UNIVERSITY BATNA 02
FACULTY OF NATURAL AND LIFE SCIENCES
TD N°02

Chromatin, chromosome and cell cycle

I. Chromatin

In the nuclei of eukaryotes, DNA is closely associated with proteins. These nucleoprotein complexes, with a DNA proportion of approximately one-third, are known as chromatin. It is only during cell division that chromatin condenses into chromosomes that are visible under light microscopy. During interphase, most of the chromatin is loose, and in these conditions a morphological distinction can be made between tightly packed heterochromatin and the less dense euchromatin.

Heterochromatin : Intensely stained chromosomal segments correspond to a high degree of packing and are showing little or no genetic activity.

Euchromatin: less tightly packed segments stain less distinctly and correspond to segments with genetic activity.

I.1. DNA and histones

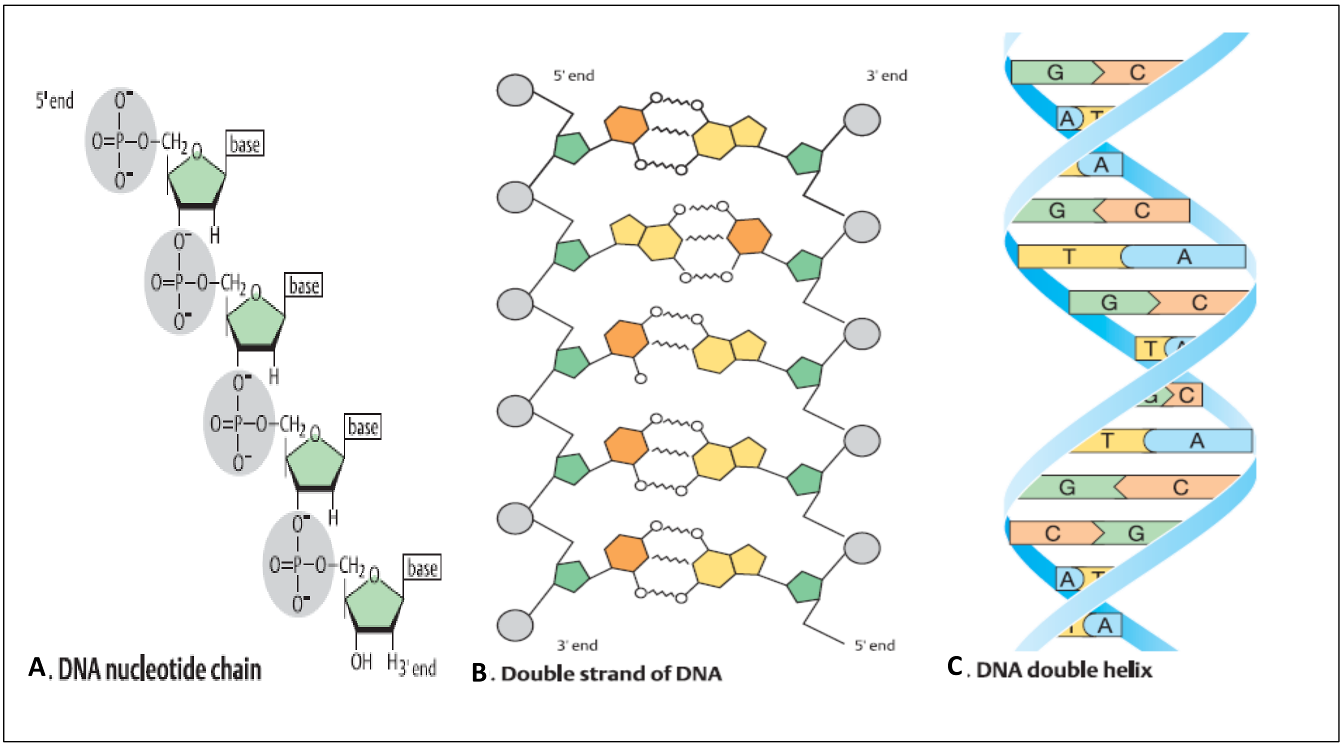
I.1.1. Deoxyribonucleic acids (DNA) : is a nucleic acid, it is a polymer of deoxyribonucleotide units. The nucleotide consists of one of the four nucleotide bases, a sugar (deoxyribose), and a phosphate group.

