Introduction to Embryology

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Learning Objectives

By the end of this lecture, students should be able to:

- Define embryology
- Distinguish between the embryonic period and fetal period
- Understand why embryology is essential for clinical medicine
- Appreciate the timeline of human development from fertilization to birth
- Explain the processes of mitosis and meiosis and their stages
- Compare mitosis and meiosis
- Understand the clinical relevance of both processes

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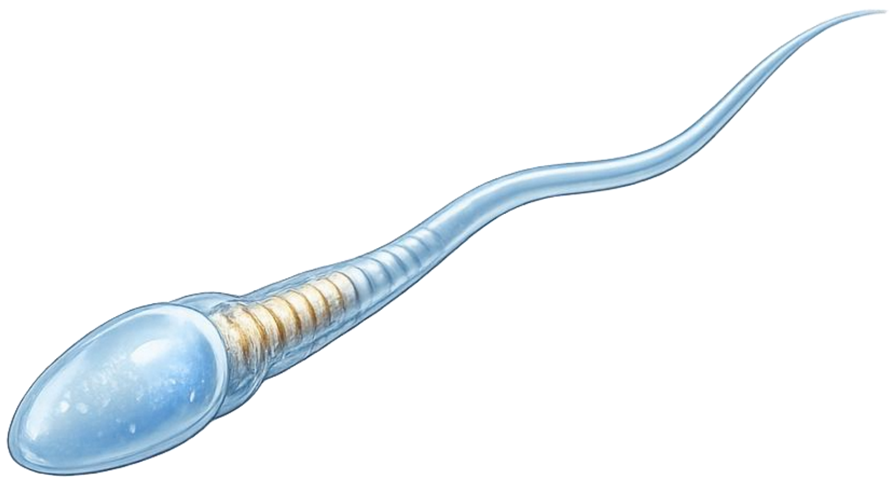
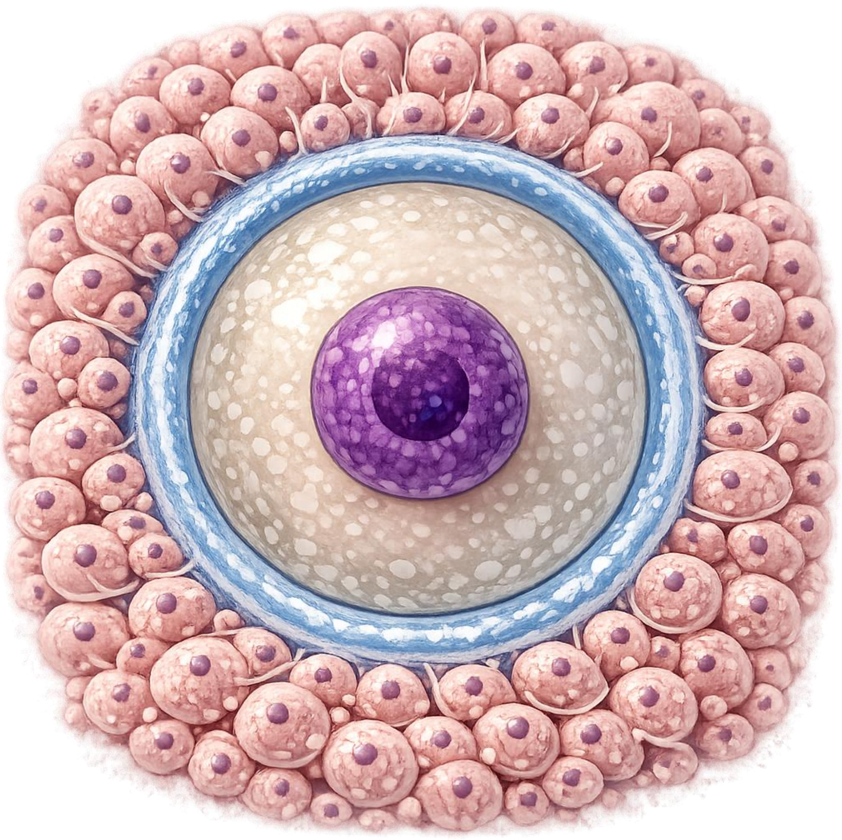
The beginning



Sperm/ Spermatozoon/ Male gamete



Ovum/ Egg cell/ Female gamete

Length of DNA in a Single Human Cell: Each diploid human cell contains about: ~2 meters of DNA

Total Length of DNA in the Entire Human Body: ~ 74 trillion meters

To Visualize This:
Total human DNA ≈ ~500 times the distance from Earth to the Sun

If you stretched all DNA from one human body end to end, it would reach beyond the solar system.

(وَتَحْسَبُ أَنَّكَ جُرْمٌ صَغِيرٌ،، وفيك إنطَوَى العالمُ الأكبرَ)

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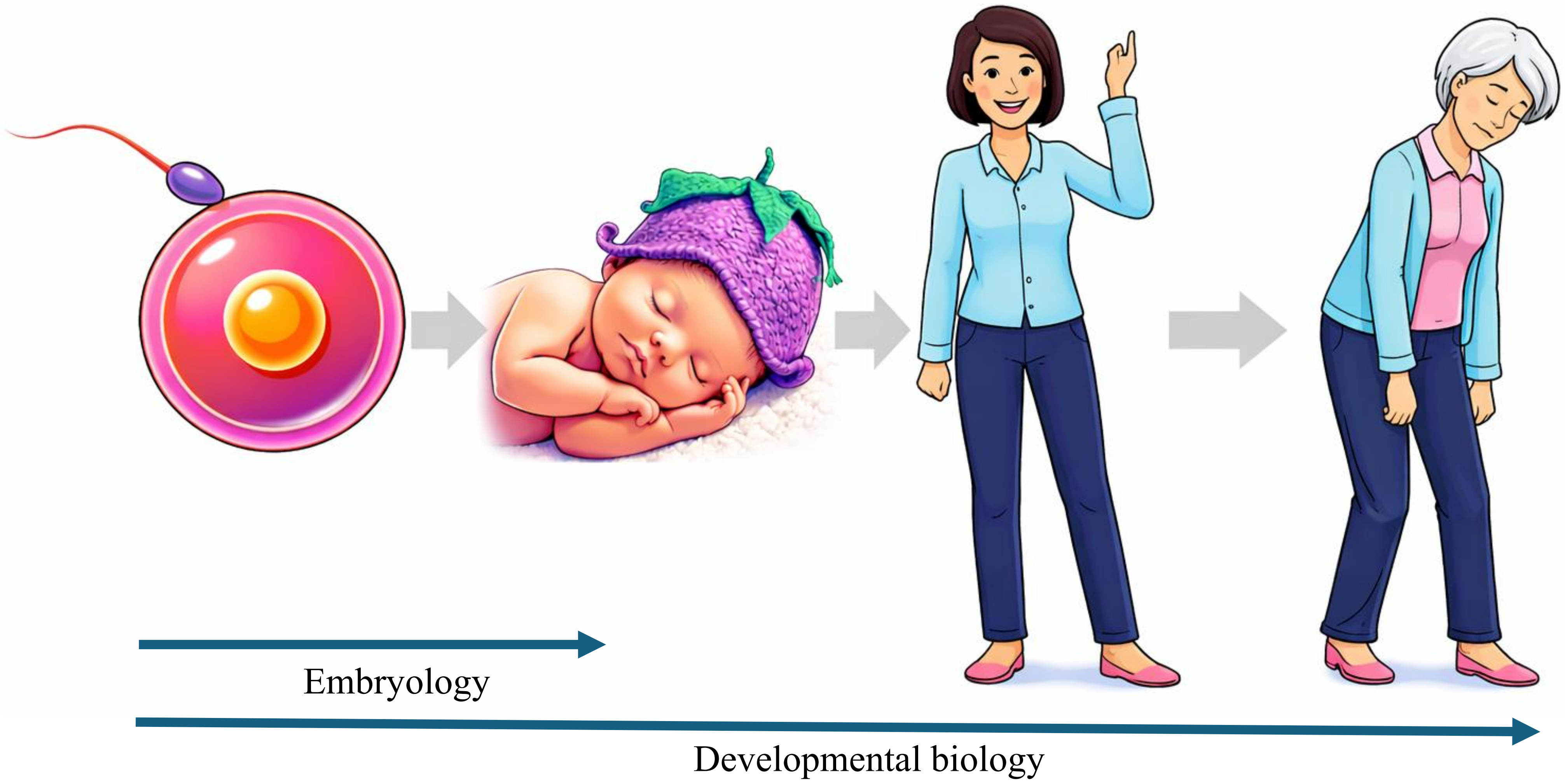
Embryology is the branch of biological science that studies the development of a human being from fertilization until birth.

It explains:

- ✓ How a single cell (zygote) becomes a multicellular organism
- ✓ How tissues, organs, and systems are formed
- ✓ Why congenital anomalies occur

Embryology is the foundation of anatomy.
You cannot fully understand adult anatomy without knowing how structures develop.

Embryology is the science that tells us how the human body is built.
When you study anatomy, you see structures as they appear in adults.
Embryology explains how these structures developed, moved, rotated, and sometimes failed to form normally.



Developmental biology is a broader scientific field that studies the mechanisms by which organisms grow and develop throughout their entire life. While **Embryology** is a branch that studies the development of an organism from fertilization to the birth.

Why Is Embryology Important for Medical Students?

Embryology helps you understand:

- ✓ Congenital anomalies (e.g., cleft lip, spina bifida)
- ✓ Normal anatomical variations
- ✓ Radiological anatomy
- ✓ Surgical anatomy
- ✓ Obstetrics and pediatrics

As future doctors, you will encounter patients with congenital anomalies.
Embryology gives you the *why*, not just the *what*.
It trains you to think developmentally—and that's a powerful clinical skill.

