Chapter 16 – Cell Division

Subject content

Content
- Mitosis
- Meiosis

Learning outcomes
(a) state the importance of mitosis in growth, repair and asexual reproduction
(b) explain the need for the production of genetically identical cells
(c) identify, with the aid of diagrams, the main stages of mitosis
(d) state what is meant by homologous pairs of chromosomes
(e) identify, with the aid of diagrams, the main stages of meiosis (names of the sub-divisions of prophase are not required)
(f) define the terms haploid and diploid, and explain the need for a reduction division process prior to fertilisation in sexual reproduction
(g) state how meiosis and fertilisation can lead to variation

Use the knowledge gained in this section in new situations or to solve related problems.

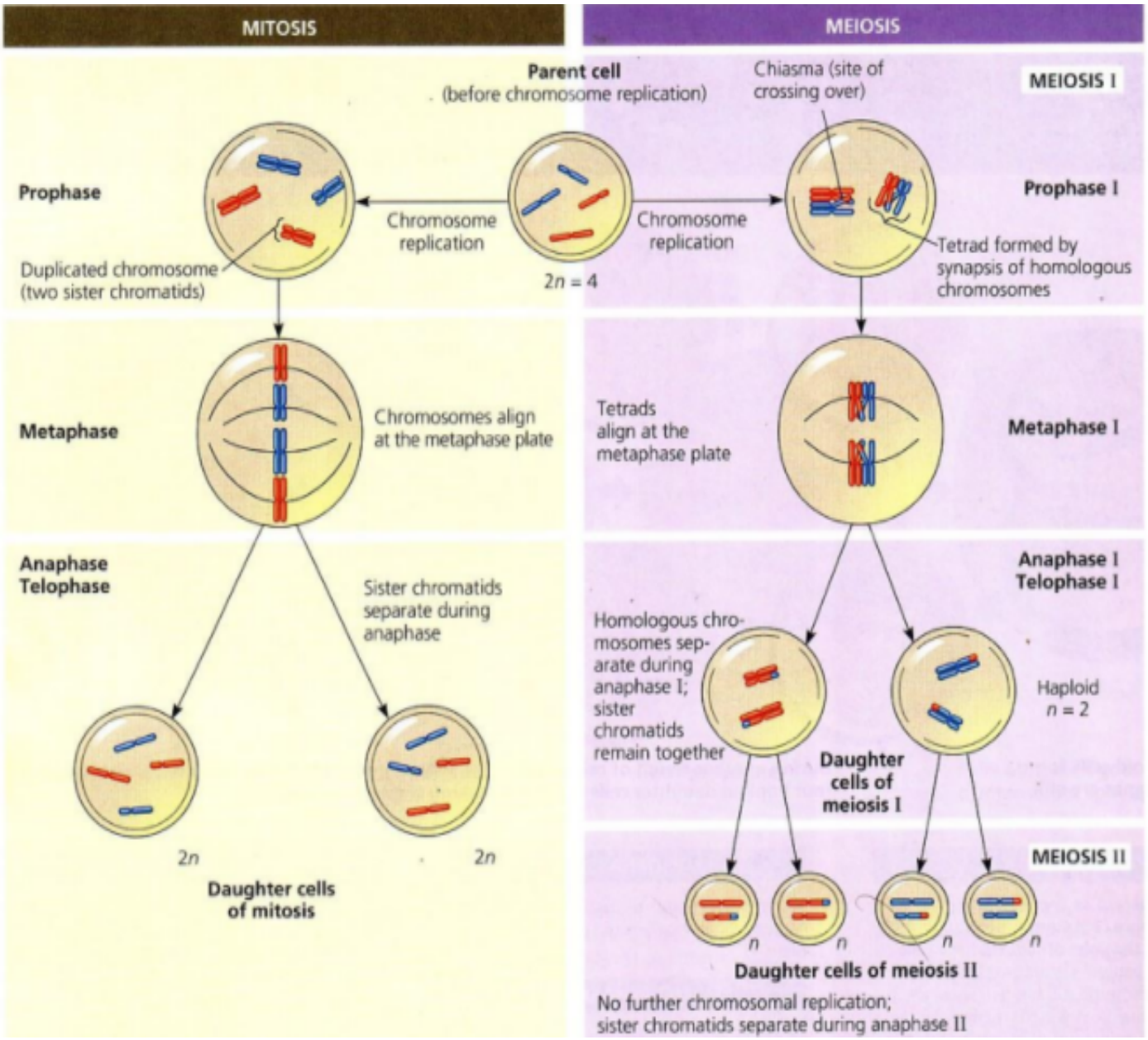
Definition

Phrase	Definition
Growth	A characteristic of all living things, is a permanent increase in size, is accompanied by cell division and differentiation to form tissues and organs
Mitosis	Nuclear division that produces 2 genetically identical daughter nuclei containing same number of chromosome as parent nucleus
Meiosis	Nuclear division that produces 4 daughter nuclei containing half the number of chromosomes as parent nucleus
Homologous pairs of chromosomes	A pair of chromosome with the same shape, size, same position of centromere and position of gene loci with the same genes in the same linear order One chromosome comes from the mother, while the other comes from the father

Ploidy

Diploid	Haploid
Diploid cell: 2 sets of chromosomes (one from each parent)	**Haploid cell**: one set of chromosome (only from one parent)
Diploid number (**2n**) e.g. 46 chromosomes in human cell	**Haploid number** (**n**) e.g. 23 chromosomes in human sperm, ovum

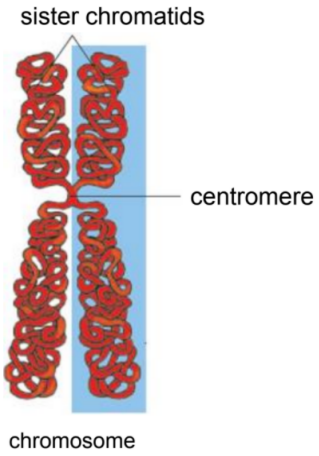
Cell division



Mitosis	Meiosis
Growth and development Genetically identical cells	Reproduction Genetically dissimilar gametes
Stages: 1. Prophase 2. Metaphase 3. Anaphase 4. Telophase	Stages: 1. Meiosis I 2. Meiosis II