The nucleotide bases in DNA are heterocyclic molecules derived from either pyrimidine or purine. The purine bases are adenine (A) and guanine (G). The pyrimidine bases are thymine (T) and cytosine (C).

The structure of DNA is a double helix, consists of two long chains of nucleotides that wind around each other in a helical (spiral) shape.

DNA is a negatively charged polymer that produces electrostatic repulsion between adjacent DNA regions. Therefore, it would be difficult for a long DNA molecule alone to fold into a small space like the nucleus.

To overcome this problem, the long, negatively charged polymer is wrapped around a basic protein complex known as a core histone octamer, which consists of the histone proteins, to form a nucleosome.



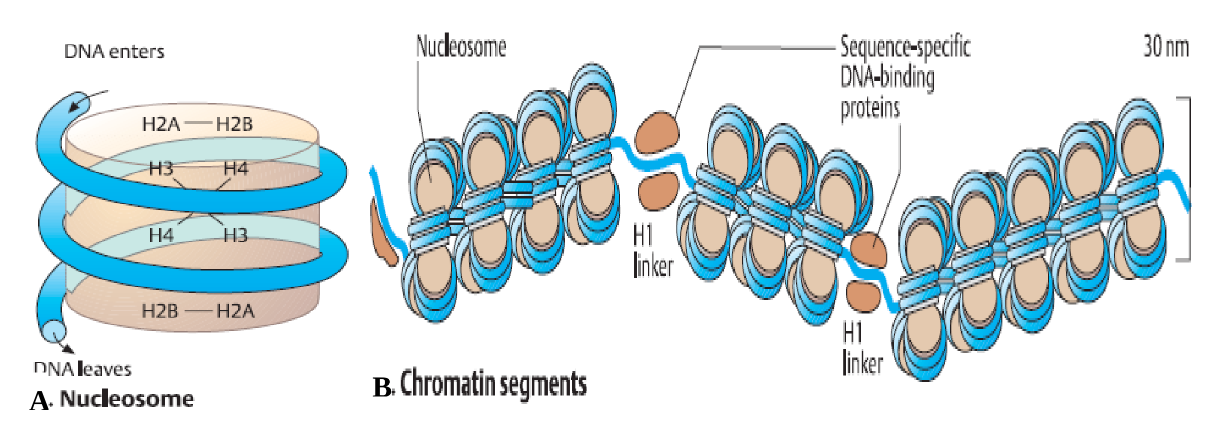
I.1.2. Histone proteins

Histones are proteins with a high proportion of positively charged amino acids (lysine and arginine), which enable them to bind firmly to the negatively charged DNA double helix. There are five types of histone molecules: H1, H2 A, H2 B, H3, and H4.

