction.

1. The mixture is placed in a PCR machine. It is heated to 90-95 °C, which causes the DNA strands to separate as the hydrogen bonds between them break.
2. The mixture is then cooled to 50-60 °C so that the primers bind (anneal) to the single DNA strands.
3. Finally, the mixture is heated to 75 °C, which is the optimum temperature for the Taq DNA polymerase enzyme to build the complementary strands of DNA.



17. How gel electrophoresis can be used to separate DNA fragments of different lengths.

- Gel electrophoresis is a technique used widely in the analysis of DNA, RNA and proteins
 - DNA fragments are created, e.g. using enzymes known as restriction endonucleases that cut DNA at specific restriction sites
 - The resulting fragments are inserted into a well at the end of a piece of agar gel, before a current is passed through the gel
- Molecules move through the agar due to the difference in charge across the gel
 - Positively charged molecules will move towards the cathode (negative pole) while negatively charged molecules will move towards the anode (positive pole)
 - DNA is negatively charged due to the phosphate groups and so when placed in an electric field the molecules move towards the anode
- The molecules are separated according to their size / mass
 - Different sized molecules move through the gel at different rates
 - The tiny pores in the gel allow smaller molecules to move quickly, whereas larger molecules move more slowly

■ The process of gel electrophoresis involves the following stages:

- An agarose gel plate is created and wells are cut into the gel at one end
- The gel is submerged in a tank containing electrolyte solution; this is a salt solution that conducts electricity
- The DNA samples are transferred into the wells using a micropipette, ensuring that a sample of DNA standard is loaded into the first well
 - ★ The purpose of the standard is to produce a set of known results with which to compare any new results
- The negative electrode is connected to the end of the plate with the wells and the positive anode is connected at the far end
 - ★ The DNA fragments move towards the anode due to the attraction between the negatively charged phosphates of DNA and the anode
 - ★ The smaller mass / shorter pieces of DNA fragments move faster and therefore further from the wells than the larger fragments
- Probes are then added, after which an X-ray image is taken or UV-light is shone onto the paper producing a pattern of bands which can be compared to the control, or standard, fragments of DNA
 - ★ Probes are single-stranded DNA sequences that are complementary to the regions of interest; they can be
 - A radioactive label which causes the probes to emit radiation that makes the X-ray film go dark, creating a pattern of dark bands
 - A fluorescent dye which fluoresces when exposed to UV light, creating a pattern of coloured bands

Analysing the results of gel electrophoresis:

- Gel electrophoresis produces a pattern of bands on the gel that represent DNA fragments of different length
 - The fragments were produced after PCR by cutting the DNA samples into pieces using restriction endonuclease enzymes
 - Restriction endonucleases cut DNA at specific locations in the DNA base sequence, so will always cut in between sections of repeated bases known as variable number tandem repeats (VNTRs)
 - VNTRs are known as micro- or mini-satellites depending on the number of repeats that occur; micro-satellites have fewer repeats than mini-satellites
 - Different people have different numbers of repeats in their VNTR regions, so the fragments will differ in length depending on whether there are few or many repeats
- Different individuals will have different lengths of DNA fragments, so a different pattern of banding will form on each profile
- Every banding pattern will be unique to an individual, so comparisons of DNA from crime scenes with that of suspects is a reliable way of finding out who was present at a crime scene

18. How DNA profiling is used for identification and determining genetic relationships between organisms.

DNA profiling is a technique that can be used to analyze a sample of DNA (e.g. one found at a crime scene) and compare it to DNA samples taken from the suspects. The DNA sample will be collected (this is usually blood, saliva, or semen) and amplified using PCR.

The PCR products are separated using gel electrophoresis, which separates the DNA fragments according to length.

The gel is visualized using UV light and the banding patterns from the suspect's DNA can be compared with that found at the crime scene.

The same technique can also be used to identify genetic relationships between people (as in paternity testing) or to determine evolutionary relationships between organisms.

19. How to determine the time of death of a mammal by examining the extent of decomposition, stage of succession, forensic entomology, body temperature and degree of muscle contraction.

Extent of decomposition:

- The process of decomposition begins soon after death
 - ★ Decomposition is carried out by organisms known as decomposers e.g. bacteria and fungi
 - Enzymes secreted from the cells of these organisms break down biological molecules in dead tissue
- The rate of decomposition will be affected by factors such as temperature and availability of oxygen
 - ★ Decomposition would be slower in anaerobic conditions and at lower temperatures but would be faster at high temperatures

Stage of succession:

- Succession refers to the change in the types of organisms found in a habitat over time
 - ★ This is often an ecology term that is applied to a habitat such as a pond or woodland, but in this case the habitat is the dead body
 - The difference between succession in ecology and in forensics is that in an ecosystem the early pioneer species are out-competed and disappear as the system matures, while in a dead body all of the newly arriving species remain as decomposition progresses
- Above ground the body would undergo the following stages of succession
 - ★ Bacteria will be found in and on the dead body immediately after TOD
 - ★ As tissue decomposition sets in it creates ideal conditions for flies to lay eggs and their larvae to hatch
 - ★ As more soft tissue is consumed by the fly larvae it creates favourable conditions for beetles to establish
 - ★ When tissue dries out over time flies will leave the body as they prefer a moisture-rich environment
 - ★ Beetles, however, can decompose dry tissue so they will remain on the body
 - ★ Once all tissues have been decomposed most organisms will leave the body
- These succession stages will differ depending on where the body is located as the accessibility to insects and availability of oxygen will be affected e.g.
 - ★ Buried in soil
 - ★ Buried in a coffin
 - ★ Under water
- The stage of succession of a body can provide information about the estimated TOD

Forensic entomology:

- A dead body provides an ideal habitat for many species of insects; the study of these insect colonies is known as forensic entomology
- Different insect species will colonise a body at different times after death, providing information about the TOD
 - ★ Flies will be found on the body within a few hours after death, while beetles will only colonise the body later
- Another clue that insects can provide is the stage of life cycle they are at
 - ★ E.g. blowfly eggs will hatch after about 24 hours so if larvae are present on the body it indicates that the person died more than 24 hours ago
 - Other insects have longer life cycles, so if only blowfly larvae are found it indicates that only 24 hours has passed since TOD
 - ★ Factors that might affect the progression of insect life cycles include
 - Drugs that may be present in the body
 - Humidity of the surroundings
 - Oxygen availability, Temperature

Body temperature:

- Respiration and other metabolic processes produce heat in living organisms
 - ★ This heat is necessary for maintaining our body temperature at around 37 °C during life
- Once a person dies metabolic reactions will eventually come to an end
 - ★ Since no more heat is produced the body temperature drops until it reaches the temperature of the surrounding environment
- Certain conditions will affect the rate at which body heat is lost e.g.
 - ★ Air temperature
 - ★ Surface area : volume ratio
 - ★ Presence of clothing

Degree of muscle contraction:

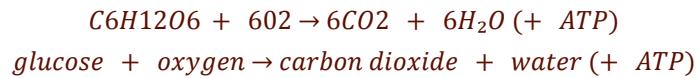
- Muscles in the body begin to contract about 4-6 hours after TOD, leading to a general stiffening of the body known as *rigor mortis*
- *Rigor mortis* comes about as a result of changes to the proteins in muscle cells after death
 - ★ Since no more oxygen reaches the muscle cells after death they will start to respire anaerobically, producing lactic acid
 - ★ The accumulation of lactic acid decreases the pH in the muscle cells, denaturing the enzymes that produce ATP
 - ★ Without ATP the myosin heads cannot be released from the actin filaments, locking the muscles in a contracted state
 - Muscles contract due to the action of two protein filaments; myosin and actin
 - The binding of myosin heads to actin proteins followed by the bending of the myosin heads causes muscle contraction
 - ATP is required to allow the myosin heads to detach from the binding sites on actin
 - ★ This leads to the stiffness that is the main characteristic of rigor mortis
- *Rigor mortis* will begin in the smaller muscles of the head and end in the larger muscles of the lower body, meaning that forensic experts can determine TOD by the progress of *rigor mortis* through the body
 - ★ *Rigor mortis* would have taken place in every muscle between 12 and 18 hours after death, but will wear off again after about 24 to 36 hours from TOD
- The process is affected by the level of muscle development and the temperature of the surroundings
 - ★ Higher temperatures will speed up the rate of *rigor mortis*

Topic 7 – Respiration, Muscles, and the Internal Environment

1. The reaction of aerobic respiration is the splitting of the respiratory substrate.

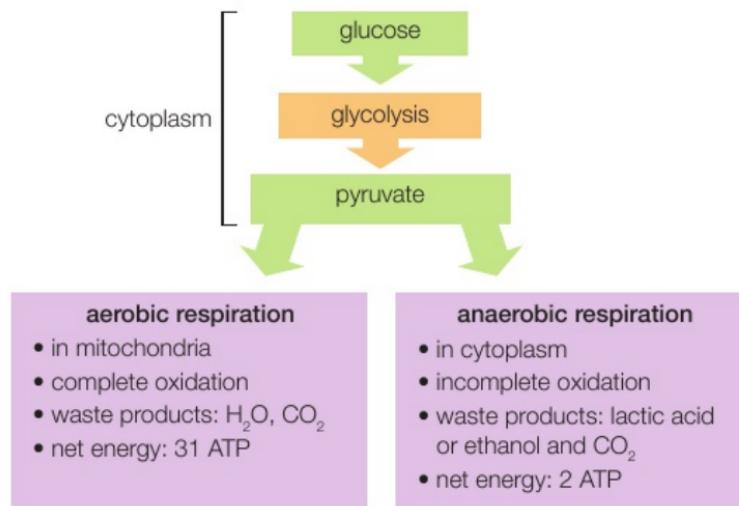
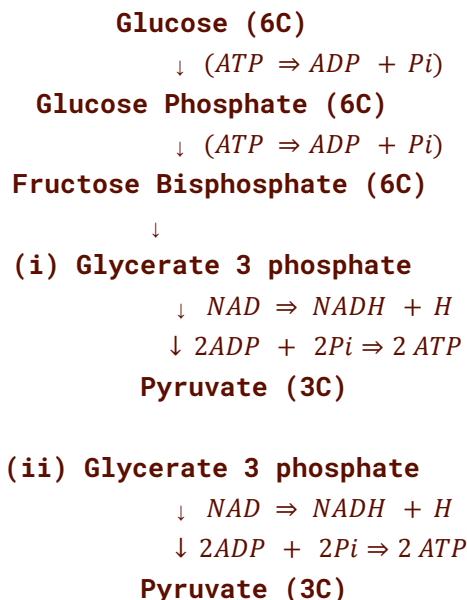
The substance that is broken down is called the **respiratory substrate**. The main respiratory substrate used by cells is glucose.

The overall reaction of **aerobic respiration** involves breaking down the **respiratory substrate** to release carbon dioxide as a waste product and reuniting hydrogen with atmospheric oxygen to form water, with the release of large amounts of energy. The volume of oxygen used and the volume of carbon dioxide produced change depending on the level of activity of the organism, the type of food being respired, and other external factors such as temperature



2. The roles of glycolysis in aerobic and anaerobic respiration, include the phosphorylation of hexoses, the production of ATP by substrate-level phosphorylation, reduced coenzyme, pyruvate, and lactate.

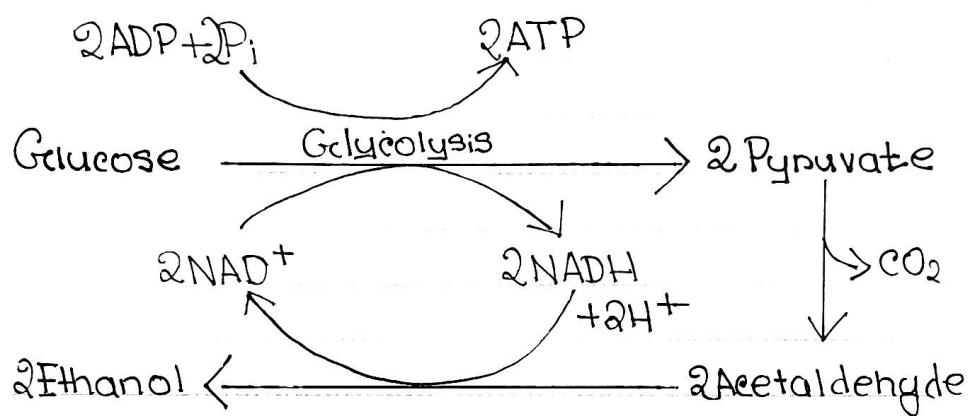
STAGE OF GLYCOLYSIS:



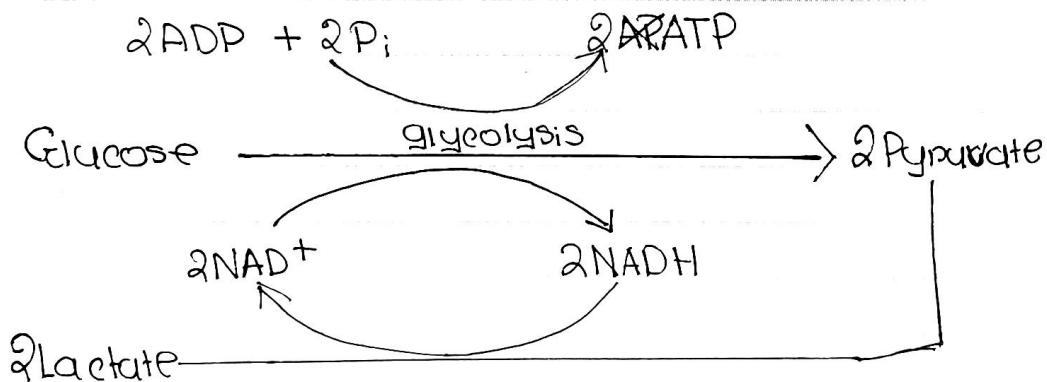
If there is plenty of oxygen the pyruvate will enter the mitochondria and be used in the aerobic reactions of the Krebs cycle. If oxygen levels are low, the pyruvate remains in the cytoplasm and is converted into either ethanol in plants or yeast) or lactate (in mammals) with no additional ATP produced. This is anaerobic respiration in the cytoplasm,

*This production of a small amount of ATP in glycolysis is known as **substrate-level phosphorylation**.*

Alcohol Production



Lactate Production

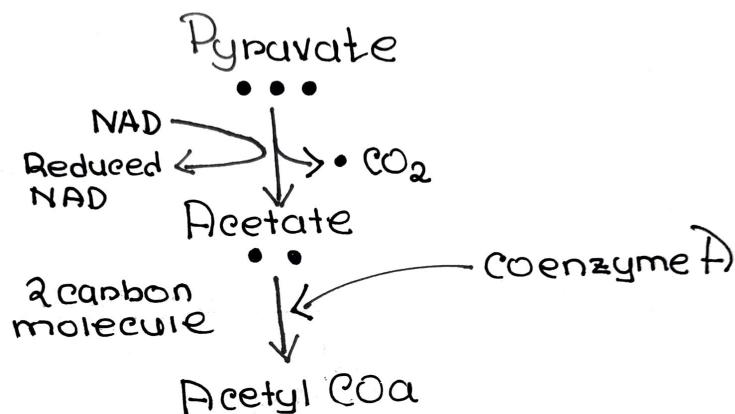


3. The role of the link reaction and the Krebs cycle in the complete oxidation of glucose and formation of carbon dioxide (CO_2) by decarboxylation, ATP by substrate-level phosphorylation, reduced NAD, and reduced FAD by dehydrogenation.

THE LINK REACTION:

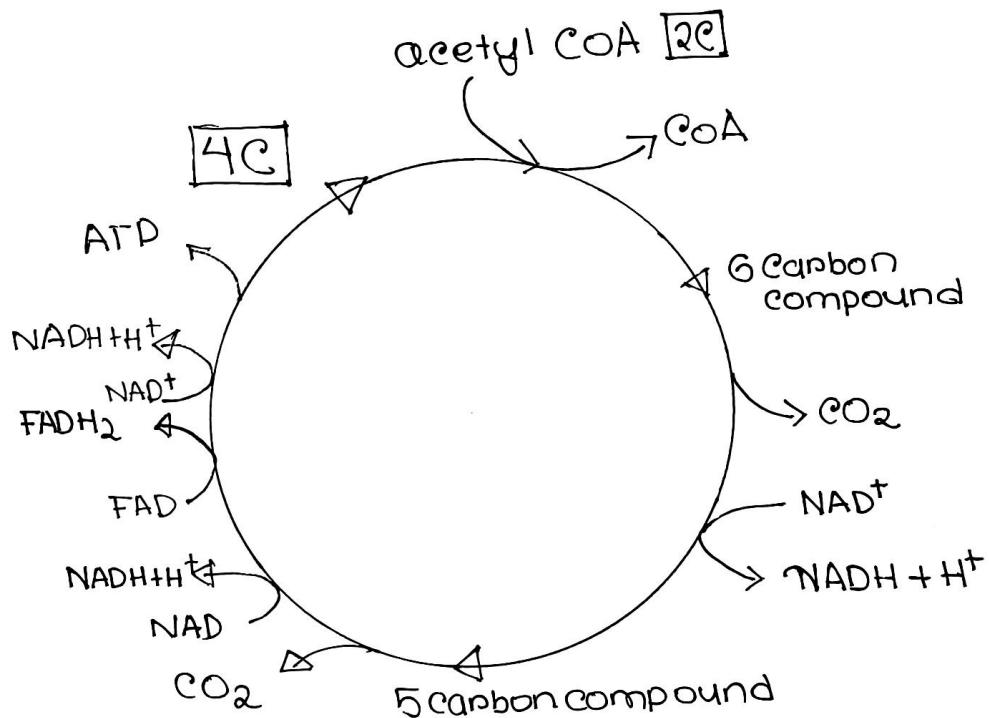
- Links glycolysis to the Krebs cycle.
- Pyruvate crosses through the mitochondrial membrane from the cytoplasm into the mitochondria.
- An atom of carbon and a molecule of oxygen is removed from pyruvate (decarboxylation), resulting in the formation of a carbon dioxide molecule and a 2-carbon compound.
- This 2C compound then joins with coenzyme A to form the compound acetyl coenzyme A (acetyl CoA). At the same time, the pyruvate is oxidized, losing hydrogen to NAD (dehydrogenation), resulting in reduced NAD.
- The reduced NAD is used later in the electron transport chain to produce ATP.
- The energy contained in the acetyl CoA is released in the Krebs cycle.
- Enzymes called **decarboxylases** to remove **carbon dioxide** and
- Enzymes called **dehydrogenases** to remove **hydrogen**.

In summary:



THE KREBS CYCLE:

- For each molecule of pyruvate that feeds into the Krebs cycle
- Three molecules of reduced NAD, one of reduced FAD and one of ATP are produced.
- The reduced NAD and reduced FAD then enter the electron transport chain.
- For each molecule of glucose that enters the glycolytic pathway,
- The Krebs cycle is completed twice because the 6C glucose molecule produces two 3C pyruvate molecules, each of which passes through the Krebs cycle.



4. How ATP is synthesized by oxidative phosphorylation associated with the electron transport chain in mitochondria, including the role of chemiosmosis and ATP synthase.

Oxidative phosphorylation is the final process of aerobic respiration.

In this process, reduced NAD or FAD from glycolysis and the Krebs cycle is used with oxygen to make ATP.

