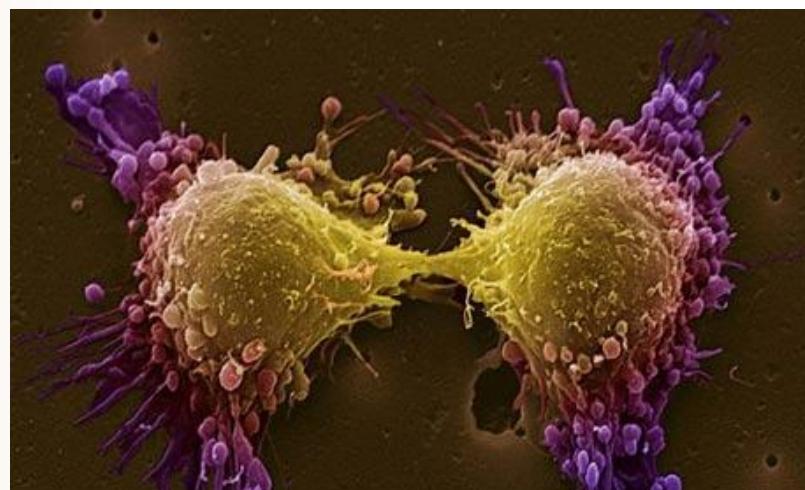


Cell division and function

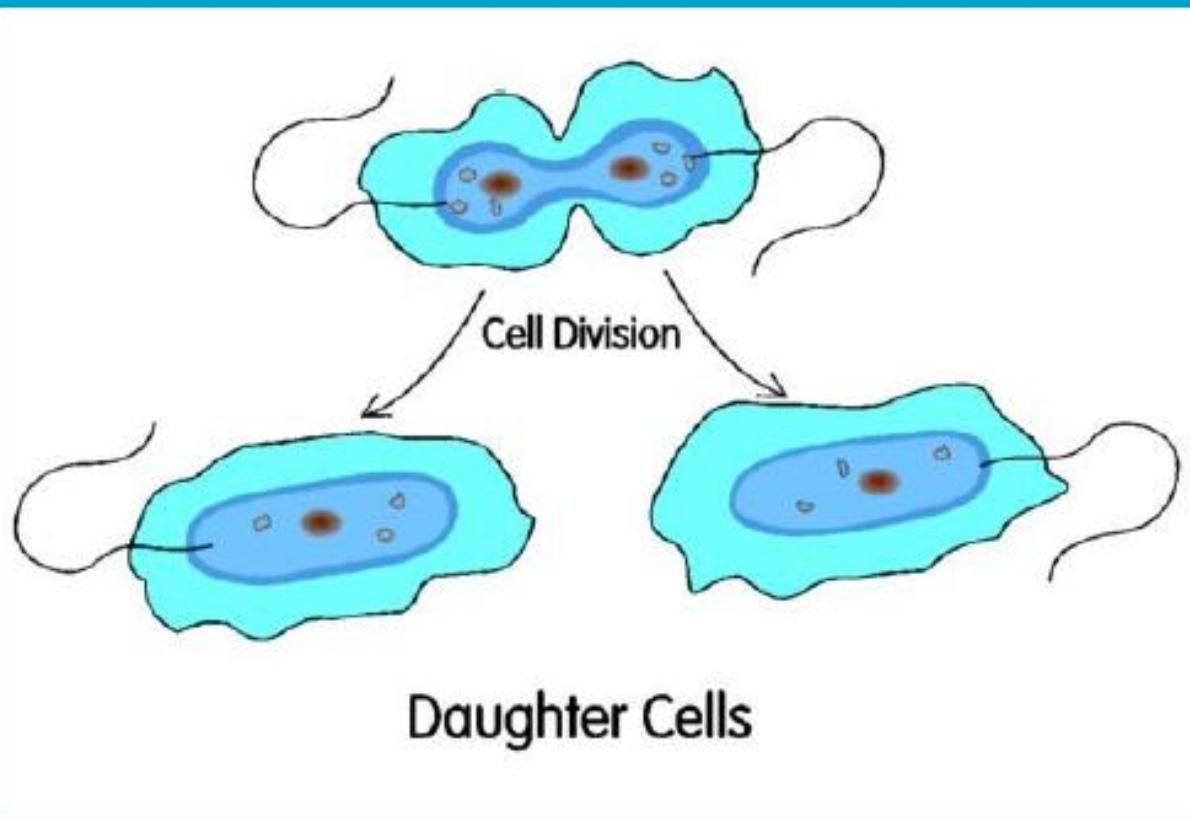


Cell Division

What is it?

Why do
Cells do it?

Why is it
important to
me?



Why do cells undergo divisions or Why cell divides?

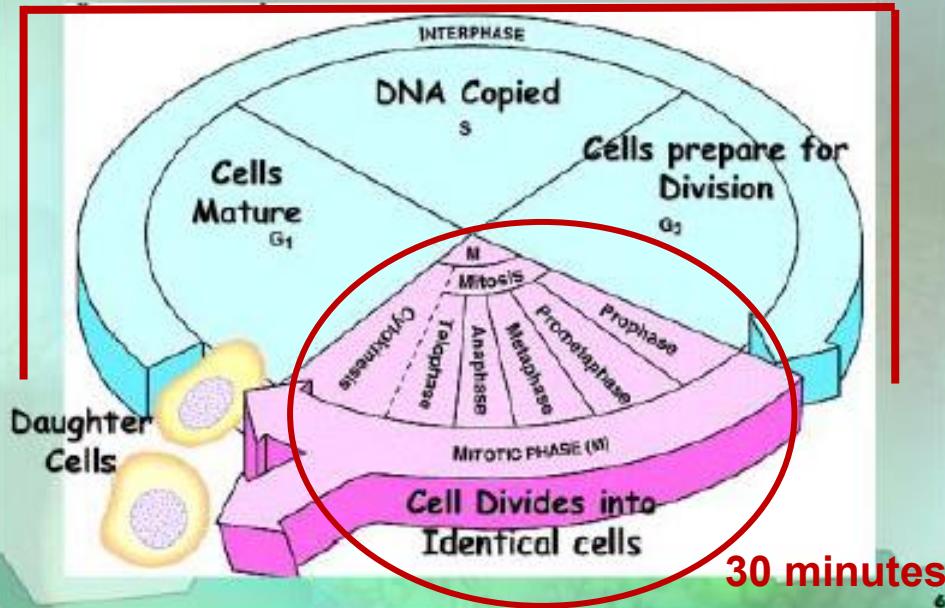
- 1). To prevent DNA overload:** If cell grows without limit, “information crisis” would develop. DNA cannot meet the demand of increasing cell size. Therefore, cell divides to increase the number rather than increasing the size.
- 2). For efficient exchange of materials:** If cell is too large, exchange of materials through cell membrane such as food and oxygen, and removal of waste products, will occur slowly and cell will die either due to starvation or toxic wastes accumulation.
- 3) Growth and reproduction:** Organisms need to grow which is fulfilled by increasing cell numbers rather than increasing cell size. For example, a single celled zygote (sperm and ova fertilization) develops by **number of cell divisions to form different parts of body and ultimately a full organism.**
- 4) Tissue repair and regeneration:** Dead and injured cells can be replaced by cell divisions.

What is cell cycle

The **cell cycle**, or **cell-division cycle**, is the series of events that take place in a cell that cause it to divide into daughter cells. These events include the duplication of its DNA (**DNA replication**) and some of its organelles, and subsequently the partitioning of its cytoplasm and other components into daughter cells in a process called cell division

Sketch of the Cell Cycle

24 hours



Five Phases of the Cell Cycle

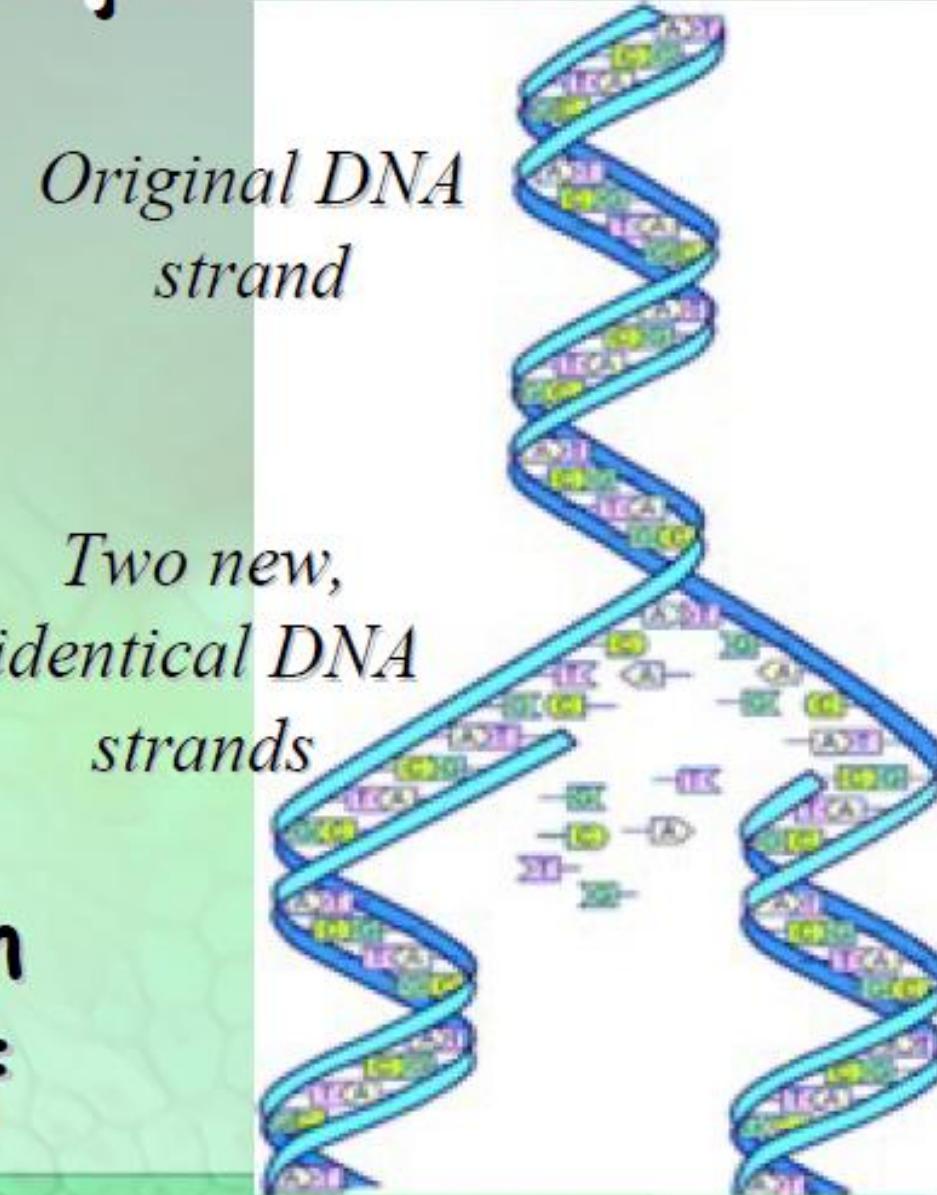
- ✓ G₁ - primary growth phase
 - ✓ S - synthesis; DNA replicated
 - ✓ G₂ - secondary growth phase
- collectively these 3 stages are called interphase*
- ✓ M - mitosis
 - ✓ C - cytokinesis

Stages of Interphase

Interphase stage of cell cycle	Important events in a particular phase
G1 (Gap 1)- primary growth phase	Increase in cell size, synthesis of proteins, carbohydrates and lipids, Synthesis of RNA, synthesis of enzymes and energy molecules. (Time duration: generally 5-6 hours, sometimes 9 hours depending upon the cell type and organism)
S (Synthesis)	Replication of DNA, synthesis of histones and formation of new nucleosomes. (Time duration: 10-12 hours)
G2 (Gap 2) - secondary growth phase	Synthesis of spindle proteins, duplication of mitochondria, , synthesis and storage of ATP molecules for M-phase, Damaged DNA is repaired. (Time duration: 4-6 hours)

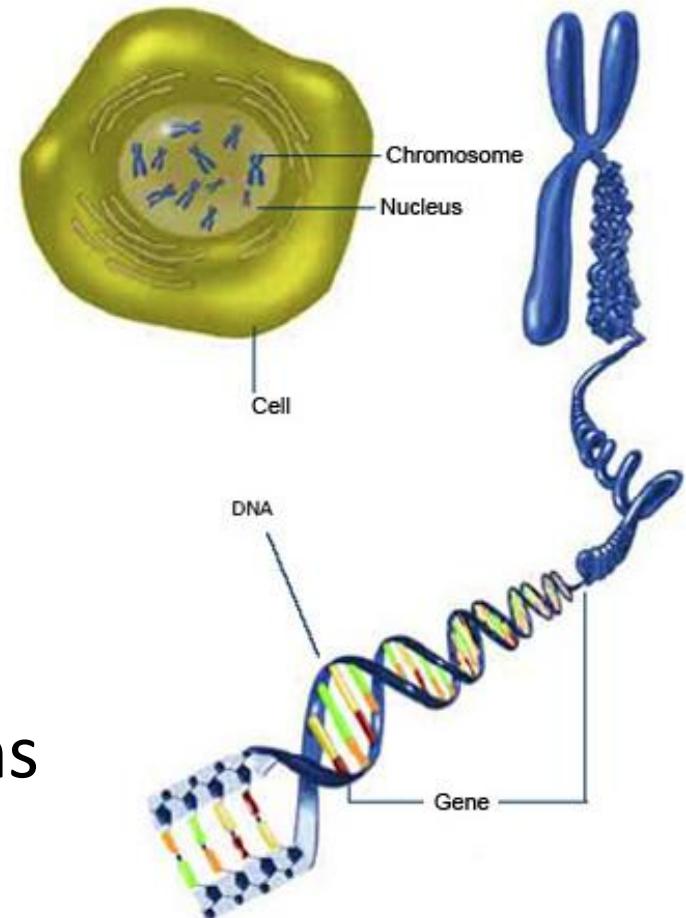
DNA Replication

- ✓ DNA must be copied or **replicated** before cell division
- ✓ Each new cell will then have an **identical copy** of the DNA



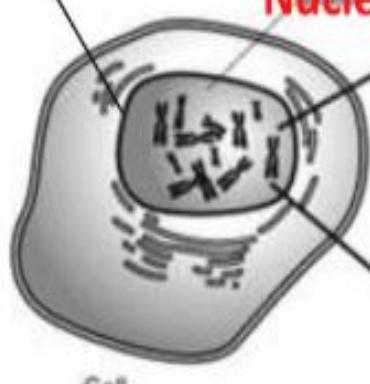
Where Do I Find DNA?