I.1.3. From chromatine to chromosome

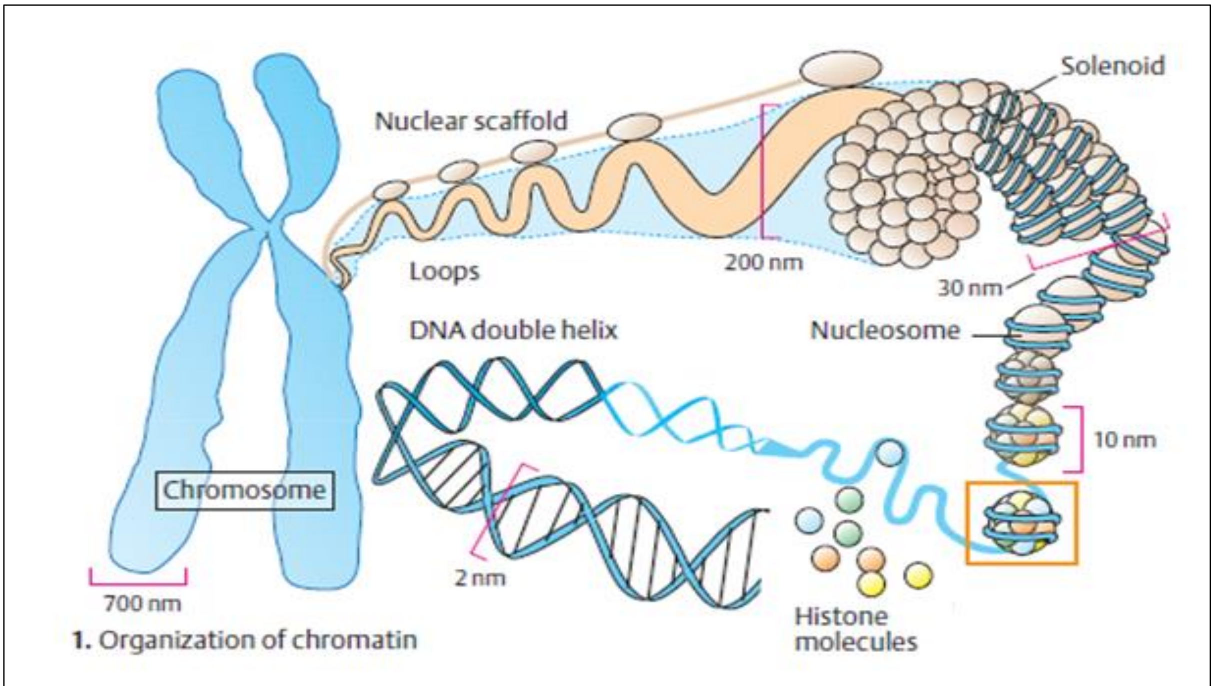
The nucleosome is a subunit of chromatin consisting of DNA wound around histone proteins in a defined spatial configuration. A nucleosome consists of about 146 bp of DNA wound twice around an octamer of histones, two copies each of H2 A, H2 B, H3, and H4, the core histones. The histone octamer forms a cylinder of 11 nm diameter and 6 nm height.

Another histone (H1) binds to DNA segments that are not directly in contact with the histone octamers (“linker” DNA). It covers about 20 bp and supports the formation of spirally wound super structures with diameters of 30 nm, known as **solenoids**.



When chromatin condenses into chromosomes, the solenoids form **loops** about 200 nm long, which already contain about 80 000 bp. The loops are bound to a protein framework (**the nuclear scaffolding)**, which in turn organizes some 20 loops to form **minibands**.