The process involves an electron transport chain, which is a series of electron carrier molecules along which electrons from reduced NAD or FAD are transferred. At the same time, the remaining hydrogen ions (protons) are used in chemiosmosis to supply the energy needed to synthesize ATP

Hydrogen atoms are removed from the compounds in glycolysis and the Krebs cycle, and hydrogen atoms, in the end, combine with oxygen atoms to form water, but it is mainly electrons that are passed along the carrier system. This is why the system is called the electron transport chain. The hydrogen ions remain in the solution. You can think of the various parts of the electron transport chain as being at different energy levels.

The first member of the chain is the highest level, and subsequent steps have lower levels. Each electron is passed down from one energy level to another driving the production of ATP.

ATP production is called oxidative phosphorylation because ADP is phosphorylated in a process that depends on the presence of oxygen. The electron transport chain model describes the sequence of reactions by which living organisms make ATP

Glycolysis occurs in the cell cytoplasm and the other stages of respiration occur in the mitochondria. The link reaction and Krebs cycle occur in the matrix of the mitochondria. The electron transport chain and ATP production occur on the inner membrane of the mitochondria,

5. What happens to lactate after a period of anaerobic respiration in animals?

The lactate is toxic so it must be oxidized back to pyruvate to enter the Krebs cycle and be respired aerobically, producing carbon dioxide, water, and ATP.

The lactate is carried to the liver in the blood. It is converted back to pyruvate and respired in the liver cells.

Oxygen is needed to oxidize the pyruvate made from the accumulated lactate. This is why you continue to breathe deeply for some time after you have finished exercising.

6. What is meant by the term respiratory quotient (RQ)?

RESPIRATORY QUOTIENTS

The amounts of oxygen used and carbon dioxide produced during cellular respiration change depending on the level of activity of the organism, the type of food being respired, and other factors. We can produce what is known as the respiratory quotient (RQ) by measuring the amounts of carbon dioxide produced and oxygen used by an organism in a given time period.

$$\text{respiratory quotient} = \frac{\text{carbon dioxide produced}}{\text{oxygen used}}$$

7. How muscles, tendons, the skeleton, and ligaments interact to enable movement, including antagonistic muscle pairs, extensors, and flexors.

Tendons: non-elastic tissue which connects muscles to bones

Ligaments: an elastic tissue that joins bones together and determines the amount of movement possible at a joint

Joints: the area where two bones are attached to permit body parts to move, they're made of fibrous connective tissue and cartilage

Skeletal muscles: muscles attached to bones, they are arranged in antagonistic pairs

Antagonistic muscle pairs: pairs of muscles which pull in opposite directions - as one muscle contracts, the other relaxes.

Flexors and extensors are antagonistic muscle pairs, such as triceps and biceps. When the triceps relaxes, the biceps contracts to lift the arm.

8. The structure of a mammalian skeletal muscle fiber.

Striated muscle, also known as skeletal muscle, makes up most of the muscles in the body and is used for voluntary movement. It is made up of large bundles of long muscle fibers. They contain myofibrils: long, cylindrical organelles that are specialized for muscle contraction, and made of actin and myosin.

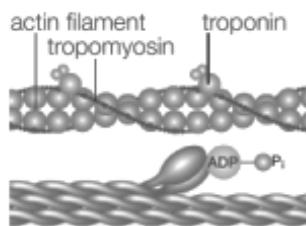
The cells also contain many nuclei and mitochondria to provide energy for movement. A muscle cell is called a sarcolemma and contains a thick filament called myosin and a thin filament called actin, during muscle contraction the actin slides over the myosin.

9. The structural and physiological differences between fast and slow twitch muscle fibers.

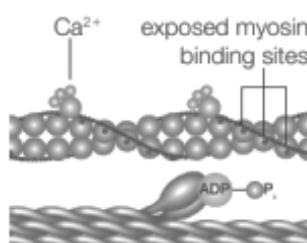
Fast twitch muscle fibre	Slow twitch muscle fibre
anaerobic	aerobic
lactate production	no lactate production
few mitochondria	many mitochondria
less ATP produced	more ATP
more creatine (phosphate)	less creatine (phosphate)
less myoglobin	more myoglobin
low capillary density	high capillary density
more glycogen	less glycogen
more easily fatigued	less easily fatigued
white /paler	red / darker
contract rapidly	contract slowly
larger diameter fibres	smaller diameter fibres
larger capacity of sarcoplasmic reticulum	smaller capacity of sarcoplasmic reticulum

10. The process of contraction of skeletal muscle in terms of the sliding filament theory, including the role of actin, myosin, troponin, tropomyosin, calcium ions (Ca^{2+}), ATP, and ATPase.

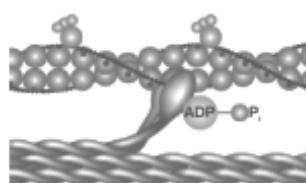
The diagram shows the actin and myosin unit before contraction starts. The myosin heads have ADP and P_i bound closely to them as well.



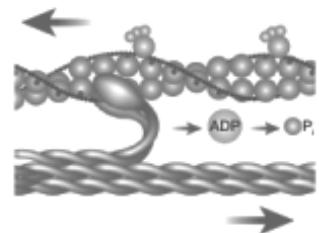
Calcium ions bind to the troponin molecules, changing their shape, so troponin molecules pull on the tropomyosin molecules they are attached to. This moves the tropomyosin away from the myosin binding sites, exposing them ready for action.



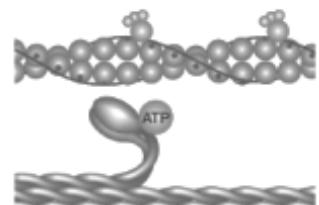
The myosin heads bind to the actin, forming an actomyosin bridge.



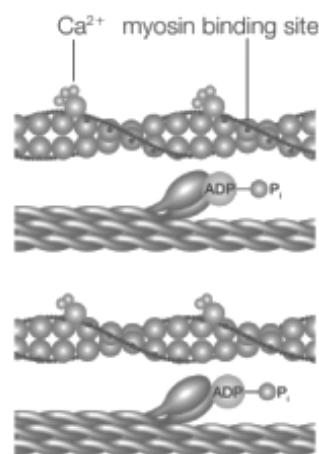
ADP and P_i are released from the myosin head. The myosin changes shape: the head bends forward moving the actin filament about 10 nm along the myosin filament, shortening the sarcomere.



Free ATP binds to the head, causing another shape change in the myosin, so the binding of the head to the actin strand is broken. This activates ATPase in the myosin head, which also needs calcium ions to work. The ATP is hydrolysed, providing the energy to return the myosin head to its original position, primed with ADP and P_i , ready to go again.



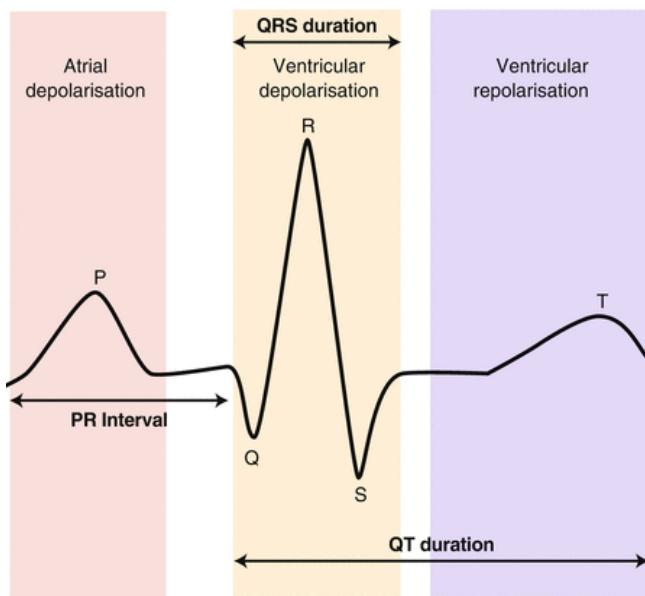
With continued stimulation, calcium ions remain in the sarcoplasm and the cycle is repeated. If not, calcium ions are pumped back into the sarcoplasmic reticulum using energy from ATP. The troponin and tropomyosin return to their original positions and the contraction is complete. The muscle fibre is relaxed.



11. How the normal electrical activity of the heart coordinates the heartbeat, including the roles of the sinoatrial node (SAN), the atrioventricular node (AVN), the bundle of His, and the Purkyne fibers.

1. SAN initiates a wave of electrical excitation
2. Electrical impulses spread across the atria /causes atria to contract;
3. (wave of electrical excitation) is delayed by AVN;
4. wave of depolarisation spreads across ventricles/causes ventricles to contract;
5. the frequency at which heart muscle fibers contract is regulated by the frequency of electrical impulses arriving at the SAN/speed at which electrical impulses spread across the heart determines the length of the cardiac cycle};

12. How the use of electrocardiograms (ECGs) can aid in the diagnosis of abnormal heart rhythms.



- Electrocardiography can be used to monitor and investigate the electrical activity of the heart
- Electrodes that are capable of detecting electric signals are placed on the skin
- These electrodes produce an electrocardiogram (ECG)
- An ECG shows a number of distinctive electrical waves produced by the activity of the heart
- A healthy heart produces a distinctive shape in an ECG

- **Tachycardia**

- When the heart beats too fast it is tachycardic
- An individual with a resting heart rate of over 100 bpm is said to have tachycardia

- **Bradycardia**

- When the heart beats too slow it is bradycardic
- An individual with a resting heart rate below 60 bpm is said to have bradycardia

- **Fibrillation**

- An irregular heartbeat will disrupt the rhythm of the heart
- The atria or ventricles stop contracting properly
- Severe cases of fibrillation can be very dangerous, even fatal

13. Define and calculate cardiac output. how variations in ventilation and cardiac output enable rapid delivery of oxygen to tissues and the removal of carbon dioxide from them.

Calculation of Cardiac Output:

Cardiac output (CO) is the term used to describe the volume of blood that is pumped by the heart (the left and right ventricle) per unit of time

Cardiac output increases when an individual is exercising

This is so that the blood supply can match the increased metabolic demands of the cells

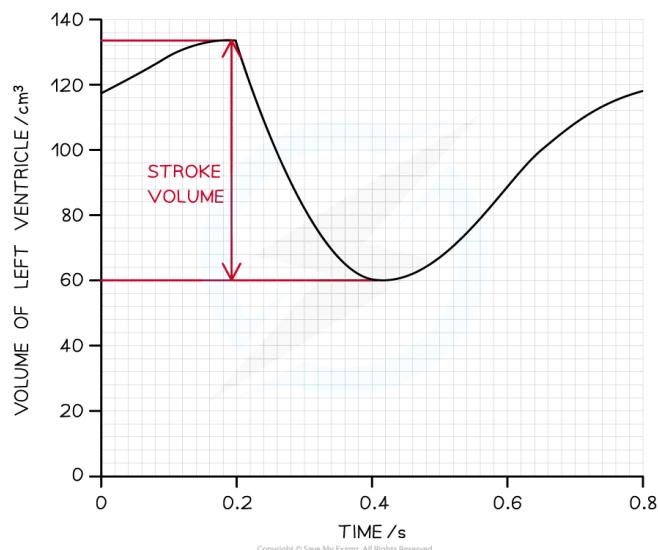
The CO of an individual can be calculated using their **heart rate and stroke volume**

Heart rate is the number of times a heart beats per minute

This can also be described as the number of cardiac cycles per minute

Stroke volume: is the volume of blood pumped out of the left ventricle during one cardiac cycle

Stroke volume graph:



Graph showing the changes in the volume of the left ventricle within one cardiac cycle; this is the stroke volume

Calculating cardiac output:

Cardiac output is found by multiplying the heart rate by the stroke volume:

Cardiac output = heart rate x stroke volume

The equation can be rearranged to find the heart rate and stroke volume if required:

Heart rate = cardiac output ÷ stroke volume

Stroke volume = cardiac output ÷ heart rate

- Cardiac output is measured in $\text{cm}^3 \text{ min}^{-1}$
- Heart rate is measured in beats per min (bpm)
- Stroke volume is measured in cm^3

Effects of Variability of Cardiac Output

During exercise, muscle contraction occurs more frequently, requiring more energy

The rate of aerobic respiration increases to meet the increase in energy demand

This means that cells require more oxygen to be delivered to them, while producing more carbon dioxide as a waste product of respiration

The body will accommodate this by making the following changes:

Increase the rate and depth of breathing which will increase the amount of oxygen entering the lungs and bloodstream, while getting rid of more carbon dioxide

Increase the heart rate which will transport the oxygen (and glucose) to the muscles much faster, while removing the additional carbon dioxide produced due to the increased rate of respiration

Effect of exercise

- The extra carbon dioxide that is produced will decrease the pH of the blood (it becomes more acidic)
- The decrease in pH is detected by receptors sensitive to changes in the chemical composition of blood
- These are called **chemoreceptors** and they are located in several places
- They are present as clusters of cells in the aorta (aortic bodies) and the carotid arteries (carotid bodies)
- In the ventilation centre of the **medulla oblongata**
- Once they are stimulated a nerve impulse is sent to the **medulla oblongata**
- The **medulla oblongata** will then send more frequent nerve impulses to the intercostal and diaphragm muscles to increase the rate and strength of contractions
- This increases the breathing rate and depth
- This results in more oxygen entering the lungs (and bloodstream), while more carbon dioxide can be exhaled and thus be removed from the bloodstream
- The decrease in carbon dioxide levels will result in the blood pH returning back to normal, which leads to the breathing rate returning to normal
- The volume of air that moves in and out of the lungs during a set time period (e.g. a minute) is known as the ventilation rate
- The ventilation rate increases during exercise due to the increase in breathing rate and depth

Control of the heart rate

- The cardiovascular control centre in the medulla oblongata unconsciously controls the heart rate by controlling the rate at which the sinoatrial node (SAN) generates electrical impulses
- These electrical impulses cause the atria to contract and therefore determines the rhythm of a heartbeat
- Changes in the internal environment of the body (e.g. blood pressure, oxygen levels) can result in a change in the heart rate
- These changes act as stimuli which is detected by baroreceptors and chemoreceptors
- Baroreceptors are found in the aortic and carotid bodies and they are stimulated by high and low blood pressure
- Chemoreceptors are found in the medulla oblongata, as well as in the aortic and carotid bodies
- They are stimulated by changes in the levels of carbon dioxide and oxygen in the blood, as well as blood pH
- Once stimulated, these receptors will send electrical impulses to the medulla oblongata

- The cardiovascular control centre in the medulla oblongata will respond by sending impulses to the SAN along sympathetic or parasympathetic neurones
- Each of these neurones release different neurotransmitters which will affect the SAN in a different way
- Sympathetic neurones will increase the rate at which the SAN generates electrical impulses, thus speeding up the heart rate
- These neurones form part of the sympathetic nervous system which prepares the body for action ('fight or flight' response) and increases the heart rate during exercise
- Parasympathetic neurones will decrease the rate at which the SAN fires, thus slowing down the heart rate
- These neurones form part of the parasympathetic nervous system which calms the body down after action ('rest and digest' response) and decreases the heart rate after exercise

Changes in heart rate

- The heart will respond in different way depending on the stimulus that it receives

High blood pressure:

- Detected by **baroreceptors** which send impulses to cardiovascular control centre
- It sends impulses along parasympathetic neurones which secrete the neurotransmitter acetylcholine
- Acetylcholine binds to receptors on SAN causing it to fire less frequently
- Heart rate slows down and blood pressure decreases back to normal

Low blood pressure:

- Detected by baroreceptors which send impulses to cardiovascular control centre
- It sends impulses along sympathetic neurones which secrete the neurotransmitter noradrenaline
- Noradrenaline binds to receptors on SAN causing it to fire more frequently
- Heart rate speeds up and blood pressure increases back to normal

➤ High blood O₂ / Low CO₂ / high pH levels

- Detected by chemoreceptors which send impulses to cardiovascular control centre
- It sends impulses along parasympathetic neurones which secrete the neurotransmitter acetylcholine
- Acetylcholine binds to receptors on SAN causing it to fire less frequently
- Heart rate slows down and O₂ / CO₂ and pH levels return to normal

➤ Low blood O₂ / High CO₂ / low pH levels (during exercise)

- Detected by chemoreceptors which send impulses to cardiovascular control centre
- It sends impulses along sympathetic neurones which secrete the neurotransmitter noradrenaline
- Noradrenaline binds to receptors on SAN causing it to fire more frequently
- Heart rate speeds up and O₂ / CO₂ and pH levels return to normal

14. How the heart rate and ventilation rate are controlled and the roles of the cardiovascular control center and the ventilation center in the medulla oblongata.

Control of the breathing rate:

- **Breathing rate** is controlled by the ventilation centres (also called respiratory centres) in the medulla oblongata
- This is one of the **three regions** that make up the brainstem, *it transfers nerve messages from the brain to the spinal cord*
- The **inspiratory centre** controls the movement of air into the lungs (**inhalation**)
- The **expiratory centre** controls the movement of air out of the lungs (**exhalation**)

The **inspiratory centre** in the medulla oblongata has the following effect on breathing:

- It sends nerve impulses along motor neurons to the intercostal muscles of the ribs and diaphragm muscles
- These muscles will contract and cause the volume of the chest to increase
- This lowers the air pressure in the lungs to slightly below atmospheric pressure
- An impulse is also sent to the expiratory centre to inhibit its action
- Due to the difference in pressure between the lungs and outside air, air will flow into the lungs
- Stretch receptors in the lungs are stimulated as they inflate with air
- Nerve impulses are sent back to the medulla oblongata which will inhibit the inspiratory centre

The **expiratory centre** is no longer inhibited and will bring about the following changes:

- It sends nerve impulses to the intercostal and diaphragm muscles
- These muscles will relax and cause the volume of the chest to decrease
- This increases the air pressure in the lungs to slightly above atmospheric pressure
- Due to the higher pressure in the lungs, air will flow out of the lungs
- As the lungs deflate, the stretch receptors become inactive which means that the inspiratory centre is no longer inhibited and the next breathing cycle can begin

15. The role of adrenaline in the fight or flight response.

The Fight or Flight Response:

During situations that create stress, fear, or excitement, the neurons of the sympathetic nervous system will stimulate the adrenal medulla (of the adrenal gland) to secrete adrenaline

Adrenaline is a hormone that will prepare your body for reacting to a stressful situation. This reaction is often called the "fight or flight" response

It is the effects of adrenaline that lead to the typical symptoms we experience during stressful situations such as increased heart rate, dry mouth, increased sweating, etc.

Adrenal gland structure:

The **adrenal medulla** is responsible for releasing the hormone adrenaline into the bloodstream to prepare the body for the "**fight or flight**" response

- Since adrenaline is a hormone, it is transported around the body in the bloodstream
- It will bind to receptors on its target organs
- One of the targets of adrenaline is the SAN, leading to an increase in the frequency of excitations
- This in turn, will increase the heart rate to supply blood to the muscle cells at a faster rate
- More blood means more oxygen and glucose that reaches the muscle cells, which in turn, increases the rate of aerobic respiration
- This releases more energy that will be used during the response to the stressful or dangerous situation
- Adrenaline will also stimulate the cardiovascular control centre in the medulla oblongata
- This increases the impulses travelling along the sympathetic neurones affecting the heart, further speeding up the heart rate
- Blood vessels to less important organs (such as the digestive system and skin) constrict so that more blood can be diverted to organs that will be involved in the "fight or flight" response
- Note that blood flow to the brain remains constant, regardless of whether the body is in a state of stress or relaxation
- The brain is one of the most important organs in the body and needs a constant blood supply in order to function properly
- The changes experienced by the body during the "fight or flight" response are controlled by a combination of nervous and hormonal responses

16. What is meant by the terms negative feedback and positive feedback control? the principle of negative feedback in maintaining systems within narrow limits.