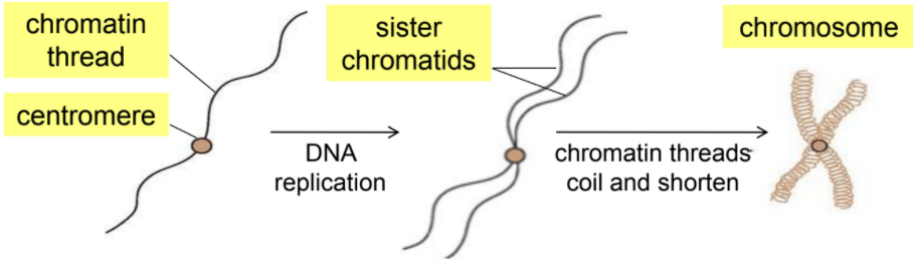
Deoxyribonucleic acid (DNA) → molecules that make up **chromosomes**

- stores genetic information → growth + vital cellular activities
- information stored as **genes** (sections of DNA)



16.1 Mitosis

DNA replication

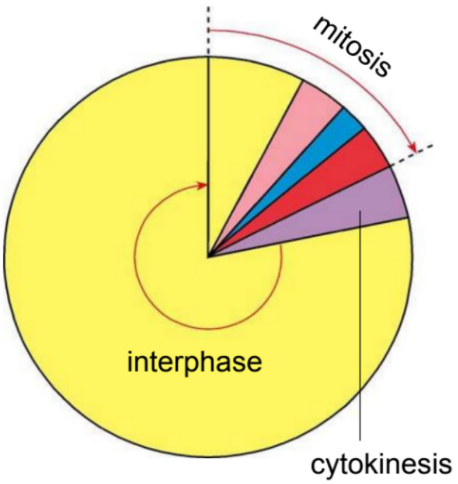


Structure	Stage	Description
chromatin thread	interphase	• Replicate → 2 genetically identical chromatin threads (joined at centromere) • DNA content doubles
chromosome	prophase	• Chromatin: condense, coil & shorten → chromosomes • Consist of 2 **sister chromatids** (identical DNA molecules)

1 centromere → 1 chromosome / 1 chromatin thread

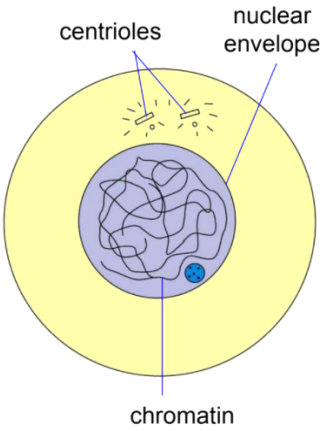
Cell cycle

1. **Interphase** (resting stage)
2. **Mitosis** (nuclear division)
3. **Cytokinesis** (cytoplasm division)



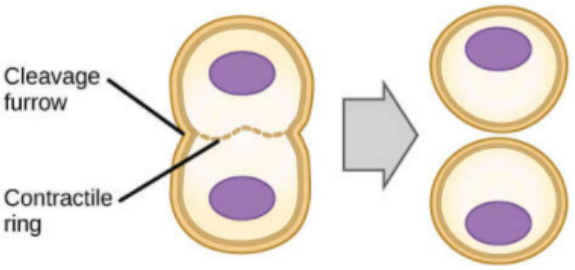
Interphase: resting / non-dividing stage

- Cell prepares for nuclear division:
  - absorb nutrients
  - builds up protoplasm
  - build up large store of energy
  - replicate DNA
  - centrioles divide
- Events:
  1. chromatin threads replicate
  2. centrioles replicate



Cytokinesis: division of cytoplasm

- **Furrows** appear in cytoplasm b/w 2 nuclei
- Furrows deepen → produce 2 genetically identical daughter cells



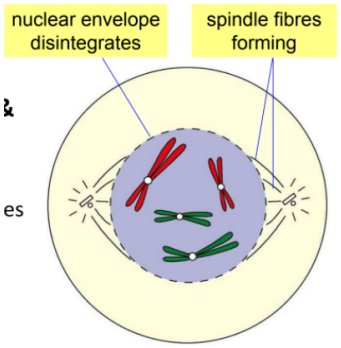
MITOSIS:

Early prophase

Chromatin threads condense

- Chromatin threads: condense, coil, shorten → chromosomes
- Each chromosome consists of 2 sister chromatids attached at centromere

Late prophase

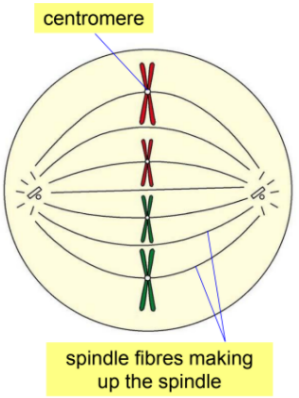


Spindle fibres form

- Asters form around centrioles
- 2 pairs of centrioles → opposite poles of cell
- Spindle fibres form: extend from one pole of cell to the other

Breakdown of **nucleolus** & **nuclear envelope**

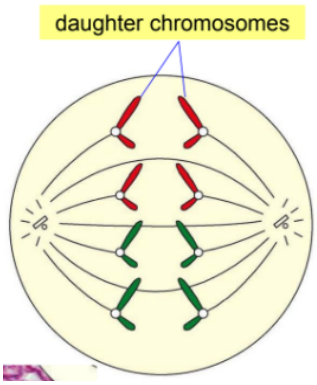
Metaphase



Chromosomes **line up** in single file along equator of spindle

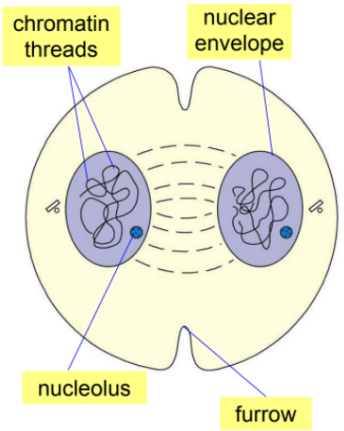
- Attached to spindle fibres at centromere

Anaphase



- Centromeres divide
- Spindle fibres shorten and pull sister chromatids apart to opposite poles
- Each sister chromatid (with own centromere) → daughter chromosome