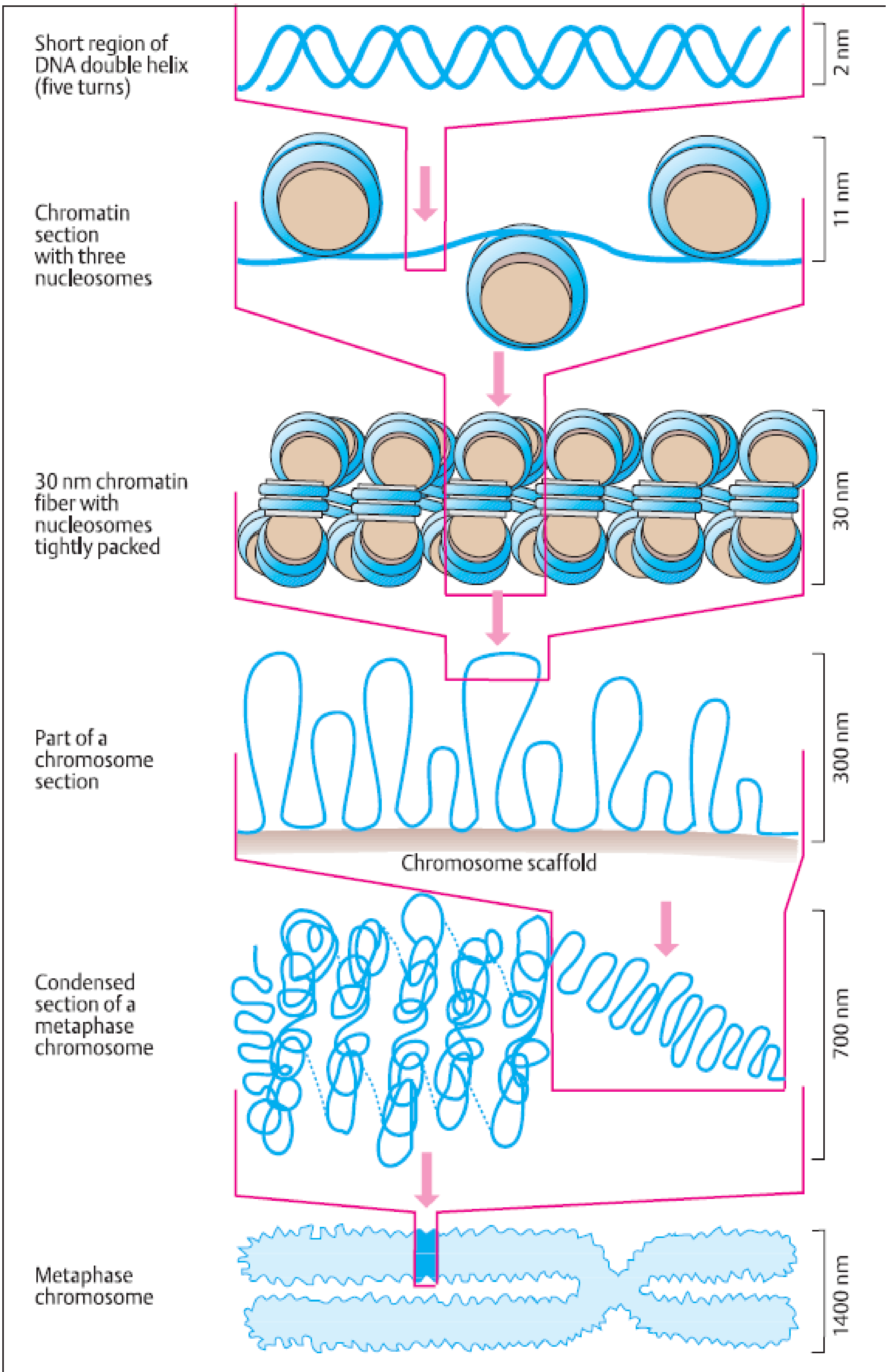
A large number of stacked minibands finally produces a chromosome. In the chromosome, the DNA is so densely packed that the smallest human **chromosome** already contains more than 50 million bp.



1. Organization of chromatin

II. Metaphase chromosomes : consists of two chromatids (sister chromatids) and the centromere, which holds them together.

The centromere may divide each of the chromatids into two chromosome arms. The regions at both ends of the chromosome are **the telomeres**. The point of attachment to the mitotic spindle fibers is the kinetochore. During metaphase and prometaphase, chromosomes can be visualized under the light microscope as discrete elongated structures, 3–7 µm long.



