Edexcel IAL Biology A Level

Topic 3: Cell Structure, Reproduction and Development

Notes

Cells

All living organisms are made of cells, there are 2 types of cell – **eukaryotic and prokaryotic cells. Bacteria cells are prokaryotic** whereas **human cells are eukaryotic**. Eukaryotic cells contain a **nucleus and membrane-bound organelles** whereas prokaryotic cells don't. Most eukaryotic cells have the same internal organelles, but **cell specialisation** means cells often differ in number and sometimes types of organelle present, for instance red blood cells have no nucleus so they have more room for transporting oxygen.

Cell organisation

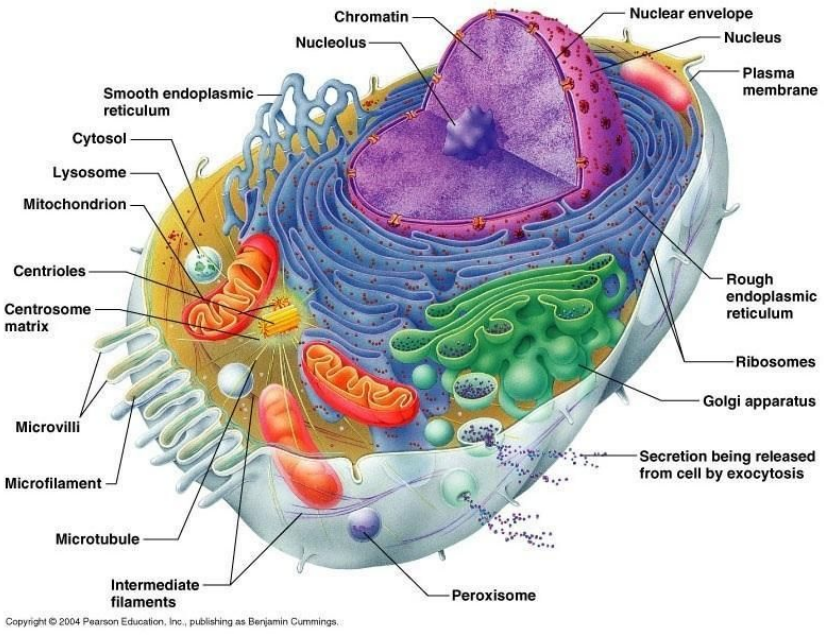
Groups of cells that carry out a **common function** are known as a **tissue**, groups of tissues that work together to carry out a **common function** form an **organ** and groups of organs that carry out a **common function** form an **organ system.**

For example, groups of cells in the stomach make up the **muscular tissue**, this tissue along with the **epithelium tissue** make up the **stomach organ,** and the stomach and various other organs, such as the pancreas and small intestines make up the **digestive system**. Many organs are part of **more than one organ system**, like the pancreas which carries out various functions for both the endocrine system and the digestive system.

Ultrasound of cells

A more detailed structure of cells called the **ultrastructure** can be obtained by using a **microscope.**

Ultrastructure of eukaryotic cells:



- **Nucleus** - surrounded by a **double membrane called the envelope** containing **pores** which enable molecules to enter and leave the nucleus. The nucleus also contains **chromatin** and a **nucleolus** which is the site of ribosome production.

- **Rough endoplasmic reticulum (RER) - a series of flattened sacs** enclosed by a membrane with ribosomes on the surface. RER **folds and processes proteins** made on the ribosomes.

- **Smooth endoplasmic reticulum** - a system of **membrane bound sacs**. SER **produces and processes lipids**.

- **Golgi apparatus** - a series of **fluid filled, flattened & curved sacs** with **vesicles** surrounding the edges. Golgi apparatus **processes and packages proteins and lipids**. It also **produces lysosomes**.

