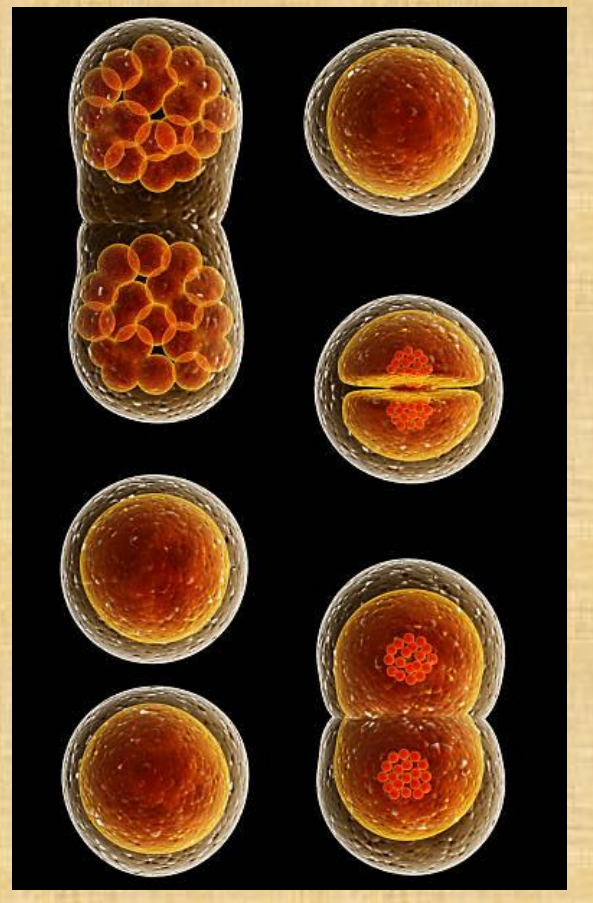
WHAT YOU HAVE LEARNT BEFORE …

- **O-level Pure Biology:**



6093 BIOLOGY GCE ORDINARY LEVEL SYLLABUS (2018)

13. Cell Division

Content

- Mitosis
- Meiosis

Learning Outcomes

Candidates should be able to:

(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.

WHAT YOU WILL LEARN …

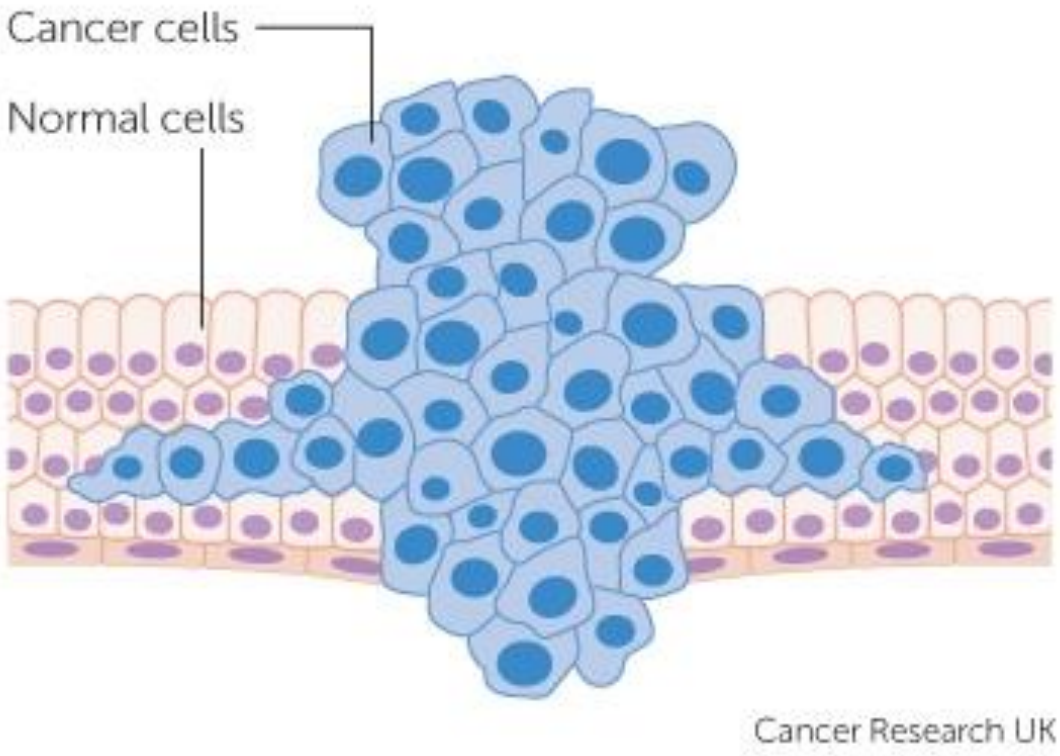
- **A-level Content:**

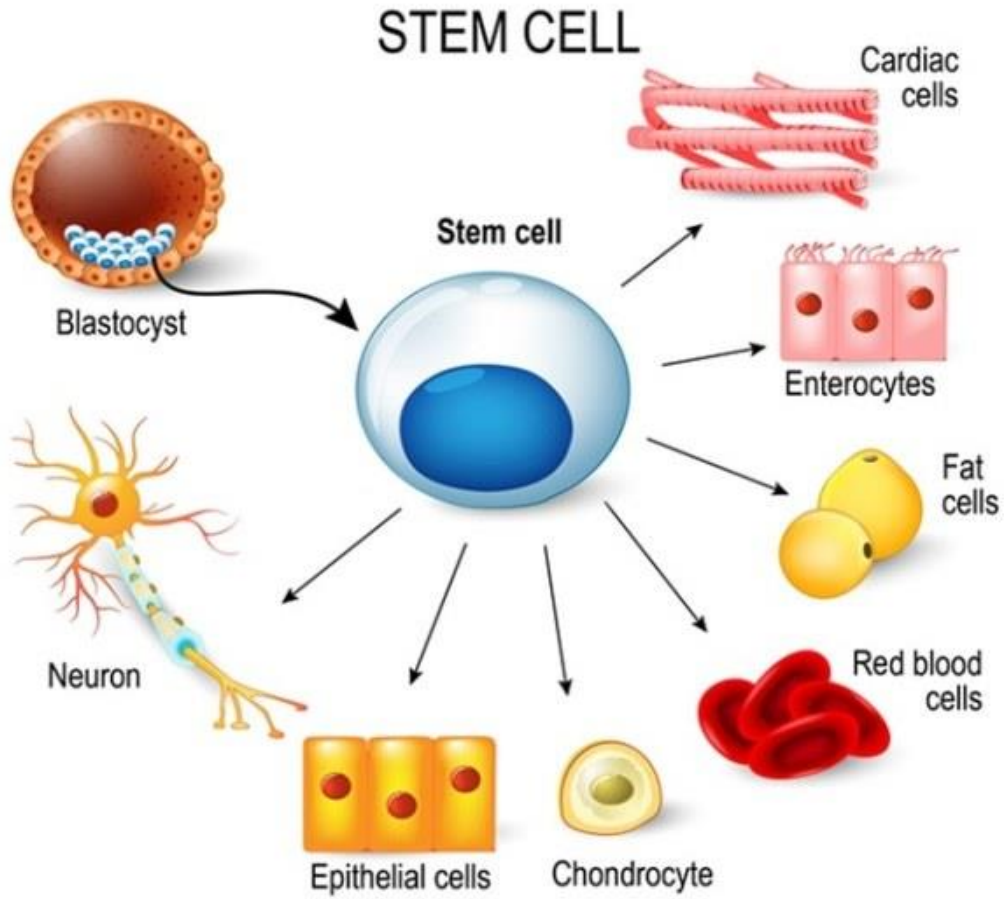
(f) describe the events that occur during the mitotic cell cycle and the main stages of mitosis (including the behaviour of chromosomes, nuclear envelope, cell surface membrane and centrioles)

(g) explain the significance of the mitotic cell cycle (including growth, repair and asexual reproduction) and the need to regulate it tightly (knowledge that dysregulation of checkpoints of cell division can result in uncontrolled cell division and cancer is required, but details of the mechanism are not required)

(j) explain the significance of the meiotic cell cycle (reduction division prior to fertilisation and cells not genetically identical) and that meiosis and random fertilisation can lead to variation (detailed description of the behaviour of chromosomes during meiosis is not required. Information about the stages and associated behaviour of the nuclear envelope, cell surface membrane and centrioles is not required.)

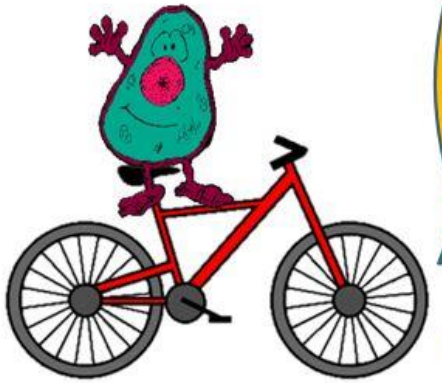
WHY SHOULD YOU LEARN THIS?

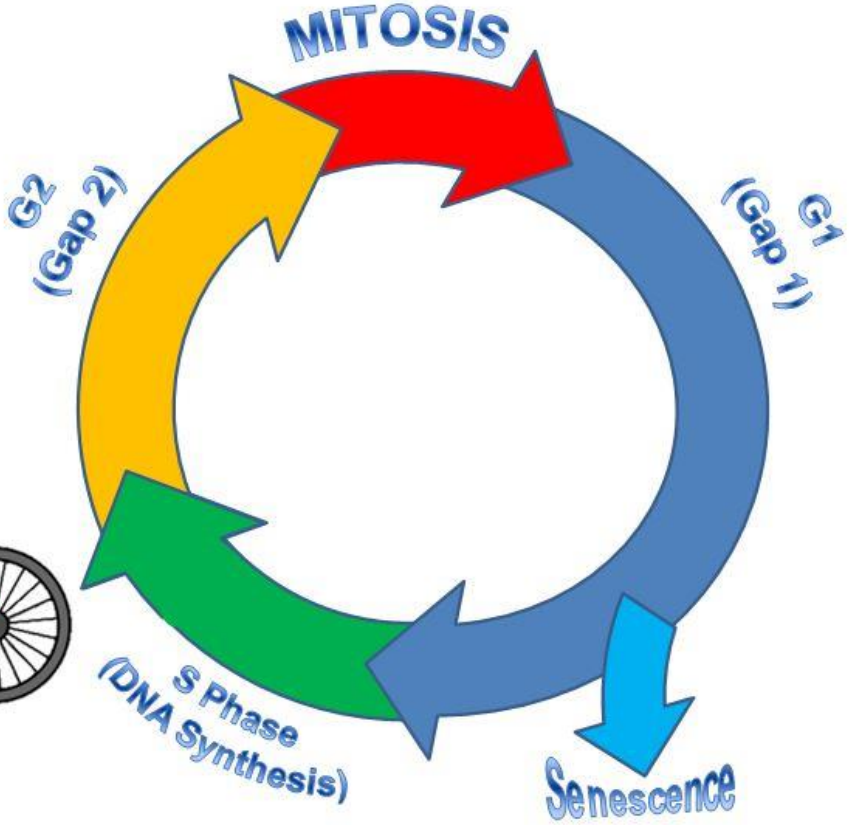




Intro to the CELL CYCLE

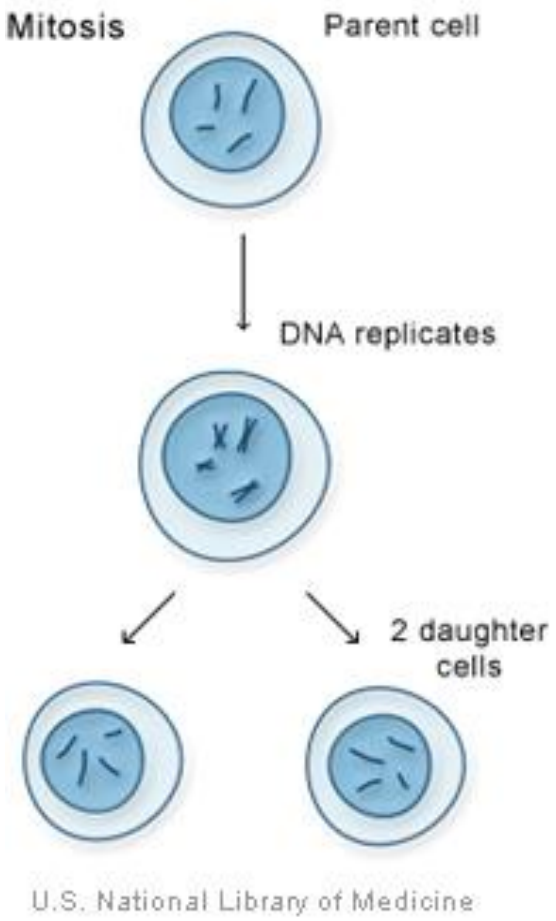
Lecture Book 4
Pg 1





CELL CYCLE *VS* CELL DIVISION

- **Cell cycle:**
  - is the **orderly program of events** in the lifetime of a cell
  - From the time it is first formed from a dividing parent until its own *division* into 2 daughter cells
- **Cell division:**
  - A process involving the division of a parent cell into new daughter cells.
  - comprising of **nuclear division and cytokinesis**



TERMINOLOGY

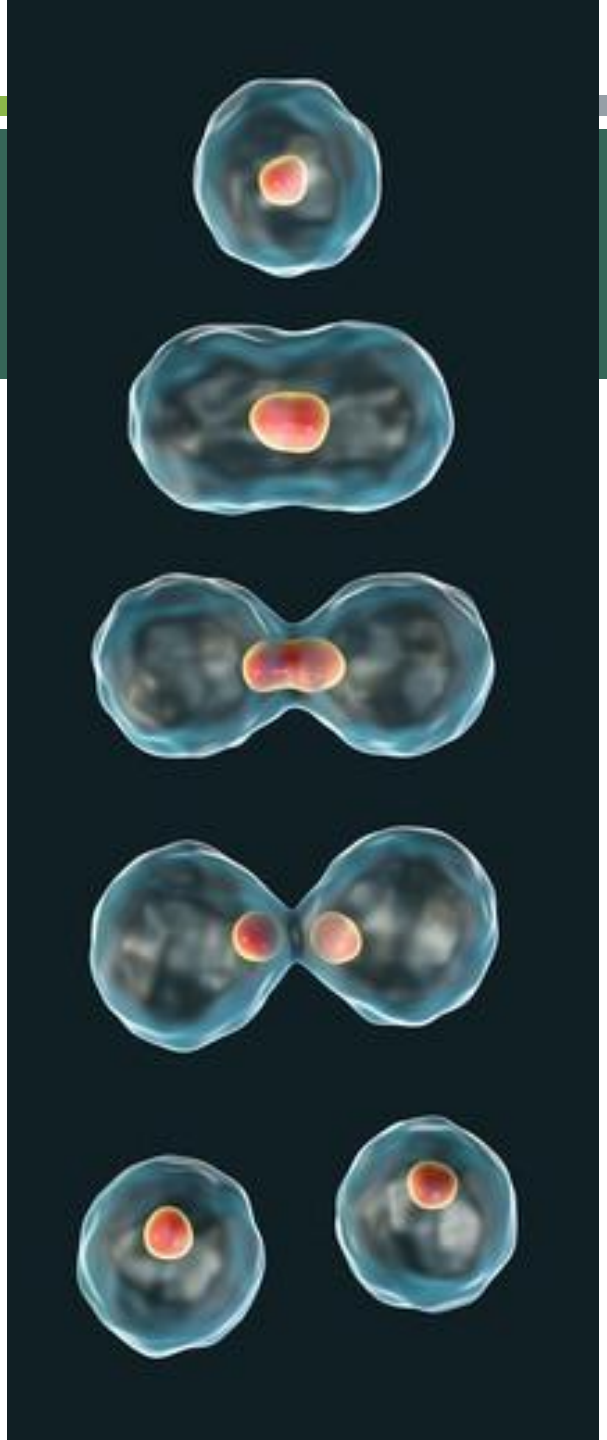
Cell Cycle = Interphase + Cell Division

Recall: Cell = Nucleus + Cytoplasm

Cell Division = Nuclear division (Mitosis / Meiosis) +

Cytoplasmic Division

a.k.a Cytokinesis

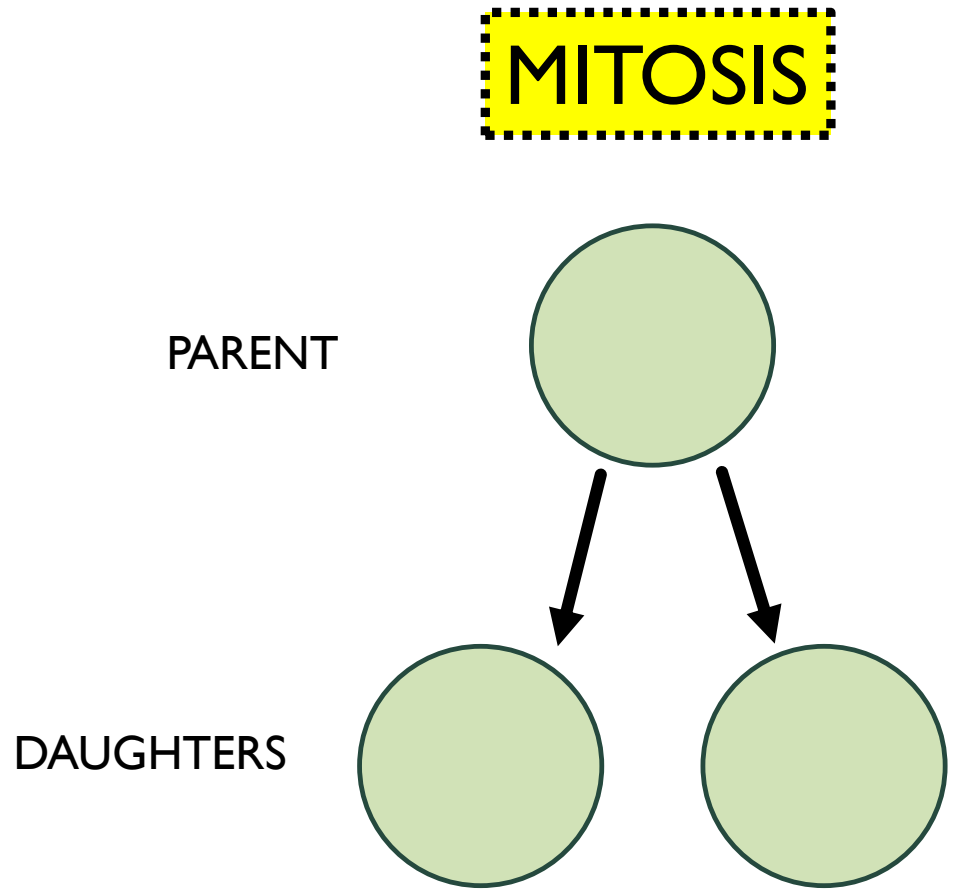


2 TYPES OF NUCLEAR DIVISION

1. **Mitosis:** produces **2 daughter nuclei** that are **genetically identical** to that of the parent.