A. DNA in a metaphase chromosome

Cell cycle

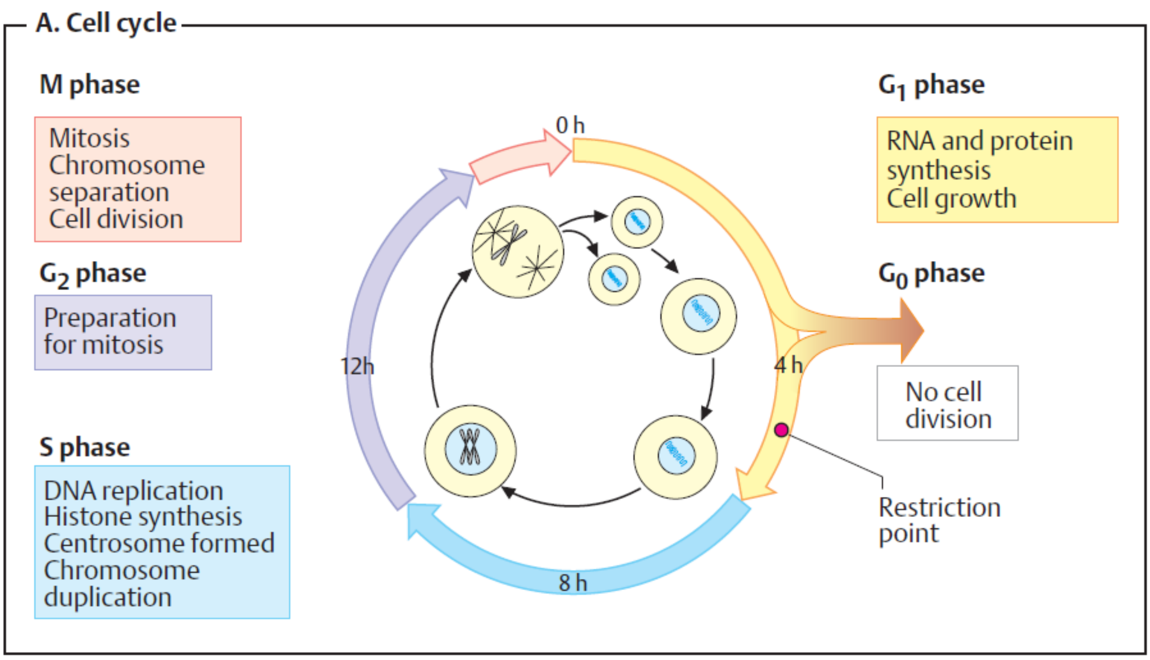
The growth of multicellular organisms depends on precise replication of individual cells followed by cell division. During replication, eukaryotic cells go through an ordered series of cyclical events. Proliferating cells undergo a cycle of division (the cell cycle), which lasts approximately 24 hours in mammalian cells in cell culture. The time from one cell division to the next is called a cell cycle. The cell cycle has two main phases, interphase and mitosis.

Interphase : is further divided into three distinct phases ; G1 (gap 1), S (DNA synthesis, lasting 6–8 hours in eukaryotic cells, at the end of which the chromosomes have been duplicated), and G2 (gap 2, lasting about 4 hours).

G1 (Gap 1) Phase: During this phase, the cell grows in size and carries out its normal metabolic functions. It's also a checkpoint where the cell assesses whether conditions are favorable for cell division.

S (Synthesis) Phase: In this phase, the cell replicates its DNA to ensure that the two daughter cells formed during division will have identical genetic information. DNA replication occurs, resulting in the formation of sister chromatids.

G2 (Gap 2) Phase: After DNA replication is complete, the cell continues to grow and prepares for cell division. Like the G1 phase, there is another checkpoint to ensure that DNA has been accurately replicated and is ready for division.



M (Mitotic) Phase: The M phase includes two main processes: mitosis and cytokinesis.

- **Mitosis:** During mitosis, the cell's nucleus divides into two daughter nuclei, each with an identical set of chromosomes. This process is further divided into several stages: prophase, metaphase, anaphase, and telophase.

Prophase: During prophase, the chromatin in the nucleus condenses into visible, discrete chromosomes. Each chromosome consists of two sister chromatids connected by a centromere. The nuclear envelope begins to break down, and the mitotic spindle, a structure made of microtubules, begins to form.

Metaphase: In metaphase, the chromosomes align at the cell's equator, known as the metaphase plate. The spindle fibers attach to the centromeres of each chromosome, ensuring that they are evenly distributed between the two daughter cells.

