Recap

We learnt about the importance of transcription and translation in protein synthesis. Transcription produces mRNA in prokaryotes and pre-mRNA in DNA. You now understand the difference between exons and introns, and how translation produces polypeptides from the codon sequence carried by mRNA.

Key Aims

1. *Gene Mutation*
2. *Chromosome Mutation*
3. *Non-Disjunction of Chromosomes*
4. *Meiosis*
5. *Sources of Genetic Diversity*

AQA Specification

Gene mutations involve a change in the base sequence of chromosomes. They can arise spontaneously during DNA replication and include base deletion and base substitution.

4.3. Genetic Diversity Can Arise as a Result of Mutations or Through Meiosis

Gene Mutations

Gene mutations involve a change in the base sequence of chromosomes.

- **Gene mutations usually happen due to replication errors.** **Polymerases** responsible for replicating the DNA can sometime make errors called "proof reading" errors, where they mistakenly add or remove a base.

- **Mutations in a single base of DNA are called point mutations.** **Point mutations** can be either the deletion of a single base, or the gain of a single incorrect base.

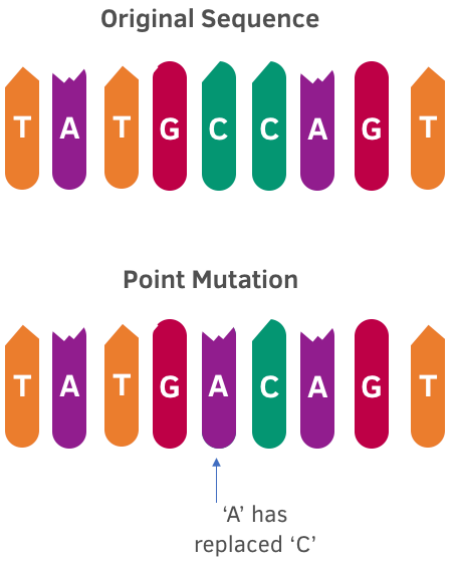

Fig 1. Point Mutation.

AQA Specification

Due to the degenerate nature of the genetic code, not all base substitutions cause a change in the sequence of encoded amino acids.

There are different types of mutations:

1) **Base pair deletions**: One or more bases are incorrectly deleted from the sequence.

2) **Base pair substitution**: One or more bases are incorrectly replaced with another base(s).

3) **Base pair insertion/addition**: One or more bases are incorrectly added to the sequence.

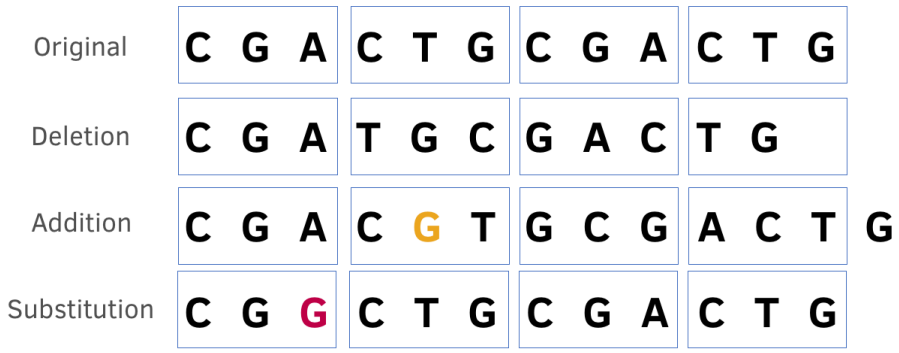

Fig 2. Types of Mutation.

Frameshift Mutations (Insertion or Deletion)

- **Base deletion or insertion can lead to frameshifts.** If you add or remove a base from the sequence, all of the bases move up or down. Therefore all of the codons change, which can have a drastic effect on how the gene is read.

Sense and Non-Sense Mutations (Substitution)

- **Base substitutions only affect one codon.** **Point mutations** involving **base substitution** can only affect the sequence of a single codon. The rest of the base sequence remains unaffected.