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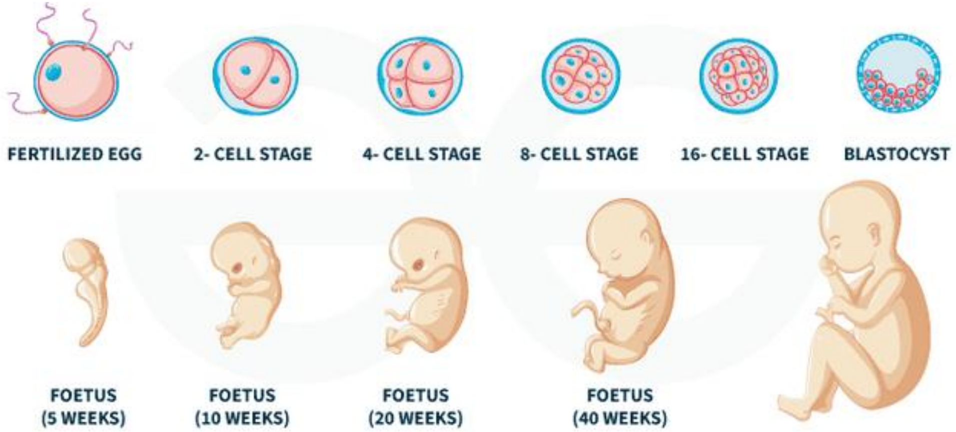
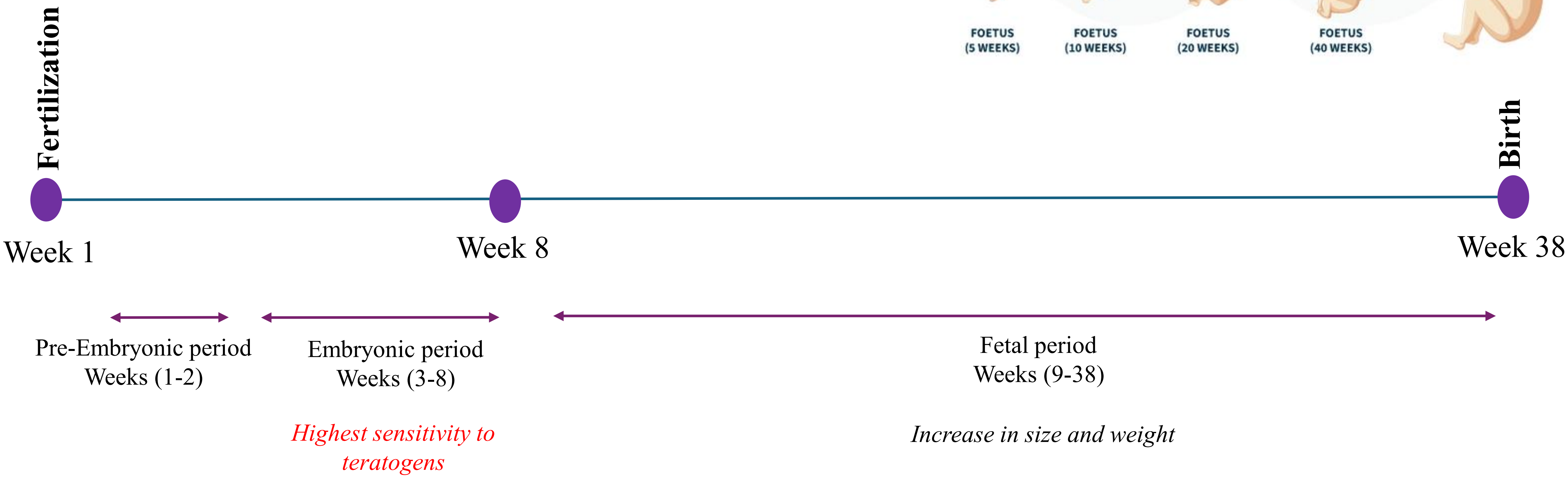
Prenatal development is divided into three major periods:

1. **Germinal period (Pre-embryonic):** weeks 1-2
2. **Embryonic period:** weeks 3-8
3. **Fetal period:** weeks 9- birth





Pregnancy lasts about **38 weeks** from fertilization, or about **40 weeks** from the first day of the last menstrual period (LMP).
The **germinal period** is from fertilization to the end of week 2. During this stage, the fertilized egg divides rapidly, forms a blastocyst, and implants in the uterus.
The **embryonic period** is from week 3 to week 8. This is when the major organs are formed, so it is the most critical stage of development.
From week 9 until birth, the **fetal period** begins. During this time, the organs grow and mature until the baby is ready for birth.

Pre-embryonic & Embryonic Period:

Is the stage of development during which:

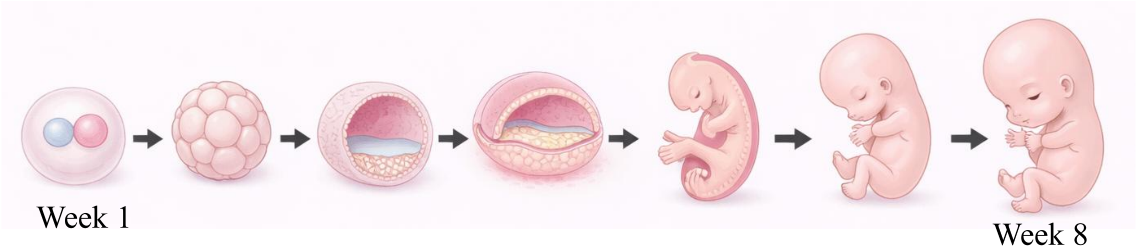
- ✓ The basic body plan is established
- ✓ All major organs begin to form

Duration

From fertilization to the end of the 8th week

Main Characteristics:

- ✓ Rapid cell division and differentiation
- ✓ Formation of the three germ layers
- ✓ Beginning of all major organ systems
- ✓ Highest sensitivity to teratogens (drugs, infections, radiation) → *embryonic period*



If something goes wrong here, the defect is usually structural and permanent.

This is why we always emphasize drug safety in early pregnancy.

Fetal Period:

Is the stage during which:

- ✓ Organs grow, mature, and become functional
- ✓ The fetus increases significantly in size and weight

Duration

From the beginning of the 9th week until birth

Main Characteristics

- ✓ Rapid growth
- ✓ Functional maturation of organs
- ✓ Lower sensitivity to teratogens compared to the embryonic period

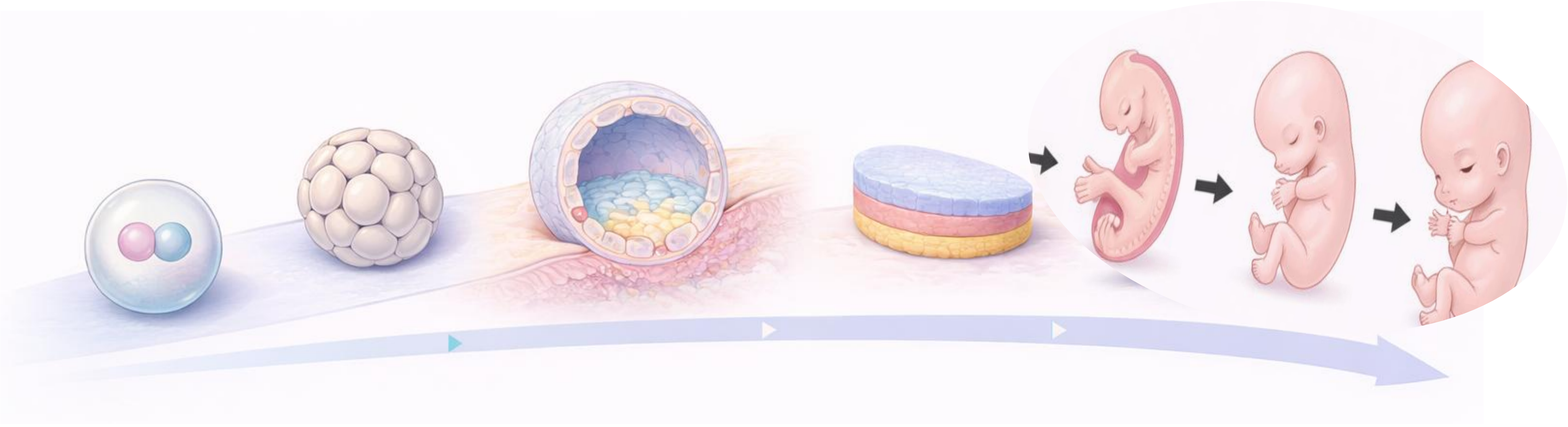
Problems during this period usually affect growth or function, rather than basic structure.

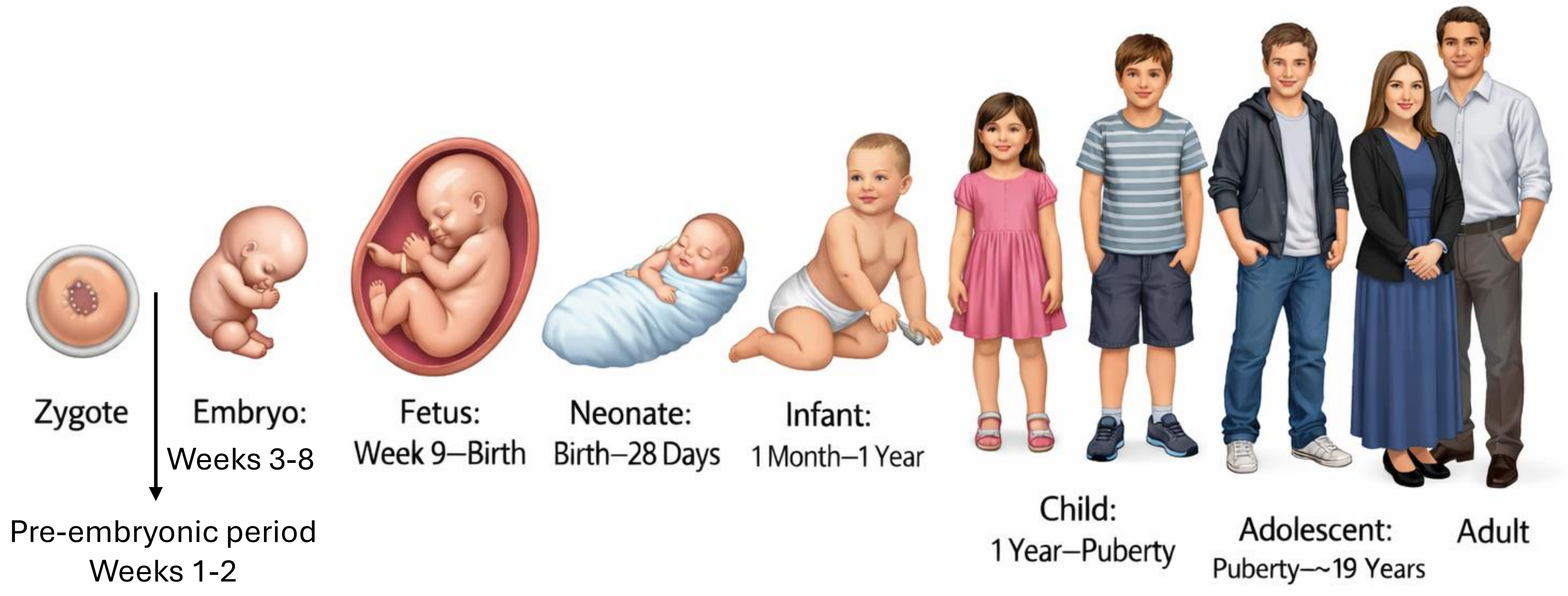
Embryogenesis is the entire process of early human development starting from fertilization and ending at the end of the 8th week of development.