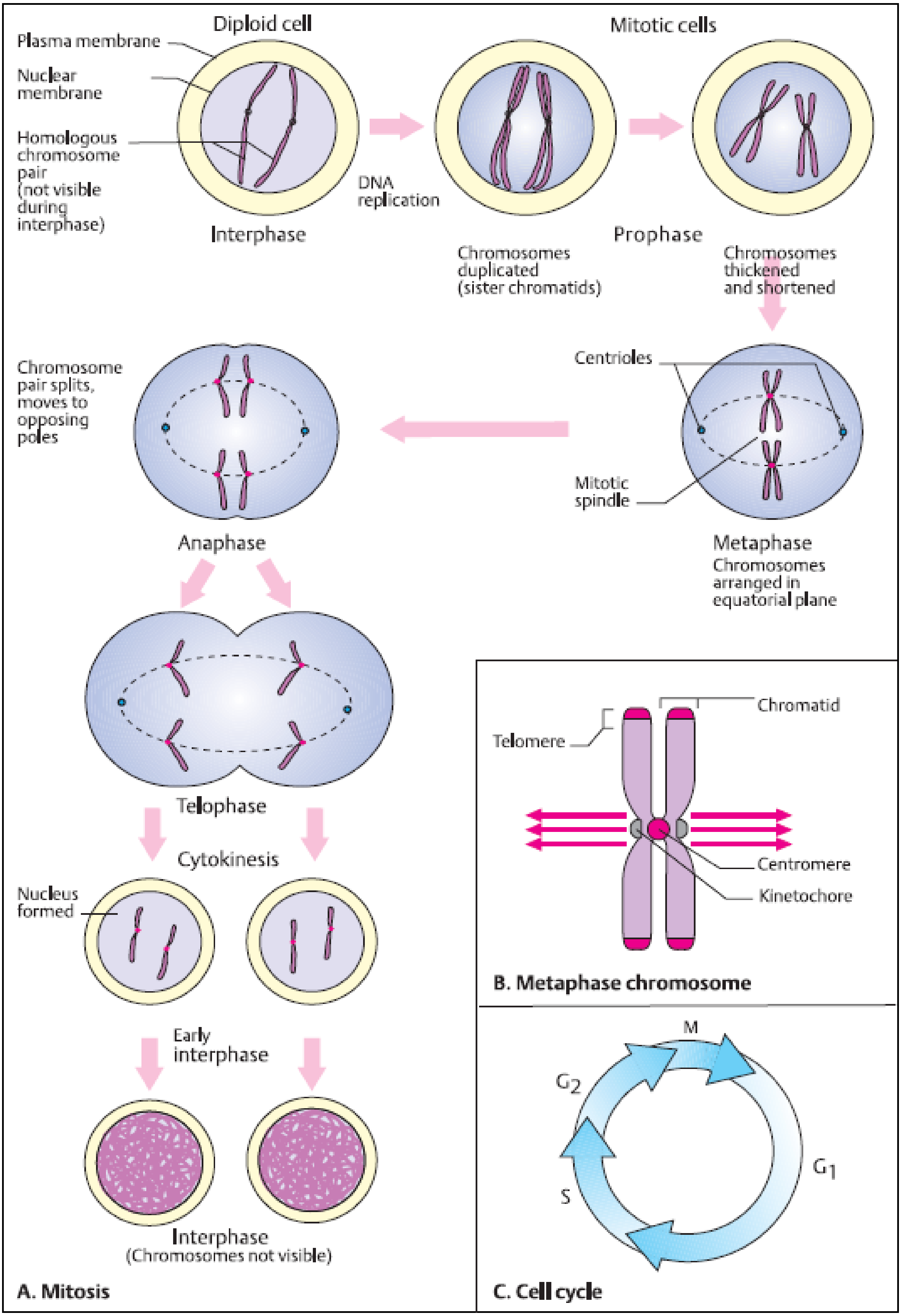
Anaphase: During anaphase, the sister chromatids are pulled apart by the spindle fibers and are moved toward opposite poles of the cell. This ensures that each daughter cell will receive an identical set of chromosomes.