- **Mitochondria** - usually **oval shaped, bound by a double membrane** called **the envelope**. The **inner membrane** is folded to form projections called **cristae** with a **matrix** on the inside, containing all the **enzymes** needed for **respiration.**

- **Centrioles - hollow cylinders** containing a ring of **microtubules** arranged at **right angles** to each other. Centrioles are involved in **cell division.**

- **Ribosomes** - these are **composed of two subunits** and are the site of **protein production.**

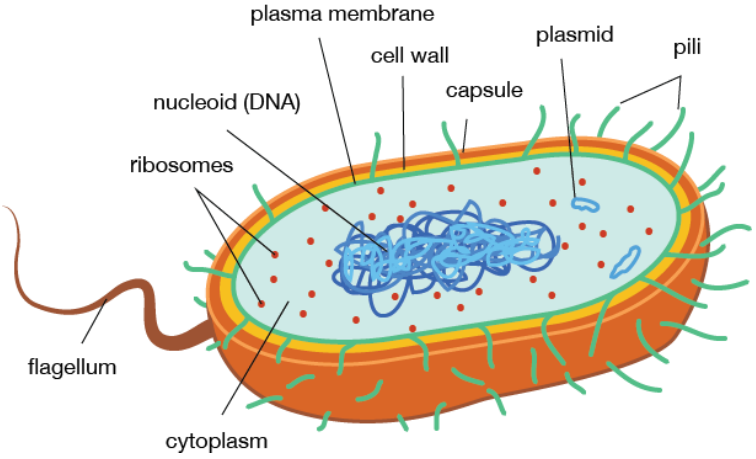
- **Lysosome** - a vesicle containing **digestive enzymes** bound by a **single membrane.**

Prokaryotic cells such as bacteria contain:

- **Cell wall** – Rigid outer covering made of **peptidoglycan**

- **Capsule** – **Protective slimy** layer which helps the cell to **retain moisture** and **adhere** to surfaces

- **Plasmid** –**Circular** piece of extra DNA



- **Flagellum**- a tail like structure which **rotates to move the cell**

- **Pili**- Hair-like structures which attach to other bacterial cells

- **Ribosomes**- Site of **protein production**

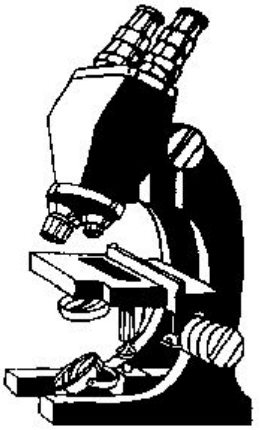
- **Mesosomes**- **Infoldings** of the inner membrane which **contain enzymes** required for **respiration**

Extracellular enzymes

Extracellular enzymes are enzymes secreted by cells into their **external environment**; enzymes are **proteins** so are synthesised in **ribosomes** free in the cytoplasm or attached to the rough endoplasmic reticulum. The polypeptide gets sent to the **Golgi apparatus**, where it is **folded** into its **3D shape**, it is then packaged in a **Golgi vesicle** which can then **fuse** with the cell surface membrane to **release the enzymes** outside of the cell. These vesicles are important to ensuring the enzymes only catalyse reactions, such as the breakdown of biological molecules, where required, in this case outside of the cell.

Studying cells

In order to understand the **functioning of cells and their organelles**, scientists must first be able to look inside and study the cells, using microscopes. How useful a microscope is for studying cells depends on its **resolution, magnification power and ease of use.**



Resolution is the degree to which it is possible to distinguish between 2 points that are close together.

Magnification is the degree to which an image of an object is larger than the object itself.
You can calculate image size, actual size and the magnification using this formula, as long as the units on image and actual size are the same:
Image size = actual size X magnification

Optical microscopes are what you'll have used in school, but these can rarely make out organelles except the nucleus; so electron microscopes are more commonly used, of which there are 2 types - **scanning electron microscope (SEM) and transmission electron microscope (TEM).** The 3 different microscopes each have advantages and disadvantages:

Optical microscope
This microscope uses **light** to form an image, light has a **longer wavelength than electrons**, so this microscope has a **lower resolution** than the electron microscopes.
Advantages:

- **Easy to use**
- Slides are **easy to prepare**
- Can view **live specimens**

Disadvantages:

- **Lowest resolution**
- **Lowest maximum magnification**
- Only **large organelles** are visible

Scanning electron microscope

This microscope **scans a beam of electrons** across the sample **which knocks off electrons** which then form an image.

Advantages:

- **Higher resolution** than optical microscope
- **Higher magnification** than optical microscope
- Forms **3D images**
- Can be used on **thick specimens**

Disadvantages:

- **Lower resolution** than TEMs

Transmission electron microscope

This microscope passes electrons through a **thin specimen**; denser regions **absorb more electrons** so less pass through creating a **darker area** on the image.

