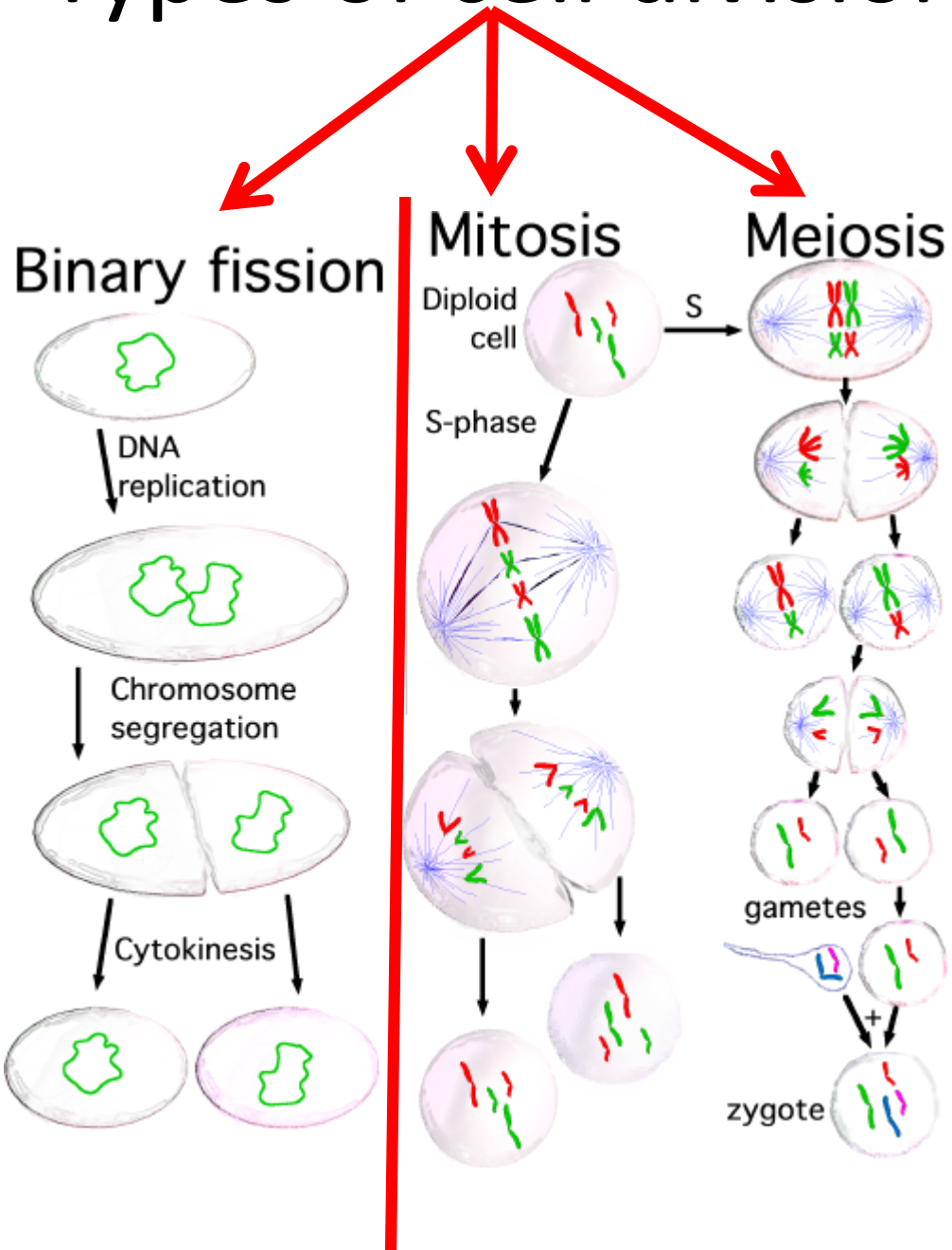
Cell division

Alexandra Stayer-Harci

Types of cell division

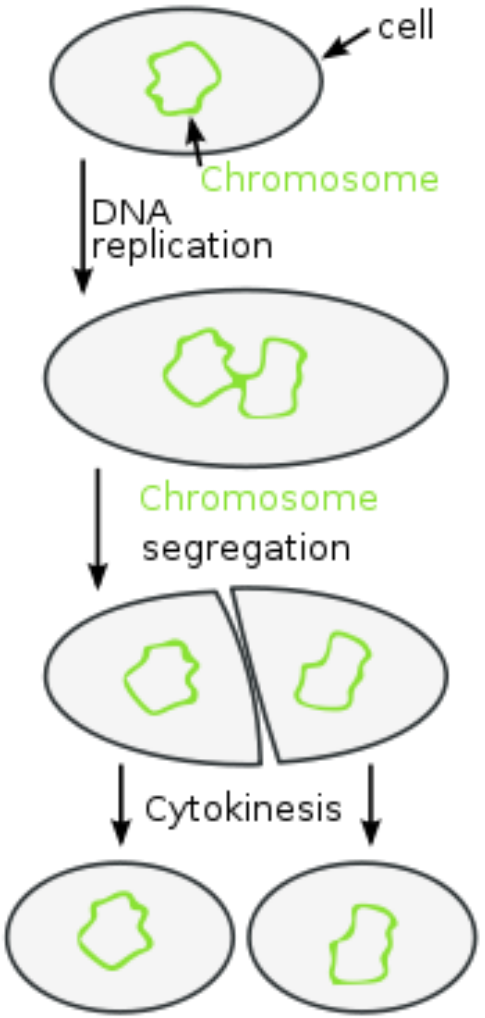
prokaryotes

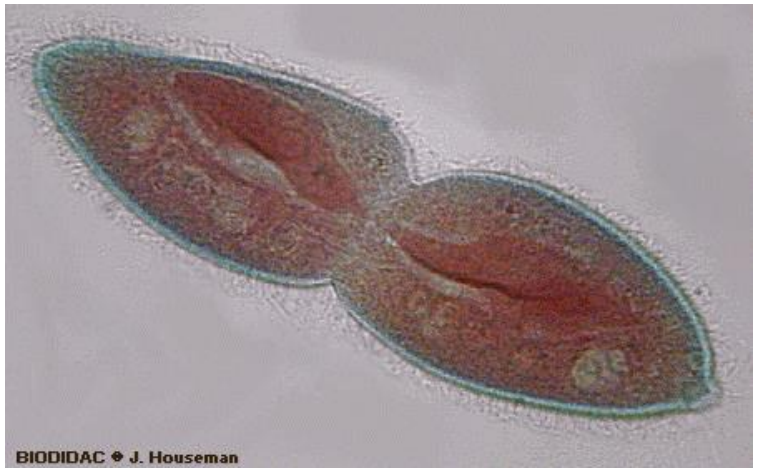
eukaryotes



Binary fission

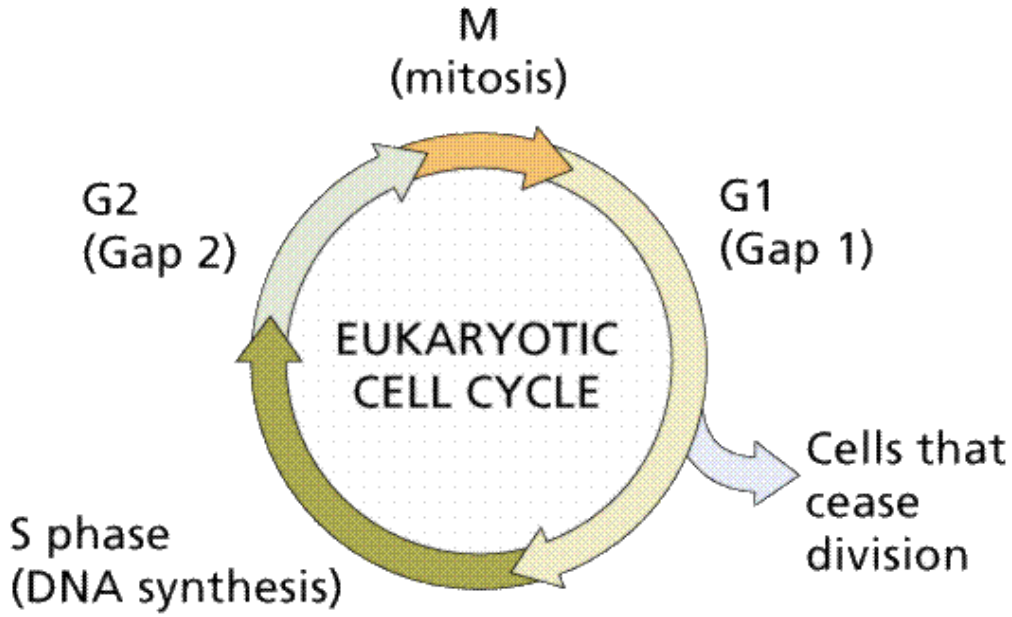
- Prokaryotic cells have no nucleus, divide by a process called binary fission:
  - it starts with DNA replication
  - the cell elongates
  - the cell membrane then grows inward and splits the cell into two daughter cells





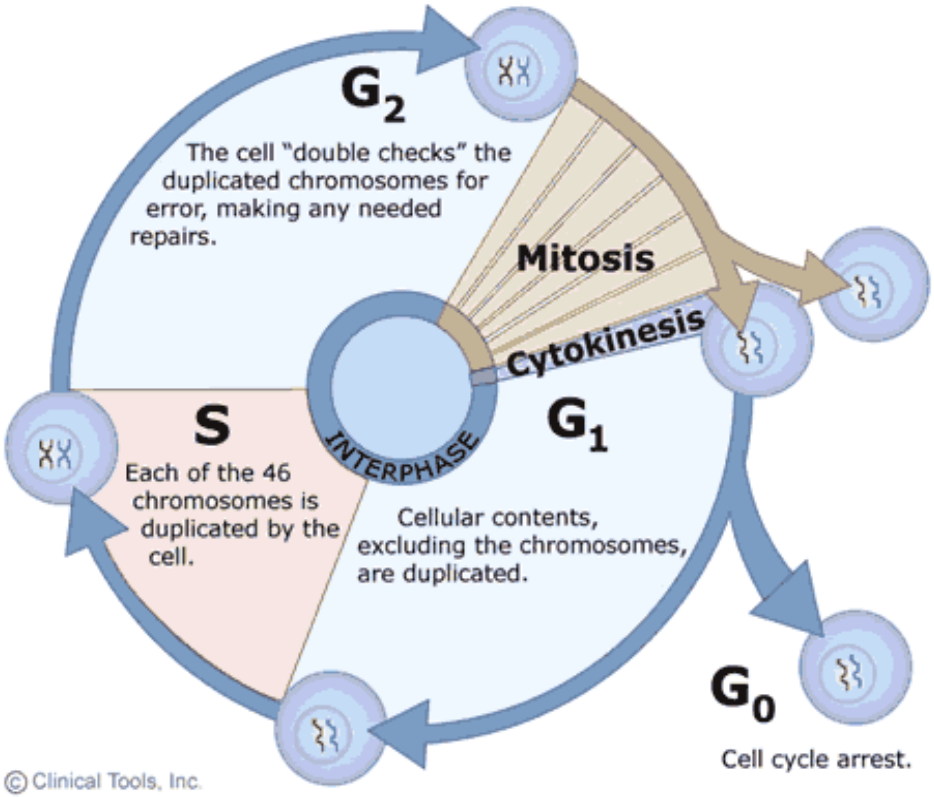
Cell cycle

- the series of events that takes place in a cell leading to its division and duplication (replication)
- two main periods:
  -interphase (G1, S, G2): during which the cell grows, accumulates nutrients needed for replication and mitosis
  -mitosis (M) phase, during which the cell splits itself into two distinct cells („daughter cells”)



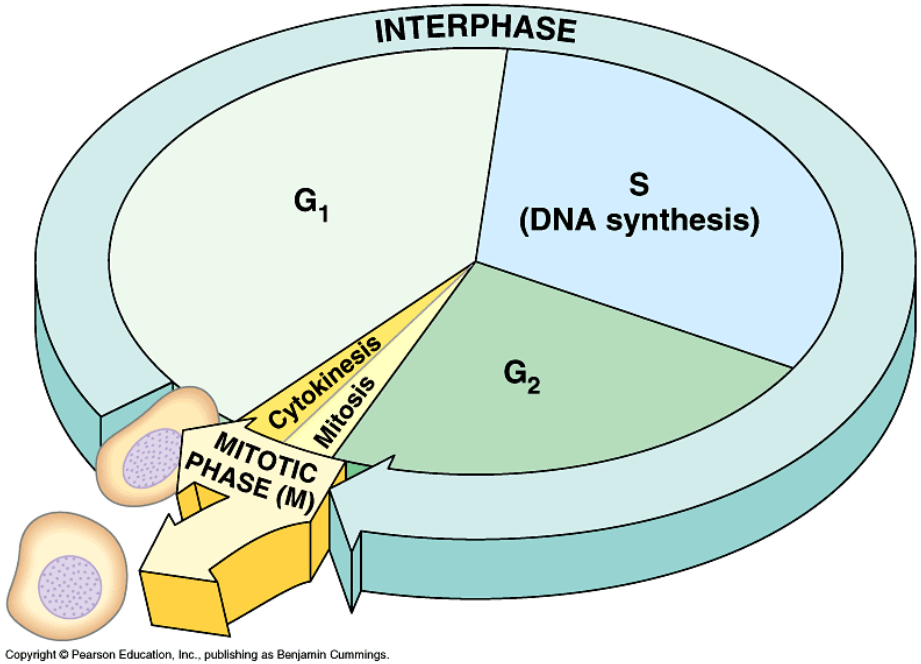
Cell cycle

State	Phase	Abbreviation	Description
quiescent/senescent	Gap 0	G_0	A resting phase where the cell has left the cycle and has stopped dividing.
Interphase	Gap 1	G_1	Cells increase in size. The *G_1 checkpoint* control mechanism ensures that everything is ready for DNA synthesis.
	Synthesis	S	DNA replication occurs during this phase.
	Gap 2	G_2	During the gap between DNA synthesis and mitosis, the cell will continue to grow. The G2 checkpoint control mechanism ensures that everything is ready to enter the M (mitosis) phase and divide.
Cell division	Mitosis	M	Cell growth stops at this stage and cellular energy is focused on the orderly division into two daughter cells. A checkpoint in the middle of mitosis (Metaphase Checkpoint) ensures that the cell is ready to complete cell division.