Telophase: In telophase, the separated chromatids, now individual chromosomes, arrive at the opposite poles of the cell. The nuclear envelope reforms around each set of chromosomes, creating two distinct nuclei. Cytokinesis, the division of the cytoplasm, also begins during this phase.

Cytokinesis: Cytokinesis is the final stage of cell division. It involves the division of the cell's cytoplasm and organelles into two daughter cells. In animal cells, a contractile ring of actin filaments pinches the cell membrane, creating two separate daughter cells. In plant cells, a new cell wall is formed between the two daughter nuclei.

Mitosis ensures that each daughter cell is genetically identical to the parent cell and has the same number of chromosomes. This process is critical for the growth and repair of multicellular organisms, as well as for maintaining tissue integrity.

Once the M phase is complete, the two daughter cells enter the G1 phase, and the cell cycle starts again. The cell cycle is tightly regulated by a variety of checkpoints and control mechanisms, which help prevent errors in DNA replication and ensure that cells only divide when necessary.


Diploid cell
Mitotic cells
Plasma membrane
Nuclear membrane
Homologous chromosome pair (not visible during interphase)
DNA replication
Interphase
Prophase
Chromosomes duplicated (sister chromatids)
Chromosomes thickened and shortened
Centrioles
Chromosome pair splits, moves to opposing poles
Mitotic spindle
Anaphase
Metaphase
Chromosomes arranged in equatorial plane
Telophase
Cytokinesis
Nucleus formed
Early interphase
Interphase
(Chromosomes not visible)
A. Mitosis
Chromatid
Telomere
Centromere
Kinetochore
B. Metaphase chromosome
M
G2
G1
S
C. Cell cycle

Meiosis

Meiosis is a specialized type of cell division that occurs in sexually reproducing organisms. It differs from mitosis, which produces two identical daughter cells, in that meiosis results in the formation of four non-identical daughter cells with half the number of chromosomes as the parent cell. A complete meiosis consists of two cell divisions, meiosis I and meiosis II.

Meiosis I

Prophase I: During prophase I, chromosomes condense and become visible. Homologous chromosomes come together and exchange genetic material in a process called crossing-over. This genetic recombination introduces variability among offspring. The nuclear envelope begins to break down, and spindle fibers form.

Metaphase I: Homologous pairs of chromosomes align at the cell's equator, known as the metaphase plate. Each homologous chromosome is attached to spindle fibers.

Anaphase I: In anaphase I, homologous chromosomes are pulled apart and move to opposite poles of the cell. This separation ensures that each daughter cell receives a unique combination of genetic material.

Telophase I: Telophase I involves the formation of two daughter cells, each with half the original chromosome number. A nuclear envelope forms around each set of chromosomes. Cytokinesis typically follows, resulting in two haploid daughter cells.

