Edexcel IAL Biology A Level

Topic 8: Coordination, Response and Gene Technology

Notes

Coordination and response

Coordination and control in animals is controlled by 2 systems - **the nervous system** and **the endocrine system** which are both responsible for carrying out responses across the body, yet have many differences:

- **The nervous system**
  - Communication is via **electrical** impulses
  - The effects are **short lived** - for instance causing one muscle contraction
  - The response is **localised**
  - **Faster** response
- **The endocrine system**
  - Communication is **via hormones** which are chemicals
  - The effects are mainly **long lasting**
  - Hormones affect a **larger area** of the body
  - **Slower** response

The nervous system is comprised of the **central nervous system (CNS)** which is made up of the **brain** and **spinal cord** and the **peripheral nervous system** which extends beyond the brain and spinal cord to the rest of the organism.

The nervous system is made up of **receptor cells** that detect changes in the internal and external environment known as **stimuli**. The sensory, motor and relay neurones of the central nervous system which coordinate a response to a stimulus and decide what to do and the **effectors** bring about the response. Effectors can be **muscles** which contract or relax as a response or **glands** that secrete chemicals such as hormones or enzymes.

The nervous system is connected by nerve cells called **neurones** which play an important role in coordinating **communication** within the nervous system.

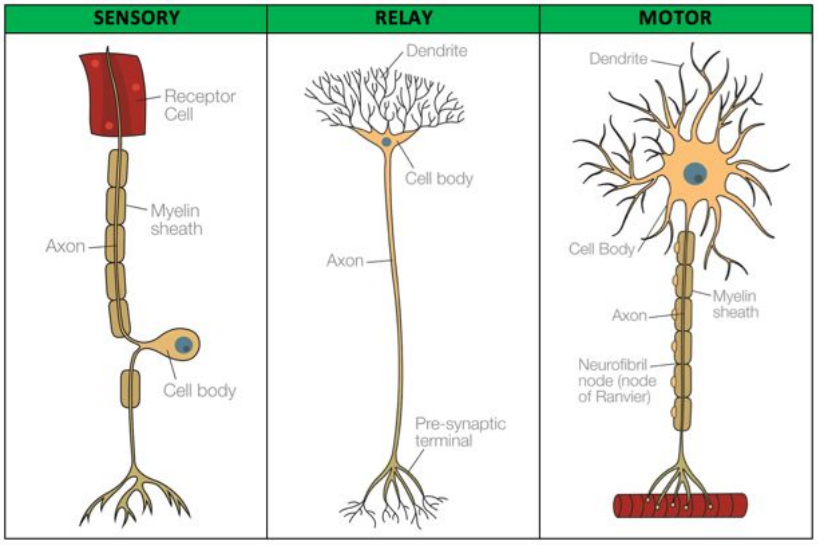
Neurones

The structure of neurones is similar, as they all have a **cell body** composed of the **nucleus** as well as organelles, such as **mitochondria,** within the cytoplasm. Apart from the essential components, they also contain extensions called **dendrites** involved in conducting impulses **towards** the cell body, as well as **axons** which conduct impulses in the opposite direction, that is **away** from the cell body.

There are three types of neurones, **sensory, motor** and **relay** with different functions which differ by the position of the cell body within the neurone.

Motor neurones are involved in transmitting electrical signals **from the central nervous system to muscles and glands** in the body. Sensory neurones transmit impulses **from receptors to the central nervous system**, whereas the relay neurones which, are located within the central

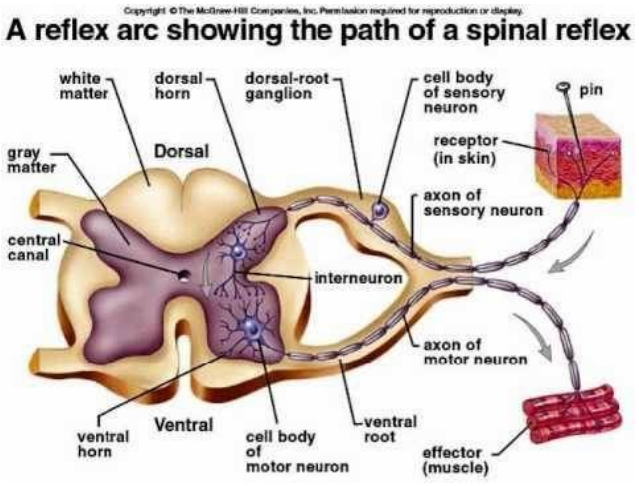
nervous system, are involved in transmitting the electrical impulses **from sensory neurones to motor neurones.**