It includes

- ✓ Fertilization
- ✓ Cleavage and blastocyst formation
- ✓ Implantation
- ✓ Formation of the bilaminar and trilaminar embryonic disc
- ✓ Body folding
- ✓ Organogenesis: Formation of organs from the three germ layers during weeks 3–8.

Time period
Week 1 to Week 8



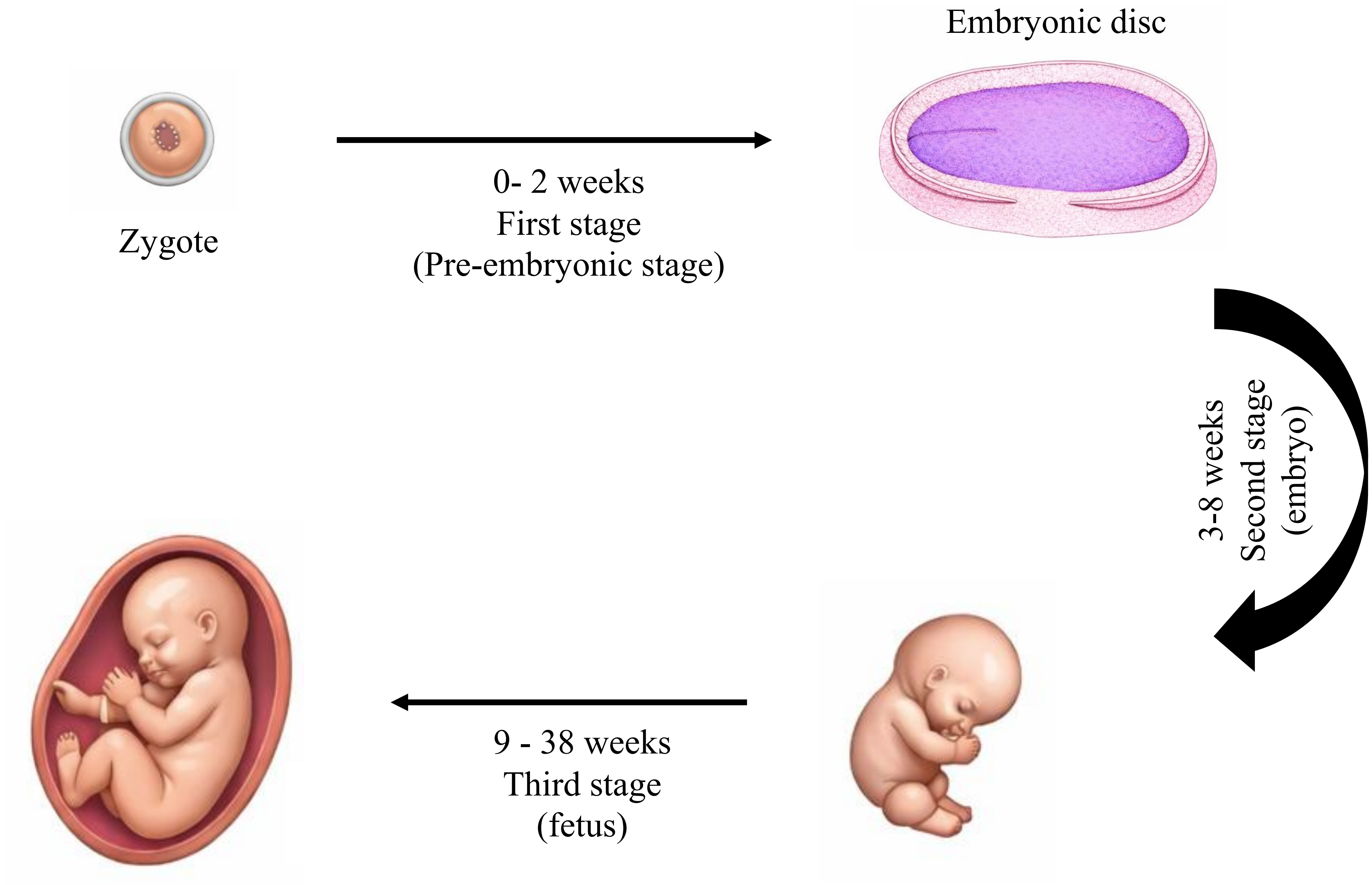


Embryo: weeks 3–8
Fetus: week 9 → birth
Neonate: birth–28 days
Infant: 1 month–1 year
Child: 1 year–puberty
Adolescent: puberty– ~19 years
Adult: after completion of growth

Prenatal: Refers to the period **before birth**. Includes:

- **Pre-embryonic period:** weeks 1-2 (fertilization, cleavage, blastulation, implantation)
- **Embryonic period:** weeks 3–8 (organ formation)
- **Fetal period:** week 9 → birth (growth and maturation)

Postnatal: Refers to the period **after birth**. Includes:
Neonatal period, Infancy, Childhood, Adolescence, and Adulthood.
Perinatal: Period **around birth**, usually from late pregnancy to shortly after delivery.
Neonatal period: The period from **birth to 28 days** of life.
Infancy: The period from the end of the neonatal period (1 month) to 1 year of age.
Childhood: The period from 1 year to the onset of puberty.
Adolescence: The period from the onset of puberty to attainment of full physical and sexual maturity.
Adulthood: The period from completion of growth and development until death.

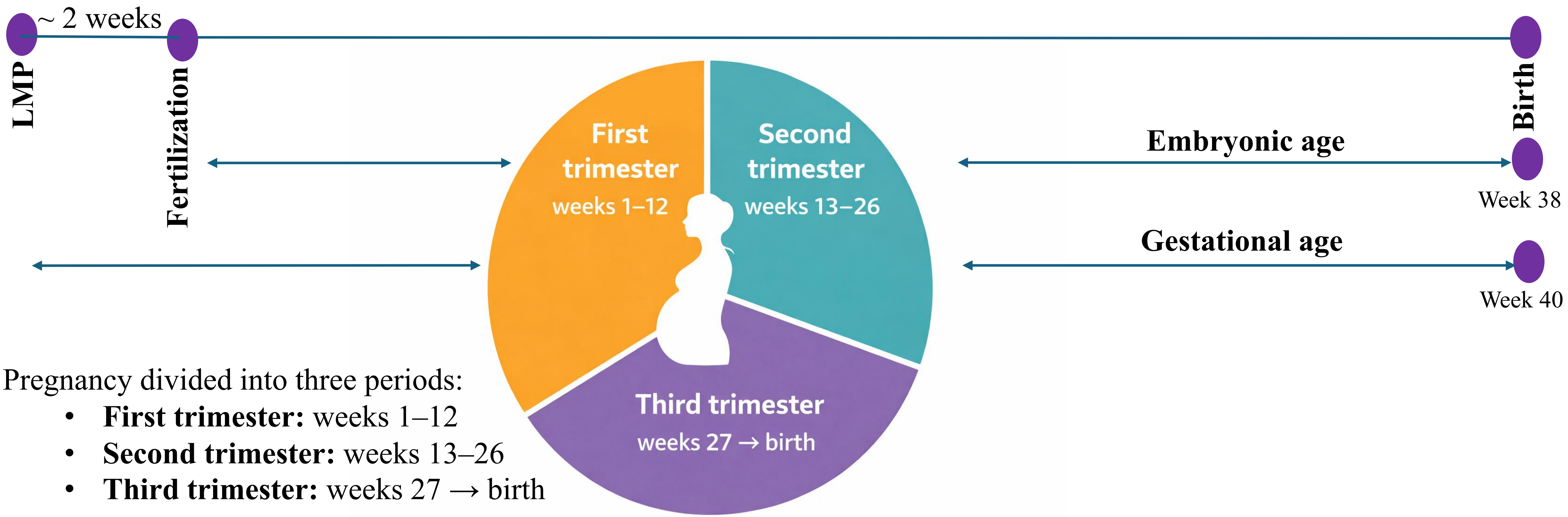

Zygote
0- 2 weeks
First stage
(Pre-embryonic stage)
Embryonic disc
3-8 weeks
Second stage
(embryo)
9 - 38 weeks
Third stage
(fetus)

Pregnancy-Related Time Terms

Gestational age refers to the time elapsed since the first day of the last menstrual period (LMP).
- ✓ Typically about two weeks before fertilization occurs.
- ✓ Used clinically.

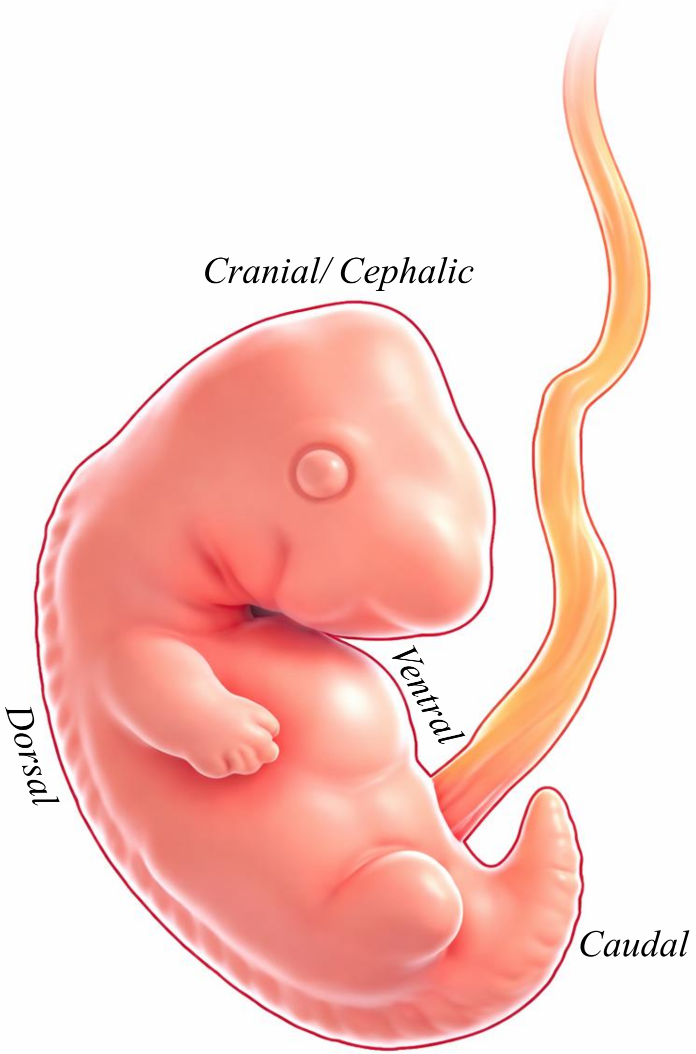
Embryonic (or fertilization) age: measures the actual age of the embryo from the time of fertilization.