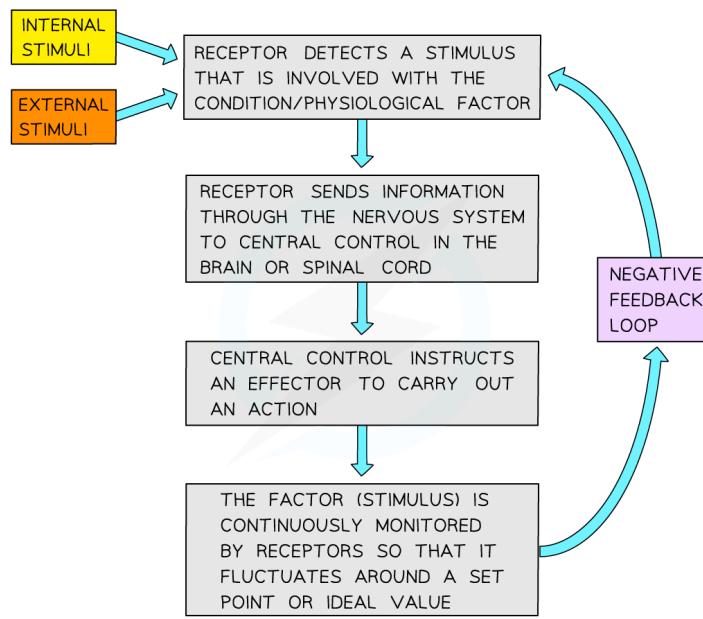
Negative & Positive Feedback:

Negative feedback:

- The majority of homeostatic control mechanisms in organisms use negative feedback to maintain homeostatic balance, i.e. to keep certain physiological factors, such as internal temperature or blood glucose concentration, within certain limits

Negative feedback control loops involve:

- If there is an increase in the factor the body responds to make the factor decrease
- If there is a decrease in the factor the body responds to make the factor increase
- Negative feedback systems work by reversing a change in the body to bring it back within normal limits, e.g.
- If body temperature rises a negative feedback system will act to lower body temperature, bringing it back to normal
- If blood glucose levels drop a negative feedback system will act to raise blood glucose, bringing it back to normal
- Negative feedback loop



- Negative feedback loops involve the monitoring of physiological factors and act to reverse any changes, keeping the factors within normal limits. Information can be transferred via nerve signals, as shown here, or by hormonal signals.

Positive feedback:

- In positive feedback loops the original stimulus produces a response that causes the factor to deviate even more from the normal range
- They enhance the effect of the original stimulus
- Positive feedback loops are useful to quickly activate a process, e.g. blood clotting to close up a wound
- When the body is injured, platelets become activated
- They release chemicals which will activate more platelets, which in turn, will release chemicals that will activate even more platelets etc.
- This ensures that the wound is quickly closed up by a blood clot before too much blood is lost or too many pathogens enter the bloodstream
- The body will revert to negative feedback mechanisms once the blood clot has formed
- Positive feedback may also kick in when homeostatic mechanisms break down
- E.g. during prolonged exposure to extreme cold hypothermia can occur; body temperature drops, resulting in decreased metabolism which in turn causes body temperature to drop further
- Since these mechanisms do not maintain a constant internal environment, they are not involved in homeostasis

17. What is meant by the term homeostasis and the role of the hypothalamus in thermoregulation?

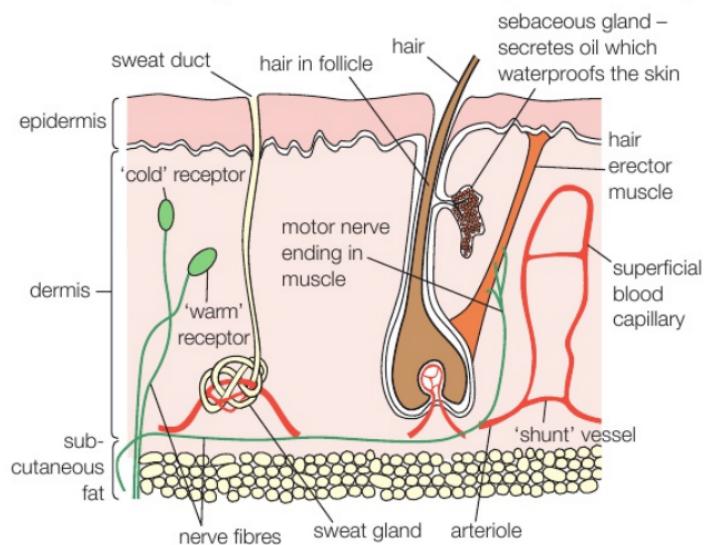
Thermoregulation:

The human body needs to maintain a temperature at which enzymes work best, around 37°C . Processes such as respiration, release energy as heat, while the body loses heat energy to its surroundings – the energy gained and lost must be regulated to maintain a constant core body temperature.

Body temperature is monitored and controlled by the thermoregulatory centre in the hypothalamus (structure within the brain)

The thermoregulatory centre contains receptors sensitive to the temperature of the blood. The skin also contains temperature receptors within the epidermal layer which send nerve impulses to the thermoregulatory centre.

A cross-section of human skin:



Human skin contains structures involved in processes that can increase or reduce heat loss to the surroundings. Temperature receptors are located within the epidermis.

Controlling body temperature

If the body temperature is too high, the hair erector muscles relax, blood vessels dilate (vasodilation) and sweat is produced from the sweat glands

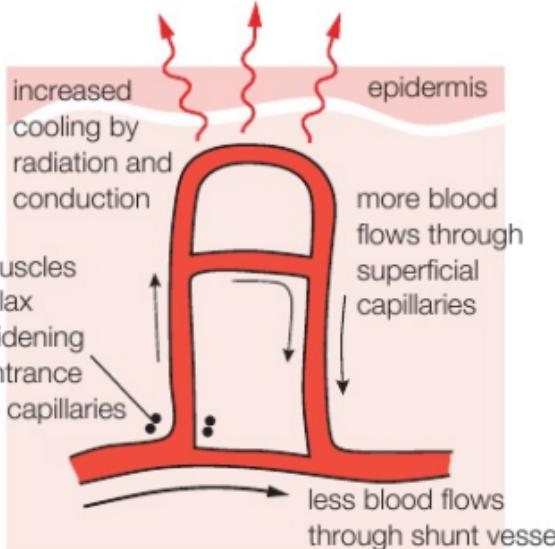
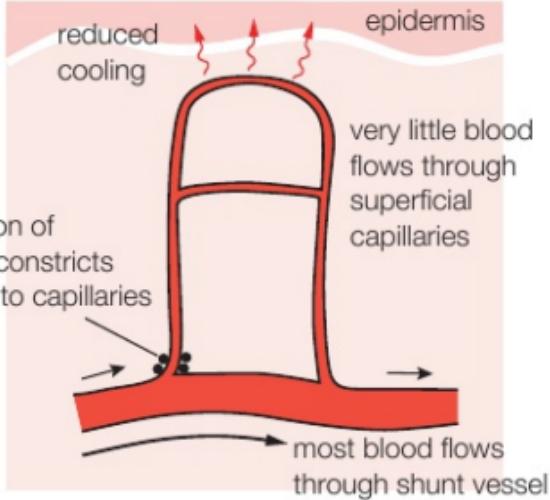
These mechanisms cause a transfer of energy from the skin to the environment, cooling the body down

Responses in the skin when the body temperature is too high and needs to decrease

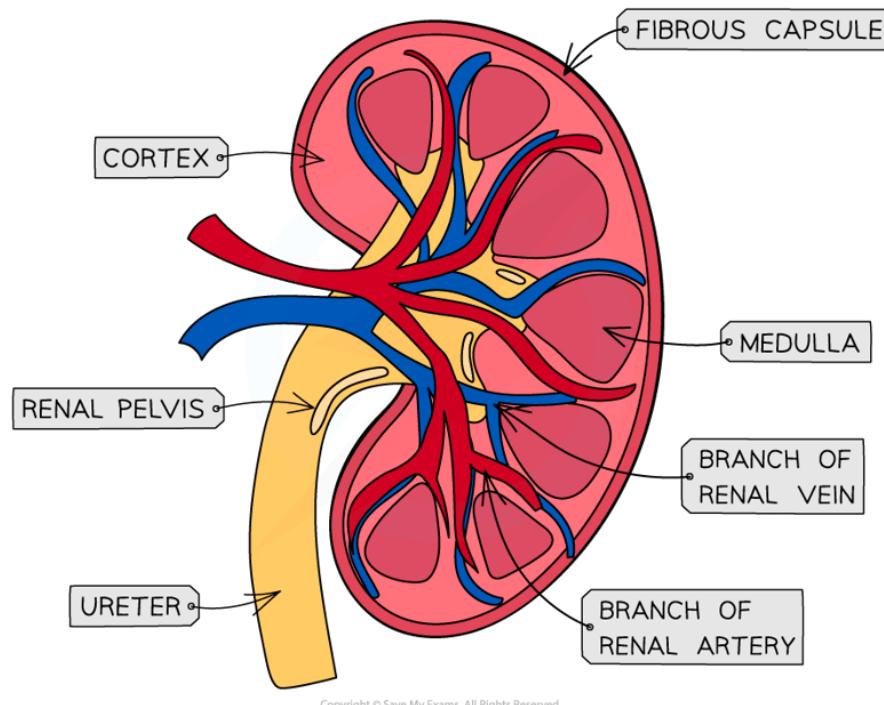
If the body temperature is too low, hair erector muscles contract, blood vessels constrict (vasoconstriction), sweating stops and skeletal muscles contract (shiver)

These mechanisms reduce heat loss to the surroundings (with skeletal muscle contraction increasing heat released in the body)

Remember homeostasis involves the maintenance of a constant internal environment; temperature control is an example of negative feedback

IN A WARM ENVIRONMENT	IN A COLD ENVIRONMENT
<ul style="list-style-type: none"> vasodilation occurs 	<ul style="list-style-type: none"> vasoconstriction occurs 
<ul style="list-style-type: none"> sphincter muscles around the arterioles leading to the superficial capillaries are not stimulated to contract and therefore relax 	<ul style="list-style-type: none"> sphincter muscles around the arterioles leading to the superficial capillaries are stimulated to contract
<ul style="list-style-type: none"> more blood can flow into these capillaries, dilating them (making them wider) with the pressure; less blood flows through deeper shunt vessels 	<ul style="list-style-type: none"> this constricts the passage of blood into these capillaries (making them narrower) so more blood flows through deeper shunt vessels
<ul style="list-style-type: none"> more blood flows close to the body surface 	<ul style="list-style-type: none"> less blood flows close to the body surface
<ul style="list-style-type: none"> as more blood flows close to the body surface, the temperature gradient between the body surface and the environment becomes greater, so cooling by conduction and radiation increases. 	<ul style="list-style-type: none"> as most blood is diverted further from the body surface, the temperature gradient between the body surface and the environment is lower, so cooling by conduction and radiation decreases.

18. The gross and microscopic structure of the mammalian kidney.



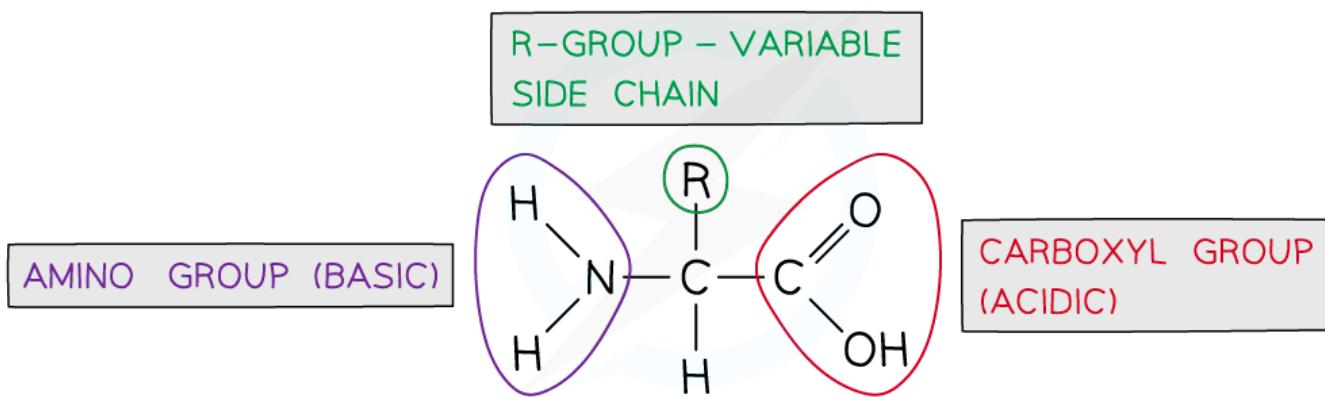
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19. How urea is produced in the liver from excess amino acids and how it is removed from the bloodstream by ultrafiltration.

Urea as a Waste Product:

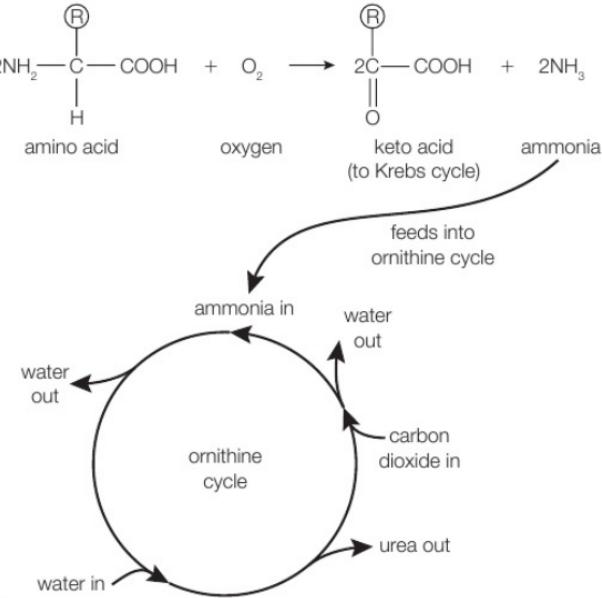
Formation of urea:

- The body cannot store excess protein or amino acids
- Liver cells, or hepatocytes, are responsible for removing the amino group from excess amino acids in a process called deamination
- During deamination the amino group ($-NH_2$) of an amino acid is removed, together with an extra hydrogen atom
- These combine to form ammonia (NH_3)
- amino acids rightwards arrow ammonia + keto acid



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- The remaining keto acid may enter the Krebs cycle to be respiration, be converted to glucose, or converted to glycogen / fat for storage
- This means that the amino acids within the protein will not be wasted but can function as a useful source of energy
- Due to its toxicity ammonia is quickly converted into less toxic urea
- This happens in a series of steps known as the ornithine cycle, which can be summarised as



- ammonia + carbon dioxide \rightarrow urea + water
- Urea forms part of urine and can be excreted by the kidneys
- Urea is filtered out of the bloodstream into the Bowman's capsule of the nephron by the process of ultrafiltration

Ultrafiltration:

Within the Bowman's capsule of each kidney nephron is a structure known as the glomerulus; these two structures together carry out the process of ultrafiltration. The blood in the glomerulus is at high pressure.

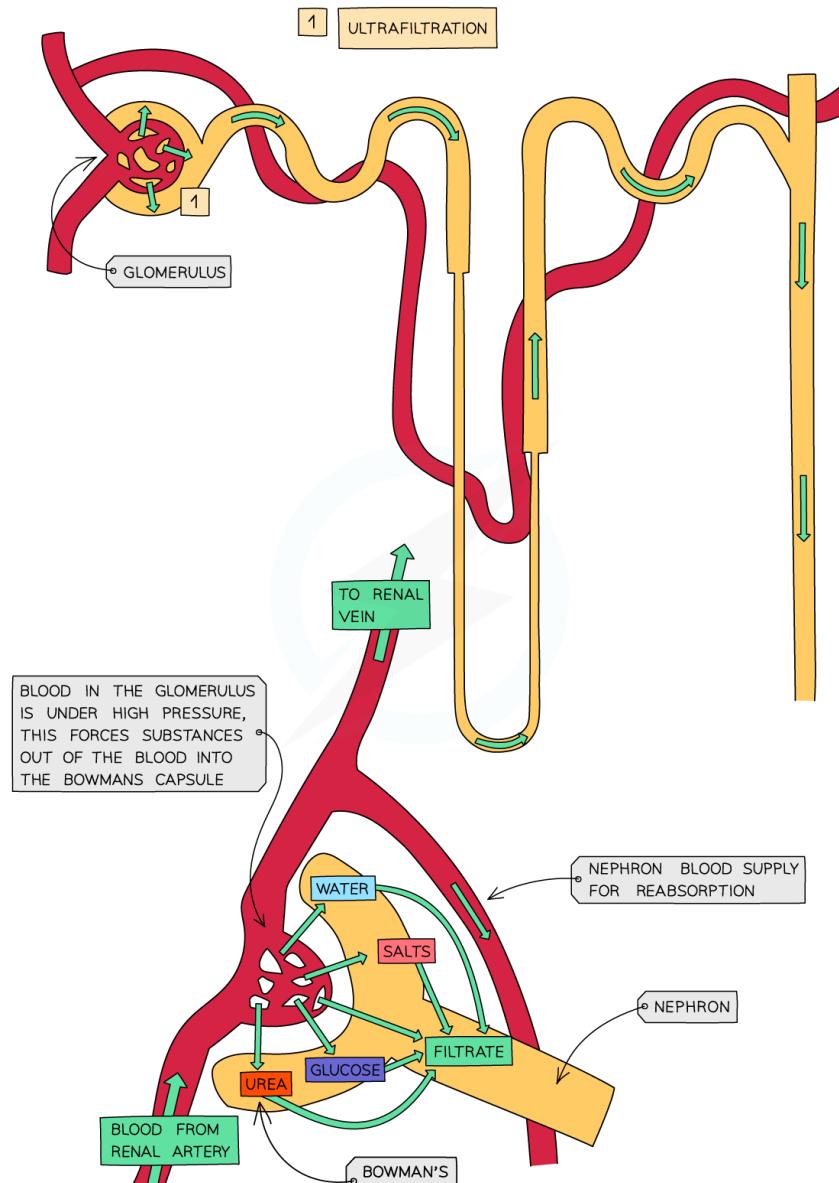
The afferent arteriole that enters the glomerulus is wider than the efferent arteriole that leaves it, increasing the blood pressure as the blood flows through the glomerulus.

This high pressure forces small molecules in the blood out of the capillaries of the glomerulus and into the Bowman's capsule.

The resulting fluid in the Bowman's capsule is called the glomerular filtrate. Large molecules such as proteins remain in the blood and do not pass into the filtrates.

During the process of ultrafiltration small molecules are forced out of the capillaries into the Bowman's capsule.

The structures within the glomerulus and Bowman's capsule are especially well adapted for ultrafiltration.