Telophase

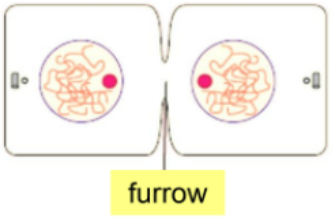
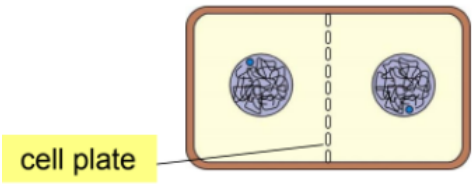


- **Chromosome** uncoil → chromatin thread
- **Spindle fibres** break down
- **Nuclear envelope** reform around each set of chromosomes at the poles
- **Nucleolus** reform

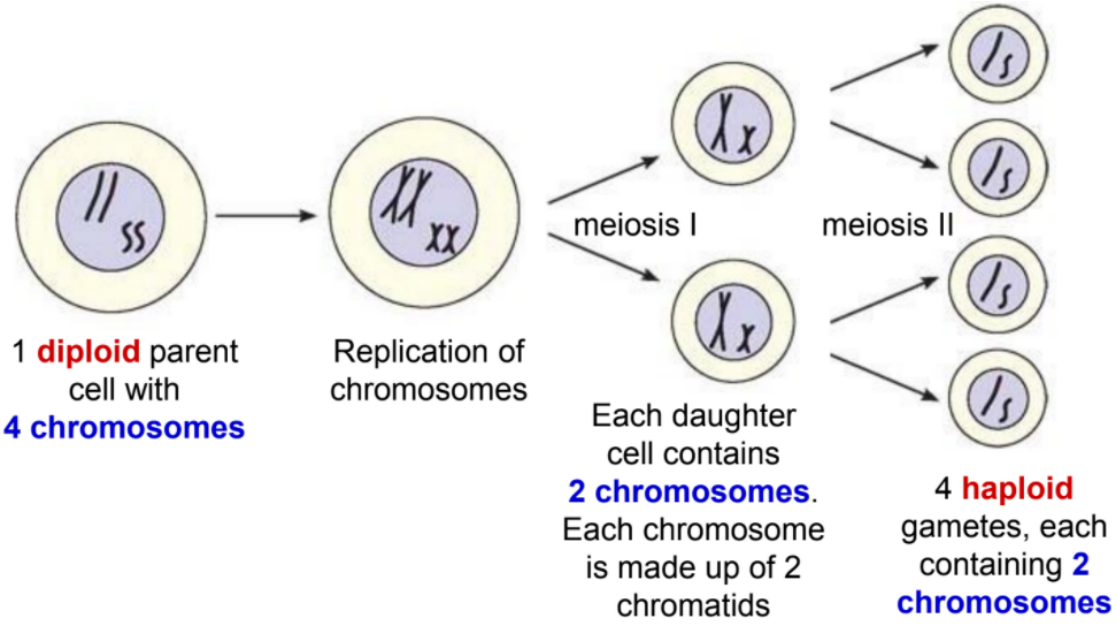
Importance of mitosis

Importance	Explanation
1. **Growth** of organism	Produce new cells for multicellular organism to grow
2. **Repair** of worn-out body parts	• Replace dead cells • New cells (Malpighian layer) seal wounds → heal
3. **Asexual reproduction** (flowering plants)	Shoots + roots • develop in storage organs (e.g. rhizomes, bulbs) • grow into new daughter plants – identical to parent plants

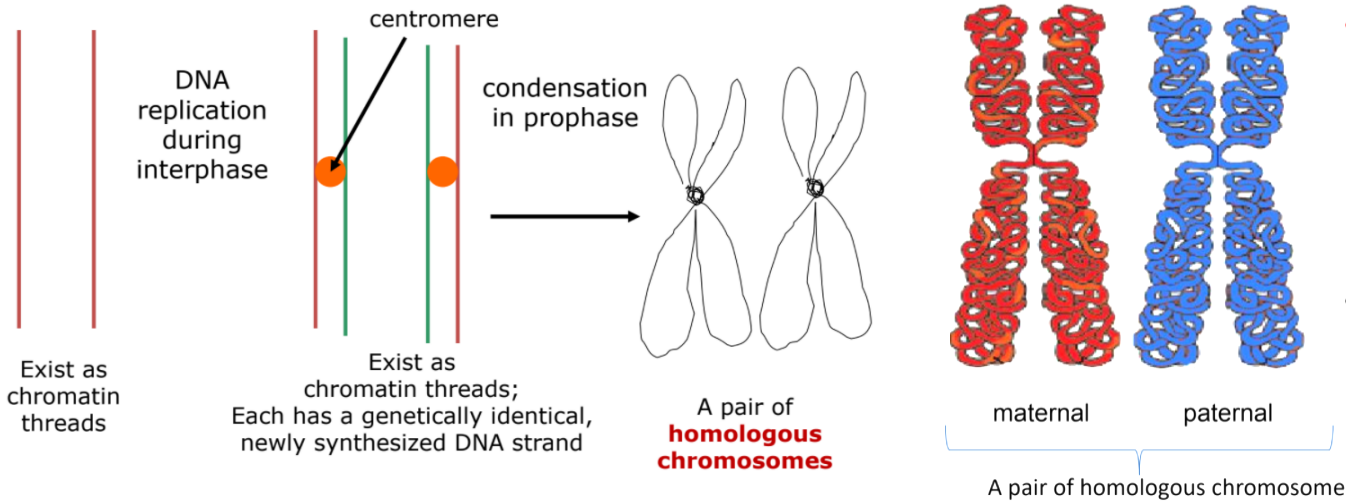
Mitosis in animal & plant cell

Aspect	**Animal**	**Plant**
Centrioles	present	absent
Asters	present	absent
Cytokinesis	✓ cleavage of cytoplasm	X cleavage of cytoplasm
	<u>Furrows</u> form in cytoplasm 	<u>Cell plate</u> form b/w daughter nuclei (fusion of fluid-filled vesicles) 