- Chromosomes are in the nucleus of every cell.
- Chromosomes are made up of DNA.
- Genes are pieces of DNA that contain the instructions for building a protein.



Nuclear membrane

Nucleus



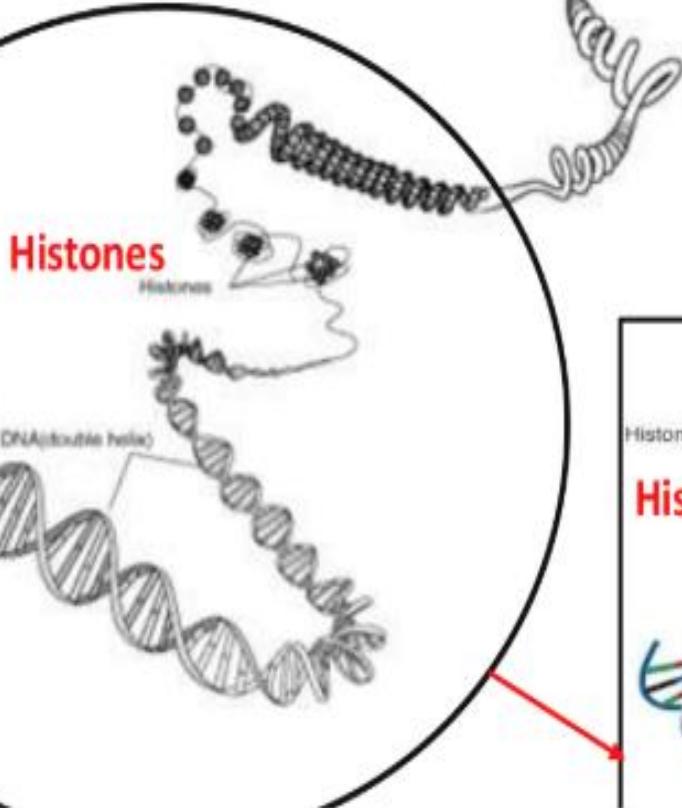
Chromosome

Chromatid Chromatid

Telomeres

Centromere

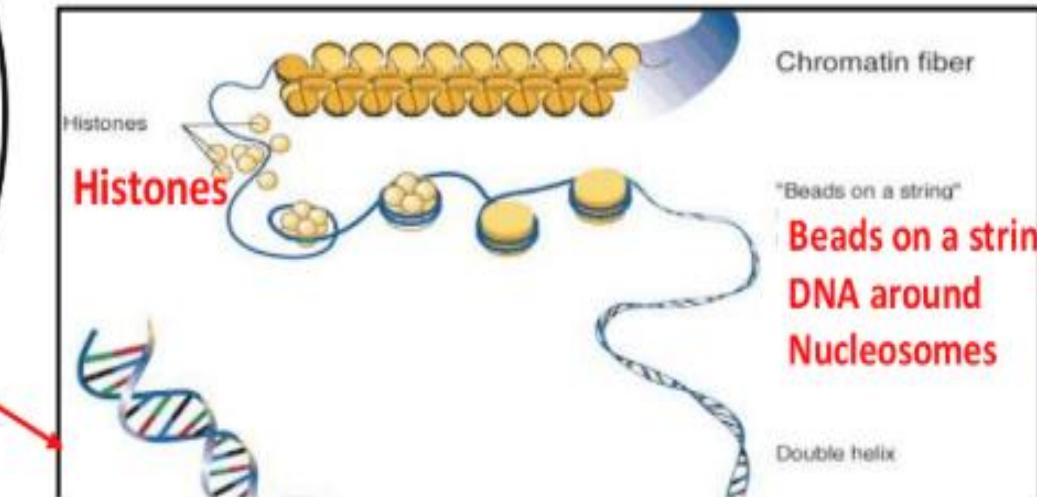
Telomeres



Histones

Histones

DNA double helix



Chromatin fiber

Histones

"Beads on a string"

**Beads on a string,
DNA around
Nucleosomes**

Double helix



Two Identical Chromatids
One is an exact copy of the other and each contains one DNA molecule.

p arm - short arm structure

Centromere

Centromere - constricted point of the chromosome

q arm - long arm structure

DNA molecule - long string like DNA molecule formed into a compact structure by proteins called histones.

Chromatids: two identical chromatids and called sister chromatids, each containing DNA molecule. DNA molecule is replicated.

Packing for the move...

When the cell is not dividing...

- DNA molecules are in extended, uncondensed form = **chromatin**
- Cell can only replicate and transcribe DNA when it is in the extended state.

When the cell is preparing for division...

- DNA molecules condense to form **chromosomes** prior to division.
 - each chromosome is a single molecule of DNA
 - easier to sort and organize the replicated DNA into daughter cells



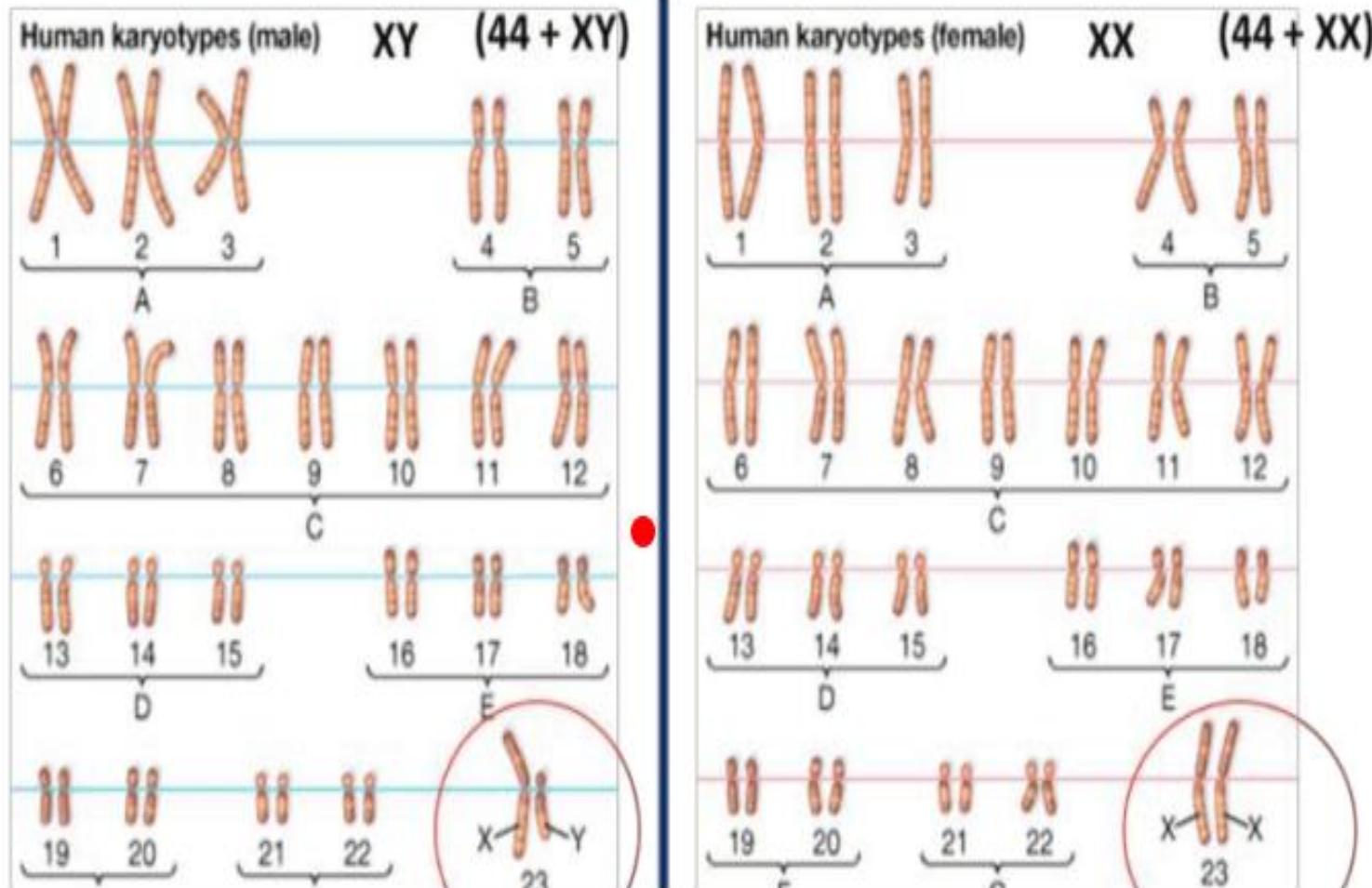
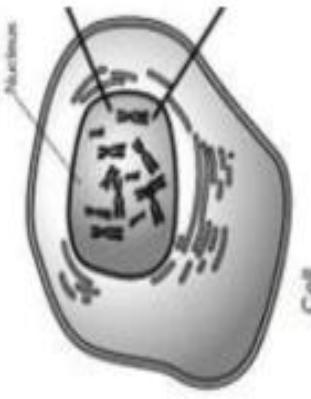
Dude, mitosis starts in five minutes...
I can't believe you're not condensed yet.

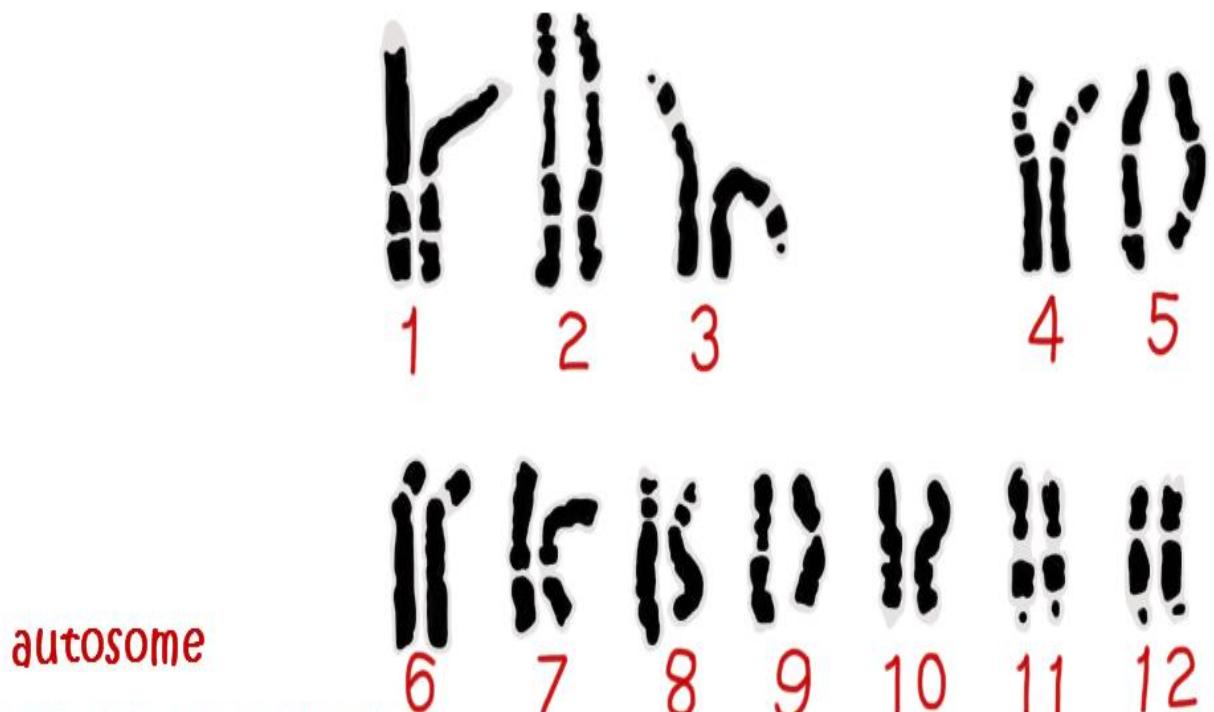
Human Karyotype of male and female (orderly arrangement of chromosomes)

A **Karyotype** is the map of individual's chromosomes, Homologous pairs of chromosomes of an individual cell. Since every cell in the human body has the same DNA and therefore the same chromosomes, the analysis of one cell is enough.

