NUCLEAR DIVISION & GENETIC ENGINEERING

Content

- Replication and division of nuclei.
- Chromosome behaviour in mitosis.
- The need for reduction division in sexual reproduction.

Learning Outcomes

Candidates should be able to:

a) explain how growth, repair and asexual reproduction in animals and plants can be brought about by mitosis.

b) explain the need for the production of genetically identical cells.

c) explain how cancer is the result of uncontrolled cell division, and list factors that can increase the chances of cancerous growth.

d) describe, with the aid of diagrams, the behaviour of chromosomes during the mitotic cell cycle, and the associated behaviour of the nuclear envelope, cell membrane and centrioles. (Names of the main stages are expected.)

e) explain what is meant by homologous pairs of chromosomes.

f) explain the meaning of the terms haploid and diploid, and the need for a reduction division prior to fertilisation in sexual reproduction. (Details of meiosis are not expected.)

Learning Outcome (a)

NUCLEAR DIVISION by MITOSIS

New cells (daughter cells) are formed by cell division. In the case of single celled organisms this is called **binary fission**. Cell division is initiated by the nucleus, and nuclear division is the first visible sign of the process of cell division. The commonest form of nuclear division is that of **mitosis** in which two genetically identical daughter nuclei are formed. Mitosis occurs in the cell division seen in growth, repair, the replacement of cells which have a limited life span like our red blood cells and skin cells, and in asexual reproduction in many plants and lower animals. The development of a multicellular organism from a fertilised egg by mitosis, means that all the cells of the body are genetically identical to the fertilised egg. The development of an organism from the fertilised egg is the story of the controlled expression of genetic information, with only a small fraction of the genes being expressed in cells as they differentiate to form tissues specialised for specific (and limited) functions. In mature cells most of the DNA is inactive all of the time.

Asexual reproduction does not involve the fertilization of gametes, and as a result of mitosis produces offspring which are genetically identical to each other (**clones**). Many multicellular organisms, especially plants, can reproduce their entire bodies in this way, either from specialised structures eg. strawberry runners, or single celled spores.

- CHECKPOINT SUMMARY
- Mitosis is nuclear division in which two daughter nuclei with the same chromosome number as the parent nucleus are produced, typically diploid nuclei producing diploid daughter nuclei.
- The daughter nuclei are therefore genetically identical to the nucleus of the cell that produced them (except for any mutations that may occur).
- Mitotic cell division is seen in growth, repair and asexual reproduction.
- As a result of mitosis in the growth of an organism from the fertilised egg, all cells are genetically identical.
- Similarly, offspring of asexual reproduction lack genetic variation.

Learning Outcome (d)

The MAIN STAGES of MITOSIS

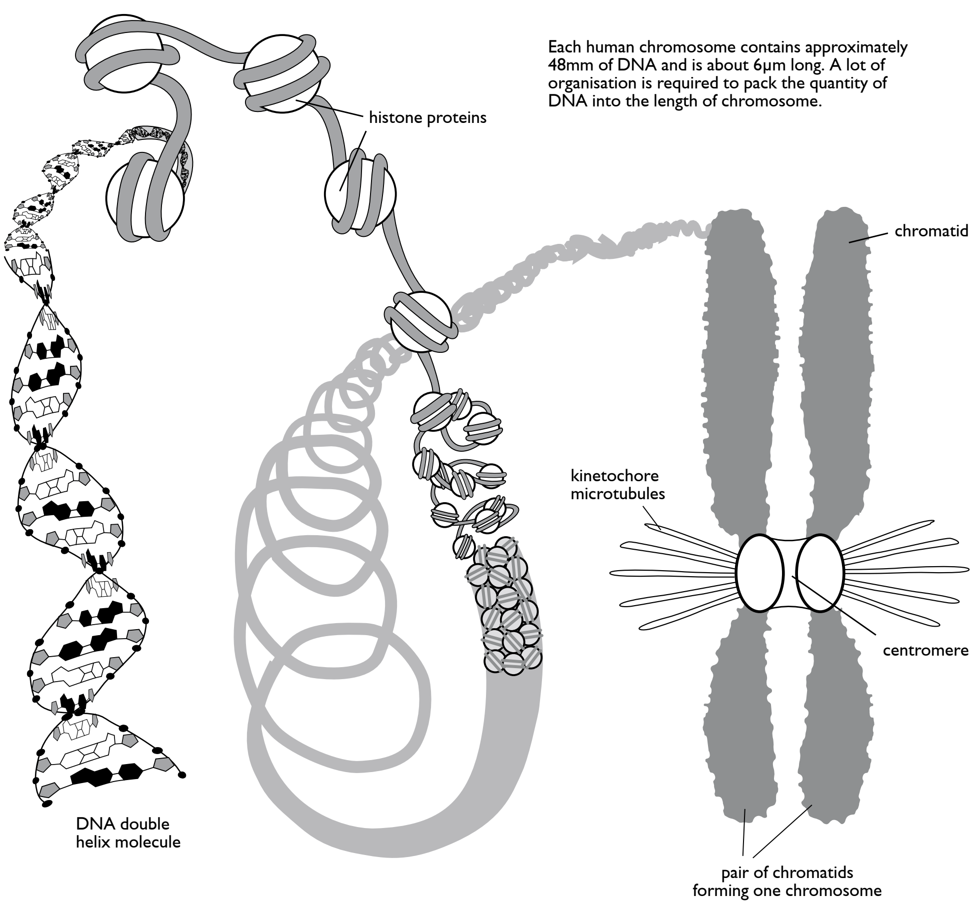
Chromosomes only become visible when stained and viewed under the light microscope when the nucleus of a cell is just about to divide. This is because only at this time is the DNA/histone mixture wound up (condensed) as tightly as it can be. By this stage the DNA has also copied itself (replicated) so each chromosome appears double, and joined at one point (the **centromere**). Whilst they remain joined in this way the two daughter chromosomes are referred to as **chromatids**.