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The blood in the glomerular capillaries is separated from the lumen of the Bowman's capsule by two cell layers with a basement membrane in between them

The first cell layer is the endothelium of the capillary; gaps between the cells allow fluid to pass through

The next layer is the mesh-like basement membrane

The second cell layer is the epithelium of the Bowman's capsule; gaps between the cells allow the passage of small molecules

As blood passes through the glomerular capillaries the gaps between the cells and the mesh-like basement membrane allow substances dissolved in the blood plasma to pass into the Bowman's capsule

The substances that pass into the Bowman's capsule make up the glomerular filtrate

The main substances that form the glomerular filtrate are

1. Amino acids
2. Water
3. Glucose
4. Urea
5. Salts (Na^+ and Cl^- ions)

Red and white blood cells and platelets remain in the blood as they are too large to pass between the cells

The basement membrane stops large protein molecules from getting through

20. Describe how solutes are selectively reabsorbed in the proximal tubule and how the loop of Henle acts as a countercurrent multiplier to increase the reabsorption of water.

Selective Reabsorption in the Kidney:

The nephron is the functional unit of the kidney and is responsible for the formation of urine

The process of urine formation in the kidneys occurs in two stages

1. Ultrafiltration
2. Selective reabsorption

Ultrafiltration i

Involves filtering small molecules from the blood at high pressure

This occurs between the glomerulus and the bowman's capsule

Selective reabsorption allows the kidney to reabsorb useful small molecules into the blood

Selective reabsorption

Many of the substances that pass into the glomerular filtrate are useful to the body

These substances are therefore reabsorbed into the blood as the filtrate passes along the nephron

This process is known as selective reabsorption since not all substances are reabsorbed

Reabsorbed substances include **water, salts, glucose, and amino acids**

- Most of this reabsorption occurs in the **proximal convoluted tubule**
- Note that while water and salts are reabsorbed in the proximal convoluted tubule, the loop of Henle and collecting duct are also involved in the reabsorption of these substances
- The lining of the proximal convoluted tubule is composed of a single layer of epithelial cells which are adapted to carry out reabsorption in several ways
- Microvilli
- Microvilli are tiny finger-like projections on the surface of epithelial cells which increase the surface area for diffusion
- Co-transporter proteins
- Many mitochondria, Tightly packed cells

Adaptations for Selective Reabsorption Table

Adaptation of proximal convoluted tubule epithelial cell	How adaptation aids reabsorption
Many microvilli present on the luminal membrane (the cell surface membrane that faces the lumen).	This increases the surface area for reabsorption.
Many co-transporter proteins in the luminal membrane.	Each type of co-transporter protein transports a specific solute (eg. glucose or a particular amino acid) across the luminal membrane.
Many mitochondria.	These provide energy for sodium-potassium ($\text{Na}^+ - \text{K}^+$) pump proteins in the basal membranes of the cells.
Cells tightly packed together.	This means that no fluid can pass between the cells (all substances reabsorbed must pass through the cells).

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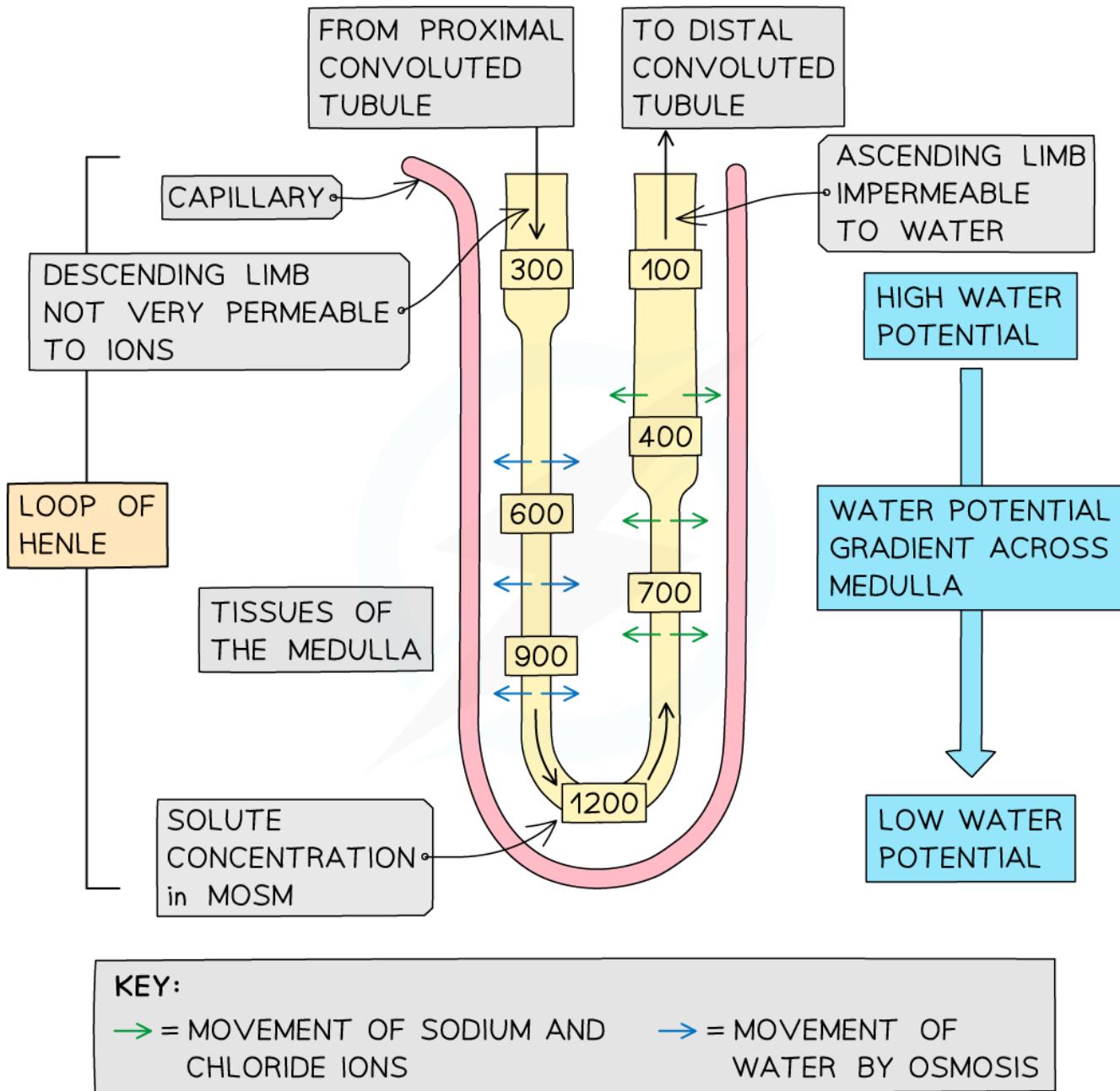
- Molecules reabsorbed from the Proximal Convolute Tubule
- Sodium ions (Na^+) are transported from the proximal convoluted tubule into the surrounding tissues by active transport
- The positively charged sodium ions creates an electrical gradient, causing chloride ions (Cl^-) to follow by diffusion
- Sugars and amino acids are transported into the surrounding tissues by co-transporter proteins which also transport sodium ions
- The movement of ions, sugars, and amino acids into the surrounding tissues lowers the water potential of the tissues, so water leaves the proximal convoluted tubule by osmosis
- Urea moves out of the proximal convoluted tubule from a high to a low concentration by diffusion
- All of the substances that leave the proximal convoluted tubule for the surrounding tissues eventually make their way into nearby capillaries down their concentration gradients

The role of the loop of Henle:

- Many animals deal with the excretion of the toxic waste product urea by dissolving it in water and excreting it
- While this method of excretion works well, it brings with it the problem of water loss
- The role of the **loop of Henle** is to enable the production of urine that is more concentrated than the blood, and to therefore conserve water
- Note that it is also possible to produce urine that is less concentrated than the blood; this is important when water intake is high to prevent blood becoming too dilute
- The **loop of Henle** achieves this by the use of a **countercurrent multiplier system**
Countercurrent refers to the opposite directions of filtrate flow in the descending and ascending limbs of the loop of Henle
Multiplier refers to the steep concentration gradient that the loop of Henle is able to generate across the medulla

■ The process in the loop of Henle:

- Sodium and chloride ions move out of the filtrate in the ascending limb of the loop of Henle into the surrounding medulla region, lowering its water potential
- The movement of ions occurs by both diffusion and active transport
- Diffusion takes place in the first part of the ascending limb
- Active transport occurs in the second part of the ascending limb
- The ascending limb of the loop of Henle is impermeable to water, so water is unable to leave the loop here by osmosis
- The water potential in the ascending limb increases as it rises back into the cortex due to the removal of solutes and retention of water
- The neighbouring descending limb is permeable to water, so water moves out of the descending limb by osmosis due to the low water potential in the medulla created by the ascending limb
- The descending limb has few transport proteins in the membranes of its cells, so has low permeability to ions
- The water potential of the filtrate decreases as the descending limb moves down into the medulla due to the loss of water and retention of ions
- The water and ions that leave the loop of Henle for the medulla make their way into the nearby capillary network



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The loop of Henle acts as a countercurrent multiplier, maximizing the reabsorption of water by creating a steep water potential gradient across the medulla

21. Describe how the pituitary gland and osmoreceptors in the hypothalamus, combined with the action of antidiuretic hormone (ADH), bring about negative feedback control of mammalian plasma concentration, urine, and blood volume.

Osmoregulation:

- The control of the water potential of body fluids is known as **osmoregulation**
- **Osmoregulation** is a key part of **homeostasis**
- Specialised sensory neurones, known as **osmoreceptors**, monitor the water potential of the blood (these osmoreceptors are found in an area of the brain known as the hypothalamus)
- If the osmoreceptors detect a decrease in the water potential of the blood, nerve impulses are sent along these sensory neurons to the posterior pituitary gland (another part of the brain just below the hypothalamus)
- These nerve impulses stimulate the posterior pituitary gland to release antidiuretic hormone (ADH)
- ADH molecules enter the blood and travel throughout the body
- ADH causes the kidneys to reabsorb more water
- This reduces the loss of water in the urine

When osmoreceptors detect a decrease in blood water potential, nerve impulses stimulate the release of ADH at the posterior pituitary gland. This ADH then travels in the blood to the kidneys, causing them to increase water reabsorption

The effect of ADH on the kidneys:

Water is reabsorbed by osmosis from the filtrate in the nephron

This reabsorption occurs as the filtrate passes through structures known as collecting ducts

ADH causes the luminal membranes (ie. those facing the lumen of the nephron) of the collecting duct cells to become more permeable to water

ADH does this by causing an increase in the number of **aquaporins (water-permeable channels)** in the membranes of the collecting duct cells.

This occurs in the following way:

- Collecting duct cells contain vesicles, the membranes of which contain many aquaporins
- ADH molecules bind to receptor proteins
- This activates the aquaporins, causing the vesicles to fuse with the membranes of the collecting duct cells
- This increases the permeability of the membrane to water
- As the filtrate in the nephron travels along the collecting duct, water molecules move from the collecting duct (high water potential), through the aquaporins, and into the tissue fluid and blood plasma in the medulla (low water potential)
- As the filtrate in the collecting duct loses water it becomes more concentrated
- As a result, a small volume of concentrated urine is produced. This flows from the kidneys, through the ureters, and into the bladder

Exam Tip:

If the water potential of the blood is too high, the exact opposite happens:

- Osmoreceptors in the hypothalamus are not stimulated
- No nerve impulses are sent to the posterior pituitary gland
- No ADH released
- Aquaporins are moved out of the luminal membranes of the collecting duct cells
- Collecting duct cells are no longer permeable to water
- The filtrate flows along collecting duct but loses no water and is very dilute
- A large volume of dilute urine is produced
- This flows from the kidneys, through the ureters, and into the bladder

22. How genes can be switched on and off by DNA transcription factors, including the role of peptide hormones acting extracellularly and steroid hormones acting intracellularly.

Hormones can alter the events inside a cell by influencing gene expression

Eukaryotes use transcription factors to control gene expression

A transcription factor is a protein that controls the transcription of genes by binding to a specific region of DNA

Effect of hormones inside cells:

Hormones that can cross the cell surface membrane, e.g. steroid hormones and thyroid hormones, are able to enter the nucleus and bind to transcription factors that are present there

Steroid hormones are lipid soluble, allowing them to pass between the phospholipids of the cell surface membrane

An example of this is the hormonal regulation of body temperature

Effect of hormones from outside cells:

Hormones that cannot cross the cell membrane, e.g. protein and peptide hormones, bind to receptors in the cell surface membrane

Examples of such hormones include

1. Adrenaline
2. Insulin
3. Glucagon
4. ADH

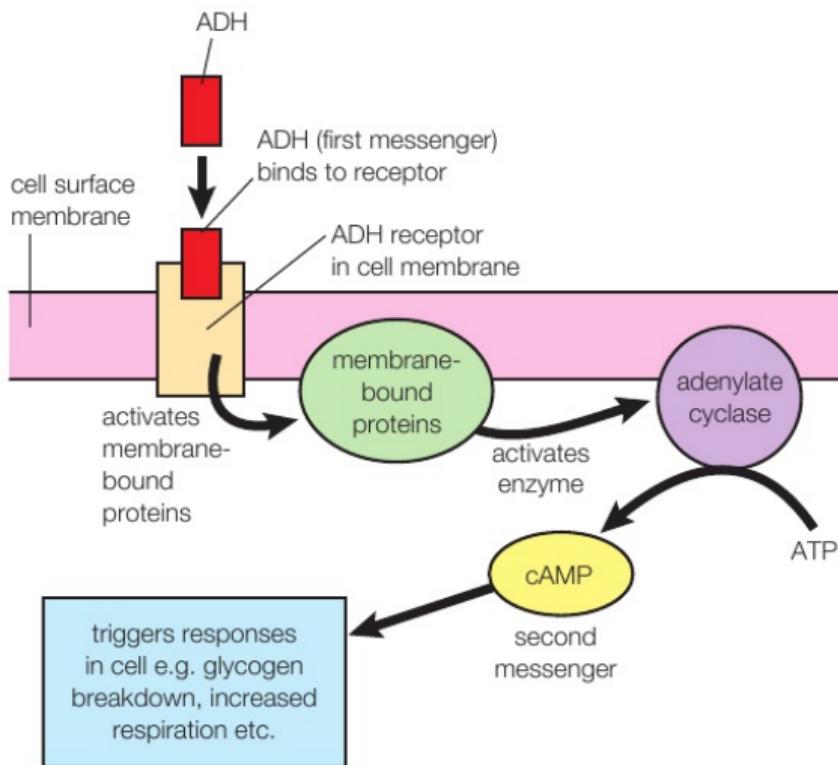
The binding of these hormones to cell surface membrane receptors initiates a process that activates messenger molecules in the cytoplasm of the cell known as second messengers

A common second messenger molecule is cyclic AMP (cAMP), formed from ATP

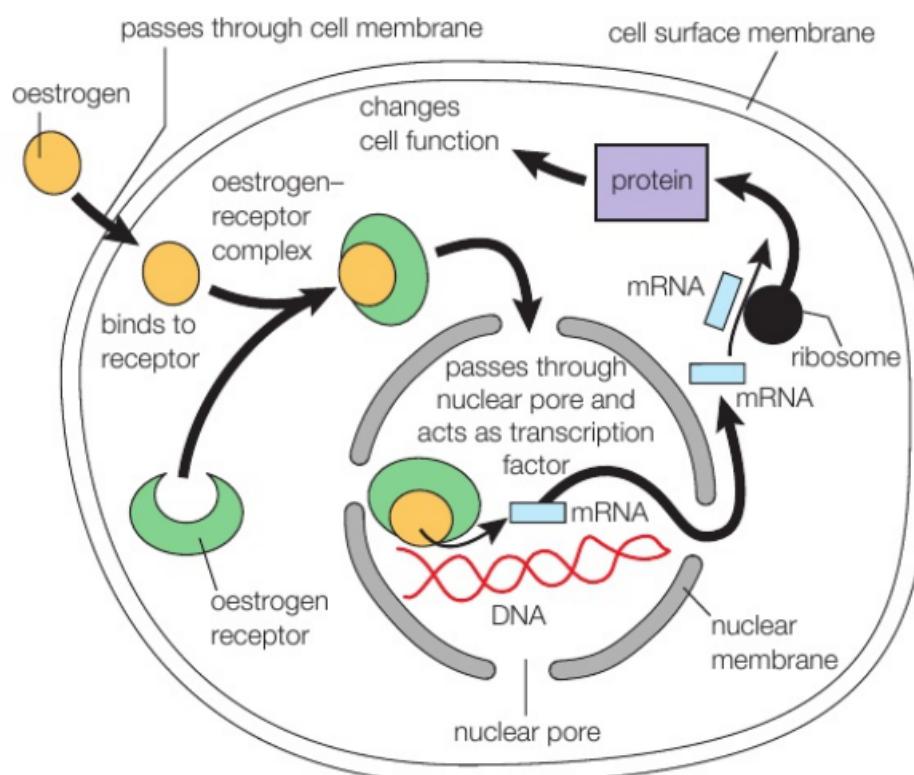
The activated second messenger molecules activate enzymes called protein kinases

Active protein kinase enzymes trigger a chain of reactions, known as a cascade, inside the cell

The cascade may result in changes to the activity of transcription factors which may then affect gene expression in the cell



Hormones such as ADH have their effect on cell metabolism via a second messenger system.



Steroid hormones, such as oestrogen, act directly as DNA transcription factors to have their effects.

Topic 8 – Coordination, Response, and Gene Technology

1. The structure and function of the sensory, relay, and motor neurons, including Schwann cells and myelin sheath.

The Human Nervous System:

Structure The human nervous system consists of:

1. Central nervous system (CNS) – the brain and spinal cord
2. Peripheral nervous system (PNS) – all of the nerves in the body

Information is sent through the nervous system as electrical impulses – these are electrical signals that pass along nerve cells known as **neurones**

A bundle of neurones is known as a **nerve**

The nerves spread out from the central nervous system to all other regions of the body and importantly, to all of the sense organs

The CNS, therefore, acts as a central coordinating centre for the impulses that come in from (or are sent out to) any part of the body

Adaptations of neurones:

- Neurones have a **cell body** (where the nucleus and main organelles are found) and cytoplasmic extensions from this body called axons and dendrites
- The axon is the main long fibre of the neurone
- Some human neurones have axons over a metre in length (but only 1 - 4 micrometres wide)
- This is far more efficient than having multiple neurones to convey information from the CNS to effectors – less time is wasted transferring electrical impulses from one cell to another
- The axon is insulated by a fatty myelin sheath with small uninsulated sections along its length (called nodes)
- This means that the electrical impulse does not travel down the whole axon, but jumps from one node to the next
- Many extensions called dendrites extend out from the cell body of the neurone and at the far end of the axon
- This means neurones can connect to many other neurones and receive impulses from them, forming a network for easy communication

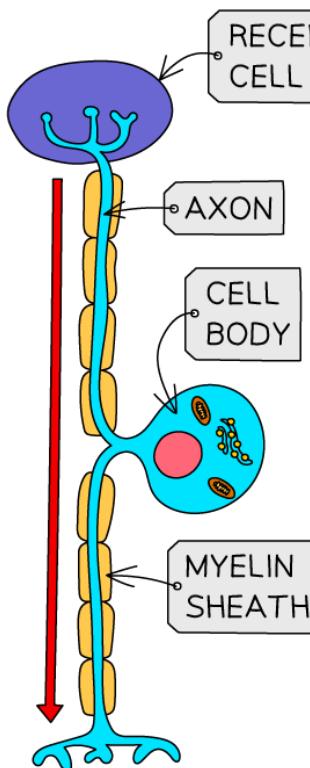
Identifying the three types of neurones

Sensory neurones are long and have a cell body branching off the middle of the axon

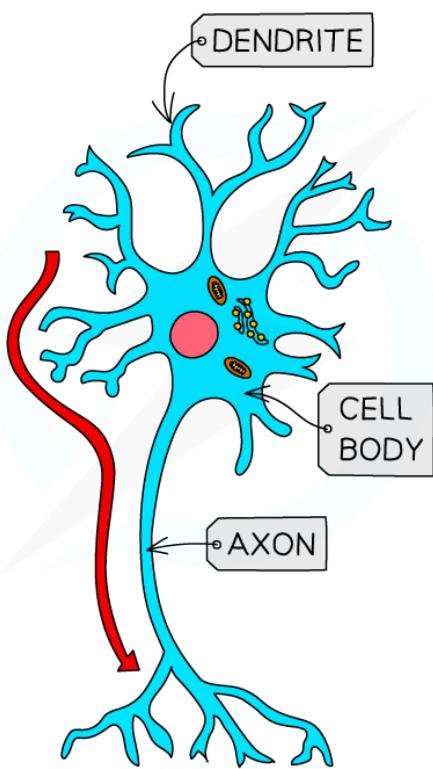
Relay neurones are short and have a small cell body at one end with many dendrites branching off it

Motor neurones are long and have a large cell body at one end with long dendrites branching off it

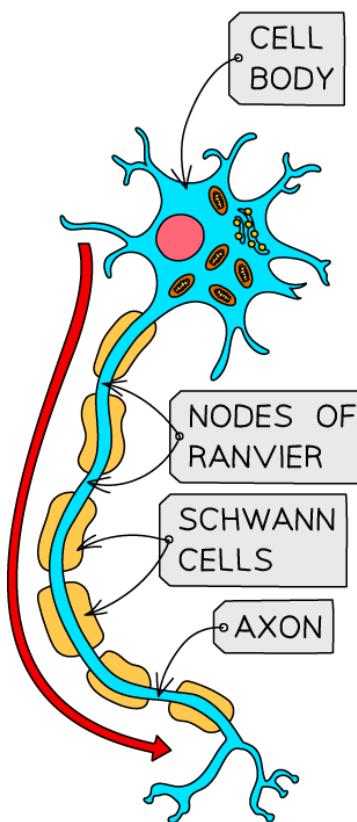
SENSORY NEURONE



RELAY NEURONE



MOTOR NEURONE



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2. How the nervous system of organisms can cause effectors to respond to a stimulus.