Advantages:

- **Highest resolution**
- **Highest magnification**
- Can see **internal structures** of organelles

Disadvantages:

- Needs very **thin specimens**
- Slides are **hard to prepare**

Staining in microscopy

Stains and dyes are **applied to tissue samples** and **bind to organelles** making them easier to view. Staining **increases the contrast** in the image formed, this can make it easier to see apart 2 objects that are close together, so **increase resolution.**

Reproduction

Chromosomes

Every cell, except sex cells, has **two** of each chromosome; one inherited from the mother, one inherited from the father, this pair is known as a **homologous pair.** A **locus** (plural: loci) is **the position of a gene on a chromosome**. Homologous chromosomes have the same genes and loci, however **the alleles possessed is different** on each chromosome.

Meiosis

Key words:

- **Chromatid** – When DNA replicates it forms chromosomes made of **two identical sister chromatids**, each containing the **same copy of genes** for that chromosome.
- **Gamete** – A **haploid sex cell**

- **Zygote** – The **diploid cell** formed when **two gametes fuse**
- **Haploid** – Describes a cell containing **half the usual amount of DNA** (for instance **sex cells** in humans that contain two chromosomes instead of 46)
- **Diploid** – Describes a cell containing a **complete set of DNA**

Variation between organisms that reproduce sexually arises through features of **meiosis** and **random fertilisation**. Meiosis is a type of cell division that gives **rise to genetic variation**, its role is to produce **haploid gamete cells,** which then **randomly fuse during fertilisation to form a zygote** with an equal mix of chromosomes from each parent. When the cell is not dividing the DNA is found as **uncondensed strands** known as **chromatin**. Once the DNA has been replicated, meiosis begins and occurs as follows:

1. **Prophase I** – The chromatin begins to **condense and shorten**, forming **chromosomes.** The **nuclear envelope** surrounding the DNA **breaks down** so the chromosomes are free in the cytoplasm. Also, **spindles** (protein strands that move the chromosomes) are made by the **centrioles**.
2. **Metaphase I** – The chromosomes are **pushed to the centre** of the cell by spindle fibres and line up in **homologous pairs.**
3. **Anaphase I** – The spindle fibres **contract and shorten** and move the chromosomes to **opposite poles** of the cell so one chromosome from each pair is at either end.
4. **Telophase I** – **two nuclear envelopes form** around each set of chromosomes.
5. **Cytokinesis** – the **cytoplasm divides** to form two cells.

The process then **repeats** for each of the two cells formed from the first division, this is known as **meiosis II**. However, during **metaphase II** there is only **one chromosome** from each pair (instead of two in metaphase I) so the chromosomes line up on their own, and in **anaphase II** the **chromatids of each chromosome are separated.** This results in **4 non-identical, haploid daughter cells.**

Genetic Variation

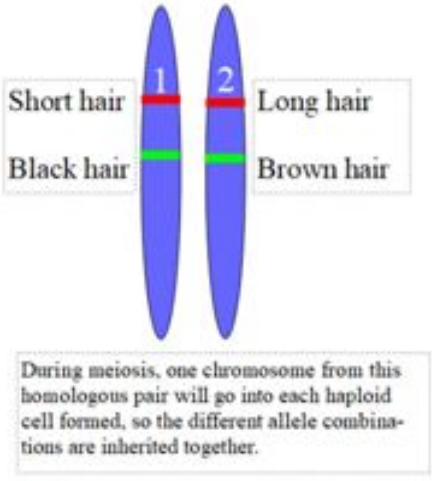
Two features of meiosis contribute to genetic variation in addition the variation created by random fertilisation of two unique gametes from different parents.

- **Independent assortment** – occurs during **metaphase I** – the order the chromosomes line up in (i.e. which side the maternal and paternal chromosomes line up in) in their pairs is random, meaning **the combinations of chromosomes going into the daughter cells is random.**

- **Crossing over –** occurs during **prophase I** – The relatively rare process whereby homologous chromosomes **swap portions of their chromatids,** which results in mixing of the parental genetic information in offspring chromosomes and **new allele combinations.** The structure formed by the homologous chromosomes formed during crossing over is known as a **bivalent**.