◆ CHECKPOINT SUMMARY

◆ Cancer is the result of uncontrolled mitotic cell division.

◆ Any factor that disrupts normal control of mitosis increases the chances of cancerous growth e.g. ultra-violet light, X-rays, and carcinogenic chemicals, e.g. tar, benzene.

Diagram showing how DNA is organised into a chromosome



Main stages of the mitotic cell cycle

Nuclear division (mitosis) occurs in four main stages, namely prophase, metaphase, anaphase and telophase.

Prophase is the first phase of mitosis, and as it begins, the DNA has already replicated, all protein synthesis has stopped, and each chromosome is condensed into the characteristic double chromatid, form. At the same time the cell rounds up, the nuclear membrane breaks down into small fragments, and a **spindle** of microtubules forms between two **microtubule organising centres (MTOCs)** at opposite poles of the cell.

Metaphase is defined as when the chromatids become attached to the spindle by structures called **kinetochores.** Kinetochores consist of microtubules and 'motor' proteins which utilise ATP energy to pull on the spindle. The effect of both sets of kinetochores pulling in opposite directions is that the chromosomes line up along the middle (equator) of the spindle.

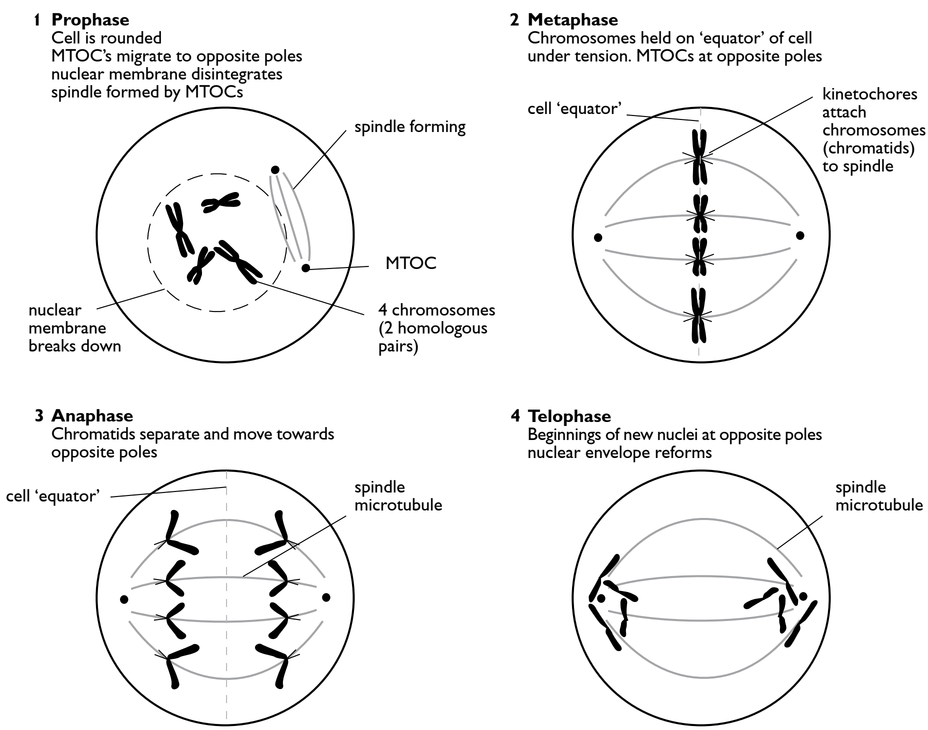
Anaphase is defined when quite suddenly, and all at once, the chromatids of each pair separate, with each being pulled under tension in opposite directions towards the poles of the cell.

Telophase is the stage when the two new, identical sets of chromosomes reach the opposite poles and a new nuclear envelope forms to surround each set.