Sense Mutations

Knowledge Recall

1. *What is a gene mutation?*
2. *What is a frameshift?*
3. *What are sense and non-sense mutations?*

- **Sense mutations code for an amino acid.** In **sense mutations**, the codon changes but an amino acid is still produced. The amino acid can be the same or may be a different one.

- **Mutations in the third base of a codon may have little effect.** Codons are triplets of bases in DNA. A mutation in the **third** base of a codon usually does not change the amino acid that needs to be encoded. In most cases as long as the **first two** bases of a codon are correct, the codon will still code for the correct amino acid even if the third base of the codon is incorrect. This is because of the degenerate nature of codons (this effect is also referred to as the **3' wobble**).

Non-Sense Mutations

- **Non-sense mutations do not produce an amino acid.** In **non-sense mutations**, usually a **STOP** codon is coded for, which leads to the production of a truncated (shortened) protein. Alternatively, there could be a significant change in the amino acid sequence of a protein.

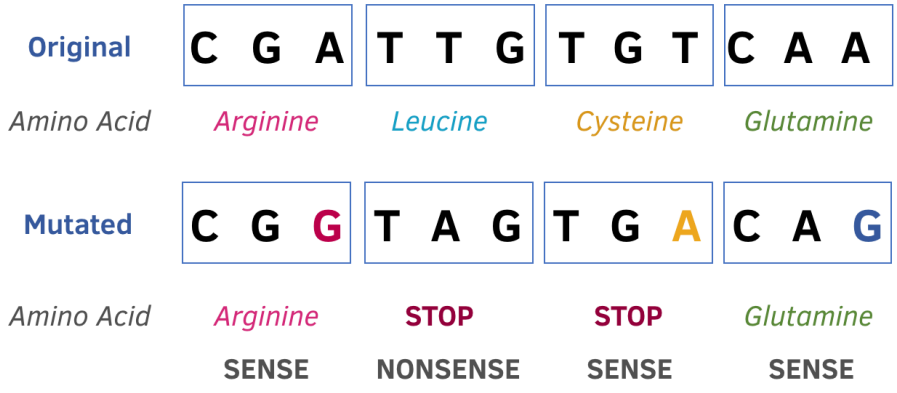

Fig 3. Sense and Non-Sense Mutations.

Good and Bad Mutations

- **Mutations are usually bad for a cell.** In most cases, **non-sense mutations** can result in severe consequences for a cell. Mutations can result in the production of **dysfunctional** proteins which can have adverse effects on a cell and can sometimes even be lethal.

- **Some mutations are beneficial.** In some cases, mutations can lead to the development of new **alleles** of a gene (e.g., mutations causing different eye colours) which can contribute to genetic diversity in a gene pool. Mutations can help in **natural selection** in particular.

AQA Specification

Mutagenic agents can increase the rate of gene mutation.

Mutagenic Agents

- **Mutagenic agents can increase the rate of gene mutations.** **Mutagenic agents** are chemical, biological or physical agents that cause changes to the DNA of cell. Examples of mutagenic agents include ionising radiation (like X-rays and gamma rays), viruses such as the Human Papilloma Virus (HPV) and chemicals such as formaldehyde and benzene.

AQA Specification

Mutations in the number of chromosomes can arise spontaneously by chromosome non-disjunction during meiosis.

Chromosomal Mutations

- **Mutations can occur in entire chromosomes.** Mutations in chromosomes usually occur in cell division during **meiosis**. This usually occurs due to **improper separation** of chromosomes during division, or during **improper chromosome recombination**.

Breakage of Chromosomes

Knowledge Recall

1. *Name and describe the different types of gene mutations.*
2. *When do chromosomal mutations usually occur?*
3. *Name and describe the different types of chromosomal mutations?*

Breakage of chromosomes during meiosis can result in:

- **Deletion**: this occurs when an entire region of a chromosome is accidentally deleted.
- **Translocation**: a portion of one chromosome accidentally switches places with a separate, non-homologous chromosome (e.g. Philadelphia Chromosome).
- **Inversion**: a portion of a chromosome can break, and re-join into the original chromosome but after inverting itself, resulting in a change in sequence.
- **Duplication**: regions in a chromosome can become duplicated.