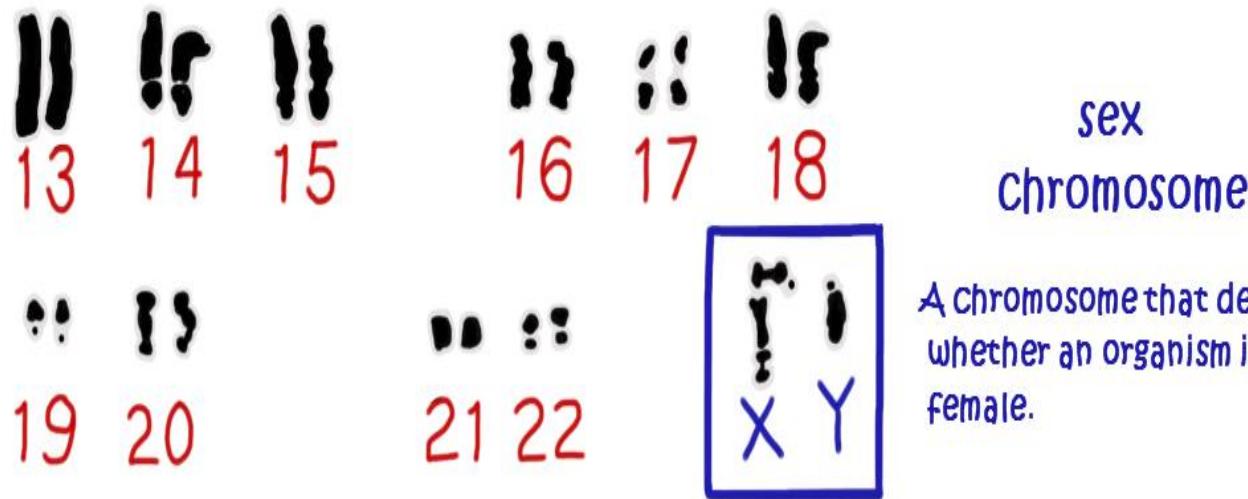
Human has 46 chromosomes, or 23 pairs of chromosomes. Also called , $2n$ or diploid

Chromosomes in duplicated forms inside the nucleus

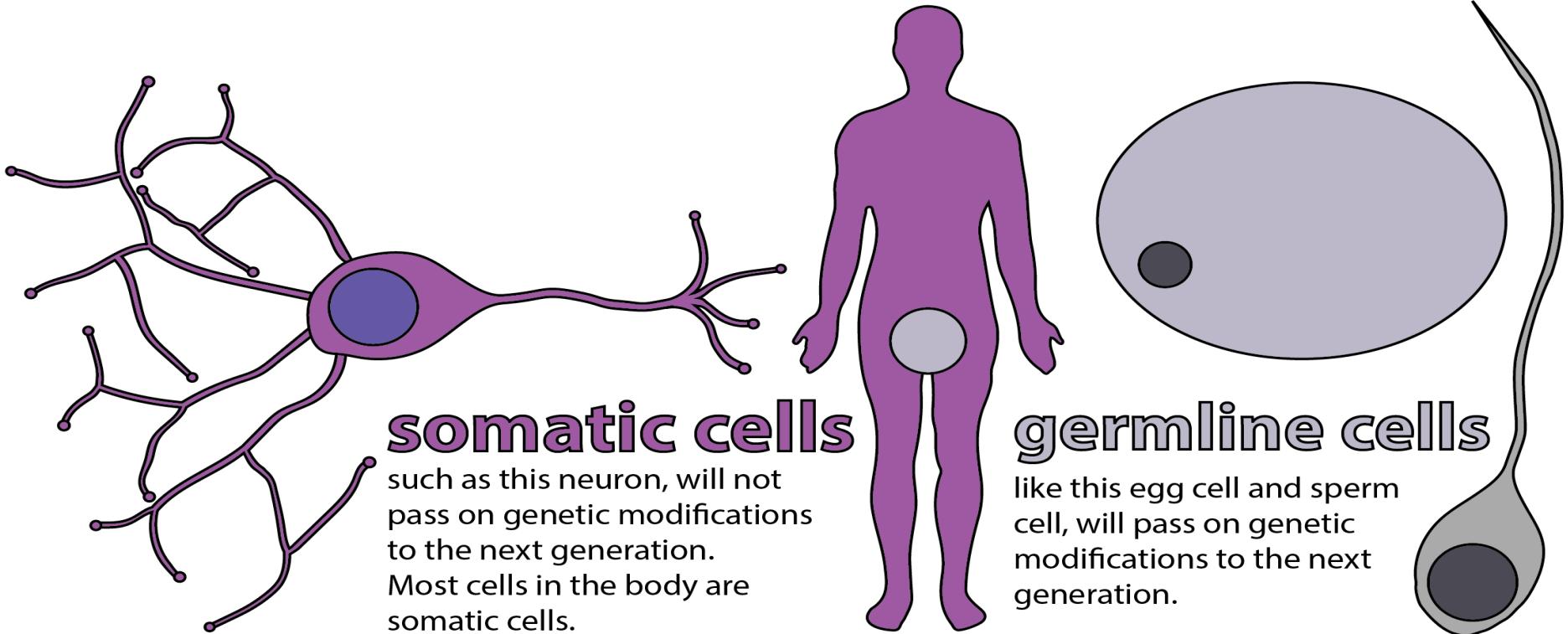




A chromosome that is not directly involved in determining the sex of an organism.



A chromosome that determines whether an organism is male or female.



Somatic Cells vs Gametic Cells

Somatic cells are cells of the body

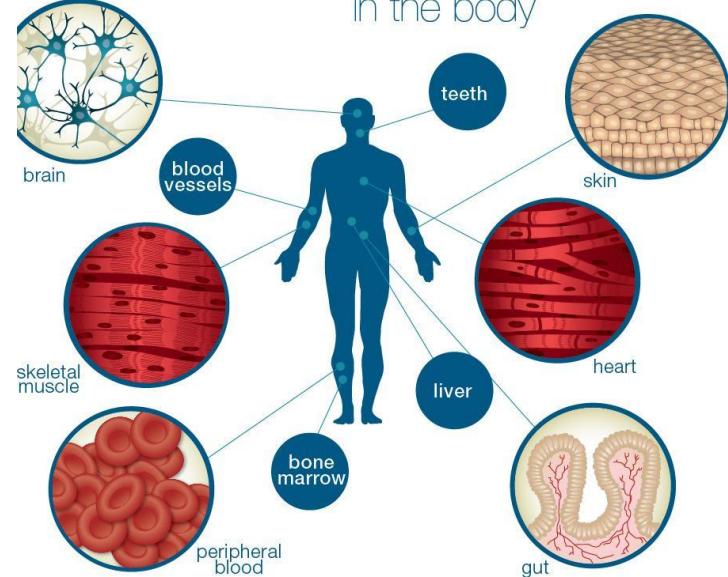
In humans somatic cells are diploid which means they contain two copies of each chromosome

Human somatic cells have 23 pairs of chromosomes for a total of 46 chromosomes

Gametes are reproductive cells such as sperm and oocytes

Gametes are haploid which means that there is one copy of each chromosome in each gamete

Locations of **Somatic Stem Cells** in the body

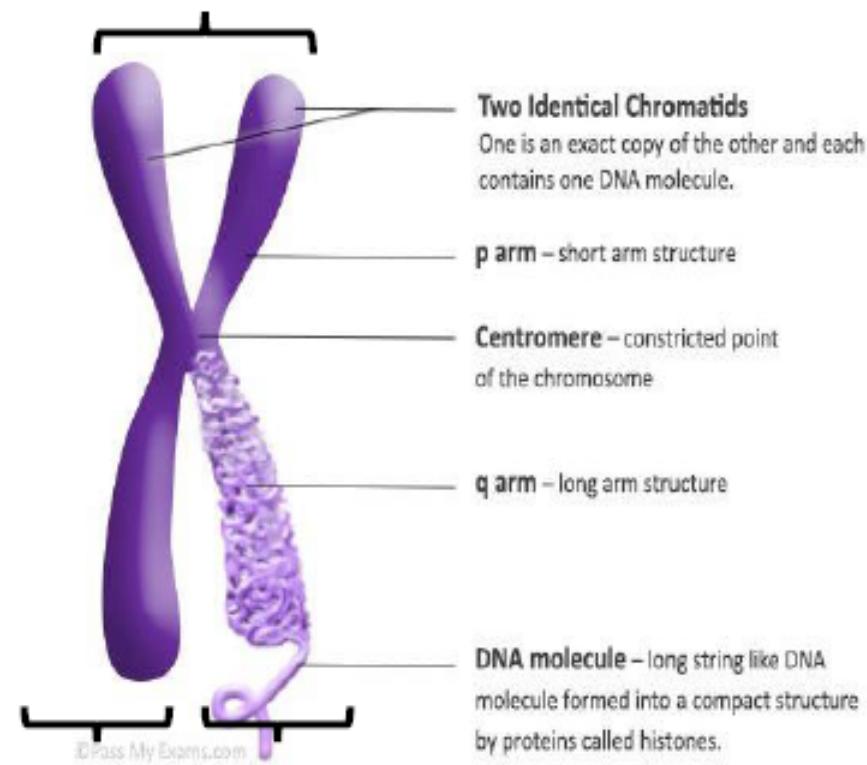


Key words to understand the process of cell divisions

1) Chromosome: A chromosome is an organized package of DNA found in the nucleus of the cell. DNA is tightly coiled and package into DNA in chromosome. Different organisms have different numbers of chromosomes. Humans have 23 pairs of chromosomes (so total 46 chromosomes)--22 pairs of numbered chromosomes, called autosomes, and one pair of sex chromosomes, X and Y..

2) Chromatid: A chromatid is one copy of a newly copied chromosome which is still joined to the original chromosome by a single centromere. Chromatids are formed after DNA replication. In other words, chromosome duplicates to form sister chromatids.

Chromosome



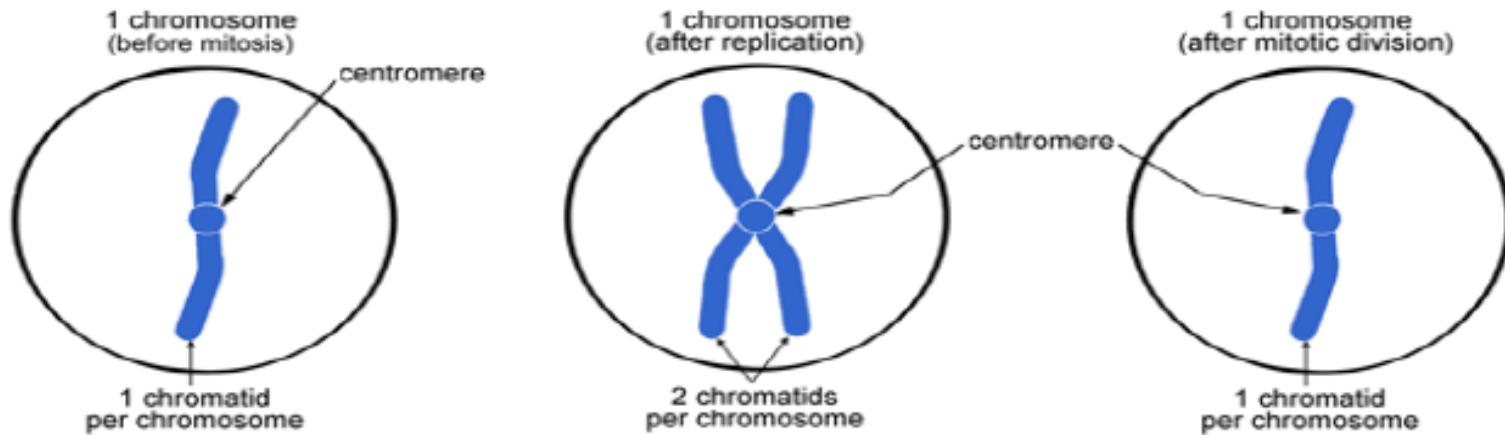
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Chromatids: two identical chromatids called sister chromatids, each containing DNA molecule. DNA molecule is replicated.

The concept 46 chromosomes----- $46 \times 2 = 92$
chromatids

*****The concept from previous slide:

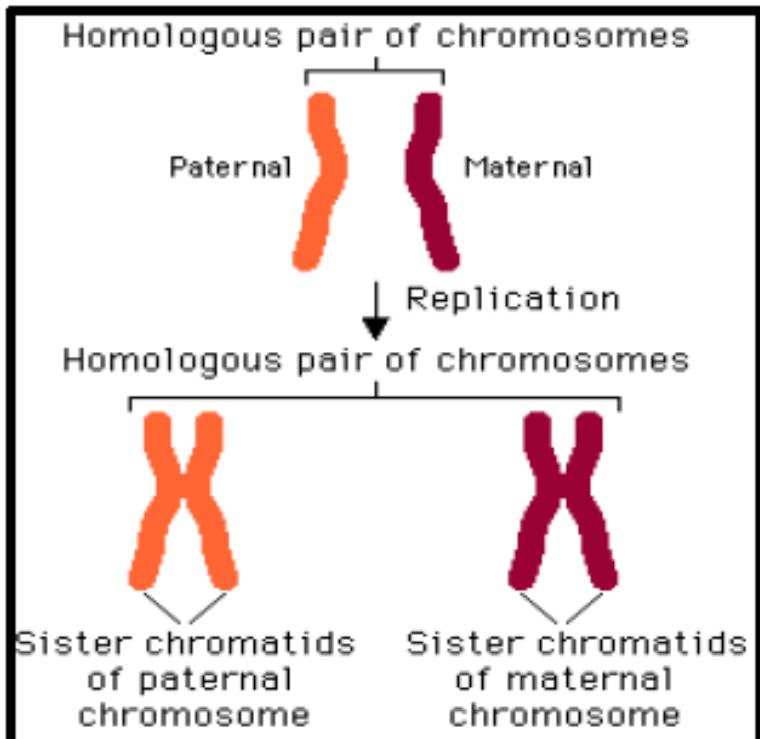
46 chromosomes----- after DNA replication chromosomes duplicates to form sister chromatids..... **$46 \times 2 = 92$ chromatids**
but 46 chromosomes.