16.2 Meiosis



Homologous chromosomes

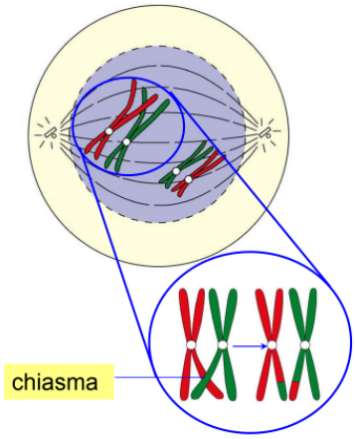


Homologous chromosomes

- have the same
  1. shape
  2. length
  3. sequence of genes
  4. position of centromere
- One member of each pair is inherited from each parent
  (One member carries maternal traits, other carries paternal traits)

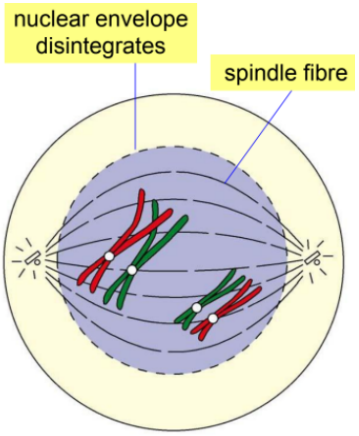
MEIOSIS I:

Early prophase I



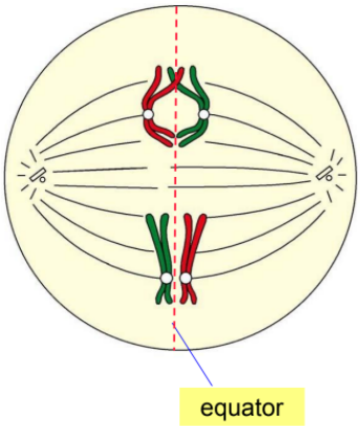
- **Synapsis**: HC pair along whole length
- **Crossing over**: Non-sister chromatids of HC cross + twist around each other at chiasma
- Strength of coiling → break → exchange genetic material

Late prophase I



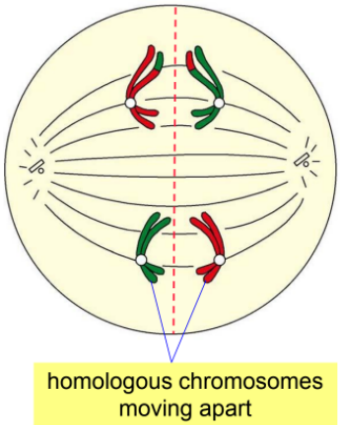
- Centrioles move to opposite poles of cell
- Nuclear envelope + nucleolus disintegrate
- Spindle fibres form

Metaphase I



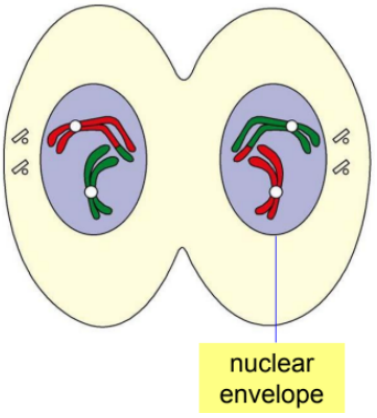
- HC arrange themselves along equator of spindle
- Spindle fibres attach to centromere of each chromosome
- **Independent assortment of HC**: random arrangement

Anaphase I



- HC separate
- Spindle fibres shorten
- One of each pair of HC is pulled to opposite pole of cell

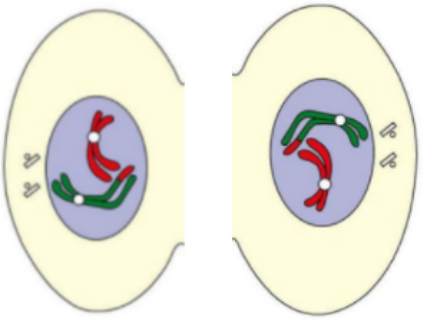
Telophase I



- Spindle fibre disintegrates
- Nuclear envelope + nucleolus reform at each pole

Most plant cells X undergo Telophase I → straight to Metaphase II

Cytokinesis I

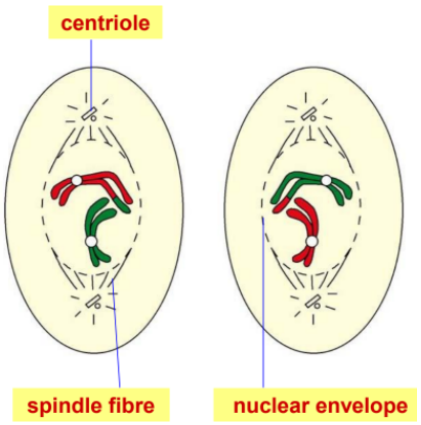


- Centrioles divide
- Cleavage form + deepen → cleave into 2
- 2 daughter cells, each with haploid no. (**n**) of chromosomes

2n → n

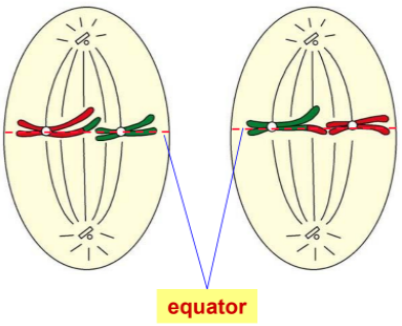
MEIOSIS II:

Prophase II



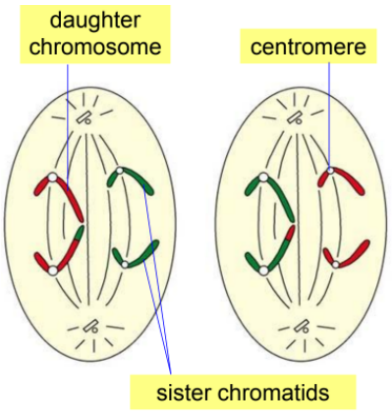
- Main events similar to prophase of mitosis & meiosis I
- Centrioles move to opposite poles of cell
- Spindle fibres appear
- Nuclear envelope + nucleolus disintegrate