Nervous System: Response to a Stimulus

- The **nervous system** enables the body to detect changes in the environment and brings about appropriate responses to ensure its safety
- Receptor cells detect changes in the environment, or stimuli
- Nerve impulses travel from the receptor cells along sensory neurones to the central nervous system, or CNS
- The CNS acts as a coordinating centre for the impulses that arrive from the receptors, determining which part of the body needs to respond and sending out a new set of impulses along motor neurones
- Motor neurones send impulses to the effectors to bring about a response
- Effectors may be muscles or glands
- Nerve impulses pass through the nervous system along the following pathway
- stimulus rightwards arrow receptor rightwards arrow sensory neurone rightwards arrow CNS rightwards arrowmotor neurone rightwards arroweffector

Pupil Response:

- An example of a nerve pathway in action is the sequence of events that leads to a change in the diameter of the pupil in the eye
- Changing pupil diameter enables the eye to control the amount of light hitting the retina
- The diameter of the pupil in the eye is determined by two sets of muscles

The circular muscles contract to constrict the pupil

The radial muscles contract to dilate the pupil

- The two sets of muscles work **antagonistically**, meaning that when one set of muscles contracts the other relaxes, and vice versa

In bright light the following events occur:

- bright light rightwards arrow light receptors in eyes rightwards arrow sensory neuron rightwards arrow CNS rightwards arrow motor neuron rightwards arrow circular muscles in iris.
- Contraction of the circular muscles in the iris of the eye causes the pupil to constrict
- This limits the amount of light entering the eye and prevents damage to the retina

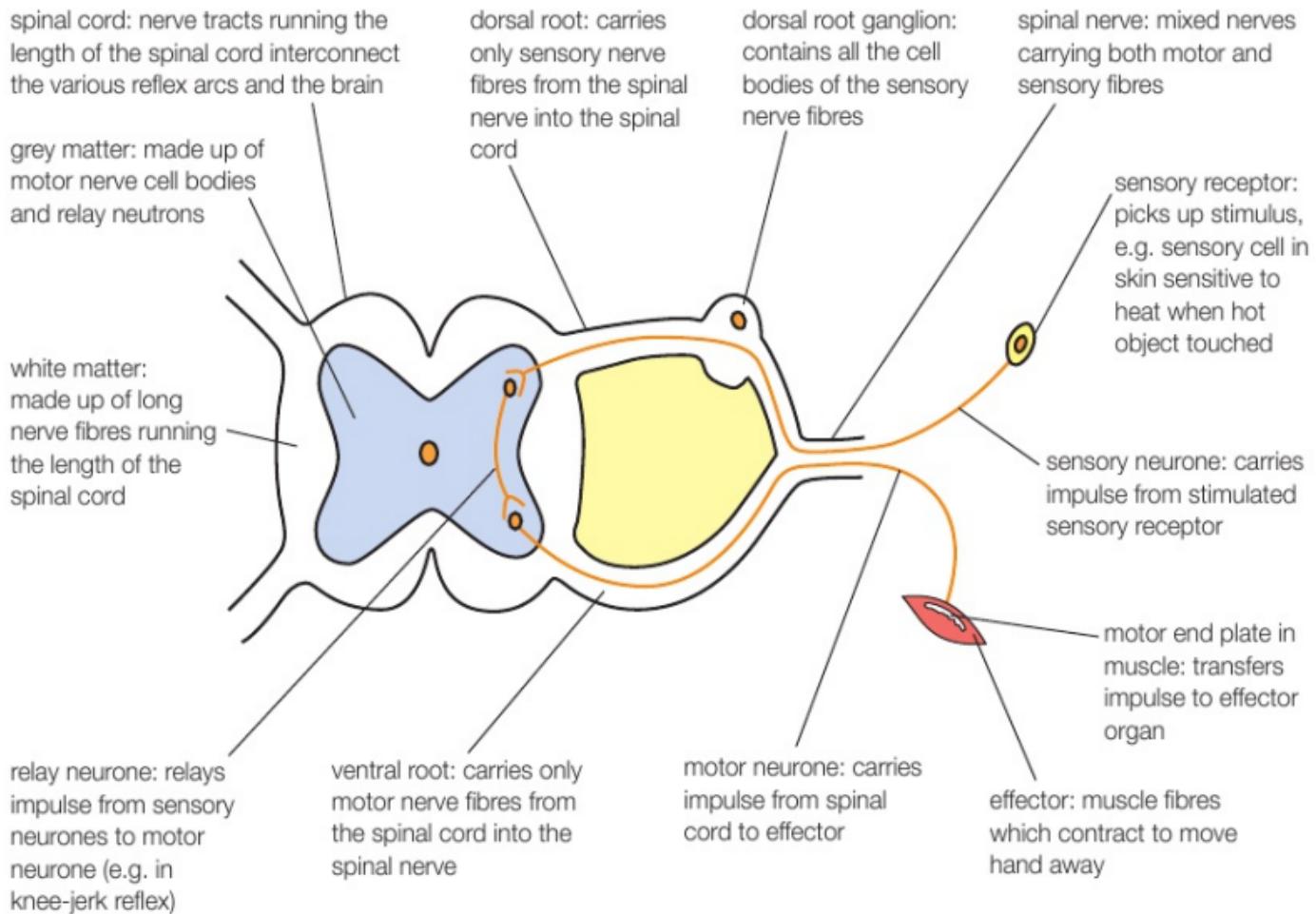
In low light the following events occur:

- low light rightwards arrow light receptors in eyes rightwards arrow sensory neuron rightwards arrow CNS rightwards arrow motor neuron rightwards arrow radial muscles in iris.
- Contraction of the radial muscles in the iris of the eye causes the pupil to dilate
- This maximizes the amount of light entering the eye, improving vision

STRUCTURE	FUNCTION
CORNEA	TRANSPARENT LENS THAT REFRACTS (BENDS) LIGHT AS IT ENTERS THE EYE
IRIS	CONTROLS HOW MUCH LIGHT ENTERS THE PUPIL
LENS	TRANSPARENT DISC THAT CAN CHANGE SHAPE TO FOCUS LIGHT ONTO THE RETINA
RETINA	CONTAINS LIGHT RECEPTOR CELLS – RODS (DETECT LIGHT INTENSITY) AND CONES (DETECT COLOUR)
OPTIC NERVE	SENSORY NEURONE THAT CARRIES IMPULSES BETWEEN THE EYE AND THE BRAIN
PUPIL	HOLE THAT ALLOWS LIGHT TO ENTER THE EYE

3. The structure and function of a spinal reflex arc, including grey matter and white matter of the spinal cord.

The Reflex Arc:



Spinal reflexes:

- A stimulus is received by a sensory receptor, for example, heat receptors in the skin or pain receptors.
- An impulse travels up the sensory neuron through the dorsal root ganglion into the grey matter of the spinal cord. It synapses with a relay neuron which then synapses with a motor neuron within the grey matter.
- The impulse passes along the motor neuron, leaving the spinal cord through the ventral root. It then travels to an effector organ, which is often a muscle.
- The motor end plate in the muscle transfers the stimulus to the muscle which then contracts, moving the body part away from danger

Cranial reflexes:

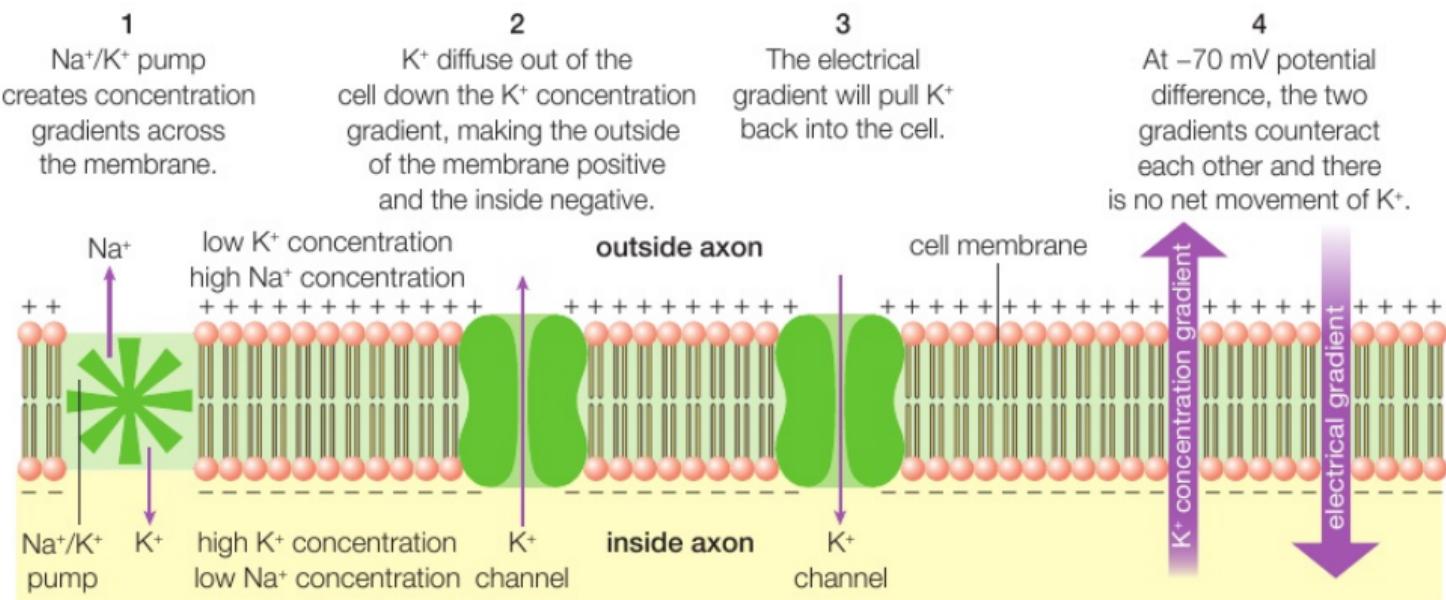
- Light may enter one or both eyes at the same time, and the effect on the pupils is the same.
- Light falling on the sensory cells of the retina causes impulses to travel along neurons in the optic nerve to the brain. The brighter the light, the bigger the frequency of action potentials.
- The impulse is detected in a control center in the midbrain.
- The impulse then travels along two neurons to further control centers.
- In the control centers the nerve impulses synapse with branches of the parasympathetic cranial nerve (the oculomotor) which transmits impulses to the iris.
- These impulses stimulate the effectors (the muscles of the iris).
- The circular muscles contract and the radial muscles relax so the pupil constricts.

4. Describe how a nerve impulse (action potential) is conducted along an axon, including changes in membrane permeability to sodium and potassium ions.

Transmission of Nerve Impulses:

- Neurones transmit electrical impulses which travel along the neuron cell surface membrane from one end of a neuron to the other
- Note that an impulse is not an electrical current that flows along neurons as if they were wires
- Instead, an impulse is a momentary reversal in the electrical potential difference across the neuron cell surface membrane
- The electrical potential difference across a membrane can also be described as the voltage across a membrane, the difference in charge across a membrane, or the membrane potential
- The different states of membrane potential across a neuron cell surface membrane during transmission of a nerve impulse include:
 - Resting potential
 - Action potential

Resting potential



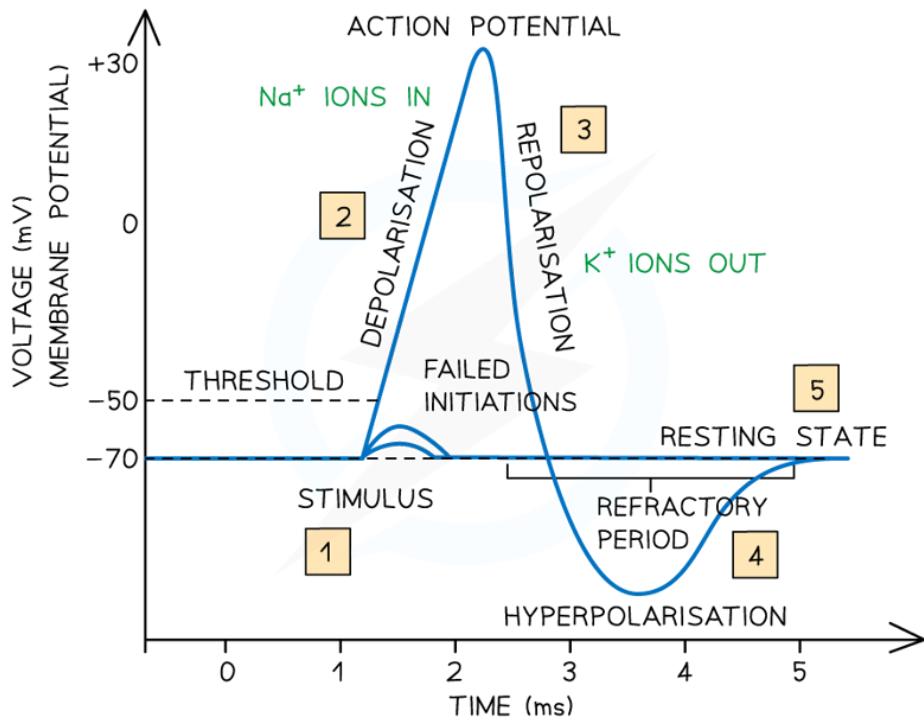
Action potential

When an impulse travels along an axon, there is a change in the permeability of the cell membrane to sodium ions. This change occurs in response to a stimulus (e.g. light, sound, touch, taste, or smell) in a sensory neuron; or the arrival of a **neurotransmitter** in a motor neuron. In the experimental situation, the stimulus is usually a very small, precisely controlled electrical impulse.

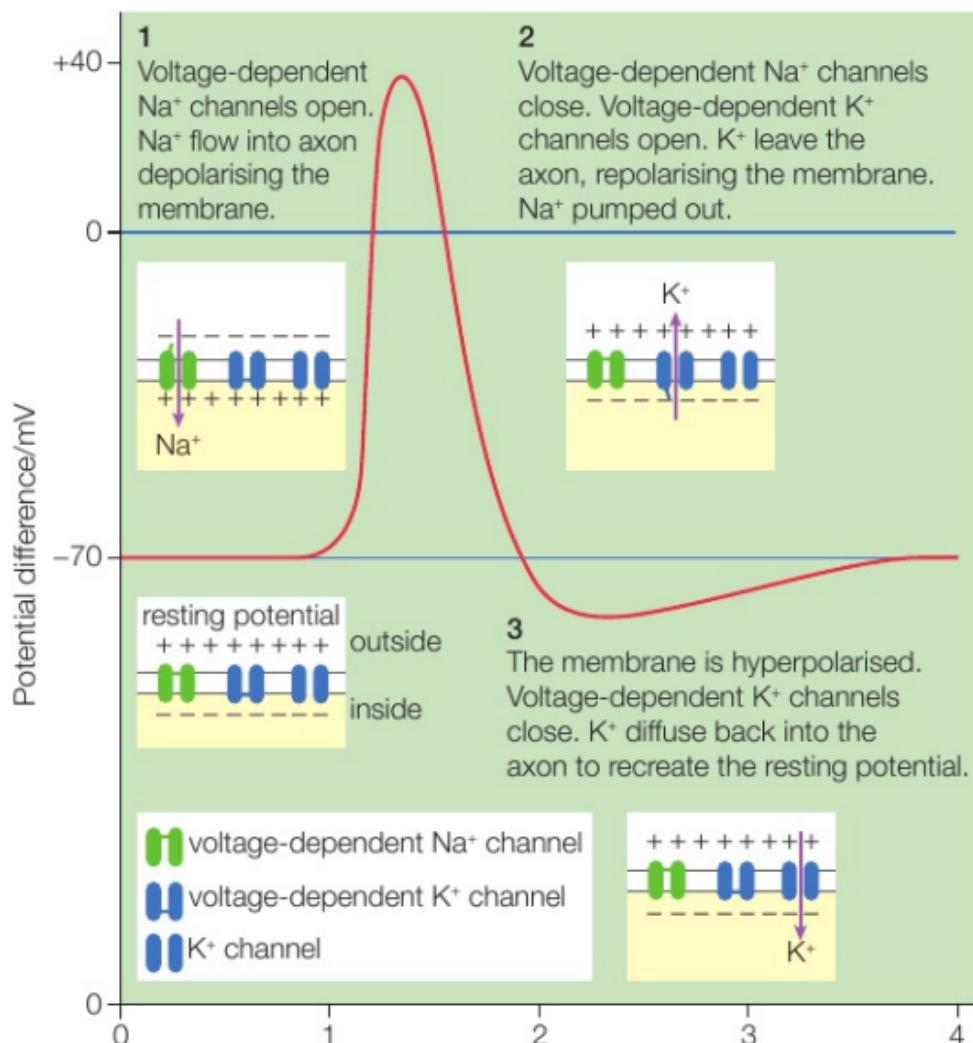
When a neuron is stimulated,

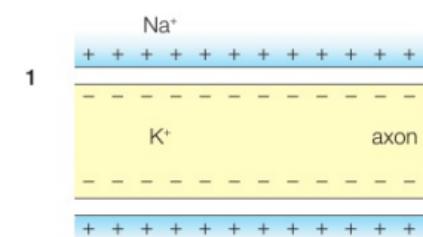
- the axon membrane shows a sudden and dramatic increase in its permeability to sodium ions.
- Specific sodium ion channels or sodium gates open up, allowing sodium ions to diffuse rapidly down their concentration and electrochemical gradients.
- As a result, the potential difference across the membrane is briefly reversed, with the cell becoming positive on the inside with respect to the outside.
- This depolarisation lasts about 1 millisecond. The potential difference across the membrane at this point is about +40 mV. This is known as the action potential.
- Remember that these events happen in any nerve fiber, not just axons.