The daughter cells should have the **same number of chromosomes** and **same genetic information** as the parent cell.

More in MITOSIS lecture!



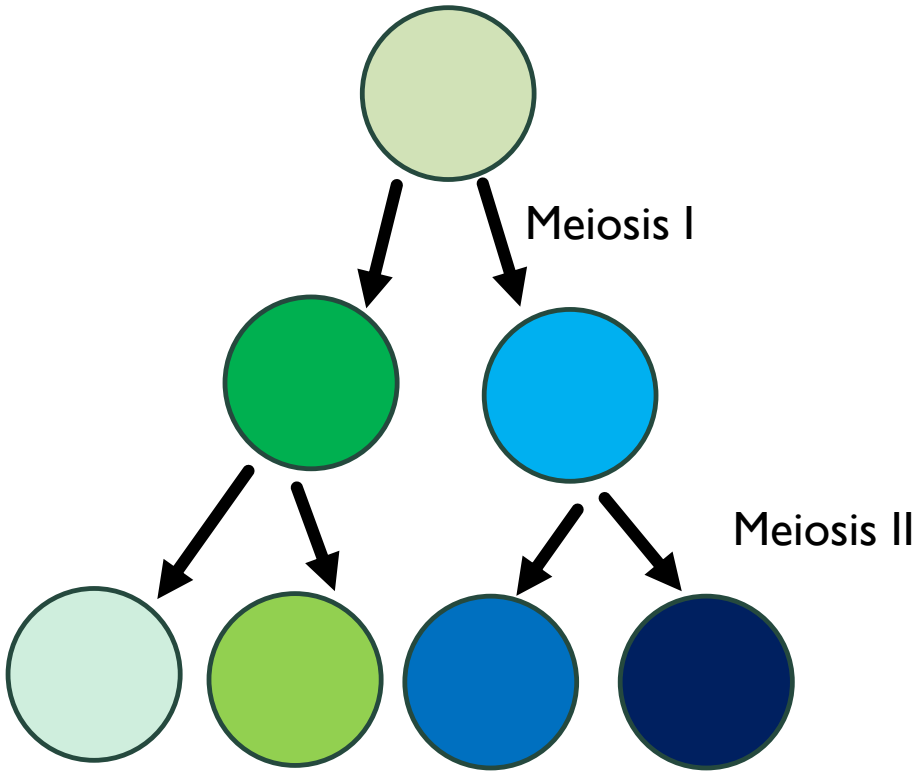
2 TYPES OF NUCLEAR DIVISION

2. **Meiosis:** Involves 2 nuclear divisions.

This produces **4 daughter nuclei** that are **not genetically identical** have **half the number of chromosomes** as that of the parent.

Details not needed in H1!

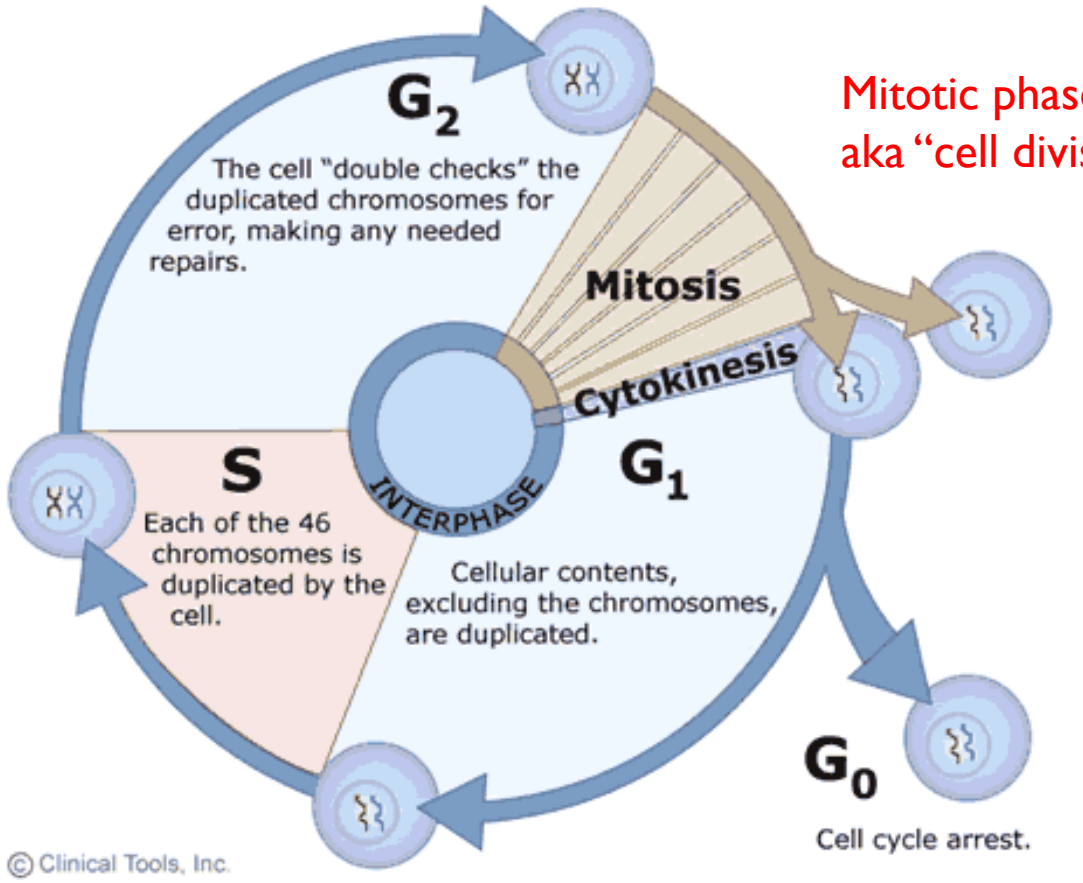
MEIOSIS



MITOTIC CELL CYCLE OVERVIEW

Mitotic cell cycle is divided into:

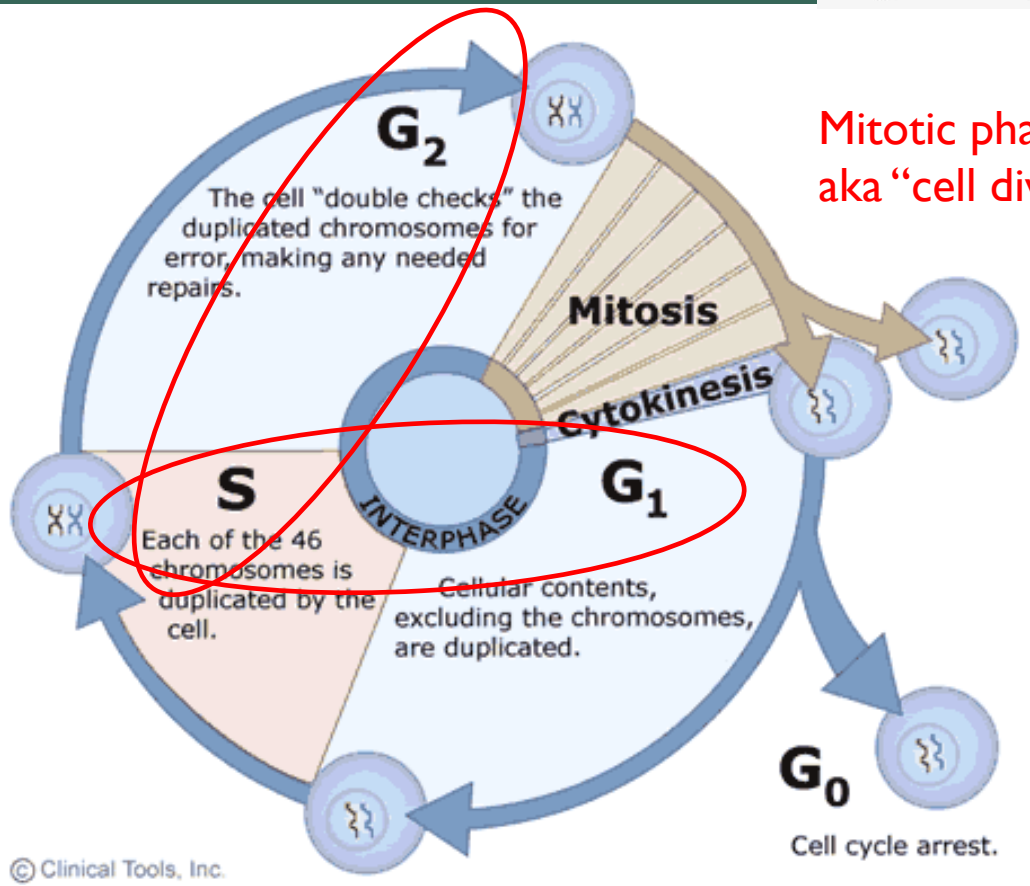
1. Interphase (G1, S & G2 phase)
2. Cell division phase comprises of:
   a. Mitosis* (nuclear division)
   b. Cytokinesis (division of cytoplasm)



Mitotic phase aka "cell division"

1) INTERPHASE

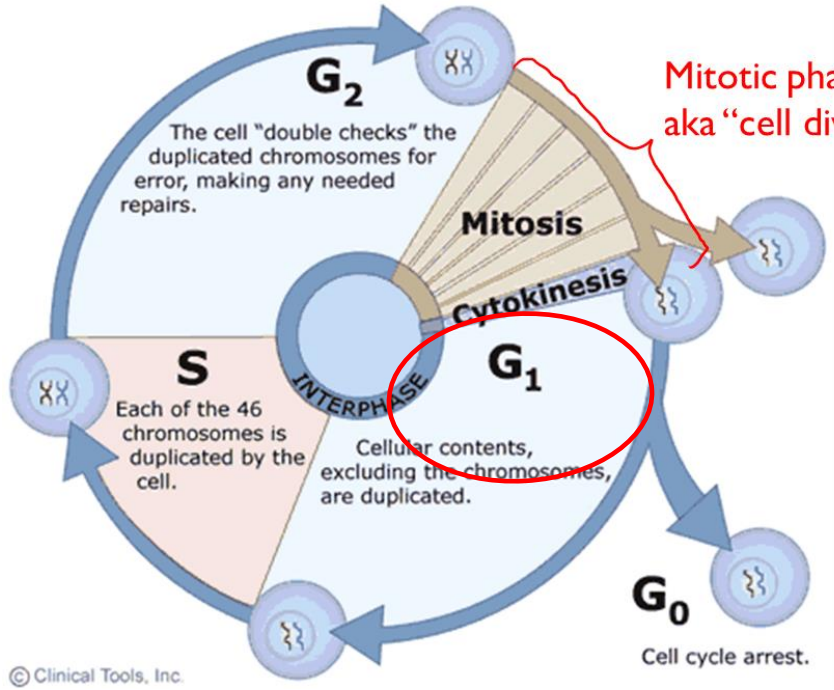
- A **period of synthesis** of materials required for carrying out all its functions and growth
- Subdivided into **G_1, S and G_2 phases**

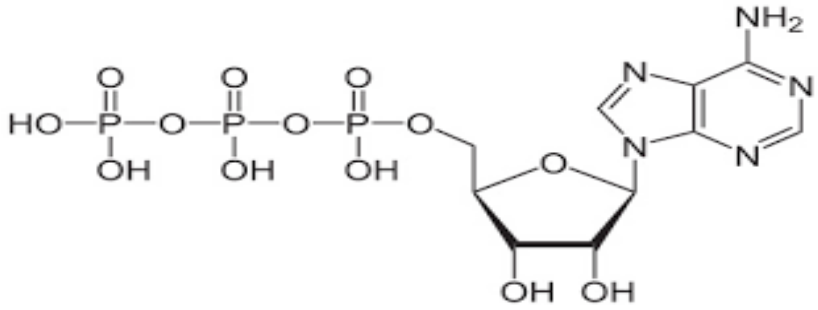


Mitotic phase aka "cell division"

1.1) INTERPHASE – G1

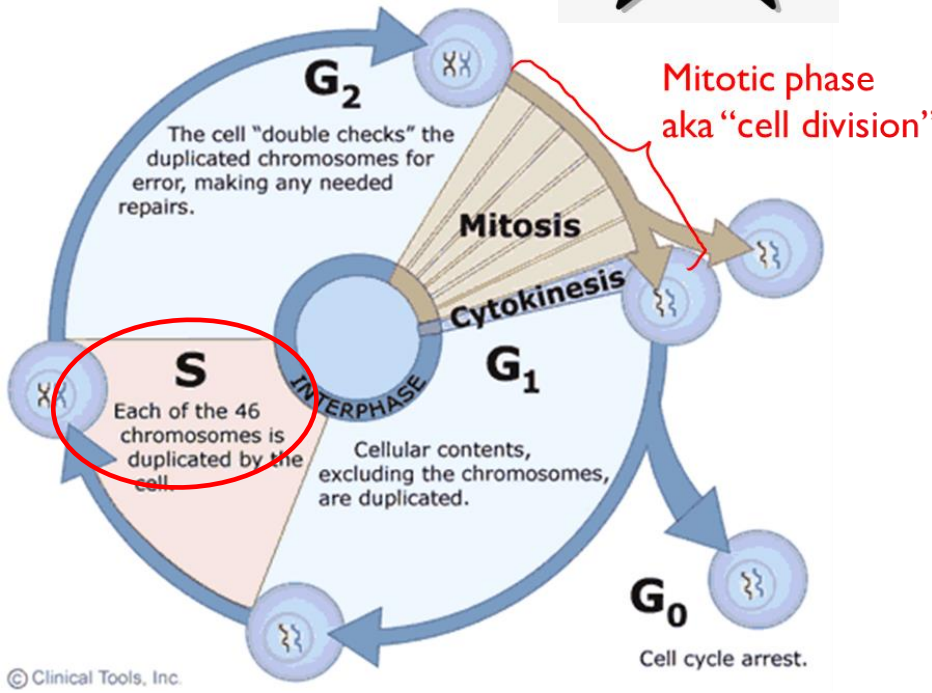
G1	• Cell **growth** (increase in size) • Free **deoxyribonucleoside triphosphates** synthesis • **Organelle** synthesis • **Proteins** and **enzymes** synthesis • **G1 Checkpoint*:** Checks that the cell is large enough with sufficient nutrients for **DNA synthesis** *[There are times when a cell will leave the cycle to go into G_0 stage and quit dividing]*

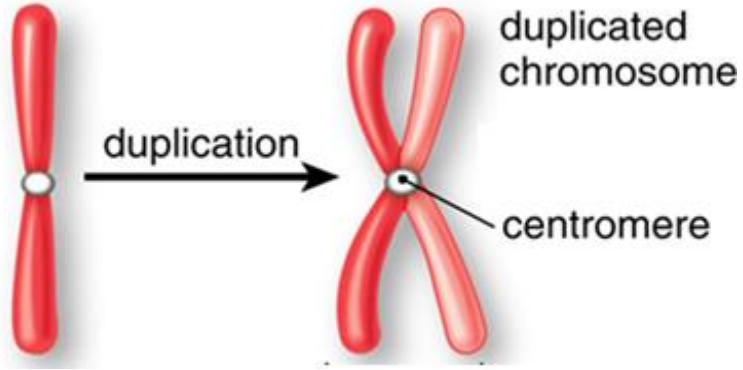


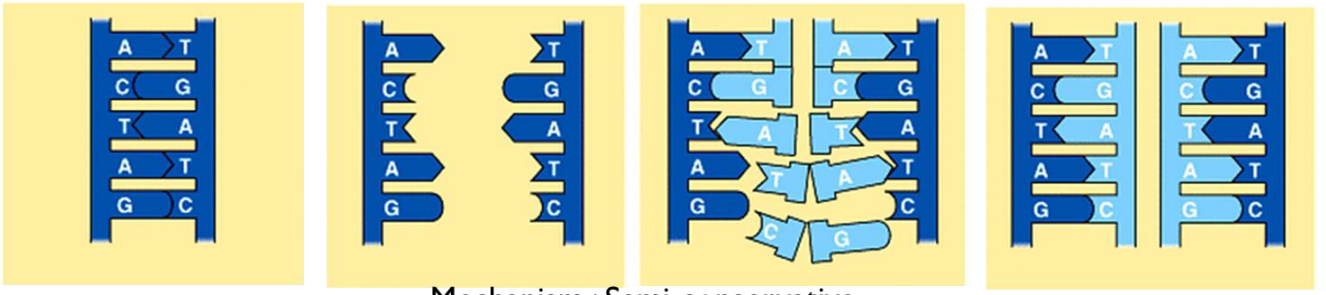


1.2) INTERPHASE - S

S	• **Semi-conservative replication** of DNA occurs • Each **duplicated chromosome** consists of **two identical sister chromatids** after replication completes. • The DNA content / Amount of DNA of the cell **doubles** during this phase