Cell cycle

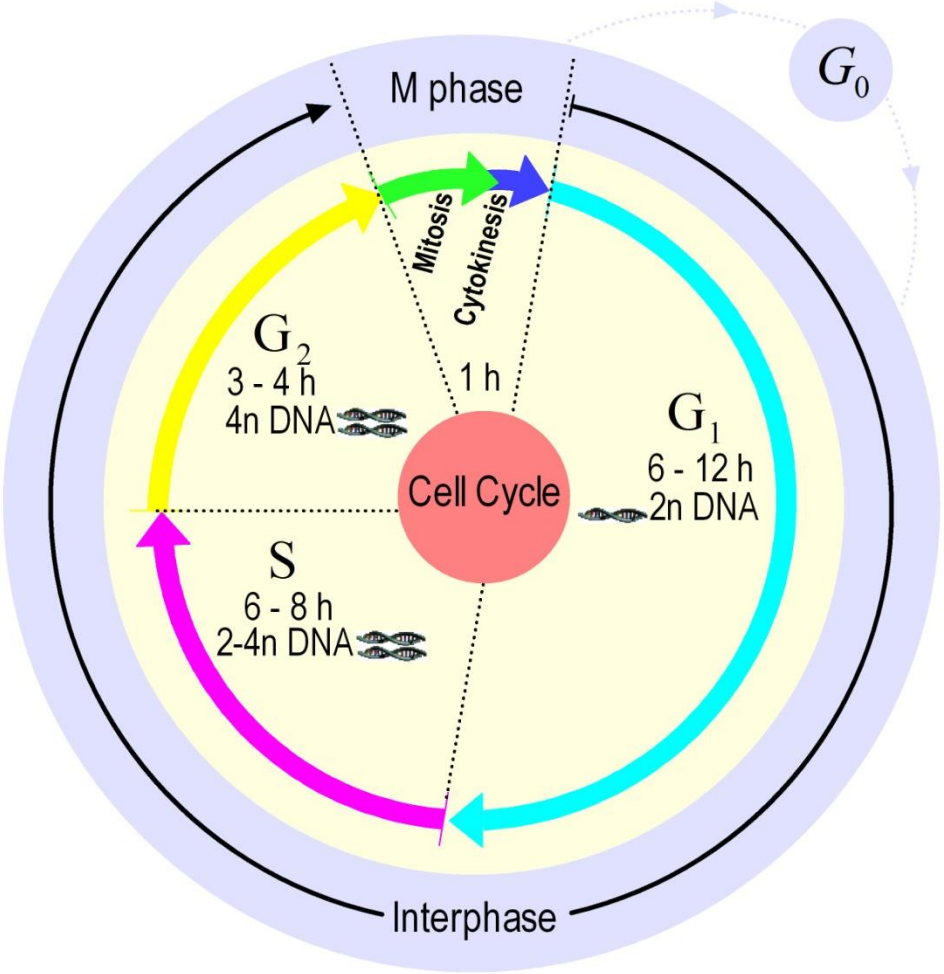
- After cell division, each of the daughter cells begin the interphase of a new cycle
- problems with the regulation of the cell cycle may lead to tumor formation
- Some genes like the cell cycle inhibitors, when they mutate → uncontrolled cell division → tumor formation



Lenght of the cell cycle

- Mammalian cells: about 24 hours (depends on the type of the cell)
- G1 phase: about 10 hours of the 24 total hours of the cell cycle
- S phase: between 6 and 8 hours
- G2 phase: is shorter, only 3 to 4 hours in most cells

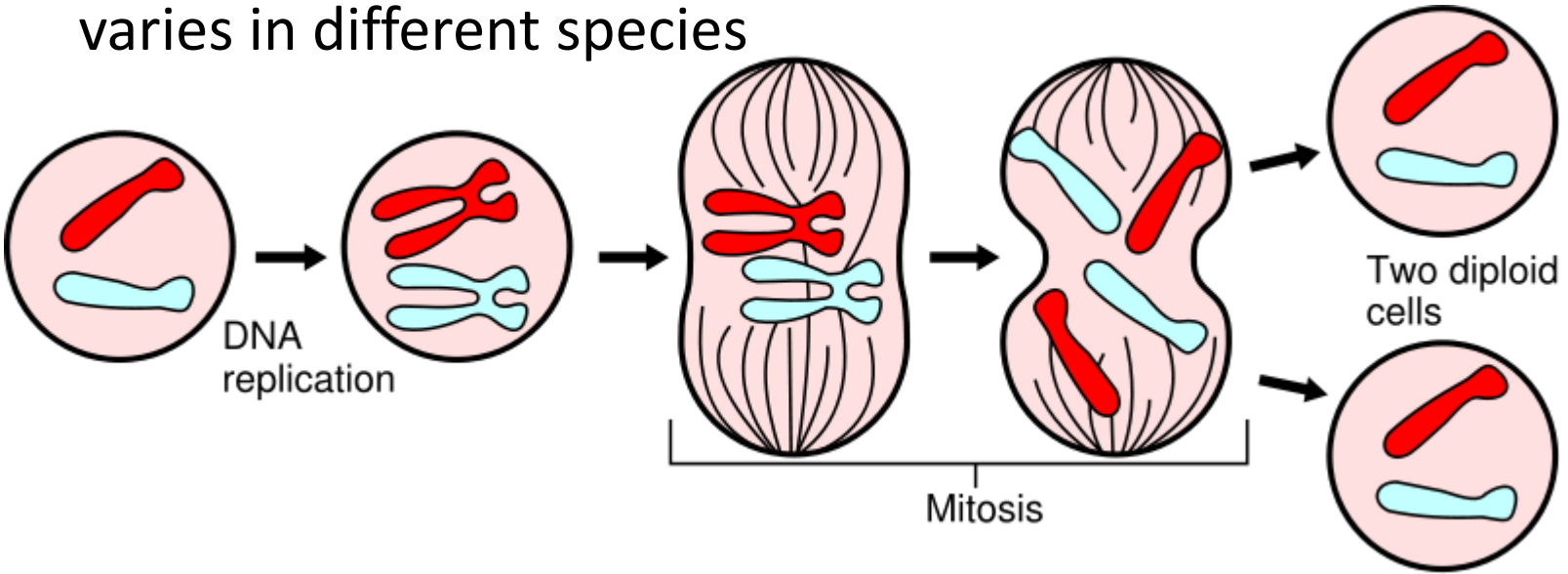
  → interphase generally takes between 18 and 20 hours
- Mitosis: takes about 1-2 hours



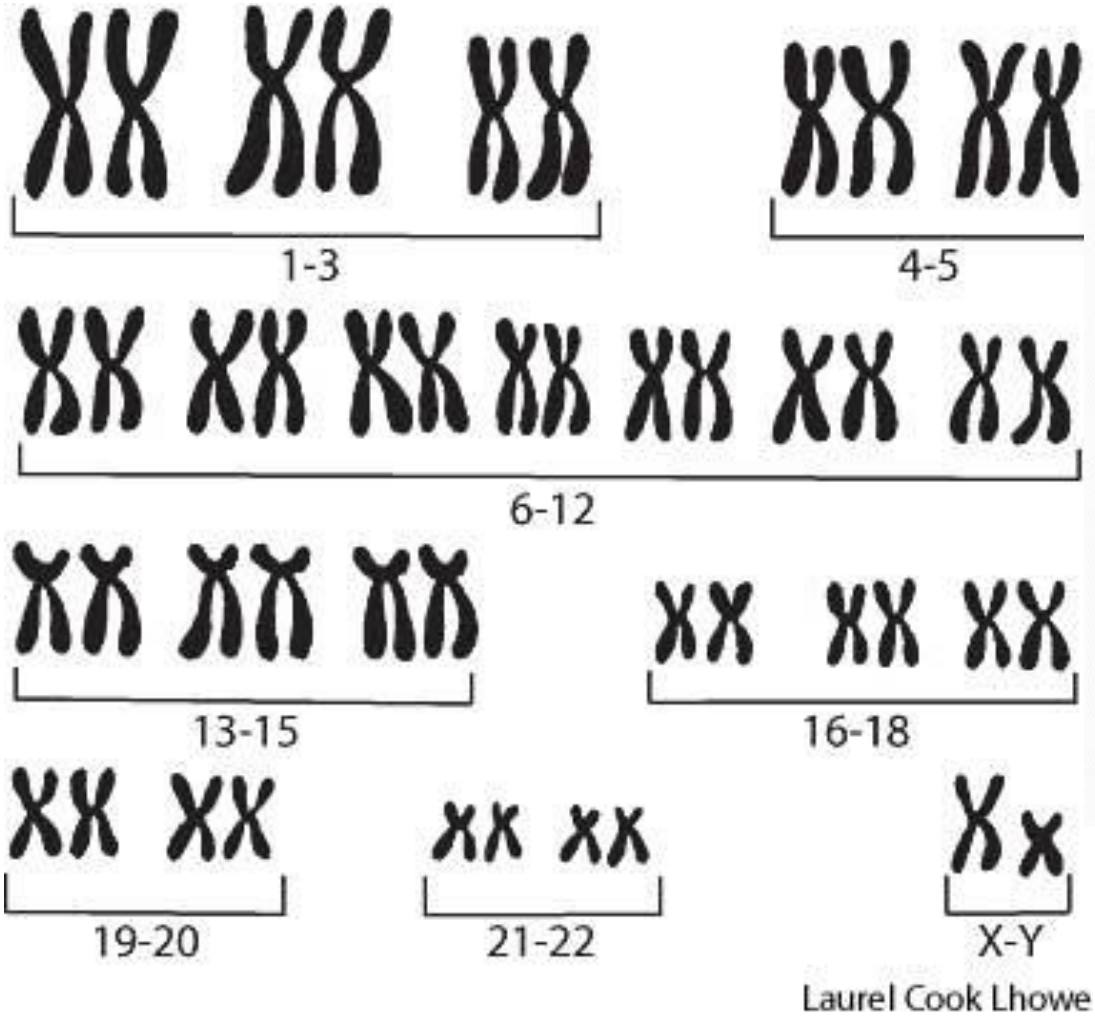
Mitosis

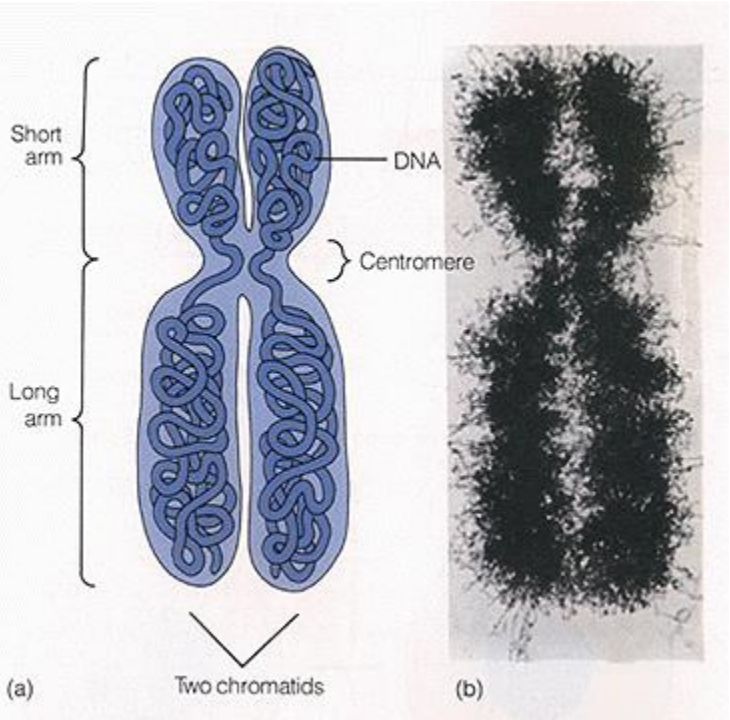
Mitosis

- is the process by which a eukaryotic cell separates the chromosomes in its cell nucleus into two identical sets in two nuclei
- It is generally followed immediately by cytokinesis, which divides the cytoplasm, organelles and cell membrane into two cells
- The two daughter cells are genetically identical to each other and to their parent cell.
- Mitosis occurs only in eukaryotic cells and the process varies in different species



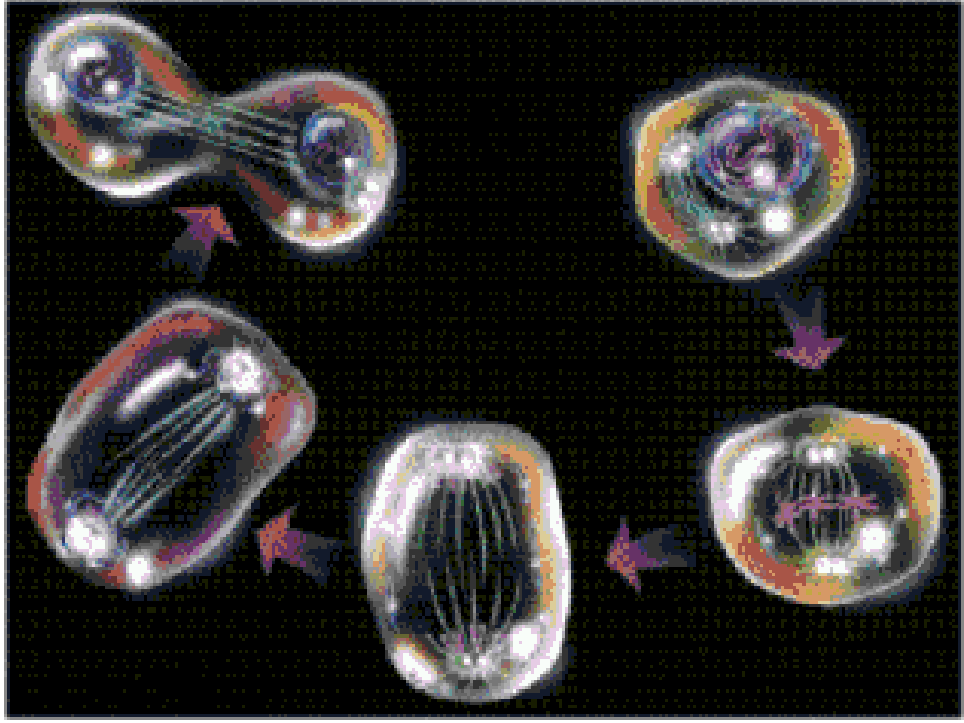
Karyotype

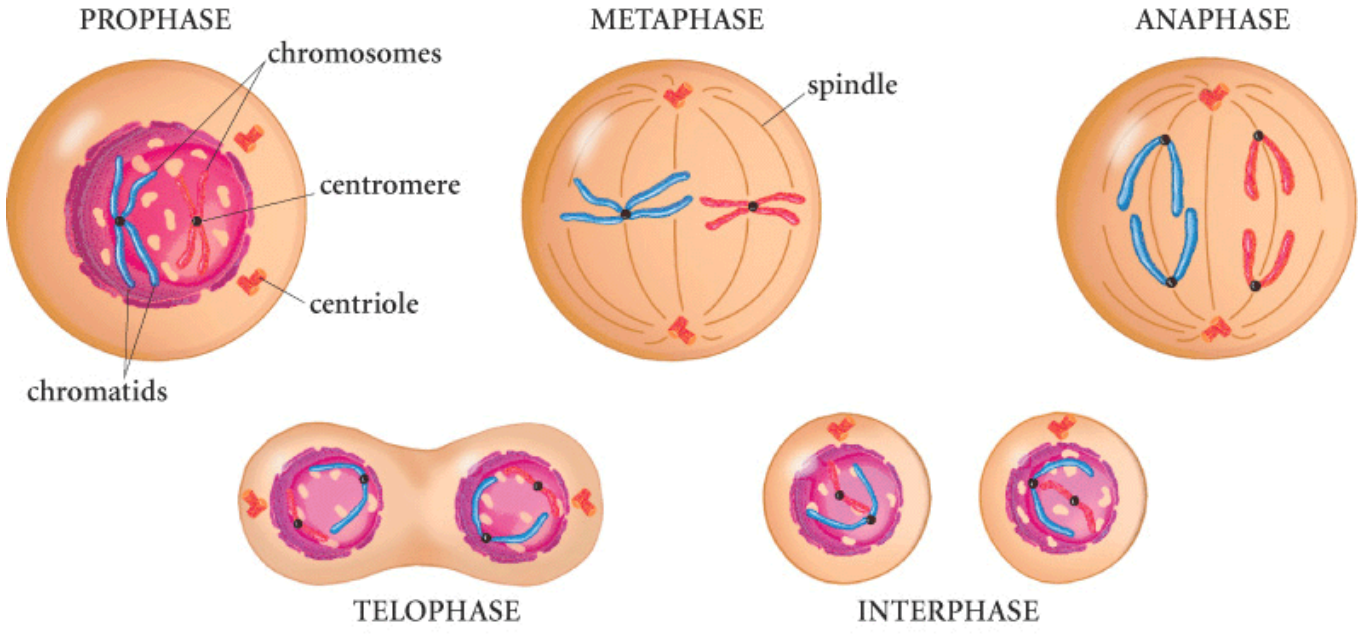

1-3
4-5
6-12
13-15
16-18
19-20
21-22
X-Y
Laurel Cook Lhowe


Short arm
Long arm
DNA
Centromere
Two chromatids
(a)
(b)