At the end of this very short depolarisation, the sodium ion channels close again and the excess sodium ions are rapidly pumped out by the active sodium pump. Also, the permeability of the membrane to potassium ions is temporarily increased. This happens because voltage-dependent potassium ion channels open as a result of the repolarisation. Consequently, potassium ions diffuse out of the axon down both a concentration gradient and an electrochemical gradient, attracted by the negative charge on the outside of the membrane. The inside of the axon becomes negative relative to the outside once again. It takes a few milliseconds before the resting potential is restored and the axon is ready to carry another impulse

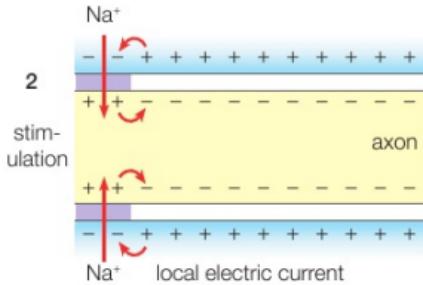


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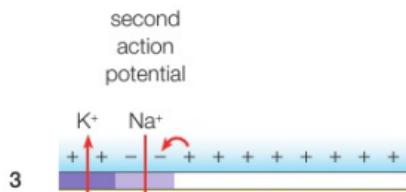
1
first
action
potential



2
stim-
ulation

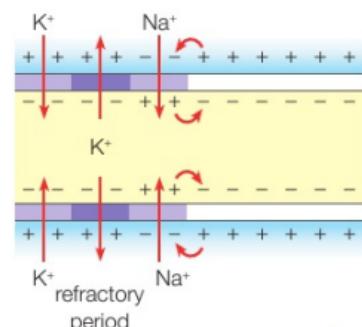
At resting potential there is positive charge on the outside of the membrane and negative charge on the inside, with high sodium ion concentration outside and high potassium ion concentration inside.

When stimulated, voltage-dependent sodium ion channels open, and sodium ions flow into the axon, depolarising the membrane. Localised electric currents are generated in the membrane.



3

third
action
potential



4

refractory
period

The potential difference in the membrane adjacent to the first action potential changes. A second action potential is initiated. At the site of the first action potential the voltage-dependent sodium ion channels close and voltage-dependent potassium ion channels open. Potassium ions leave the axon, repolarising the membrane. The membrane becomes hyperpolarised.

A third action potential is initiated by the second. In this way local electric currents cause the nerve impulse to move along the axon. At the site of the first action potential, potassium ions diffuse back into the axon, restoring the resting potential.

progress of the impulse →

1

NODE AT REFRACTORY PERIOD:

- MEMBRANE BECOMING REPOLARISED
- Na^+ CHANNEL PROTEINS CLOSED
- K^+ CHANNEL PROTEINS OPEN

3

NODE BECOMING DEPOLARISED:

- MEMBRANE POTENTIAL MOVING TOWARDS THRESHOLD LEVEL
- Na^+ CHANNELS STARTING TO OPEN BUT MANY STILL CLOSED
- K^+ CHANNEL PROTEINS CLOSED

2

NODE AT ACTION POTENTIAL:

- MEMBRANE FULLY DEPOLARISED ($+30\text{mV}$)
- ALL Na^+ CHANNEL PROTEINS OPEN
- K^+ CHANNEL PROTEINS CLOSED

4

NODE AT RESTING POTENTIAL:

- MEMBRANE POTENTIAL AROUND -70mV
- Na^+ CHANNEL PROTEINS CLOSED
- K^+ CHANNEL PROTEINS CLOSED

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The all-or-nothing principle

Action potentials are either generated or not generated depending on whether the threshold potential is reached; there is no such thing as a small or large action potential. If a stimulus is weak only a few sodium ion channels will open and the membrane won't be sufficiently depolarised to reach the threshold potential; an action potential will not be generated.

If a stimulus is strong enough to raise the membrane potential above the threshold potential then an action potential will be generated.

This is the **all-or-nothing principle**.

An impulse is only transmitted if the initial stimulus is sufficient to increase the membrane potential above a threshold potential.

Stimulus size can be detected by the brain because as the intensity of a stimulus increases, the frequency of action potentials transmitted along the neurone increases. This means that a small stimulus may only lead to one action potential, while a large stimulus may lead to several action potentials in a row.

5. The role of myelination in saltatory conduction.

Factors that Affect the Speed of Conduction:

The speed of conduction of an impulse refers to how quickly the impulse is transmitted along a neurone.

It is determined by multiple factors:

- The presence or absence of myelin
(ie. whether or not the axon is insulated by a myelin sheath)
- The diameter of the axon
- Temperature
- Myelination

In unmyelinated neurons, the speed of conduction is very slow

- This is because depolarisation must occur along the whole membrane of the axon
- By insulating the axon membrane, the presence of myelin increases the speed at which action potentials can travel along the neurone:
- The myelin sheath is formed from Schwann cells
- In sections of the axon that are surrounded by a myelin sheath, depolarisation (and the action potentials that this would lead to) cannot occur, as the myelin sheath stops the diffusion of sodium ions and potassium ions
- Action potentials can only occur at the nodes of Ranvier (small uninsulated sections of the axon)
- The local circuits of current that trigger depolarisation in the next section of the axon membrane exist between the nodes of Ranvier
- The presence of Schwann cells means the action potentials 'jump' from one node to the next, this is known as **saltatory conduction**
- Saltatory conduction allows the impulse to travel much faster than in an unmyelinated axon of the same diameter

Diameter

An impulse will be conducted at a higher speed along neurones with thicker axons compared to those with thinner axons

Thicker axons have an axon membrane with a greater surface area over which the diffusion of ions can occur

Temperature

- Some animals, such as mammals, maintain very stable body temperatures.
- Temperature does not usually affect the speed of nerve impulses in these animals
- Colder conditions can slow down the conduction of nerve impulses
- The colder temperatures mean there is less kinetic energy available for the facilitated diffusion of potassium and sodium ions during an action potential

6. Describe the structure and function of synapses in nerve impulse transmission, including the role of neurotransmitters and acetylcholi

The Role of Neurotransmitters:

- Neurones do not actually come into direct contact with each other
- Where the dendrites of two neurons meet (to make a connection between the neurones) a junction known as a synapse is formed
- At a synapse, there is a very small gap between neurones
- This very small gap is known as the synaptic cleft or synaptic gap
- Electrical impulses cannot travel directly from one neurone to the next due to the synaptic cleft (electricity cannot 'jump' the gap)
- Instead, the electrical signal is briefly converted to a chemical signal that can cross the synaptic cleft
- The chemical signalling molecules used to transfer the signal between neurones at a synapse are known as neurotransmitters
- Once these neurotransmitters cross the synaptic cleft and meet the neurone on the opposite side, the signal is converted back into an electrical impulse, which can then pass along the neurone

'

How an impulse is passed across a synapse:

- The electrical impulse travels along the first axon (of the first neurone, known as the presynaptic neurone)
- This triggers the end of the presynaptic neurone to release chemical messengers called neurotransmitters from vesicles
- These vesicles fuse with the presynaptic membrane, releasing their contents into the synaptic cleft
- The neurotransmitters diffuse across the synaptic cleft and bind with receptor molecules on the membrane of the second neurone (known as the postsynaptic membrane)
- This stimulates the second neurone to generate an electrical impulse (which then travels down the second axon)
- The neurotransmitters are then destroyed to prevent continued stimulation of the second neurone (otherwise the neurotransmitters would cause repeated impulses to be sent)
- Synapses ensure that impulses only travel in one direction, avoiding the confusion that would be caused within the nervous system if impulses were able to travel in both directions

Exam Tip

- For maximum marks, you will need to understand the structure and functioning of a synapse and explain what happens at each step. Exam questions about neurotransmitters are a good opportunity for examiners to introduce unfamiliar examples and contexts, so remember the following:
 -
 - Neurotransmitters move by diffusion – remember, this requires a concentration gradient and is a passive process
 - Receptors that are complementary in shape to neurotransmitters are located on the postsynaptic neurone
 - Drugs (such as heroin, ecstasy, and cocaine) can bind to neurotransmitter receptors, triggering impulses in different regions of the brain

7. Explain how the pupil dilates and contracts

The Pupil Reflex:

This is a reflex action carried out to protect the retina from damage in bright light and protect us from not seeing objects in dim light

In dim light the pupil dilates (widens) in order to allow as much light into the eye as possible

In bright light the pupil constricts (narrows) in order to prevent too much light entering the eye and damaging the retina

8. Describe how the effects of drugs can be caused by their influence on nerve impulse transmissions, such as nicotine, lidocaine, and cobra venom alpha toxin, the use of L-DOPA in the treatment of Parkinson's disease, and the action of MDMA (ecstasy).

Action of Drugs on Synapses

- The chemicals in drugs can have a major impact on the functioning of the brain and nervous system
- Some prescription drugs can have a beneficial effect on those suffering from neurological disorders while recreational drugs can have a damaging or even fatal effect
- Many drugs impact the nervous system by altering the events that occur at a synapse

Drugs can increase transmission of impulses at a synapse by:

- Causing more neurotransmitter to be produced in the synaptic knob
- Causing more neurotransmitter to be released at the presynaptic membrane
- Imitating the effect of a neurotransmitter by binding to and activating receptors on the postsynaptic membrane
- Preventing the breakdown of neurotransmitters by enzymes
- Preventing the reuptake of neurotransmitters by the presynaptic cell

Drugs can decrease transmission of impulses at a synapse by:

- Preventing production of neurotransmitter in the presynaptic knob
- Preventing the release of neurotransmitter at the presynaptic membrane
- Enabling neurotransmitter to gradually leak out of the presynaptic knob so there is little left when an action potential arrives
- The neurotransmitter that leaks out of the cell is destroyed by enzymes
- Binding to receptors on the postsynaptic membrane and so preventing neurotransmitters from binding

MDMA:

- MDMA is a recreational drug that is also known as ecstasy
- Its use and sale are criminal offences in most parts of the world
- MDMA affects multiple neurotransmitters, most notably serotonin
- MDMA inhibits the reuptake of serotonin into the presynaptic neurone by binding to the specific proteins that enable serotonin reuptake, located on the presynaptic membrane; this increases the amount of serotonin present in the brain
- Serotonin is usually reabsorbed into the presynaptic neurone to be recycled for future action potentials
- MDMA also triggers the release of further serotonin from presynaptic neurones, further adding to the increase
- Serotonin can affect people in many ways including their mood, anxiety and sleep

- When an individual takes MDMA they may feel extreme euphoria and enhanced touch and bodily sensations

L-dopa:

L-dopa is a drug used to treat the symptoms of Parkinson's disease

It has a very similar structure to dopamine; a neurotransmitter present at lower levels than usual in the brains of those who suffer from Parkinson's disease

L-dopa is transported from the blood into the brain, where it is converted into dopamine in a reaction catalysed by the enzyme dopa-decarboxylase

The effect is to increase levels of dopamine in the brain

Note, dopamine cannot be given directly to those who have Parkinson's disease as it cannot cross the barrier between the blood and the brain

Increased levels of dopamine mean that more nerve impulses are transmitted in parts of the brain that control movement, giving sufferers better control over their movement and lessening the symptoms of Parkinson's disease

9. Describe how the nervous systems of organisms can detect stimuli (to rods in the retina of mammals, the roles of rhodopsin, opsin, retinal, sodium ions, cation channels, and hyperpolarisation of rod cells in forming action potentials in the optic neurons).

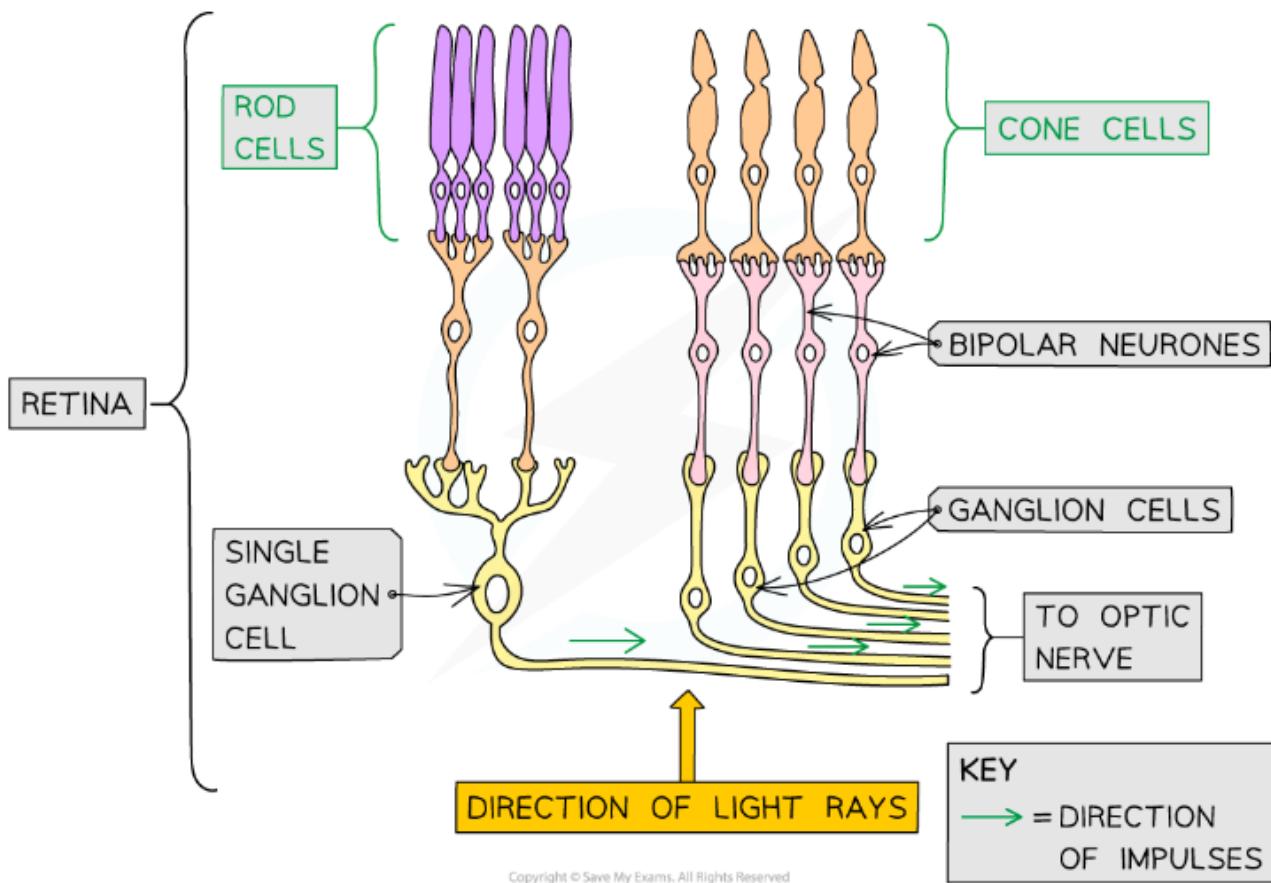
Detection of Stimuli:

- The eye is a sense organ containing receptors sensitive to light intensity and wavelength
 - Receptors are specialized cells that can generate an electrical impulse in a sensory neuron when stimulated by a particular stimulus e.g. light receptors are stimulated when light falls on them
- Light enters the eye through the pupil and is focused onto a region of the retina called the fovea
 - The amount of light that enters the eye is controlled by the muscles of the iris
 - Light is focused using the lens, the shape of which is controlled by ciliary muscles attached to the lens by suspensory ligaments
 - The muscles change the shape of the lens to allow it to focus light reflected from objects at different distances from the eye
 - The fovea contains many light receptors, or photoreceptors
- The retina contains two types of photoreceptors:**
 - Rod cells**
 - Primarily located around the outer retina
 - Sensitive to light intensity so can detect the presence and brightness of light
 - Images generated using information from only rod cells is black and white
 - Cone cells**
 - Mostly found grouped together in the fovea
 - Sensitive to different wavelengths of visible light so detect colour

- Cone cells can be red-sensitive, green-sensitive, or blue-sensitive
- The number of red-, green-, and blue-sensitive cone cells stimulated will determine the colours seen
- Images generated using information from cone cells will be in colour
 -
- Action potentials generated in the photoreceptor are transmitted to the brain via the optic nerve
 - The optic nerve leaves the back of the eye from a region known as the blind spot

Photoreceptors generate nerve impulses

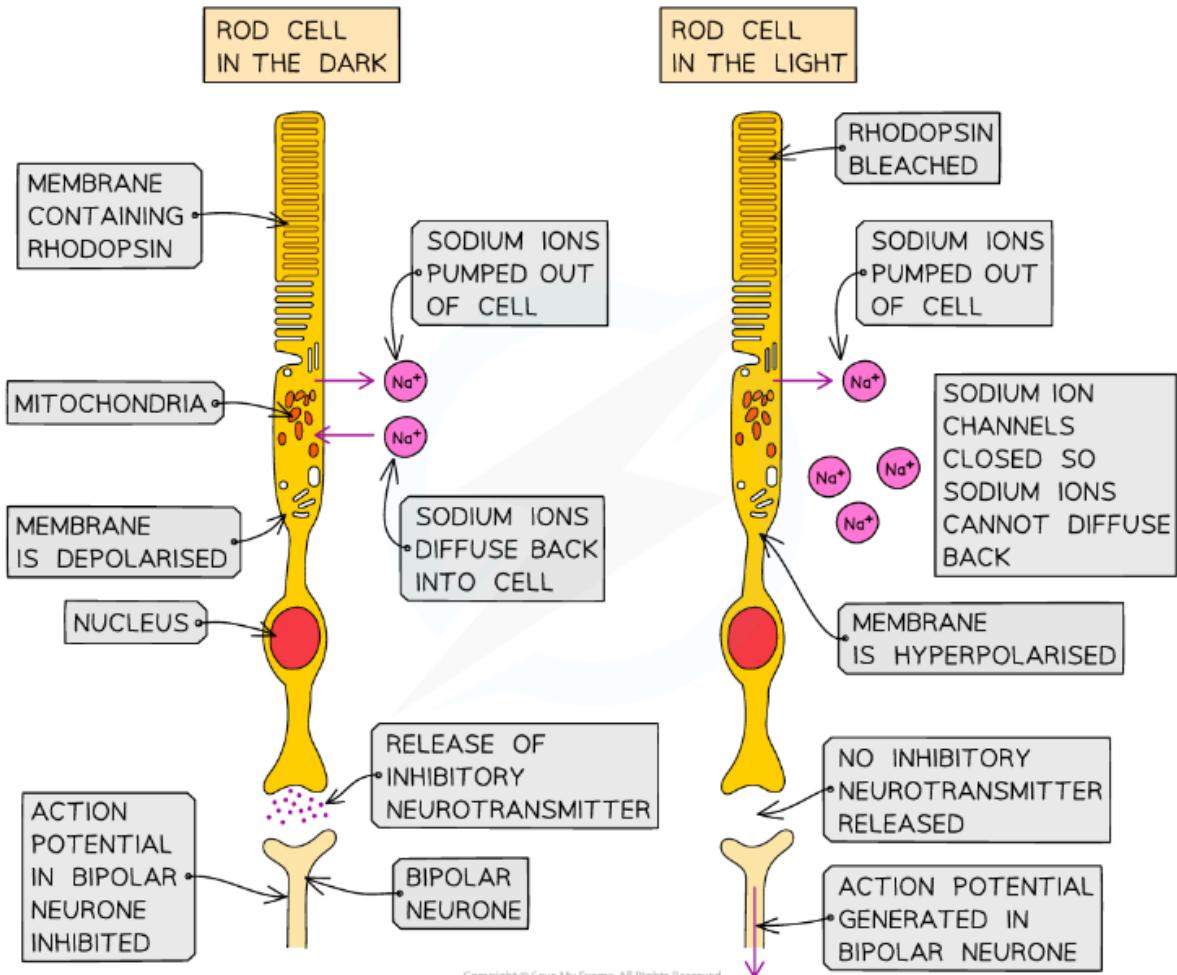
- Photoreceptors in the eye generate action potentials when stimulated by bright enough light (rods), or by light of a particular wavelength (cones)
- Light-sensitive pigments inside the photoreceptors are bleached when light falls on them e.g.
 - Rod cells contain a light-sensitive pigment called rhodopsin
 - When light hits rhodopsin it breaks apart into constituent parts retinal and opsin
 - The breaking apart of rhodopsin is known as bleaching
- The bleaching of light-sensitive pigments causes a chemical change in the photoreceptor that results in the generation of a nerve impulse
- Nerve impulses travel along a bipolar neurone to the optic nerve, which carries information to the brain
 - The blind spot contains no photoreceptors