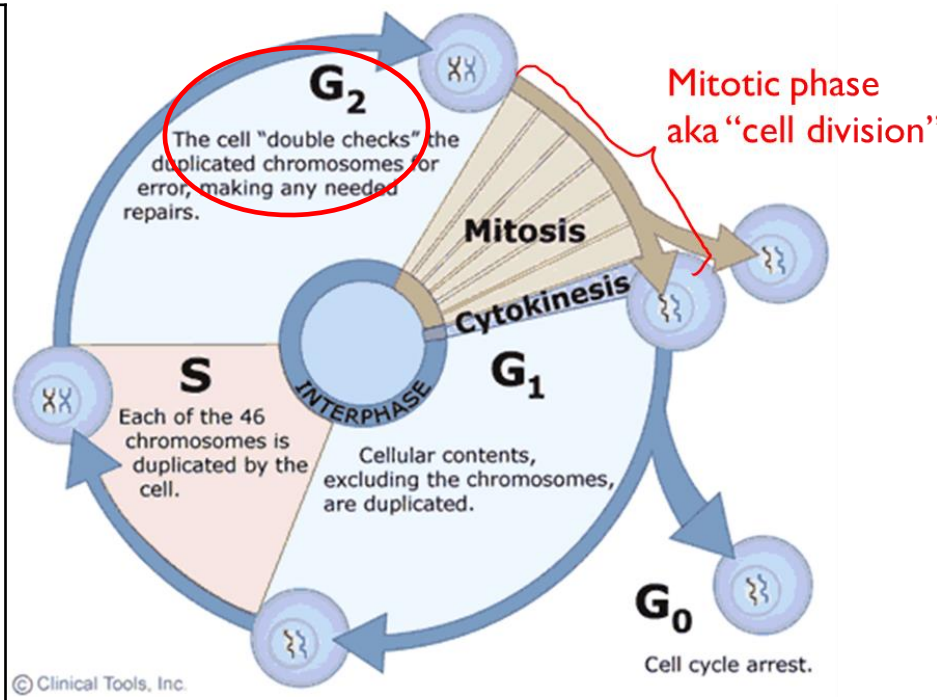




Mechanism : Semi-conservative DNA replication

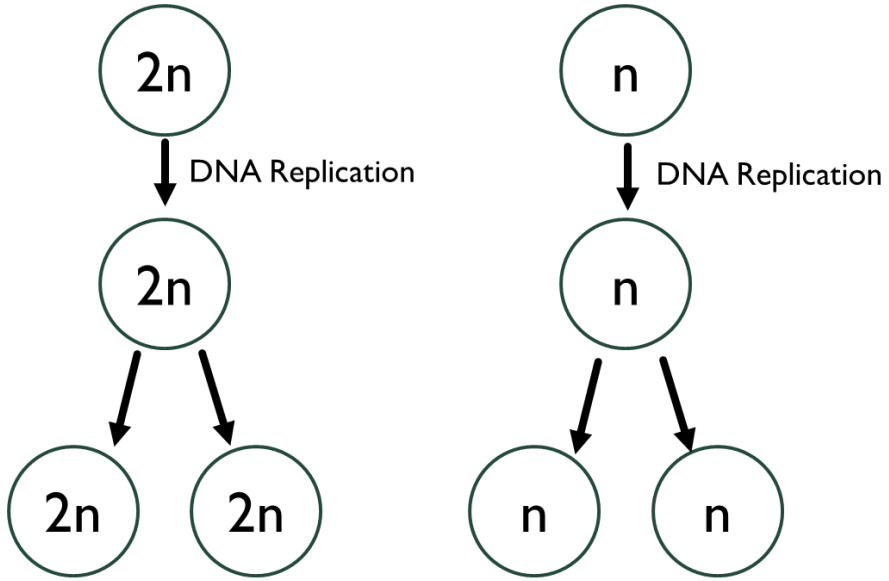
1.3) INTERPHASE – G2

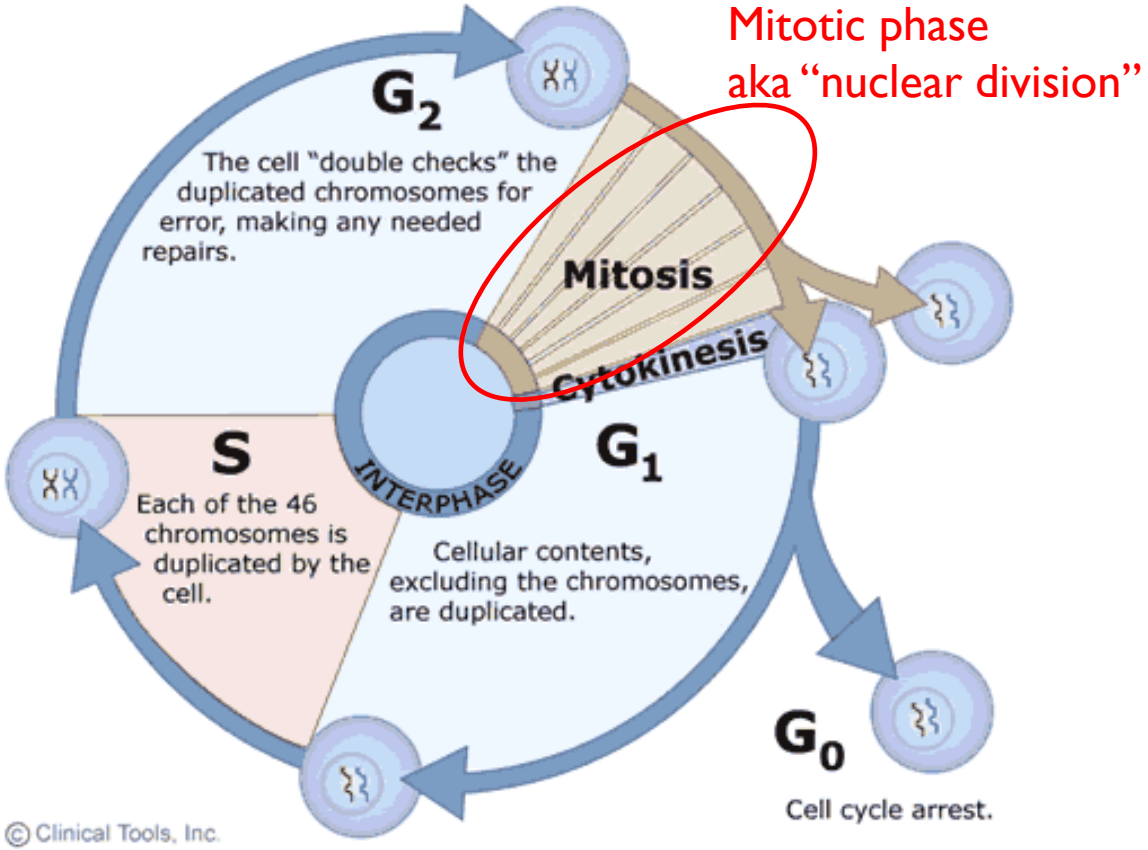
G2	• Cell **growth** • **ATP** production from increased rate of cellular respiration • Production of **microtubules** in preparation for nuclear division • **G2 Checkpoint***: Checks for the success of DNA replication and that the cell is ready for **mitosis and cytokinesis**



2A) MITOSIS

- **Division of nucleus** to produce **2 daughter nuclei** with identical sets of chromosomes as the parent cell.



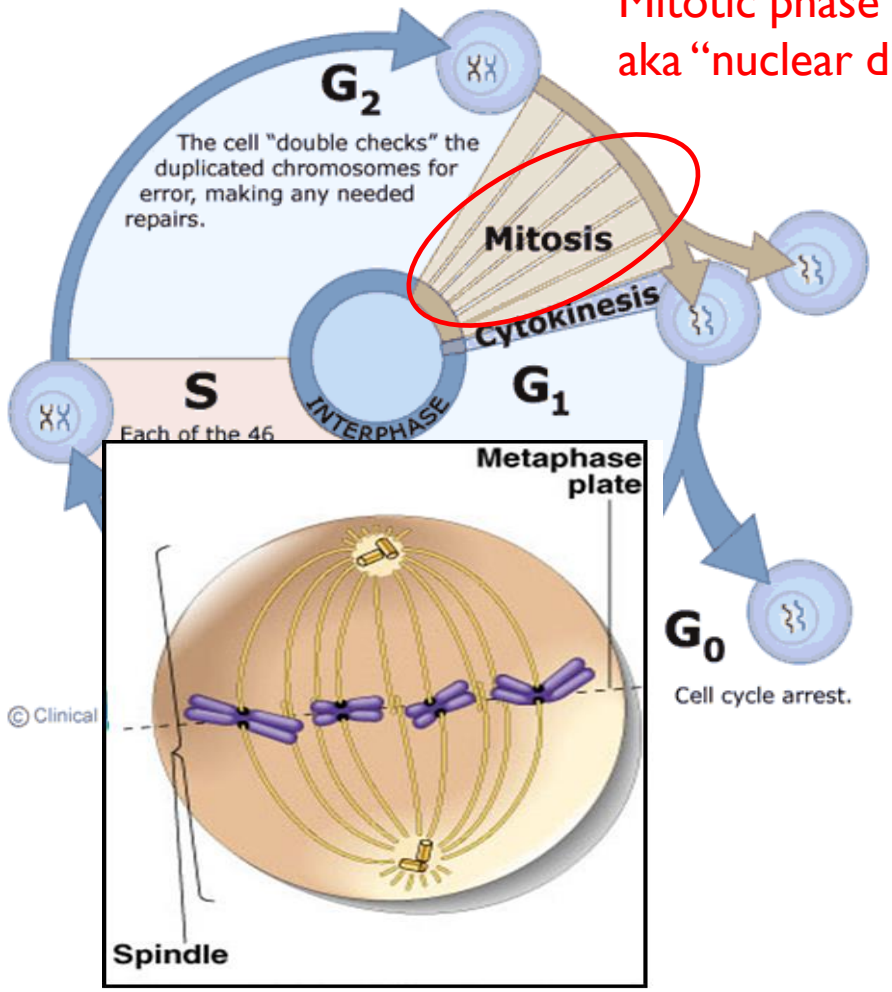


2A) MITOSIS - PMAT

- Nuclear division has 4 phases – **Prophase, Metaphase, Anaphase, and Telophase**.

- **M Checkpoint*** – Checks for **chromosome attachment** to the mitotic **spindle fibres** at the metaphase plate so that chromosomes are equally shared between daughter cells.

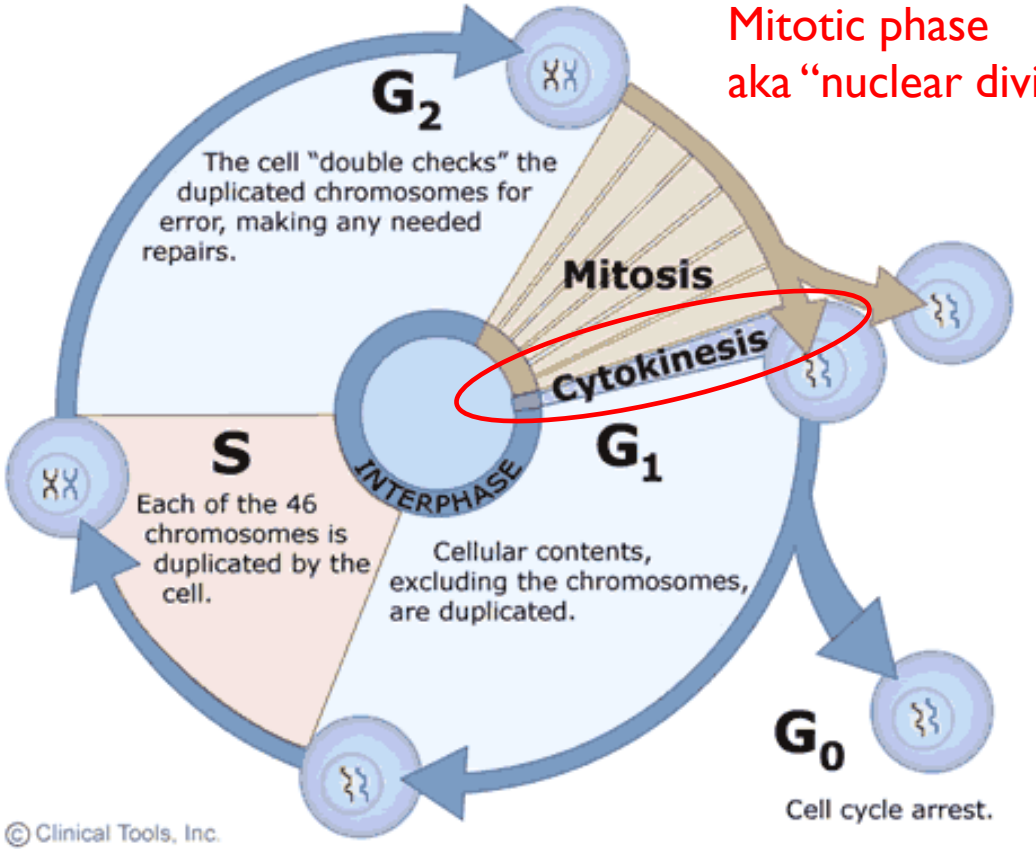
Mitotic phase
aka "nuclear division"



2B) CYTOKINESIS

- Equal **division of** **cytoplasm** and organelles between daughter cells via cleavage of cell surface membrane in animal cells or via cell plate formation in plant cells.
- Occurs right after Telophase of Mitosis

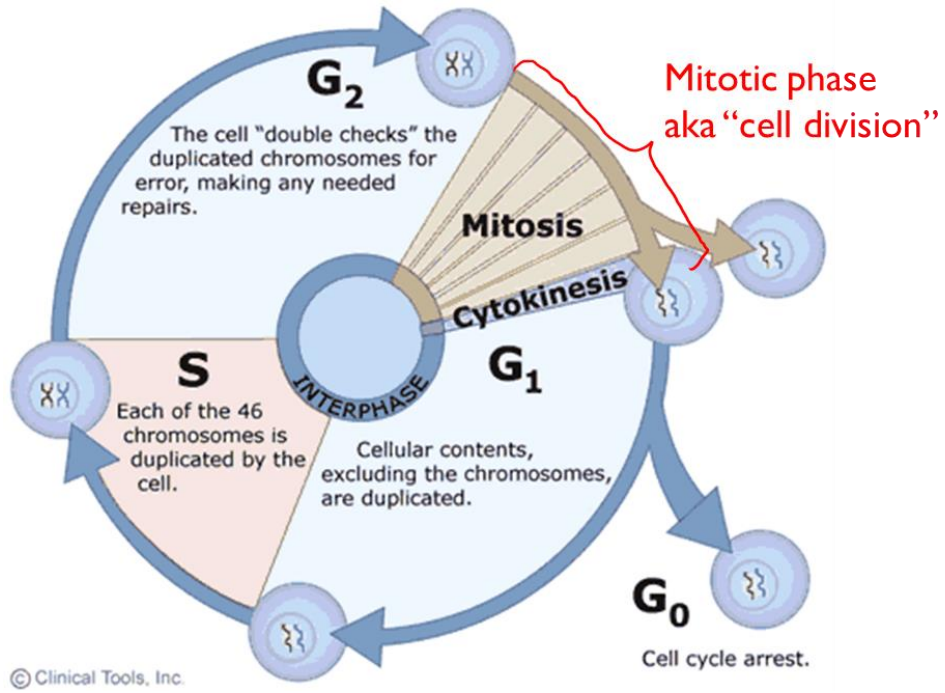
Mitotic phase
aka "nuclear division"



Not in notes

Cell Type	Cell-Cycle Times
Early frog embryo cells	30 minutes
Yeast cells	1.5–3 hours
Intestinal epithelial cells	~12 hours
Mammalian fibroblasts in culture	~20 hours
Human liver cells	~1 year

Interphase	**G1**	• Cell **growth** (increase in size) • Free **deoxyribonucleoside triphosphates** synthesis • **Organelle** synthesis • **Proteins** and **enzymes** synthesis • **G1 Checkpoint*:** Checks that the cell is large enough with sufficient nutrien for **DNA synthesis** *[There are times when a cell will leave the cycle to go into G_0 stage and qu dividing. For example:* *Brain neurons: End stage development with no further division* *Liver cells: Temporary resting period]*
	S	• **Semi-conservative replication** of DNA occurs • Each **duplicated chromosome** consists of **two identical sister chromatid** after replication completes. • The DNA content / Amount of DNA of the cell **doubles** during this phase
	G2	• Cell **growth** • **ATP** production from increased rate of cellular respiration • Production of **microtubules** in preparation for nuclear division • **G2 Checkpoint***: Checks for the success of DNA replication and that the cell ready for **mitosis and cytokinesis**
Mitosis (Nuclear division)		• Nuclear division has 4 phases – **Prophase**, **Metaphase**, **Anaphase**, **an Telophase**. (***P**olice **M**eets **A** **T**hief)* • **M Checkpoint* –** Checks for **chromosome attachment** to the mitotic **spindl fibres** at the metaphase plate so that chromosomes are equally shared betwee daughter cells.
Cytokinesis (Cell division)		• Equal **division of cytoplasm** and organelles between daughter cells v cleavage of cell surface membrane in animal cells or via cell plate formation i plant cells.



