STUDY UNIT 1
MITOSIS AND MEIOSIS

Klug, Cummings & Spencer Chapter 2

Life depends on cell division and reproduction of organisms. Process involves transfer of genetic material. New somatic (body) cells – genetic information stays identical → MITOSIS.

New sex cells (gametes) – genetic content is reduced and information is recombined to generate variation → MEIOSIS.

Where is the genetic material found?

In eukaryotes:
• Nuclear genes:
• Cytoplasmic genes:

In prokaryotes:
• Nucleoid:

Genetic material is DNA.

Morphology of eukaryotic metaphase chromosomes
• Chromosomes visualised during
• Chromosome in metaphase has
• Metaphase chromosomes consist of 2 replicated DNA molecules (identical)
• Two molecules attached
• Centromere position determines

Fig 2.3

Chromatids
• Metaphase chromosome consists of 2 identical DNA molecules obtained by DNA replication → chromatids.
• One chromatid
• Sister chromatids
• Once sister chromatids have separated during cell division, each becomes an individual chromosome in the new daughter cells.
**TERMINOLOGY**

**Diploid number** (2n)  (somatic number)
- Number of chromosomes in any
  - Represented by “2n”.
  - Somatic cells of all individuals of the same species contain the same number of chromosomes.
    - *eg* human *Drosophila*
  - Chromosomes usually present
certain somatic cells $\rightarrow$ meiosis $\rightarrow$ gametes

**HAPLOID number** (n)  (gametic number)
- Number of chromosomes in a
  - Represented by “n”.
  - *Always half of the 2n number.*
    - *eg* human, *Drosophila*
  - Full DNA sequence of an organism’s haploid set of chromosomes =
    - Table 2.1

**How many sets of chromosomes?**

Most higher organisms are **diploid**:
- Have 2 sets of chromosomes,
  - One set derived originally
    - the other from
  - Chromosomes in somatic cells are found

One pair of identical chromosomes =

Some organisms (mostly plants) are **polyploid**
- Somatic cells have >2 sets of chromosomes (3n, 4n etc)

**Homologous chromosomes**
- Identical in length & centromere position.
- Carry the same genes at the same loci in the same order.
- Similar, but not identical, in nucleotide sequence.

**Non-homologous chromosomes**
- Can differ in length & centromere position.
- Do not carry the same genes.
- Differ completely in nucleotide sequence.

**Chromosome types**

**Autosomes**

**Sex-determining chromosomes** (X/Y)
- E.g. in humans:
  - $\Delta$ 44 autosomes (22 pairs) + 1 X + 1 Y
  - $\Omega$ 44 autosomes (22 pairs) + 2 X
Definitions

Gene:
(A DNA sequence of which the product directs the metabolic activity of cells.)

Locus:
(A specific gene will always occupy the same position on the same chromosome in all individuals of a particular species.)

E.g. the gene responsible for flower colour in peas is designated gene A, and is located in the middle of the short arm of chromosome 1.

Alleles:

(Small variations in DNA sequence.) Alleles of a gene always occur at the same locus on homologous chromosomes.

E.g. Gene A has two possible alleles (differ slightly in DNA sequence)

A-allele: encodes functional version of enzyme A → purple pigment

a-allele: encodes non-functional version of enzyme A → no pigment

An individual can have three possible different combinations of these two different alleles:

Genotype: or or

Phenotype:

Consider a homologous chromosome pair:

locus for trait 1 (G - locus)
locus for trait 2 (A - locus)
locus for trait 3 (B - locus)

Homozygotic: two alleles at a particular locus are

Heterozygotic: two alleles at a particular locus

Rules for describing genes

• Use letter(s) of the alphabet to indicate a gene (locus) e.g.

• For different alleles of a particular gene, use the same letter(s), but indicate alternative forms using

A - locus with 2 alleles: A, a or a₁,a²
B - locus with 3 alleles: B₁, B², B³
colour locus with 4 alleles: C, c₁h, c²h, c
In a population there may be many different alleles for a specific locus.

In one individual (diploids) only **two** alleles can be present at a specific locus, as there are only 2 positions on the homologous chromosome pair.

Eg: One locus with 3 alleles: \(a^1 \ a^2 \ a^3\)

Individuals in population may be one of 6 possible genotypes:

- **Homozygotes**
- **Heterozygotes**

**GENOTYPES**

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**MITOSIS**

- Single-celled zygote (product of fertilisation)
- Growth
- Mitosis
- Multicellular organism
- Cytokinesis
- Wound healing
- Cell replacement

Daughter cells are genetically identical to parent cell

No variation is created.