Therefore, gestational age is generally ***about two weeks longer*** *than embryonic age*



Pregnancy divided into three periods:
- **First trimester:** weeks 1–12
- **Second trimester:** weeks 13–26
- **Third trimester:** weeks 27 → birth

In embryology, **directional terms** are slightly different from adult anatomical terms because the embryo undergoes folding and rotation.



Embryo

Fetus

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The **cell cycle** is the sequence of events through which a cell:

- ✓ Grows
- ✓ Replicates its DNA
- ✓ Divides into two cells

Before a cell divides, it must prepare itself carefully.
The cell cycle is the organized timetable that controls when a cell grows, copies its DNA, and finally divides.
This process is tightly regulated to protect genetic information.

Main Phases of the Cell Cycle:

1. Interphase (longest phase)

1. G1 phase
2. S phase
3. G2 phase

Interphase is the period between cell divisions
It includes:

- ✓ Cell growth
- ✓ DNA replication
- ✓ Preparation for mitosis

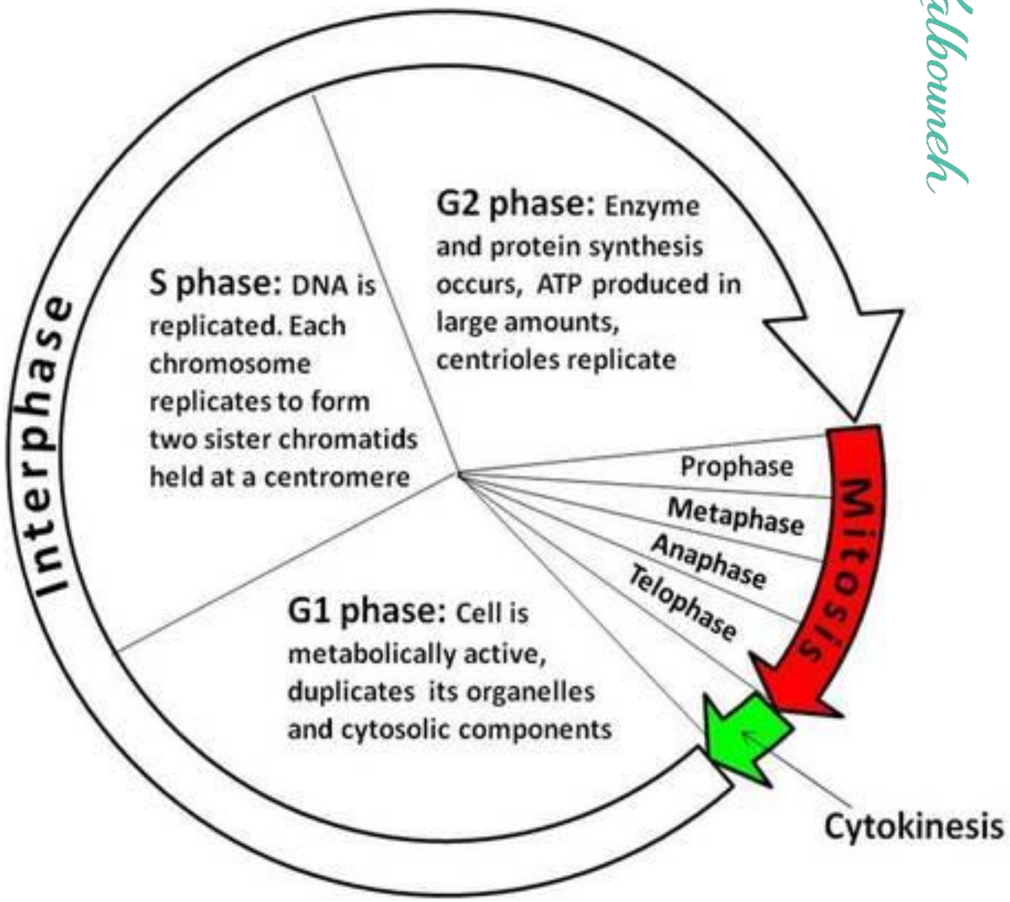
Interphase = **G1 + S + G2**

Note: Interphase is not a resting stage.
It is an active period where the cell grows and prepares for division.
Most of the cell's life is spent in interphase.

M phase is when all the preparation pays off.
The nucleus divides first, followed by the cytoplasm, resulting in two identical cells.

2. M phase

1. Mitosis → nuclear division
2. Cytokinesis → cytoplasmic division



Note: The cell cycle has two major parts.
Most of the time, the cell is not dividing—it is preparing.
Actual division occupies only a small portion of the cycle.

G1 Phase (First Gap Phase)

During **G1 phase**:

✓ Cell increases in size
✓ Proteins and organelles are synthesized
✓ Cell performs its normal functions

This is the **decision-making phase**

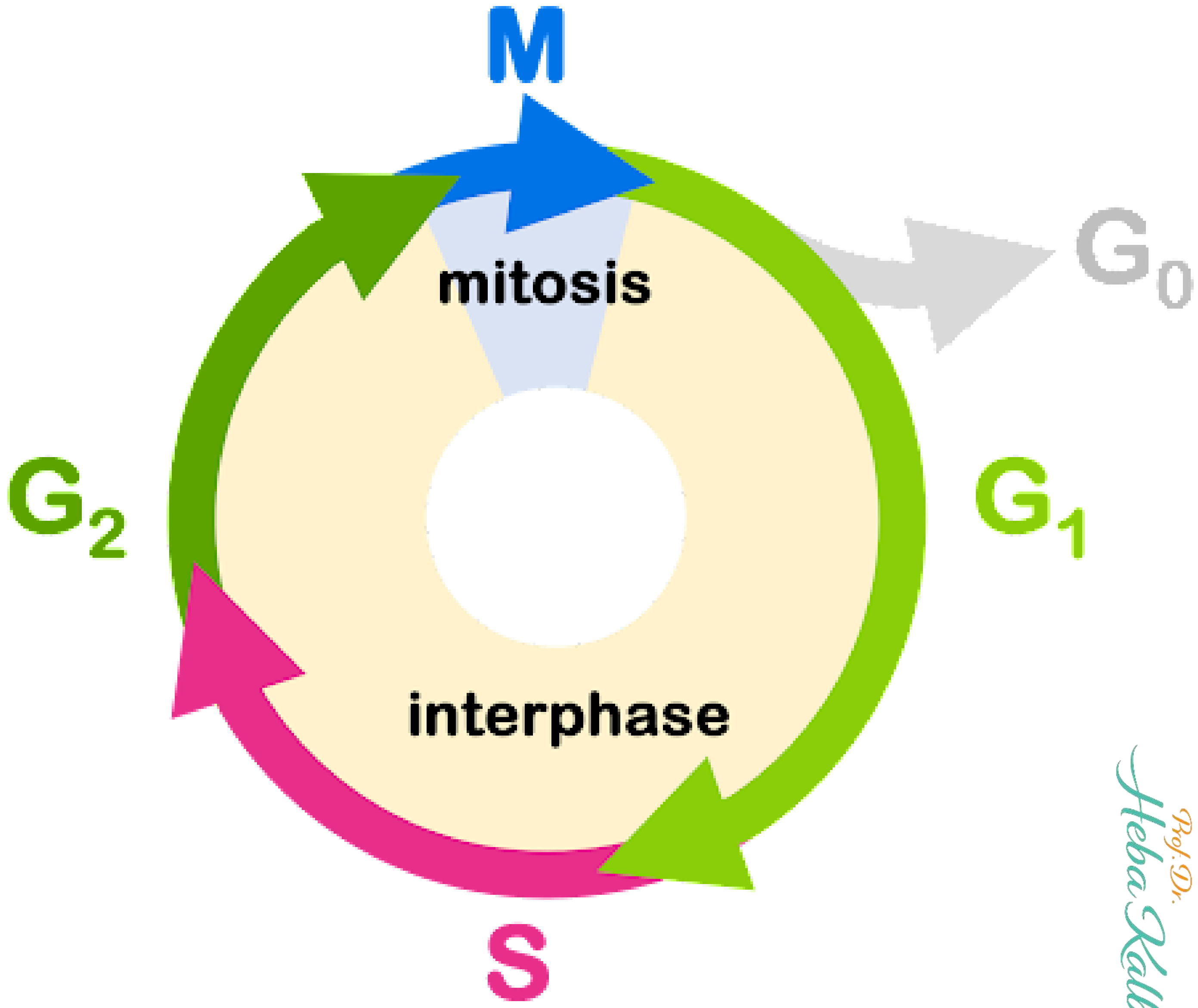
In G1 phase, the cell asks an important question:
'Am I ready to divide?'
If conditions are favorable, the cell continues.
If not, it may stop or enter a resting phase."