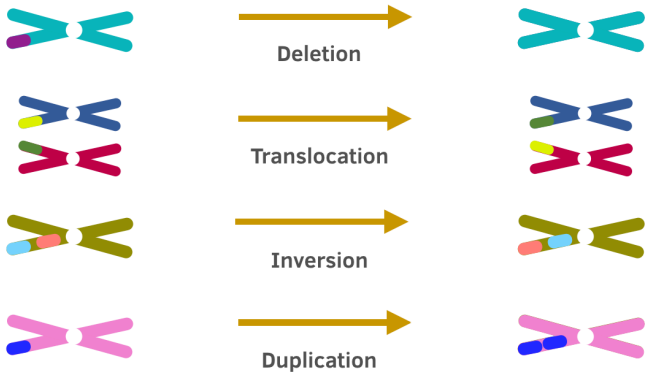

Fig 4. Mutations in Chromosomes During Meiosis.

Knowledge Recall

1. *What are non-disjunction mutations and when do they usually occur?*
2. *Which genetic mutation causes Down's syndrome?*

Non-Disjunction

Non-disjunction mutations involve a problem in the separation of chromosomes during meiosis. This can result in the loss of an entire chromosome in one daughter cell, and a gain of a chromosome in another daughter cell.

- **Improper separation occurs during anaphase and telophase.** Non-disjunction results from improper separation of chromosomes during **anaphase** and **telophase** of **meiosis**.

- **Down's Syndrome occurs when there is an extra chromosome 21.** **Trisomy 21** (**Down's syndrome**) results from non-disjunction during meiosis. The sex cells of one parent can have three copies of chromosome 21, resulting in an offspring with three copies of chromosome 21 which causes Down's syndrome.

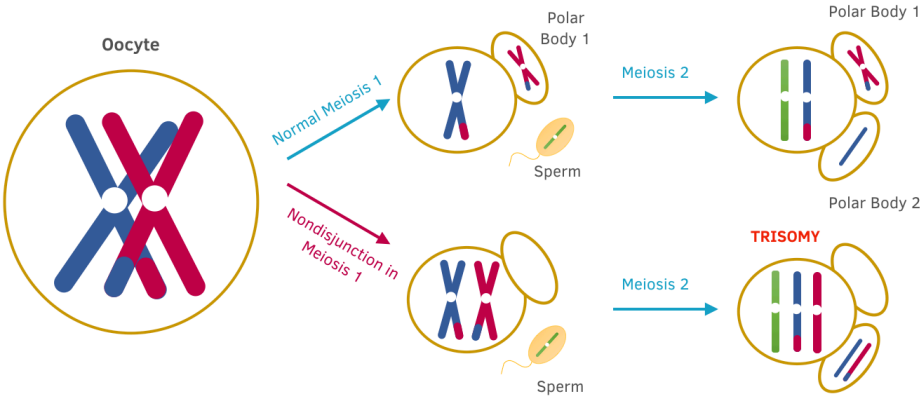

Fig 5. Non-disjunction of Chromosomes in Meiosis. Chromosome mutations can happen during meiosis I or meiosis II.

Knowledge Recall

1. *Why are mutations during meiosis usually not harmful?*
2. *Describe the process of mitosis.*
3. *What is apoptosis?*

Non-Disjunction in Mitosis

Non-disjunction, as well as other chromosomal mutations, can occur in both **mitosis** and **meiosis**.

- **Mutations in mitosis are generally not very harmful.**
  - In most cases, the cell can undergo **apoptosis** after detecting genetic abnormalities.
  - In some cases, these chromosomal mutations can result in **defective cells** such as cancer cells (e.g. Philadelphia chromosome)
  - Mutations arising in **mitosis** are **not** heritable by off-spring.