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**THE CELL CYCLE**

- **Fig 2.5**
- **Fig 2.6**

**Interphase**

- Longest phase.
- G1, G2 phases → metabolic activity, cell growth, cell differentiation.
- S phase → DNA synthesis
  - chromosomes duplicate = DNA replication
  - one dsDNA molecule (chromatid) converted to two dsDNA molecules (2 chromatids) → chromosomes consists of 2 sister chromatids.
- G0 phase → viable but resting

**Prophase:**

- Chromatin condenses.
- Nuclear membrane disappears.
- Centrioles migrate.
- Spindle fibers form.

\[2n = 4\]

**Fig 2.7(a)**

**Metaphase:**

- Spindle fibers bind to kinetochores.
- Chromosomes align on equator between poles.

**Fig 2.7(d)**
Anaphase:
• Sister chromatids separate at centromere.
• Daughter chromosomes move to opposite poles.  
  \[\text{Fig 2.7(e)}\]

Telophase:
• One complete sets of chromosomes at each poles.
• Chromosomes uncoil.
• Nuclear membrane forms.
• Cytokinesis - cell plate / constriction.
  
  Two genetically identical daughter cells have formed, cells return to interphase.
  \[\text{Fig 2.7(f)}\]

Cell cycle regulation and checkpoints
• Cyclins, kinases, other target proteins
• G1/S checkpoint:
• G2/M checkpoint:
• M checkpoint:

Chromatin and chromosomes
• Folded-fiber model  
  \[\text{Fig 2.13}\]

MEIOSIS
During sexual reproduction:

Diploid parental cells → meiosis → Haploid gametes or spores

Male and female gametes fuse during fertilisation to form a diploid zygote.

Involves two cell divisions: meiosis I and meiosis II

One round of DNA replication before prophase I.

OVERVIEW MEIOSIS I
• Homologous chromosomes form pairs →
• Crossing over occurs between homologous chromosomes.
• Independent assortment occurs.
• Homologous chromosomes separate from one another

This is the

Chromosome number (number of centromeres)
OVERVIEW MEIOSIS II

- Sister chromatids from the same chromosome
- Each dyad

This is the number of centromeres remains

Product = 4 haploid gametes

PROPHASE I

- Longest and most complex phase of meiosis.
- 5 phases:
  - leptonema
  - zygonema
  - pachynema
  - diplonema
  - diakinesis

Leptonema

2n = 4

Zygonema

Pachynema

Fig 2.9

Diplonema

Diakinesis

Metaphase I

Second mechanism to generate variation

Anaphase I

Fig 2.10

Telophase I

Prophase II

Metaphase II

Anaphase II

Fig 2.10

Telophase II

Haploid gametes

Spermatogenesis vs Oogenesis

Spermatogonium  Oogonium

Primary spermatocyte  Primary oocyte

Secondary spermatocytes  First polar body

Spermatids  Secondary oocyte

Ootid  Second polar body

Spermatozoa  Ovum
Alteration of generations in a diploid plant

Fig 2.12

Nondisjunction (abnormal meiosis)

- Happens occasionally during meiosis I or meiosis II.
- Separation (disjunction) of chromosomes of tetrad or chromatids of dyad does NOT occur.
- Gametes with abnormal number of chromosomes.

How is variation created during meiosis?

Crossing over and independent assortment. Both take place during meiosis I.

1. Crossing-over
   - Recombination of segments between
   - Occurs during
   - Requires
   - Very accurate process, no material gets lost or is added.

Synaptonemal complex forms between closely associated homologs

Fig 2.14

Crossing over occurs within central element

- At least 1 crossover / tetrad required for correct segregation.
- Several crossovers per tetrad possible.
- Crossover produces chromosome with hybrid of maternal and paternal chromatid segments.
- Crossover occurs independently in each cell → genetically unique chromosomes in each gamete.

Note:
2. Independent assortment
   • Recombination of
   • Occurs during
   • Determined by orientation of
   • Occurs independently for each
   • Can generate $2^n$ different gametes

Note:

\[
2^3 = 8 \text{ different gametes}
\]

\[\text{If } n = 23 (\text{humans}):\]
\[
2^{23} = 8 \times 10^6
\]

Number of potential genetic combinations in offspring:
\[
(8 \times 10^6)^2 = 64 \times 10^{12}
\]

Mitosis Meiosis

Fig 2.8

At the end of a study unit:
   • Revise the work by using the textbook and lecture material.
   • Work through the additional study material on ClickUP (animations and summaries).
   • Use internet study material [http://www.prenhall.com/klugconcepts8](http://www.prenhall.com/klugconcepts8).
   • Test yourself by using the studyguide (aims, terms, questions) & the problems in the practical guide.