Metaphase II



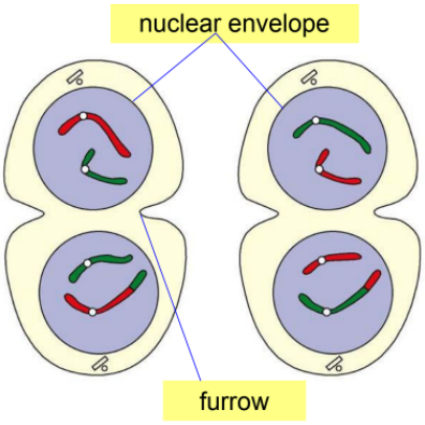
- Chromosomes arrange themselves along equator of spindle
- Spindle fibre attach to centromere of each chromosome

Anaphase II



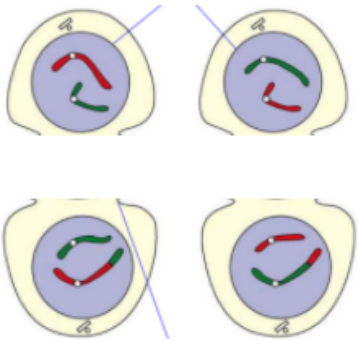
- Spindle fibre shorten
- Centromeres divide
- Chromatids separated + pulled to opposite poles of cell → referred to as daughter chromosomes

Telophase II



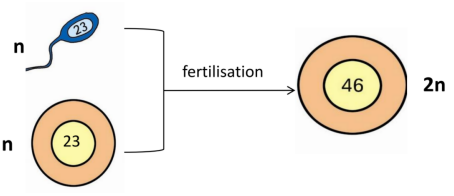
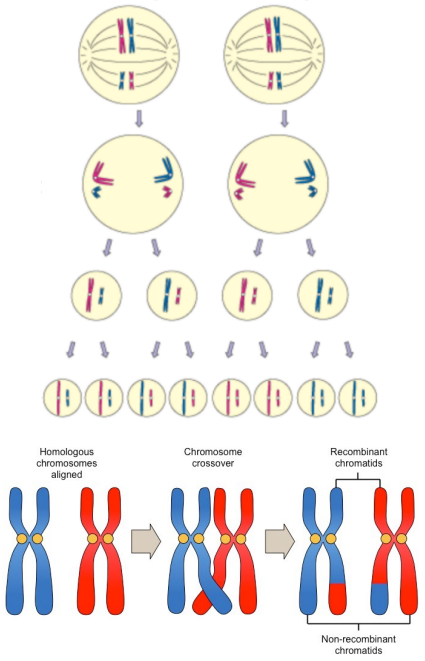
- Chromosomes reach opposite poles of spindle → uncoil + lengthen → chromatin threads
- Spindle fibre disintegrate
- Nuclear envelope + nucleolus reform

Cytokinesis II



- Cleavage form + deepen
- Cells divide → 4 daughter cells, haploid no. (**n**) of chromosomes

Importance of meiosis

Importance	Explanation	Figure
1. **Haploid gametes**	• Fertilisation: haploid (n) nuclei of male + female gamete → diploid (2n) nucleus of zygote • Restore <u>diploid no.</u> of chromosomes in zygote → maintain <u>normal no.</u> in species through successive generations	
2. **Genetic variation**	• Variation 1) <u>crossing over</u> b/w non-sister chromatids of HC (prophase I) → new combination of allele along chromosomes 2) <u>independent assortment</u> of HC (metaphase I) → new combination of chromosomes in gamete 3) randomness of <u>fertilisation</u> • Variation in gametes → variation in offspring • Increase chance of species survival during changes in environment → pass on favourable genes to offspring	

Difference b/w mitosis & meiosis

Aspect	**Mitosis**	**Meiosis**
Daughter cells	chromosomes = parent cell	chromosomes = ½ parent cell
	genetically identical	not genetically identical
	2 from 1 parent cell	4 from 1 parent cell
Pairing of HC	✘	✓
Crossing over	✘	✓
Nuclear divisions	1	2
Cells involved	Normal body cells	Germ cells in gonads
Purpose	Growth + repair of body parts	Gamete formation

Typical questions

Multiple choice questions

1 The list gives some of the stages involved in gamete and zygote formation.

1. prophase I of meiosis
2. prophase II of meiosis
3. metaphase I of meiosis
4. fertilisation

During which stages do events occur that increase genetic variation in the zygote?

(N2011/P1/Q32)

A 1, 2 and 3
B 1, 3 and 4
C 2 and 3 only
D 3 and 4 only

2 What describes homologous chromosomes? (N2011/P1/Q33 / N2014/P1/Q31)

A two chromatids that are joined together to form one chromosome
B two chromatids that have identical alleles
C two chromosomes that form a pair at the start of meiosis
D two chromosomes that have identical alleles

3 The mass of DNA in the nucleus of a diploid body cell is represented by 2D.

How much DNA will there be in a gamete and in the zygote? (N2012/P1/Q31)

	DNA in gamete	DNA in zygote
A	D	2D
B	2D	4D
C	½ D	D
D	2D	2D

4 To which of the processes shown does mitosis contribute? (N2012/P1/Q32)

	genetic variation	increase in cell number	replacement of damaged cells
A	✔	✔	✘
B	✔	✘	✘
C	✘	✔	✔
D	✘	✘	✔

5 When does a cell division occur that involves a reduction in chromosome numbers?
(N2013/P1/Q31)

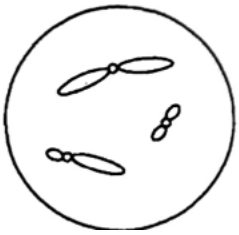
A during the formation of new cells in the skin
B during the formation of sperm in the testis
C in the haploid cells in the ovary
D in the zygote immediately after fertilisation

6 Which statement about homologous chromosomes is correct? (N2013/P1/Q32)

A They contain identical DNA.
B They contain the same genes in the same position.
C They have identical alleles.
D They replicate during meiosis only.