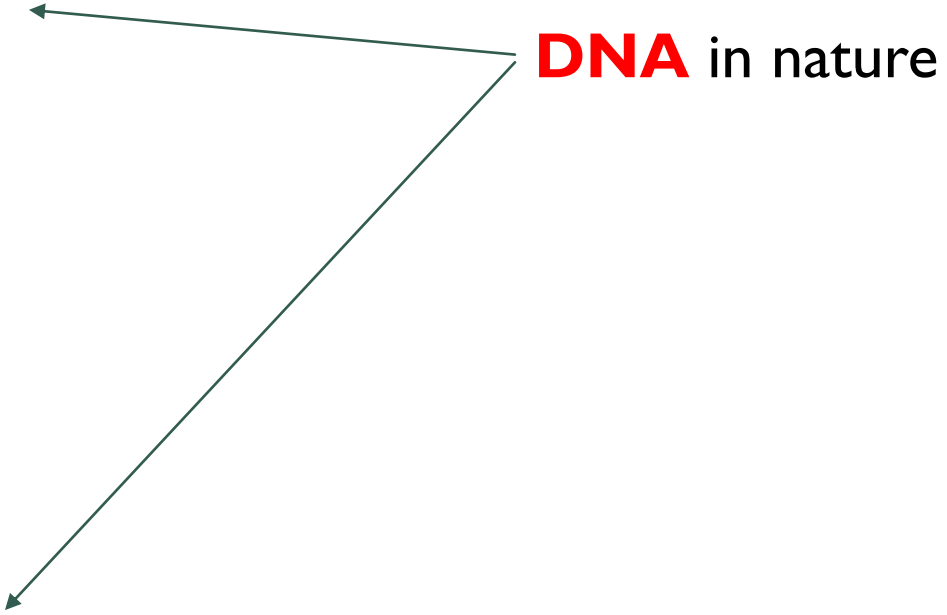
A **checkpoint** in the cell cycle is a **control point** where stop and go-ahead signals in G1, G2 phases in interphase and M (refer to Mitosis) phase can **regulate** the cycle.

Not in notes

MITOSIS: 'C' JARGON

MITOSIS: 'C' JARGON

1) **C**hromatin
2) **C**hromosomes
3) (duplicated) **C**hromosomes
4) **C**hromatids
5) (homologous) **C**hromosomes
6) **C**entrioles
7) **C**entrosomes
8) **C**entromeres



MITOSIS: 'C' JARGON

1) **C**hromatin
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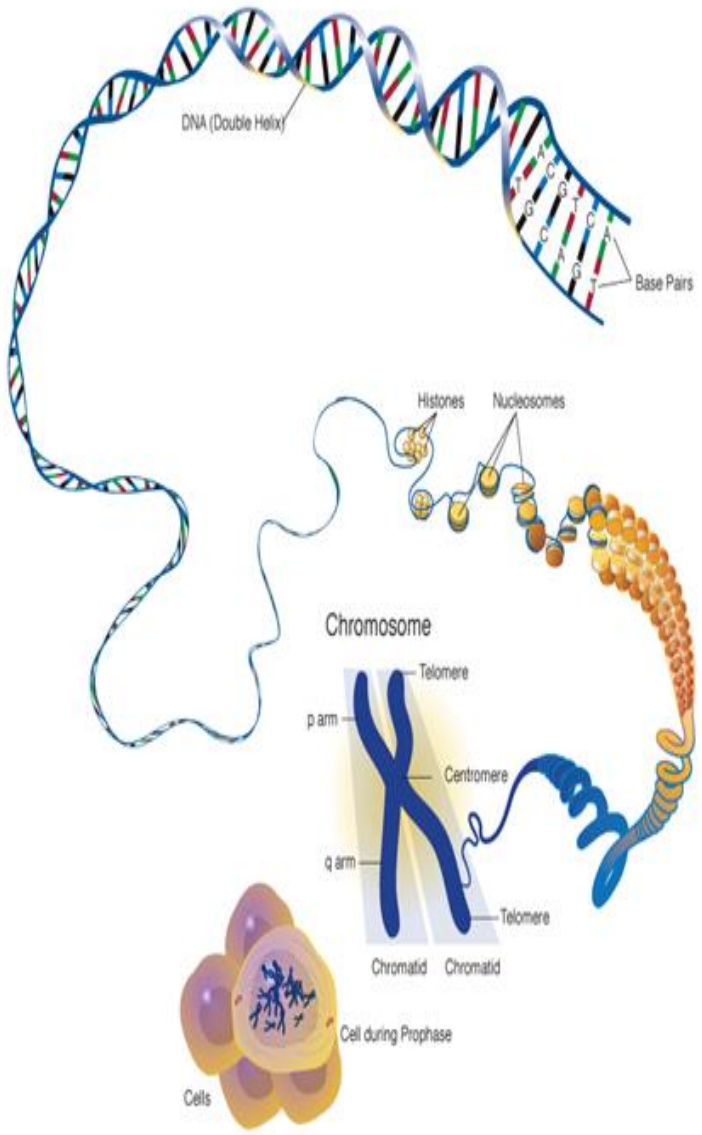
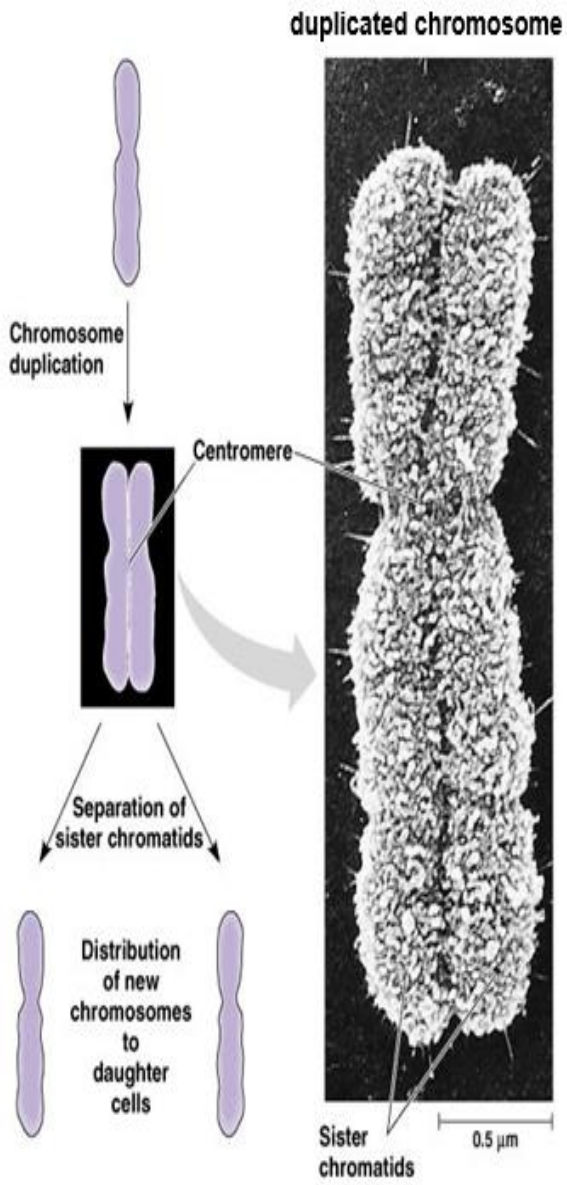
3) (duplicated) **C**hromosomes
4) **C**hromatids
5) (homologous) **C**hromosomes
6) **C**entrioles
7) **C**entrosomes
8) **C**entromeres

- Terms used to describe the genetic material (**DNA**) at different **stages** (interphase, mitosis, cytokinesis, meiosis) and **phases** (prophase, metaphase, anaphase and telophase) in the cell cycle.

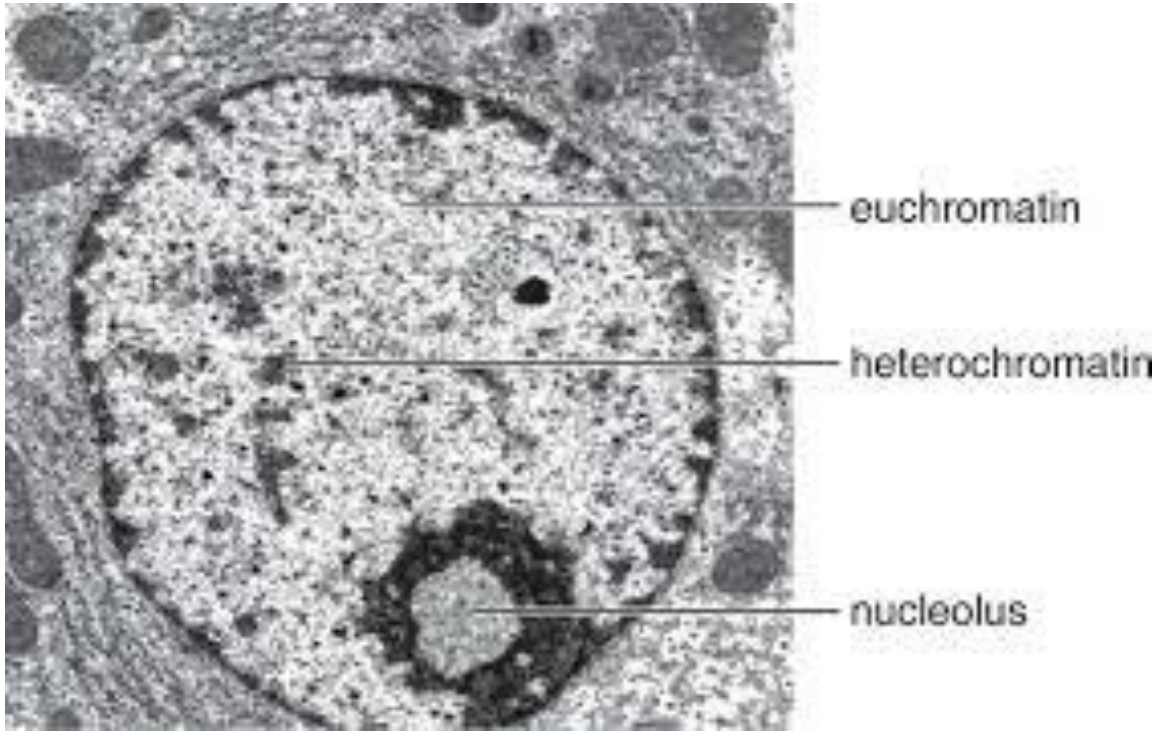




- Terms used to describe the genetic material (**DNA**) at different **stages** (interphase, mitosis, cytokinesis, meiosis) and **phases** (prophase, metaphase, anaphase and telophase) in the cell cycle.

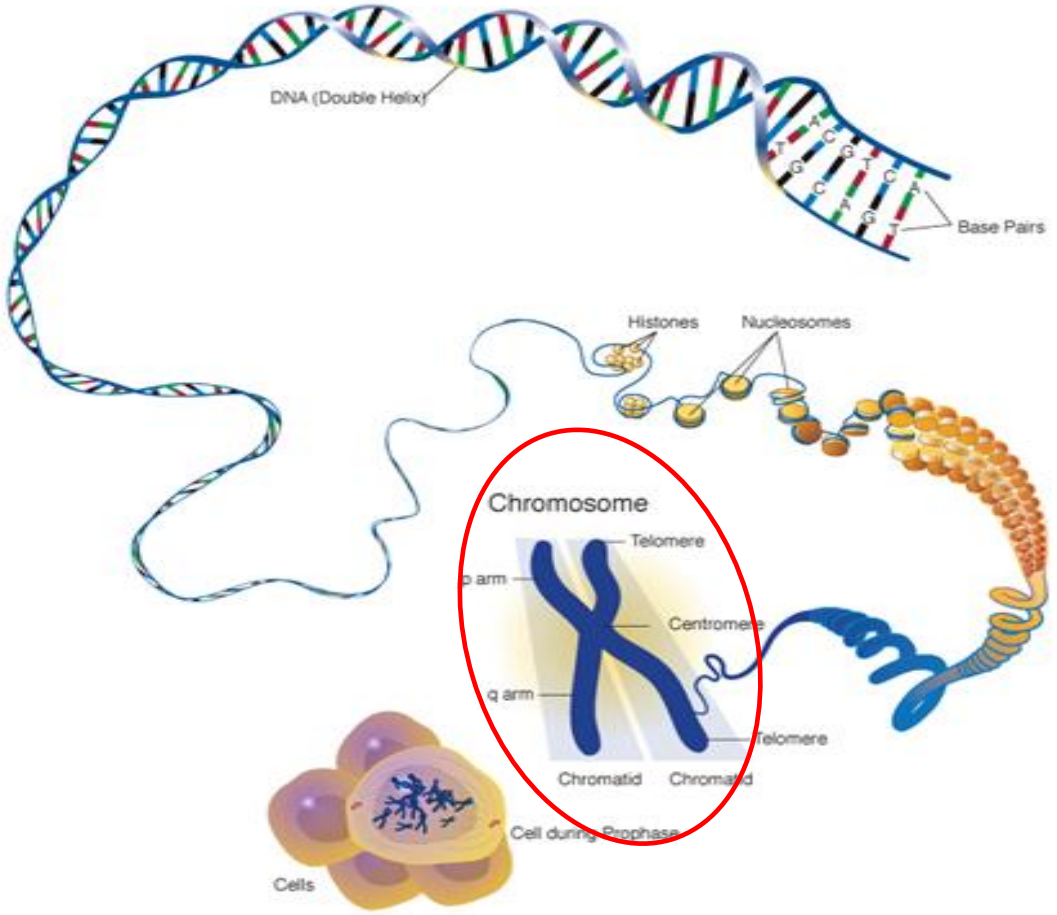
1. CHROMATIN

- A mass of very **long** and **thin** fibres throughout the nucleus when the cell is **not** dividing
- During early interphase
- Varies in its degree of condensation during the process of cell division.

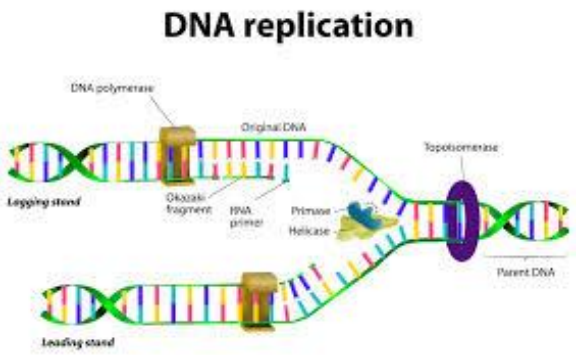


2. CHROMOSOMES

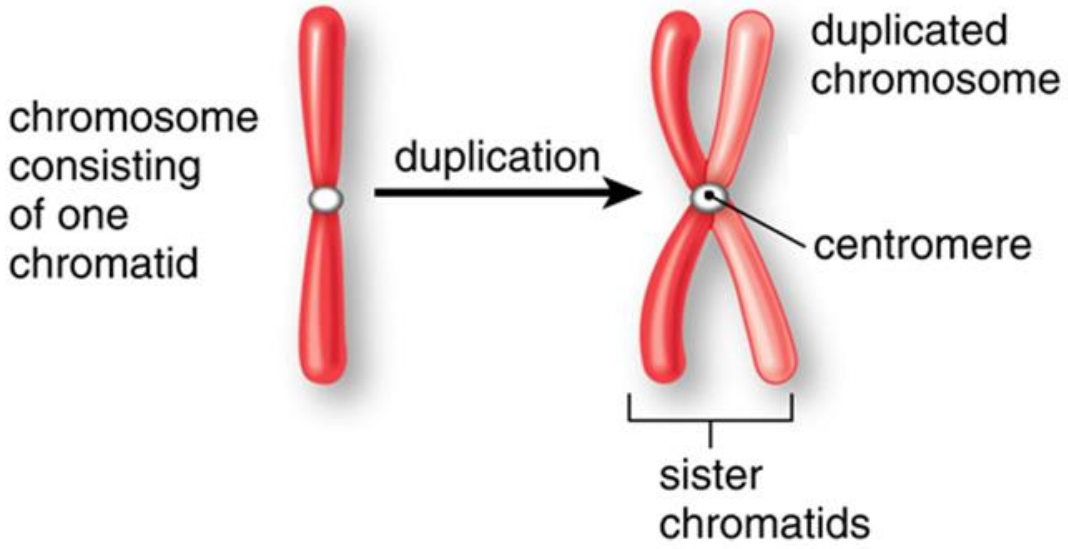
- Resulted as chromatin fibre **condense** into a much more **compact** structure (appearing shorter and thicker) just before nuclear division.
- During **Prophase!**



3. (DUPLICATED) CHROMOSOMES



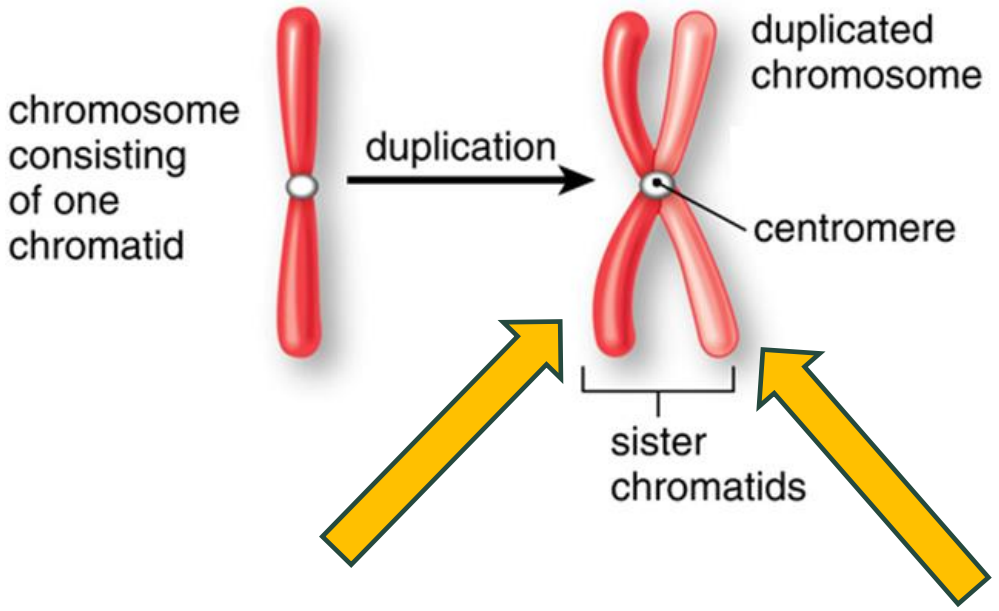
- **DNA replication** occurs during **S phase** of interphase
- At the end of DNA replication, there are **2 genetically identical DNA molecules**, held together at a point along their length called the **centromere**,
- Forms a structure known as **duplicated chromosome** also known as **double structure**.