◆ CHECKPOINT SUMMARY

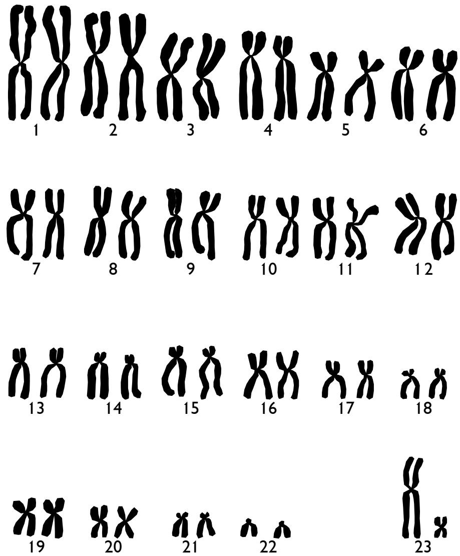
- ◆ The DNA replicates in interphase so that in the first stage of mitosis (prophase) the chromosomes appear as double structures of two chromatids (daughter chromosomes) joined at the centromere.
- ◆ The nuclear spindle apparatus(NSA) forms from the dissolution of the nuclear membrane and the centrioles replicate and migrate to either pole of the NSA.
- ◆ The centromeres align on the equator of the NSA (metaphase).
- ◆ The centromeres divide and the chromatids are moved to the opposite poles (anaphase).
- ◆ Two new daughter nuclei are formed (telophase).

Diagram to show stages in mitosis

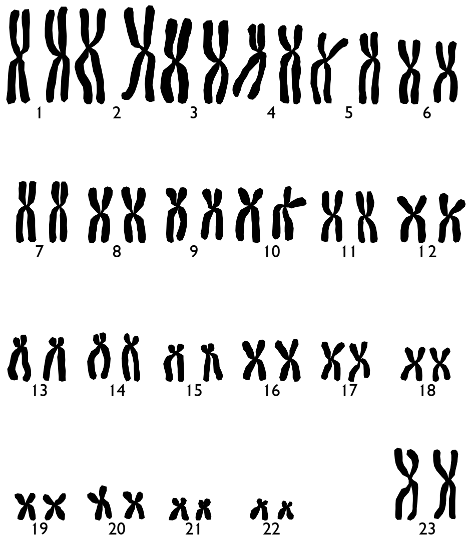


HOMOLOGOUS PAIRS of CHROMOSOMES in Humans

Karyotype normal human male



Karyotype normal human female



The DNA in eukaryotic cells is combined with **special nuclear** proteins **(histones)** to form 46 separate chromosomes. These 46 chromosomes constitute what is called the human **karyotype**.

The 46 chromosomes exist as two sets of 23 chromosomes, one set of which is inherited from the mother's egg, and the other set from the father's sperm.
The chromosomes of a pair have the same shape and structure and carry copies of the same genes (albeit often in a slightly modified form or **allele**). The chromosomes of a pair are said to be **homologous**.

The sex chromosomes (X and Y chromosomes) are only partially homologous and carry different genes on their non-homologous 'arms', e.g. the Y chromosome carries male determining genes joined to a phosphate group, and a nitrogen-containing organic base. There are four different types of nucleotide in DNA each with a different organic base. The bases are **adenine** (A) and **guanine** (G) which belong to a group of chemicals called **purines**, and **cytosine** (C) and **thymine** (T) which belong to group called **pyrimidines**. Chains of nucleotides link up by condensation reactions, with the sugar and phosphate molecules forming the 'spine' of each strand of the molecule, with the bases to one side.

DNA consists of two such chains or strands linked by **hydrogen bonds** which form between pairs of bases. As the hydrogen bonds form, so the two strands of the DNA molecule twist into the spiral structure known as the double helix. Hydrogen bonds form only between specific pairs, namely A with T and C with G. The strands are therefore complementar**y** to each other. The sequence along one strand determines the sequence of the other (complementary) strand. The understanding of the structure of the DNA double helix was one of the most significant breakthroughs in Biology.

RNA (Ribo(se)nucleic acid), like DNA, is a polymer made up of repeating nucleotides. It differs from DNA in the following three ways.

RNA is single stranded, not double stranded.

The pentose sugar in RNA is ribose, not deoxyribose (molecules of ribose contain an additional oxygen atom).

The pyrimidine base Uracil (U) is found instead of Thymine (T).

Living cells produce three different types of RNA in their nuclei, each designed to carry out a specific function in protein synthesis.

Messenger RNA (mRNA) consists of a single strand, between 75 and 3000 nucleotides long, produced in the nucleus as an exact copy of a selected section of the DNA code. The mRNA molecules travel out of the nucleus to the ribosomes where proteins are synthesised.

Transfer RNA (tRNA) is a shorter length of RNA, between 75 and 90 nucleotides long, twisted into a characteristic shape which allows one end to attach to a specific amino acid, and the other to expose a triplet of bases called the anti-codon which attaches to mRNA at the site of protein synthesis. tRNA molecules bring amino acids to their correct position as the proteins are being assembled. Each type of amino acid is carried by a different type of tRNA molecule with a specific anti-codon.

Ribosomal RNA (rRNA) consists of more than 1000 nucleotides and is found in ribosomes which are composed of an approximately equal mixture of proteins and rRNA. Ribosomal RNA is manufactured within the nucleolus.

The Nucleotides of DNA