Chapter VI

Transmission of genetic characters in eukaryotes

Inheritance of characters

- The transmission, within a living species or cell lineage, of characteristics from one generation to the next
- During their development, cells act according to their specialization. The cell fulfills two essential missions: copying its genes for cell division and using its genes to produce its proteins responsible for the expression of hereditary characteristics.

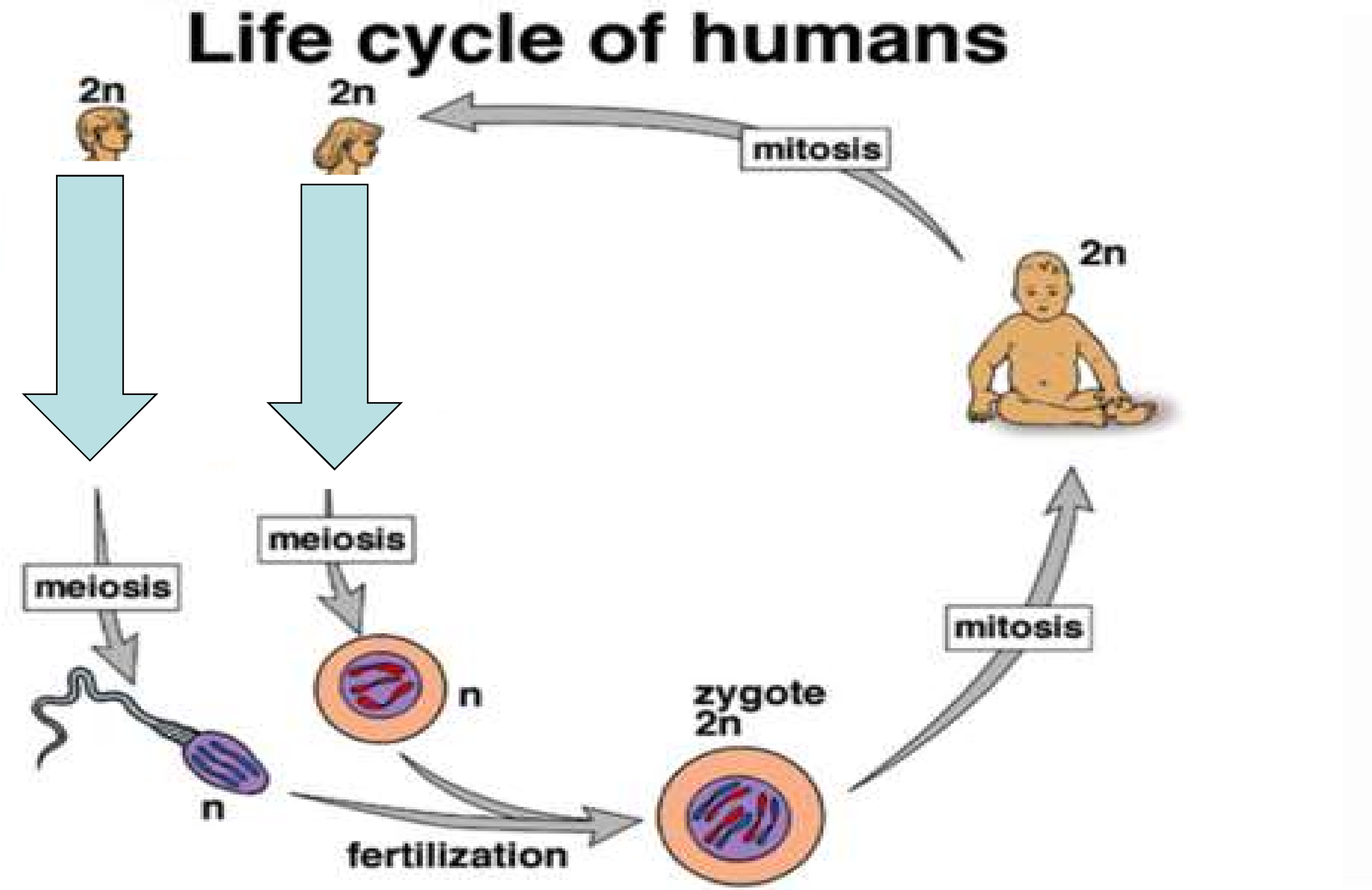
Transmission of characteristics from one generation to the next

Cell Division

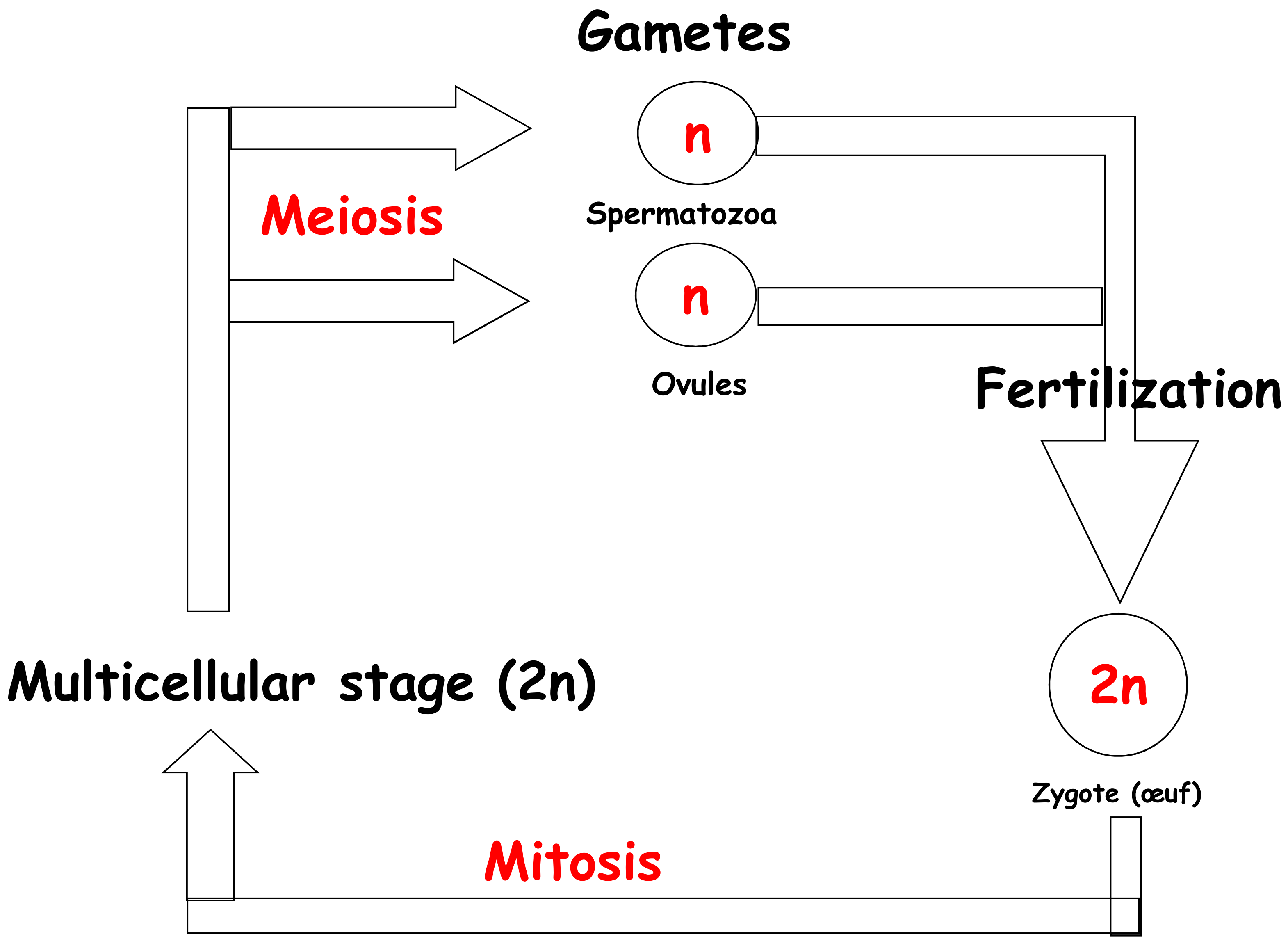
Cell Division

- An integral part of the cell cycle
- The result is two genetically identical daughter cells,
- The cells duplicate their genetic materiale before they divide, ensuring that each daughter cell receives an exact copy of the genetic material, DNA.

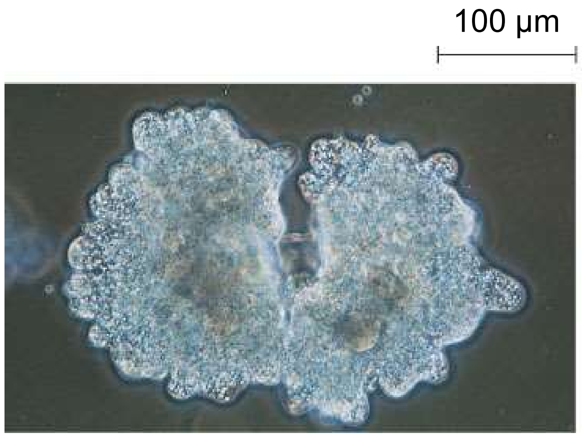
From one generation of individuals to the next



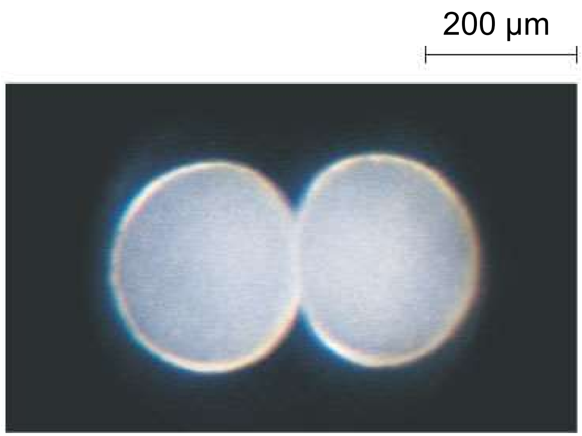
Cell Division



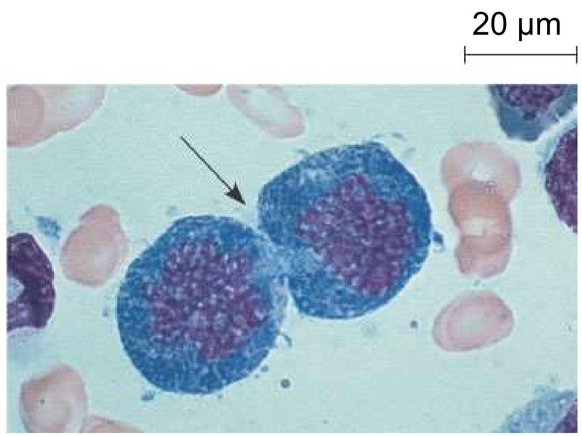
Objectives of Cell Division



(a) Reproduction. An amoeba, which is a single-cell eukaryote, is divided into two cells. Each new cell will be a whole organism.



(b) Growth and development. This photograph shows an embryo shortly after the fertilized egg divided, forming two cells.