The action of rod cells:

- The way in which rod cells pass information to the optic nerve is a bit back-to-front in comparison to the action of other nerve cells; rather than initiating an action potential when they are depolarised, rod cells initiate action potentials in neighbouring bipolar neurones when they are hyperpolarised
- In the dark the following occurs inside rod cells
 - Sodium ions are actively pumped out of rod cells, generating a concentration gradient
 - Sodium ions (Na^+) are positively charged ions, also known as cations
 - Sodium ions diffuse back down this concentration gradient into the rod cell via sodium channels
 - Sodium channels are also known as cation channels because they allow the movement of positively charged ions
 - At this stage there is little difference in charge between the outside and inside of the rod cell, and the cell is said to be depolarised
 - In reality the inside of the rod cell is slightly negative in comparison to the outside

- The depolarised rod cell releases neurotransmitters which diffuse across a synapse to a bipolar neurone
- Rather than initiating an action potential in the bipolar neurone this neurotransmitter inhibits the generation of an action potential, preventing a nerve impulse from being sent to the optic nerve
 - This neurotransmitter is said to be an inhibitory neurotransmitter
- **In the light the following occurs inside rod cells**
 - Light bleaches rhodopsin, causing it to break apart into retinal and opsin
 - The bleaching of rhodopsin causes the sodium ion channels in the cell surface membrane of the rod cell to close, preventing sodium ions from diffusing back into the rod cell
 - The active transport of sodium ions out of the cell is still taking place, so sodium ions are removed from the cell but not able to return
 - The lack of positively charged ions entering the rod cell causes its interior to become more negative until it reaches a hyperpolarised state
 - A membrane that is hyperpolarised has a more negative potential difference across it than the resting -70 mV
 - The hyperpolarised rod cell stops releasing an inhibitory neurotransmitter, so the generation of an action potential in the neighbouring bipolar neurone is no longer inhibited
 - An action potential is generated in the bipolar neurone attached to the rod cell and an impulse is sent to the optic nerve



10. What is meant by the term habituation?

Habituation

- Animals must respond to changes in their external and internal environments in order to survive
 - Changes in the environment, or stimuli (singular stimulus) are detected by specialised receptor cells
 - Receptor cells send signals via either the nervous system or the hormonal system to the body's co-ordination centres in the brain or spinal cord
 - Signals are then sent on to the parts of the body which respond, known as the effectors
- The process of detecting and responding to stimuli requires energy, so it is important that animals don't waste energy responding to non-threatening stimuli
 - Animals need to conserve energy for essential processes that increase their survival chances
- If a stimulus is repeated many times with no negative outcome then an animal will learn not to respond to it; this process is known as habituation
 - An animal that doesn't respond to a stimulus is said to be habituated to that stimulus
- Examples of habituation include
 - Humans no longer noticing a new smell or sound after a period of exposure
 - Wild animals losing their fear of humans after regular non-harmful contact
 - Animals learning not to be alarmed by the presence of non-predatory species
- If a stimulus to which an animal has become habituated changes, then the nervous system will respond to it again
 - E.g. a constant low-level sound that suddenly becomes louder

The process of habituation:

- Animals become habituated due to changes in the transmission of nerve impulses from one neurone to the next
 - Nerve impulses are transmitted across synapses by the diffusion of chemical neurotransmitters
 - Neurotransmitters are released at the presynaptic membrane in response to an influx of calcium ions
- When habituation has taken place fewer calcium ions move into the presynaptic neurone on arrival of a nerve impulse
- As a result, less neurotransmitter is released and an action potential is less likely to be generated in the postsynaptic neurone
 - Fewer molecules of neurotransmitter bind to receptors on the postsynaptic membrane
 - Fewer sodium ion channels open
 - Fewer sodium ions move into the axon and the charge inside the axon remains negative
 - Threshold potential is not reached

- The nerve impulse, therefore, does not reach the effector organ and the animal does not respond to the stimulus

11. Describe how phytochrome, auxin (IAA), and gibberellins bring about responses in plants, including their effects on transcription.

Effects of Plant Hormones:

- Just like animals, the survival of plants is dependent on their ability to respond to changes in their environment; this maximises their survival chances e.g.
 - Growing towards light maximises the rate of photosynthesis and therefore glucose production
 - Producing harmful or foul-tasting chemicals in response to being eaten by a herbivore reduces the likelihood of being eaten
 - Producing flowers at the right time of year increases the chances of reproducing successfully
- Plants can respond to several types of stimuli e.g.
 - Light
 - Gravity
 - Physical objects
 - Herbivory
 - Water
 - Physical touch
- Unlike many animals, plants do not possess a nervous system; the responses of plants rely on chemical substances that are released or altered in response to a stimulus

Phytochrome

- Flowering in plants is controlled by the stimulus of night length
 - Nights are shorter during the spring and summer and longer in the autumn and winter
 - Some plants flower when nights are short and some flower when nights are long
- When the nights reach a certain length, genes that control flowering may be switched on or off, leading to the activation or inhibition of flowering
 - Genes that are switched on are expressed, leading to production of the polypeptides for which they code, while genes that are switched off are not expressed, so the polypeptides for which they code are not produced
- The length of night can be detected by a plant because it determines the quantities of different forms of a pigment called phytochrome in the leaf

The phytochrome pigment exists in two forms

- PR is the inactive form of phytochrome, it absorbs light from the red part of the spectrum (wavelength 660 nm)
- PFR is the active form of phytochrome, it absorbs light from the far red part of the spectrum (wavelength 730 nm)

Absorption of different wavelengths of light causes a reversible conversion between the PR and PFR forms of phytochrome

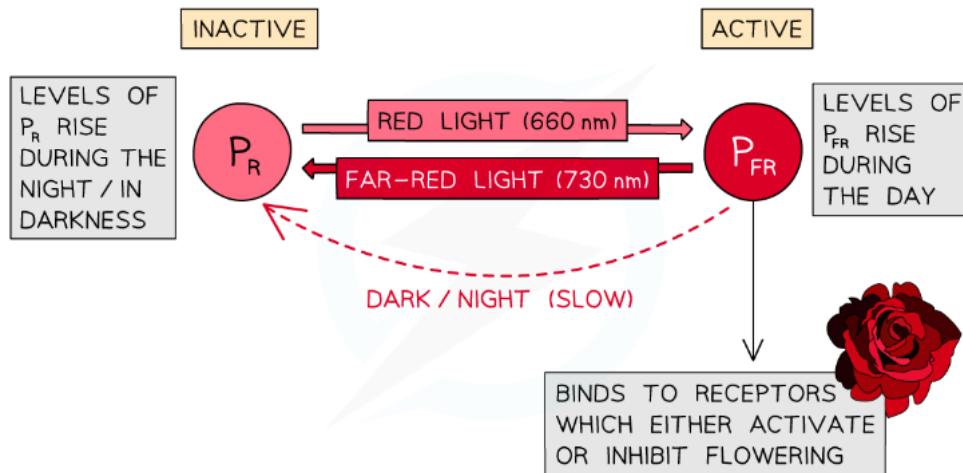
- When PR absorbs red light (660 nm) it is converted into PFR
- When PFR absorbs far red light (730 nm) it is converted back into PR
- In the absence of red light, the unstable PFR gradually converts back into PR

During the day levels of PFR rise

- Sunlight contains more wavelengths at 660 nm than 730 so the conversion from PR to PFR occurs more rapidly in the daytime than the conversion from PFR to PR

During the night levels of PR rise

- Red light wavelengths are not available in the darkness and PFR converts slowly back to PR



- E.g. long day plants

- Long day plants flower when the nights are short e.g. in summer
 - When nights are short, the day length is longer, hence the term 'long day plants'
- In long day plants high levels of the active form of phytochrome activate flowering
- Flowering occurs due to the following process
 - Days are long so PR is converted to PFR at a greater rate than PFR is converted to PR
 - The active form of phytochrome, PFR, is present at high levels
 - High levels of PFR activate flowering
 - PFR activates expression of genes that stimulate flowering
 - It is thought that PFR acts as a transcription factor
 - The active gene is transcribed and translated
 - The resulting protein causes flowers to be produced rather than stems and leaves

Growth factors

- Plants can respond to stimuli in various ways, including by altering their growth
 - E.g. a seedling will bend and grow towards the light because there is more growth on the shaded side than on the illuminated side
- This type of directional growth response is referred to as a tropism
 - Phototropism is a growth response to light
 - Geotropism is a growth response to gravity
 - The response to gravity is also known as gravitropism
- Tropisms can be positive or negative
 - Positive tropisms involve growth towards a stimulus
 - E.g. positive phototropism is a growth response towards light
 - Negative tropisms involve growth away from a stimulus
 - E.g. negative geotropism is a growth response away from gravity i.e. upwards
- The growth responses of plants rely on chemical substances that are released in response to a stimulus
- These chemical growth factors act in a similar way to the hormones that are found in animals
 - Plant growth factors are sometimes referred to as plant hormones as they are chemical messengers
- Growth factors are produced in the growing parts of a plant before moving from the growing regions to other tissues where they regulate cell growth in response to a directional stimulus
 - E.g. auxin is a growth factor that stimulates cell elongation in plant shoots and inhibits growth in cells in plant roots
- Other examples of plant hormones along with some of their regulatory roles include
 - **Gibberellins**
 - Stem elongation
 - Flowering
 - Seed germination
 - Cytokinins
 - Cell growth and division
 - Abscisic acid (ABA)
 - Leaf loss
 - Seed dormancy
 - Ethene
 - Fruit ripening
 - Flowering

Indoleacetic acid

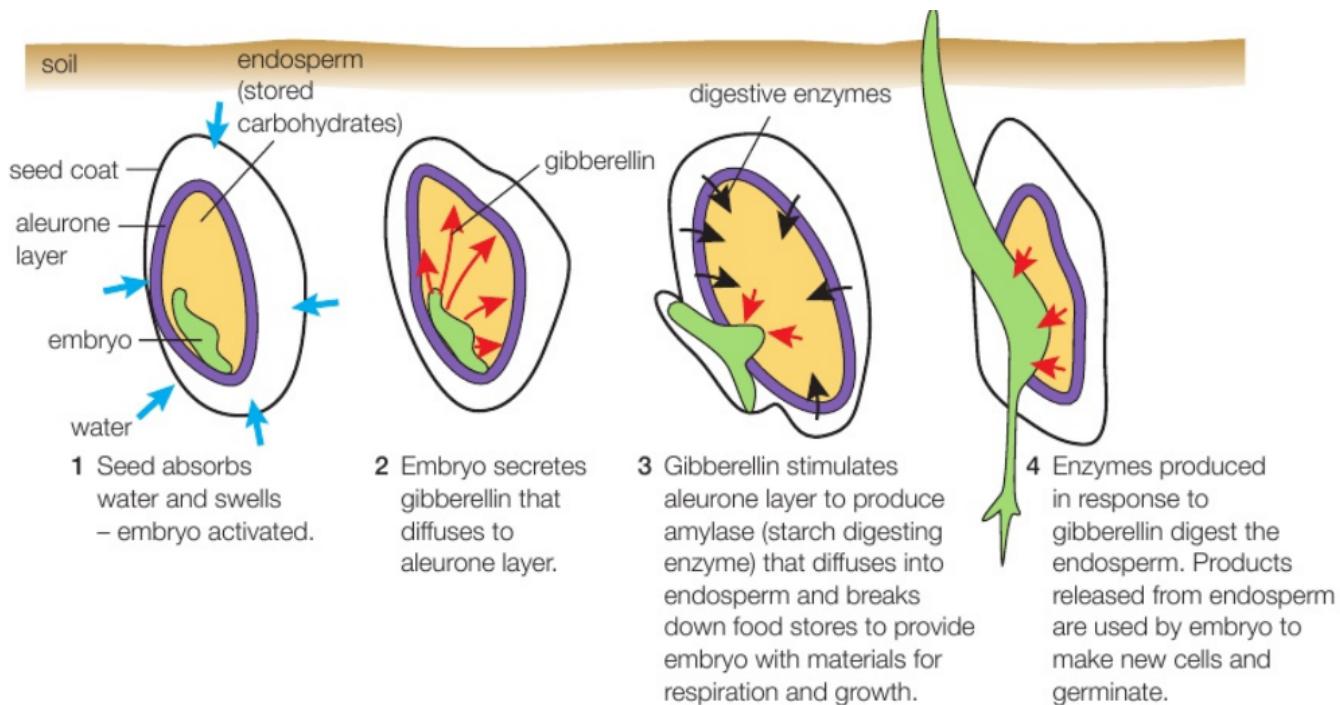
- Indoleacetic acid, or IAA, is a type of auxin
 - Auxins are a group of plant growth factors that influence many aspects of plant growth, e.g.
 - Apical dominance; the suppression of the growth of side shoots by auxins in the growing shoot tip
 - Promoting the growth of roots at low concentrations and inhibiting the growth of roots at high concentrations
 - Phototropism in shoots
- It is thought that IAA brings about plant responses such as phototropism by altering the transcription of genes inside plant cells
 - Altering the expression of genes that code for proteins involved with cell growth can affect the growth of a plant
- IAA is produced by cells in the growing parts of a plant before it is redistributed to other plant tissues
 - IAA can be transported from cell to cell by diffusion and active transport
 - Transport of IAA over longer distances occurs in the phloem
- The redistribution of IAA is affected by environmental stimuli such as light and gravity, leading to an uneven distribution of IAA in different parts of the plant
 - This brings about uneven plant growth

IAA in plant shoots:

- Light affects the growth of plant shoots in a response known as phototropism
- The concentration of IAA determines the rate of cell elongation within the stem
 - A higher concentration of IAA causes an increase in the rate of cell elongation by increasing the stretching ability of cell walls
 - If the concentration of IAA is not uniform across the stem then uneven cell growth can occur
- When light shines on a stem from one side, IAA is transported from the illuminated side of a shoot to the shaded side
- An IAA gradient is established, with more on the shaded side and less on the illuminated side
- The higher concentration of auxin on the shaded side of the shoot causes a faster rate of cell elongation, and the shoot bends towards the source of light

Gibberellins

- Gibberellins are a type of plant growth regulator involved in controlling seed germination, stem elongation, flowering, and fruit development



12. How coordination in animals is brought about through nervous and hormonal control.

Nervous & Hormonal Coordination

- Both plants and animals must respond to changes in their external and internal environments in order to survive
 - They need to
 - Find favourable external conditions e.g. avoiding locations that are too hot or cold
 - Find food
 - Avoid harm e.g. from predators or high blood glucose
- While plants use chemical signals to co-ordinate responses to stimuli, animals bring about coordination by both nervous and hormonal control
- Changes in the environment, or stimuli (singular stimulus) are detected by specialised receptor cells
 - Receptor cells are located in the sense organs e.g. the nose and eyes
 - Receptor cells can also be found inside the body e.g. pressure receptors in the blood vessels
- Receptor cells send signals via either the nervous system or the hormonal system to the body's co-ordination centres in the brain or spinal cord
- Signals are then sent on to the parts of the body which respond, known as the effectors
 - Effectors can be either muscles or glands e.g.
 - An arm muscle would respond to a hot surface by contracting to move the hand away
 - The pancreas responds to high blood sugar by secreting insulin

The nervous system

- The human nervous system consists of
 - **Central nervous system (CNS) – the brain and spinal cord**
 - **Peripheral nervous system (PNS) – all of the nerves in the body**
- The nervous system allows detection of stimuli in our surroundings and the coordination of the body's responses to the stimuli
- Information is sent through the nervous system in the form of electrical impulses that pass along nerve cells known as neurones
 - A bundle of neurones is known as a nerve
 - There are different types of neurones including sensory neurones, relay neurones, and motor neurones
- The nerves connect the receptors in the sense organs with the CNS, and connect the CNS with effectors
 - The CNS acts as a central coordinating centre for the impulses that come in from, and are sent out to, any part of the body
- Nerve impulses pass through the nervous system along the following pathway

stimulus - receptor - sensory neurone - CNS - motor neurone - effector

- An example of this nerve pathway in action might be
- hot surface - pain receptor in skin of hand - sensory neurone - CNS - motor neurone - arm muscle**
- The muscle in the arm responds by contracting to move the hand away from the hot surface

The hormonal system:

- Hormones are chemical substances produced by endocrine glands and carried by the blood
 - Endocrine glands are ductless and secrete hormones directly into the blood
 - Hormones are sometimes known as chemical messengers
- Hormones transmit information from one part of an organism to another and bring about change by altering the activity of one or more specific target organs
 - Hormones can leave the blood and bind to specific receptors on the cell surface membranes of target organs
- Hormones are slower in action than nerve impulses and are therefore used to control functions that do not need instant responses
- Endocrine glands that produce hormones in animals are known collectively as the endocrine system
 - Endocrine glands can be stimulated to secrete hormones by the action of another hormone or by the arrival of a nerve impulse

- The pathway of hormone action is as follows

stimulus - receptor - hormone - effector

- An example of this pathway in action might be

high blood sugar - cells in the pancreas -insulin - liver cells

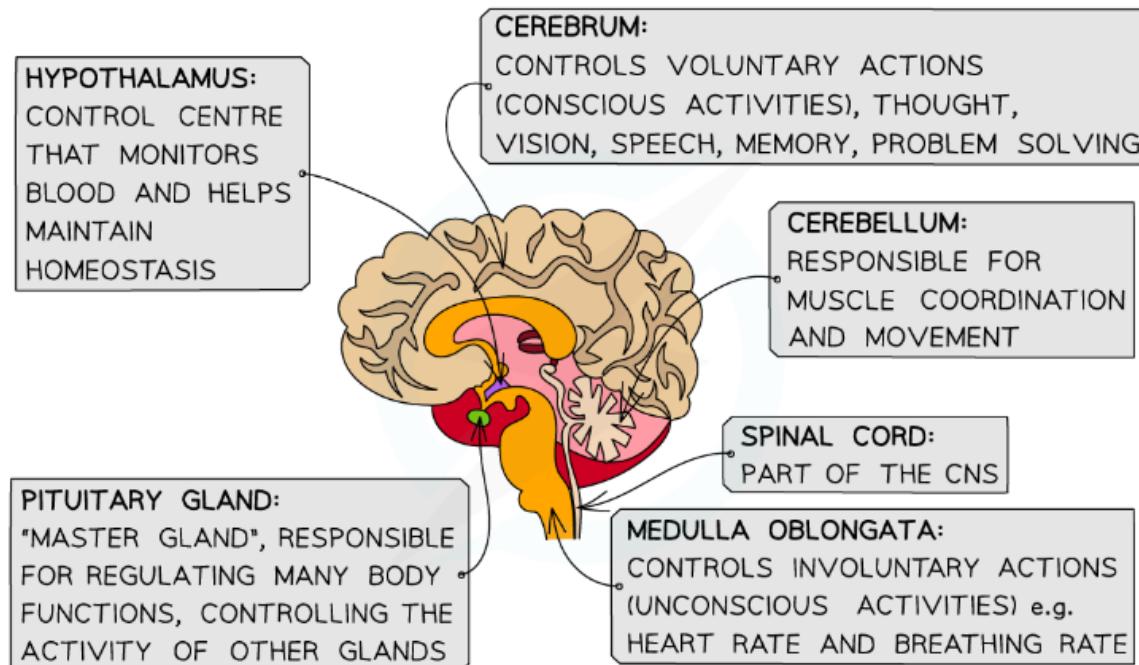
- The liver cells respond to insulin by converting glucose into glycogen

	NERVOUS SYSTEM	ENDOCRINE SYSTEM
MADE UP OF:	NERVES (NEURONES), BRAIN, SPINAL CORD	GLANDS
TYPE OF MESSAGE:	ELECTRICAL IMPULSE	CHEMICAL HORMONE
SPEED OF TRANSMISSION:	VERY FAST	SLOWER
LENGTH OF EFFECT:	SHORT – UNTIL NERVE IMPULSES STOP	LONGER – UNTIL HORMONE IS BROKEN DOWN

13. Location and main functions of the cerebral hemispheres, hypothalamus, pituitary gland, cerebellum, and medulla oblongata of the human brain.