Phases of mitosis

- Prophase
- Metaphase
- Anaphase
- Telophase
- Cytokinesis

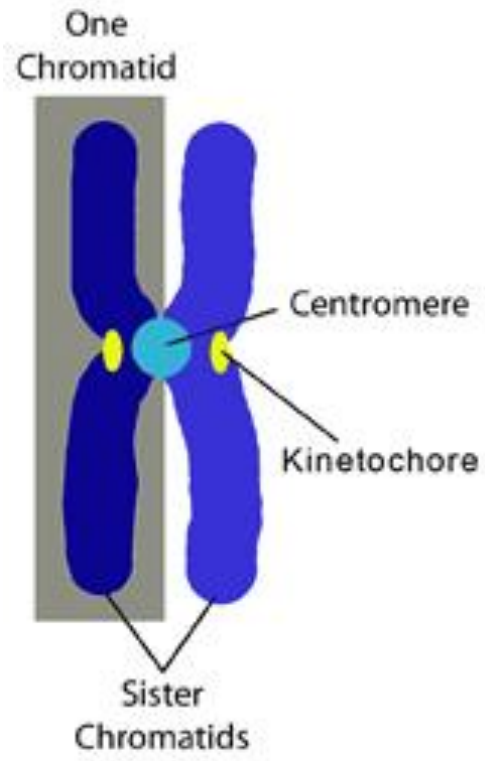


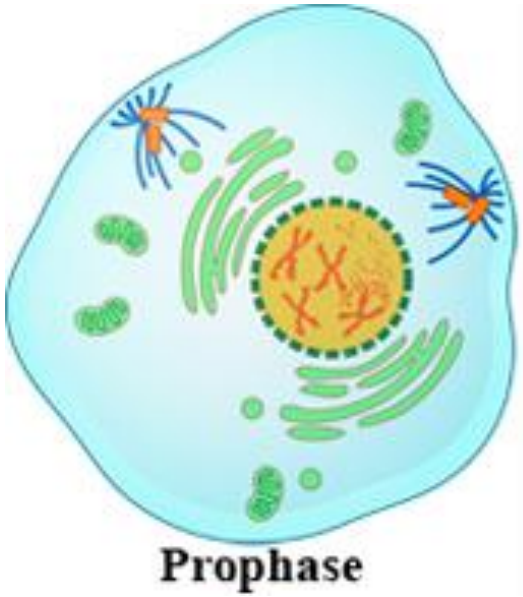


Prophase

DNA:

- chromatin condenses together into a highly ordered structure called a chromosome
- Because of DNA duplication in the S phase, the replicated chromosomes have two sister chromatids
- Are bound together at the centromere

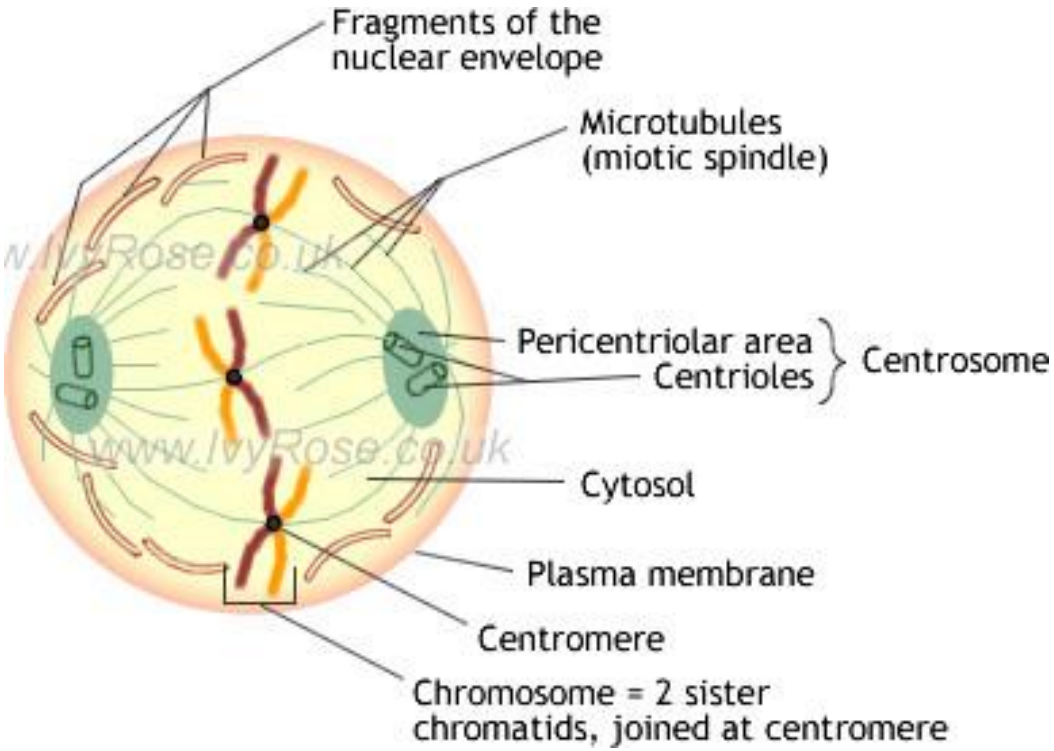




Prophase

<u>Cell organelles:</u>

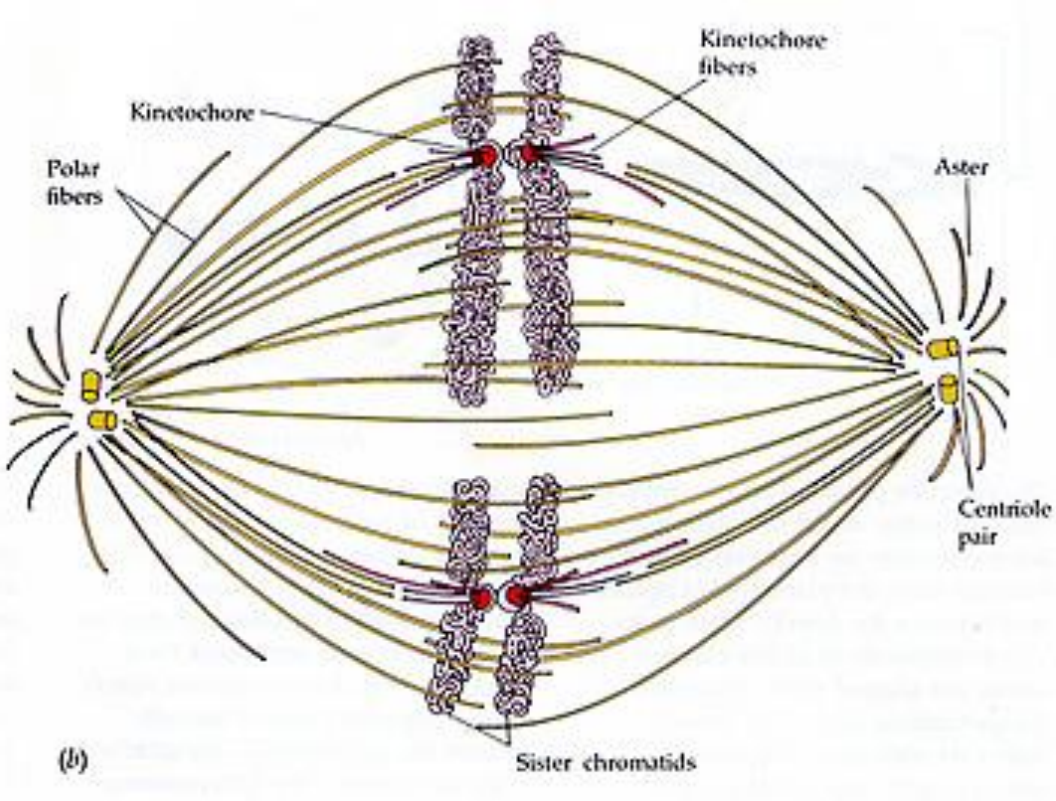
- nuclear membrane breaks down
- Endoplasmic reticulum, Golgi apparatus, nucleolus disappear

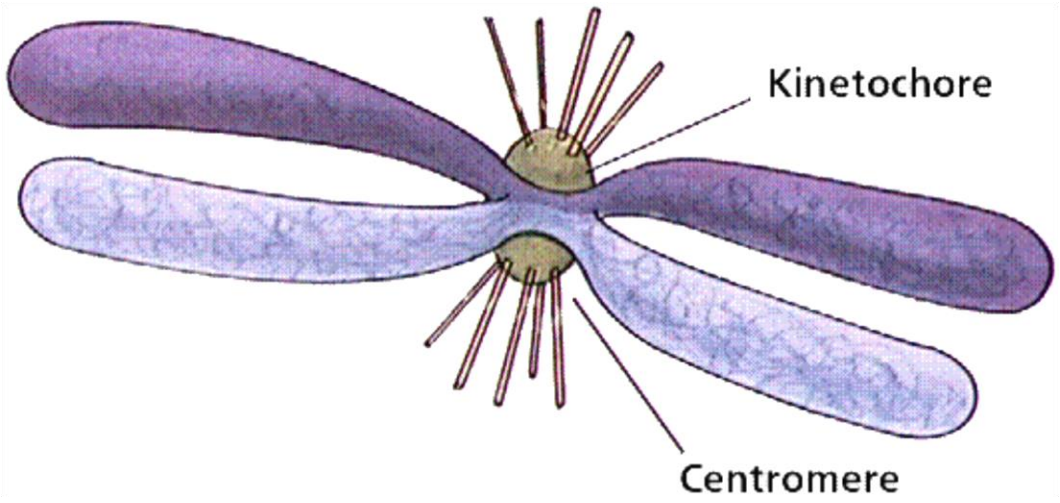


Metaphase

Mitotic spindle:

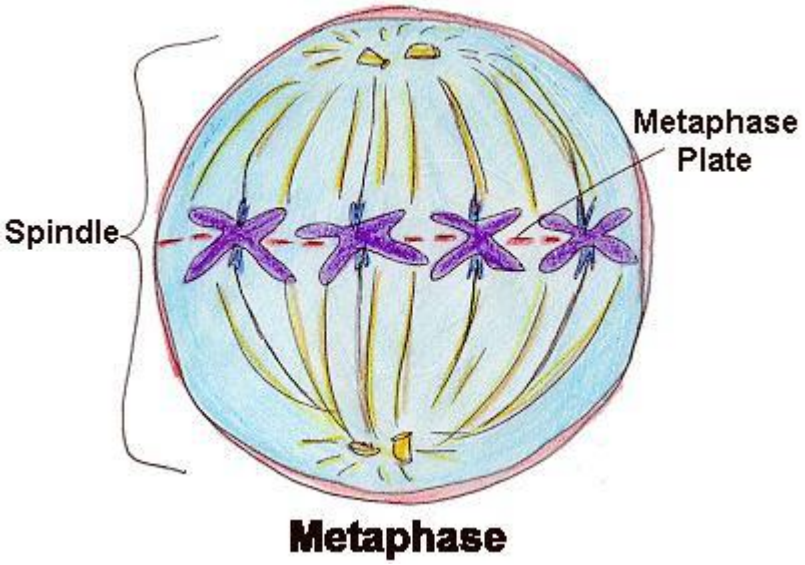
- part of the cytoskeleton (microtubulus)
- The mitotic spindle is formed from the centrioles and begins to elongate
- the spindle fibers attach to each chromosome at a specialized protein structure called the kinetochore, it is located at the centromere of each chromosome
- Other spindle fibers (nonkinetochore microtubules) elongate, but instead of attaching to chromosomes, they interact with spindle from the opposite pole