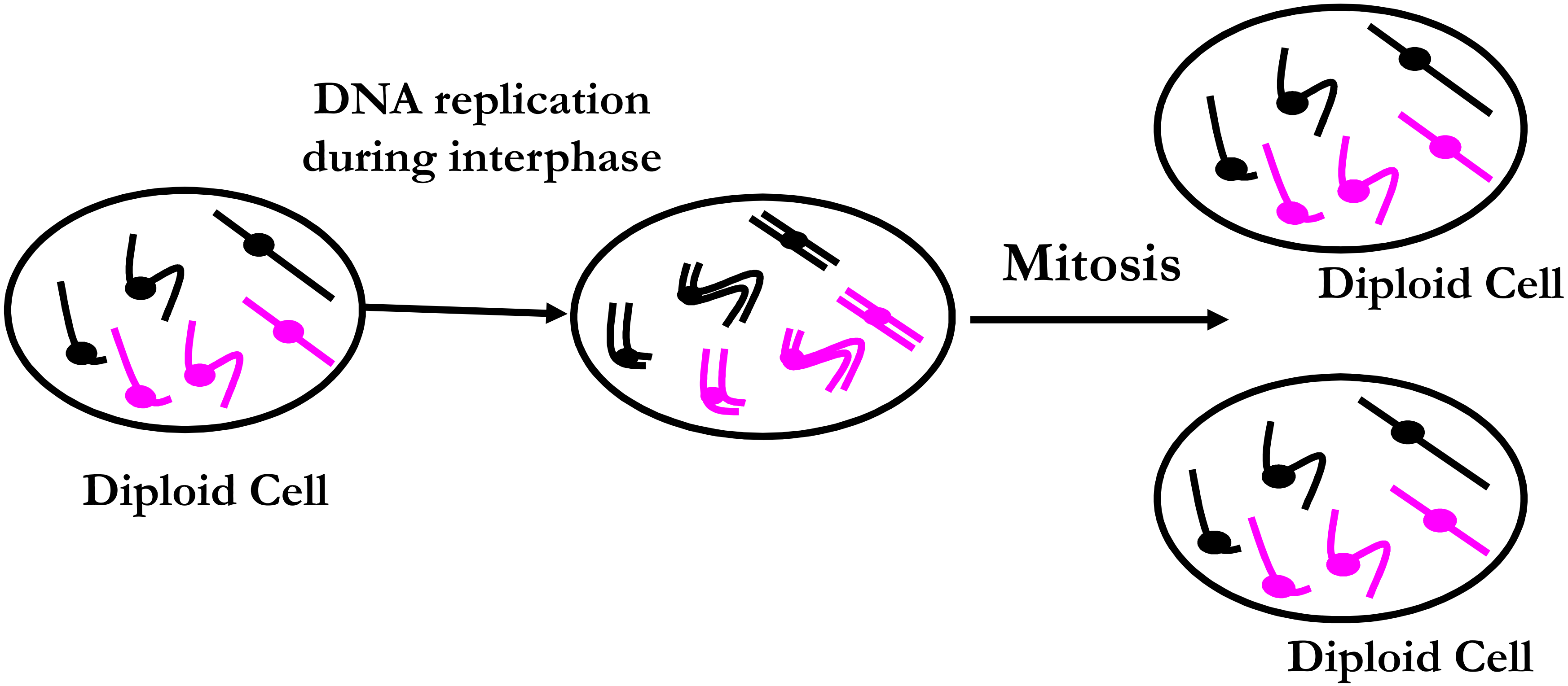


(c) Tissue renewal and repair. These divisions of bone marrow cells give rise to new blood cells.

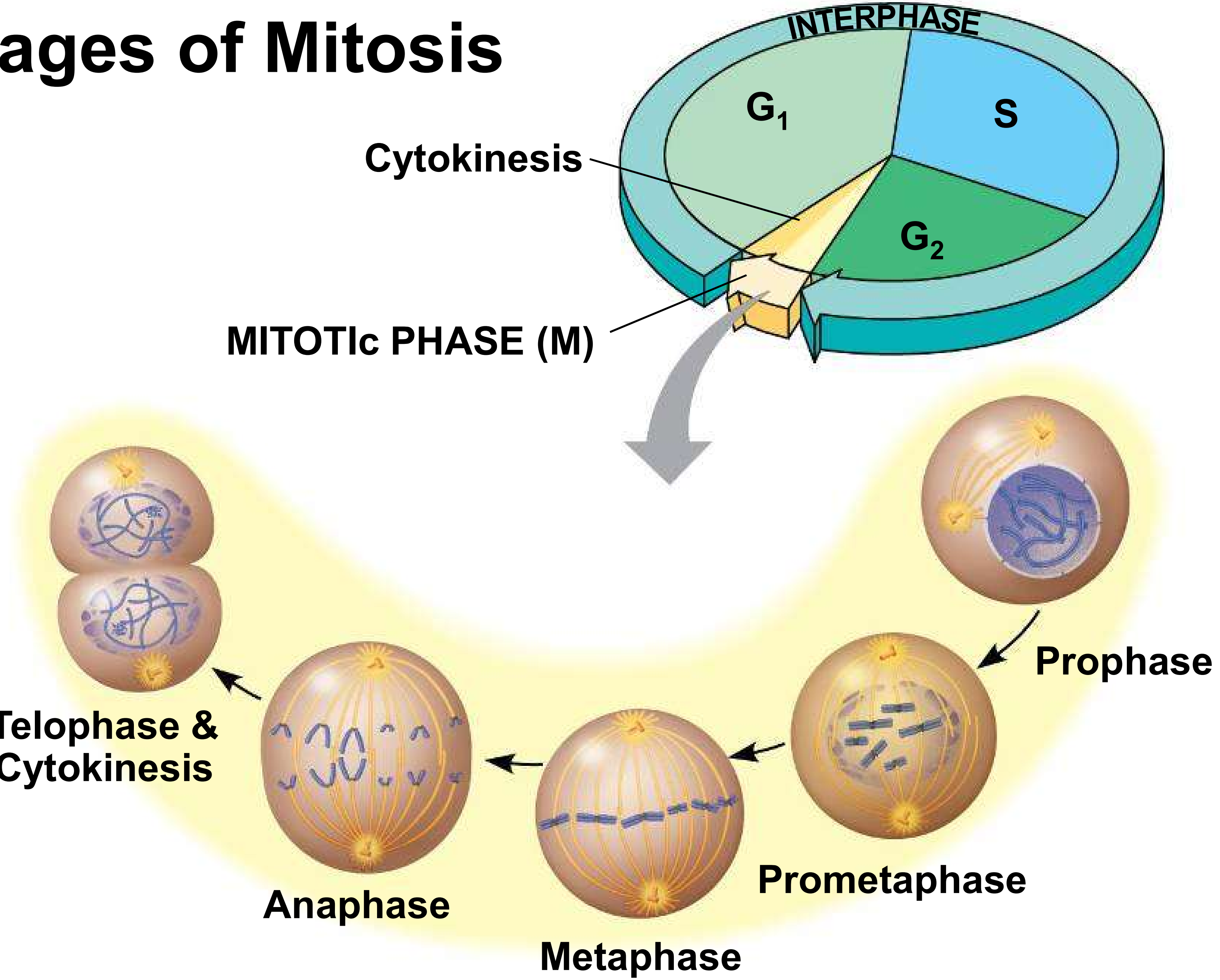
Mitosis - division of somatic cells

Mitosis

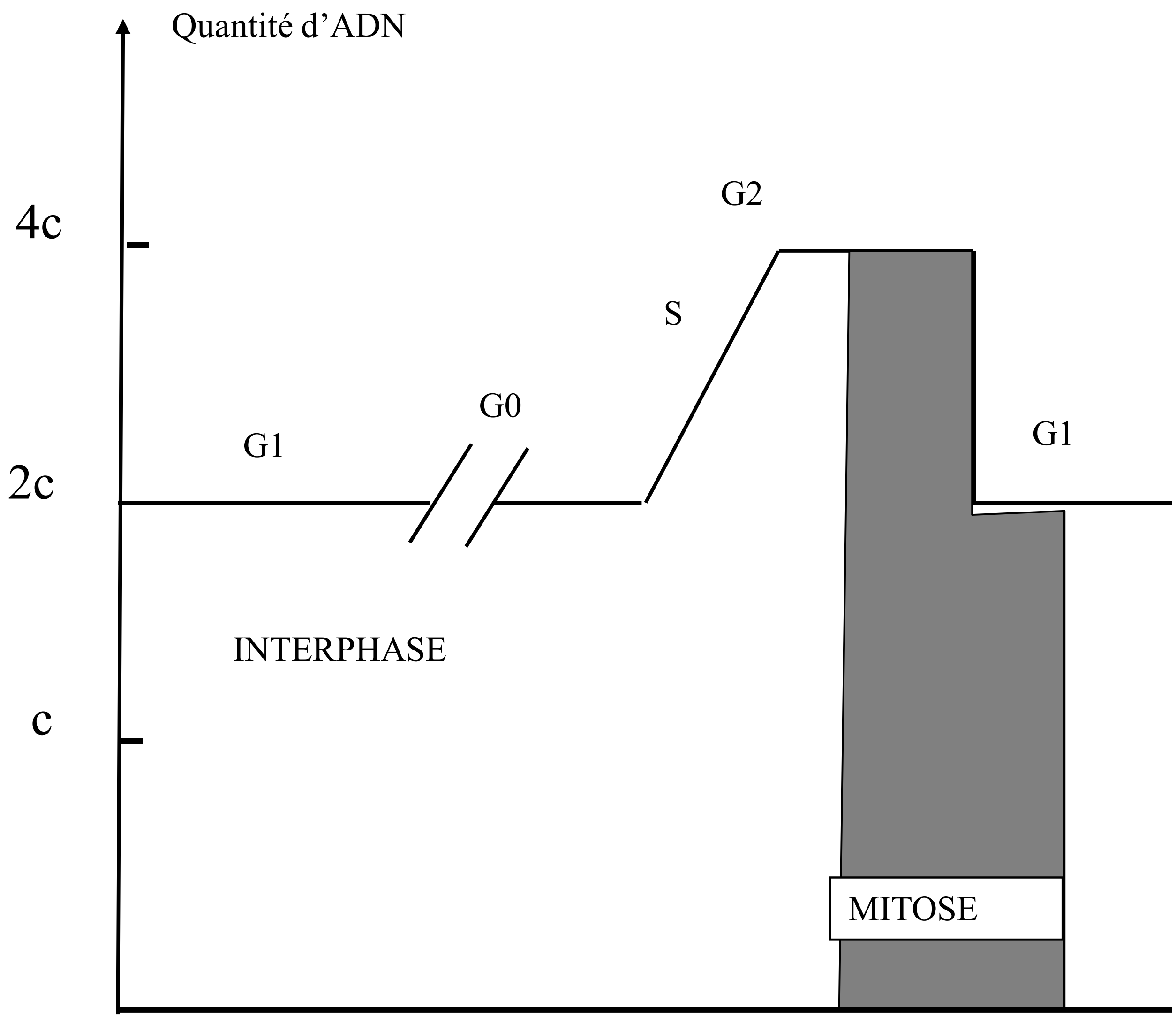
- During mitosis, the cell divides into two daughter cells.
- Each new cell receives a copy of each chromosome that was present in the original cell.
- Produces 2 new cells that are genetically identical to the original cell.