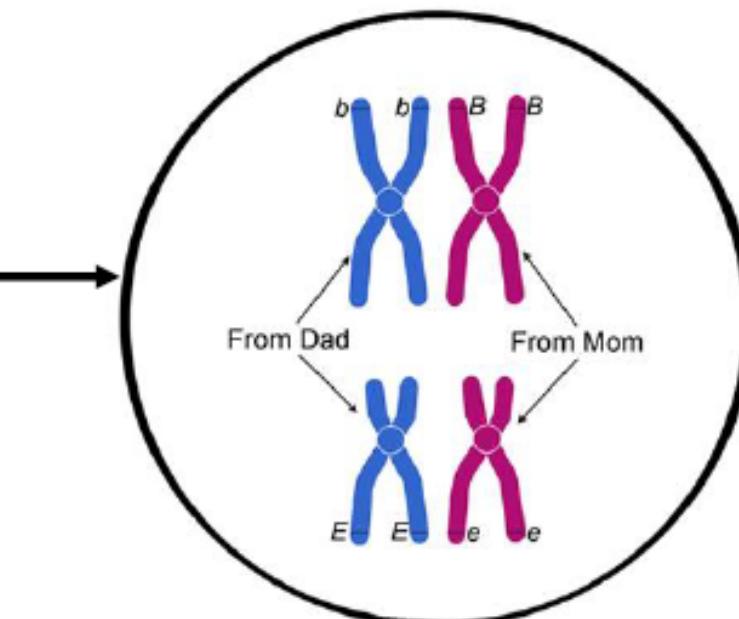
Solve this question?

3) Homologous chromosomes/ homologs/

homologous chromosomes. One pair of chromosomes with the same gene sequence, loci, chromosomal length, and centromere location. In a homologous pair, one chromosome is inherited from father (paternal) and other is inherited from mother (maternal). The DNA sequences of homologous chromosomes are usually not exactly identical. Humans have 23 pairs of homologous chromosomes.



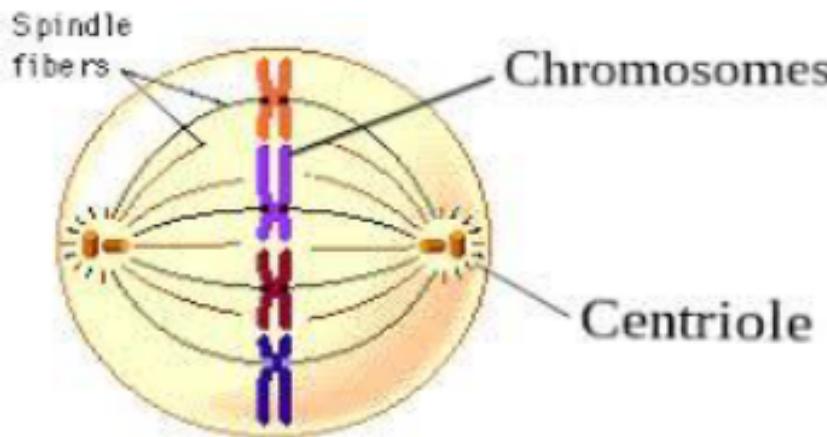
Here, two pairs of homologous chromosomes. One pair blue and pink inherited from dad and mom respectively. **B, b, E and e** are gene segments that are aligned together in homologs.



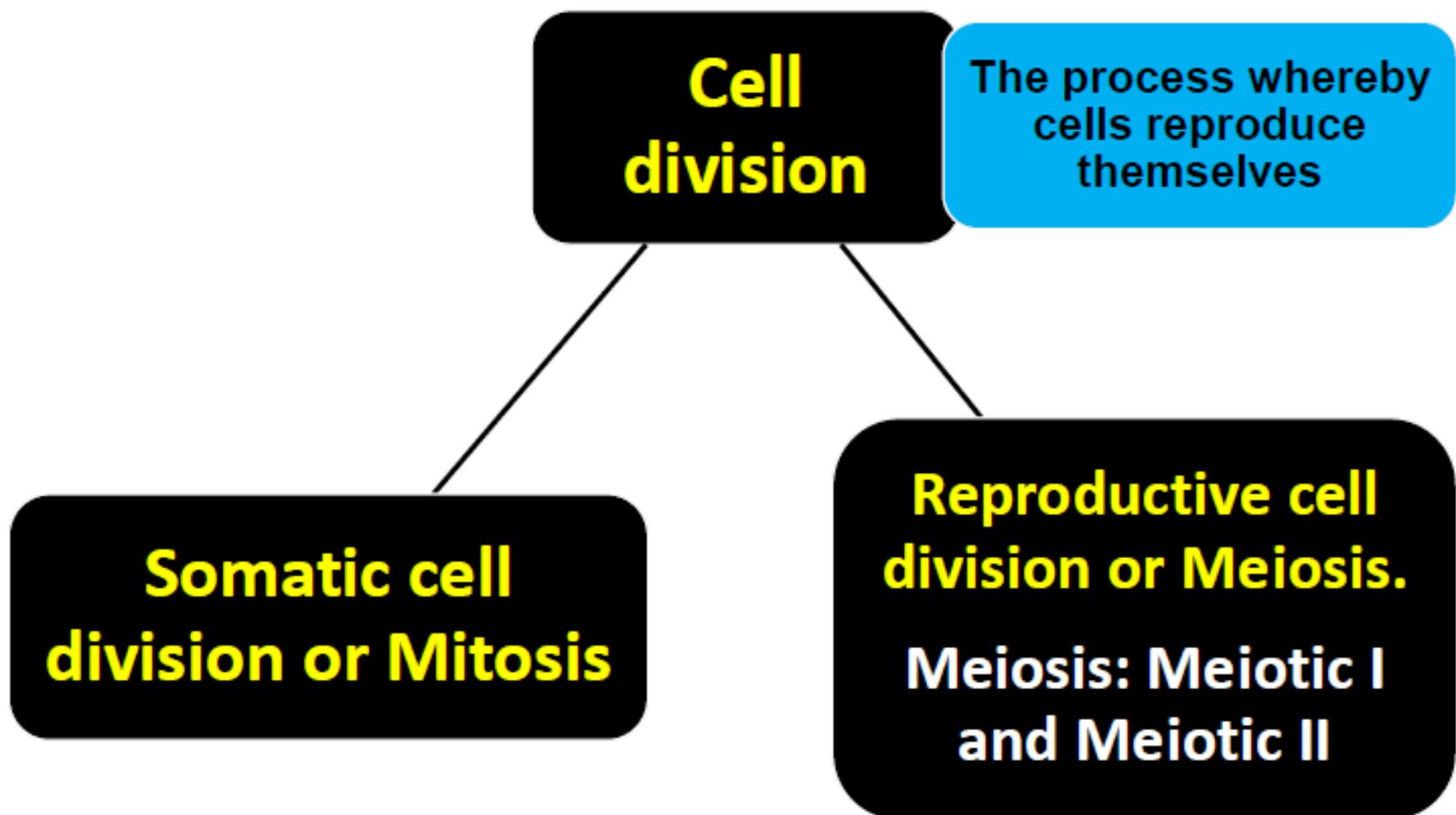
4) Diploid: Diploid is a cell or organism that has paired chromosomes, one from each parent. In humans, all somatic cells other than gametes are **diploid** and have 23 pairs of chromosomes.

5) Haploid: Only single set of chromosomes present in cells. No homologous pairs. For example, Human gametes (egg and sperm cells) contain a single set of chromosomes and are known as haploid.

6) Spindle fibers: They are filaments made up of microtubules that form the **mitotic spindle** in cell division, i.e. mitosis and meiosis. They are chiefly involved in moving and separating the chromosomes into daughter cells during cell division.

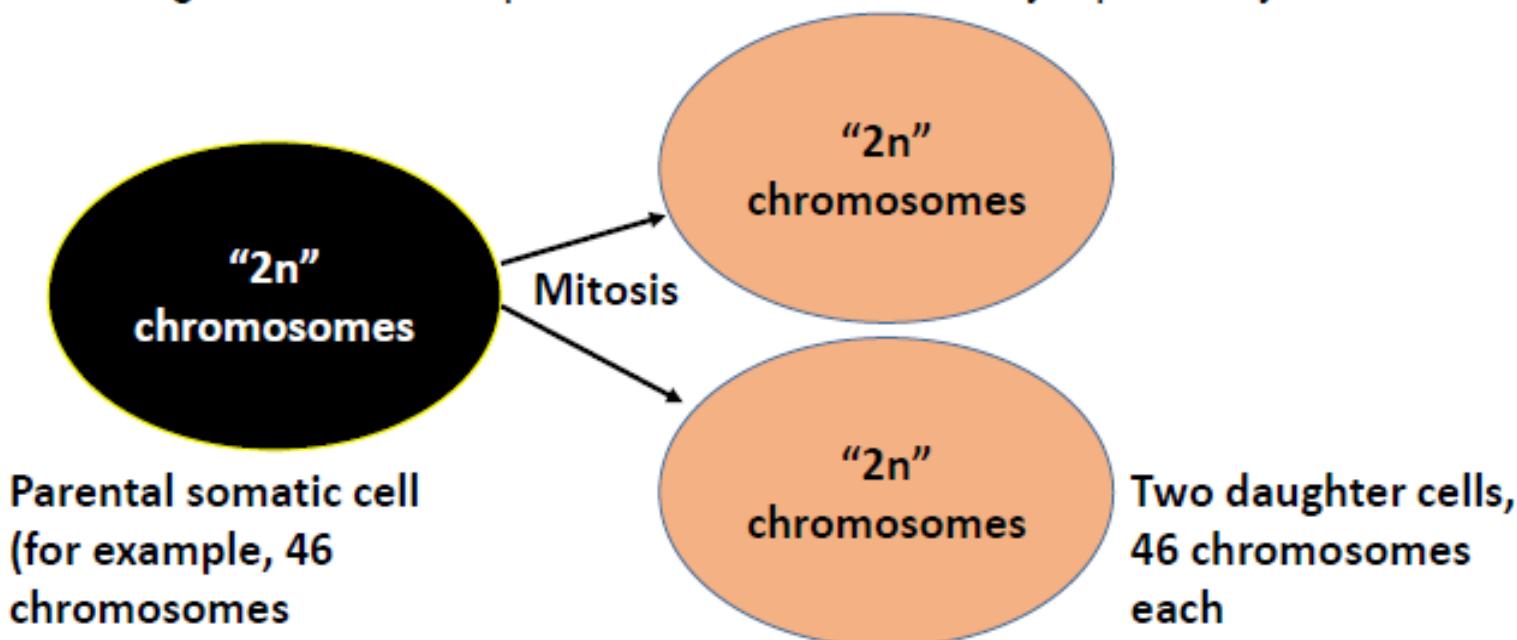


After interphase stage of cell cycle, **cell divides by two processes either mitosis and meiosis**, depending on the cells that is undergoing division.



Somatic cell division or Mitosis

- 1) A cell divides into two identical cells. (**Equational division**)
- 2) The same genetic material is passed on to the newly formed cells. So after mitosis, each newly formed cell has the same number of chromosomes as the original cell. For example, if the cell has 46 chromosomes, each daughter cell will have 46 chromosomes, or **parental cell diploid state ($2n$) is maintained in daughter cells.**
- 3) **Significance of mitosis:** mitotic cell division maintains replaces dead or injured cells and adds new ones for tissue growth. For example, skin cells are continually replaced by somatic cell division.

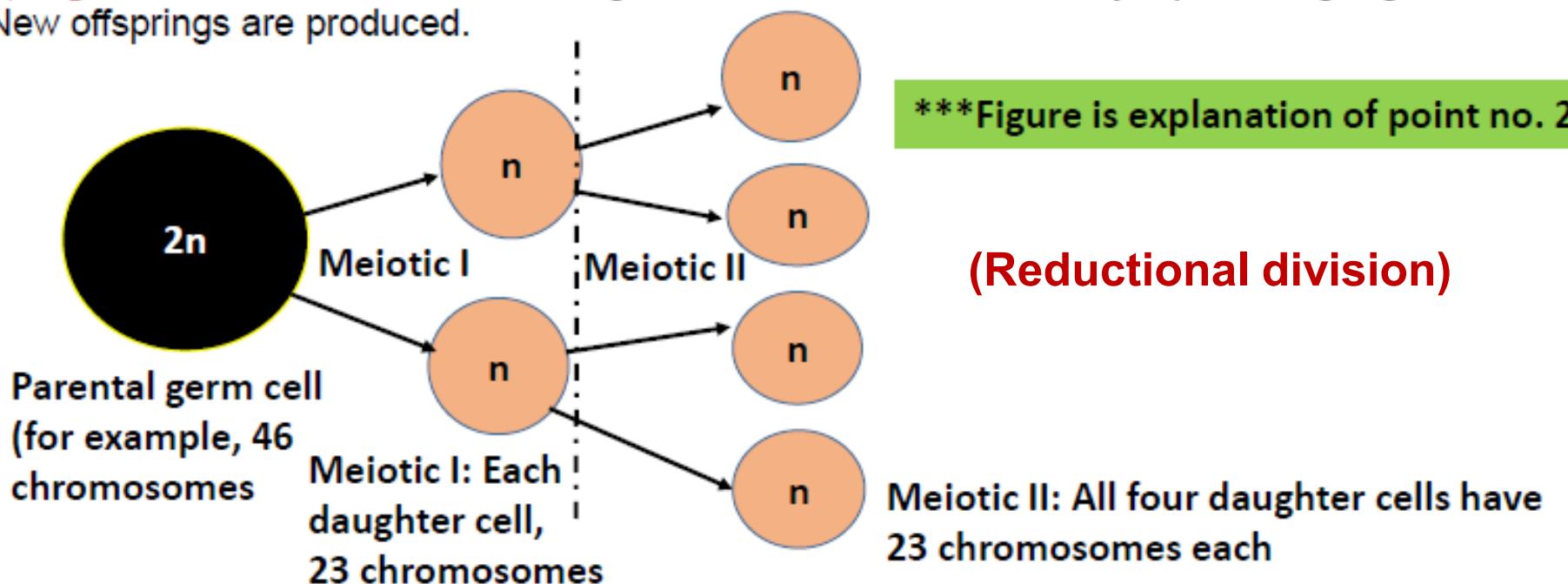


Reproductive cell division or Meiosis

- 1) **Meiotic cell division occurs** in reproductive cells called germ cells to produce gametes-sperm and ova. Germ cells are testes in males, and ovaries in females.
- 2) **Meiotic division separates** first pair of homologous chromosomes (meiotic I: reducing $2n$ number of chromosomes to " n " chromosomes, and so two daughter cells will have half the number of chromosome as its parental cell; meiotic II: mitotic division of the meiotic I daughter cells. So , in meiosis 4 daughter cells are produced with " n " of chromosomes.