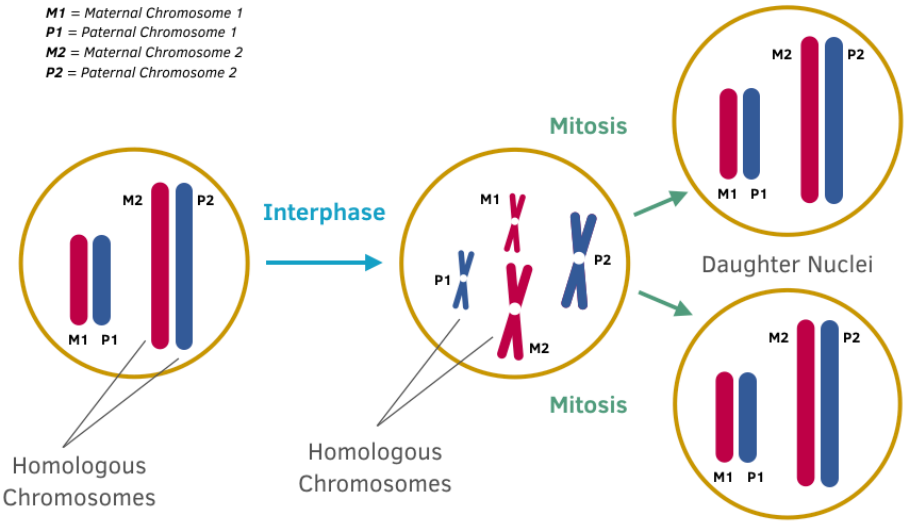

Fig 6. Mitosis.

- **Mutations in meiosis can be inherited by off-spring.**
  - **Meiosis**, as you will see in this chapter, is the mechanism of division for **gametes** (sperm and egg).
  - Gametes are responsible for transferring genetic information to offspring.
  - Mutations in gametic chromosomes can result in those mutations being **inherited** by an offspring.

AQA Specification

Meiosis produces daughter cells that are genetically different from each other.

Meiosis

Introduction to Meiosis

Earlier we learnt about **mitosis**, which is how somatic (body) cells divide and how **asexual reproduction** can occur.

Meiosis is the process of cell division which gives rise to gametes. For the most part, meiosis is very similar to mitosis.

AQA Specification

Understand that two nuclear divisions result usually in the formation of four haploid daughter cells from a single diploid parent cell.

- **Gametes are the sperm and egg.** **Gametes** in most organisms are referred to as the **sperm** (for males) and the **egg** (for females). During fertilisation they join to form a **zygote**, which then divides by mitosis to produce more and more cells.

- **Meiosis is needed for sexual reproduction.** Meiosis is necessary for proper sexual reproduction to occur. Without meiosis, there are no sex cells and hence no fertilisation.

- **Meiosis produces 4 haploid daughter cells.** Whereas mitosis produced **2 identical diploid** daughter cells, meiosis produces **4 non-identical haploid** daughter cells. Therefore during fertilisation, when the egg and sperm fuse, **two haploid cells** join to form **one diploid cell**. In the final diploid cell, half the chromosomes come from the egg (mother) and half from the sperm (father).

- **Meiosis leads to genetic diversity.** The 4 daughter cells produced in meiosis are not genetically-identical. So sperm cells can vary from each other, and likewise egg cells can be different to other egg cells. And any sperm cell can be matched with any egg cell, so many combinations can occur.