7 The diagram below represents the nucleus of a body cell of an organism.

Which diagram does **not** represent a possible gamete nucleus produced by the organism?
(N2014/P1/Q32)

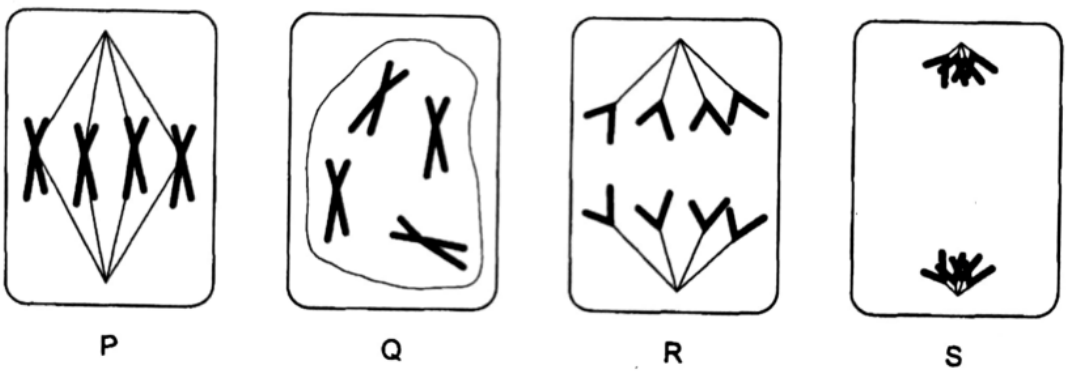
A


B


C


D

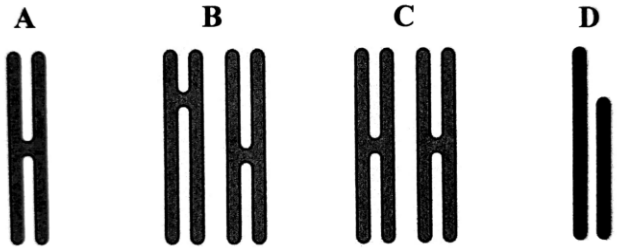

8 The diagram shows some of the events that happen during mitosis.



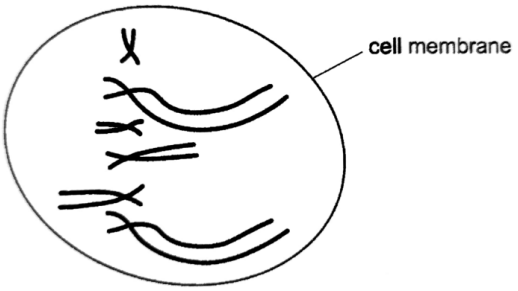
What is the correct sequence for these events during mitosis? (N2014/P1/Q33)

A P → Q → R → S
B P → R → Q → S
C Q → P → R → S
D S → P → Q → R

9 Which diagram represents a pair of homologous chromosomes? (N2015/P1/Q31)



10 The diagram shows the chromosomes in a dividing cell.



Which stage of cell division is shown? (N2015/P1/Q32)

A metaphase of a diploid cell dividing by meiosis
B metaphase of a diploid cell dividing by mitosis
C telophase of a haploid cell dividing by meiosis
D telophase of a haploid cell dividing by mitosis

11 Some events which occur during meiosis are listed.

1. crossing-over between chromatids of homologous chromosomes
2. halving of chromosome number
3. independent assortment of homologous chromosomes
4. pairing of homologous chromosomes

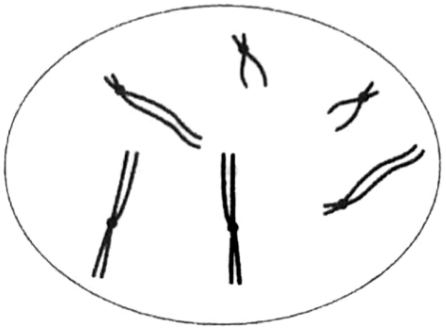
Which two events help to produce genetic variation? (N2015/P1/Q33)

A 1 and 2
B 1 and 3
C 2 and 4
D 3 and 4

12 Which row gives the chromosome number in the nuclei of different cells during the life cycle of a human? (N2017/P1/Q31)

	cells from which gametes develop	gametes	cells of the embryo
A	diploid	diploid	haploid
B	diploid	haploid	diploid
C	haploid	diploid	haploid
D	haploid	haploid	diploid

13 The diagram shows chromosomes during mitosis.



How many pairs of homologous chromosomes are shown and which stage of mitosis is shown? (N2017/P1/Q33)

	number of pairs of homologous chromosomes	stage of mitosis
A	3	prophase
B	3	telophase
C	6	prophase
D	6	telophase

14 Which statement about a pair of homologous chromosomes is correct? (N2018/P1/Q31)

A They always have identical alleles.
B They contain bases in the same sequences.
C They contain the same genes in the same position.
D They form pairs in mitosis and meiosis.

15 Where does genetic variation occur in the production of offspring? (N2018/P1/Q33)

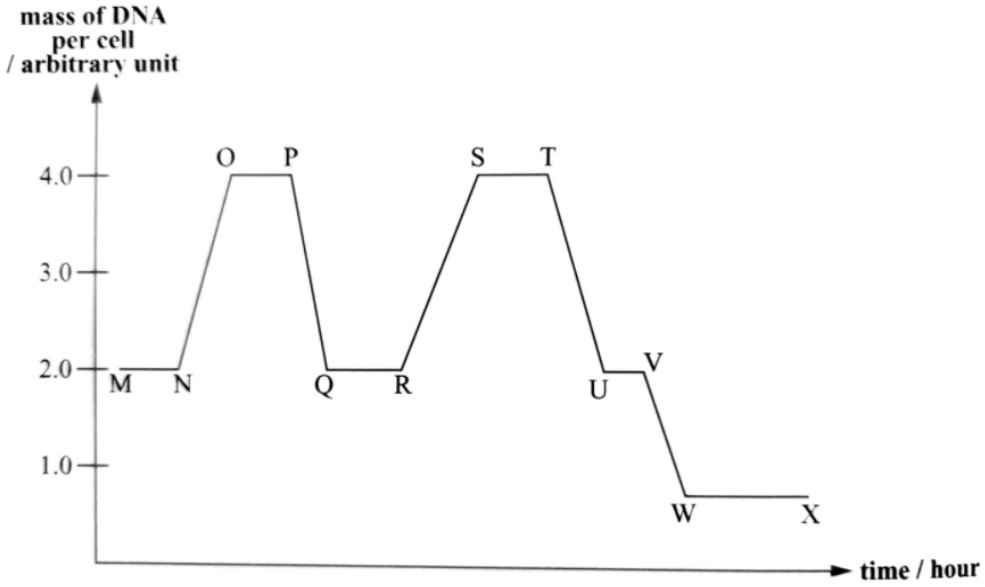
1. prophase 1 meiosis
2. metaphase 1 meiosis
3. prophase 2 meiosis
4. fertilisation

A 1, 2 and 4
B 1, 3 and 4
C 2 and 3 only
D 2 and 4 only

16 In which structure are cells dividing through mitosis only?

A stamen
B carpel
C testis
D heart

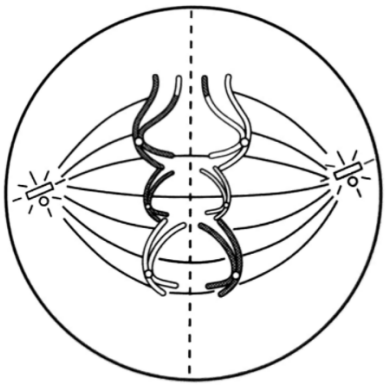
17 The graph below shows the mass of DNA in a cell over time.