Stages of Mitosis



DNA during Mitosis



Cell Cycle Phases

- Interphase
  - G_1 – first growth
  - S - replicated genome (DNA synthesis)
  - G_2 – second growth
- M – Mitosis
  - Prophase
  - Prométaphase
  - Metaphase
  - Anaphase
  - Télophase
- C - Cytokinesis

Cell Cycle Phases

- Interphase (about 90% of the cell cycle) can be divided into subphases
  - **G_1 phase** ("first gap")
  - **S phase** ("synthesis")
  - **G_2 phase** ("second gap")
- The cell develops through all three phases, but chromosomes are duplicated only during the S phase

Interphase

- G_1 - Cells undergo major growth
- S - Each chromosome replicates (Synthesis) to produce two sister chromatids
  - Attached to the centromere
  - Contains an attachment site (kinetochore)
- G_2 - Chromosomes Condense - Assembling the Machinery for Division

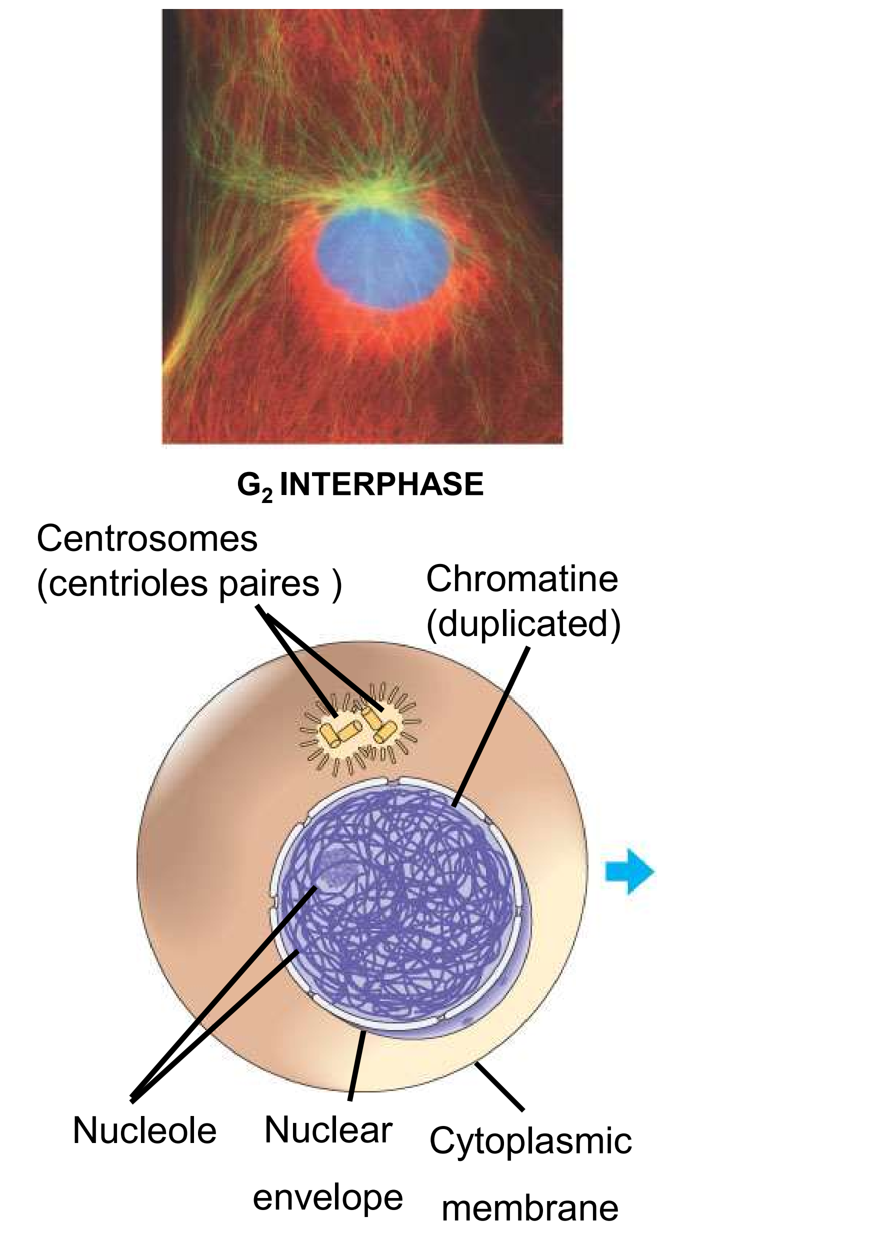
Mitosis stages

- Mitosis is divided into five phases
  - **Prophase**
  - **Prometaphase**
  - **Metaphase**
  - **Anaphase**
  - **Telophase**
- Cytokinesis overlaps with the later stages of mitosis

End of G2 of the Interphase

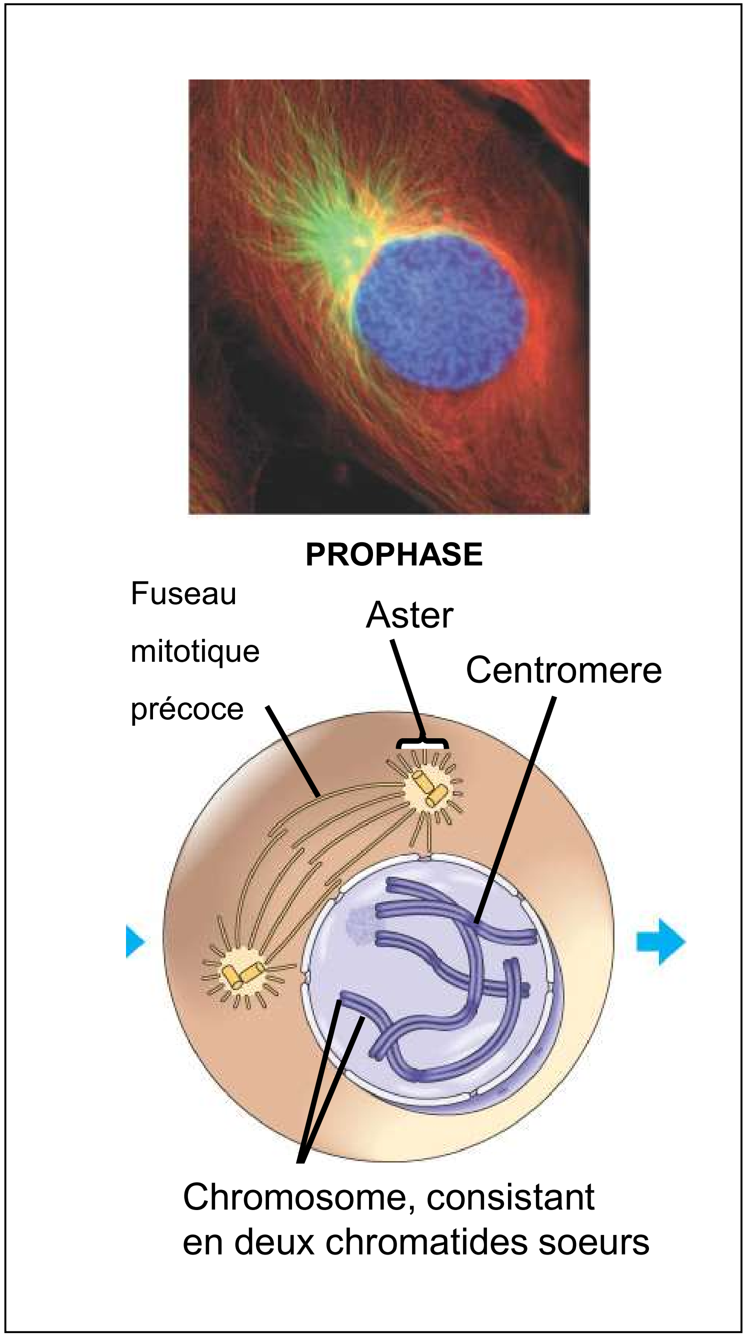
•A nuclear envelope delimits the nucleus.
•The nucleus contains one or more nucleoli
•Two centrosomes formed by the replication of a single centrosome.
•In animal cells, each centrosome characterizes two centrioles.
•Chromosomes, duplicated during the S phase, cannot be seen individually because they are not yet condensed

Light microscopes show the division of lung cells of a newt, which has 22 chromosomes in its somatic cells (chromosomes appear blue, microtubules green, intermediate filaments red). For simplicity, the drawings show only four chromosomes.



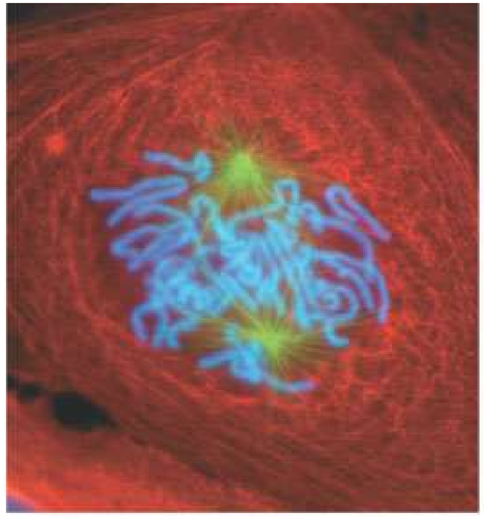
Prophase

• Chromatin filaments condense into chromatids to form chromosomes in the nucleus.
•The cell's centrioles replicate in two pairs and are distributed to each pole of the nucleus.
•Microtubules develop in mitotic spindles, a kind of rail on which the chromosomes will move.
•The nuclear membrane disintegrates.

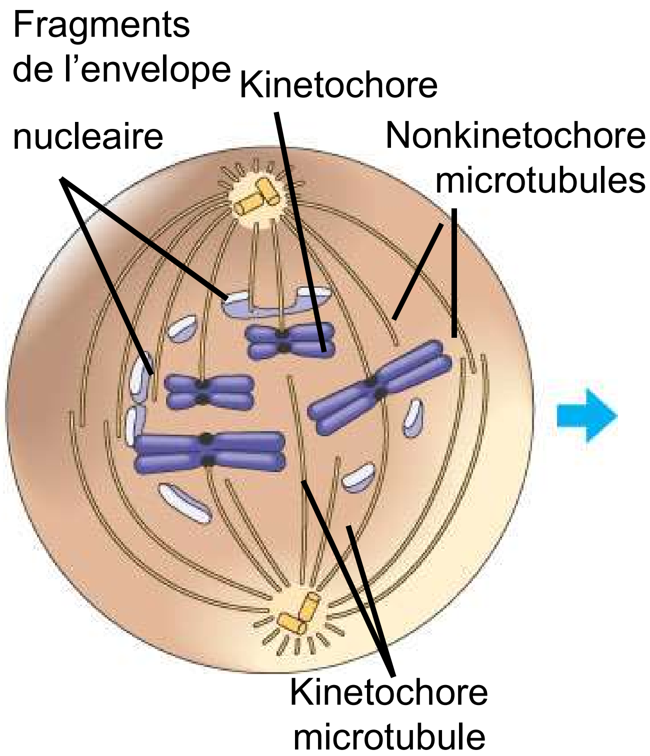


Prométaphase

• The nuclear membrane ruptures into vesicles.
•The chromosomes are highly condensed and bind to the kinetochores (assembly of proteins at the centromeres of the chromosomes).

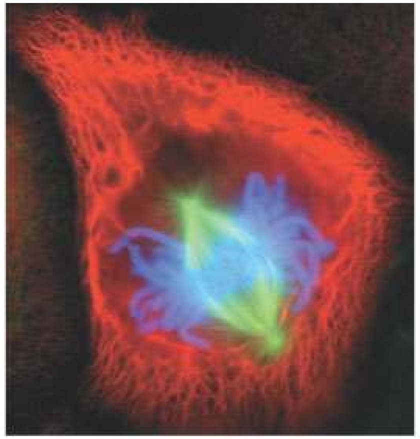


PROMETAPHASE

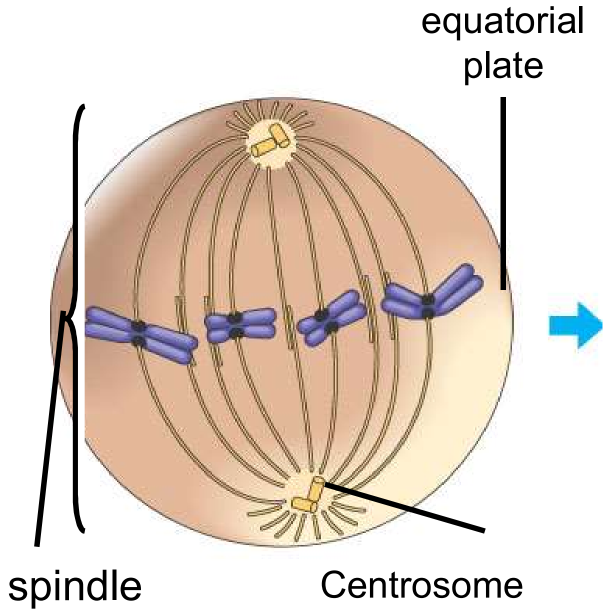


Metaphase

•Metaphase is the longest stage of mitosis, lasting about 20 minutes.
•Microtubules capture the chromosomes at the kinetochores.
•When capture is achieved on both sides, the microtubules place the chromosomes equidistant from the poles (at the equator), forming the equatorial plate.
•Until the last chromosome is in place, the other chromosomes are waiting.



