Chromosomes and Meiosis

Chromosomes are long, thread-like structures that form part of the chromatin network in the nuclei of cells. They are made up of a strand of DNA wound around histones (proteins). They absorb dye very easily, allowing them to be seen under a microscope, and were discovered in 1888.

In somatic (body) cells of diploid organisms:

- Each cell contains the same number of chromosomes
- The chromosomes are made up of two sets. One chromosome of each pair comes from the mother (the maternal chromosome) and the other from the father (the paternal chromosome). Therefore, they are referred to as diploid cells
- For every paternal chromosome, there is a matching maternal chromosome. Together, they form a homologous pair. The two chromosomes in the pair are identical in size and shape, and have the same genes in the same places, though the alleles for each trait are not necessarily the same
- The DNA of each chromosome replicates to form two identical threads (chromatids) joined by a centromere. This takes place during the interphase of a cell, between cell divisions
- The replication of DNA is extremely important, as it ensures that each daughter cell receives a complete copy of the genetic material

Homologous Chromosomes:

![Diagram of Homologous Chromosomes](http://consultingstudent.wordpress.com)
Karyotype:

A picture showing the set of chromosomes in a cell is called a karyotype. It shows the number, size and shape of the chromosomes during metaphase of mitosis. They are useful as they can show whether a cell comes from a male or a female (males will have an X and a Y gonosome, while females will have two X gonosomes), and show us abnormal chromosomes.

Chromosome Number:

Each species has a specific number of chromosomes in its somatic cells. Some organisms have the same chromosome numbers, but this does not mean that they are related. It is the similarities in the DNA of the chromosomes that show relationships, not their number. –ploidy refers to the number of chromosomes in a cell. Diploid cells contain 2n (the full chromosome number) chromosomes – these are somatic cells. Haploid cells only contain n number of chromosomes – these are the gametes (sex cells).

Meiosis:

Meiosis is cell division that takes place in the reproductive organs of an organism to produce gametes in animals and spores in plants.

- During meiosis, the number of chromosomes is reduced from two sets (2n) to only one set (n) in each of the daughter cells formed.
- The gametes/spores formed are haploid cells, as they have only one set of chromosomes – only one chromosome from each homologous pair.
- In animals, meiosis occurs in the testes (formation of sperm – spermatogenesis) and ovaries (formation of eggs – oogenesis).

During sexual reproduction a male haploid gamete fuses with a female haploid gamete during fertilisation, forming a diploid zygote. This ensures that the offspring receive genetic material from both parents, allowing for variation in a species.

The DNA of the parent cells is replicated during interphase, before meiosis and mitosis occur. In meiosis, however, this is followed by two divisions:

- **Meiosis 1** is a reduction division – two cells are formed, each with half the number of chromosomes of the parent cell (haploid).
- **Meiosis 2** is a copying division, involving the two haploid cells formed during meiosis 1. They each divide by mitosis, resulting in 4 haploid cells.
Meiosis 1 (reduction division):

Early Prophase
- The chromosomes become short and fat, and are visible as two chromatids joined by a centromere. This is the same as in mitosis, but from there the chromosomes behave differently.

Late Prophase
- The chromosomes of homologous pairs lie alongside each other, forming a bivalent.
- The centrioles move to opposite poles.
- A spindle of protein threads, develops across the cell from the two centrioles.
- It is at this point that crossing over occurs. This will be explained later.

Metaphase
- The bivalents line up on the equator of the cell.
- The centromeres become attached to the spindle fibres.

Anaphase
- The centromeres do not split. The bivalents are separated and the chromosomes (not the chromatids) are pulled away from each other by the spindle threads.
- The chromosomes move to opposite poles of the cell.

Telophase
- The cytoplasm then divides (cytokinesis) to form two haploid cells, having only one of each homologous pair of chromosomes.

Meiosis 2 (copying division):
The two chromatids making up each chromosome need to separate. Each of the haploid cells divides again by mitosis, separating the chromatids so that one goes to each daughter cell.
Crossing Over:

Crossing over is the mutual exchange of pieces of chromosome, so that groups of genes are swapped between paternal and maternal chromosomes. This takes place during late prophase of meiosis 1.