The structure of neurones, that is the **length of axons** as well as the **polarised nature** of the neurone membrane in the **resting state** where the outside of the membrane is positively charged and the inside is negatively charged, enables the neurones to carry electrical impulses called **action potentials.**

The **speed** at which the electrical potential is carried can be increased with the help of the **myelin sheath** which serves as an **insulator of axons and dendrons,** produced by **Schwann cells**. The mechanism by which the speed is increased is known as **saltatory conduction** where the action potential **jumps** between gaps in the myelin sheath, called **nodes of Ranvier.** Movement of the impulse is **much faster** by saltatory conduction since the entire length of the neurone is not polarised by the opening and closing of sodium and potassium ion channels - only the clusters of these ion channels found at the nodes of Ranvier need to be **depolarised** in order to pass the action potential along.

Spinal reflex arc



The central nervous system is made up of 2 types of tissue - **grey matter** and **white matter**. Grey matter contains dendrons, axons and cell bodies and is where the synapses between neurones lie and forms a **butterfly shape** in the spinal cord. White matter contains **only axons** so it is the tissue that links between areas of grey matter.

The **reflex arc** is an **automatic response** that's role is to protect the body from harm. A reflex arc occurs as follows:

1. **A potentially harmful stimulus** is detected by **receptors** - for instance a very hot pan on arm skin.
2. **Sensory neurones** take an impulse to the **relay neurones** in the CNS.
3. A **response** is coordinated in the spinal cord so the impulse does not need to travel to the brain - this makes the response **faster** therefore more likely to protect the body.
4. The impulse passes directly from a **relay neurone** to a **motor neurone** which carries the impulse to an effector.
5. The **effector** carries out the response - in this case muscles moving the arm away from the burning pan.

The pupil

The **dilation and contraction** of muscles in the iris control how much light enters the eye via the pupil and is an example of a **reflex**. There are **photosensitive cells** on the **retina** of the eye that are sensitive to light, these receptor cells are the start of the **reflex arc** that prevents damage occurring to the **retina**. In low light levels the pupil dilate to allow more light in whereas in high light levels the pupils constrict so less reaches the retina. The **lens** of the eye focuses the light on the retina where the photoreceptors are located, specifically the **fovea**.

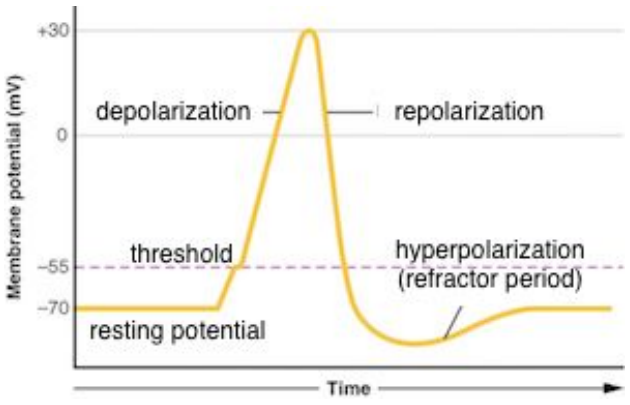
Action potentials

As previously mentioned, nerve cells are polarised in their **resting state.** This occurs as a result of imbalance between **sodium ions and potassium ions**, thus giving the inside of the nerve cell a negative charge in comparison to the external environment. As a result of the **polarisation**, there is a difference in the voltage across the neurone membrane, with a value of **-70mV** known as the **resting potential.**

This resting potential is generated as well as maintained with the help of **sodium-potassium pump** which moves sodium ions out of the neurone thus creating an **electrochemical gradient** as the concentration of sodium ions is higher outside the cell, this is because the membrane is not permeable to sodium ions. The sodium-potassium pump is also involved in transporting the potassium ions into the neurone. However, the potassium ions diffuse back out due to the presence of potassium ion channels. As a result of that, the outside of the cell is **positively charged** due to the imbalance of positively charged ions.