Which segments of the graph correspond to the following processes?

	mitosis	meiosis I	meiosis II	DNA replication
A	NQ	RU	UW	MN and QR
B	NQ	RU	UW	NO and RS
C	OP	ST	UV	NO and RS
D	OP	ST	UV	MN and QR

18 The diagram shows a cell during meiosis.

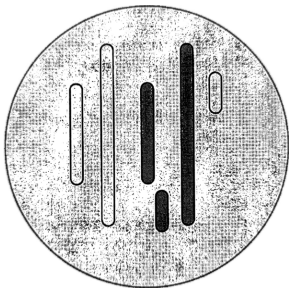


Which of the following statements is incorrect?

A There are three pairs of homologous chromosomes.
B One crossing over event between sister chromatids has taken place.
C The cell is undergoing reductive division.
D The cells produced at the end of the process are genetically dissimilar.

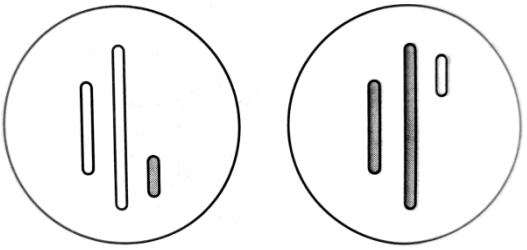
Structured questions

1 The figure below shows the chromosomes in an animal cell.

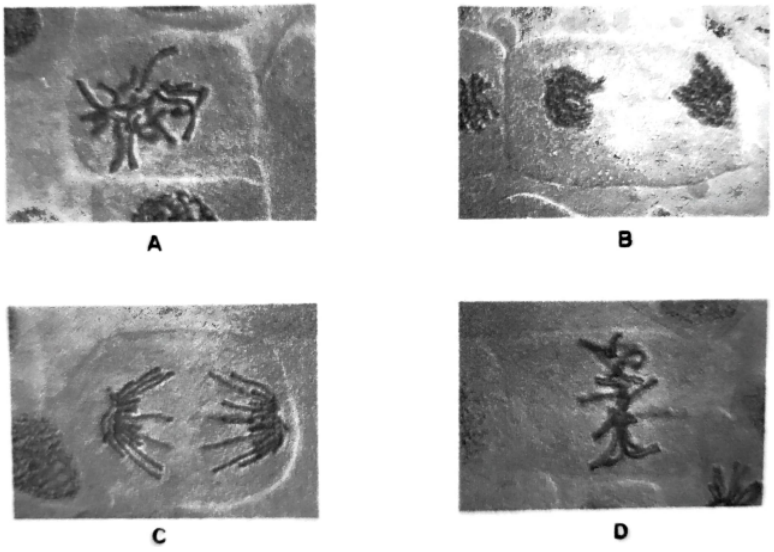


In the spaces below, draw diagrams to show the chromosomes of **two** gametes that may be formed when this cell divides by meiosis. [2]

(N2012/P2/A7b)



2 The figure below shows four stages, A, B, C and D, in mitosis in bluebell, *Hyacinthoides non-scripta*.



Name each of the stages shown in the figure below. [4]

(N2014/P2/A6b)