Gene linkage

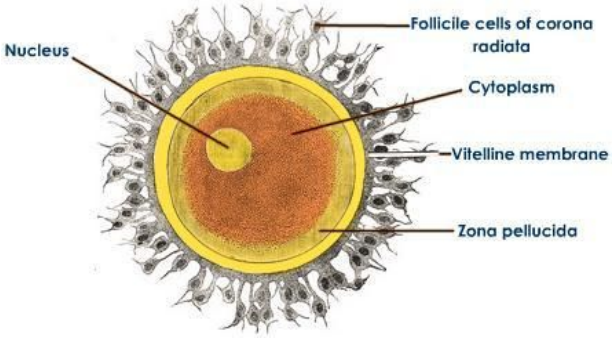
If two genes are located on the same chromosome, then they will be **inherited together,** as during meiosis, one whole chromosome is passed to the gamete (except in the case of crossing over during meiosis), this is known as **chromosome linkage.**



During meiosis, one chromosome from this homologous pair will go into each haploid cell formed, so the different allele combinations are inherited together.

For instance, if a dog has the genes for hair length and hair colour on the same chromosome; and one of its homologous chromosomes contains the alleles for long and brown hair, and the second chromosome contains the alleles for short and blond hair, then the only allele combinations it can pass on to offspring are still long and brown, or short and brown - as **one chromosome containing both is passed on to each haploid gamete cell.**

Mammalian gametes and fertilisation

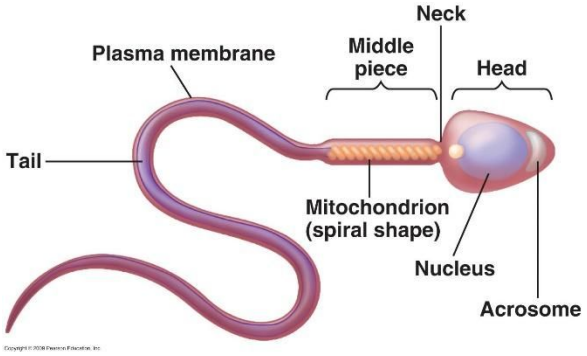


Egg cell:

- It contains **zona pellucida** which is a **protective coating** which the sperm have to penetrate in order for fertilisation to occur, the main purpose of zona pellucida is to **stop more than one sperm fertilising the egg.**
- It contains a **haploid nucleus** so that a full set of chromosomes is restored at fertilisation
- **Cortical granules** are organelles that release substances which cause the **zona pellucida to harden.**
- **Follicle cells** form a **protective coating** around the egg.

Sperm cell:

- Sperm cells contain a lot of **mitochondria** to provide the energy for **rotation of the flagellum** which enables it to move and swim towards the egg.
- **Acrosome** contains **digestive enzymes** which **break down the zona pellucida** and allow sperm to penetrate the egg.

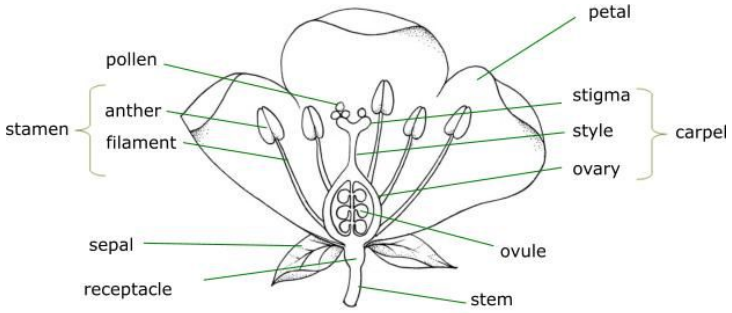


Fertilisation in mammals occurs as following:

1. The sperm head meets the **protective jelly layer** around the egg cell called the zona pellucida and **acrosome reaction** occurs – enzymes **digest** the zona pellucida in order to enable sperm to reach the egg.
2. The sperm head **fuses** with the **cell membrane** of the egg cell thus allowing the **sperm nucleus to enter the egg cell.**
3. **Cortical reaction** occurs which causes the zona pellucida to **harden** therefore preventing other sperm from entering the egg cell.
4. **The nuclei fuse** and a full set of chromosomes is restored thus creating a **diploid zygote.**

Flowering plants

Structure of flowers



The image above illustrates a generalised flower structure. The **stamen** is the male part of the plant consisting of a **long filament with anthers at the end,** which are involved in the production of male gametes in the form of **pollen grains.** The **carpel** is the female part of the plant which is the site of **ovule development.**

The process in which pollen grains produced by anthers are transferred to female reproductive organs of a plant in the form of stigma is known as **pollination**. Pollination can either occur with the help of **wind or insects.** The product of fertilisation is the **seed** which then develops into a **fruit**.