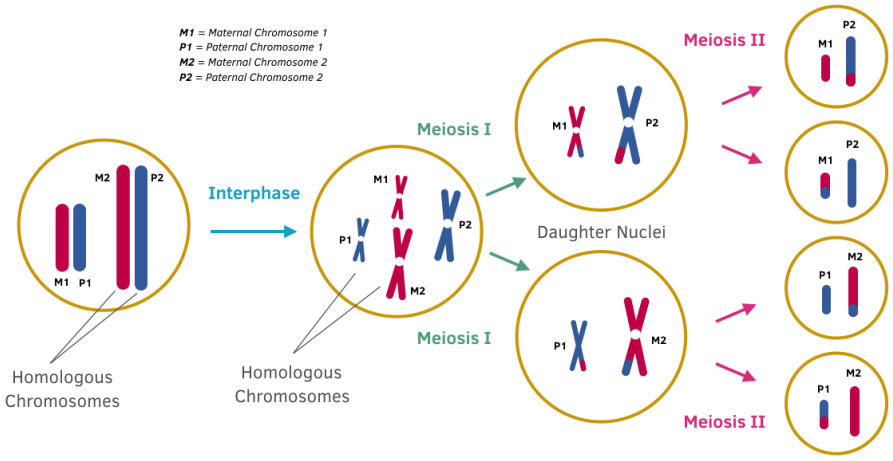

Fig 7. Overview of Meiosis.

Knowledge Recall

1. *What is meiosis?*
2. *How are gametes different from normal body cells?*
3. *What is the difference between mitosis and meiosis?*

Mechanism of Meiosis

Meiosis is essentially two rounds of **mitosis**, but with some very important differences. You start with **1 diploid** cell, and end up with **4 haploid** cells.

1) Interphase

Skills Development

To help you understand meiosis you could examine meiosis in prepared slides of suitable plant or animal tissue.

Before meiosis I, **interphase** occurs. There is DNA replication and growth of the cell, just like we learnt in the previous tutorial on mitosis. Interphase consists of two phases:

1. **S phase** - DNA replication
2. **Growth phase (G1 + G2)** - new proteins and organelles are made

2) Meiosis I

- **Meiosis I is essentially like mitosis.** **Meiosis I** results in the production of **two diploid daughter cells**. Each of the phases of meiosis I are the same as normal mitosis, except we refer to them as prophase I, metaphase I, anaphase I, and telophase I.

- **Crossing over occurs in meiosis I.** During meiosis I, a very important event known as **crossing over** occurs during prophase I. This does not occur in mitosis. We will learn more about this later.

- **Two diploid daughter cells are produced.** The remainder of meiosis I is exactly the same as mitosis. The homologous chromosomes are separated from each other and assorted into **two diploid daughter cells**.

Knowledge Recall

1. *When does crossing over occur?*
2. *What happens during interphase?*
3. *What is the role of spindle fibres in meiosis and mitosis?*

3) Meiosis II

During meiosis II, the two diploid daughter cells divide in order to produce a total of **four haploid daughter cells**, each with a **single copy** of every chromosome (only 23 chromosomes total per cell). The steps of meiosis II are summarised below:

a) Prophase II

- If the nuclear envelope was re-made after telophase I, it will break down again.
- The nucleolus disintegrates, the chromosomes condense and spindles are made.

b) Metaphase II

- The chromosomes line up in the centre (equator) and bind to the spindle fibres at the centromeres.
- The chromatids of each chromosome are **independently assorted** (see later).

c) Anaphase II

- The spindle fibres pull the chromatids to opposite ends of the cell. The centromere divides.

d) Telophase II

- In each cell, two nuclear envelopes will develop to form two haploid nuclei.
- The two cell divide by cytokinesis to produce four haploid daughter cells.