Upon stimulation, the neurone cell membrane becomes **depolarised**. This occurs as following:

1. Firstly, the **excitation** of neurone cell triggered by **stimulus** causes the **sodium ion channels to open**. As a result making it more **permeable** to sodium ions which subsequently diffuse into the neurone down the **electrochemical gradient,** making the inside **less negative.**



2. Upon reaching the **threshold** of **-55mV,** even more sodium channels open eventually giving a **potential difference of +30mV** which is the end of the depolarisation and start of **repolarisation**. This is achieved as a result of **sodium ion channels closing and potassium ion channels opening.**

3. The potassium ions diffuse **out** of the neurone down the concentration gradient and eventually **restore the resting potential**. However, as the closing of potassium ion channels is slightly delayed, this leads to **hyperpolarisation** i.e. when the potential difference becomes greater than the resting potential.

4. The resting potential is then achieved with the help of the **sodium-potassium pump** which returns the potential difference to the value of **-70mV**.

5. The action potential travels along the neurone as a **wave of depolarisation** where the sodium ions move to the **adjacent resting region** where they trigger a change in potential difference, thus stimulating another **action potential.**

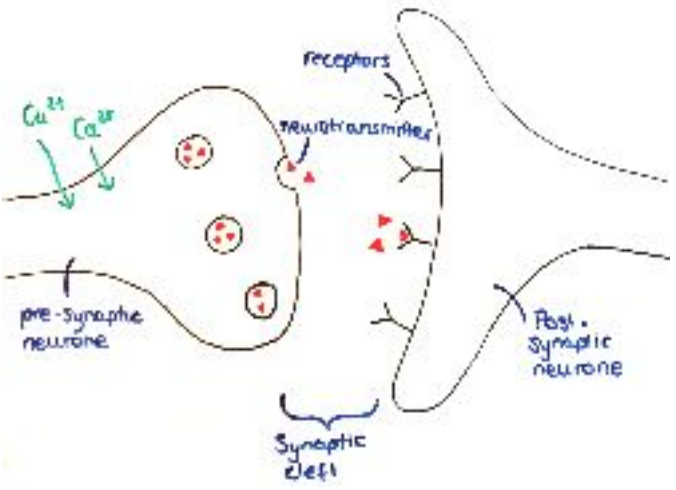
Afterwards, there is a short period during which the neurone membrane cannot be excited as the sodium channels enter the **recovery stage**. This period is known as the **refractory period** and serves an important role in ensuring that the action potentials can pass in **one direction only** as discrete signals.

Synapses

Synapses are junctions between two neurones.

Action potentials are passed from one neurone to the next across the synapse in the following way:

1. Upon the arrival of an action potential, **the presynaptic membrane depolarises** therefore causing the **calcium channels to open** which subsequently allow calcium ions to enter the neurone.
2. The presence of calcium ions in the neurone causes the **fusion of synaptic vesicles** filled with a particular neurotransmitter, such as **acetylcholine,** to fuse with the presynaptic membrane. Thus causing the **release of neurotransmitter** into the **synaptic cleft,** that is the **gap** between the two neurones.



3. The neurotransmitter **binds to the receptors** located on the **postsynaptic membrane** therefore stimulating the **opening of cation channels** which enable sodium ions to enter the neurone.

4. As a result of that, **the membrane depolarises** therefore **triggering another action potential** in the postsynaptic neurone.

This process only occurs if the neurotransmitter originates from an **excitatory neurone.** In the case of **inhibitory neurones**, **chloride ion channels open,** thus causing **hyperpolarisation** of the postsynaptic membrane therefore triggering a new action potential becomes more difficult.

This sequence of events is controlled with the help of **digestive enzymes** in the **synaptic cleft** which serve to **break down** the neurotransmitter to **prevent overstimulation** of the post-synaptic membrane. Following the breakdown of the neurotransmitter, it is taken up by the pre-synaptic membrane and reused. Apart from this, the presence of receptors on one side of the synapse only, that is the post-synaptic side serves to ensure that the action potential can only travel in **one direction only.**

The effects of drugs on the nervous system

Many drugs, both legal and illegal, create their effects by altering the normal functioning of the nervous system.