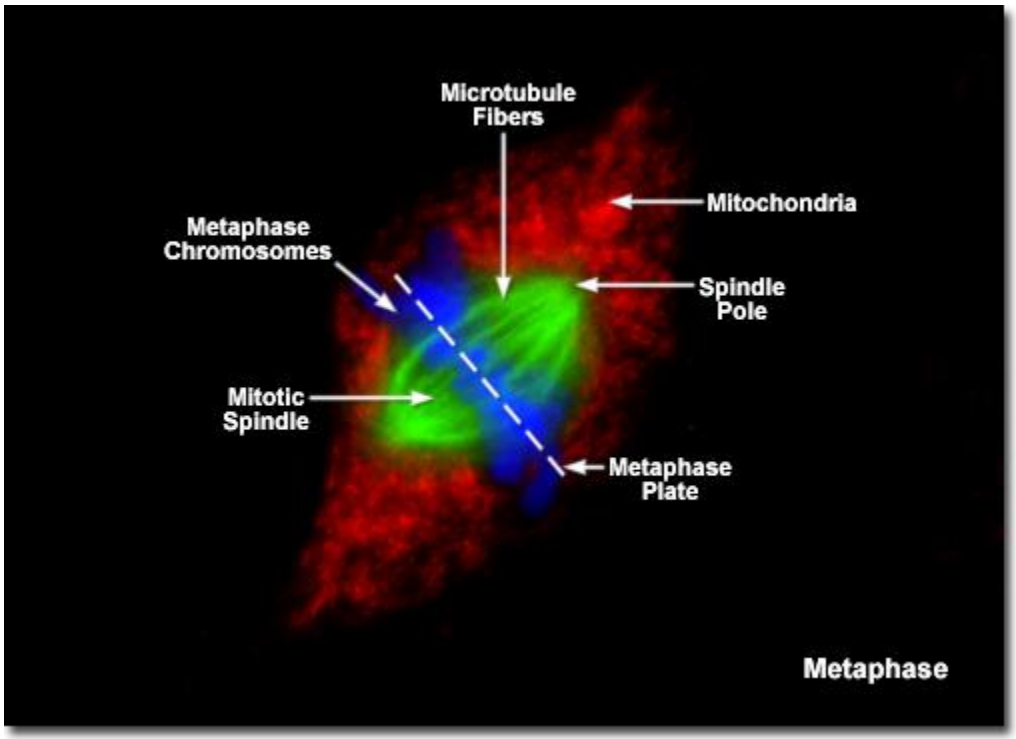




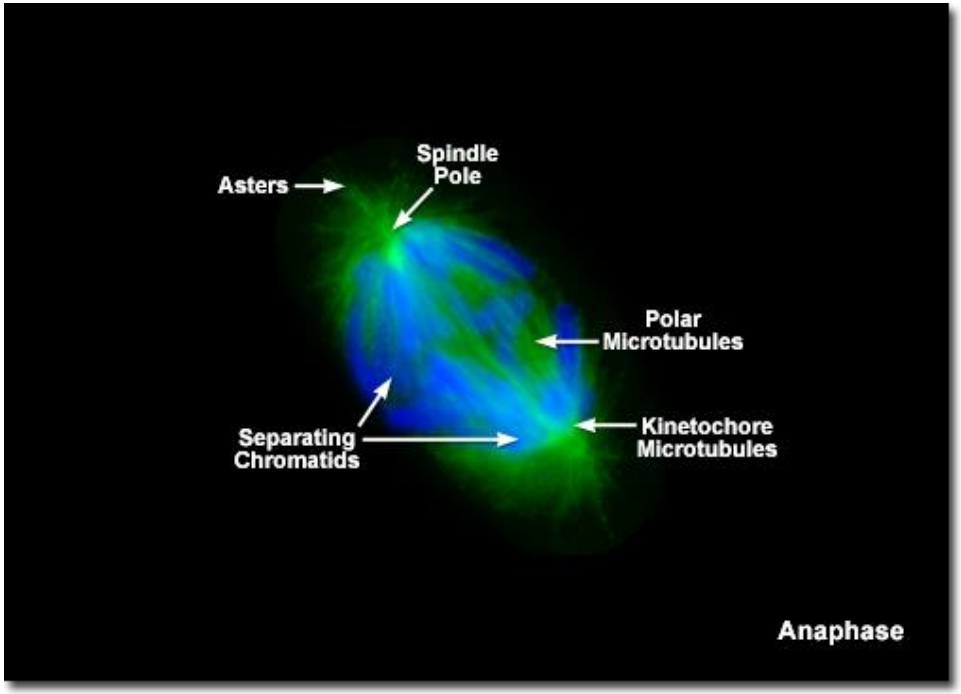
Metaphase

- Chromosomes are along the metaphase plate, an imaginary line that is equidistant from the two centrosome poles
- Each sister chromatid is attached to a kinetochore microtubule coming from the pole.





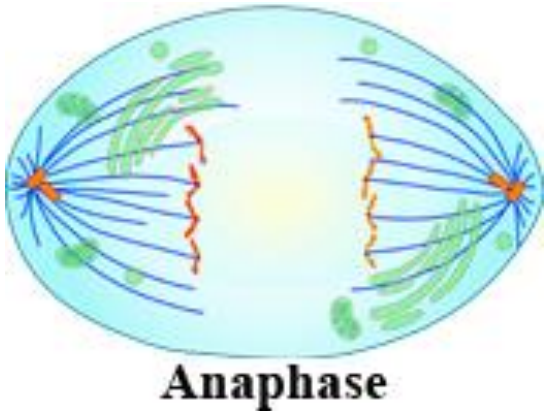
Anaphase



- When microtubules attach to the kinetochore region and the chromosomes have lined up along the metaphase plate, the cell starts the anaphase

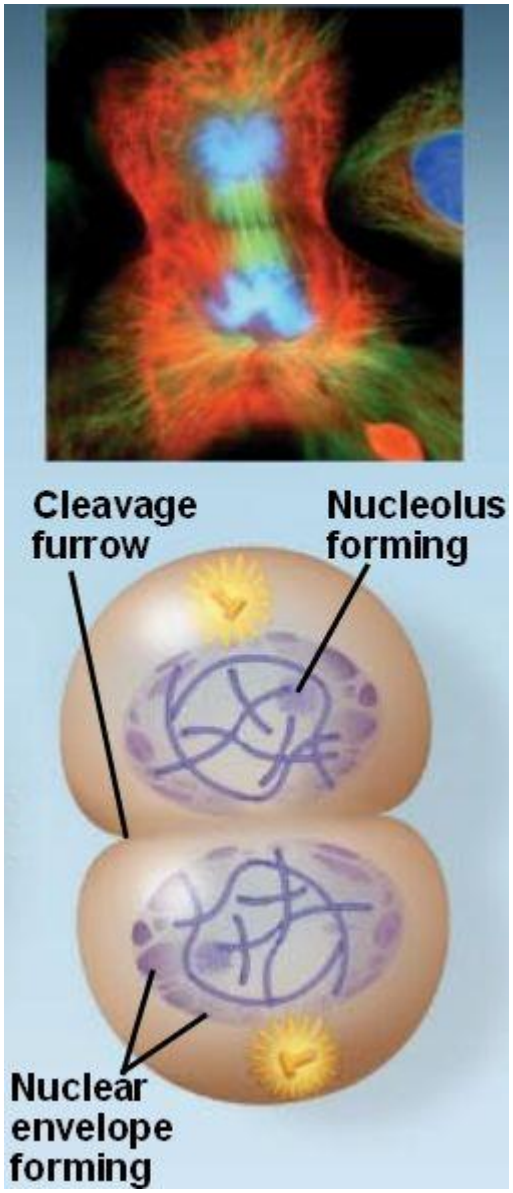
Two events then occur:

- the proteins that bind sister chromatids are cleaved,
- The cleaved sisterchromatids are pulled apart by shortening kinetochore microtubules and move toward the poles. Nonkinetochore microtubules elongate, pulling the centrosomes apart to opposite ends of the cell.



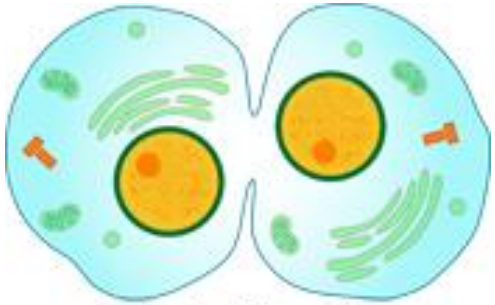
Telophase

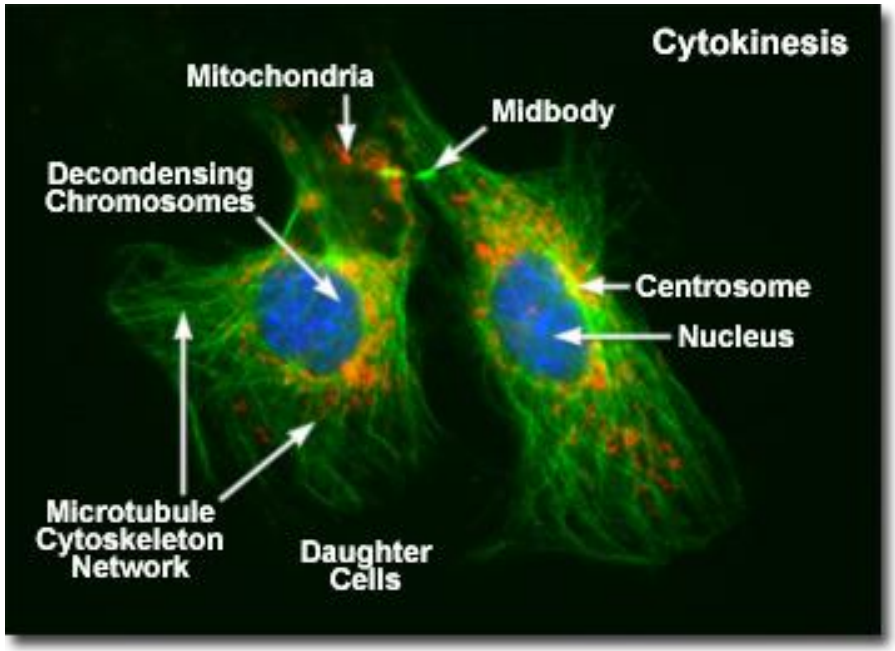
- Is the reversal of prophase
- nonkinetochore microtubules continue to lengthen, elongating the cell even more
- A new nuclear membrane forms around the separated chromosomes → Both sets of chromosomes have new nuclei and unfold back into chromatin
- Nucleolus, endoplasmic reticulum and Golgi apparatus reappear
- Mitosis is complete, but cell division is not yet complete!

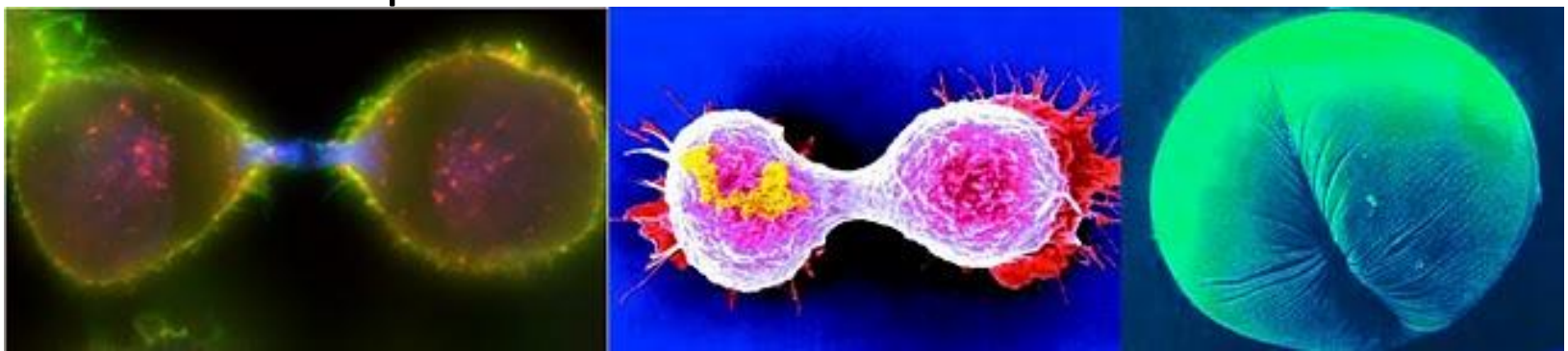


Cytokinesis

- separate process that begins at the same time as telophase
- Is necessary for completing cell division
- a cleavage furrow (pinch) containing a contractile ring (actin-filaments) develops to separate the cells
- Each daughter cell has a complete copy of the genome of its parent cell
- The end of cytokinesis marks the end of the M-phase







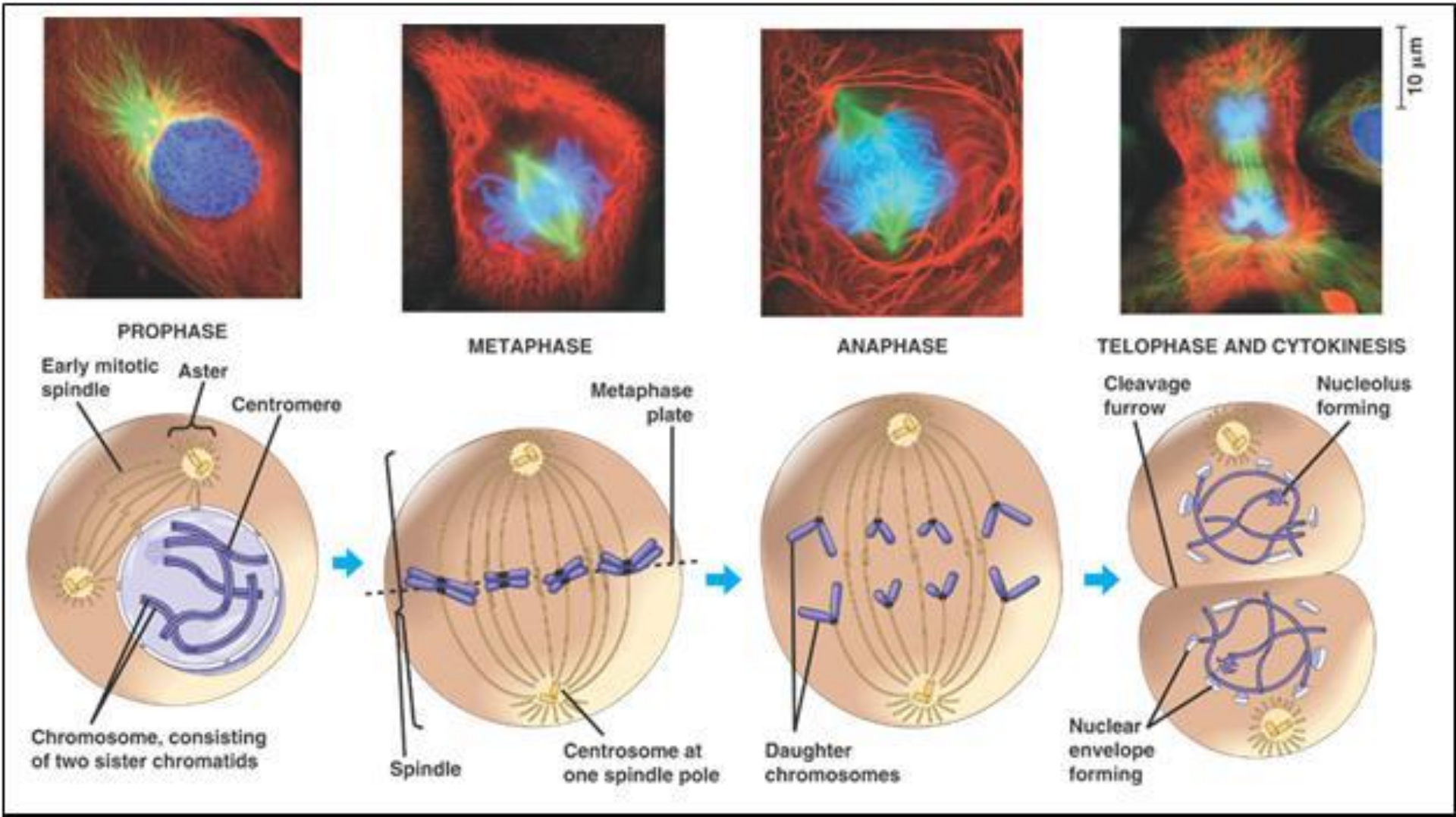
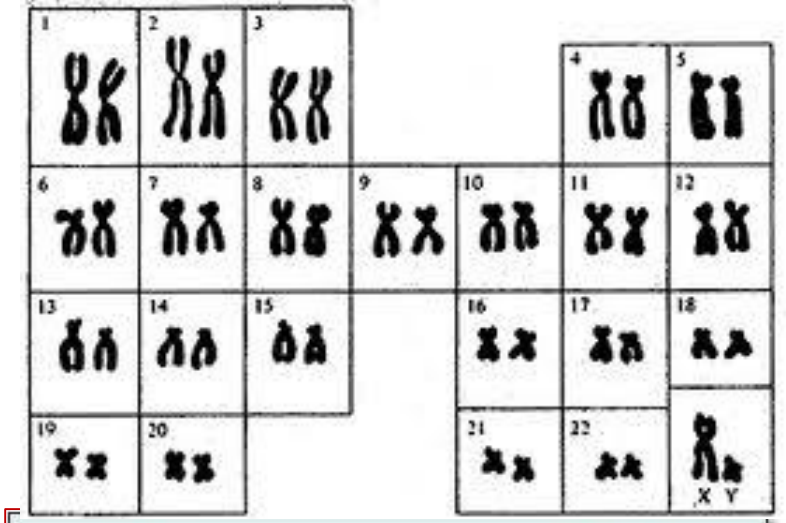