- The homologous pairs of chromosomes come together to form bivalents. This process is called synapsis. They may swap pieces of their inner chromatids by breaking and reforming their DNA while paired up
- The points of crossing over, where the chromatids break, are called chiasmata
- Some genes from a maternal chromosome swap places with some genes from the paternal chromosome, forming a recombinant chromatid. The outer, unchanged chromatids are called parentals

Crossing over is important as this exchange of genetic material results in chromatids with a unique combination of genes. This increases variation among the daughter cells, and is why the offspring do not look the same as their parents or each other. However, mistakes may be made during this exchange, which can lead to potentially harmful mutations.

Reasons for the importance of Meiosis:

1. Halving the number of chromosomes during the formation of gametes prevent the doubling of the chromosome number after fertilisation
2. Leads to new gene combinations, which introduce variation into the species. We will now look at genetic variation and mutations in greater detail

Genetic Variations and Mutations:

Variation is the differences between organisms of the same species. In organisms that reproduce sexually, every one of the offspring possesses a unique combination of genes (except identical twins). These variations are because their genotypes (genetic make-up) are different as a result of:

- The crossing over of pieces of chromatids
- The random movement of paternal and maternal chromosomes to opposite poles during anaphase of meiosis 1. This is called independent assortment of chromosomes and results in every egg and sperm formed containing a mixture of maternal and paternal chromosomes
- The chance of which sperm will fertilise the egg. Any of several million could do so, but only one will, meaning that there are millions of potential combinations of genes
- Mutations
  - A sudden and unpredictable change in the genetic make-up of an organism. This may be caused by:
    - A gene mutation
    - A chromosome mutation. This can only occur during meiosis. It involves a change in the structure and distribution of one or more chromosomes and results in a change in the cell’s karyotype
Polyploidy is a chromosome mutation, a condition of having more than two sets of chromosomes. It is rare in animals, but common among ferns and flowering plants. Wheat, for example, has strains that are tetraploid (4n – four sets of chromosomes) and hexaploid (6n – six sets) after centuries of hybridisation by humans. It may occur:

- Naturally in some plant tissues
- As a result of abnormal meiosis. If the chromosomes do not separate during anaphase 1, the gametes will be diploid and form a tetraploid zygote when fused

Advantages include the instant creation of a new species, and therefore an important role in evolution of plants. Through biotechnology, we have created many species of polyploidy plants, with larger flowers, fruits and storage organs

Anaploidy is also a type of chromosome mutation. Cells have extra chromosomes or missing chromosomes. Individuals affected have characteristics known as syndromes. An example of this is Down syndrome, which occurs in children born with an extra copy of chromosome 21. They have (2n+1) chromosomes, a condition known as trisomy.

- During oogenesis, the two number 21 chromosomes do not separate properly during anaphase 1; both move end up in one daughter cell instead of one in each of the two daughter cells formed
- This results in an egg with 2 number 21 chromosomes
- If this egg is fertilised, the zygote will have three number 21 chromosomes (one from the father and two from the mother) and a total of 47 chromosomes per cell instead of 46
- As the embryo develops by mitosis, each cell will have 47 chromosomes

Children with Down syndrome exhibit the following characteristics:

- Children have varying degrees of mental retardation
- Distinctive flattened facial features and slightly slanting eyes
- Short stubby toes, a large head and ears that may develop differently
- Often heart defects and other health issues
- Tend to have a happy, loving nature

Although the health issues such as heart defects can be treated, there is no cure. Down syndrome is a relatively common syndrome, affecting about 1 in 900 births. The chances of a mother having a child with Down syndrome increase with her age; a 40 year old woman will have a much greater chance than a 30 year old woman. This is known as the maternal age effect.

Blood tests and ultrasounds conducted early in pregnancy can alert doctors to a risk of Down syndrome in the foetus. It can be confirmed 11 weeks after conception and allows expectant mothers more time to decide whether or not to undergo the risky follow-up test (an amniocentesis – the extraction of cells from the amniotic fluid, which may result in a miscarriage) or to abort the foetus.