1 DNA molecule = 2 DNA strands

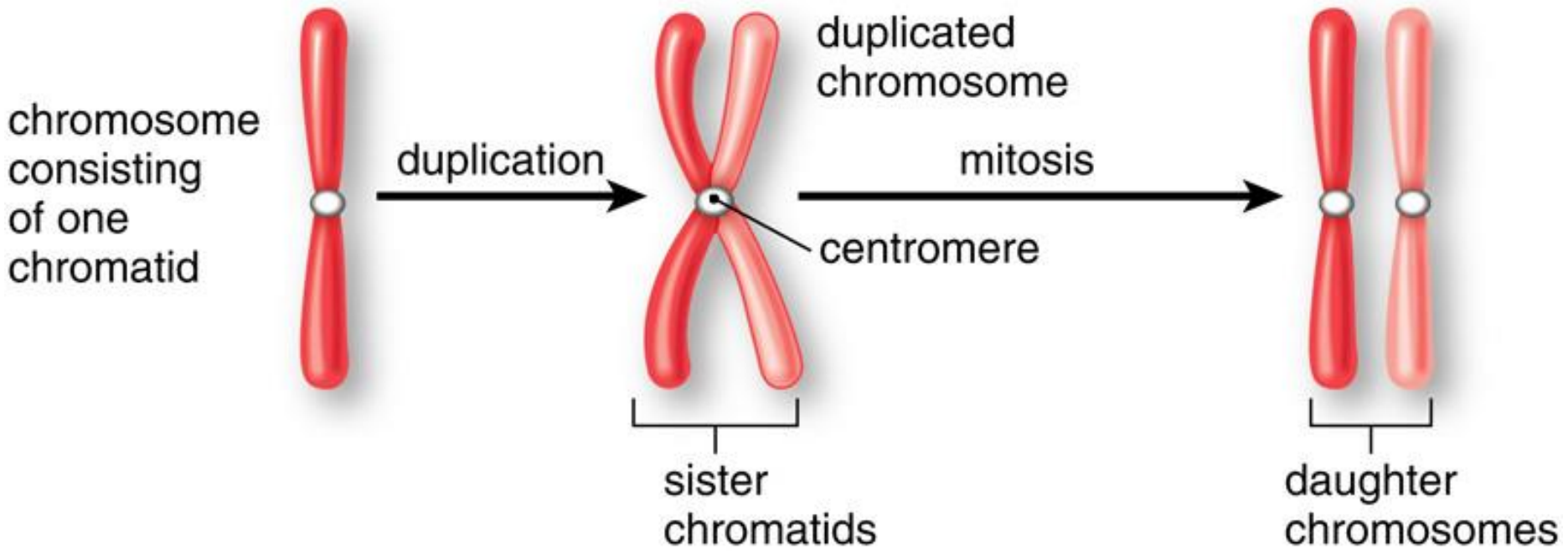
4. CHROMATID

- Chromatids correspond to the 2 identical parts of the **duplicated chromosome**.
- Since the 2 chromatids are **identical**, they are termed as **sister chromatids**
- Each chromatid in a duplicated chromosome is **one DNA molecule**.



4. CHROMATID

As soon as sister chromatids are **pulled apart** during cell division, they can be referred to as individual **chromosomes** again.



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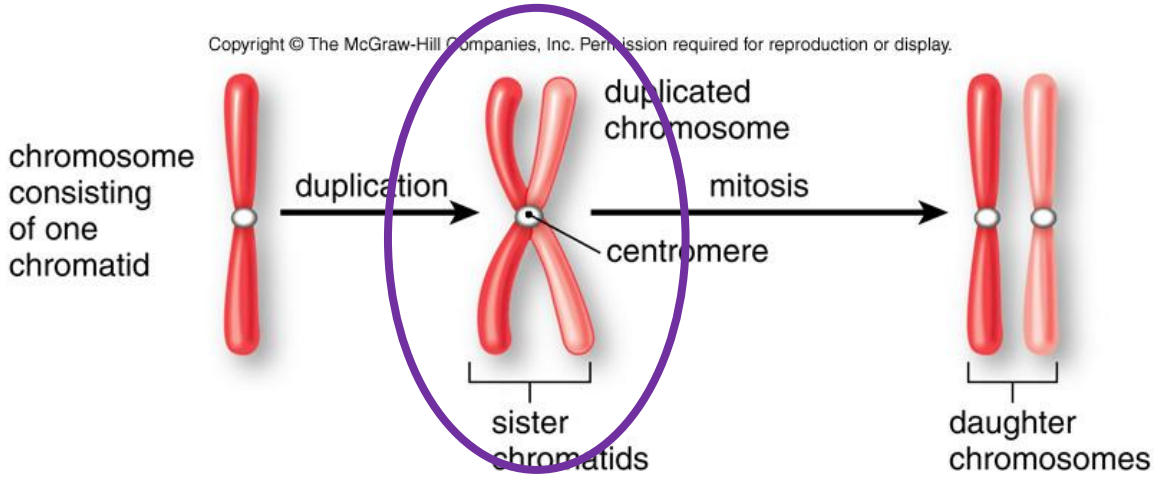
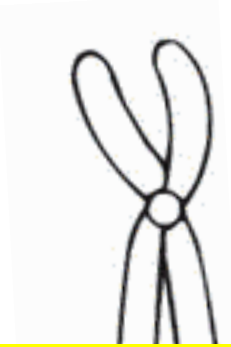


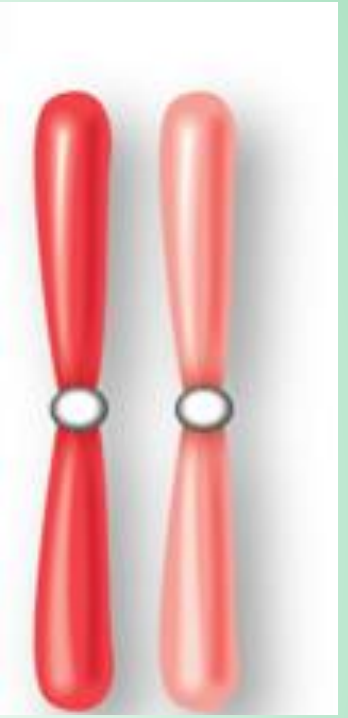
Note: double structure exists after DNA replication (after S phase of interphase onwards) until **metaphase** of **mitosis**

BUT in **meiosis**, double structure exists after DNA replication through meiosis I to **metaphase II** of meiosis II.

Not in notes

Number of chromosomes?





Pro Tip for counting:
1 centromere = 1 chromosome!

1

Unduplicated chromosome (1chromatid)

1

Duplicated chromosome (2 identical sister chromatids)

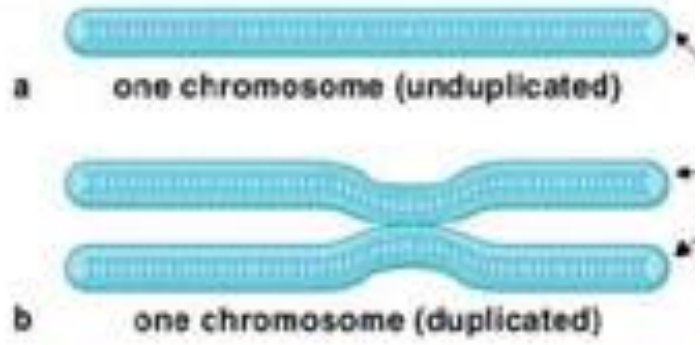
2

Separated daughter chromosomes

Not in notes

Number of DNA molecules?

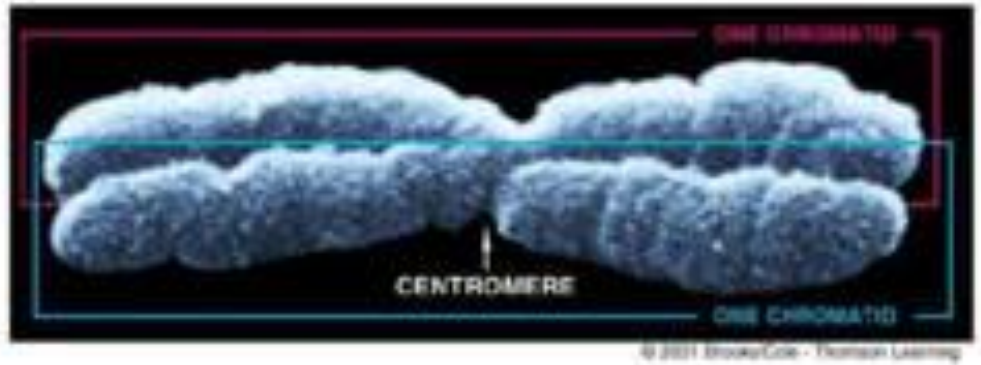
Chromosomes are made of DNA molecules



1 2 strands

2 4 strands

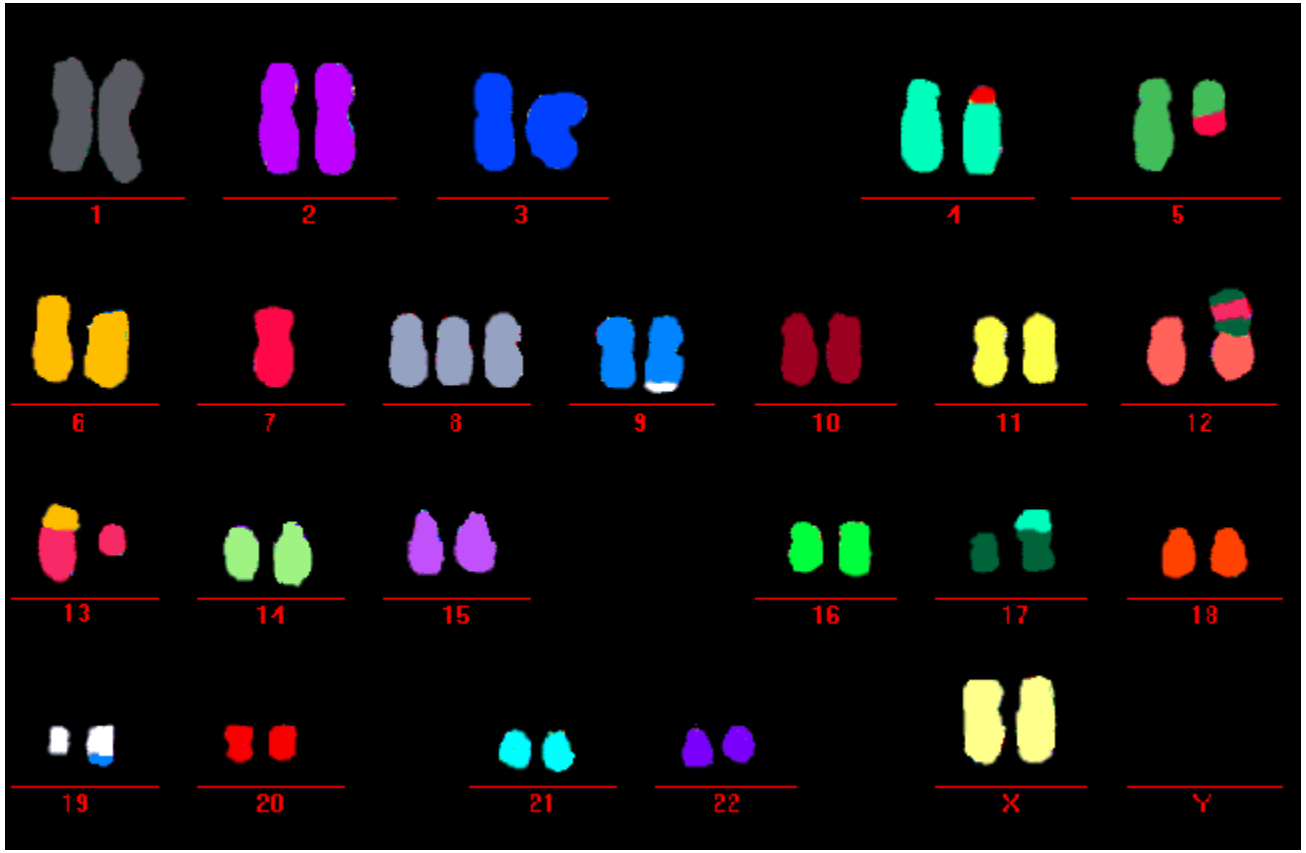
1 DNA molecule = 2 DNA strands



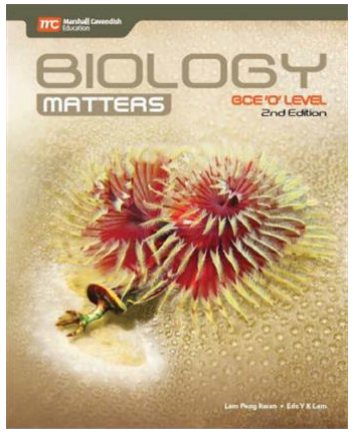
DNA content = Amount of DNA = Number of DNA strands