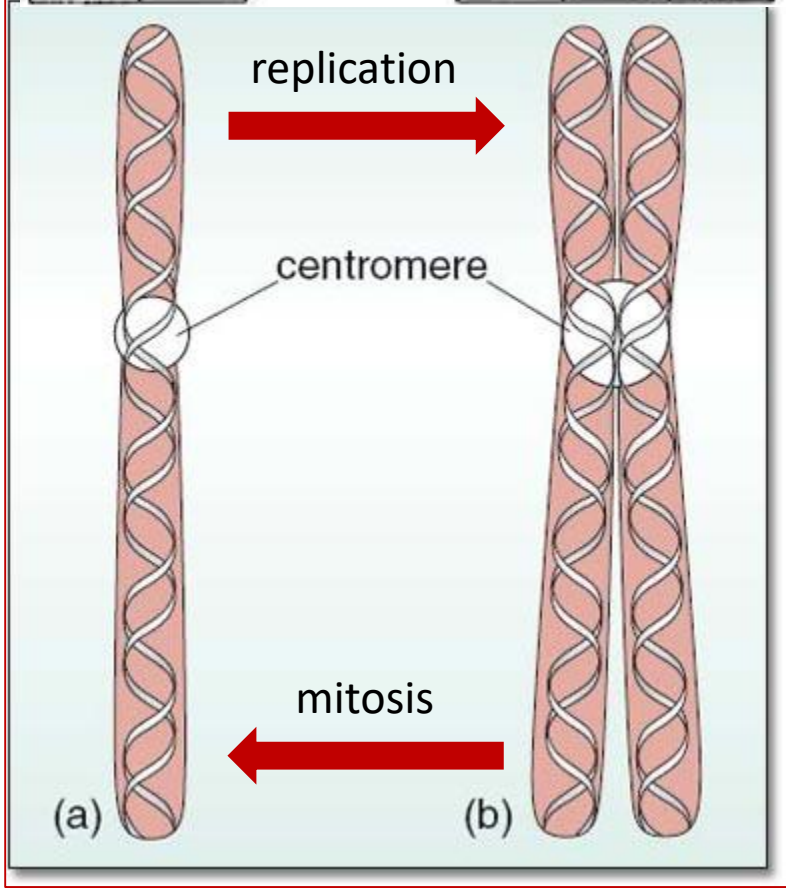
FIGURE 2: *The four stages of Mitosis.*

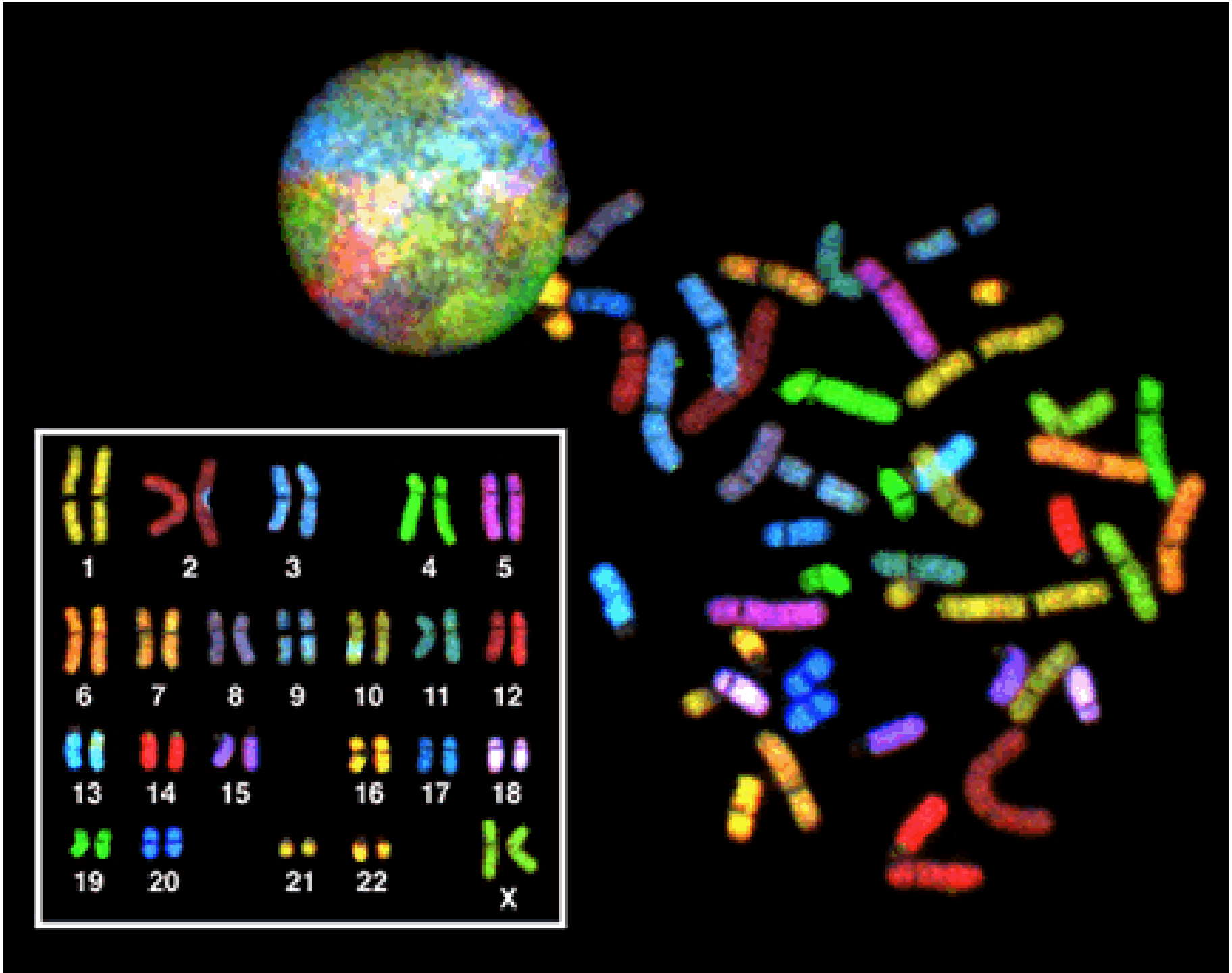
Meiosis

The normal karyotype

- 23 pairs of chromosome (22 pairs of autosomes + 2 sexchromosomes)
- female → XX
- male → XY
- 1 chromosome = 1 DNA strand+ proteins
- 2 sets of chromosomes one from the mother, one from the father → diploid (2n)
- reproductive cells (egg, sperm), have one set of chromosomes ⟶ haploid (n)
- sperm (n) + egg (n) ⟶ embryo (2n)



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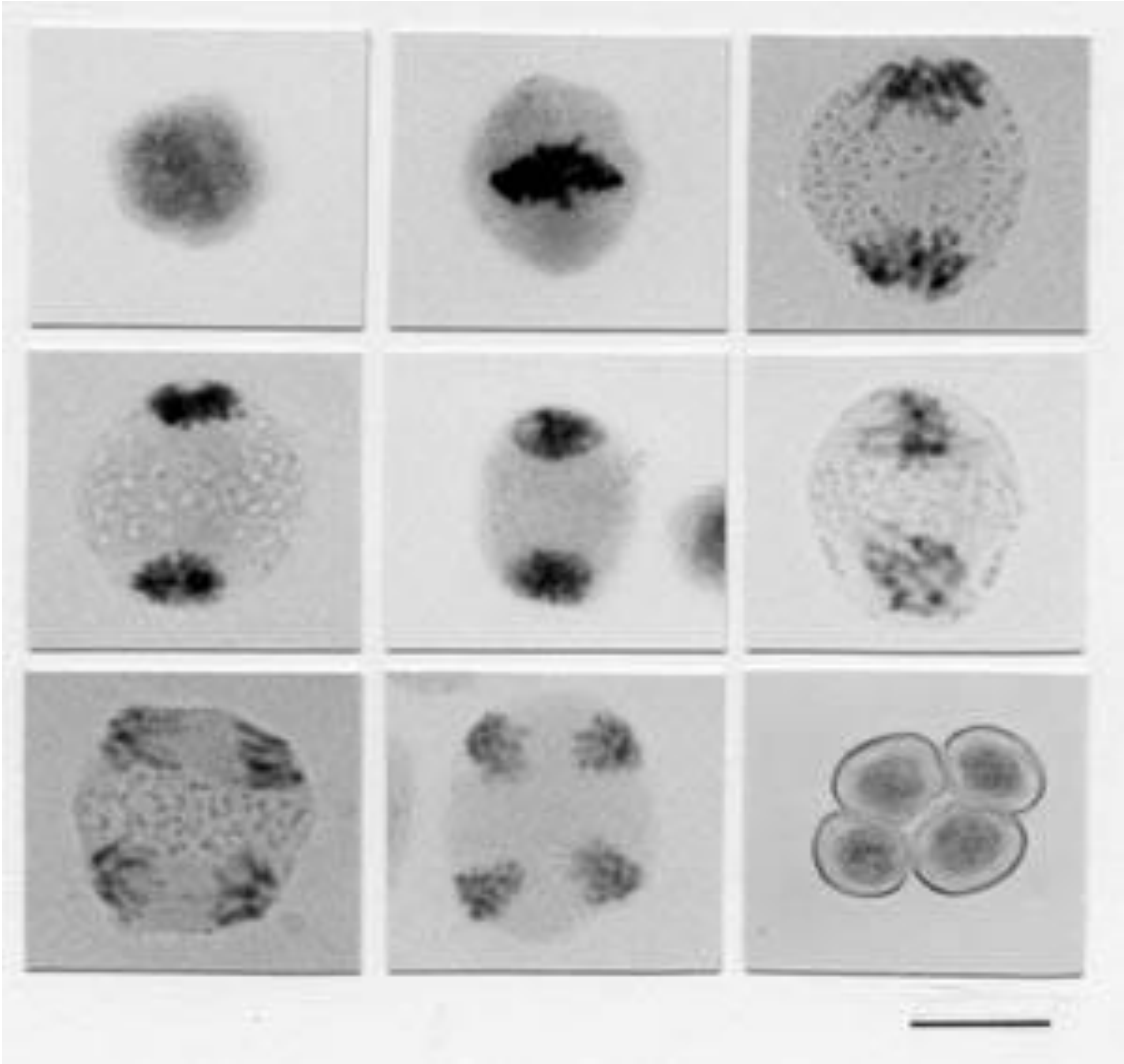
Meiosis

- reductional division → the number of chromosomes per cell is cut in half
- always results in the formation of gametes
- before it begins, the DNA in the original cell is replicated (4n) → two rounds of division, result: four haploid (n) cells
- essential for sexual reproduction
- in all eukaryotes

Phases of meiosis

- Meiosis I.
  - Prophase I.
  - Metaphase I.
  - Anaphase I.
  - Telophase I.
- Meiosis II.
  - Prophase II.
  - Metaphase II.
  - Anaphase II.
  - Telophase II.

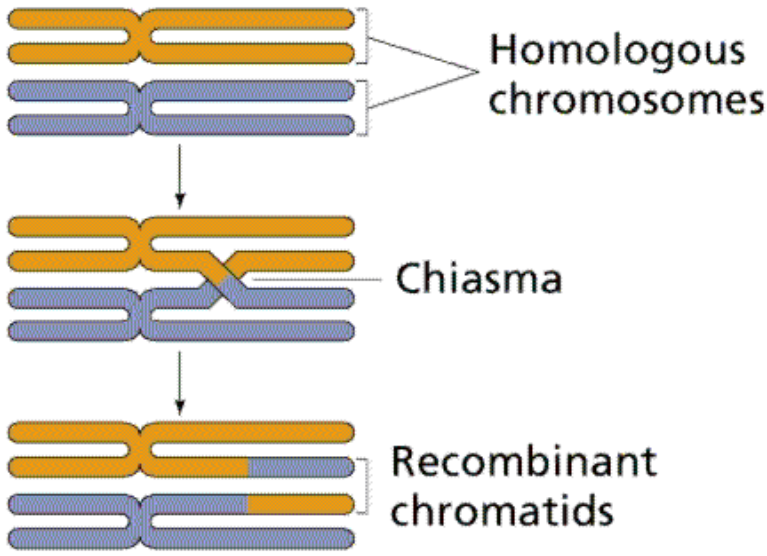


Meiosis I.

SEPARATES HOMOLOGOUS CHROMOSOMES!!!

Prophase I.

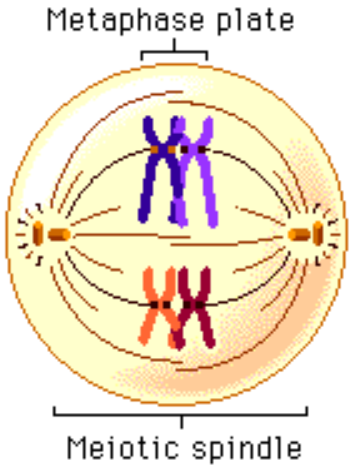
- DNA is exchanged between homologous chromosomes → homologous recombination / crossing over → genetic variation
- chiasma: two homologous non-sister chromatids exchange genetic material



Meiosis I.

Metaphase I.

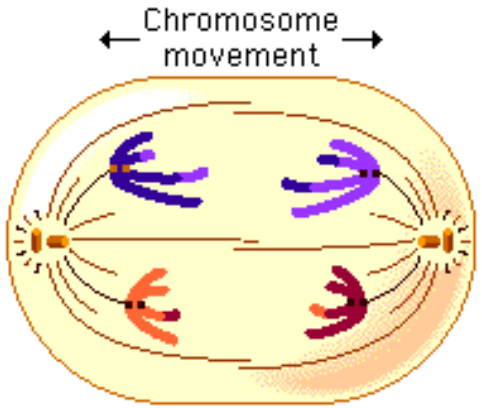
- homologous pairs move together along the metaphase plate
- microtubules from both centrioles attach to their respective kinetochores



Meiosis I.

Anaphase I.

- kinetochore microtubules shorten and pulling homologous chromosomes apart
- nonkinetochore microtubules lengthen
- the cell elongates in preparation for division

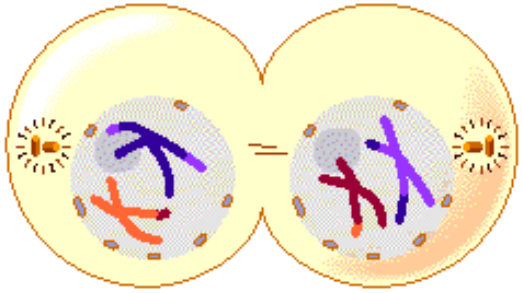


Meiosis I.