After meiosis, each newly formed cell has the half number of chromosomes as the original cell. For example, if the cell has 46 chromosomes, each daughter cell will have 23 chromosomes, or parental cell diploid state ($2n$) is changed to " n " in daughter cells.

- 3) **Significance of meiosis:** the next generation is formed in sexually reproducing organisms. New offsprings are produced.

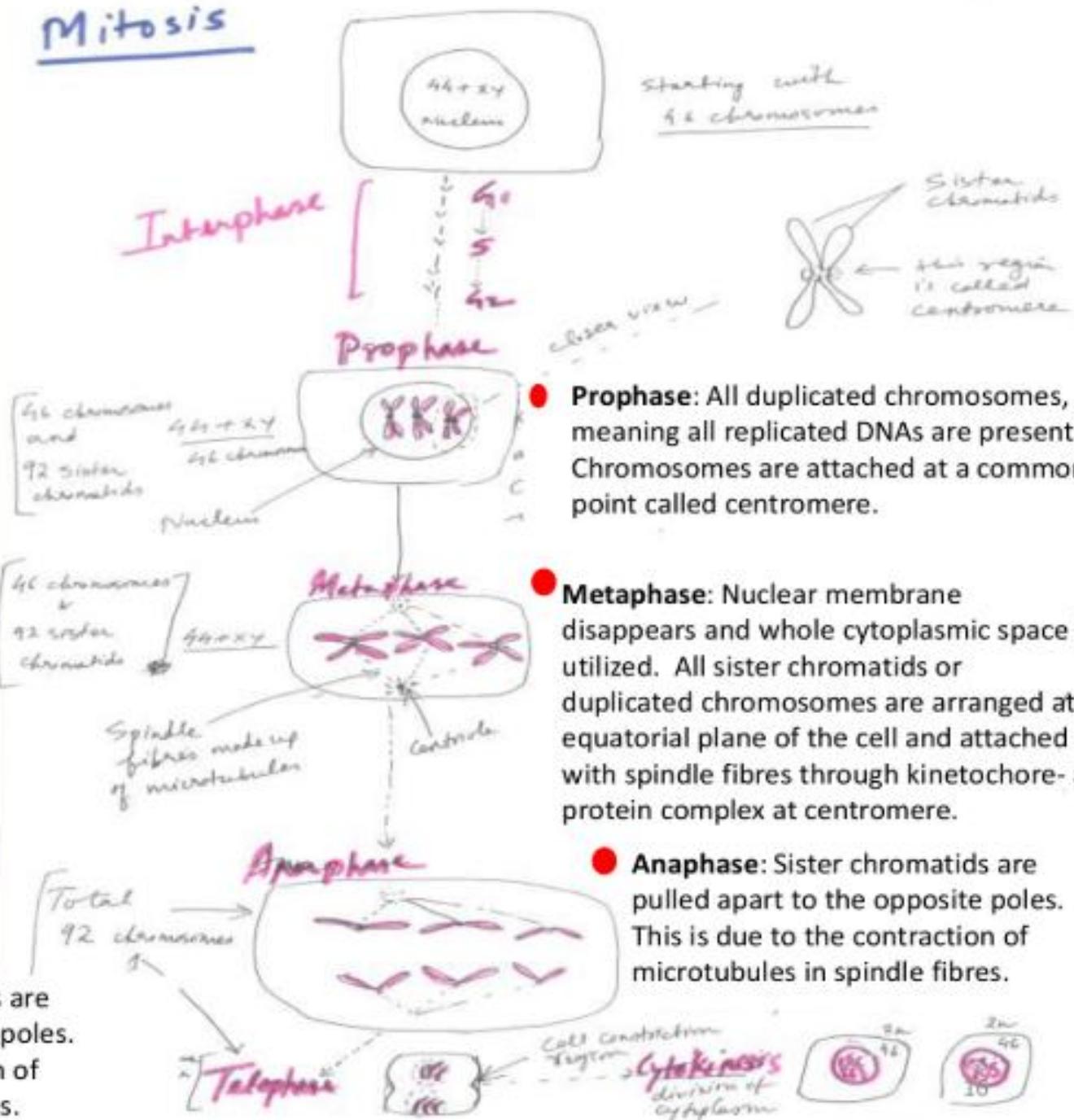


Mitosis cell division: different stages

Stages in mitosis: (PMAT)

1. Interphase
2. Prophase-intact nuclear membrane
3. Metaphase-no nuclear membrane
4. Anaphase-no nuclear membrane
5. Telophase-nuclear membrane reappears
6. Cytokinesis: division of cytoplasm that leads to two daughter cells with nucleus in each cell

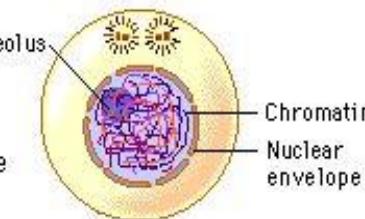
Mitosis



● **Telophase:** Sister chromatids are pulled apart to the opposite poles. This is due to the contraction of microtubules in spindle fibres.

Interphase

The nucleolus and the nuclear envelope are distinct and the chromosomes are in the form of threadlike chromatin.



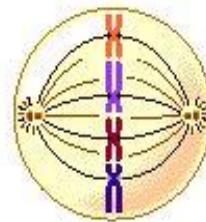
Prophase

The chromosomes appear condensed, and the nuclear envelope is not apparent.



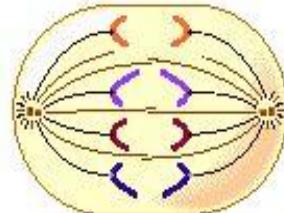
Metaphase

Thick, coiled chromosomes, each with two chromatids, are lined up on the metaphase plate.



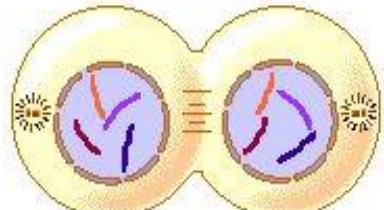
Anaphase

The chromatids of each chromosome have separated and are moving toward the poles.



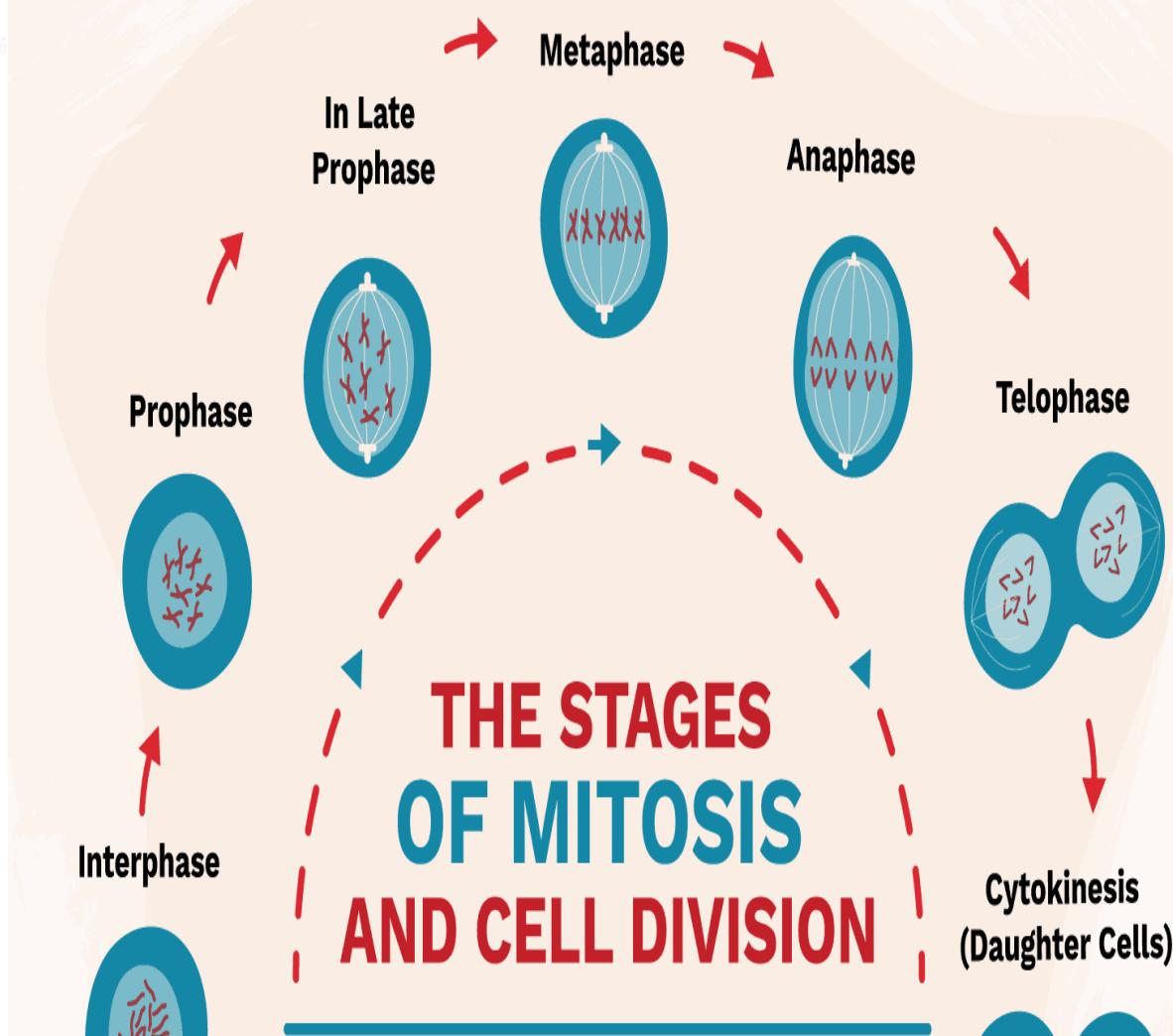
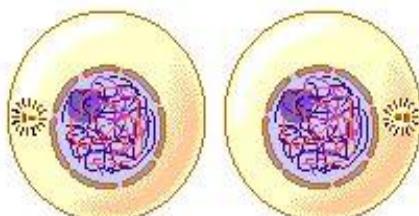
Telophase

The chromosomes are at the poles, and are becoming more diffuse. The nuclear envelope is reforming. The cytoplasm may be dividing.



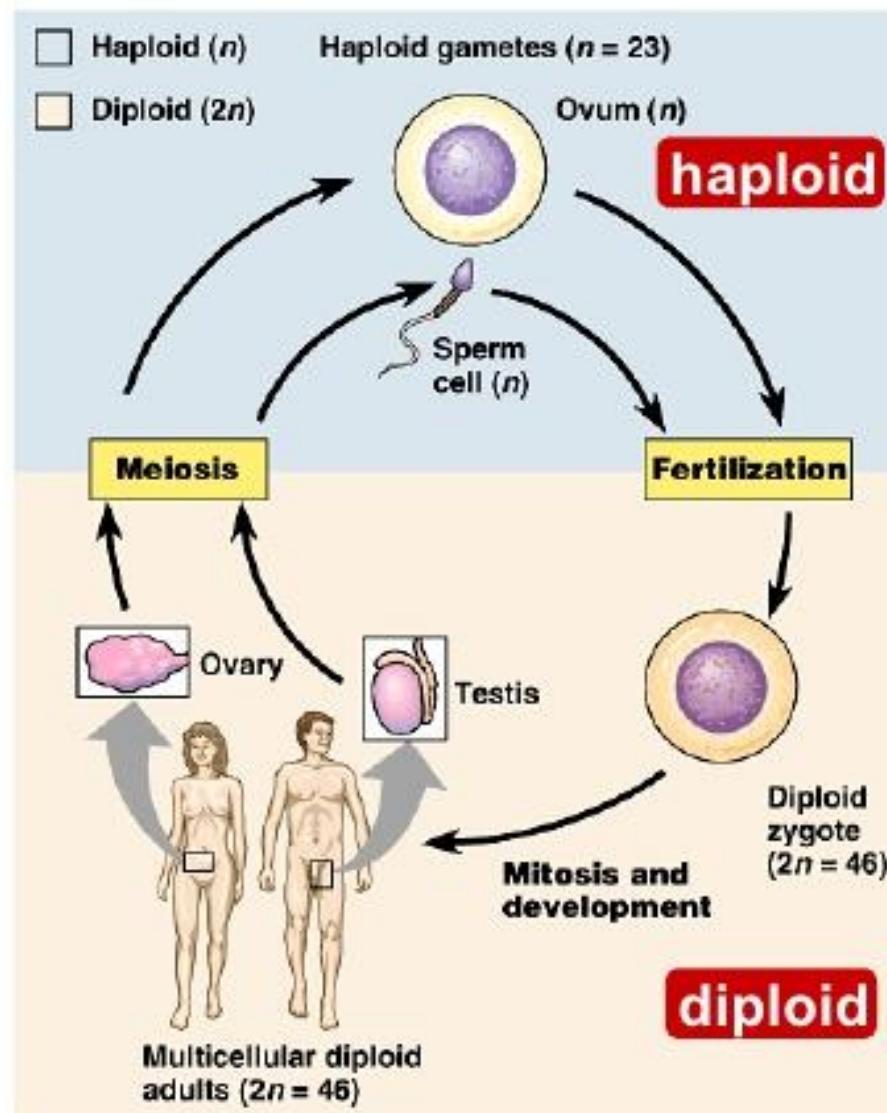
Cytokinesis

Division into two daughter cells is completed.



Meiosis: production of gametes

- Alternating stages
 - ◆ chromosome number must be reduced
 - diploid → haploid
 - $2n$ → n
 - ◆ humans: $46 \rightarrow 23$
 - meiosis reduces chromosome number
 - makes gametes
 - ◆ fertilization restores chromosome number
 - haploid → diploid
 - n → $2n$



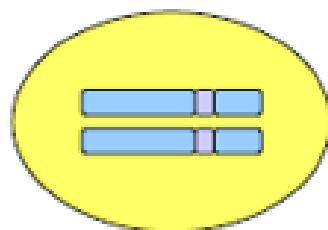
Why form gametes?