S	▪ The DNA content of the cell **doubles** during this phase

5. HOMOLOGOUS CHROMOSOMES



RECAP

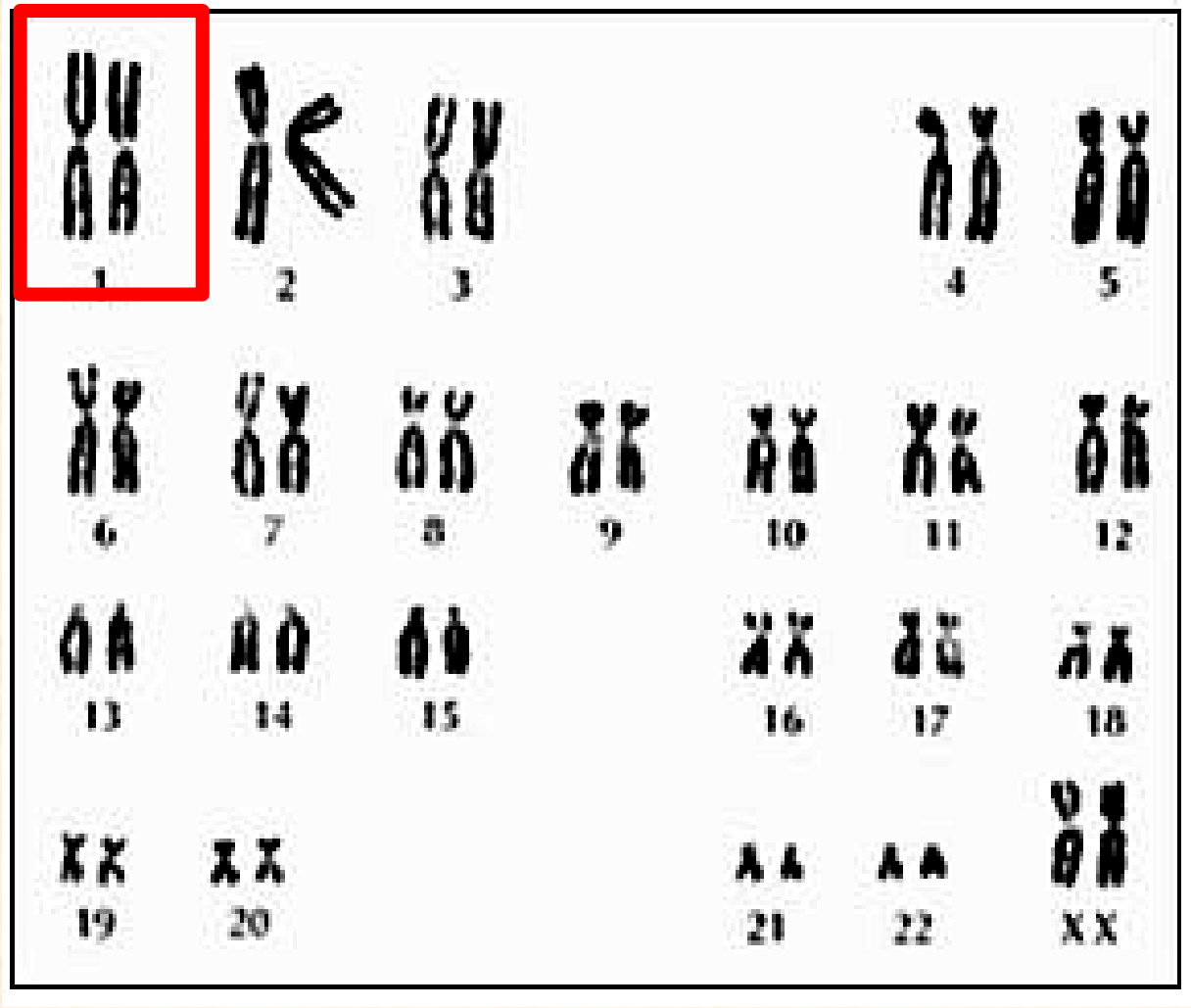


Karyogram

One homologous pair of chromosomes

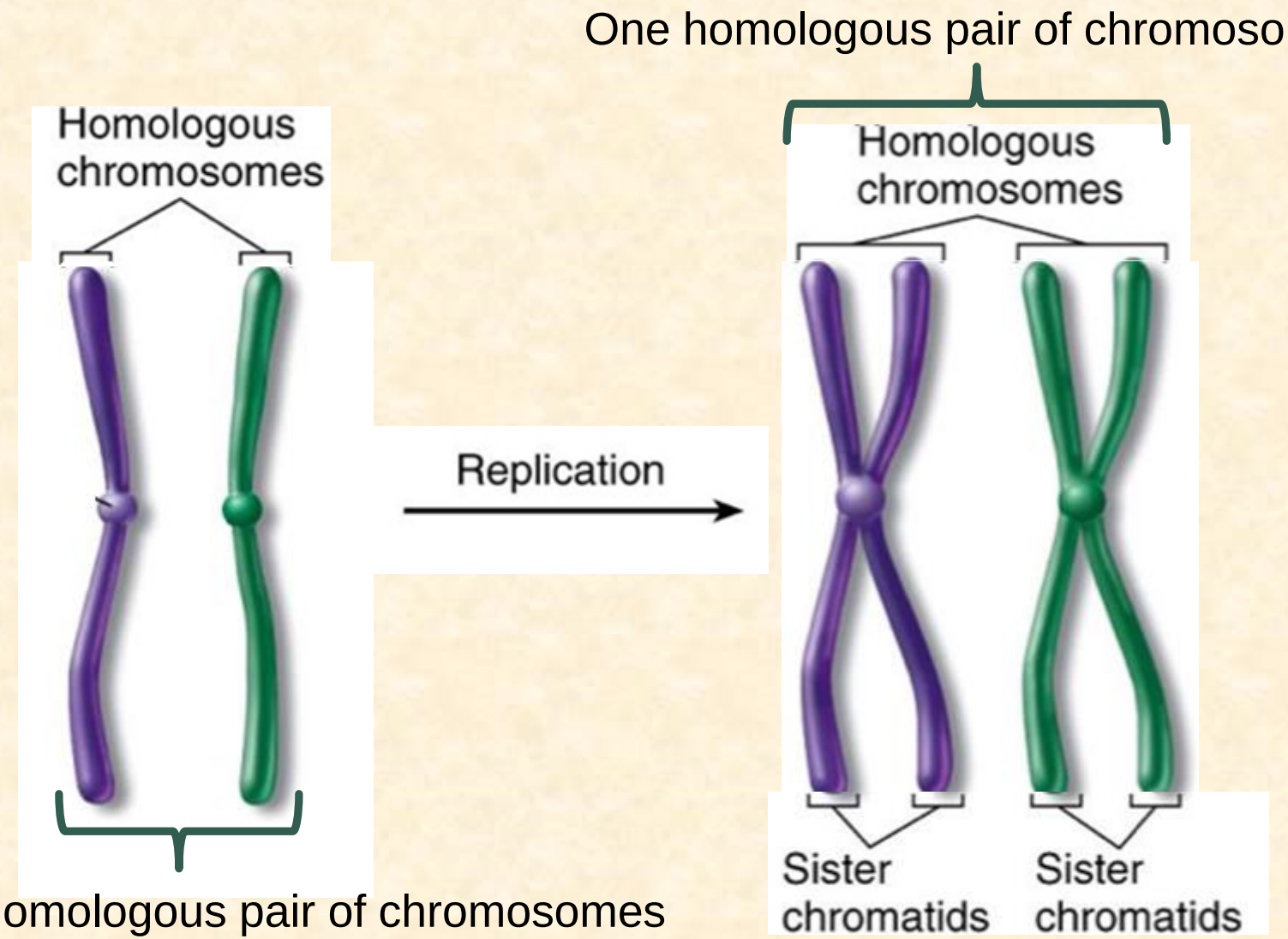
How many homologous pairs of chromosomes do humans have?

23 pairs



Karyogram = a photograph of the chromosomes of a cell, arranged in homologous pairs and in a numbered sequence. (page 7 shows the process of obtaining a karyogram)

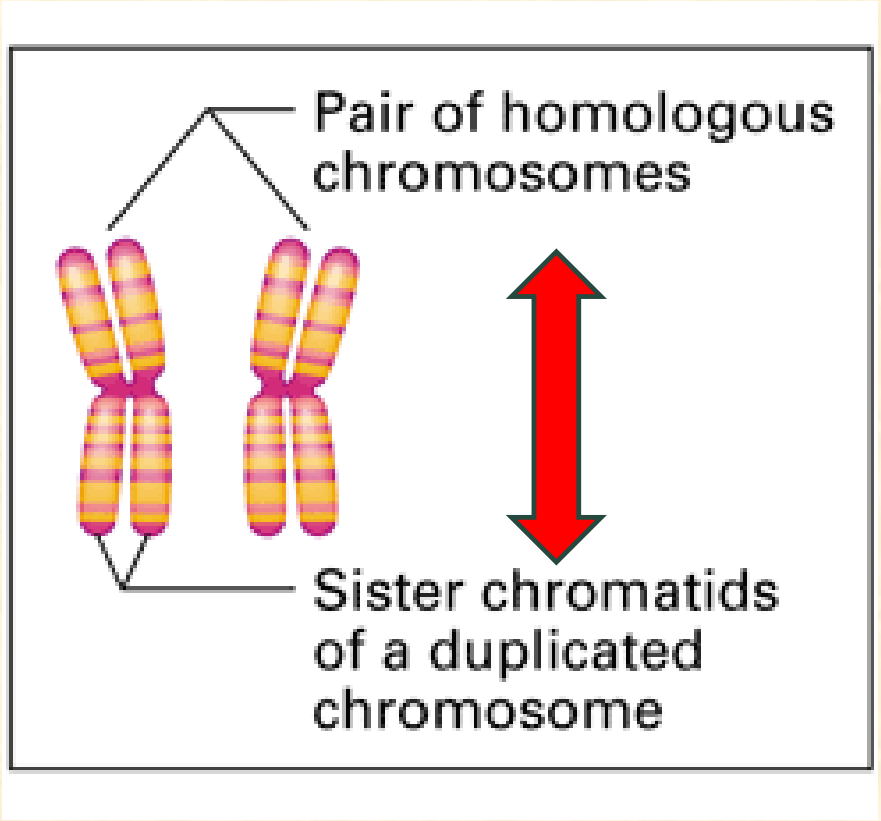
HOMOLOGOUS CHROMOSOMES



HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

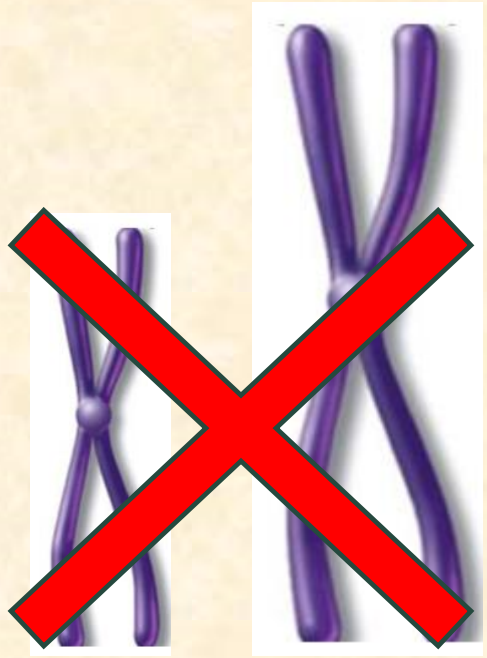
  1) same length



HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

  1) same length

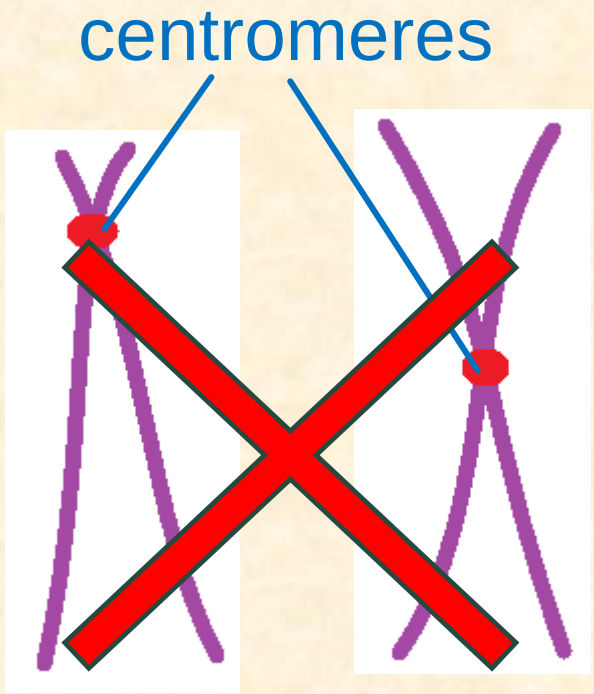


Not homologous (different length)

HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

  ➢ same centromere position



Not homologous
(different centromere position)

HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

  3) **Same gene loci** / carry genes that code for the same characteristic at the same corresponding loci

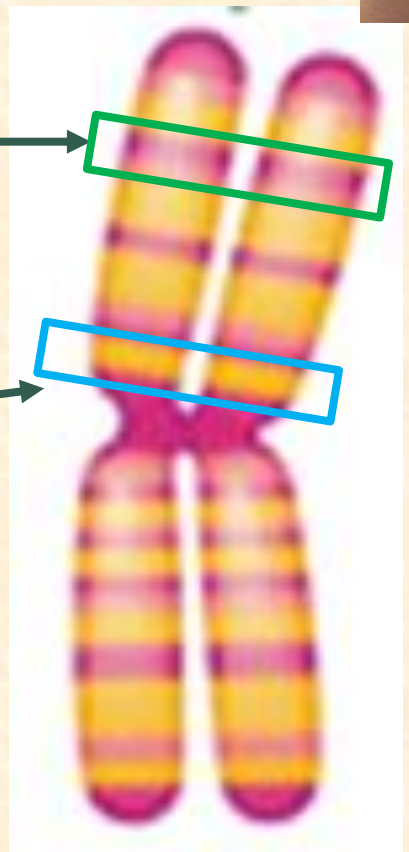
So what is gene loci???

LOCUS (SINGULAR) OR LOCI (PLURAL)

Location/position of a particular gene on a chromosome

Gene for **eye colour** is at this locus

Gene for **hair colour** is at this locus

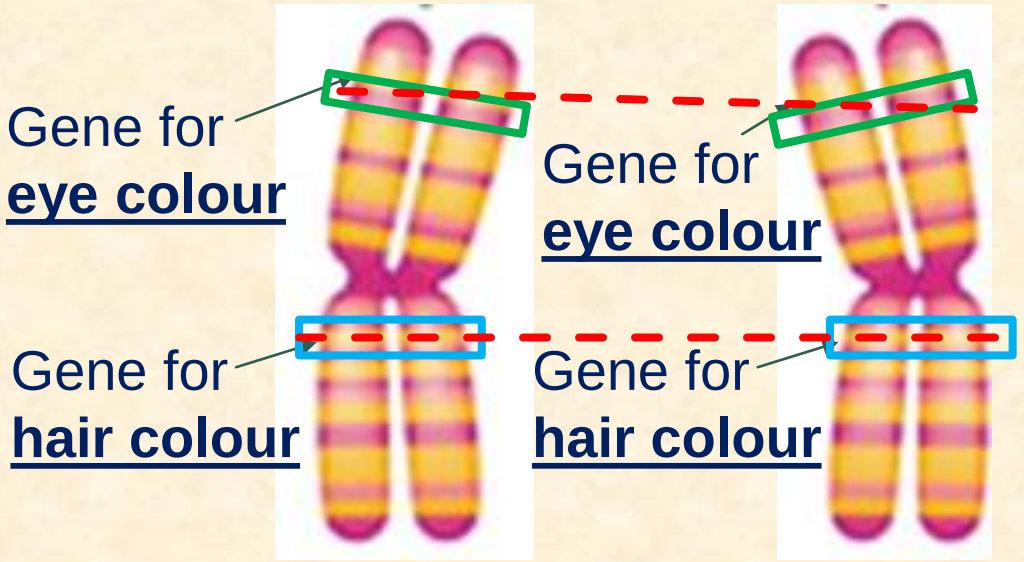


e.g. **17q12** → long arm of chr17

HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

  3) **Same gene loci** / carry genes that code for the same characteristic at the same corresponding loci

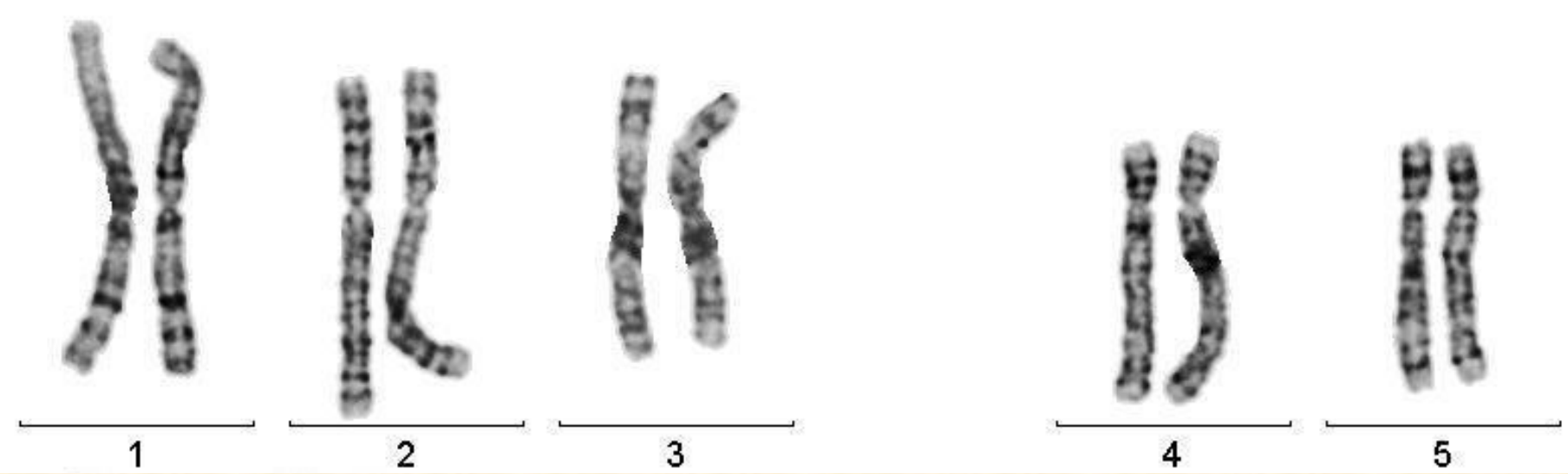


Homologous (same gene loci)

HOMOLOGOUS CHROMOSOMES

- A pair of homologous chromosomes have:

  4) Same staining pattern in a **karyogram**.



Not in notes

Differences in homologous chromosomes: They may carry different alleles for the same gene.

ALLELE VS GENE

- For understanding, remember this example:

  Gene: Eye colour
  Allele: Brown, blue, gray, green etc

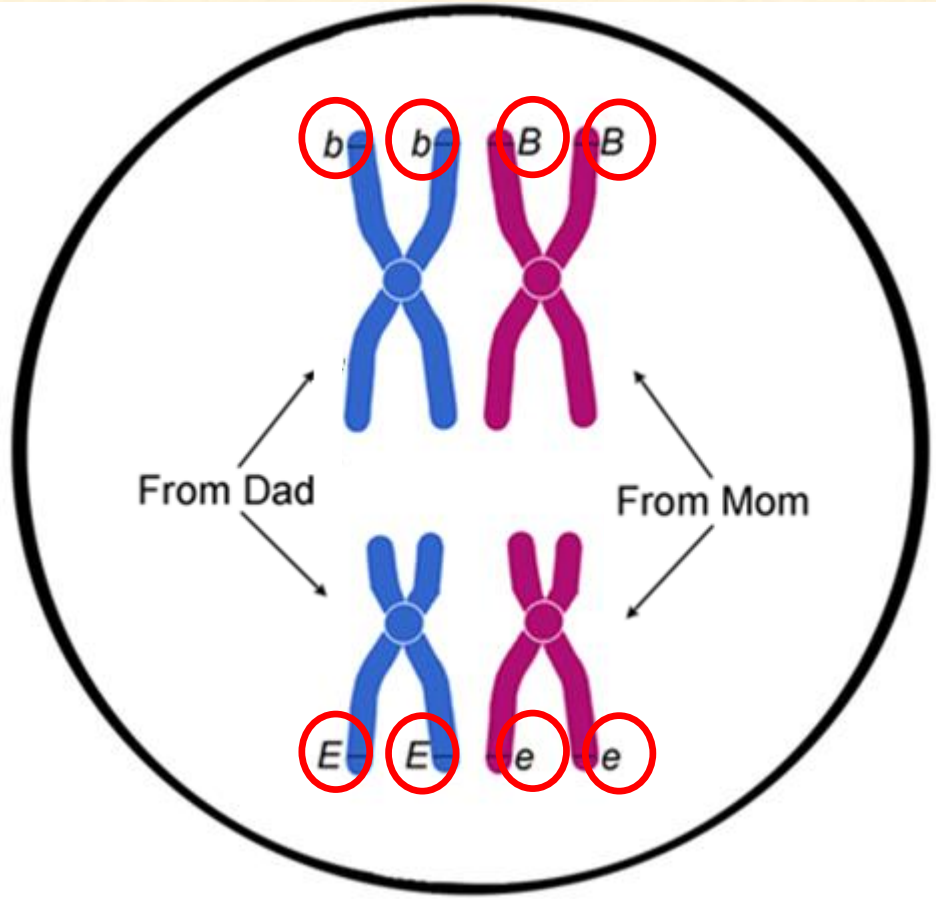
Gene for **eye colour**

Allele: blue color

Gene for **eye colour**

Allele: brown color

HOMOLOGOUS CHROMOSOMES



B and b are alleles of a gene

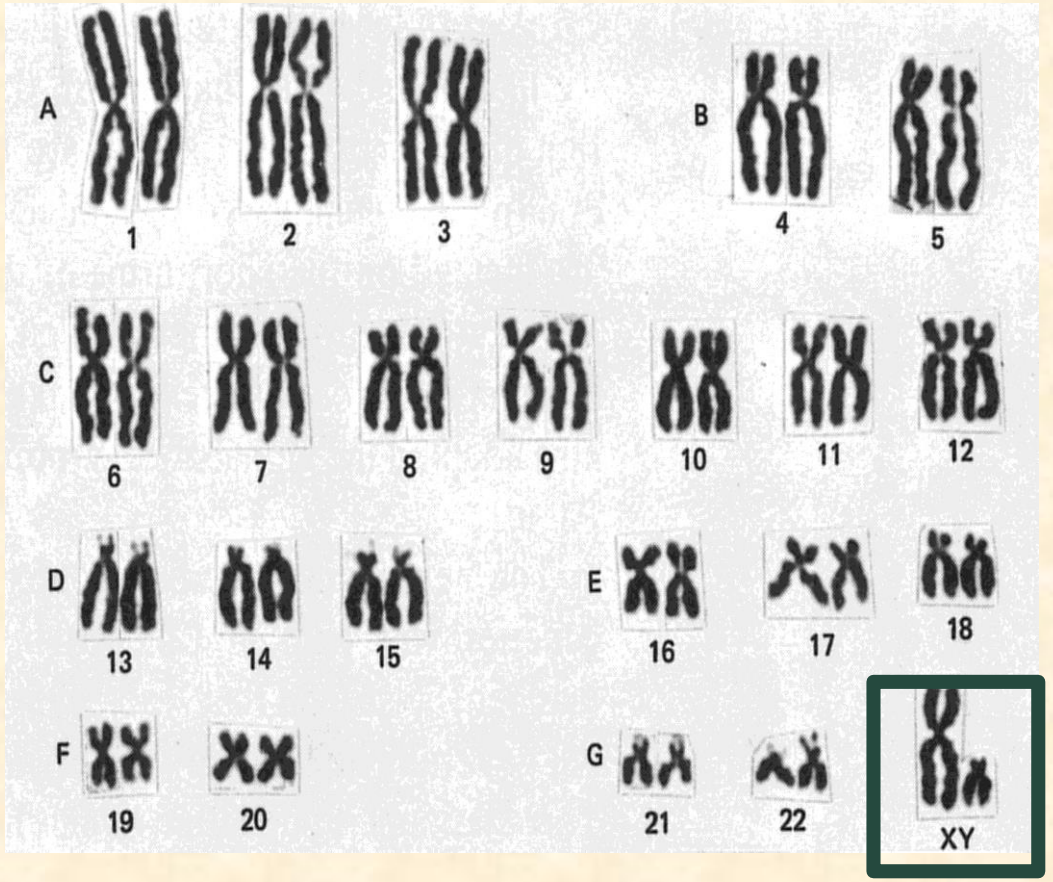
Gene B/b

E and e are alleles of another gene **Gene E/e**

Gene B/b & Gene E/e are on different pairs of homologous chromosomes

Notice something unusual?