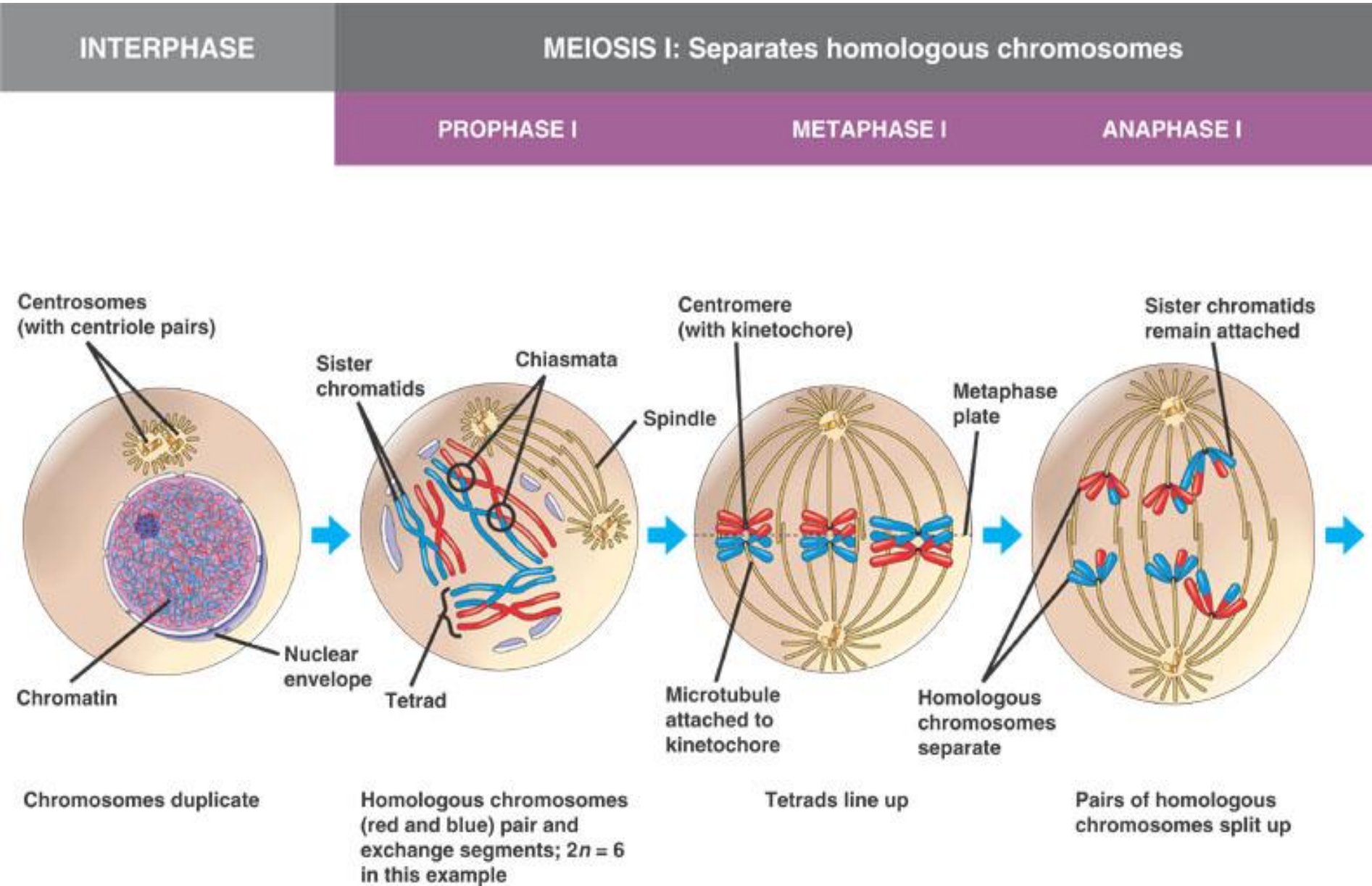
Telophase I.

- the chromosomes arrive at the poles
- new nuclear membrane surrounds each set of chromosomes
- The chromosomes uncoil back into chromatin

Cytokinesis



Meiosis I.


INTERPHASE
MEIOSIS I: Separates homologous chromosomes
PROPHASE I
METAPHASE I
ANAPHASE I
Centrosomes (with centriole pairs)
Chromatin
Nuclear envelope
Sister chromatids
Chiasmata
Spindle
Tetrad
Centromere (with kinetochore)
Microtubule attached to kinetochore
Metaphase plate
Homologous chromosomes separate
Sister chromatids remain attached
Chromosomes duplicate
Homologous chromosomes (red and blue) pair and exchange segments; 2n = 6 in this example
Tetrads line up
Pairs of homologous chromosomes split up

Meiosis II.

SEPARATES THE SISTERCHROMATIDS!!!

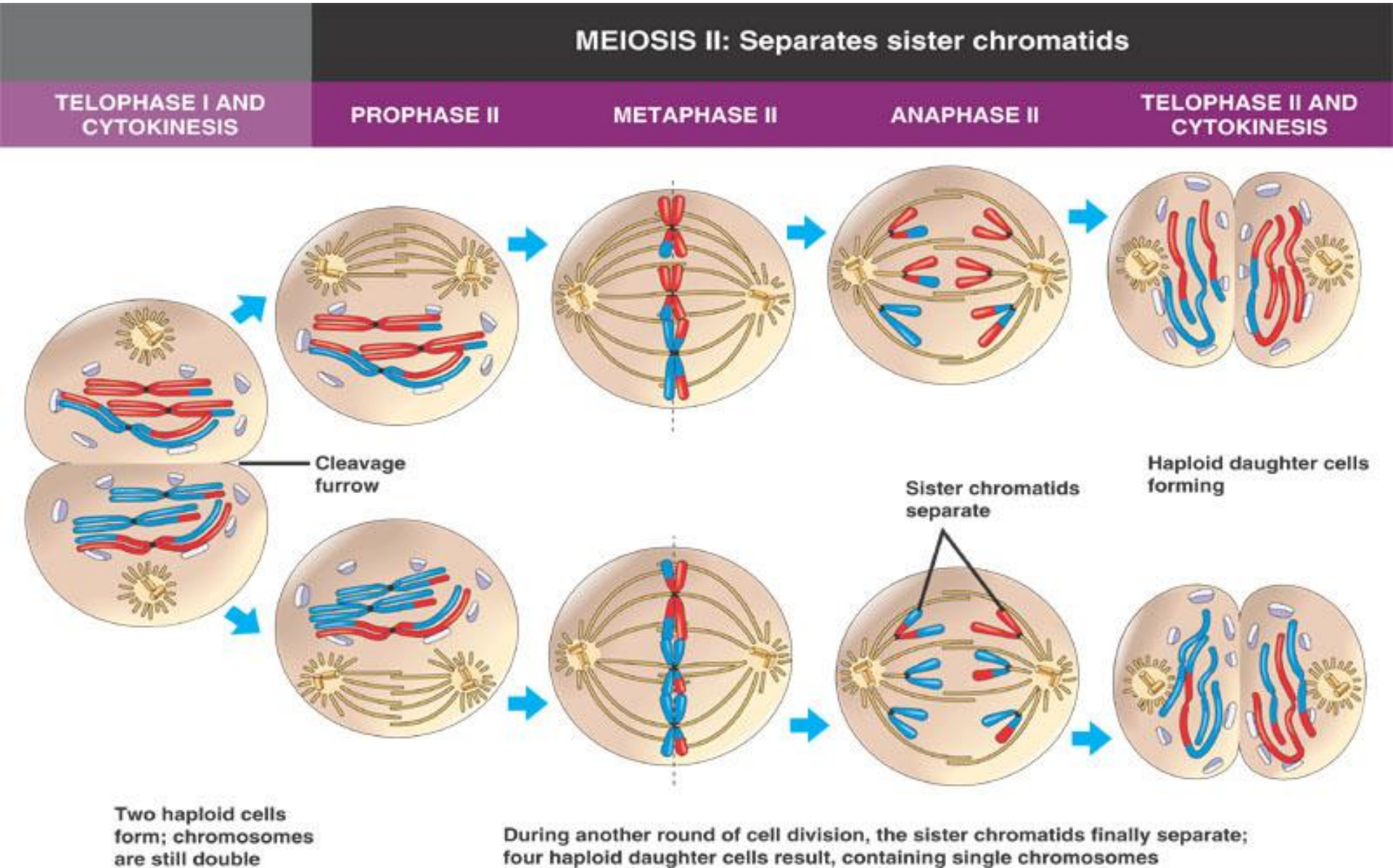
- cells may enter a period of rest → interkinesis / interphase II
- no DNA replication during this stage!!!
- is similar to mitosis
- result: 4 haploid cells

Meiosis II.

- Prophase II: Centrioles move to the polar regions and arrange spindle fibers for the second meiotic division
- Metaphase II: the centromeres attach to spindle fibers
- Anaphase II: the centromeres are cleaved, microtubules pull the sister chromatids toward opposing poles
- Telophase II: lengthening of the chromosomes and disappearance of the spindle, nuclear membrane reform

Meiosis is now complete and ends up with four new daughter cells.

Meiosis II.


MEIOSIS II: Separates sister chromatids
TELOPHASE I AND CYTOKINESIS
PROPHASE II
METAPHASE II
ANAPHASE II
TELOPHASE II AND CYTOKINESIS
Cleavage furrow
Sister chromatids separate
Haploid daughter cells forming
Two haploid cells form; chromosomes are still double
During another round of cell division, the sister chromatids finally separate; four haploid daughter cells result, containing single chromosomes

Significance

1. stable sexual reproduction

- without meiosis → exponential increase in chromosome count
- polyploidy: the state of having three or more sets of chromosomes (3n, 4n, 5n,…)
  -by human: extreme developmental abnormalities or lethality
  -by plants: tolerated

Significance

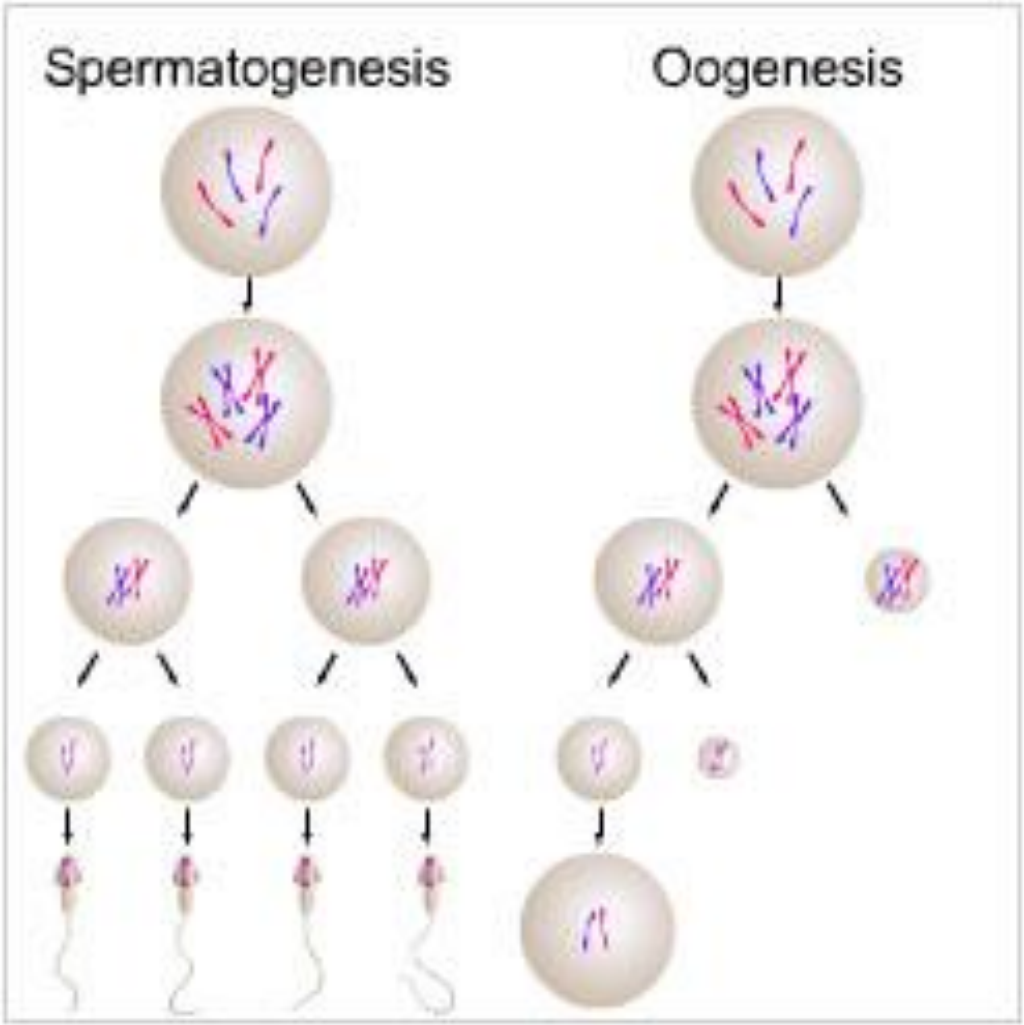
2. Meiosis generates genetic diversity in two ways:

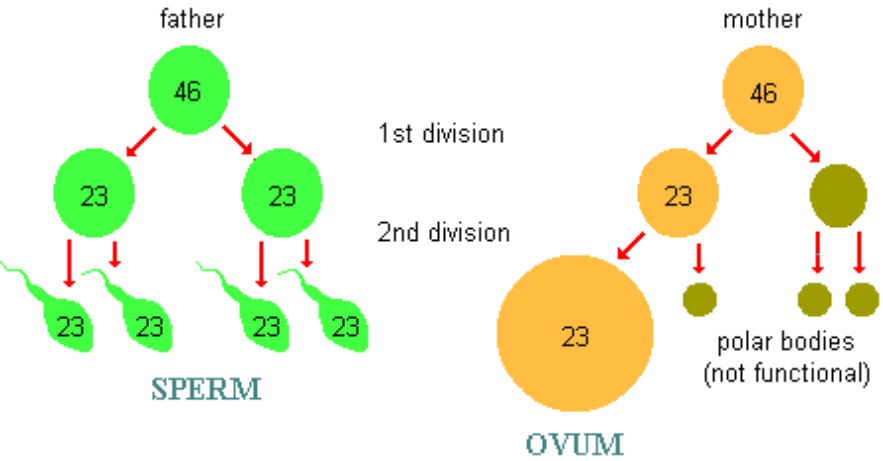
- (1) independent alignment and subsequent separation of homologous chromosome pairs during the first meiotic division; and
- (2) physical exchange of homologous chromosomal regions by homologous recombination during prophase I results in new combinations of DNA within chromosomes

Gametogenesis

- **Male:**
  1. meiotic division starts at puberty and continous until death
- **Female:**
  1. meiotic division: during the embryonic development (until crossing over)

  2. meiotic division: during ovulation → meiosis is completed after the fertilization