METAPHASE

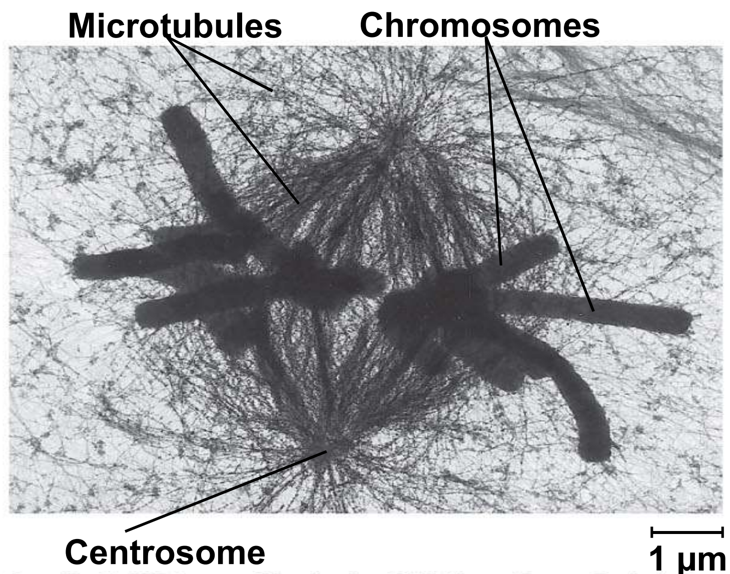


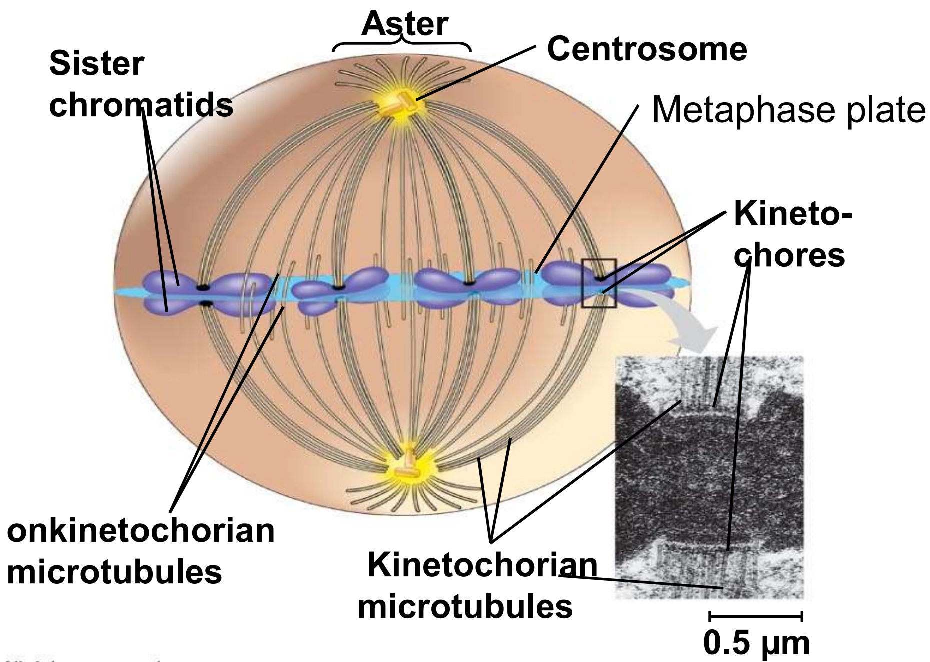
The mitotic spindle

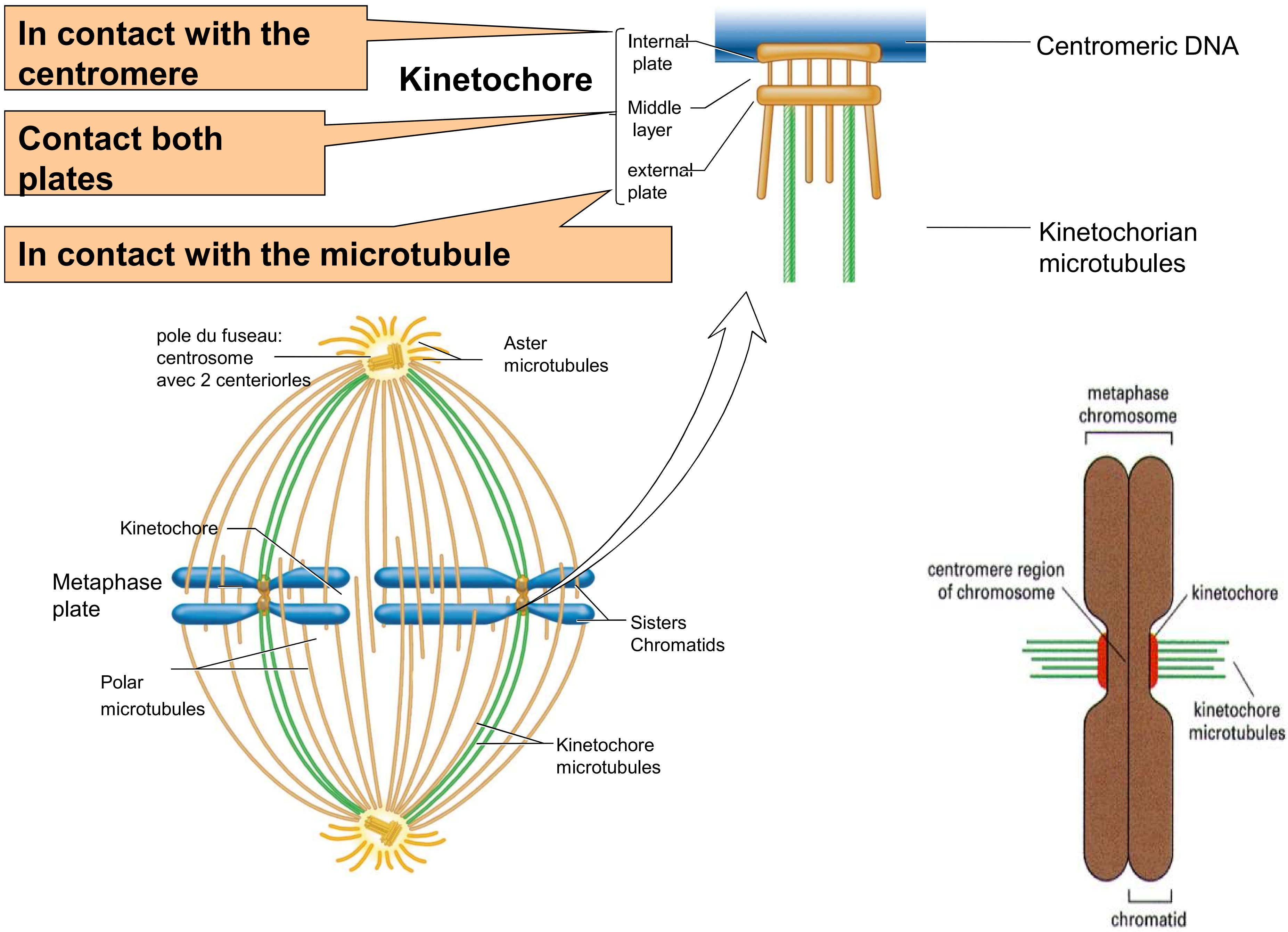
- The spindle consists of centrosomes, spindle microtubules, and asters
- The microtubule apparatus controls the movement of chromosomes during mitosis
- The centrosomes replicate, forming two centrosomes that migrate to opposite ends of the cell
- Assembly of spindle microtubules begins in the centrosome, (the microtubule organizing center)
- An aster (a radial bundle of short microtubules) extends from each centrosome

The mitotic spindle

- Some spindle microtubules attach to the kinetochores of chromosomes and move the chromosomes to the metaphase plate
- In anaphase, sister chromatids separate and move along the kinetochore microtubules to opposite ends of the cell



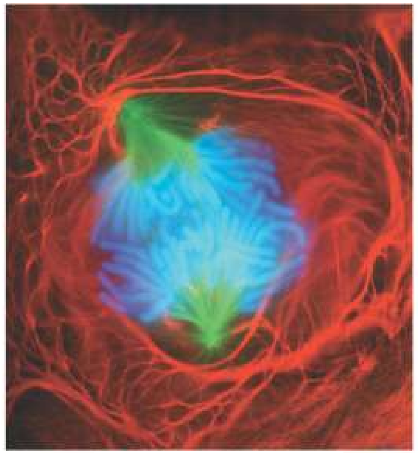




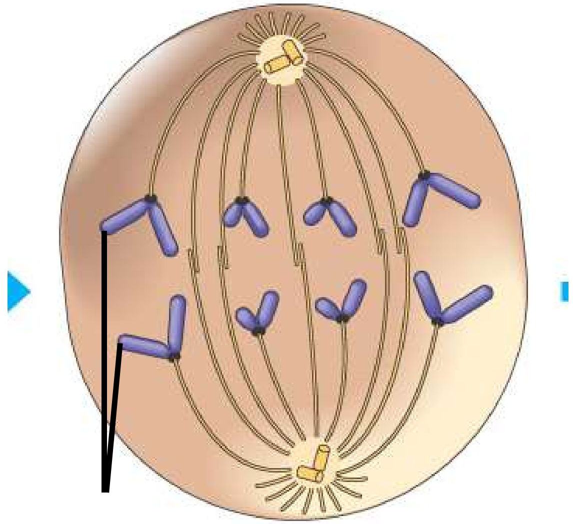
In contact with the centromere
Contact both plates
In contact with the microtubule
Kinetochore
Internal plate
Middle layer
external plate
Centromeric DNA
Kinetochorian microtubules
pole du fuseau: centrosome avec 2 centeriorles
Aster microtubules
Kinetochore
Metaphase plate
Sisters Chromatids
Polar microtubules
Kinetochore microtubules
metaphase chromosome
centromere region of chromosome
kinetochore
kinetochore microtubules
chromatid

Anaphase

• The chromosomes are all arranged at the equator of the cell.
• The chromatids of each chromosome separate at the centromere which cleaves.
• The kinetochore motors move the chromatids towards the opposite poles of the cell (a set of 46 chromosomes with one chromatid at each pole).



ANAPHASE



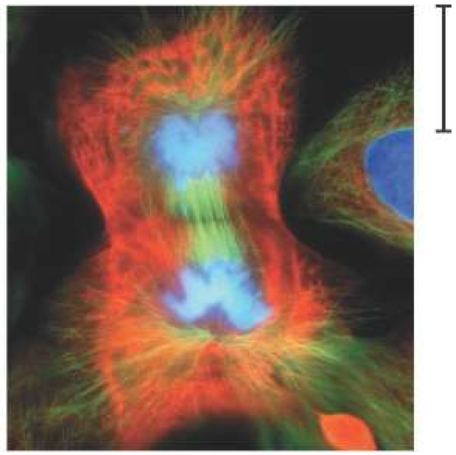
Telophase

• A nuclear membrane forms, the spindle fades.