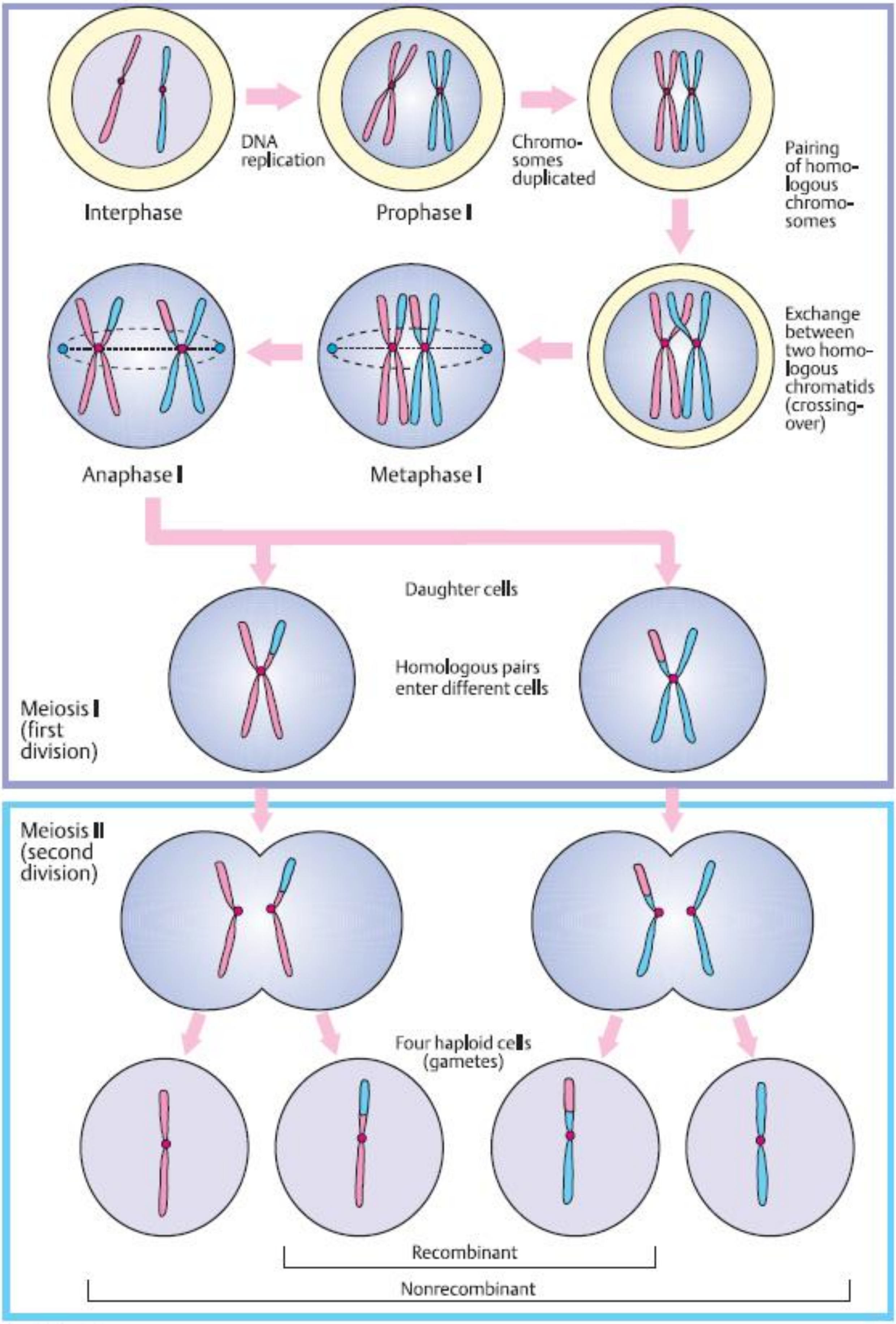
Meiosis II: Meiosis II is similar to mitosis and further divides the two haploid daughter cells produced in meiosis I. The stages are as follows:

Prophase II: Chromosomes in each haploid cell condense, and a new spindle apparatus forms. There is no crossing-over during this phase.

Metaphase II: Chromosomes align at the metaphase plate in both haploid cells.

Anaphase II: Sister chromatids of each chromosome are pulled apart and move to opposite poles.

Telophase II: The separated sister chromatids arrive at the opposite poles of the cells, and a nuclear envelope forms around each set. Cytokinesis then follows.


DNA
replication
Chromo-
somes
duplicated
Pairing
of homo-
logous
chromo-
somes
Interphase
Prophase I
Exchange
between
two homo-
logous
chromatids
(crossing-
over)
Anaphase I
Metaphase I
Daughter cells
Homologous pairs
enter different cells
Meiosis I
(first
division)
Meiosis II
(second
division)
Four haploid cells
(gametes)
Recombinant
Nonrecombinant

A. Meiosis