Double fertilisation

Plant fertilisation occurs as following:

1. Pollen grain composed of the **pollen tube cell** and the **generative cell** adheres to the **stigma**, where it subsequently **germinates to produce a pollen tube.**

2. The pollen tube grows down the stigma, **secreting digestive enzyme** which digest the surrounding tissue and use it as a source of **nutrients**.

3. The pollen tube grows through a gap between the integuments, known as the **microphyle,** into the **embryo sac.**

4. The **generative cell** of the pollen **divides** to produce two sperm cells which enter the embryo sac.

5. One of the male gametes **fuses** with the female nucleus to form a **zygote.**

6. The other **male gamete fuses with two polar nuclei to form an endosperm nucleus** which serves as a source of nutrients for the embryo.

7. **The fertilised ovule divides by mitosis** to form the embryo consisting of the developing shoot known as the **plumule**, developing root known as the **radicle** and one or two **cotyledons**. The integuments become the seed coat, the ovule becomes the seed and ovary becomes the fruit.

Mitosis

Mitosis is the **asexual** process by which all **somatic cells** (non-sex cells) divide to produce new cells, so that organisms can **grow and repair and replace damaged cells.** Mitosis occurs by the same stages as meiosis:

1. **Prophase** – The **chromatin** begins to **condense and shorten**, forming chromosomes. The **nuclear envelope** surrounding the **DNA breaks down** so the chromosomes are free in the cytoplasm. Also, spindles (protein strands that move the chromosomes) are made by the centrioles.
2. **Metaphase** – The **chromosomes are pushed to the centre of the cell** by spindle fibres and line up on their own.
3. **Anaphase** – The **spindle fibres contract and shorten** and move the chromosomes to **opposite poles of the cell** so one chromosome from each pair is at either end.
4. **Telophase** – **two nuclear envelopes** form around each set of chromosomes.
5. Cytokinesis – the cytoplasm divides to form **two cells.**

Mitosis ends after **one division** so that the **two resulting daughter cells are diploid.** Since the resulting cells have **no mixing or combining of genetic information**, they are **genetically identical** to each other and the parent cell, making mitosis the ideal process for **normal growth** in organisms.

The cell cycle

The cell cycle is the series of stages a cell goes through in its lifetime and consists of 4 main stages, with cells spending around **10% of the cycle in mitosis**, the other **90% in the other stages that make up interphase:**

- **Growth 1** – The cell grows, synthesises proteins and carries out its function.

- S phase – The cell carries out its usual function as well as replicates its DNA in preparation for mitosis.
- Growth 2 – The cell continues to grow and synthesise proteins, as well as **making proteins needed for cell division** such as spindle fibres.
- Mitosis – The cell divides.

Calculating the mitotic index

Mitotic index is a measure of the proportion of cells that are dividing in a tissue sample and is calculated when observing cells under a light or electron microscope. Cells such as those in skin, which replace cells quickly, have a high mitotic index.

It is calculated using the following formula:
Number of cells with visible chromosomes ÷ total number of cells observed.

Stem cells

Stem cells are undifferentiated cells which can keep dividing to give rise to other cell types in a process known as specialisation. There are 4 types of stem cell - totipotent, pluripotent, multipotent and unipotent stem cells.

Totipotent cells can give rise to **all types of specialised cells** including placental cells and pluripotent cells are able to give rise to many types of specialised cells apart from placental cells. During development, totipotent cells translate only part of their DNA, resulting in cell specialisation.

A morula is an early-stage embryo formed 3-4 days after fertilisation. It consists of 16 cells only and contains totipotent cells that can differentiate into all cells including the placental cells. By **4-5 day**s after fertilisation the morula has developed into a blastocyst - a mass of 200-300 cells that contains an inner cell mass which develops into the embryo. Cells present in the blastocyst are pluripotent.