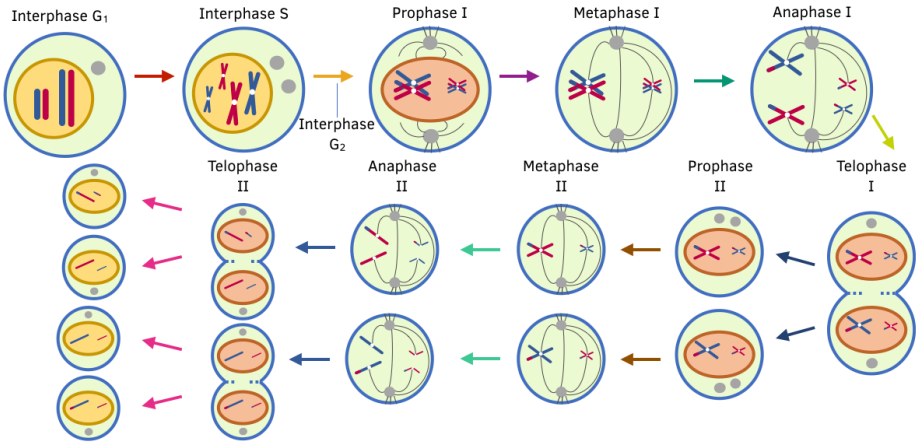

Fig 8. Mechanism of Meiosis.

AQA Specification

Understand that crossing over between homologous chromosomes results in further genetic variation among daughter cells.

Sources of Genetic Diversity

There are two key sources of genetic diversity in meiosis: **crossing over** and **independent assortment**.

Crossing Over

We mentioned crossing over above when discussing meiosis I. In crossing over, two homologous chromosomes come together and align, and then recombine and swap parts with each other.

1. **Bivalents develop**. Homologous chromosomes come together to form **bivalents**.

2. **Chiasmata form**. Non-sister chromatids wrap around each other, and they join up at certain points (called **chiasmata**)

3. **Chromosomes break**. The chromosomes can break up at the chiasmata, and sections of chromosomes may swap over between

Knowledge Recall

1. *What is a haploid cell?*
2. *What are the two sources of genetic diversity in meiosis?*
3. *Describe the mechanism of crossing over.*

Study Mind Tip

There is no crossing over in Meiosis I.

non-sister chromatids. The swapping over is only between non-sister chromatids.

4. **Recombination occurs**. The final chromatids still have the same genes, but they may have different alleles.

Overall, crossing over results in the creation of new alleles and ensures that offspring are not genetically identical to their parents.

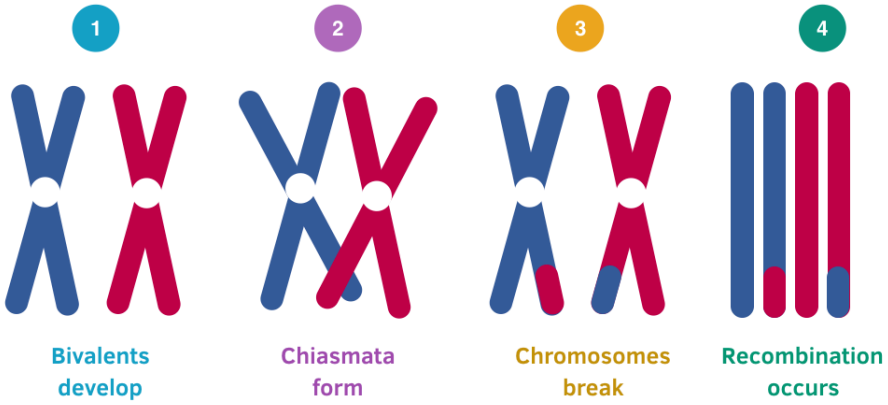

Fig 10. Crossing Over During Meiosis.

AQA Specification

Understand that genetically different daughter cells result from the independent segregation of homologous chromosomes.

Independent Assortment

In meiosis II, each pair of homologous chromosomes is split up. Remember, in any cell the homologous pair consists of two chromosomes which may or may not be identical. When the pair splits up, each daughter cell will receive one chromosome. The allocation of this is completely **random** - hence we call it independent assortment.

In terms of a textbook definition, **independent assortment** means that each chromosome is inherited randomly and independent of other chromosomes - i.e. the inheritance of one chromosome does not affect the inheritance of another chromosome.

Study Mind Tip

Independent assortment happens in mitosis too, but it doesn't really matter because all chromosomes are the same.