Nicotine - nicotine is carried by the tar in cigarette smoke and is absorbed in the lungs into the bloodstream, reaching the brain in under 10 seconds. In the brain, nicotine **mimics the effect of the neurotransmitter acetylcholine** and **binds to cholinergic receptors** at synapses, triggering action potentials. Since acetylcholine is important in controlling things like **mood, appetite and memory,** nicotine also affects these. Nicotine also increases levels of **dopamine**, which triggers feelings of pleasure and reward, contributing to the drug's **addictiveness**.

Lidocaine - Lidocaine is a **local anaesthetic** that numbs tissues in a specific area. It works by **blocking sodium ion channels** and prevents neurones in affected areas from sending impulses to the brain - meaning no feelings of pain are stimulated.

Cobra venom alpha toxin - Acetylcholine is the **neurotransmitter** found at **neuromuscular junctions**, so triggers muscle contractions. The cobra venom alpha toxin is a venom released by some species of cobra that **binds to acetylcholine receptors**, including at neuromuscular junctions. Instead of mimicking the effect of acetylcholine the venom instead blocks the receptors, causing **a postsynaptic block** and meaning no action potential and therefore no muscle contraction is generated - resulting in **paralysis**.

L-DOPA - The drug **levodopa** is used in the treatment of **Parkinson's disease** which occurs when there is not enough dopamine in the brain. L-DOPA is a **precursor to dopamine** which can cross the **blood-brain barrier** which dopamine cannot do. When in the central or peripheral nervous system L-DOPA is then converted into dopamine, thereby reducing symptoms of Parkinson's since the level of dopamine in the brain is somewhat restored.

MDMA - MDMA causes the release of the neurotransmitter **serotonin and dopamine** into synapses, leading to an **increase in the binding of these to receptors** on the postsynaptic neurones. This fires action potentials that lead to **euphoric feelings, increased sociability and happiness.** Once taken orally the effects of MDMA occur between 30-60 minutes after being consumed and last between 2 and 6 hours.

Vision

Cells specialised for detection of stimuli are known as receptors. Sense organs, such as the eye, are composed of groups of receptors.

Photoreceptors are light receptors located in the eye. Subsequently, the nerve impulses received by the photoreceptors cells are then carried via the **optic nerve** to the brain. The point where the optic nerve leaves the eye is known as the **blind spot** as there are **no photoreceptor cells** located there. The two types of photoreceptors in the retina are **cones** involved in **colour vision** whereas **rods** can only produce **monochromatic vision.** Apart from the type of vision they provide, the two photoreceptors differ in their level of **sensitivity** – cones can only work in bright conditions whereas rods are much more sensitive and dim light is sufficient for them to work.

Rods contain a **light-sensitive pigment** called **rhodopsin** which absorbs light energy and splits into **retinal and opsin.**

In the dark, the rods aren't stimulated as the sodium ions diffuse into the cell through open sodium ion channels whilst being actively pumped out of the cell by active transport. As a result of that, the inside of the cell is **only slightly more negative** compared to the outside, thus causing the membrane to be **slightly depolarised**. Therefore, the release of neurotransmitter called **glutamate** is released.

Glutamate serves to **inhibit the neurones** which connect the **rod cells to the optic nerve**, as a result **no information is transmitted to the brain.** In the presence of light, the rhodopsin splits into retinal and opsin. Opsin binds to the membrane of the cells thus causing the sodium ion to close without affecting the transport of sodium ions out of the cell via active transport. Therefore the membrane becomes **hyperpolarised** meaning no glutamate transmitter is released into the synaptic cleft. Thus an **action potential forms** and is transmitted to the brain via the optic nerve and subsequently processed by the brain.

Habituation

Habituation is a phenomenon where an organism becomes **insensitive to repeated stimuli over time** which does not threaten their survival or does not benefit then in any way. It is a type of **learned behaviour.** Examples include ignoring familiar sounds and responding to unfamiliar ones.

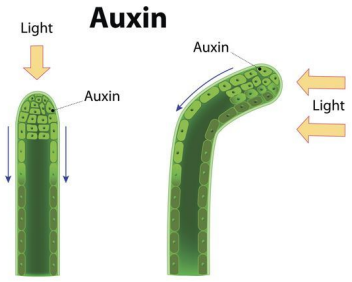
Habituation occurs when the **calcium channels become less responsive**, as a result reducing the amount of calcium ions which cross the presynaptic membrane with the purpose of triggering neurotransmitter release. As a consequence, **less depolarisation** of the post-synaptic membrane occurs therefore **no action potential is triggered.**

Invertebrates such as snails, sea slugs and tortoises can be used to **investigate habituation** in a similar way where the animal is repeatedly stimulated, for instance by tapping the shell of a tortoise until it stops responding to the stimulus.