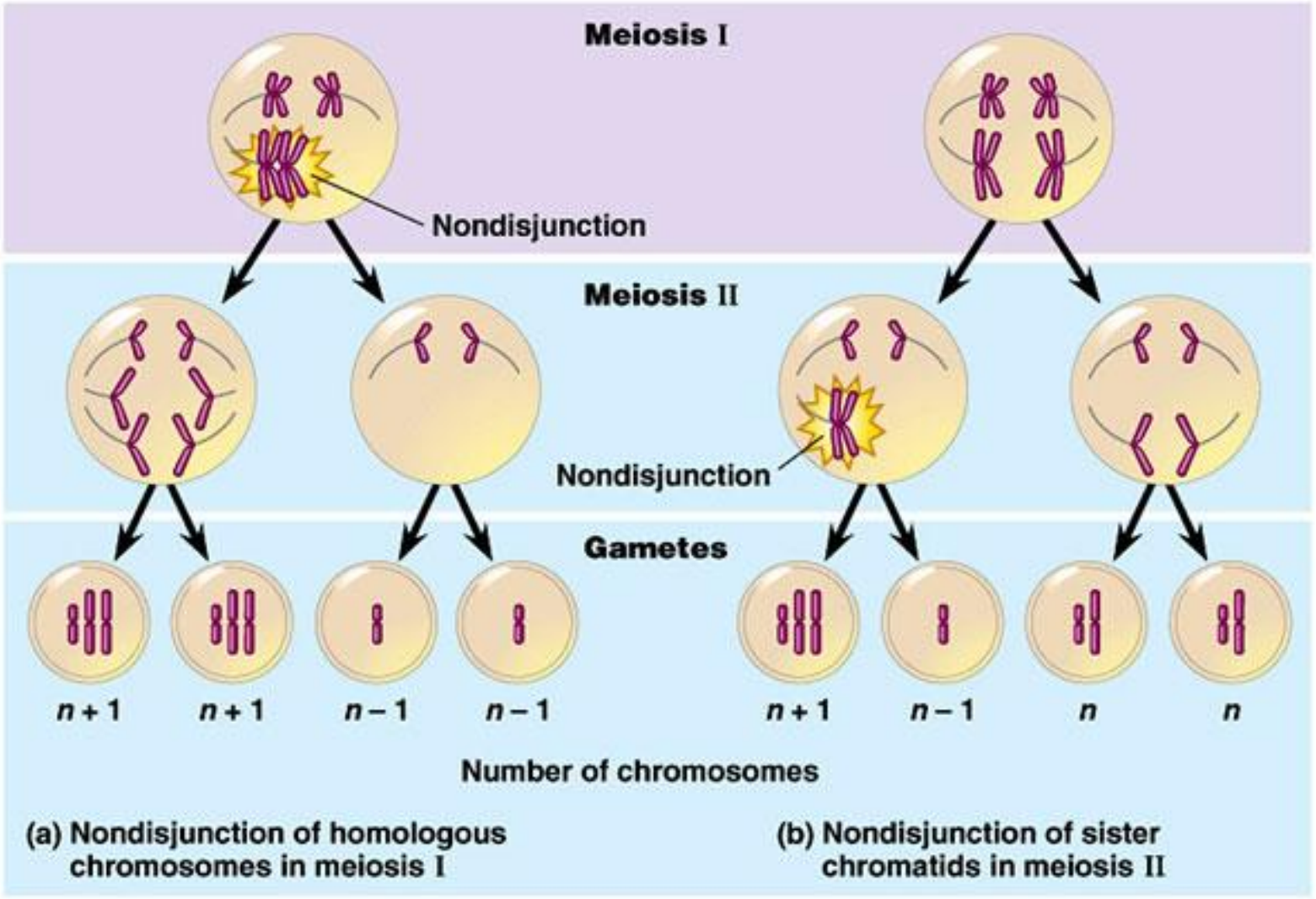




Nondisjunction

- normal separation of chromosomes in meiosis I. or sister chromatids in meiosis II. is termed **disjunction**
- if the separation is not normal, it is called **nondisjunction**
- gametes have too many (trisomy) or too few (monosomy) of a particular chromosome
- can occur in the meiosis I. or meiosis II.

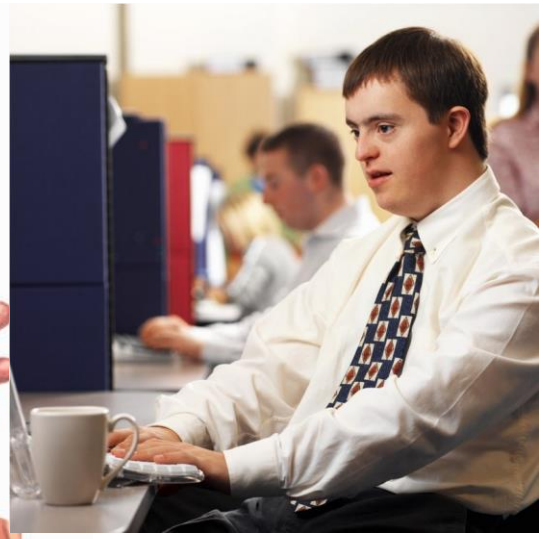
Nondisjunction

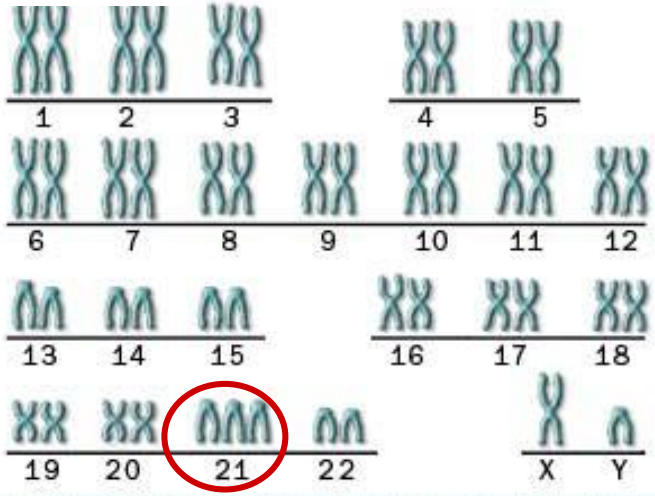


Result of the nondisjunction

- Down Syndrome - trisomy of chromosome 21
- Patau Syndrome - trisomy of chromosome 13
- Edward Syndrome - trisomy of chromosome 18
- Klinefelter Syndrome - extra X chromosomes in males - i.e. XXY, XXXY, XXXXY
- Turner Syndrome - lacking of one X chromosome in females - i.e. XO
- Triple X syndrome - an extra X chromosome in females
- XYY Syndrome - an extra Y chromosome in males

Down-syndrome (trisomy 21)

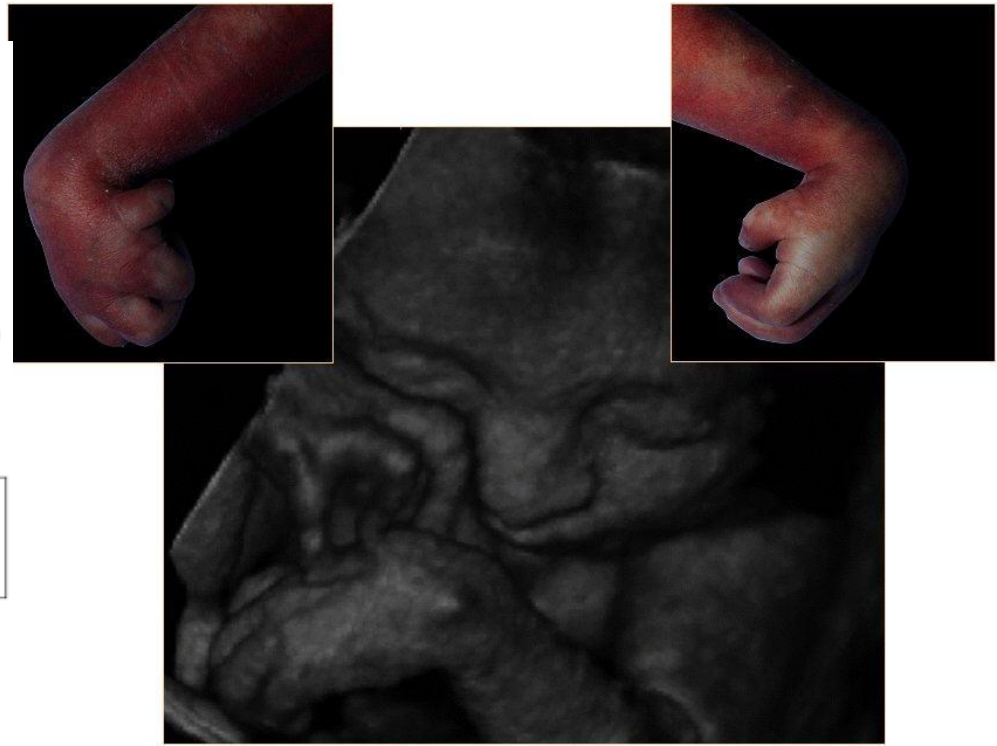




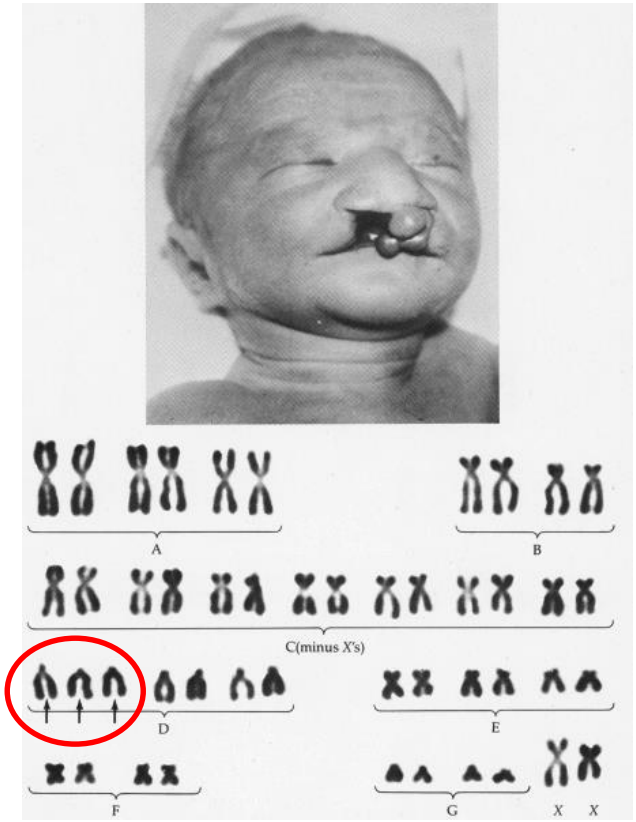
- lower than average cognitive ability
- incidence increases as the mother's age increases
- almond shape to the eyes
- epicanthic fold of the eyelid
- bigger space between the big and second toes
- simian crease

Edwards-syndrome (trisomy 18)

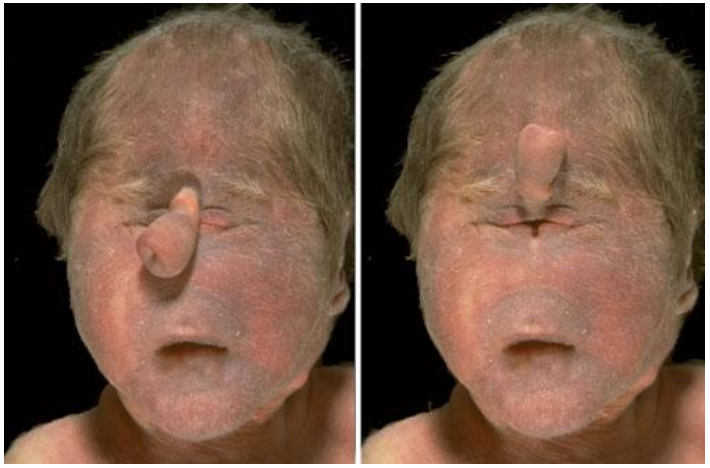
- very low rate of survival
- heart abnormalities
- kidney malformations
- other internal organ disorders
- 5–10% survive their first year of life



Patau-syndrome (trisomy 13)



- heart and kidney defects
- structural eye defects
- deformed feet
- overlapping of fingers over thumb
- extra digits

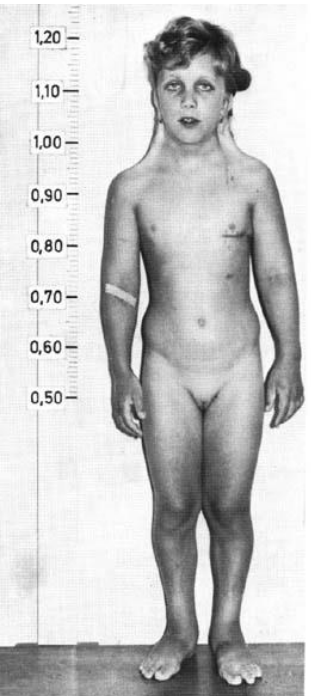


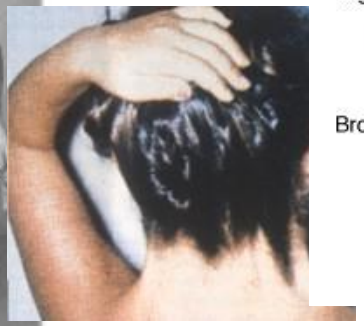
Nondisjunction of the sex chromosomes

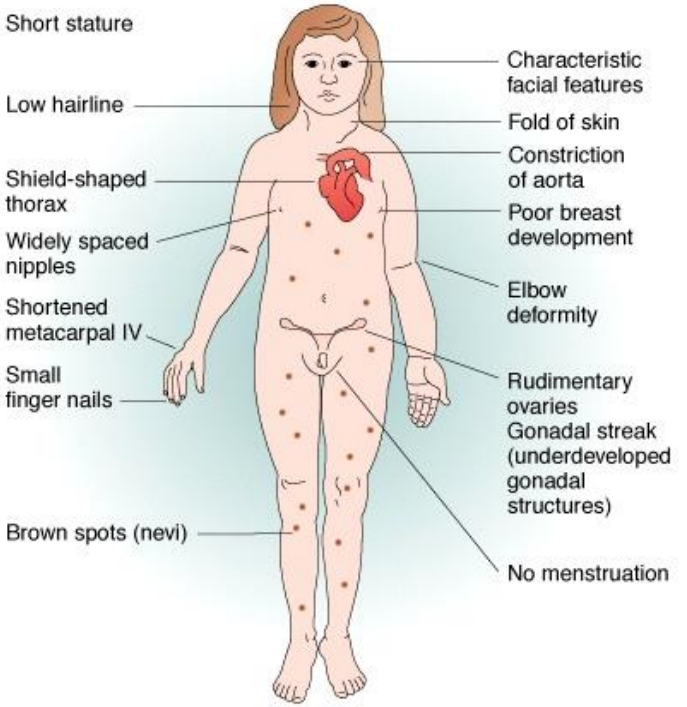
	XY	0
X	XXY Klinefelter	X0 Turner
X	XXY Klinefelter	X0 Turner