Measuring Genetic Diversity

Genetic diversity resulting from meiosis can be measured:

Skills Development

Students could use the expression 2n to calculate the possible number of different combinations of chromosomes following meiosis, without crossing over. And derive a formula from this to calculate the possible number of different combinations of chromosomes following random fertilisation of two gametes, where n is the number of homologous chromosomes pairs.

Study Mind Tip

Crossing over means that all chromosomes are not the same in meiosis I, so there is also independent assortment in meiosis I. However, the key to independent assortment giving the most diversity is due to meiosis II.

n = number of homologous pairs

- Due to the **splitting** in **meiosis**, the possible number of combinations of chromosomes in gametes is **2n**.

- Due to **independent assortment**, each chromosome can undergo a further randomisation and pairing. Therefore, the overall number of possible chromosome combinations in a single gametic cell is **$(2n)^2$**, where n is the total number of pairs of homologous chromosomes in an organism.

For example:

1. Humans have 23 pairs of chromosomes, hence n = 23.
2. 2n = 46
3. $(2n)^2 = 2{,}116$
4. This means that there are 2,116 different possible combinations of chromosomes which can be inherited by a single offspring.

Mitosis vs. Meiosis

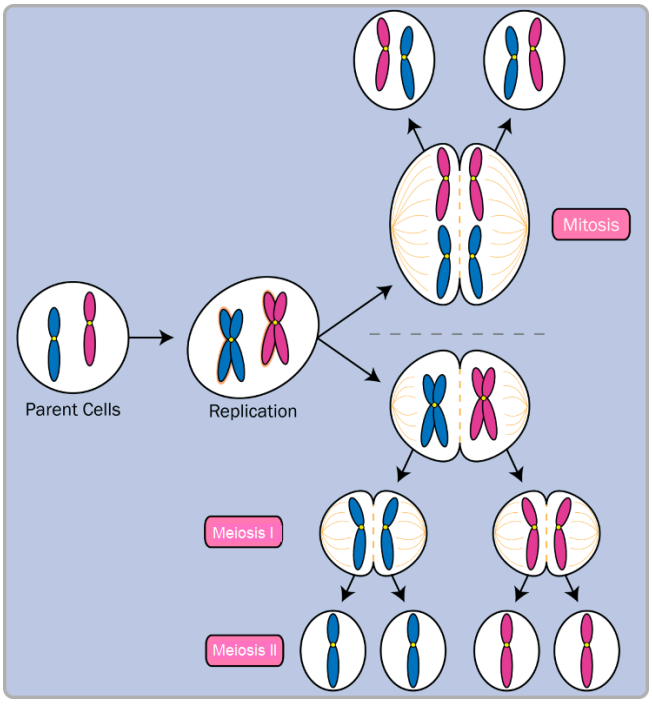

Fig 11. Mitosis vs. Meiosis.

Study Mind Tip

A comparison of mitosis and meiosis can easily be the focus of an exam question. Make sure you understand this table well, because it is the key to understanding these two types of cell division!

Knowledge Recall

1. *What does independent assortment mean?*
2. *What are the differences between mitosis and meiosis?*

	Mitosis	Meiosis
Number of Daughter Cells	2 daughter cells	4 daughter cells
Genetic diversity between daughter cells	Genetically identical daughter cells	Genetically different daughter cells
Genetic diversity between parent and daughter cells	Daughter cells genetically identical to parent cell	Daughter cells genetically different to parent cell
Chromosome Number	Daughter cells are diploid - have full number of chromosomes, and same as parent cell	Daughter cells are haploid - have half the number of chromosomes, and half of parent cell
Stages	Prophase I, Metaphse I, Anaphase I, Telophase I	Prophase I, Metaphase I, Anaphase I, Telophase I, Prophase II, Metaphase II, Anaphase II, Telophase II.
Crossing Over	No	Yes
Separation of Homologous Pairs	Homologous pairs do not get separated	Homologous pairs are get separated in anaphase II

Fig 12. Comparison of Mitosis and Meiosis.