G0 Phase (Resting Phase)

✓ Some cells leave the cell cycle and enter **G0**
✓ Cells in G0:
- Are metabolically active
- Do not divide

Examples:

- Neurons
- Cardiac muscle cells



S Phase (Synthesis Phase)

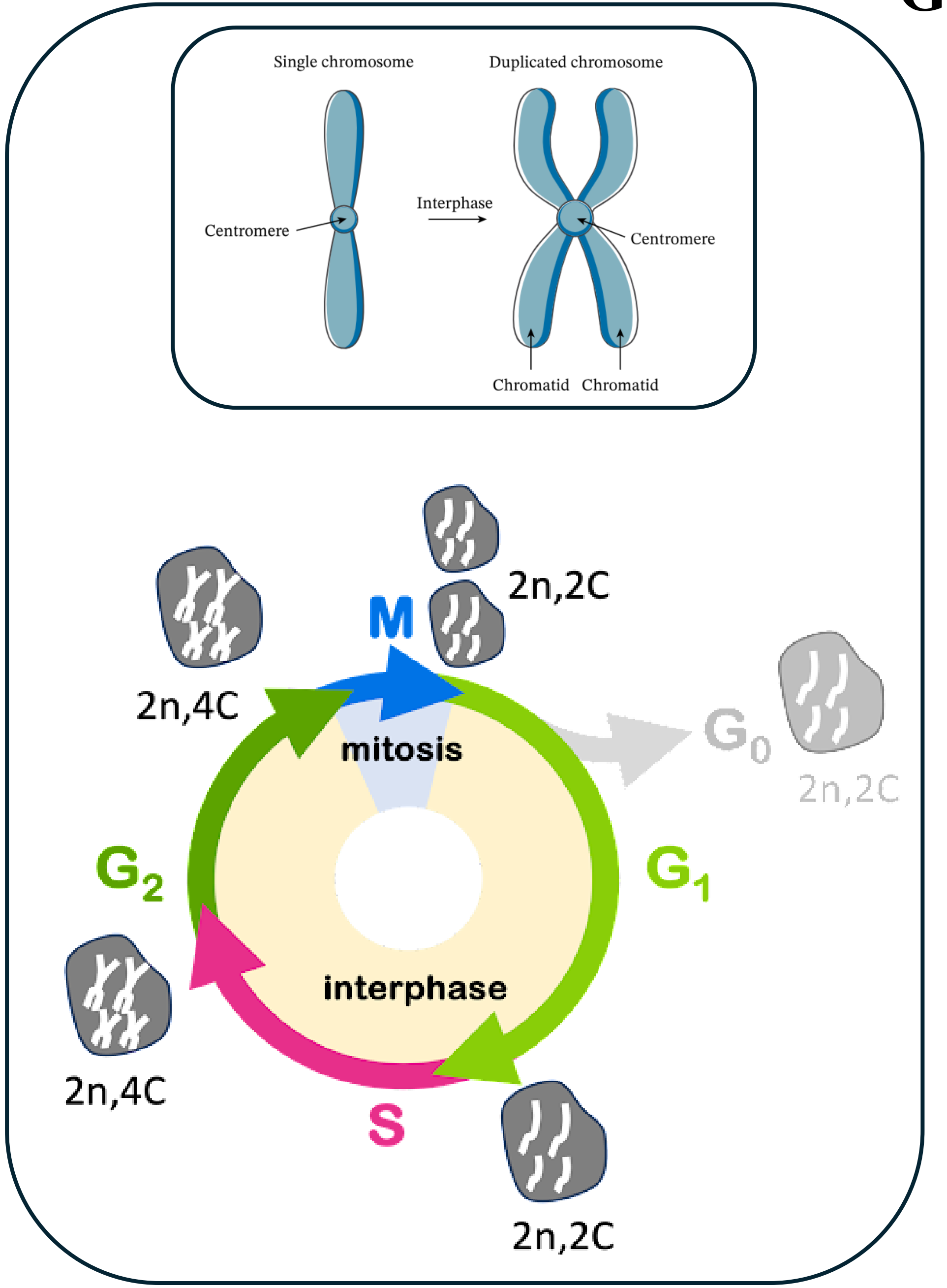
During **S phase**:

✓ DNA is **replicated**

✓ Each chromosome forms **two identical sister chromatids**

✓ Chromosome number does NOT change

S phase is the most critical part of interphase. DNA replication must be accurate because any mistake will be passed to daughter cells. At the end of this phase, each chromosome has two sister chromatids.



G2 Phase (Second Gap Phase)

During **G2 phase**:

✓ Cell continues to grow

✓ Proteins for mitosis are produced

✓ DNA is checked for errors

✓ Final preparation for mitosis

G2 is the final quality-control stage. The cell checks whether DNA replication was completed correctly before division begins.

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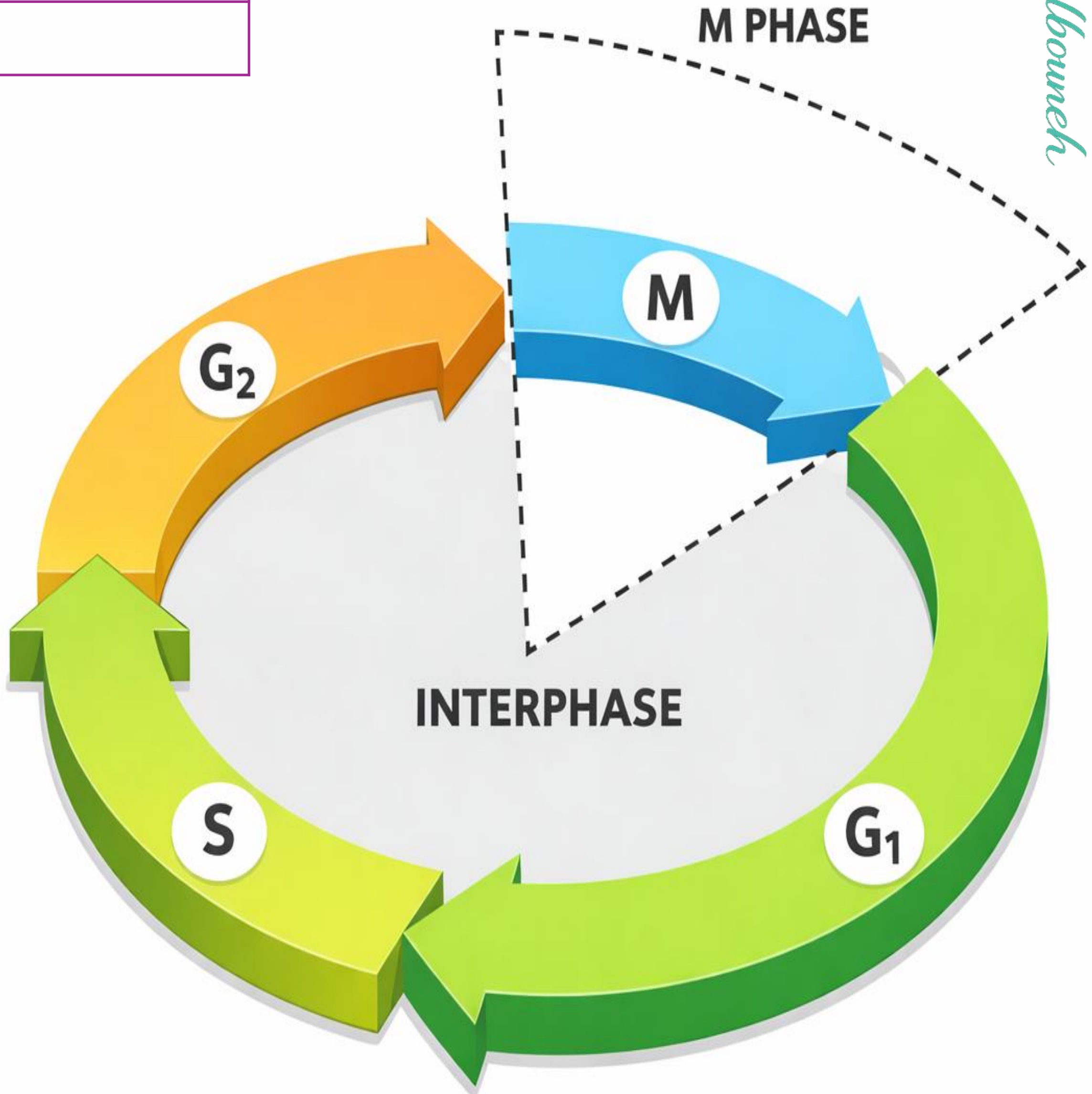
Feature	Interphase	M Phase
Duration	Long	Short
Main activity	Growth & DNA replication	Cell division
DNA	Replicated	Separated

Most of the cell's life is spent preparing, not dividing.
Mitosis is short but highly organized.



Clinical Correlation

✓ Uncontrolled cell cycle → cancer
✓ Chemotherapy targets rapidly dividing cells
✓ Understanding the cell cycle is essential for:
- Pathology
- Oncology
- Embryology

Before a cell divides, it must grow, copy its DNA, and check for errors.