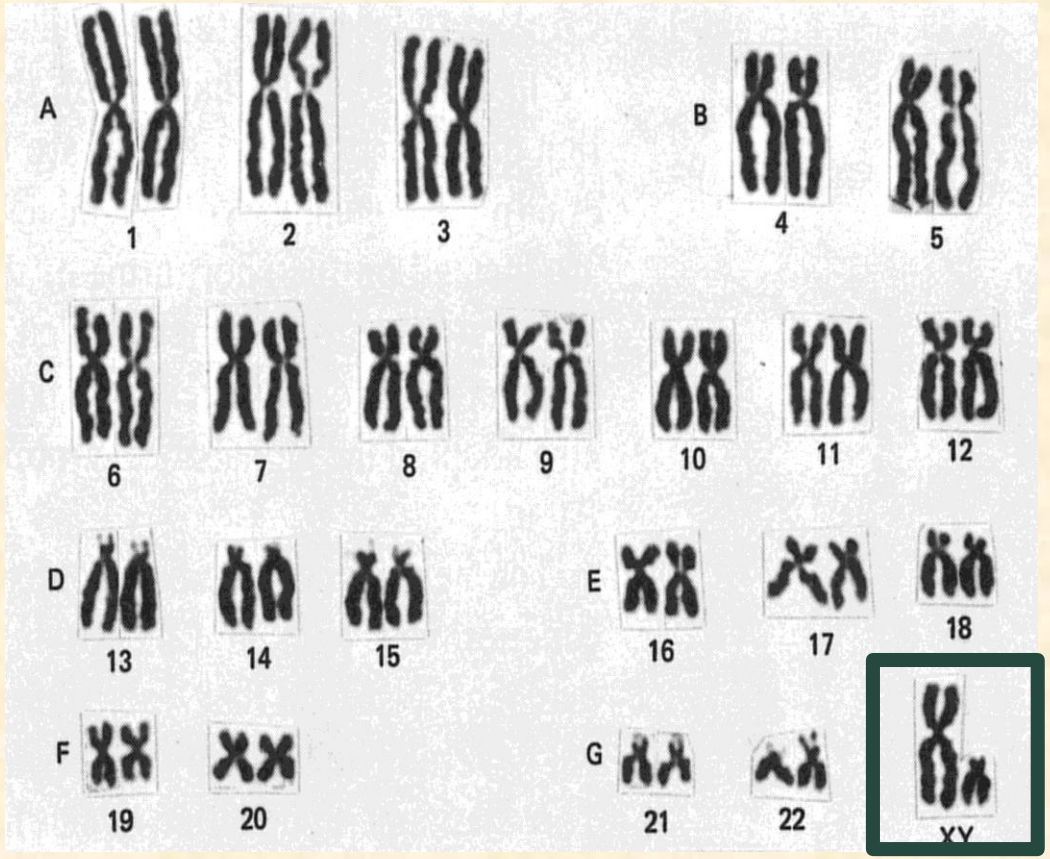
The **X** and **Y** chromosomes in humans and certain species are paired together in a karyogram



SEX CHROMOSOMES

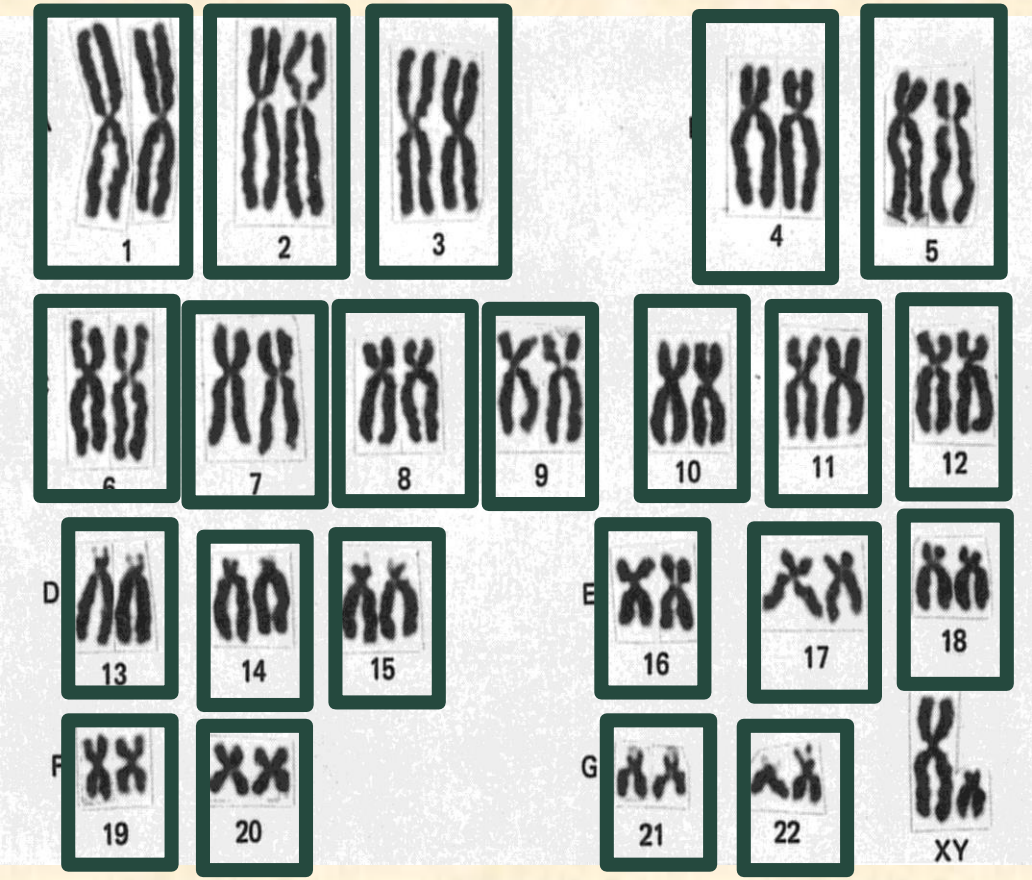
- They are the **exception** as they do not exactly fit into the definition of a pair of homologous chromosomes.
- In man, only small parts of the X and Y are homologous. Most of the genes carried on the X chromosome do not have counterparts on the tiny Y chromosome
- i.e. X & Y chromosomes do not have the same length, centromere position or gene loci

SEX CHROMOSOMES VS AUTOSOMES



- Last pair of chromosomes are the **sex chromosomes** as they determine an individual's sex.

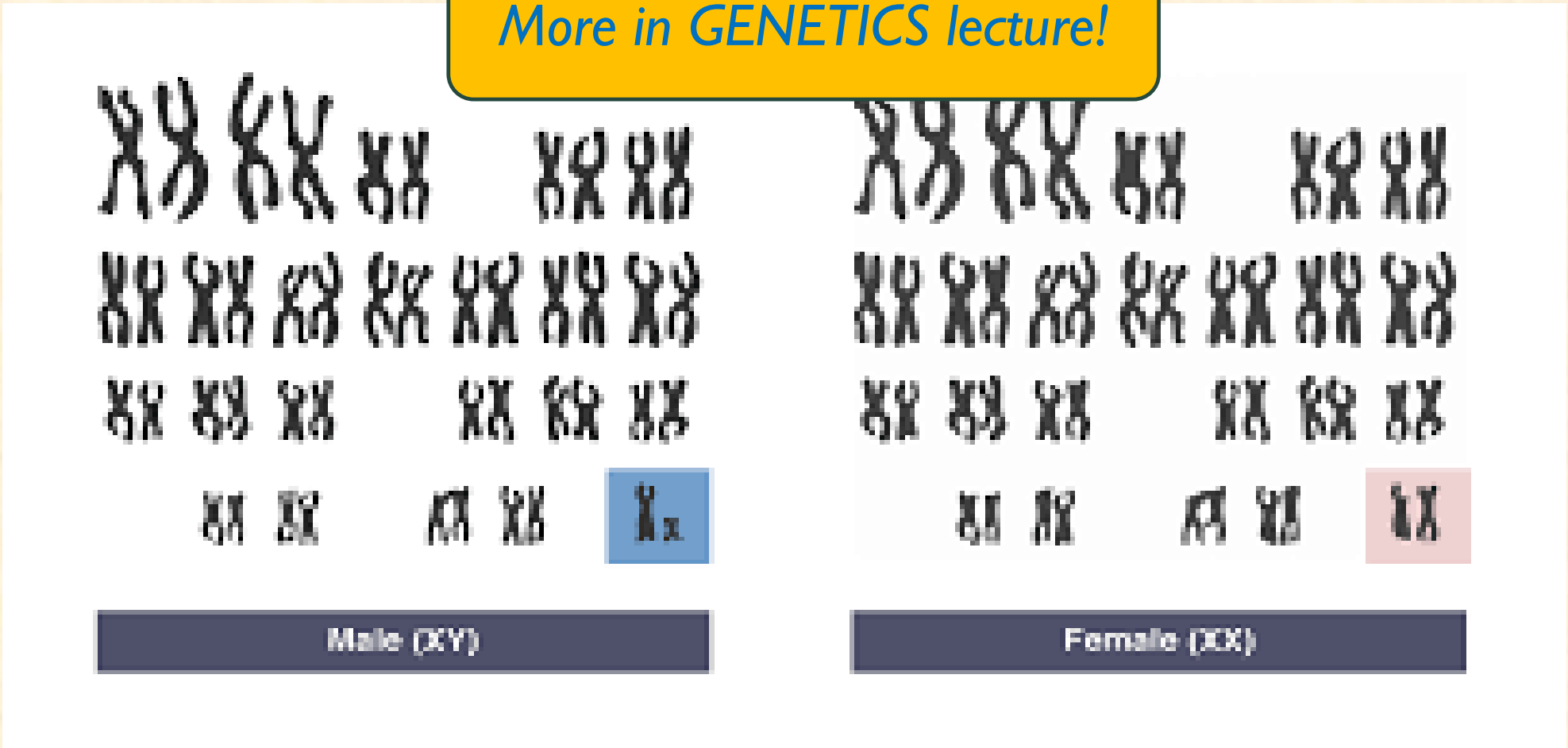
SEX CHROMOSOMES VS AUTOSOMES



All other chromosomes apart from the sex chromosomes are termed **autosomes**.

SEX CHROMOSOMES VS AUTOSOMES

More in GENETICS lecture!



Note: For humans (but not all species)

MITOSIS: 'C' JARGON

1) **C**hromatin
2) **C**hromosomes
3) (duplicated) **C**hromosomes
4) **C**hromatids
5) (homologous) **C**hromosomes
6) **C**entrioles
7) **C**entrosomes
8) **C**entromeres

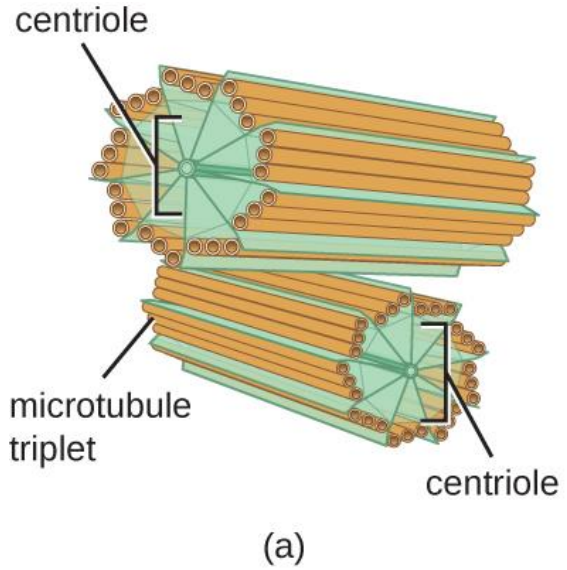
DNA in nature

6. CENTRIOLES & CENTROSOME

Centrioles

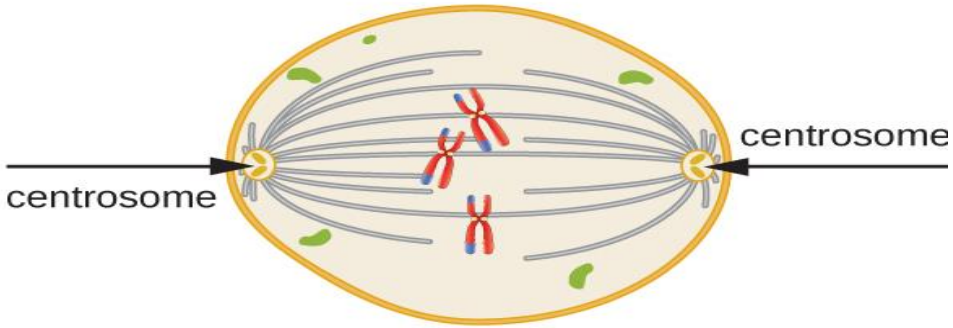
- Exist as a pair of rod-like structures (cylinders), positioned at right angles to each other
- Each cylinder = 9 triplets of microtubules arranged in a ring.