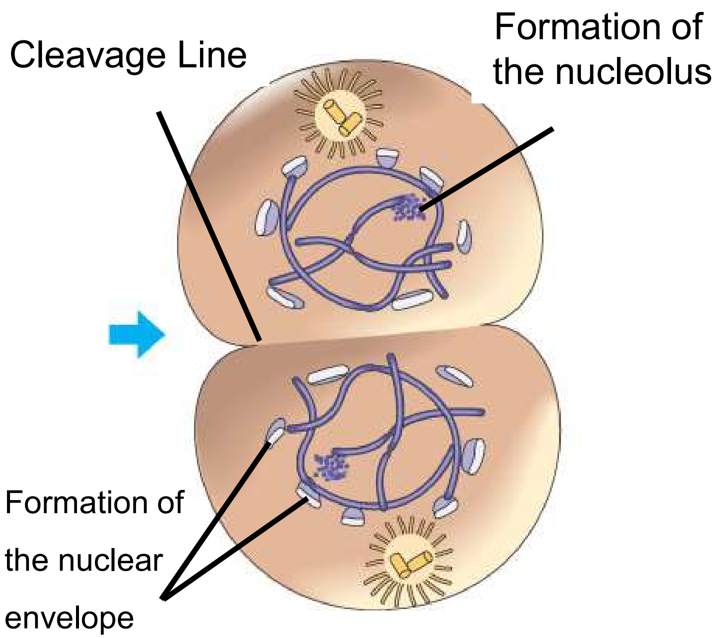
•A cleavage Line between the daughter cells is created.

•All the daughter chromosomes are at the poles.

•The kinetochore microtubules have disappeared.

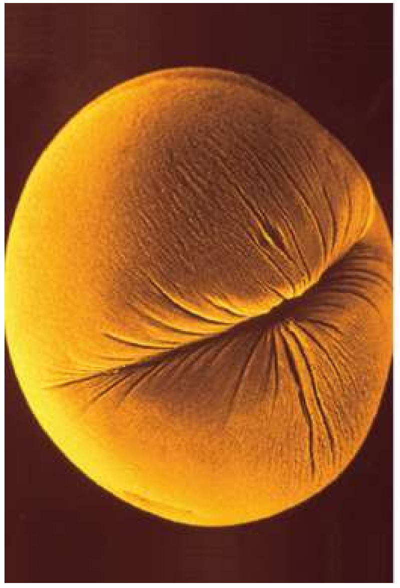


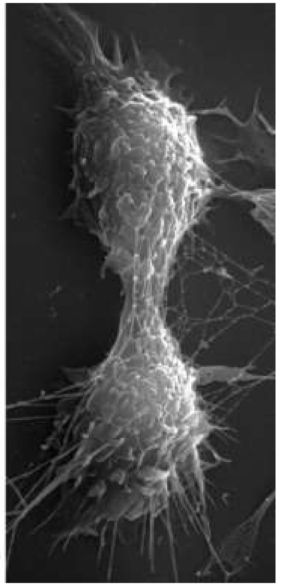
TELOPHASE AND CYTOKINESIS



Cytokinesis

- Mitosis is complete and the cell begins its cleavage process.
- The most visible of the changes is the progressive invagination of the plasma membrane, around the center of the cell and in the equatorial plane.
- A contractile ring has formed and it is this which is responsible for this deformation.
- The division furrow thus created becomes deeper and deeper, until the two daughter cells are completely separated.





Meiosis - Sexual Life Cycle

(germ cell division)

Meiosis - Sexual Life Cycle

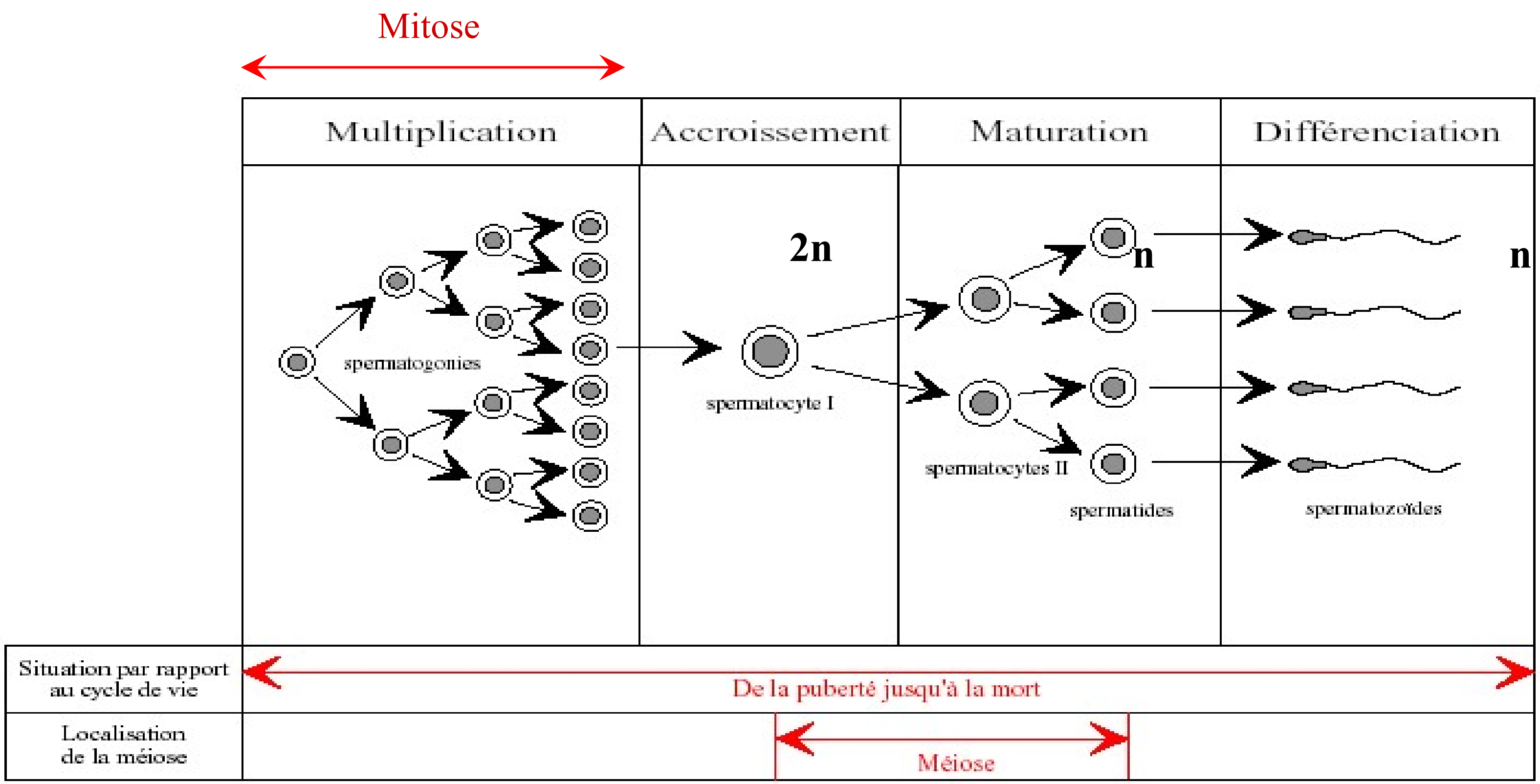
- Sexual reproduction is the most common way for eukaryotic organisms to produce offspring.
  - Parents make gametes containing half the amount of genetic material
    - These gametes fuse with each other during **fertilization** to begin the life of a new organism
    - The process of forming gametes is called **gametogenesis**
  - Most eukaryotic species are **heterogamous** (produce gametes that are morphologically different)

Meiosis - Sexual Life Cycle

- Gametes are usually haploid
  - They contain only one unique set of chromosomes
- Gametes are 1n, while diploid cells are 2n
  - A diploid human cell contains 46 chromosomes
  - A human gamete contains only 23 chromosomes
- During meiosis, haploid cells are produced from diploid cells
  - So, the chromosomes must be properly sorted and distributed in order to reduce the chromosome number to half of its original value
  - Chez l'être humain, par exemple, un gamète doit recevoir un chromosome provenant de chacune des 23 paires

Meiosis - Definition

Transformation of a parent cell (via a double division) into four daughter cells that contain only half of the chromosomes of the parent cell.
Each daughter cell receives one homologue from each pair that was originally in the parent cell.

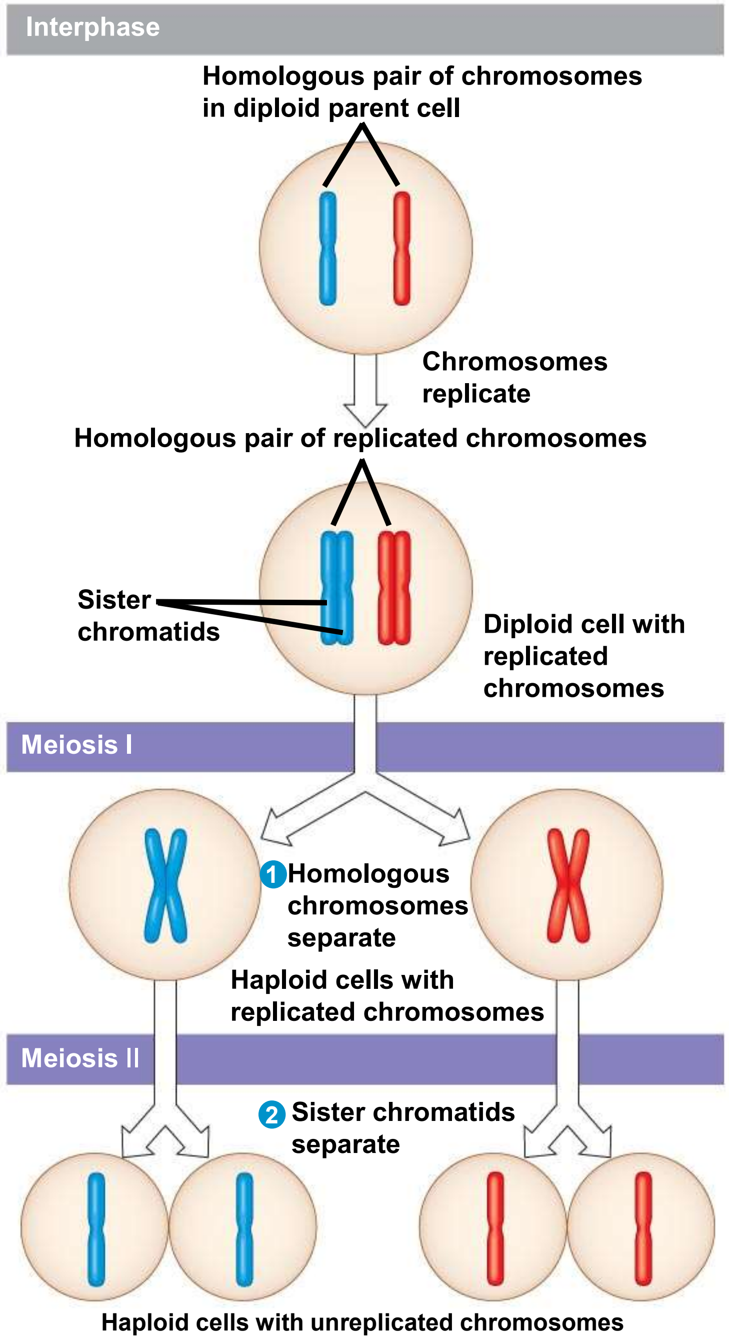


Exemple de la spermatogénèse

The two homologous chromosomes of each pair replicate and become 2 double chromosomes.

The first division separates each pair of homologues.

The second division separates each double chromosome (returns it to the single state).



Interphase

2 chromosomes

$2n = 2$

$n = 1$

Meiosis I

Reductional division

1 chromosome

The number of chromosomes is reduced by half.