Chemical control in plants

Plants respond to **external stimuli** to increase their chance of survival. For instance, they exhibit **tropisms**, that is **growth responses controlled by a direction stimulus.** An example of tropism is **phototropism** where the direction of growth is determined by the direction of light.

Apart from being affected by light, plants are also affected by **changes in day length.** This kind of sensitivity is known as **photoperiodism** where the plants **flower and germinate** in response to day length. This response is coordinated by a photoreceptor called **phytochrome**. The phytochrome exists in two states, **P_R** which is the **inactive** form and **P_{FR}** which is the **active** form. The **ratio** of P_R to P_{FR} tells a plant what time of day it is and how long days are lasting.



Plant growth is also controlled by **indoleacetic acid (IAA)** which is an important **auxin** produced in the tips and shoots of flowering plants. The Wdistribution of IAA around the plant controls **tropism.** For instance, if IAA is unevenly distributed, it causes uneven growth of the plant to occur.

When the shoot is illuminated from all sides, the auxins are distributed evenly and move down the shoot tip thus causing **elongation of cells across the zone of elongation.** Whereas if the shoot is only illuminated from one side, the auxins move towards the **shaded part** of the shoot thus causing **elongation** of the shaded side only. This results in bending of the shoot towards the light.

Tropisms are directional growth responses of plants and include:

- **Phototropism** - the growth response to **light**, shoots exhibit positive phototropism as they grow towards light, whereas roots exhibit negative phototropism and grow away from light

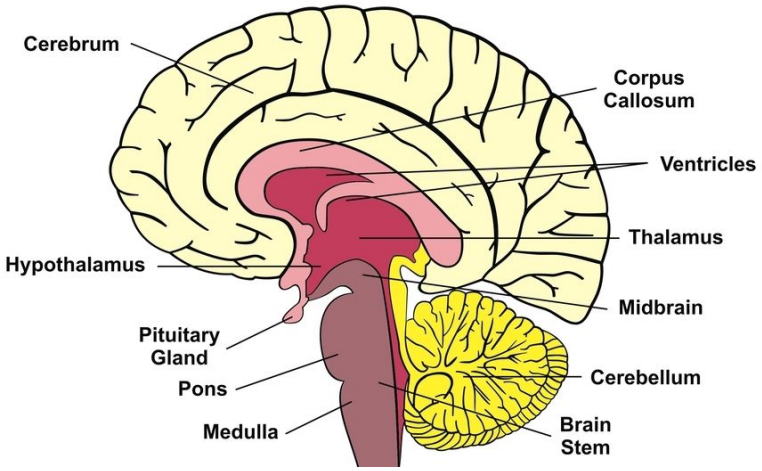
- **Geotropism** - a growth response to **gravity**. Roots grow with gravity thus they exhibit positive geotropism, whereas shoots exhibit negative geotropism and oppose the force of gravity

- **Chemotropism** - a growth response to **chemicals**

Plant growth responses can also be triggered by **plant growth regulators.** Examples include **auxins** which promote cell elongation, **gibberellins** which promote **seed germination and stem growth**, **abscisic acid** which **inhibits seeds germination and causes closing of stomata** and **ethane** which is a gas that **promotes ripening of fruit**.

The brain

Brain structure



- **Cerebrum** - this is the largest part of the brain composed of two halves known as the **cerebral hemispheres.** The cerebrum is involved in controlling vision, thinking, learning, emotions as well as voluntary control of the body– collectively referred to as **advanced mental activity.** The cerebrum contains many different parts:
    - **Corpus callosum** - a band that **connects the two cerebral hemispheres**
    - **Parietal lobe** - this controls **orientation, movement,** some types of **recognition** and **memory**
    - **Occipital lobe -** located at the back of the cerebrum this is known as the **visual cortex**
    - **Temporal lobe** - this processes **auditory information**

- **Cerebellum** - located underneath the cerebrum this plays an important role in **coordinating muscle movements** as well as **balance**