- **Organises** the **synthesis and assembly** of *spindle fibres* during nuclear division.
- Position of the pair of centrioles at each pole during nuclear division important in **determining the polarity of the cells**;



Centrosome

- Region occupied by a pair of centrioles
- Microtubule organizing centre



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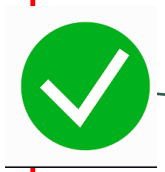
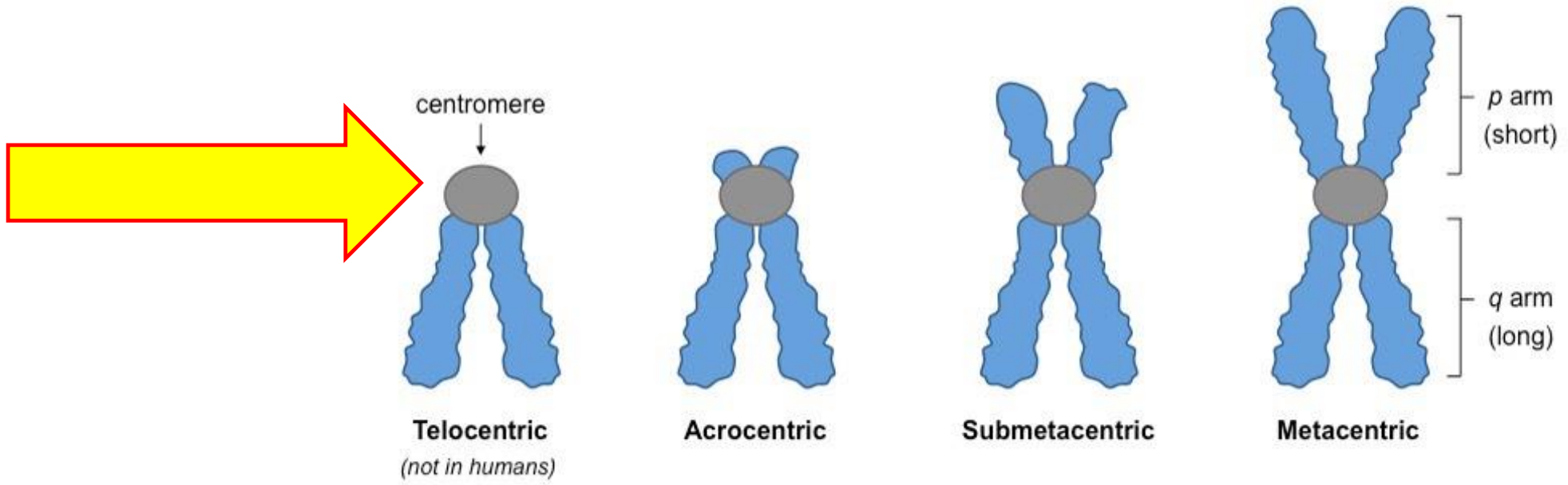


DNA in nature

7. CENTROMERES

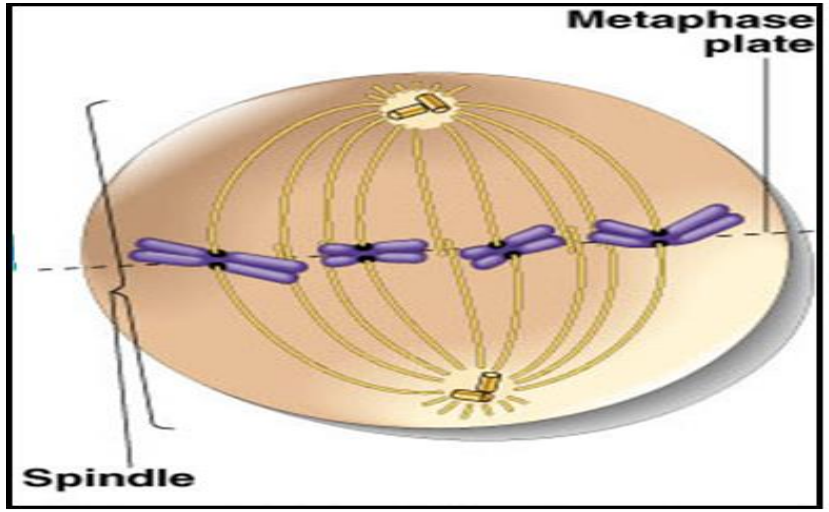
- **Repetitive (non-coding) DNA sequence** involved in the **adhesion of sister chromatids** after semi-conservative DNA replication.
- Can be found **anywhere** along the length of the chromosomes

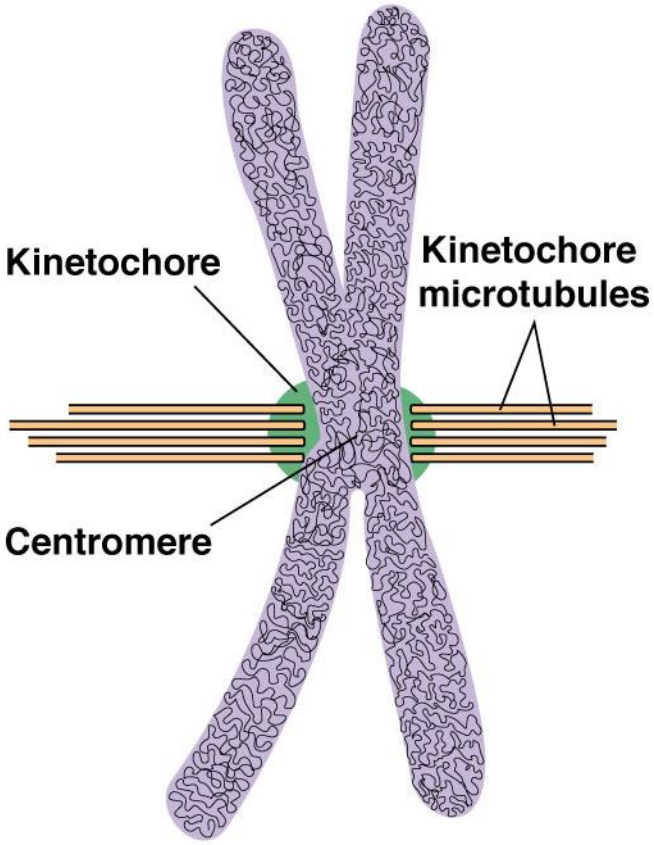


7. CENTROMERES

Required for the correct **alignment** and **segregation** (separation) of:

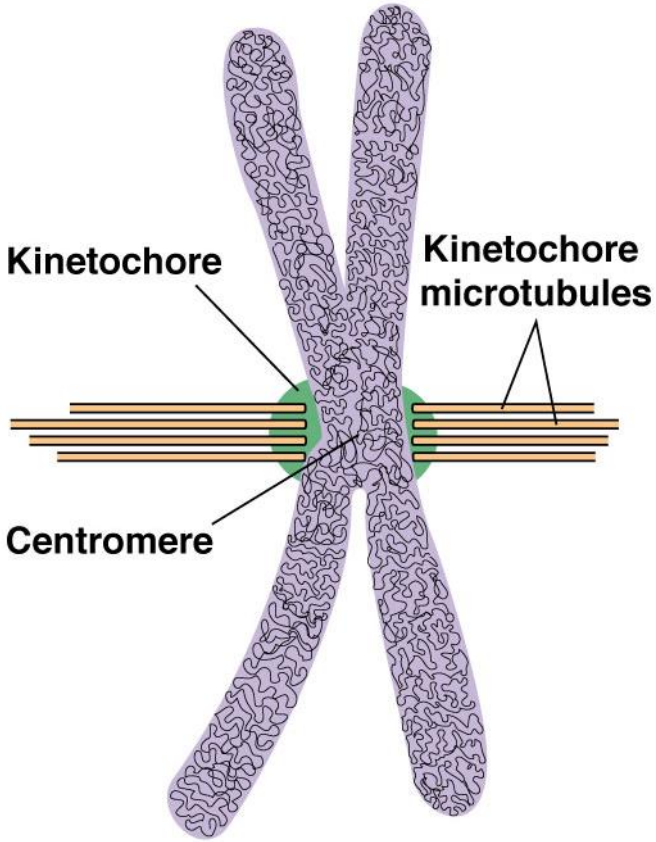
(1) sister chromatids in mitosis and
(2) homologous chromosomes in meiosis I.
and
(3) chromatids in meiosis II





7. CENTROMERES

- During nuclear division, a **protein complex** known as the **kinetochore assembles** on the **centromeres (DNA).**
- The kinetochore interacts with the **kinetochore microtubules** that **pull** the **sister chromatids** away from each other to opposite poles of the cell.



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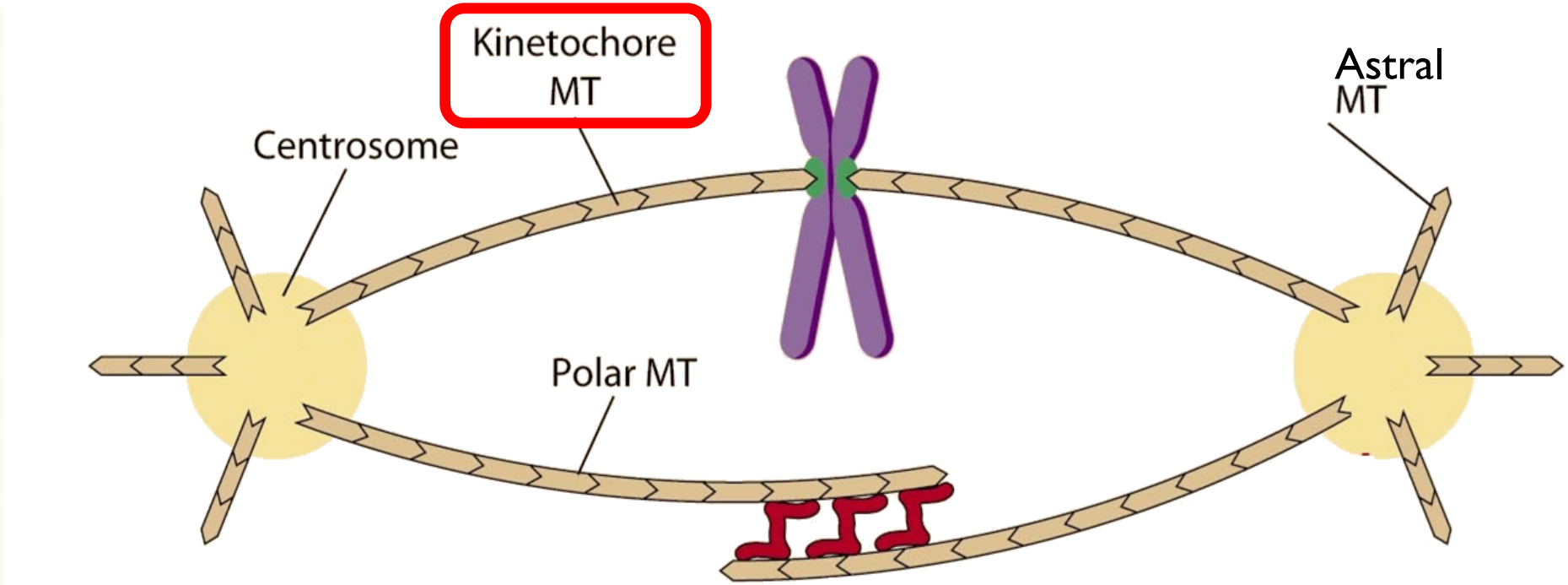
DNA in nature

8. SPINDLE FIBRES:
TYPES OF MICROTUBULES INVOLVED IN NUCLEAR DIVISION



3 types of microtubules:

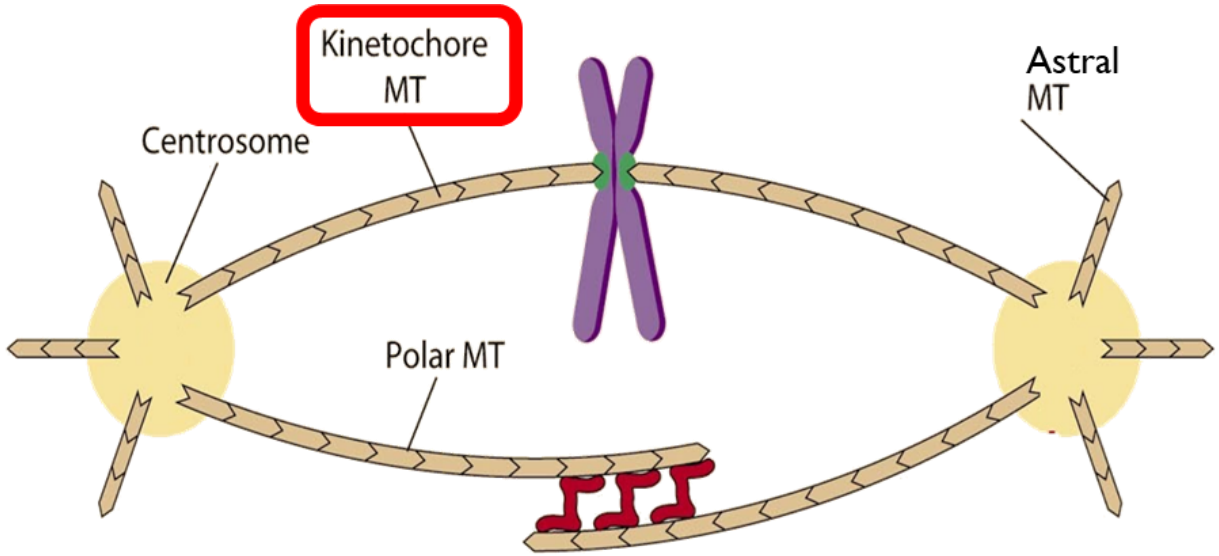
kinetochore MT, polar MT and astral MT

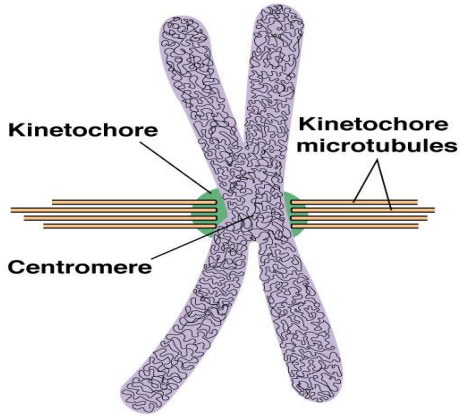
SPINDLE FIBRES: A) KINETOCHORE MT

- Refer to microtubules that attach to the **kinetochore** (protein complex) formed on centromeres.
- **Function**:

- Serve to **attach chromosomes** to the spindle

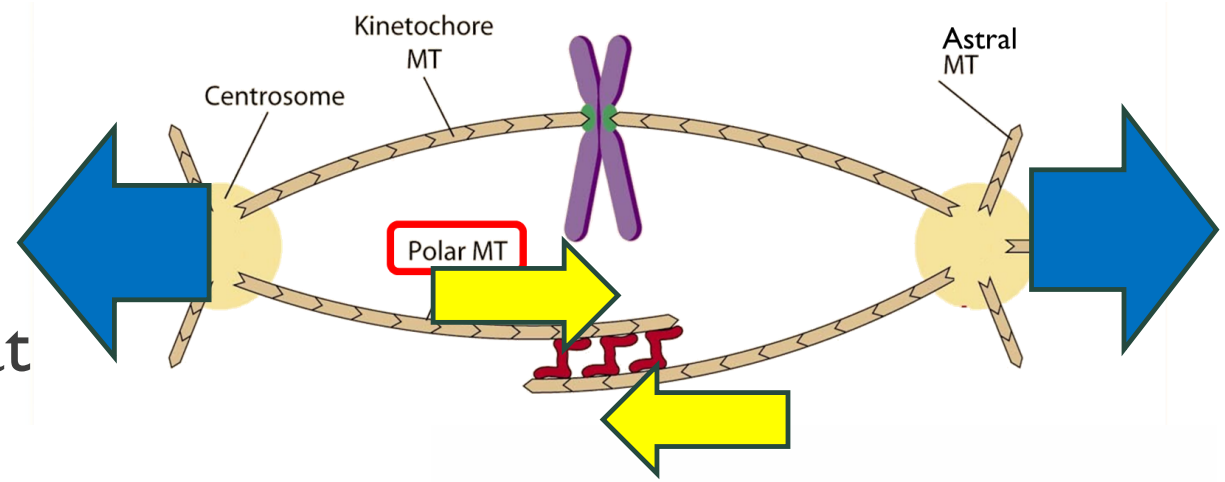
- **Shorten** during anaphase so that the chromosomes can **separated** & **PULLED** to opposite poles of the cell.

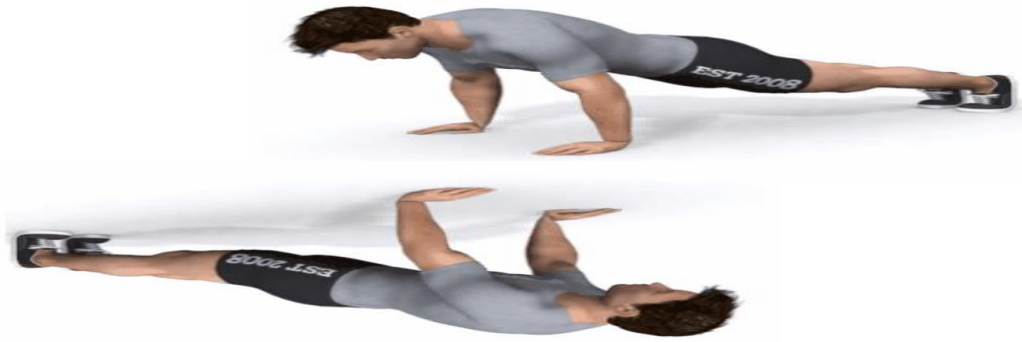




SPINDLE FIBRES: B) POLAR MT

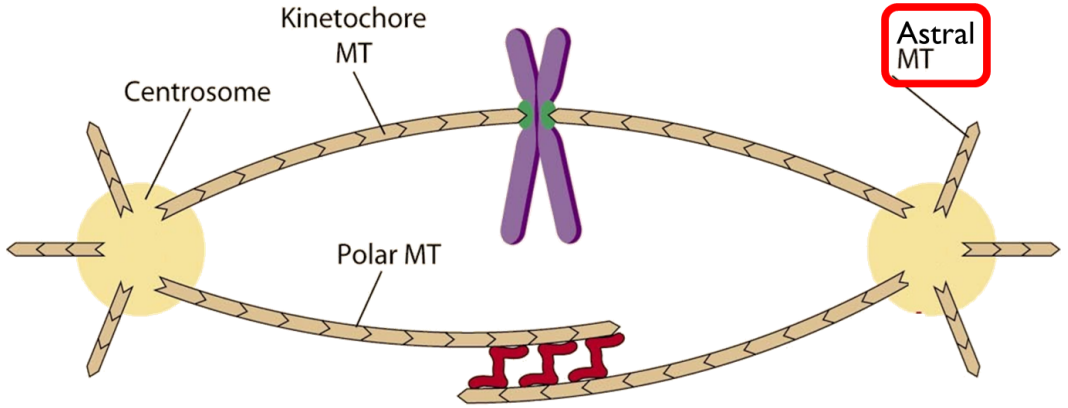
- Aka **overlap microtubules**
- Refer to microtubules that extend from the centrosomes towards the centre of the cell.
- **Overlap** with polar microtubules that radiate from the centrosome of the opposite pole.
- **Elongate** during anaphase to **PUSH** opposite poles apart resulting in **elongation of the cell**.





SPINDLE FIBRES: C) ASTRAL MT

- Refer to short microtubules that extend from the centrosomes at each pole towards the cell surface membrane in a cell undergoing nuclear division
- Thought to contribute to the forces that separate the poles, and function as **'braces'** for **orienting and positioning the spindle** in the cell.



SUMMARY OF KEY TERMS

- Cell division – nuclear division (mitosis/meiosis) & cytokinesis
- Interphase (G1, S, G2 phase)
- Cell cycle checkpoints (G1, G2, M)
- Ploidy – Diploid vs Haploid

- Spindle: centrosome + spindle fibres
- Spindle fibres

(Kinetochore, polar, astral MT)

- Chromatin
- Chromosomes
- (duplicated) Chromosomes
- Chromatids
- Homologous chromosomes
- Centromeres
- Centrioles
- Centrosomes