Meiosis II

Equational division

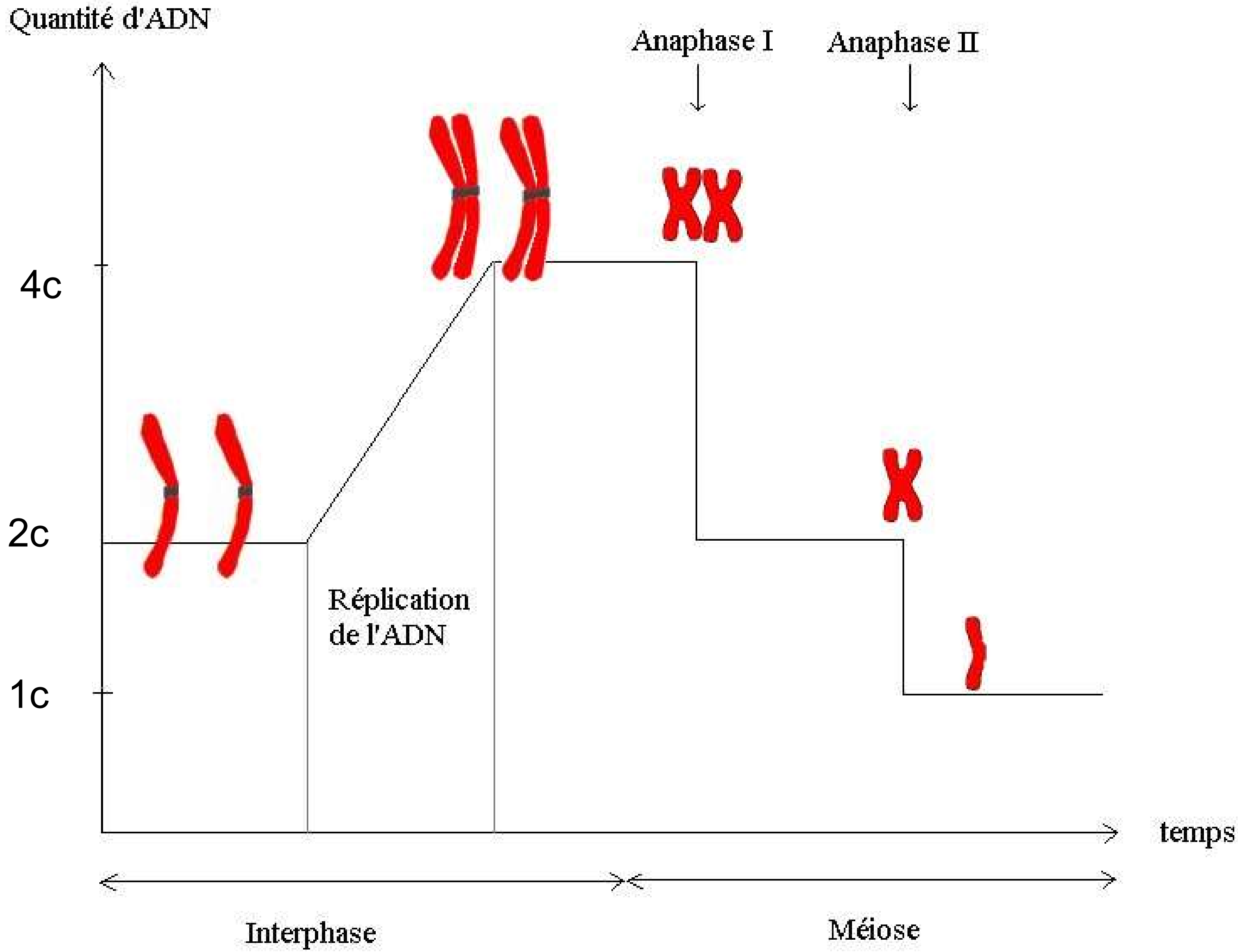
1 chromosome

We keep the same number of chromosomes.

MEIOSIS

- Like mitosis, meiosis begins after interphase of the cell cycle
- Unlike mitosis, meiosis involves two successive divisions
- These successive divisions are called meiosis I (**reductional division**) and meiosis II (**equational division**)
  - Each meiotic division is subdivided into/
    - Prophase
    - Prometaphase
    - Métaphase
    - Anaphase
    - Telophase

Evolution of the quantity of DNA per cell



MEIOSE I

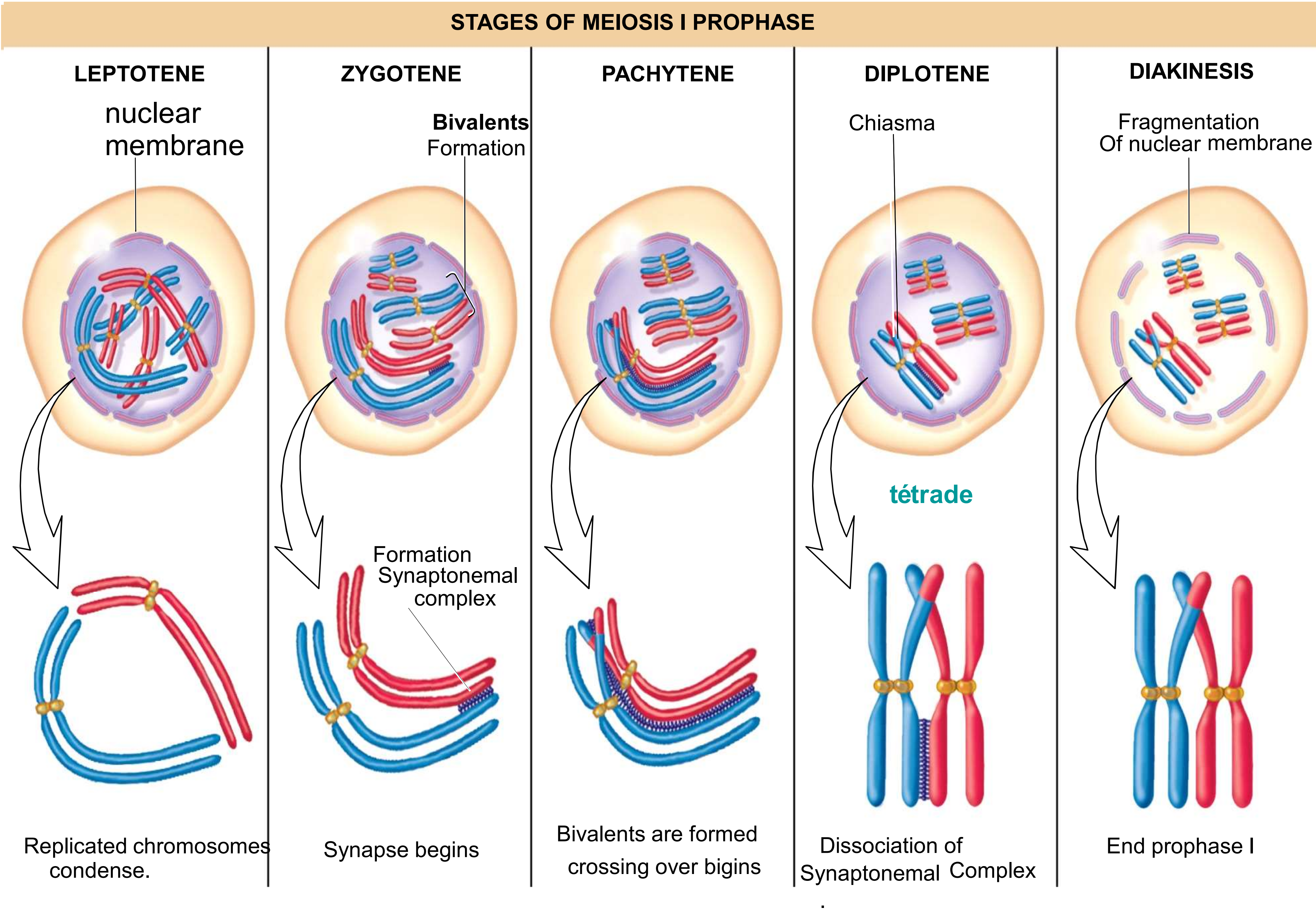
- For meiosis, make sure you distinguish:

- **Bivalents**
- **dyads**
- **Tetrads**
- **Chromosomes**
- **Chromatids**

- Note at each step the number of sister chromatids per chromosome

MEIOSE I

- La Prophase I est encore subdivisé en cinq étapes connues sous le nom
  - Leptoténe
  - Zygoténe
  - Pachytène
  - Diplotène
  - Diakinèse


STAGES OF MEIOSIS I PROPHASE
LEPTOTENE
ZYGOTENE
PACHYTENE
DIPLOTENE
DIAKINESIS
nuclear membrane
Bivalents
Formation
Chiasma
Fragmentation
Of nuclear membrane
tétrade
Formation
Synaptonemal
complex
Replicated chromosomes
condense.
Synapse begins
Bivalents are formed
crossing over bigins
Dissociation of
Synaptonemal Complex
End prophase I

Meiotic prophase I :

Leptotene

Chromosomes begin to condense, homologous dyads (replicated chromosomes) first become visible as linear chains of DNA.

Zygotene

The chromosomes condense further. Homologous chromosome pairs and their chromatids begin to form the synapse.

Pachytene

Synapse is completed by chromosomes forming tetrads. Crossover takes place. Synapsed chromosomes thicken.

Diploptene

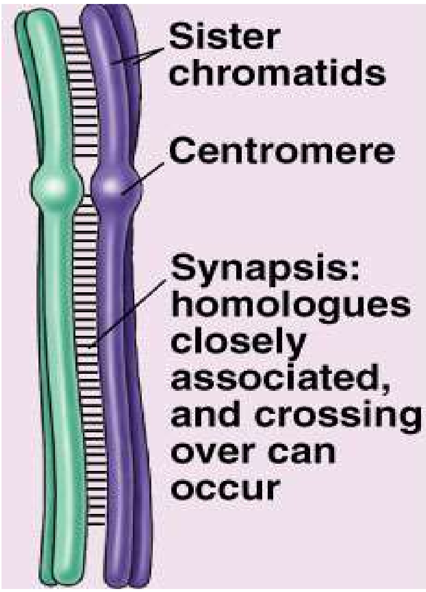
The chromosomes condense further. Dissociation of synapses begins. The chromatids of homologous chromosomes remain connected to the chiasma where the crossover may have occurred.