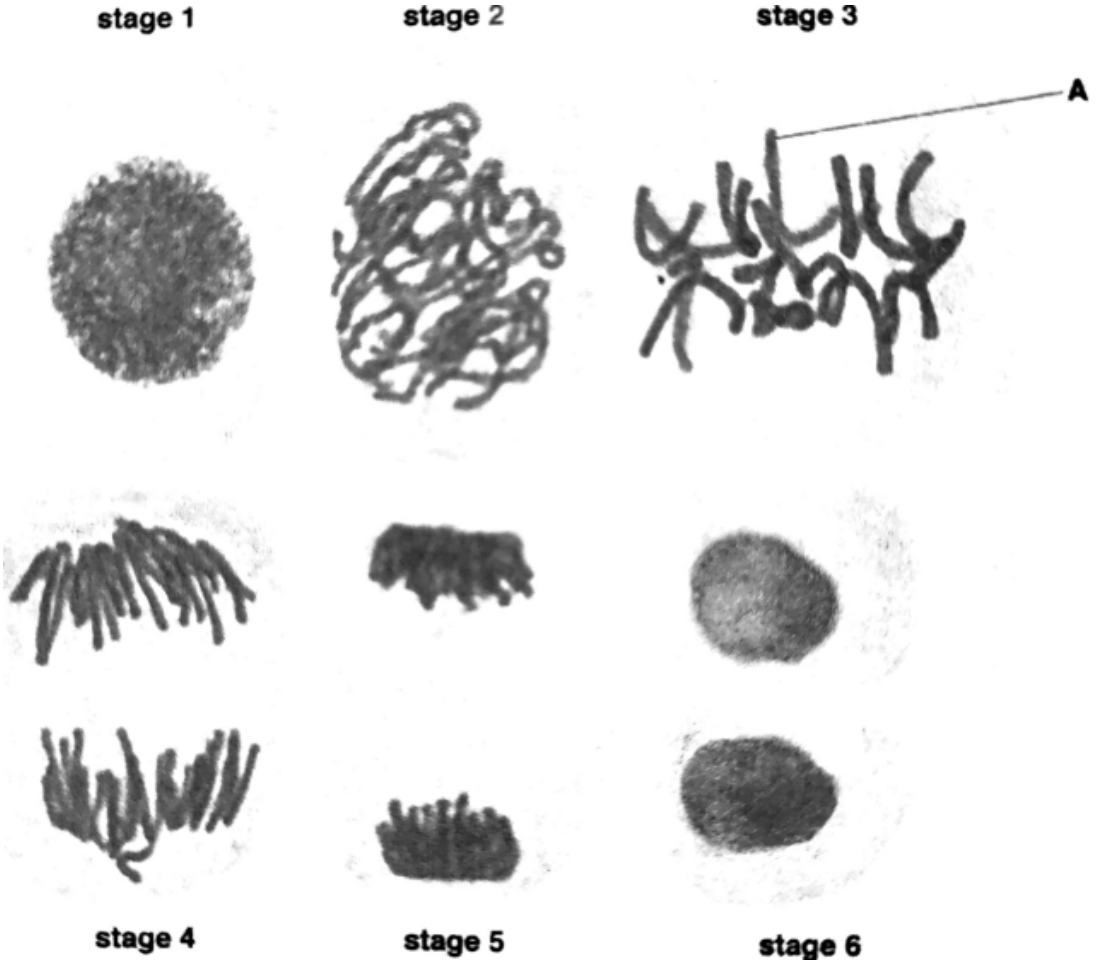
A: Prophase

B: Telophase

C: Anaphase

D: Metaphase

3 The figure below shows some of the stages in cell division in the root tip of an onion plant (*Allium* species).



(N2018/P2/A1a)

(a) State the name of the structure labelled **A** in the figure above. [1]

Chromosome

(b) State the name of the stages labelled **3** and **4** in the figure above. [2]

Stage 3: Metaphase

Stage 4: Anaphase

4 Describe the events taking place in the cell during the stage of anaphase in mitosis. [3]

- Centromeres connecting the pair of sister chromatids separate.
- Spindle fibres shorten and pull the sister chromatics apart towards the opposite poles of the cell.
- The separated chromatids form a daughter chromosome each.

5 Describe the events taking place during the prophase in mitosis. [5]

- Chromatin molecules condense, coil and shorten to form chromatids.
- Two sister chromatids formed from replicated chromatin threads are connected at their centromeres to form a chromosome.
- Structures known as asters form around the centrioles and the pair of centrioles move towards opposite poles of the cell.
- The nucleolus and nuclear envelope disintegrate.
- Spindle is formed with spindle fibres extending from one pole of the cell to the other.

6 Compare the stages of anaphase I and anaphase II in meiosis. [2]

- Both anaphase I and anaphase II involve the shortening of spindle fibres from the two poles of the cell.
- Anaphase I involves the separation of pairs of homologous chromosomes; anaphase II involves the separation of sister chromatids.
- Anaphase I does not involve the separation of centromeres; anaphase II involves the separation of centromeres.

7 Meiosis is the nuclear division process resulting in the production of four haploid cells from a diploid parent cell.

(a) Explain what is meant by the terms *diploid* and *haploid*. [2]

- Diploid is the number of chromosomes in a normal body cell of the organism.
- Haploid is the number of chromosomes in a gamete.

(b) Explain the need for meiosis prior to fertilisation in sexual reproduction. [5]

- Meiosis results in the production of haploid gametes from diploid normal body cells in the reproductive systems of the organisms.
- One haploid female gamete is then able to fuse with one haploid male gamete to form a diploid zygote during fertilisation.
- The diploid zygote then undergoes mitosis and grows into a new organism that has the same number of chromosomes as the normal body cells of the parents.
- Hence, meiosis is required to maintain the number of chromosomes of the organism across generations.

8 List the similarities and differences between mitosis and meiosis. [6]

SIMILARITIES:

- Both are nuclear division processes.
- Both consist of the prophase, metaphase, anaphase and telophase stages.

DIFFERENCES:

- Mitosis results in the production of two genetically identical daughter nuclei; meiosis results in the production of four genetically dissimilar daughter nuclei.
- Mitosis is important for growth, repair of worn-out body parts and asexual reproduction; meiosis is important for gamete production.
- Mitosis involves only one division process; meiosis involves two successive division processes.
- Mitosis does not involve crossing over; meiosis involves crossing over.

9 The figure below is a diagram of an animal cell at the start of prophase of mitosis.

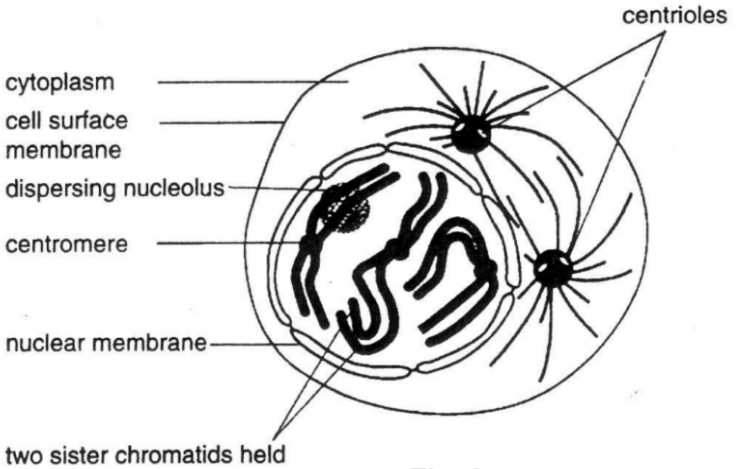


Fig. 2

(a) Explain why chromosomes appear as double structures at the start of prophase. [2]

- During interphase, DNA replicates to form two genetically identical sister chromatids that are attached at the centromere.
- Chromatin threads condense, coil and shorten to become chromosomes which are visible.

(b) State the changes that occur between the start of prophase and the end of metaphase to:

(i) the nuclear membrane [1]

- During prophase, nuclear membrane disintegrates / breaks down.

(ii) the centrioles [2]

- During prophase, centrioles move to opposite poles of cell. Asters and spindle fibres form, extending from one pole to the other.
- During metaphase, spindle fibres attach to centromeres of each chromosome.

(iii) the chromosomes [2]

- During prophase, chromatin threads condense, coil and shorten to form chromosomes.
- During metaphase, chromosomes arrange themselves in a single row at the equator of spindle. Spindle fibres are attached to the centromere of each chromosome.