- Sperm and eggs(ova) are gametes
- Goal: Reduce genetic material by half

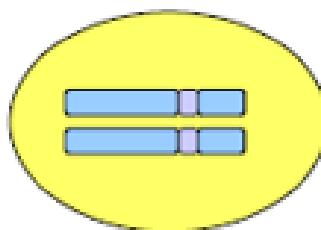
from mom

from dad

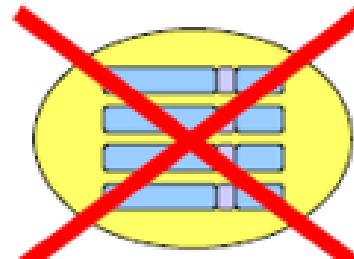
child



46 chromosomes



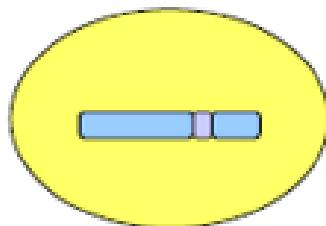
46 chromosomes



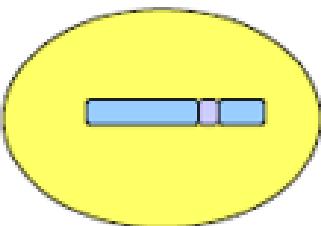
too
much!

92 chromosomes

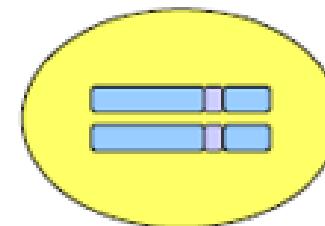
meiosis reduces
genetic content



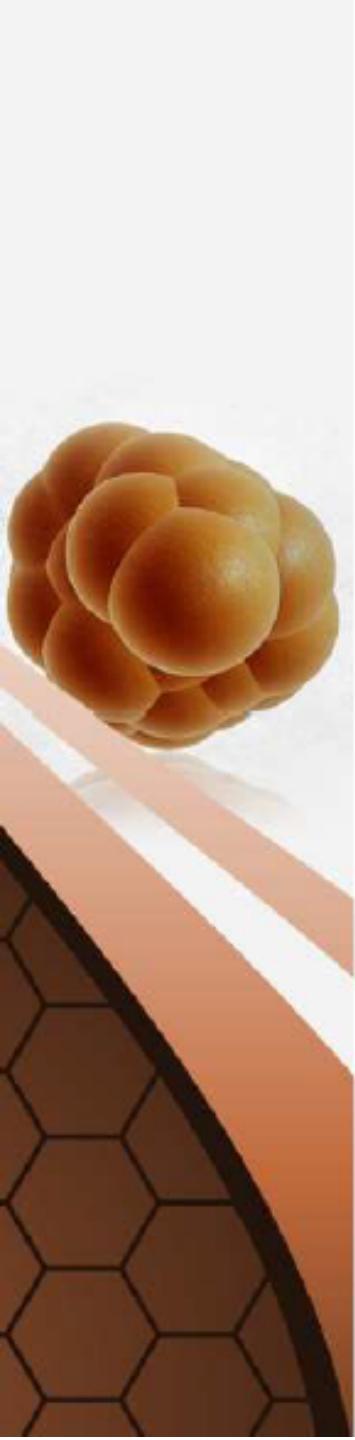
23 chromosomes



23 chromosomes



46 chromosomes



Meiosis is a **process** where a single cell divides twice to produce four cells containing half the original amount of genetic information.

Interphase

Meiosis I

Prophase I

Metaphase I

Anaphase I

Telophase I

Cytokinesis

Meiosis II

Prophase II

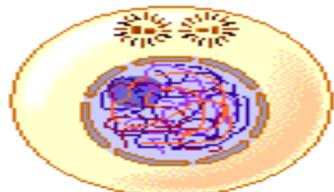
Metaphase II

Anaphase II

Telophase II

Cytokinesis

Interphase



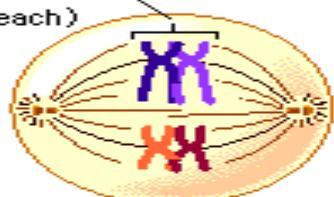
MEIOSIS I



Prophase I

Synapsis and crossing over occur.

Tetrad (paired homologous chromosomes with two chromatids each)



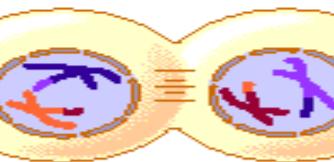
Metaphase I

Tetrads line up on the metaphase plate.

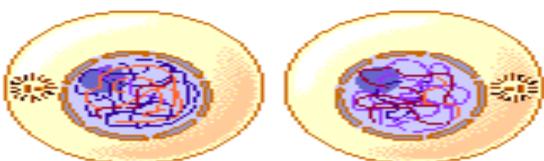


Anaphase I

Homologous pairs separate.



Telophase I



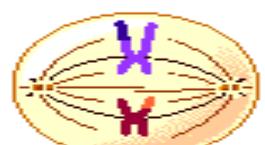
Cytokinesis I

To Prophase II

MEIOSIS II



Prophase II



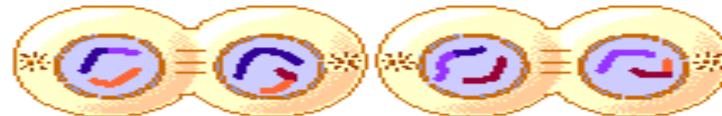
Metaphase II

Chromosomes line up on the metaphase plate.



Anaphase II

Sister chromatids separate.



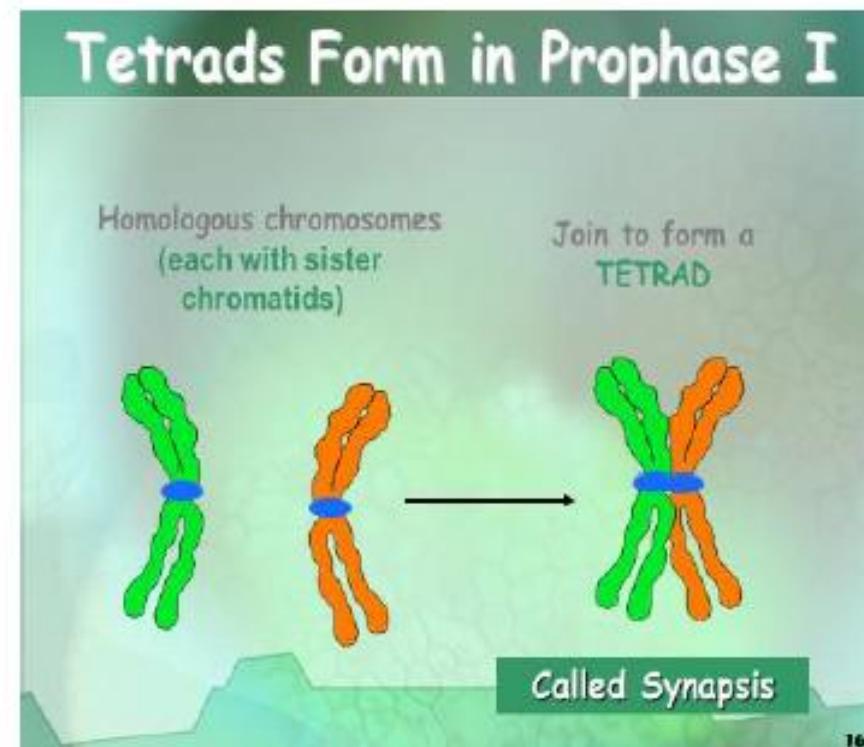
Telophase II



Cytokinesis II

4 haploid daughter cells are formed, each having only one chromosome of each homologous pair.

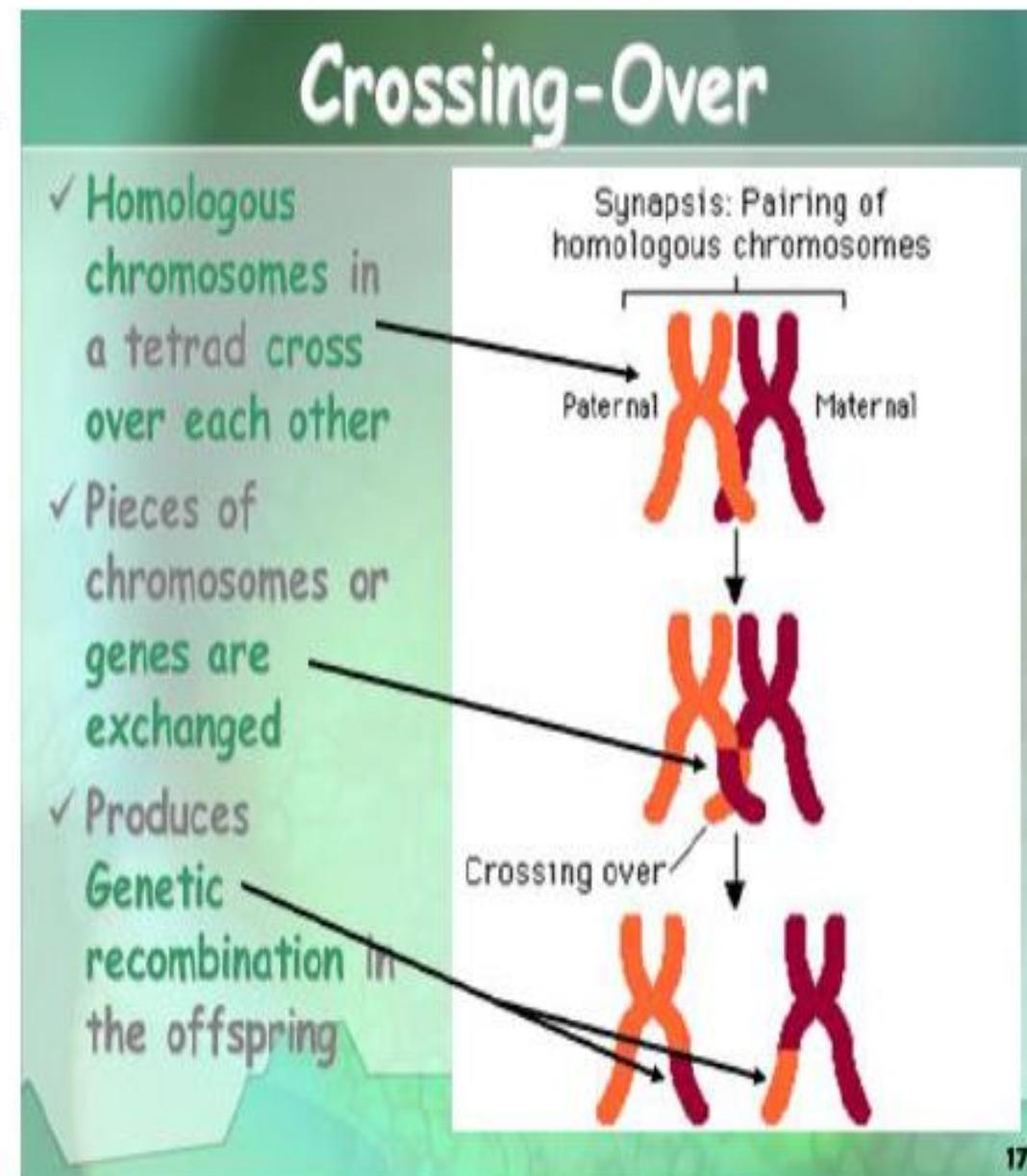
Prophase I of meiosis I – important stage for crossing over and exchange of genetic material



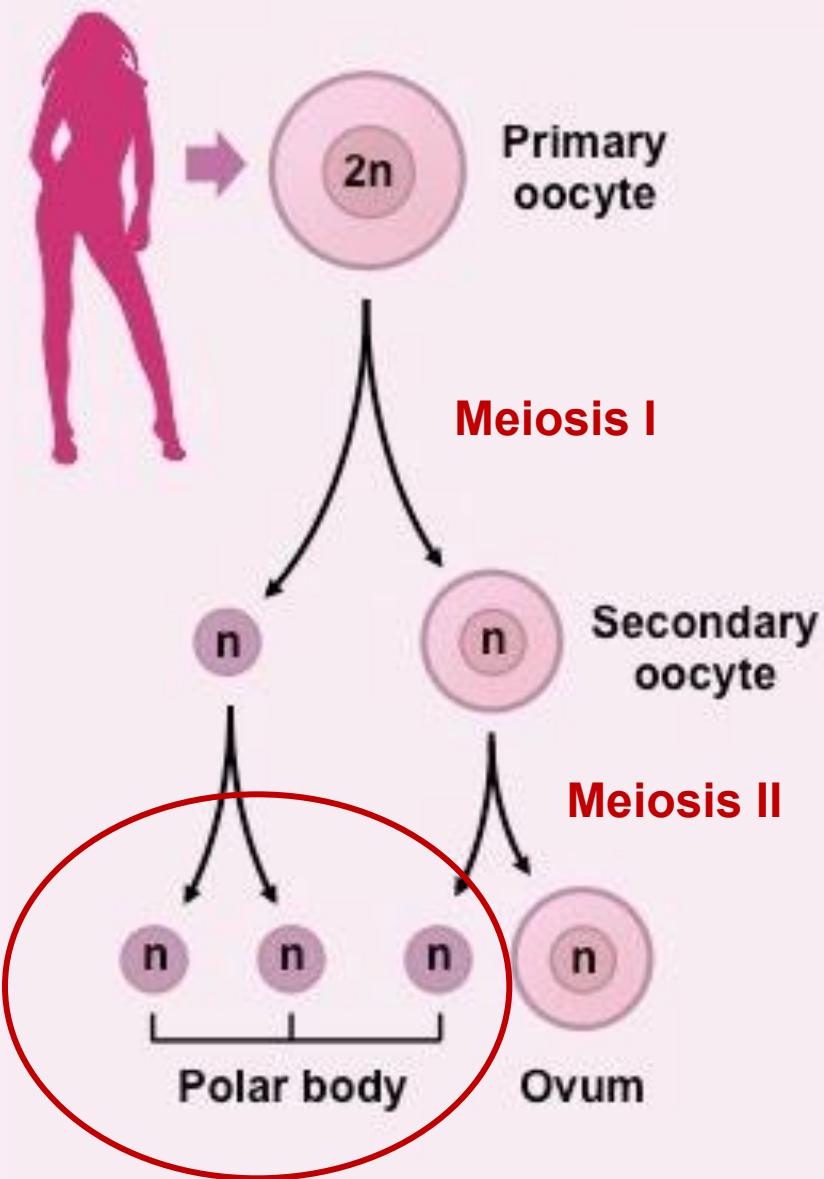
Tetrads formation and crossing over are important processes of meiosis which result in genetic variation among organism. In simple words, there is exchange of genetic material between “mom and dad” that results in offspring “with mom and dad characters”.