- **Hypothalamus** - found just beneath the middle part of the brain this is involved in **thermoregulation** as well as production of **hormones** that are involved in control of the pituitary gland

- **Medulla oblongata** - located at the base of the brain this controls many vital body processes such as **breathing, heart rate and blood pressure**

- **Pituitary gland** - its main function is to **secrete various hormones**, such as oxytocin and FSH. It's located on the underside of the brain and attached to the hypothalamus

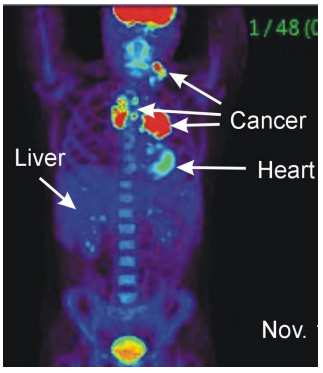
Observing the brain

Magnetic resonance imaging (MRI) – MRI scanners use a **magnetic field and radio waves** for imaging soft tissues such as the brain. MRI can be used for diagnosis as diseased tissue can be seen, for instance in multiple sclerosis. It can be used to investigate **brain structure and function** as well as **medical diagnosis** of tumours by helping to determine the exact size and location of the tumour.

Functional magnetic resonance imaging (fMRI) – a modified version of MRI where the brain can be **seen in action whilst performing tasks** as it monitors the uptake of oxygen. Similarly to MRI, it can be used for studying brain structure and function in action. It can be used for medical diagnosis of conditions which are caused by **abnormal activity of the brain**, such as seizures.

Computed tomography (CT) - uses radiation in the form of **X-rays** to produce **cross-section images** of the brain. It is based on the idea that denser structures absorb more radiation than the less dense ones, therefore they show up lighter on the scan. CT can be used to investigate brain structure and function, for instance via studying damaged brain structure where loss of function is seen. They can also be used for medical diagnosis as it shows up **damaged/abnormal areas,** such as where bleeding in the brain occurs after a stroke.

Positron emission tomography (PET) - this is a form of imaging that looks at **metabolism** in the body and shows where some areas are metabolising more than others. The person being scanned is given a **radioactive tracer** containing glucose which is taken into cells as they respire; the radioactivity emitted from areas of high metabolism, such as in growing cancer, can be detected by the PET scan. It can be used to help observe **cancer growth and spread** and help diagnose **dementia**.



Illnesses of the brain

Imbalances in certain naturally-occurring brain chemicals can contribute to ill health in the brain, such as **parkinson's disease** and **depression**.

Parkinson's disease

Parkinson's is a **progressive neurodegenerative disease** that worsens over time. It is caused by the destruction of neurones in a region of the midbrain called the **substantia nigra**. The result of this cell death is that there is **not enough dopamine** in this area and this causes problems with **movement**. Common early symptoms include shaking, stiffness and difficulty walking and as Parkinson's progresses many sufferers also develop **dementia and depression.**

There is currently no cure to Parkinson's, largely due to the lack of knowledge and understanding of its cause. However, it is treated with a drug called **levodopa (L-DOPA)** which aims to **improve the symptoms.**

Depression

Depression is commonly caused by an **imbalance of chemicals in the brain,** namely **serotonin**. Serotonin is a **neurotransmitter** made in the brain and needed for communication across the nervous system. It is thought that low levels of one of the so-called **'happy hormones'** leads to **lowered moods and depression.**

Gene technology

Key words:

- **Recombinant DNA** - a piece of DNA containing **DNA from more than 1 organism**
- **Transgenic organism** - an organism containing **recombinant DNA**
- **Sticky ends** - small sections of **unpaired and overhanging bases** at the end of a DNA fragment
- **Genome** - the **complete set of genes** in an organism
- **Vector** - something used to **transfer the desired gene** into another organism
- **Gene therapy** - altering the genes in human cells to **treat genetic disorders**
- **cDNA -** A **complementary** piece of DNA, commonly made from mRNA

Genetically modifying organisms to make drugs

Organisms including animals, plants and bacteria can be genetically modified to produce **useful substances** such as drugs. For instance, bacteria are widely used today to produce human insulin to be given to diabetics; the working human insulin gene is inserted in bacterial plasmids which are taken up by bacteria and then **transcribed and translated to produce insulin.**

Making recombinant DNA

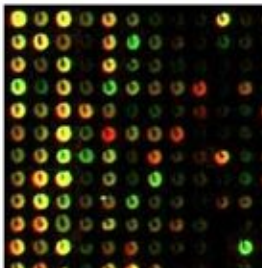
To make recombinant DNA the **desired gene** must first be **isolated**. This is often done using **restriction endonuclease enzymes** which **recognise and cut** at sections of DNA either side of the desired gene, isolating it.