Totipotent cells only occur in the morula stage in mammalian embryos whereas other type of stem cells such as pluripotent, multipotent and unipotent cells are found in mature mammals. Pluripotent stem cells are commonly used in treating human disorders by replacing damaged tissue. Unipotent cells, such as cardiomyocytes can only differentiate into one cell type. Potency of cells tends to decrease with age - when you are older, you have **fewer pluripotent and multipotent stem cells.**

Sources and uses

Sources of stem cells include embryonic stem cells, adult stem cells and fused cells. Stem cells can be used to treat a variety of diseases such as diabetes, multiple sclerosis and

Parkinson's disease. They can also be used to replace damaged tissues such as nerve tissue in spinal cord injuries.

Ethical issues

However, there are many ethical issues related to the use of stem cells, stem cells could **save many lives** and **improve the quality of life** of many people, however many people believe it's unethical as **embryos are killed** in the process of stem cell extraction. Moreover, there's a **risk of infection** when cells are transplanted and they could also become cancerous.

Cell specialisation

Stem cells can develop into **all the different cells in the body** - from long neurones to biconcave red blood cells. All specialised cells have different features, functions and structures, yet they all have the same genetic information within them and it is the process of **cell specialisation** that produces all the different cells. The process is as follows:

1. Certain genes within the genome are **activated** under the correct conditions - when certain proteins and chemicals are present.
2. Other genes are **unactivated**.
3. The genes activated are **transcribed** to form **mRNA** which moves to the ribosome to be **translated into polypeptides.**
4. The proteins produced change the cell; **changing its structure and controlling its processes.**
5. These changes and protein production are what makes the cell **specialised**. The changes are **virtually irreversible** - a specialised cell **can not revert back to a stem cell.**

Phenotype

The phenotype is **the characteristics expressed due to genetics and the environment.** Certain things are only affected by genetics, for instance the colour of your eyes, but a lot of things are affected by a **combination** of the 2, such as skin colour - your genes dictate the natural colour of your skin, but exposure to sunlight can darken it. Another example is how tall a plant has the potential to grow, yet it is the environment (nutrient and water availability, sunlight and space) that dictates how tall a plant actually grows.

Epigenetics

Epigenetics is the study of changes of gene expression due to the environment, without a change in the bases of DNA, but by the addition of chemical groups that affect how easy it is to transcribe genes.

Methylation of DNA

Methylation is **adding methyl groups** (CH3), a type of epigenetic marker, to DNA. The methyl group is added between the bases **guanine and cytosine** on DNA and makes it **harder for RNA polymerase to bind**, so the gene is **transcribed less and therefore translated less,** effectively turning it off. **Hypermethylation** (adding too many methyl groups) turns genes **off**, whereas **hypomethylation** (too few methyl groups attached) **activates** genes.

Acetylation of histones

Histones are proteins that DNA associates with to **coil and condense into chromosomes.** In order for a gene to be transcribed the DNA must be **uncondensed so the transcription enzymes can bind to it**, the addition or removal of acetyl groups - a type of epigenetic marker - affects how easily the DNA can unravel and be transcribed. The **more** that attach**, the more the chromatin unravels**, so the **easier it is for genes to be transcribed.**

Epigenetic changes across generations

Epigenetic changes can be passed onto **offspring**. Most epigenetic markers are **removed during meiosis, but some remain**, meaning environmental changes in grandparent's lives can affect their offspring's expression of genes. **Reprogramming** is the process of **removing the epigenome** and occurs at various points in a species lifetime, however **1% of genes evade the reprogramming,** meaning some epigenetic markers remain.

Polygenic inheritance

Polygenic inheritance is where features of the phenotype are controlled by **several different genes** and often the **environment** too. For instance, it is thought that **height** is controlled by over 400 genes and also the environment dictates how tall an organism actually grows, due to factors like availability of nutrients.

Polygenic inheritance leads to **continuous variation**. When considering the effects of 1 gene we often look at the outcome of different alleles. Very simple - such as whether a labrador's coat will be black or brown, when in reality there is a whole spectrum of colours and different shades the coat could be, this is continuous variation. Height again varies across organisms across an **entire range,** a person is not simple 'short' or 'tall' and this is due to the **interactions of multiple genes.**

Multiple alleles

Phenotypes are also affected by **multiple alleles**, this is where there are **at least 3 different alleles for a gene** - as opposed to just 1 dominant and 1 recessive allele for each gene. A common example of this is the alleles for **blood groups** - I^A, I^B, and I^O , with the O allele being recessive, and A and B being codominant, resulting in 4 possible phenotypes - blood group A, B, AB and O.