1) Prophase I is the longest phase of meiosis and divided into 5 stages- leptotene, zygotene, pachytene, diplotene, diakinesis. Zygotene stage is characterized by **tetrad formation (Synapsis)**. Pachytene is characterized by **crossing over** (exchange of genes) between non sister chromatids.

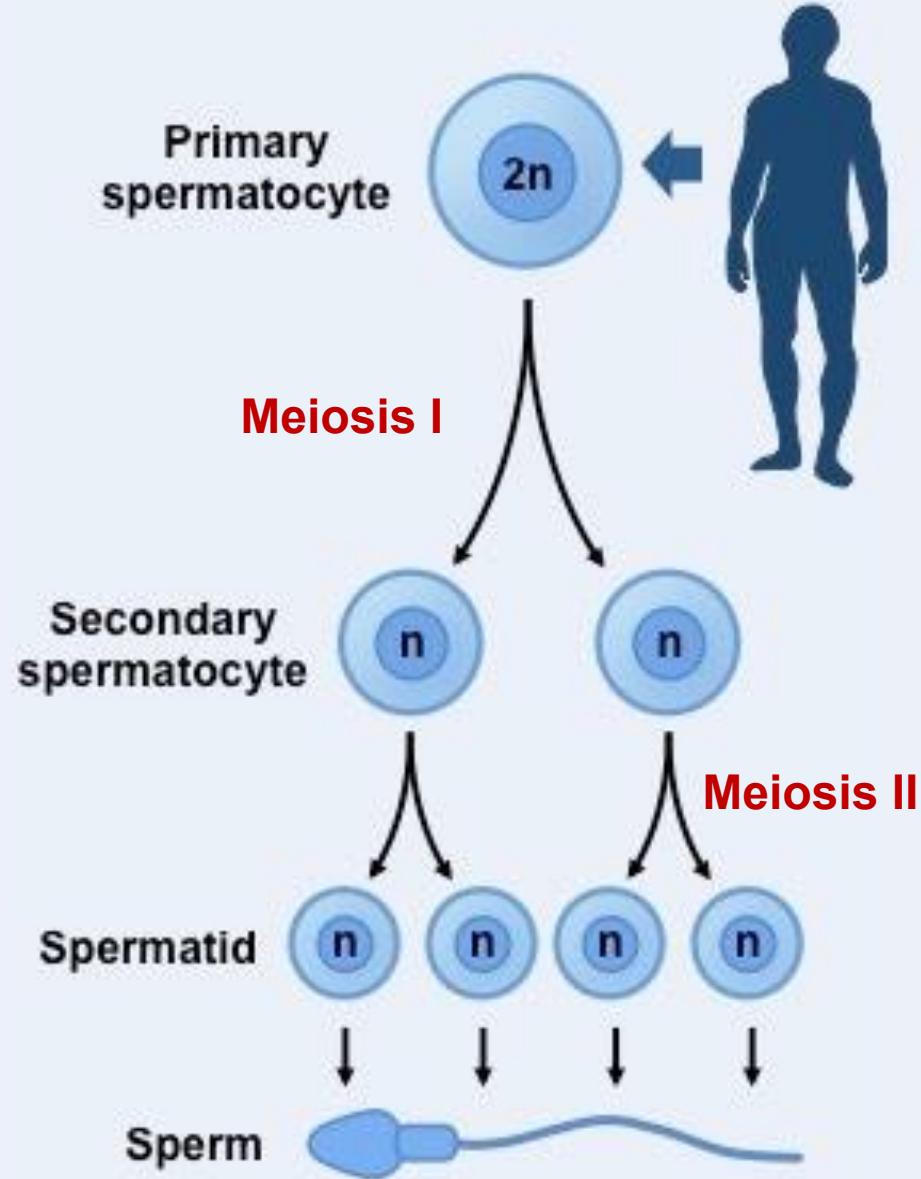
2) The point at which crossing over takes place is called **chiasmata**. Exchange of genetic segments produces genetic recombination in the offspring, and brings variation in traits.



OOGENESIS



SPERMATOGENESIS

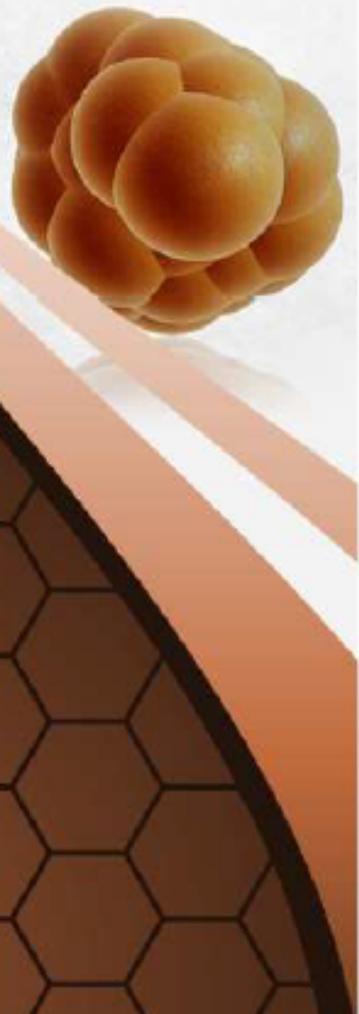


Chromosomes and chromatids numbers in cell divisions

Phase (Mitosis)	# Chromosomes	# Chromatids
Prophase	46	92
Metaphase	46	92
Anaphase	92	92
Telophase	92	92
End of Mitosis (separated cells)	46	46

Phase (Meiosis I)	# Chromosomes	# Chromatids
Prophase I	46	92
Metaphase I	46	92
Anaphase I	46	92
Telophase I	46	92
End of Meiosis I (separated cells)	23	46

Phase (Meiosis II)	# Chromosomes	# Chromatids
Prophase II	23	46
Metaphase II	23	46
Anaphase II	46	46
Telophase II	46	46
End of Meiosis II (separated cells)	23	23



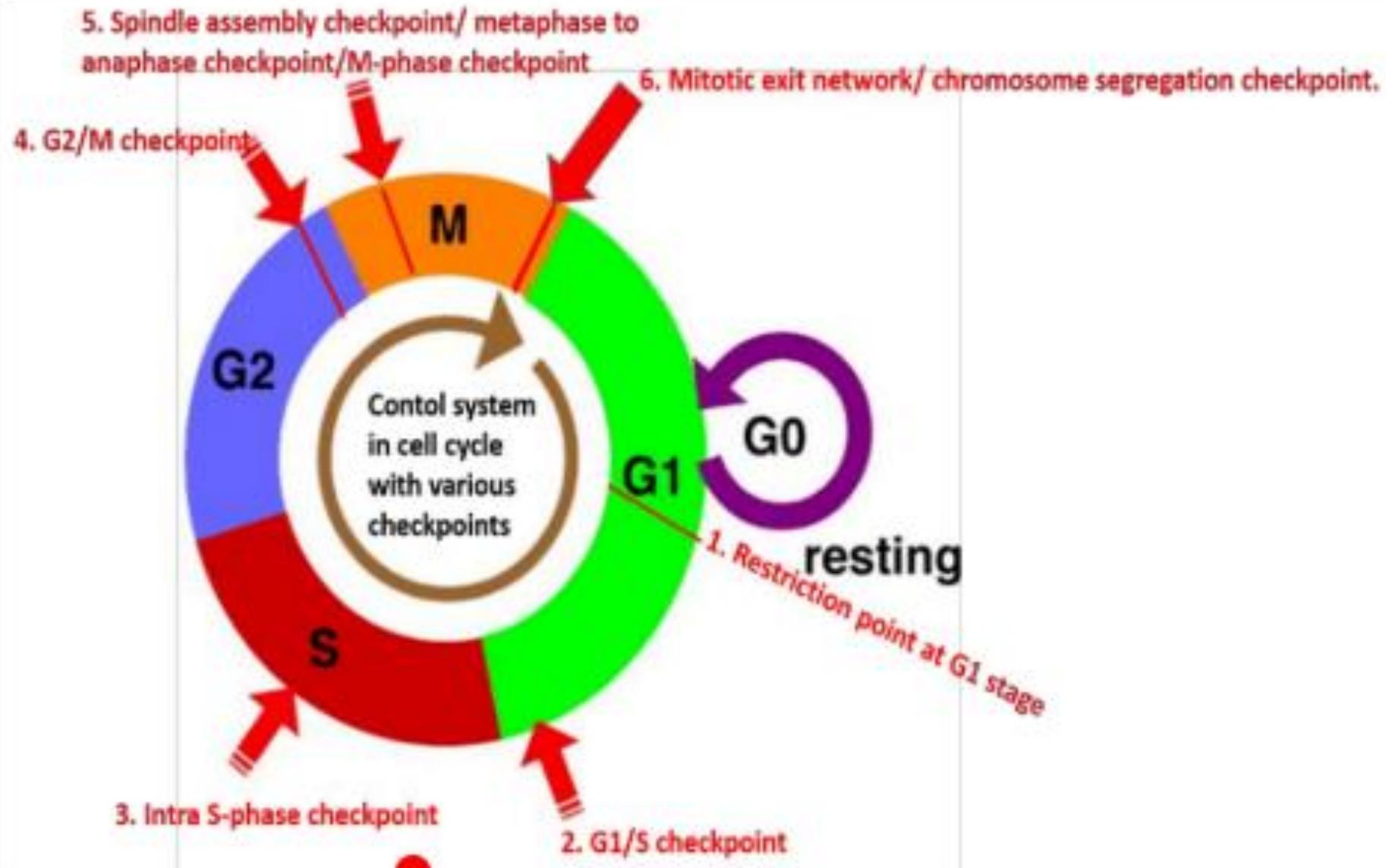
mitosis

1. All organism
2. Asexual
3. Genetically - identical cells
4. No crossing over occurs
5. No pairing of homologous chromosome
6. One cell division occurs
7. 2 diploid cells are produced

meiosis

1. Reproductive cells of humans, plants, animals & fungi
2. Sexual
3. Genetically - Different cells
4. Crossing over occurs
5. Pairing of homologous chromosome
6. Two cell division occurs
7. Four haploid cells are produced

Cell cycle control and different checkpoints



1) Restriction point at G1 stage.

a) This is a point of no return at which cell is committed to divide or die by becoming unresponsive to any more external signals. If the cell has improper size or other defects it **enters the temporary stage of resting called G₀ phase**.

2) G₁/S checkpoint



a) Keeps an eye over DNA damages and ensures that everything is ready for DNA synthesis.
b) Ensures the **proper cell size and availability of nutrients required for further stage of the cell cycle**. If any of these are not adequate, there will be **cell arrest and cell go for apoptosis (cell death)**.

3) Intra S-phase
checkpoint

a) This occurs at the middle of the S-phase which is the phase of synthesis of DNA.
b) **keeps an eye over proper DNA replication**, any damages or lesions in DNA will stall replication forks during replication process and so on

4) G2/M checkpoint

- a) If DNA synthesis is not completed, cells do not enter into mitotic phase and goes for apoptosis.
- b) checks for the mitotic machineries that are required for the next stages. Cell ensures that all the materials are available for carry out division through next stage as well as genome integrity is also maintained

5) Spindle assembly checkpoint or metaphase to anaphase checkpoint

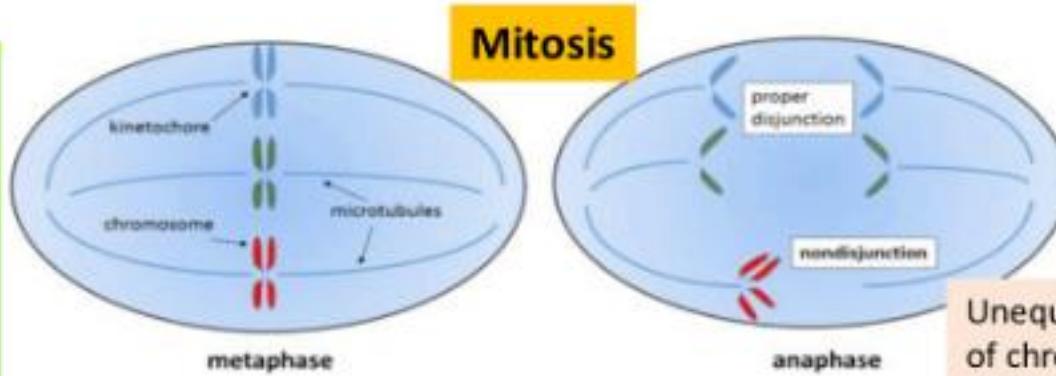
- a) This checkpoint **works between metaphase to anaphase stage of M-phase**.
- b) **Improper assembly of mitotic spindle fibres prevents the initiation of anaphase.** When spindle fails to attach to the kinetochore of one sister chromatid, the checkpoint do not allow it to enter the anaphase.