Cell Cycle Checkpoints

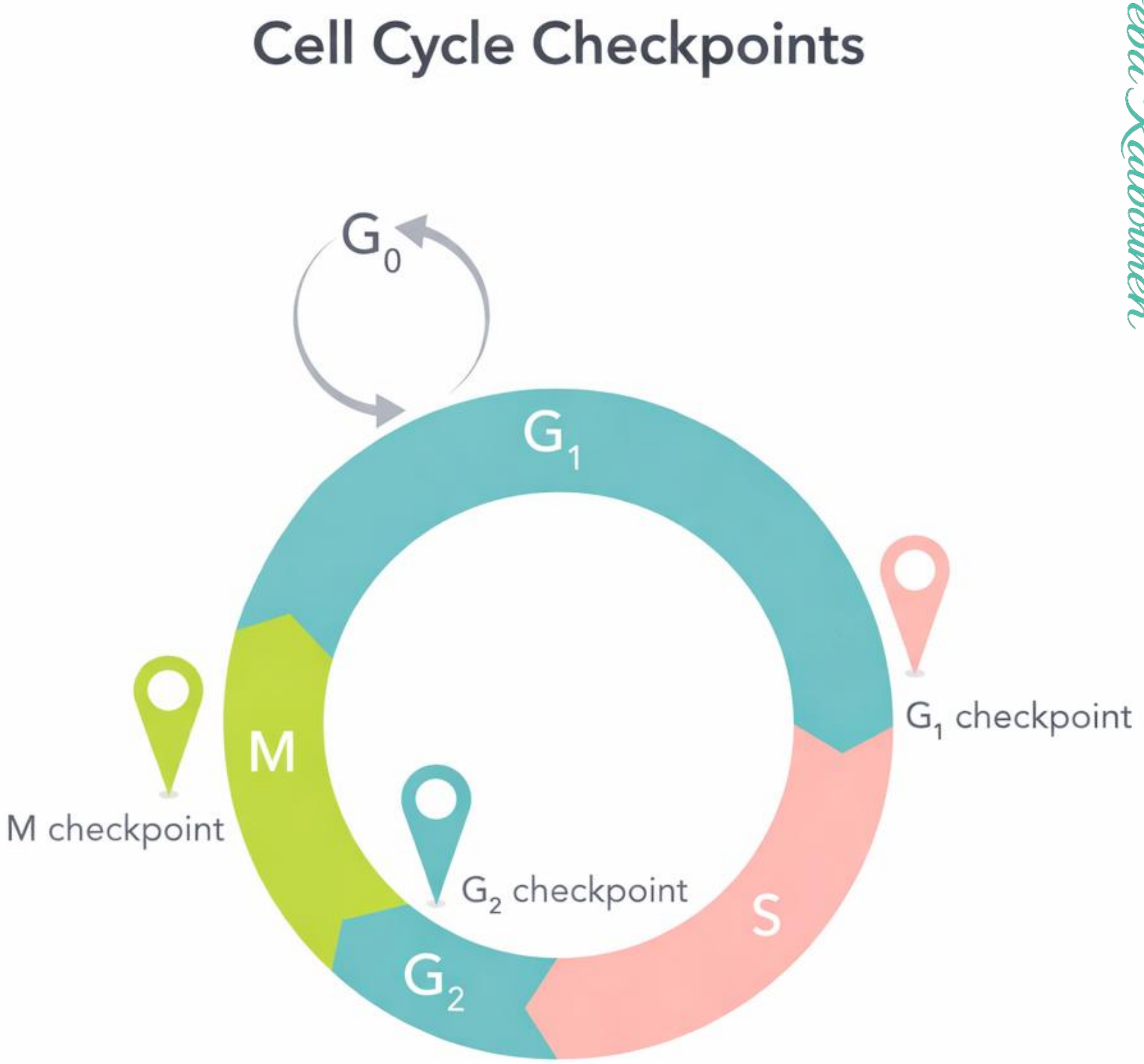
Checkpoints ensure:

- ✓ DNA integrity
- ✓ Proper cell size
- ✓ Correct chromosome replication

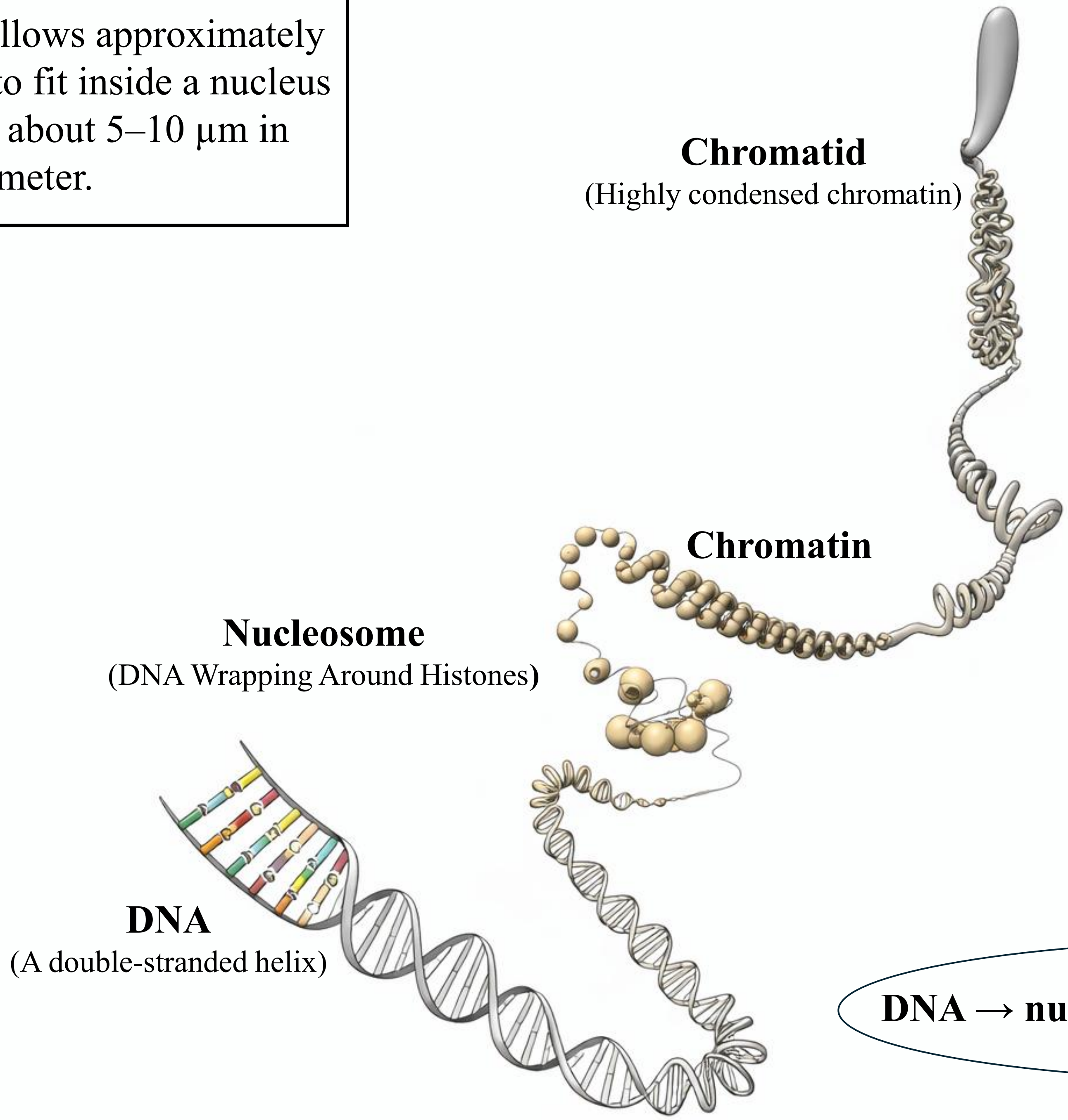
Major checkpoints:

- G1 checkpoint
- G2 checkpoint
- Metaphase checkpoint

The cell cycle has checkpoints similar to security gates. If a problem is detected, the cycle stops until it is fixed. Failure of these checkpoints can lead to cancer.



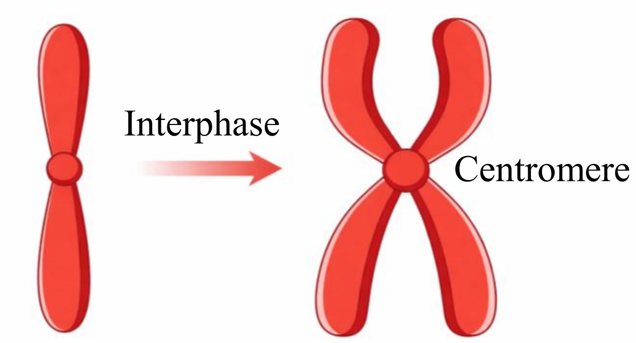
Note:
DNA packaging allows approximately 2 meters of DNA to fit inside a nucleus measuring only about 5–10 µm in diameter.

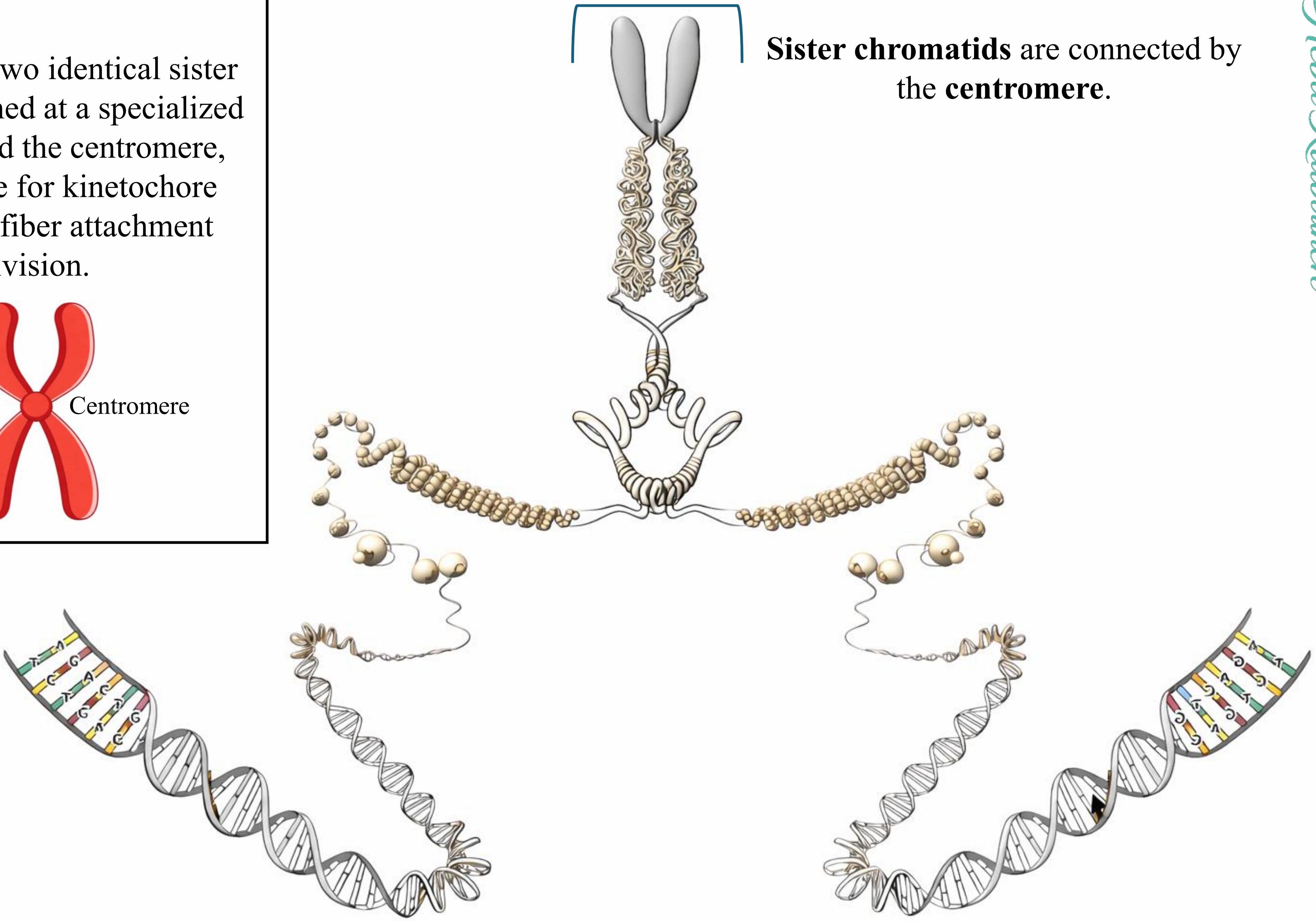


DNA → nucleosome → chromatin → chromatid.