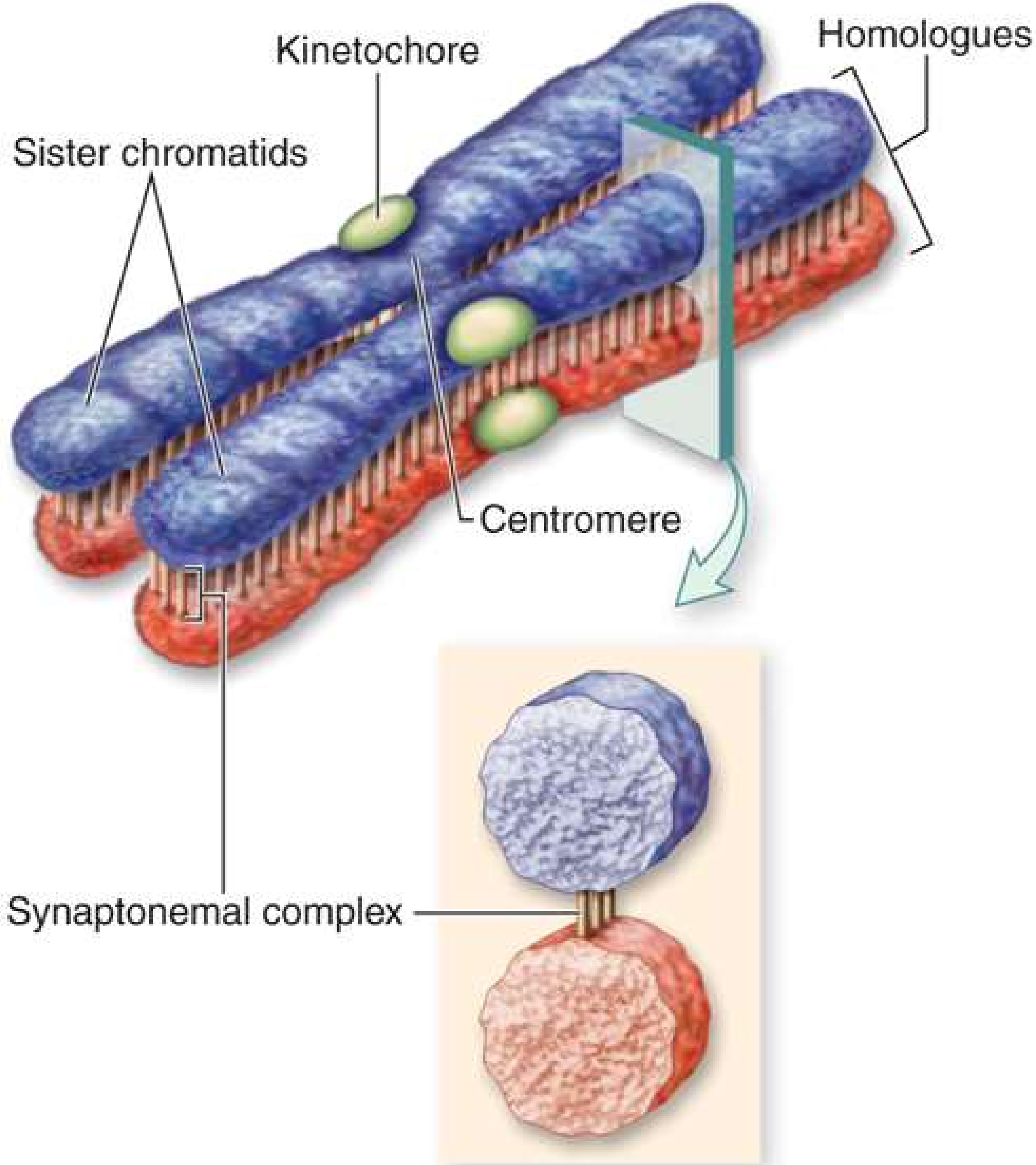
Diakinesis

The chromosomes condense further. Tetrads form cross-like shapes. Chiasma move toward the ends of the chromatids of homologous chromosomes. Dissociation of the synapses is eventually completed and the homologs separate from each other.

Synaptonémal complexe :

- Formed between homologous chromosomes
- May not be necessary for pairing
- Precise role poorly understood





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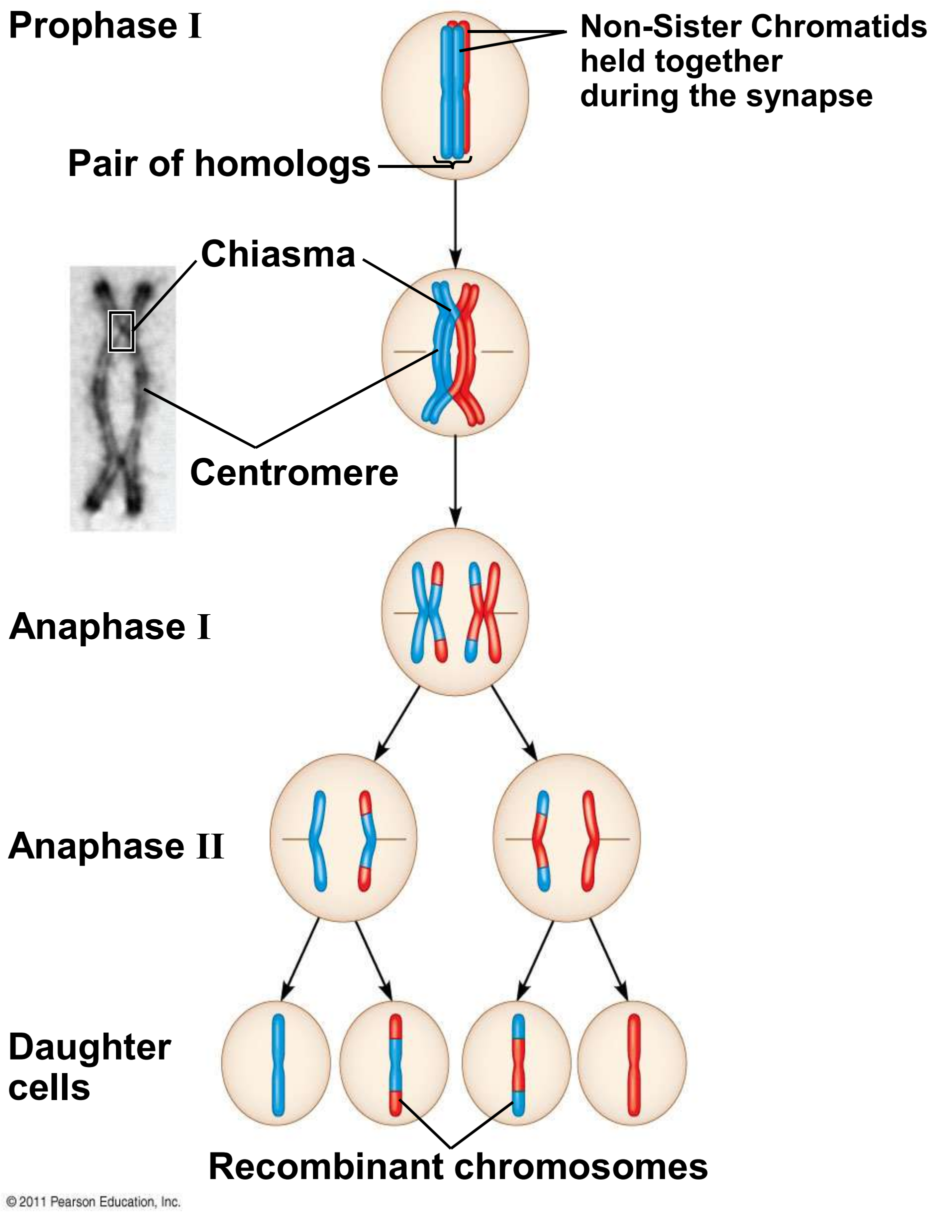
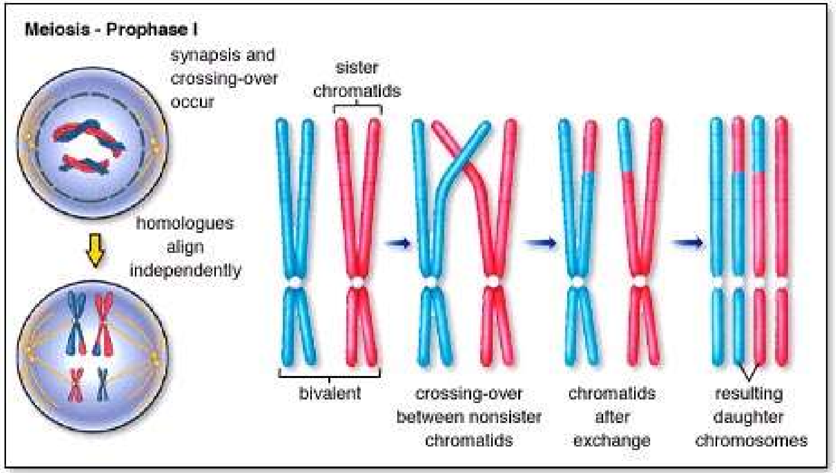


Crossing Over (recombinaison)

- Crossing over produces recombinant chromosomes, which combine DNA inherited from each parent
- Begins very early in prophase I, as homologous chromosomes pair up
  - Homologous portions of two non-sister chromatids are exchanged
- Contributes to genetic variation by combining DNA from two parents into a single chromosome

Crossing Over (recombinaison)

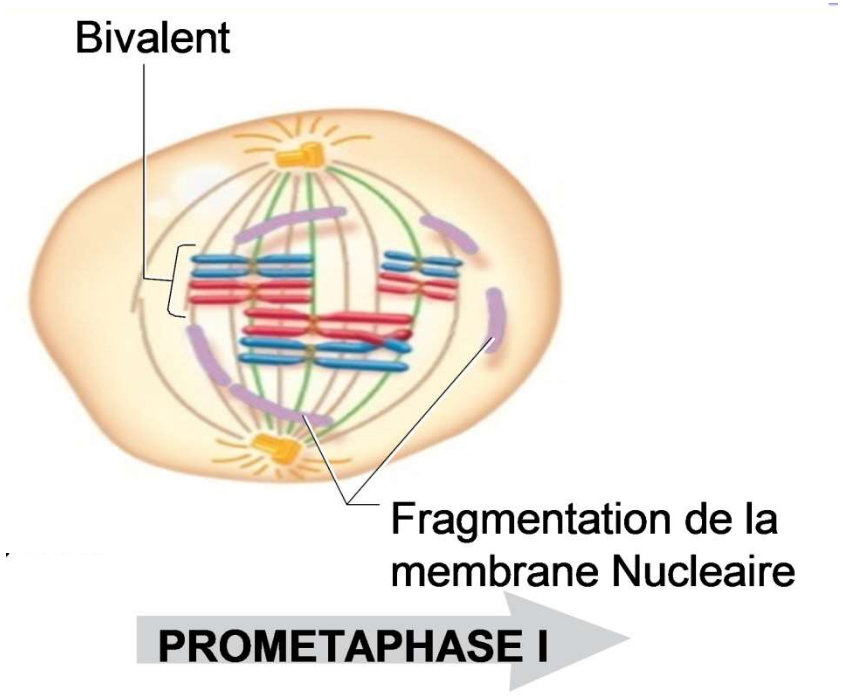
- The segments that are exchanged are similar in sequence and are on the same locations on each
- The crossed region is called chiasma - region where the two chromosomes are physically connected
  - Each tetrad usually has more than one chiasma
- Requires an enzyme called a recombinase
- Major source of **genetic variation**



MEIOSIS I

Prometaphase I

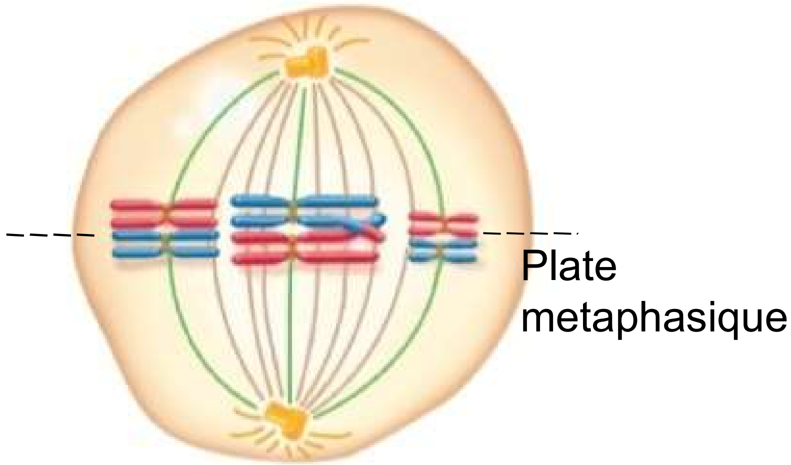
- Kinetochore microtubules attach to chromosomes. There are two kinetochores per chromosome, always on the centromere, but unlike mitosis, they are not diametrically opposed, but side by side (so as to separate only homologous chromosomes). It should be noted that in mammals, there is not just one microtubule per kinetochore but between 15 and 40.