Human Brain Structures & Functions

- The brain, alongside the spinal cord, is part of the central nervous system (CNS)
- The brain is made of billions of interconnected neurones
- Within the brain are different regions that carry out different function



The cerebrum

- The cerebrum is the largest part of the brain in humans, accounting for about 80% of the total mass of the brain
- It carries out a large variety of functions involved with conscious activities, including:
 - **Vision**
 - **Hearing**
 - **Speech**
 - **Thinking**
 - **Memory**
- The cerebrum is divided into two halves known as the cerebral hemispheres
 - The hemispheres are joined together by a band of nerve fibres known as the corpus callosum
 - The right hemisphere controls the left side of the body and the left one controls the right side
- The cerebrum has a thin outer layer known as the cerebral cortex or 'grey matter'
 - The cerebral cortex consists of the cell bodies of neurones
 - It is highly folded, which increases its surface area and allows it to contain a greater number of neurones
 - With more neurones in the brain, more neurone connections can be made
 - This is important, as the more connections between neurones in the brain, the greater the ability of the brain to carry out more complex behaviours
- Beneath the cerebral cortex or grey matter layer is the 'white matter'
 - **The white matter consists of the myelinated axons of neurones**

The hypothalamus:

- The hypothalamus monitors the blood as it flows through the brain and, in response, releases hormones or stimulates the neighbouring pituitary gland to release hormones
 - The hypothalamus plays an important role in some homeostatic mechanisms
- **Hypothalamus functions include**
 - **Regulating body temperature**
 - The hypothalamus monitors blood temperature and initiates a homeostatic response if this temperature gets too high or too low
 - **Osmoregulation**
 - Cells in the hypothalamus monitor the water balance of the blood and releases the hormone ADH if the blood becomes too concentrated
 - ADH increases absorption of water in the kidneys
 - **Regulating digestive activity**
 - The hypothalamus regulates the hormones that control appetite as well as the secretion of digestive enzymes

- **Controlling endocrine functions**
 - The hypothalamus causes the pituitary gland to release hormones that control a variety of processes e.g. metabolism, growth and development, puberty, sexual functions, sleep, and mood

Pituitary gland

- The pituitary gland is located below the hypothalamus
- Its role is to produce a range of hormones
 - Some of these directly influence and regulate processes in the body while some stimulate the release of further hormones from other endocrine glands
- The pituitary gland is divided into two sections; the anterior pituitary and posterior pituitary
 - The anterior pituitary produces and releases hormones
 - The posterior pituitary stores and releases hormones produced by the hypothalamus e.g. ADH and oxytocin

The cerebellum

- The cerebellum coordinates movement
 - This includes balance; a highly complex function that requires coordination between multiple parts, including the eyes, semicircular canals in the ears, and many muscles

The medulla oblongata

- Also known as the medulla
- The medulla contains co-ordination centres that control different unconscious functions e.g.
 - The cardiac centre controls heart rate
 - The respiratory centre controls breathing rate
- The medulla controls functions that are able to maintain life even if other parts of the brain are damaged

14. Describe how magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and computed tomography (CT) are used in medical diagnosis and the investigation of brain structure and Function(advantages and disadvantages).

Computerised Tomography

- Computerised tomography, or CT, scans produce cross-section images of the brain using x-ray radiation
 - A beam of x-rays are aimed at a patient from all angles around the body
 - Digital x-ray detectors are used to pick up the x-rays as they exit the patient's body
 - Denser tissue absorbs more of the x-ray radiation so shows up as a lighter region on a scan
- A scan produced in this way shows physical structures of the brain and allows visualisation of any tissue damage
 - E.g. blood is less dense than brain tissue so a CT scan can be used to locate damaged blood vessels and areas of bleeding after a patient has had a stroke

- The scans don't directly show the functions of the regions of the brain but it is possible to link visible symptoms with the location of any tissue damage

Magnetic Resonance Imaging

- Magnetic Resonance Imaging, or MRI, uses a combination of a magnetic field and radio waves to generate images through the body
 - The patient being scanned must remain very still while inside a large magnet
- Soft tissues can be seen clearly using MRI, and images produced are at a higher resolution than those produced from CT scanning
- As with CT scanning, MRI is useful for identifying areas of abnormal or damaged tissue, but only enables brain function to be analysed by linking damage on a scan with visible symptoms in a patient
- MRI is especially useful for tumour diagnosis as tumours show up clearly in images generated in this way
- MRI scans are considerably more expensive to carry out than CT scans but do not carry the risk associated with the use of potentially harmful x-rays
 - MRI scans are often the imaging method of choice during long-term therapies

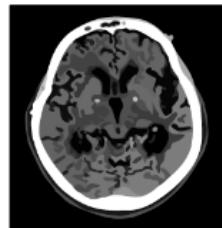
Functional MRI

- Functional MRI, or fMRI, functions in a similar way to MRI, making use of a magnetic field and radio waves to generate images of brain structure
- The difference between MRI and fMRI is that fMRI scans allow brain function to be studied in real time
 - fMRI scans show the location of oxygenated blood in the brain, therefore indicating which brain regions are active at any one time
 - The scanner measures the ratio of oxygenated to deoxygenated haemoglobin
 - Patients can be asked to carry out particular actions, answer questions, or think about a specific topic while inside a scanner and the change in blood flow to regions of the brain can be assessed
 - The region of the brain associated with the activity or thought will 'light up' in the scanner
 - This can be used in medical diagnosis e.g. searching for the cause of seizures, or in psychology research

Positron Emission Tomography

- PET scans use radioactive tracers which collect in areas where there is increased blood flow, metabolism, or neurotransmitter activity
 - The tracer is introduced to the blood in advance of the scan so that it can be detected by the scanner
 - E.g. a radioactive tracer might be radioactively labelled glucose; glucose will be transported in the blood and will be present in high concentrations in metabolically active areas of the brain
- The scanner can detect areas of high radioactivity, and so the movement of the tracer through the body and any accumulation of tracer in the brain can be seen

- The amount of radioactive tracer present in a brain region can indicate whether that region is active or inactive
 - This has been useful in building an understanding of specific diseases such as Alzheimer's where brain activity in certain regions decreases
 -



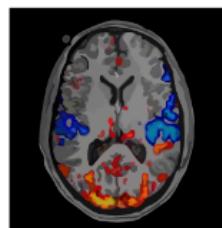
CT

- USES X-RAYS
- SHOWS STRUCTURE BUT NOT FUNCTION



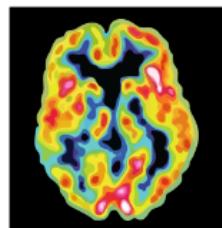
MRI

- USES A MAGNETIC FIELD AND RADIO WAVES
- SHOWS STRUCTURE BUT NOT FUNCTION
- HIGHER QUALITY IMAGES THAN CT



fMRI

- SIMILAR TO MRI
- SHOWS PRESENCE OF OXYGENATED BLOOD
- SHOWS STRUCTURE AND FUNCTION



PET

- USES RADIOACTIVE TRACERS
- SHOWS LEVELS OF BRAIN ACTIVITY
- SHOWS STRUCTURE AND FUNCTION

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15. Details of Parkinson's disease and depression.

Brain Disease

- Neurotransmitters are chemicals that transmit nerve impulses across synapses
- Some disorders and diseases are linked to an imbalance of neurotransmitters in the brain
- Two examples are
 - Parkinson's disease
 - Depression

Parkinson's disease

- Parkinson's disease is a brain disorder that affects the co-ordination of movement, caused by the loss of neurones in some parts of the brain
- Symptoms include
 - A tremor to the specific parts of the body
 - Slow movement
 - Stiff and inflexible muscles
 - Difficulties with balance
 - Changes to speech
- The lost neurones normally produce the neurotransmitter dopamine
 - *Dopamine is involved in muscle control*
- Individuals that suffer from Parkinson's disease produce insufficient amounts of dopamine due to the loss of dopamine-producing neurones
 - Less dopamine is released into the synaptic cleft meaning less is able to bind with receptors on the postsynaptic membrane
 - Fewer sodium channels on the membrane are opened so depolarisation of the postsynaptic neurone does not occur
 - This leads to fewer action potentials which creates the symptoms such as tremors and slow movement

- Different types of drug can be used to treat this disease
 - **Dopamine agonists**
 - Produce the same effect as dopamine by binding to and activating the dopamine receptors on the postsynaptic membrane
 - **Dopamine precursors**
 - These are chemicals that can be converted into dopamine in the neurones
 - E.g. L-dopa
 - **Enzyme inhibitors**
 - Monoamine oxidase B (MAOB) inhibitors inhibit the activity of enzymes that would normally break down dopamine in the synaptic cleft, raising levels of dopamine present in the brain
- Research into other treatments for Parkinson's disease is currently ongoing, with some promising future possibilities in the areas of
 - **Gene therapy**
 - This would involve the addition of genes to the affected cells in the brain to either increase dopamine production or prevent the destruction of dopamine-producing cells
 - **Stem cell therapy**
 - Stem cells could be used to replace the lost dopamine-producing cells in the brain

Depression

- Low levels of the neurotransmitter serotonin have been linked to depression
 - Serotonin transmits nerve impulses through the areas of the brain that control mood
 - Low levels of serotonin increase episodes of depression
- Other brain chemicals linked to depression include noradrenaline and dopamine
- Some drugs that have been developed for the treatment of depression, known as antidepressants, work by increasing the levels of relevant neurotransmitters in the brain
 - **SSRIs (selective serotonin reuptake inhibitors)** are a class of antidepressant that prevent the uptake of serotonin at synapses; this increases the overall levels of serotonin in the brain
 - **TCA (tricyclic antidepressants)** increase levels of both serotonin and noradrenaline in the brain
 - **MAOB inhibitors** inhibit enzymes that would otherwise break down neurotransmitters in the synaptic clefts in the brain

16. Describe how drugs can be produced using genetically modified organisms (plants, animals, and microorganisms).

Genetically modified micro-organisms

- Restriction enzymes are used to remove the gene coding for a desired protein from an organism's genome
 - The protein coded for here will be responsible for the characteristic desired in the GMO e.g. the ability to produce insulin
- Many copies of the gene are made using the polymerase chain reaction, or PCR
 - The enzyme DNA polymerase is used to join free nucleotides into new strands of DNA that are complementary to the original strand
- These copies are inserted into small loops of DNA called plasmids, which then transfer the copies into micro-organisms
 - The plasmids are said to be DNA vectors
 - The enzyme DNA ligase catalyzes the joining of the desired gene to the plasmid vector
- The genetically modified micro-organisms are grown in large fermenters containing nutrients, enabling them to multiply and produce large quantities of the new protein
- The protein can be isolated and purified before being packaged and distributed
 - Human insulin and human blood clotting factors are examples of medicinal proteins
- A similar process can be used to insert desired genes from other organisms into plant cells
- After the gene is inserted into a plasmid and then transferred to a bacterial cell, the bacteria can be used to infect plant cells; the bacterium acts as a vector for introducing the gene into the plant DNA
 - Note that this isn't the only method of introducing new genes into plant cells
 - Another method involves a 'gene gun'; tiny pellets are coated with the desired DNA and then fired into the plant cells
- The gene is transferred from the bacterial cell into the plant cell nucleus, after which the plant cell is stimulated to multiply and grow into an adult plant
 - produced by genetically modified bacteria

Genetically modified animals

- The gene that codes for the desired protein is injected into the nucleus of a zygote
- The zygote is implanted into the uterus of a surrogate animal where it develops into an adult animal
 - Every cell of this genetically modified animal will contain a copy of the gene coding for the desired protein
- The protein can be purified from e.g. the milk of the animal
 - Human blood clotting proteins can be produced from the milk of genetically modified animals

17. Explain how recombinant DNA can be produced, including the roles of restriction endonucleases and DNA ligases.

Artificial copies of the desired gene can be made by taking an mRNA molecule transcribed from the gene and using it to produce the correct DNA sequence.

This uses the **reverse enzyme transcriptase**. It reverses the transcription process to produce complementary DNA (cDNA) which can act as an artificial gene. Each type of **restriction endonuclease** will cut DNA only at specific (restricted) sites within a particular DNA sequence. Some restriction endonucleases cut the two ends of the gene to produce sticky ends. Sticky ends make it easier to attach new pieces of DNA to them.

The next step is to integrate the new gene into a **vector**. Plasmids are frequently used as vectors to carry the DNA into a host bacterial cell. **DNA ligases** are used as 'genetic glue' to combine pieces of DNA. Once the plasmid is incorporated into the host nucleus, it forms part of the new recombinant DNA of the genetically engineered or transformed organism. Successfully transformed cells can be identified, isolated, and cultivated on an industrial scale so that the proteins they make can be harvested for human use.

18. How recombinant DNA can be inserted into other cells.

- Sections of DNA can be transferred from one organism's DNA to that of another, creating recombinant DNA
- In order to create recombinant DNA, desired genes, such as the gene for human insulin, need to be transferred into new types of cell; there are several different ways of doing this, e.g.
 - Vectors, e.g.
 - DNA plasmids
 - Viruses
 - Liposomes
 - Gene guns
 - Microinjection
- Once a section of DNA has been transferred into a new cell it needs to be incorporated into the cell's genetic material in order to be transcribed and translated

Plasmid vectors:

- Plasmids are small, circular rings of double-stranded DNA that can be found in some bacterial cells, as well as some other cell types
- To insert the desired gene into the circular DNA of a plasmid, it is cut open using a restriction endonuclease
- DNA ligase is then used to join the desired gene to the plasmid DNA; this creates a recombinant plasmid
- The recombinant plasmid DNA can then be transferred into other cells, usually bacteria, by a process called transformation

Viral vectors:

- Viruses reproduce by inserting their DNA into the cells of other organisms, making them ideal vectors for the process of creating transformed cells
- Viruses exist that infect animal cells, plant cells, and bacterial cells, so viral vectors can be used to transform many cell types

Liposome vectors:

- Liposomes are small, spherical vesicles, surrounded by a phospholipid bilayer
- Liposomes can be used as vectors because they can fuse with the cell surface membranes of host cells
- These vesicles can also be used in gene therapy to carry non-mutated genes into host cells

Gene guns

- The fragments of DNA containing the desired gene can be used to coat tiny pellets of gold or tungsten which are then fired at high speed into the cells that are to be transformed
- Cells that avoid damage are able to incorporate the new DNA into their genome

Microinjection

- A fine glass micropipette is used to transfer DNA into a cell
- This is a common laboratory technique for transferring genetic material into animal cells for the creation of transgenic animals

19. Describe how microarrays can be used to identify active genes.

- A DNA microarray is a slide on which there are thousands of spots.
- Each spot is in a specific position and contains a known DNA sequence.
- The mRNA samples are then collected.
- Scientists usually use a reference sample with a known gene sequence and an experimental sample.
- Reverse transcriptase enzymes convert the mRNA into cDNA.
- Each sample is given a fluorescent label.
- Usually, the known sample is given a green fluorescent label and the experimental sample is given a red fluorescent label.

- The labeled DNA samples are mixed together and applied to the microarray slide, where they bind to the matching DNA probes.
- This process is called **hybridization**.

After **hybridization**, the microarray is scanned to measure the fluorescent light produced by the different spots.

- If both samples express a gene equally, the light will appear yellow (a mixture of red and green light).
- If the experimental sample is expressing more than the control, the spot will appear **red**.
- If the sample is expressing less than the control, the spot will appear **green**.
- We can collect very large amounts of data using this technology.

20. What is meant by the term bioinformatics?

Bioinformatics is a field that develops methods and software tools for understanding biological data, in particular when the data sets are large and complex. It includes the development of algorithms, mathematical models, and statistical tests which can help us interpret the enormous quantities of data that are generated.

21. Describe the risks and benefits associated with the use of genetically modified Organisms.

Risks & Benefits of Using GMOs

While GMOs can be used for medical benefit, there is still much concern about the potential impacts of changing the genes of organisms, as well as the ethics of genetically modifying animals

These concerns are often amplified when the GMOs are crop plants destined for human consumption

Risks and Benefits of Genetic Engineering

Benefits of genetic engineering	Risks of genetic engineering
Crops can be modified to produce higher yields and have increased nutritional value, reducing famine and malnutrition	There are concerns about the long-term impacts of using genetically modified food organisms on human health
Crops can be modified to be resistant to pests and reduce pesticide use; this lowers production costs and decreases environmental damage	Some are concerned that pests may develop resistance to the modified crop defences, leading to increased use of pesticides
Enzymes used in industrial processes can be produced from genetically modified organisms; this is very cost effective	There could be transmission of genetic material between genetically modified organisms and non-GM organisms
Diseases can be treated with human proteins produced by genetically modified organisms instead of with animal proteins; this reduces the risk of allergic reactions and is more effective	Genetically modified crops are often grown in large fields, creating monocultures that are bad for biodiversity
Vaccines can be produced in genetically modified plant tissues; these do not need refrigeration, making them more accessible to people living in rural areas	Genetically modified crop varieties are usually owned by the companies that develop them, so seeds can be very expensive
Genetically modified organisms guarantee a low-cost supply of some human medications	Some have moral objections to genetically modifying animals for the sole purpose of benefiting humans

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