Isolated DNA fragments can be placed in plasmids in a following way:

1. **Plasmid** and gene are cut with **the same restriction enzyme** to create **complementary ends**. If sticky ends are missing, they can be added.
2. Plasmids are used as **vectors** to move the desired gene into other organisms because they exist naturally and are small and easy to use.
3. The fragments are **incubated** with the plasmids and **mixed with the enzyme DNA ligase.** If a plasmid takes up the insert, base pairing takes place between the complementary ends which are then sealed with the use of DNA ligase which forms **phosphodiester linkages.**
4. A **recombinant DNA molecule** is created

Microarrays

Microarrays can be used to determine **which genes are expressed within cells** of an organism. An array is set up containing the **cDNA** of the gene(s) being tested for the presence of. The person's fragmented DNA sample is **fluorescently labelled** then washed over the array; if they contain the allele for any of the gene probes on the array then their DNA will **hybridise** to the probe and **fluoresce**, showing the gene is present.



Bioinformatics

Bioinformatics is the science of collecting and analysing complex biological data such as genetic codes. It can be used to build and store **databases** of genomes and gene sequences of thousands of organisms, meaning it can be used to compare **genetic relationships** between species and within species.

Modifying organisms

Microorganisms

In the formation of transgenic microorganisms, **electroporation** is used to stimulate bacterial cells to take up transformed plasmids. Electroporation facilitates the process by **increasing the permeability of bacterial membranes** thus increasing the chance of success. This is achieved via the use of **calcium salts** and **rapid temperature increase** from 0 to 40 degrees. Bacteria which have successfully taken up a plasmid can be identified with the help of **marker genes.**

For instance, if a plasmid contains an **antibiotic resistance gene**, the bacteria will be resistant to the antibiotic, and if grown on the media, only the bacteria which have been successfully transformed will survive. Other types of vectors include **bacteriophages, liposomes and yeast.**

Plants

One of the most common GM plants is **rapeseed**. A recombinant plasmid is produced as shown above and then inserted into bacteria which can **infect** the rapeseed plant cells, inserting the plasmid containing the desired gene into plant cells, **transforming** them.

Animals

Inserting recombinant DNA into animal cells can be done by **modifying fertilised egg cells.** This is known as **germ line therapy**, since all resulting cells produced from the transformed zygote will contain the desired gene, this is currently banned in humans however a type of gene therapy known as **somatic cell therapy** which only transforms specific adult body cells is allowed.

Recombinant DNA can be inserted into host cells in the following ways:

- **Virus** - these infect host cells and **insert their RNA and DNA** into their genome
- **Microinjection** - using a very **fine glass pipette** to physically insert the desired DNA into fertilised egg cells
- **Microprojectile** - inserting the DNA by firing it at **very high speed** into the cell
- **Liposome wrapping** - liposomes can **fuse** with the cell surface membrane and release their contents inside of the cell and have been used to **deliver recombinant DNA** to cells

Risks and benefits of genetic modification

Benefits:

- GM crops are modified to have a **higher yield, increased nutritional value** and **pest resistance,** all of which can help **reduce malnutrition** in third world countries.
- **Medication** and **treatments** (such as insulin for diabetics) can be produced **quickly and cheaply**, making them more **affordable**
- Potential use for **gene therapy** in treating human disorders
- Can produce large quantities of **enzymes** cheaply which can then be used as **catalysts** industrially

Risks:

- Could lead to **monoculture** of farmers growing only 1 GM crop, leading to **reduced biodiversity**
- **Superweeds** could arise if genes for **herbicide and pest resistance** get into the rest of the environment through breeding with GM plants
- **Genetic modification** of humans can be seen as **unethical** and lead to **designer babies** and **prejudices** against those with genetic disorders
- Companies who own genetic modification technology could seek to profit out of it further and **limit the use of technology** that could save lives