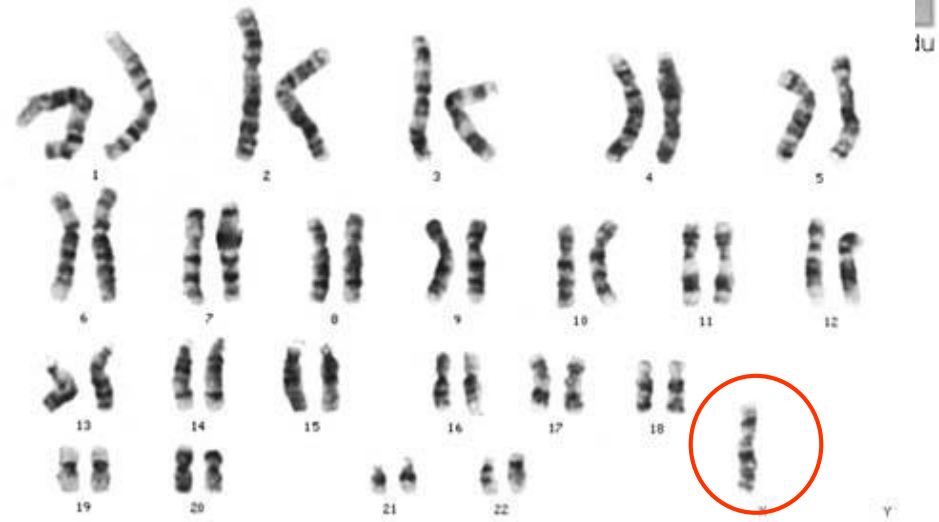
	X	Y
XX	XXX Triple-X	XXY Klinefelter
0	X0 Turner	Y0 lethal

Turner syndrome (XO)



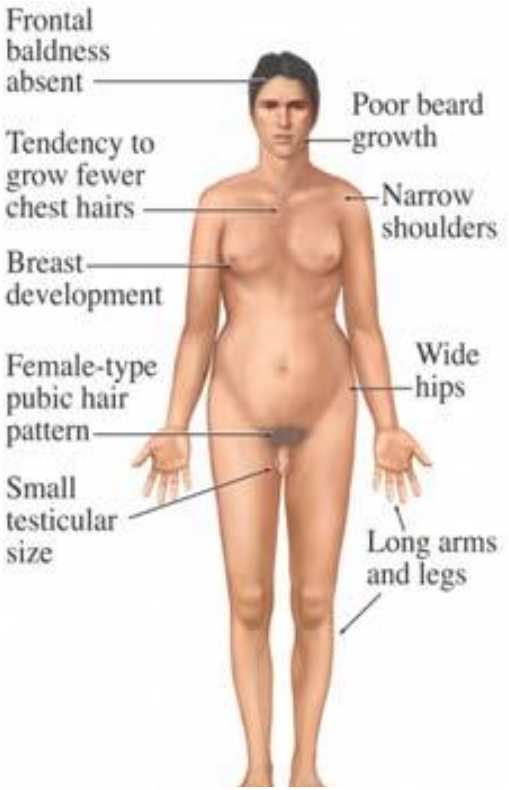


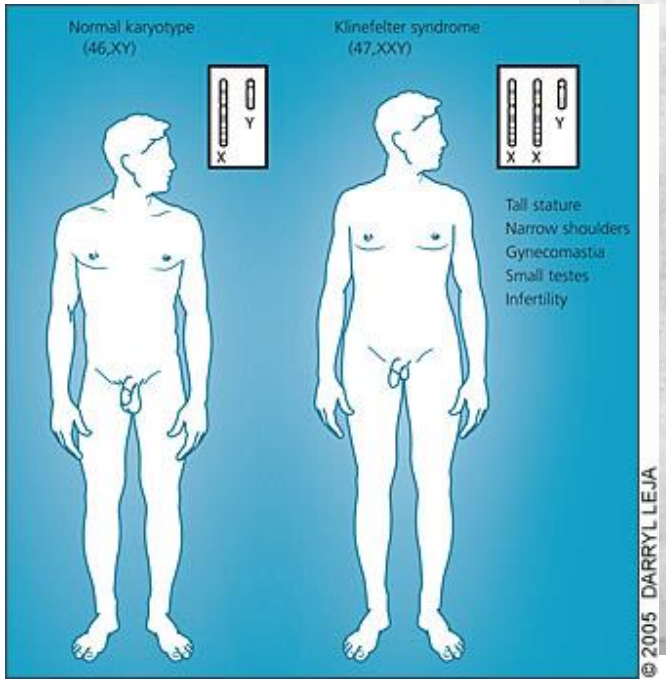


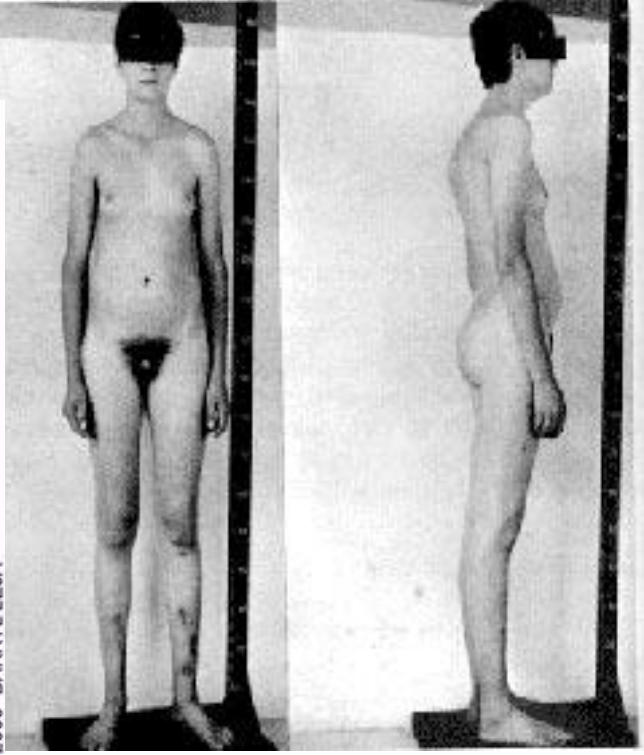


- one of the X chromosomes is absent
- short, broad chest, low hairline, low-set ears, and webbed necks
- gonadal dysfunction (non-working ovaries → absence of menstrual cycle → sterility)

Klinefelter's syndrome



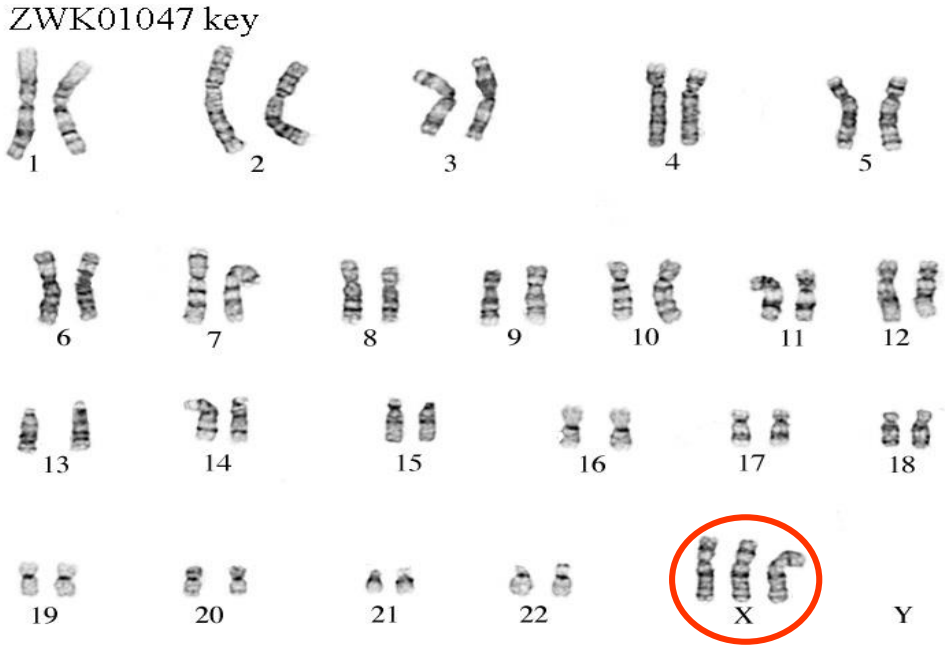




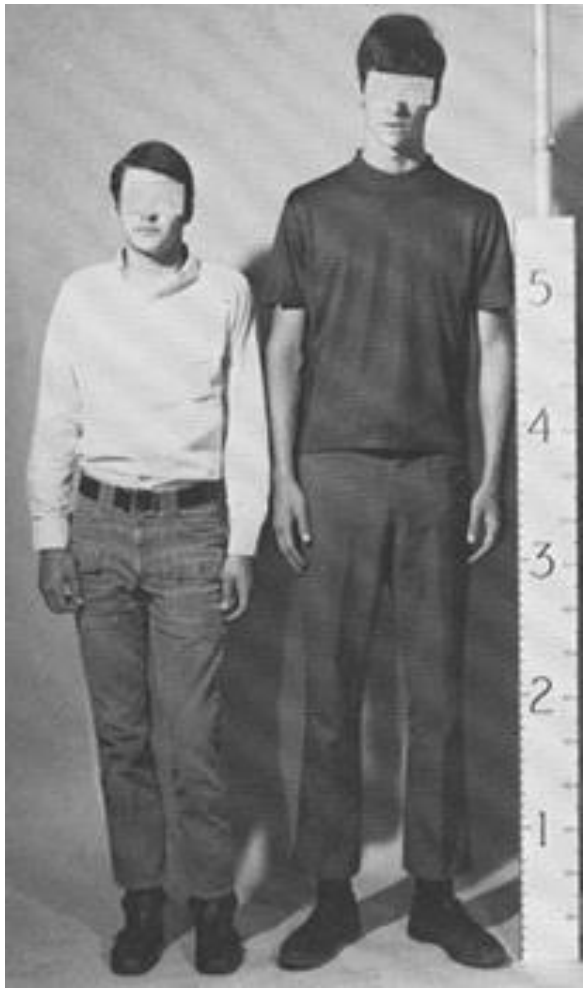
- males have an extra X chromosome
- small testicles and reduced fertility
- increased breast development
- low serum testosterone level

Triple-X-syndrome (3-5X)

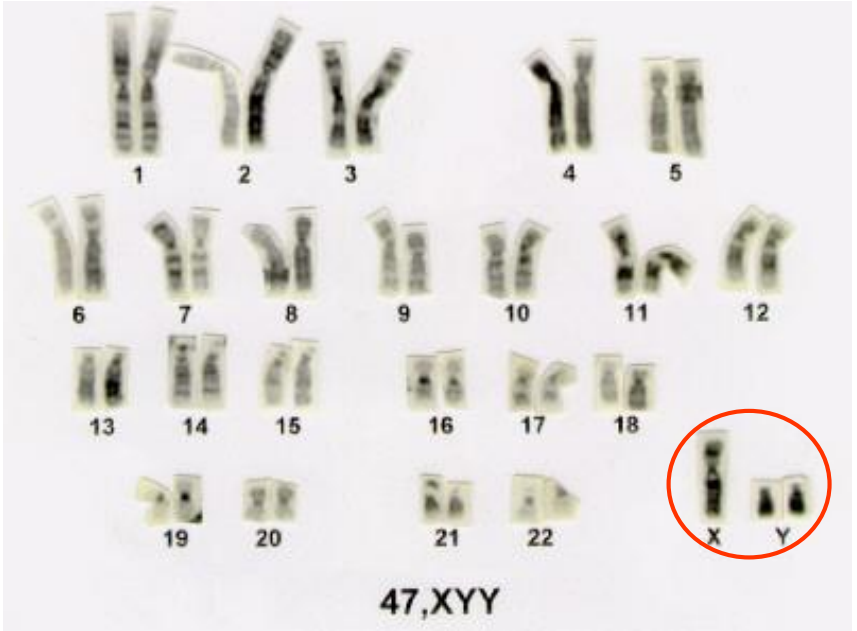
- presence of an extra X chromosome of a human female
- most often causes no unusual physical features or medical problems
- taller than average
- have normal sexual development



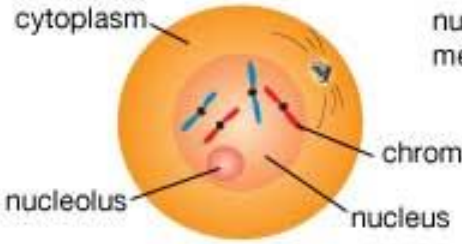
XYY-syndrome



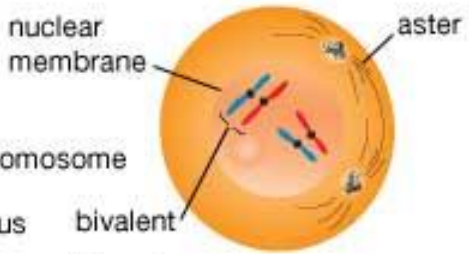
- causes no unusual physical features or medical problems
- normal sexual development and usually have normal fertility
- taller than the average



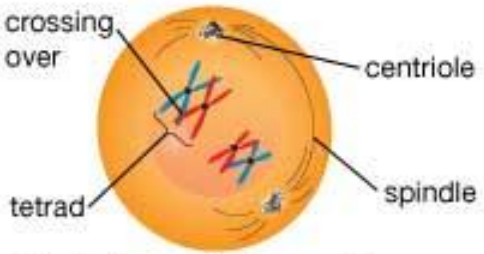
Meiosis, or sex cell division



At the onset of meiosis, DNA strands thicken into chromosomes. Homologous, or like, chromosomes begin to approach each other.

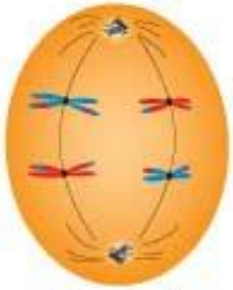


Homologous chromosomes pair to form bivalents. The centrioles divide and move to opposite poles of the cell.

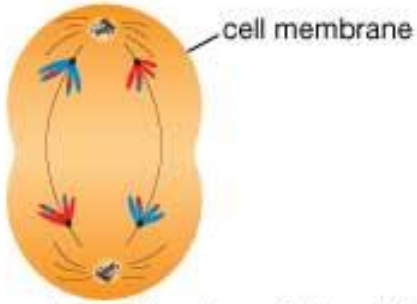


The bivalents duplicate to form tetrads, or four-chromatid groups. The nuclear membrane disintegrates. Crossing over (recombination) occurs.

In metaphase I, the tetrads, attached to spindle fibers at their centromeres, line up at mid-cell.



In early anaphase I, the tetrads separate, and the paired chromatids move along the spindle to their respective centrioles.

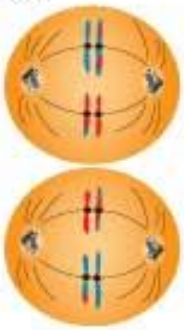


In late anaphase I, the chromatids have almost reached the spindle poles. The cell membrane begins to constrict.

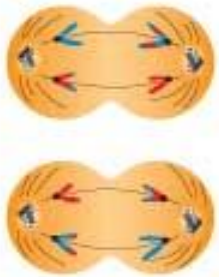
In telophase I, nuclear membranes enclose the separated chromatids. The cell membrane completes its constriction.

The first meiotic division ends. There are now two cells, each with the same number of chromatids as the parent cell.

Prophase II begins. In the second meiotic division, homologous chromatids do not duplicate but merely separate.



In metaphase II, the chromatids line up at mid-cell. The centrioles and asters are at the poles. A spindle has formed.



In anaphase II, the now-separated chromatids approach their respective poles. The cell membrane begins to constrict.

Telophase II has been completed. There are now four cells, each with half the number of chromosomes of the parent cell.