6) Mitotic exit network or chromosome segregation checkpoint.

- a) **Proper segregation of daughter chromosomes during telophase and cytokinesis** is monitored by this checkpoint.

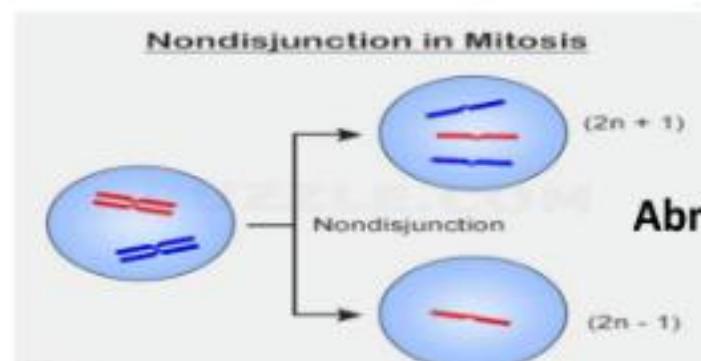
Non disjunction:

Failure of Spindle-assembly checkpoint or metaphase to anaphase transition causing unequal distribution of chromosomes in daughter cells.



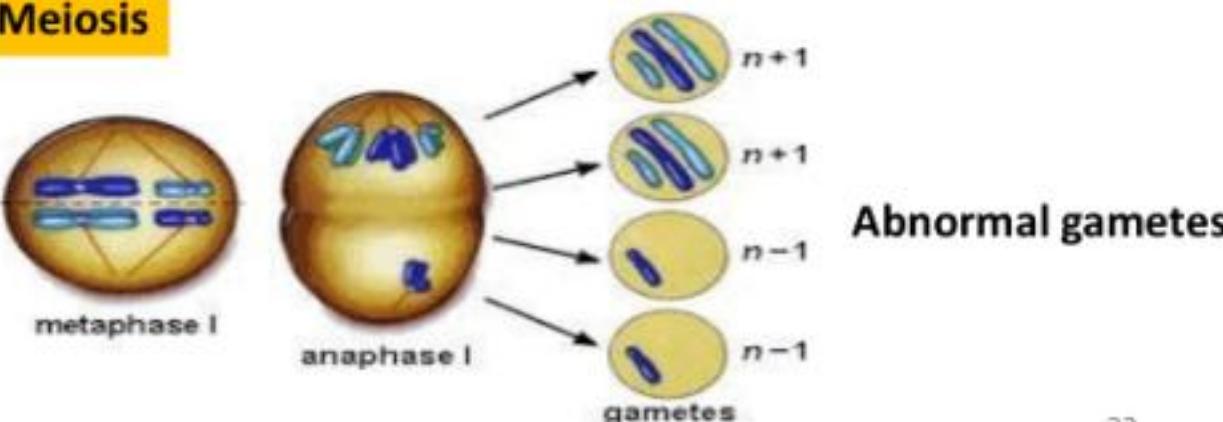
Mitosis

Unequal distribution of chromosome during metaphase to anaphase transition: failure of spindle – assembly checkpoint



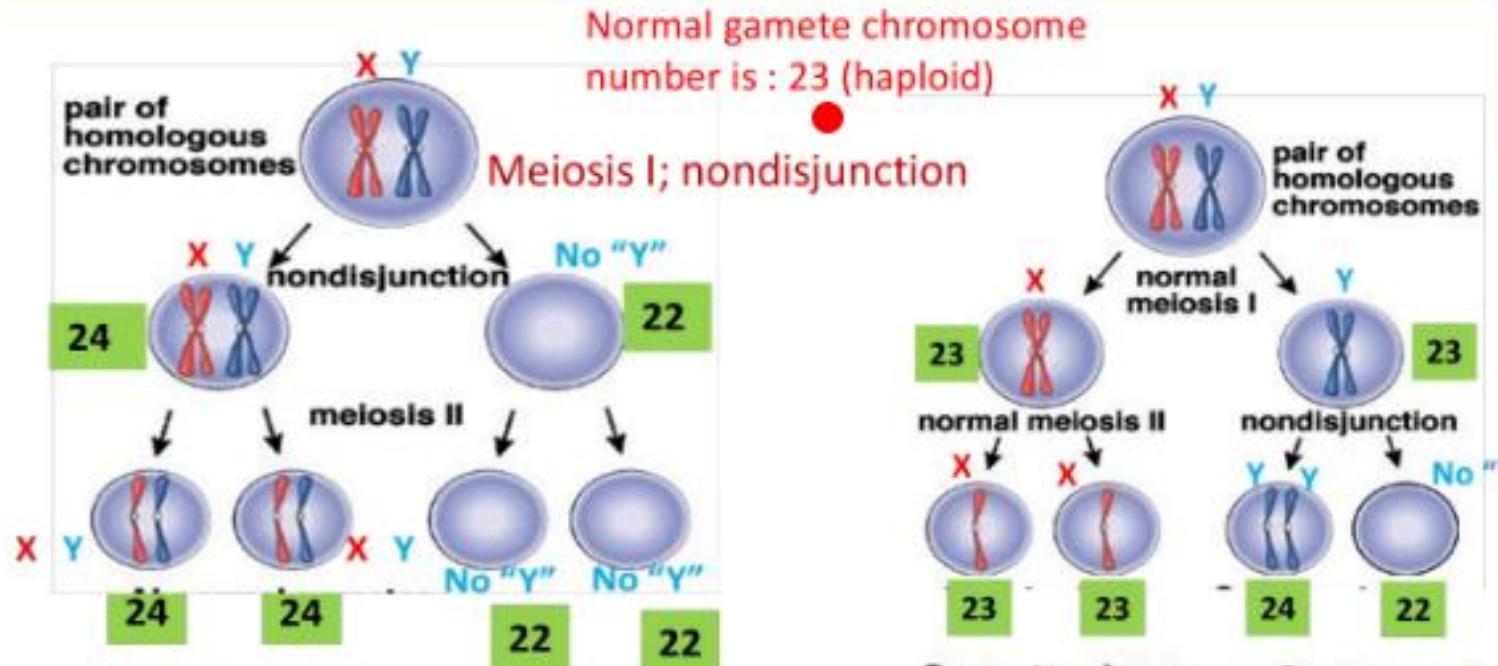
Abnormal daughter cells

Meiosis



Why "abnormal" because normal chromosome number is not maintained?

Non-disjunction can happen either in meiosis I ... metaphase to anaphase transition or meiosis II during metaphase to anaphase transition



Taking example here the separation of X and Y homologous pair.

Meiosis II; nondisjunction in one of the daughter cells.

Abnormal gametes:
two gametes have one extra and
two gametes have one less
chromosome than normal.

Gametes have usual number of chromosomes.

One gamete has one extra and the other has one less chromosome.

"Abnormal Sperms"..... **22 + XY** (24 chromosome) X Normal ovum..... **22 + X**

Fertilization

44 + XXY Klinefelter's syndrome

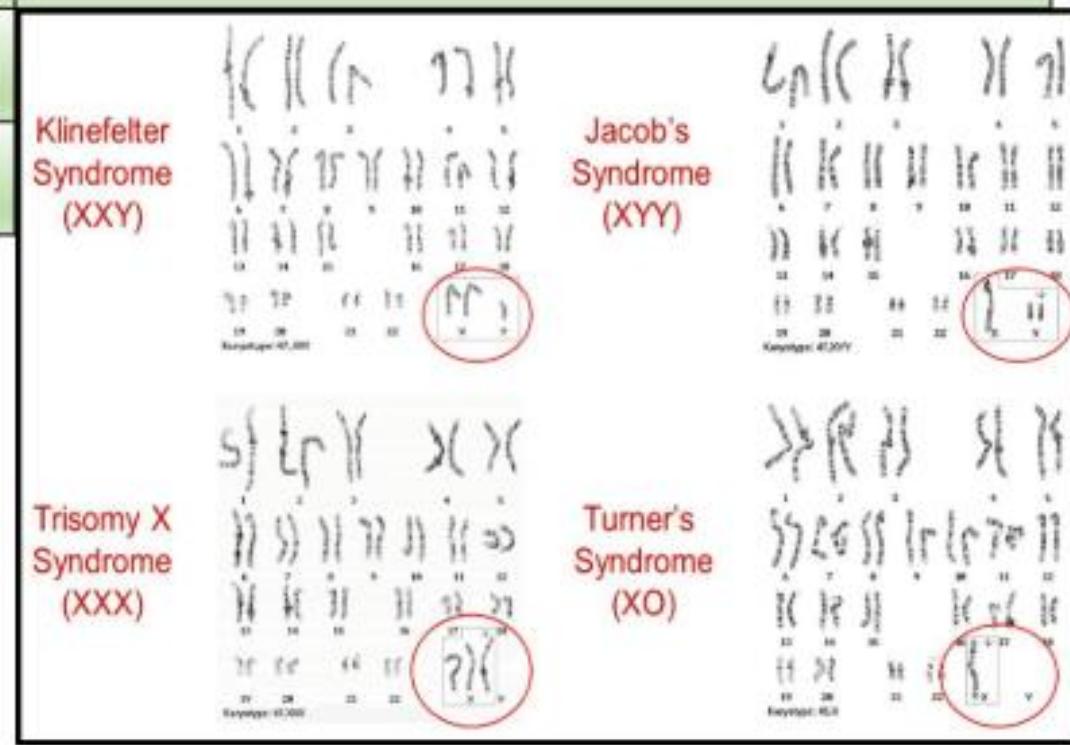
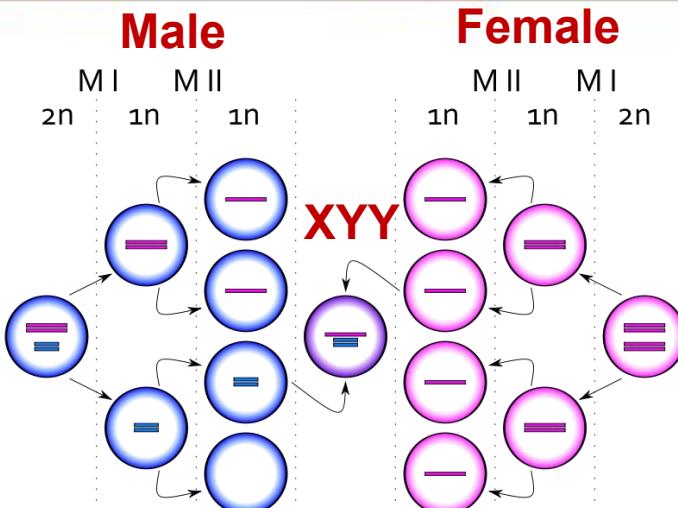
"Abnormal Sperms"..... **22 + O** (22 chromosome) X Normal ovum..... **22 + X**

Fertilization

44 + XO Turner's syndrome

Disorders due to Non Disjunction of Sex chromosomes

Non-disjunction in Sex chromosomes	Individual's chromosome notation	Physical appearance and symptoms
1) Turner's syndrome	44 + XO	Women with one X-chromosome, short height, webbed neck, lack of underarm and pubic hair, underdeveloped ovaries
2) Klinefelter's syndrome	44 + XXY	Symptoms in males include like tall height, low IQ scores, speech and language difficulty, sterility
3) Jacob's Syndrome	44 + XYY	
4) Trisomy X syndrome	44 + XXX	



Non-disjunction in "Autosomes"	notation	Symptoms
1) Trisomy 18 (Edward's Syndrome)	45 + XX or 45 + XY (extra copy of chromosome 18)	Slow growth before birth, low birth weight, abnormal organ growth, heart defects, small head, 90-95% mortality rate during the first year.
2) Trisomy 13 (Patau syndrome)	45 + XX or 45 + XY (extra copy of chromosome 13)	Heart defects, abnormalities of the eyes, ears, brain and spinal cord, cleft palate and/or lip, small head, low IQ scores, speech and language difficulty, sterility
3) Trisomy 21 (Down Syndrome)	45 + XX or 45 + XY (extra copy of chromosome 21)	   <ul style="list-style-type: none"> Decreased muscle tone at birth Excess skin at the nape of the neck Flattened nose Upward slanting eyes Small ears Small mouth Wide, short hands with short fingers Separated joints between the bones of the skull Single crease in the palm of the hand White spots on the colored part of the eye

Sample questions

1) If cell has 46 chromosomes at the beginning of mitosis, then at anaphase there would be a total of

- a) 46 chromosomes
- b) 92 chromosomes
- c) 23 chromatids
- d) 46 chromatids

2) If a cell has 46 chromosomes at the beginning of meiosis, then at anaphase I there would be a total of

- a) 23 chromatids
- b) 46 chromatids
- c) 46 chromosomes
- d) 92 chromosomes

3) During cell cycle sister chromatids are pulled apart during

- a) Metaphase
- b) Anaphase
- c) Prophase
- d) Interphase

4) The minimum number of meiotic division to obtain 100 sperms

- a) 25
- b) 50
- c) 75
- d) 100

5) How many generations and mitotic divisions are required to produce 128 cells ?

- a) 6 and 126
- b) 7 and 127
- c) 5 and 125
- d) 4 and 124

6). Homologous chromosome include

- a) one smaller and one bigger chromosome
- b) one chromosome from each parent
- c) one complete and one incomplete chromosome
- d) none of the above

7) T/F: Interphase is usually divided into 3 phases: G1, S, G2.

8) The _____ is the regular sequence of growth and division that cells undergo.

9) _____ is the stage of the cell cycle where the cell grows to its mature size, copies its DNA, and prepares to divide.

10) Cells can not get too big because:

- A. there is not enough DNA to support large cells
- B. diffusion is too slow to provide for large cells
- C. the surface area of a cell increases too fast for the cell membrane to meet its needs.
- D. all of the above

11) DNA is replicated during:

- A. interphase
- B. prophase
- C. metaphase
- D. cytokinesis