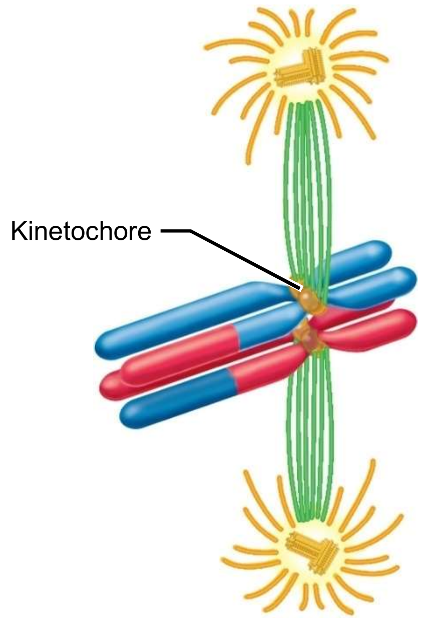


MEIOSIS I

Metaphase I

- Bivalents are organized along the metaphase plate
  - Sister chromatid pairs are aligned in a double row, rather than a single row as in mitosis
  - The arrangement is random with respect to homologous chromosomes (blue and red)
  - Furthermore
    - A pair of sister chromatids is linked at one of the poles
    - And the homologous pair is connected to the opposite pole





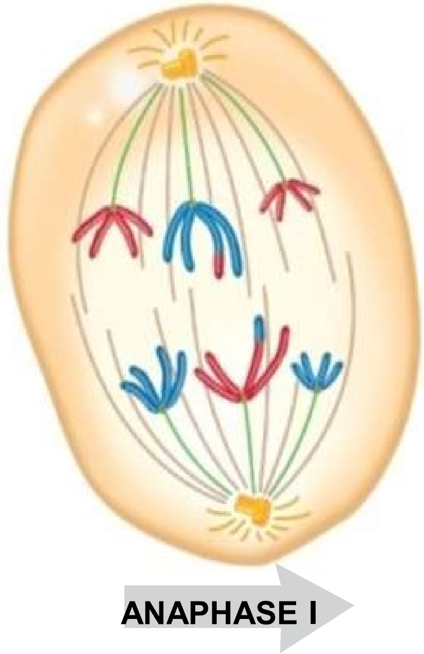
MEIOSIS I

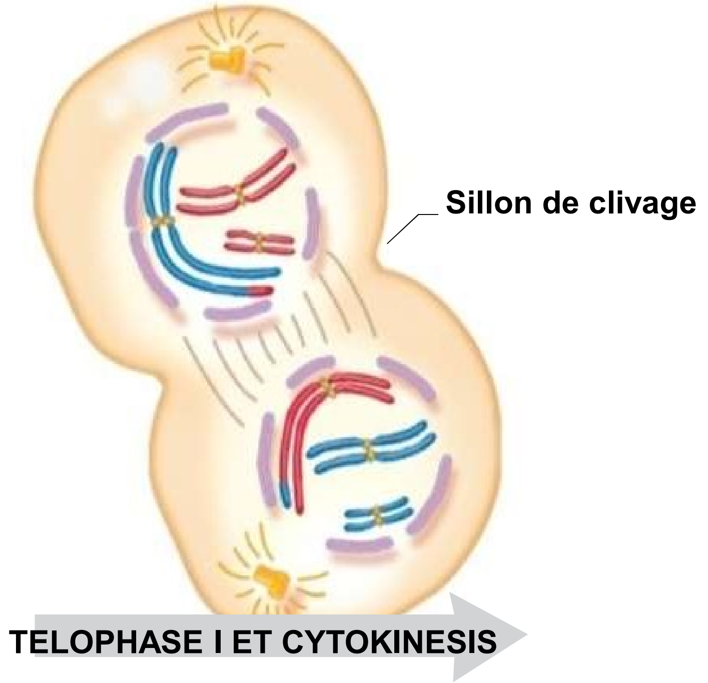
Anaphase I

The pairs of homologous chromosomes separate from each other.
However, the connection that holds the sister chromatids together does not break.

Telophase I & cytokinesis

Sister chromatids reach their respective poles and decondense.
Reformation of the nuclear envelope to produce two separate nuclei.



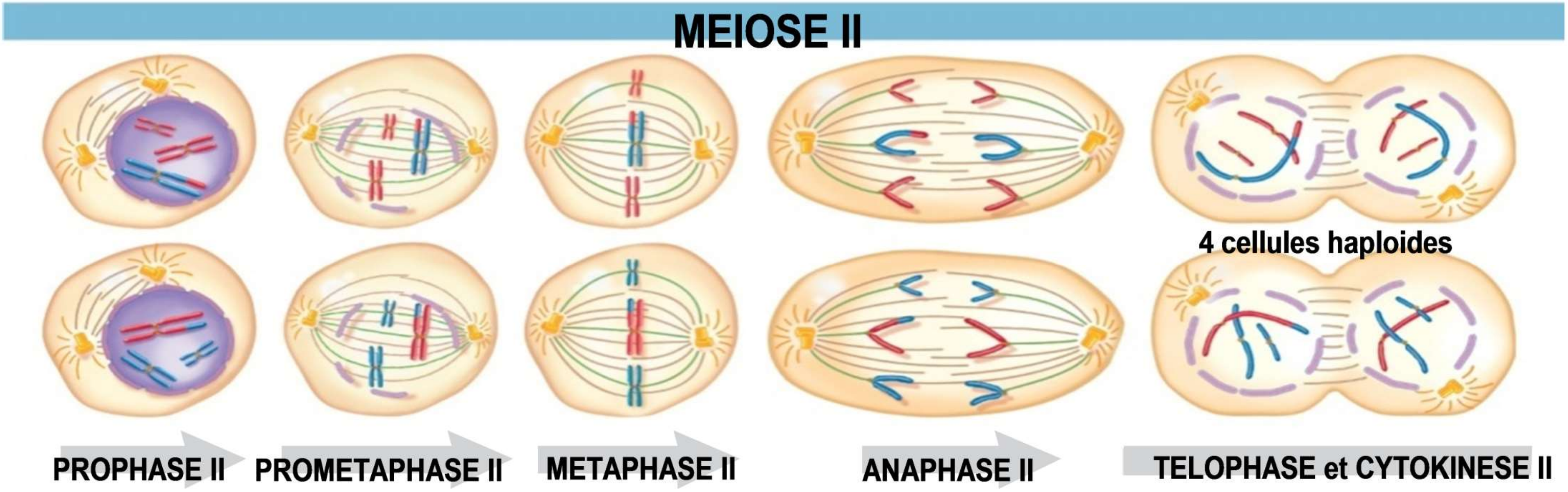


Meiosis: Interkinesis (interphase 2)

- Meiosis I is followed by Interkinesis and then by meiosis II
    - Interkinesis varies in time
    - No S phase (no DNA replication)
    - generally short
- The events that occur during meiosis II are similar to those that occur during mitosis.
- However, the starting point is different :
    - For a diploid organism with 6 chromosomes
        - Mitosis begins with 12 chromatids as six pairs of sister chromatids
        - Meiosis II begins with 6 chromatids joined as three pairs of sister chromatids

MEIOSIS II

Prophase II	Prometaphase II	Metaphase II	Anaphase II	Telophase II & cytokinesis
The two centrioles of each of the new cells move apart and a new division spindle is formed. Each chromosome now binds to the spindle and begins its movement towards the equtorial plate.	Same as for mitosis: kinetochore microtubules attach to the kinetochores, at a rate of one kinetochore per chromatid, on either side of the centromere	All chromosomes are now located at the equatorial plate.	The sister chromatids of each double chromosome separate from each other, forming single chromosomes. These move towards one or the other pole.	Four daughter nuclei are formed. After division of the cytoplasm, each new cell is haploid (n) and the number of chromosomes has been reduced by half. Each of these cells can become a gamete.



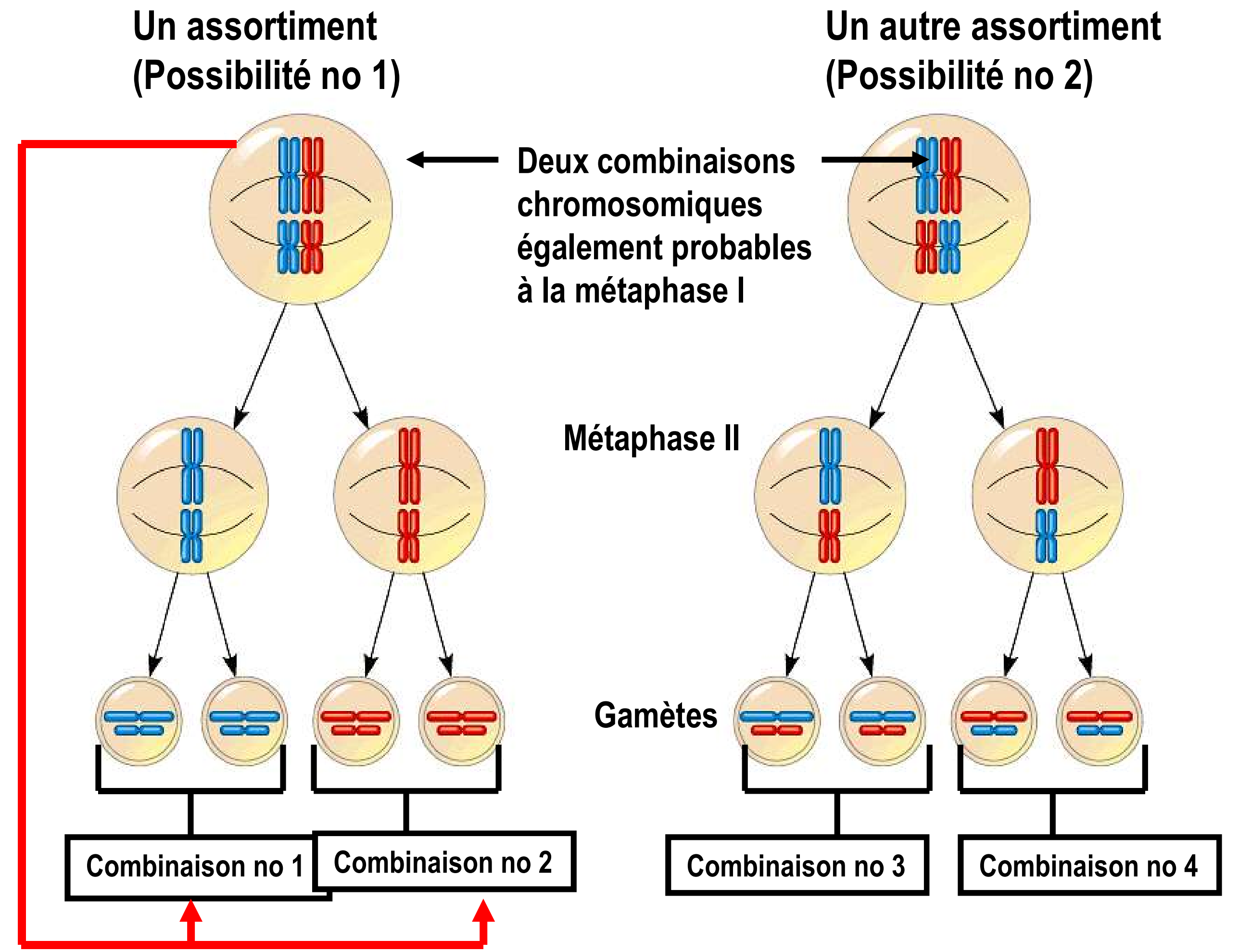
In metaphase 1, independent assortments mix the chromosomes

The pairs of homologous chromosomes are arranged randomly on either side of the equatorial plate, independently of the other pairs. Thus, one or the other of the (2) homologs can be found in a gamete.

Each arrangement is equivalent to an assortment and each assortment produces two kinds of gametes.

The possible number of different assortments and the resulting number of gametes can be easily calculated.

2^{n-1} possible assortments produce 2^n kinds of gametes where n is the number of chromosomes pairs



Campbell (2eéd.) — Figure 13.9 : 259

- For AaBb: # gametes = 2^2 = 4

AB

Ab

aB

ab

- For AaBbCc: # gametes = 2^3 = 8

ABC

ABc

AbC

Abc

aBC

aBc

abC

abc