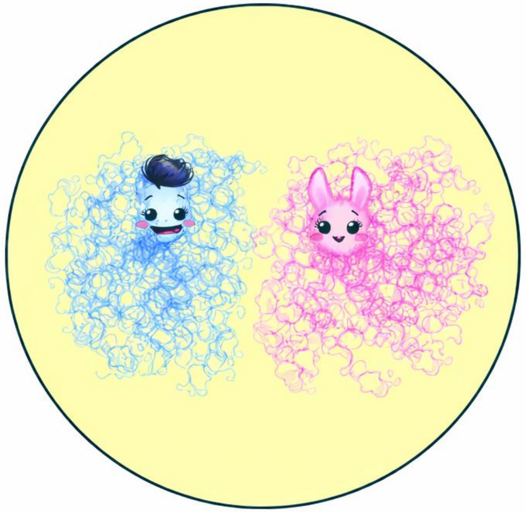
DNA replication

After DNA replication, two identical sister chromatids remain attached at a specialized constricted region called the centromere, which serves as the site for kinetochore formation and spindle fiber attachment during cell division.

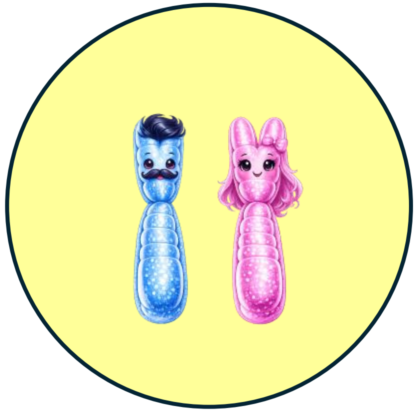




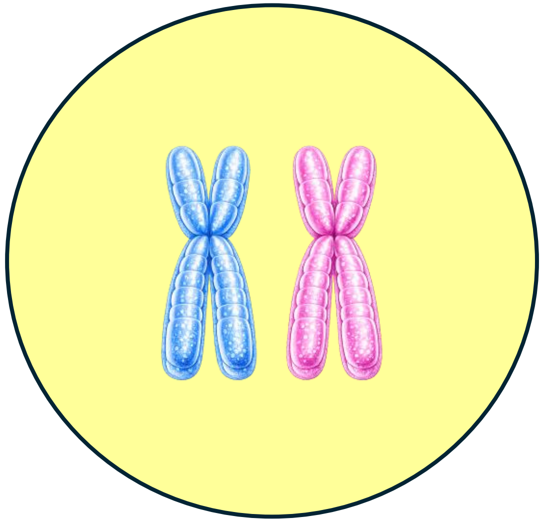
Sister chromatids are connected by the **centromere**.



DNA condensation (packaging)



DNA replication



Dispersed chromatin = active, working DNA

- ✓ DNA is loosely packed
- ✓ Found during interphase
- ✓ Allows gene expression and normal cell activity
- ✓ Looks like a fine, thread-like network

Condensed chromatid = compact DNA for division

2n, 2C

- **23 paternal chromosomes** (unreplicated, one chromatid)
- **23 maternal chromosomes** (unreplicated, one chromatid)

- ✓ DNA is tightly packed
- ✓ Found during cell division (mitosis/meiosis)
- ✓ Allows accurate separation of genetic material
- ✓ Appears as thick, visible rod-like structures

Condensed chromatid = compact DNA for division

2n, 4C

- **23 paternal chromosomes** (replicated, two sister chromatids)
- **23 maternal chromosomes** (replicated, two sister chromatids)

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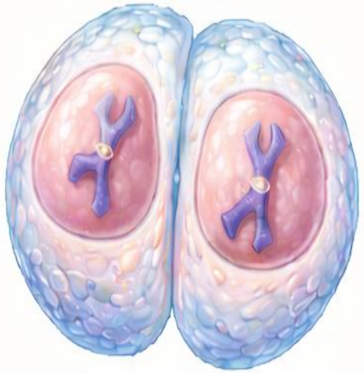
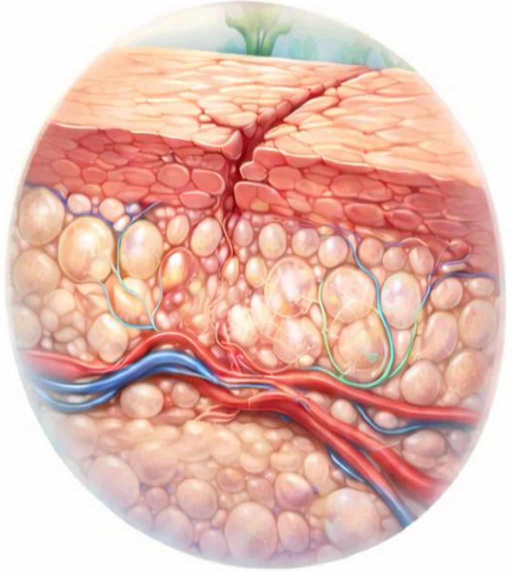
Why Do Cells Divide?

Cell division is essential for:
- ✓ Growth
- ✓ Tissue repair and renewal
- ✓ Formation of gametes (sperm and ova)

There are two main types of cell division:
- ✓ **Mitosis** → division of somatic (body) cells
- ✓ **Meiosis** → division of germ cells to form gametes





Note: Multicellular eukaryotes are made of two fundamental cell types: **germ** and **somatic** cells.

- ✓ **Germ cells** produce gametes and are the only cells that can undergo meiosis *(as well as mitosis)*.
- ✓ **Somatic cells** are all the other cells that form the building blocks of the body and they only divide by mitosis.

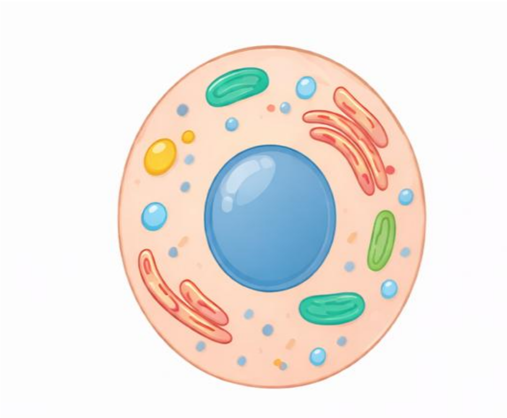
Somatic cells

- ✓ All the **body cells** that make up tissues and organs (e.g., skin, muscle, liver).
- ✓ **Function:** growth, structure, repair, and maintenance of the body.
- ✓ **Chromosome content:** diploid (**2n = 46 chromosomes** in humans).
- ✓ **Division:** divide by **mitosis**.
- ✓ **Genetic role:** changes (mutations) are **not inherited**.

Germ cells

- ✓ Cells that give rise to **gametes** (sperm and oocytes).
- ✓ **Function:** reproduction and transmission of genetic information to the next generation.
- ✓ **Chromosome content:** start diploid (**2n**) → gametes become haploid (**n = 23 chromosomes**).
- ✓ **Division:** undergo **meiosis** to form gametes (& undergo mitosis for proliferation!)
- ✓ **Genetic role:** genetic changes **can be inherited**.

Somatic mutations affect only the individual, whereas germ-line mutations can be transmitted to offspring.



Somatic cells are diploid cells, produced by mitosis, genetically identical

Gametes are haploid cells, produced by meiosis, genetically unique

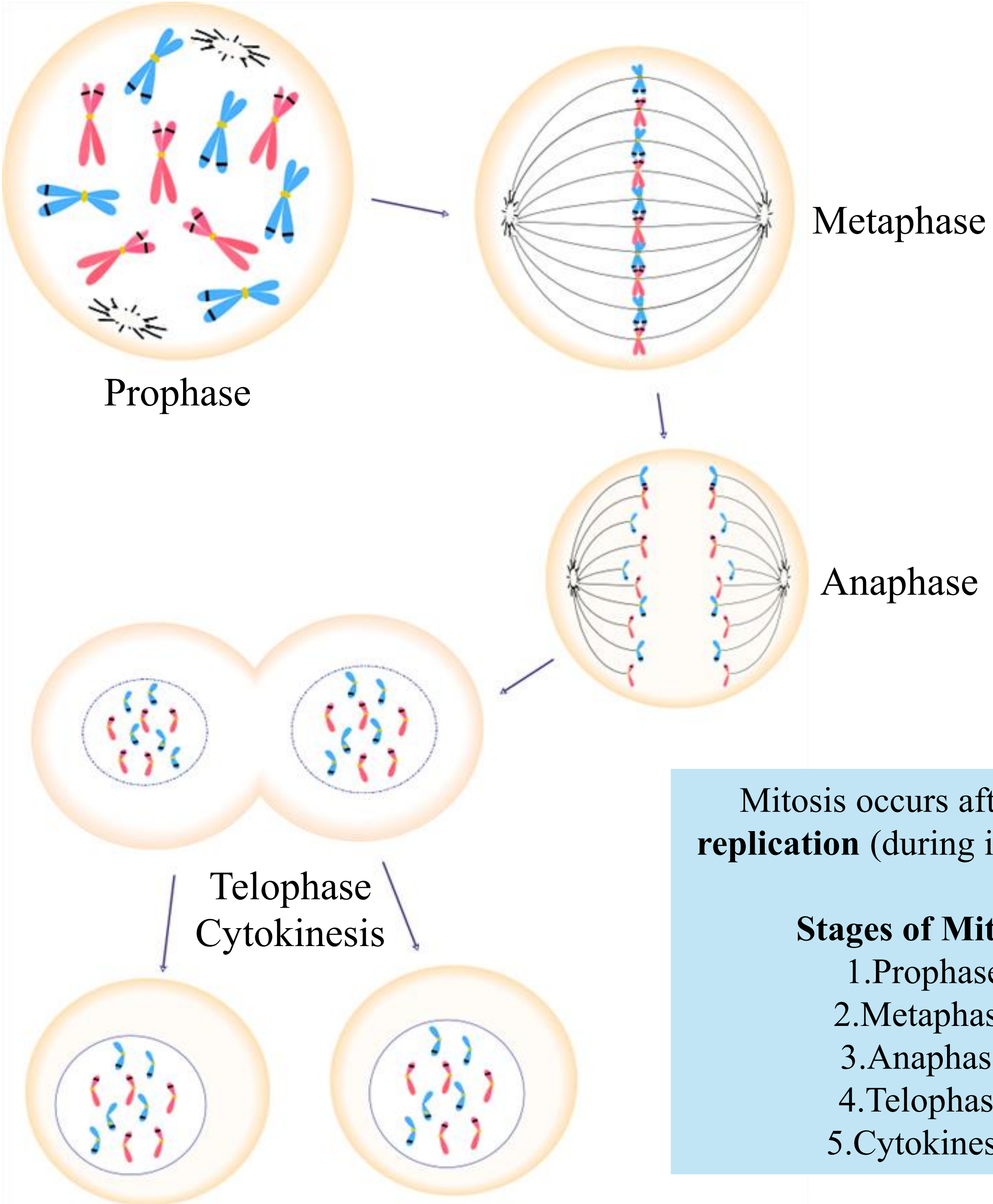
Mitosis is the type of cell division in which:

- ✓ One parent cell divides into two genetically identical daughter cells
- ✓ Each daughter cell has the same number of chromosomes as the parent cell

Importance of Mitosis

- Growth during development
- Replacement of damaged or dead cells
- Maintenance of tissues

Mitosis is responsible for maintaining the body.
Every time your skin renews itself or a wound heals, mitosis is taking place.



Mitosis occurs after **DNA replication** (during interphase).

Stages of Mitosis

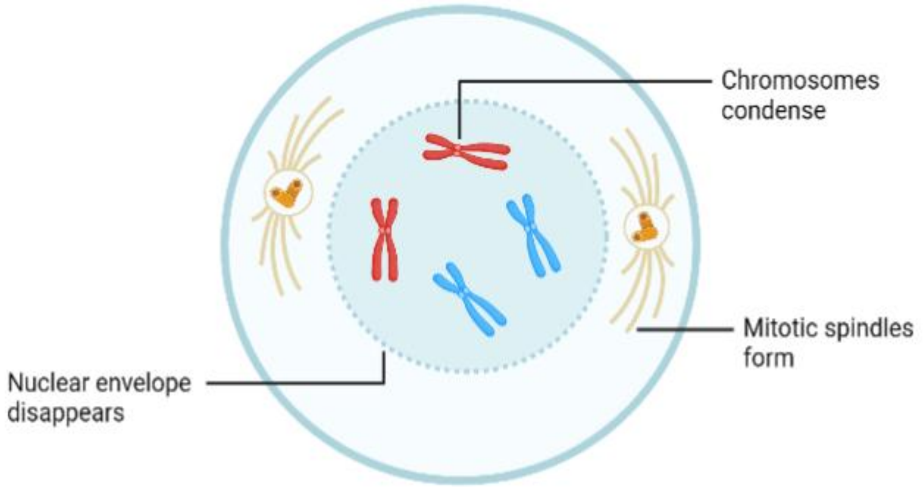
1.Prophase
2.Metaphase
3.Anaphase
4.Telophase
5.Cytokinesis

DNA **P**acked into chromatids

Prophase

- ✓ Chromosomes condense and become visible
- ✓ Nuclear membrane disappears
- ✓ Spindle fibers form

In prophase, chromosomes become visible for the first time.
The cell is preparing to divide.

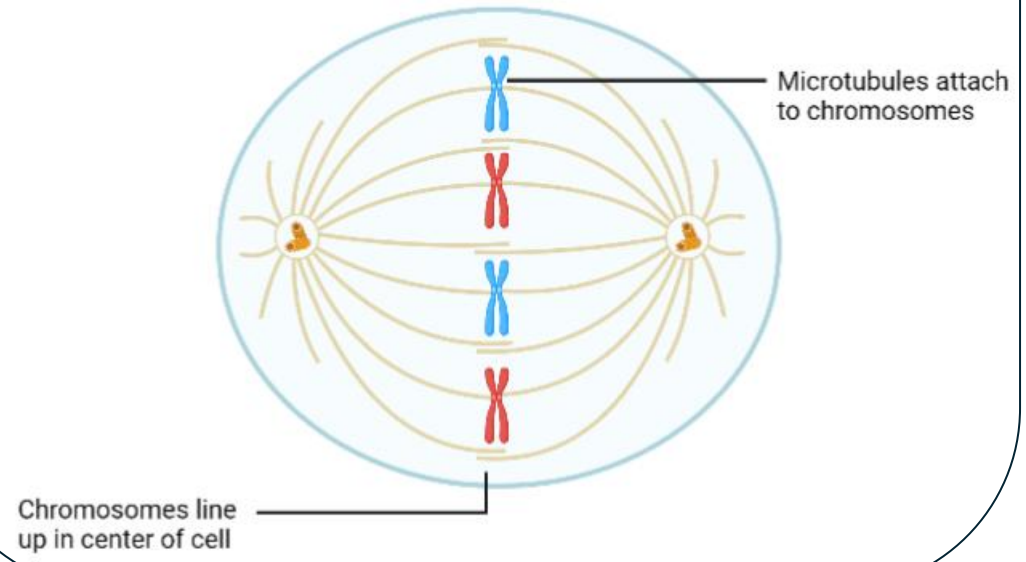


Chromosomes are arranged onto the **M**idline

Metaphase

- ✓ Chromosomes align at the **equatorial plane**
- ✓ Spindle fibers attach to centromeres

Metaphase is all about alignment.
Chromosomes line up in the middle of the cell.

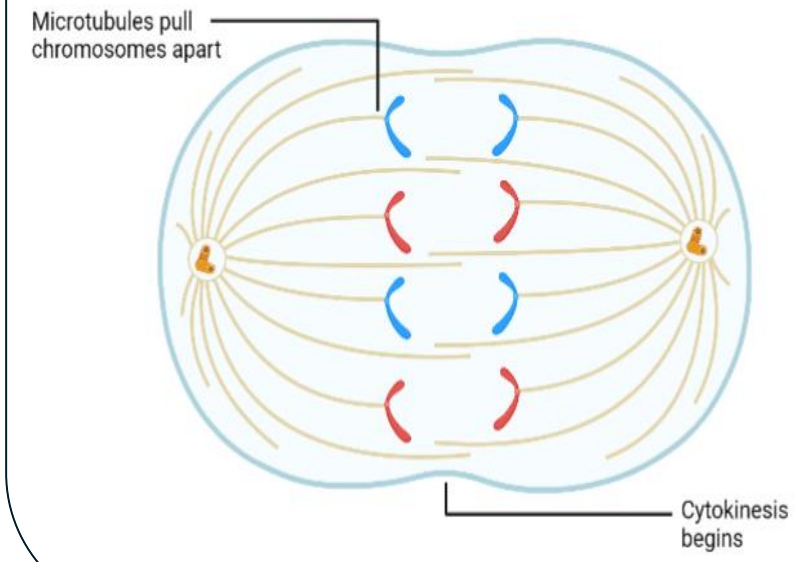


Anaphase

Chromatids move Away

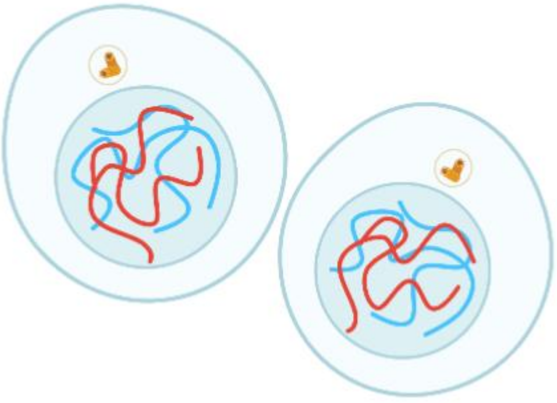
- ✓ Sister chromatids separate
- ✓ Move toward opposite poles

In anaphase, separation occurs. Each chromatid is pulled to opposite sides of the cell.



Cytokinesis

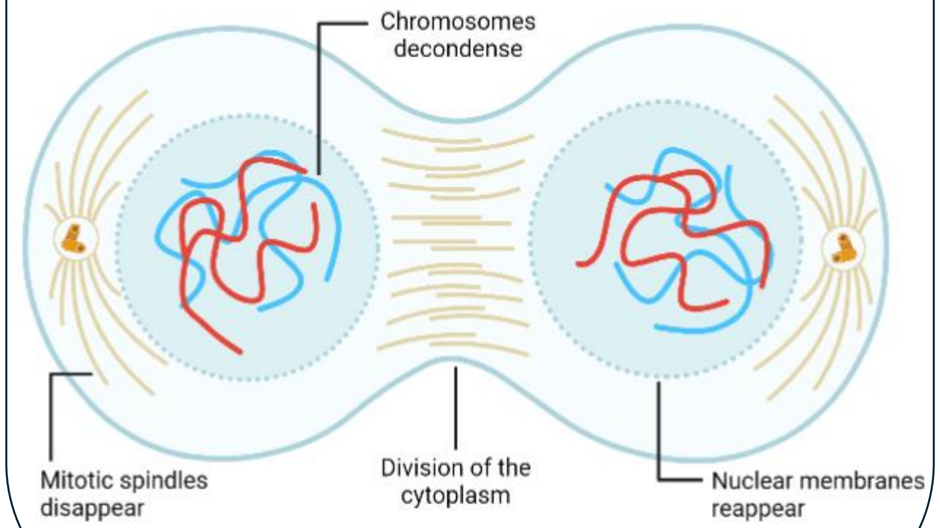
- ✓ Division of cytoplasm
- ✓ Two identical daughter cells formed


2 identical daughter cells are formed

Telophase

- ✓ Nuclear membranes reform
- ✓ Chromosomes decondense

In telophase, the cell starts to look normal again, but now there are two nuclei.



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Meiosis is a special type of cell division that:

- ✓ Produces gametes
- ✓ Reduces chromosome number from diploid (46) to haploid (23)
- ✓ Produces genetically different cells

Where Does Meiosis Occur?

- ✓ Germ cells in the testes and ovaries

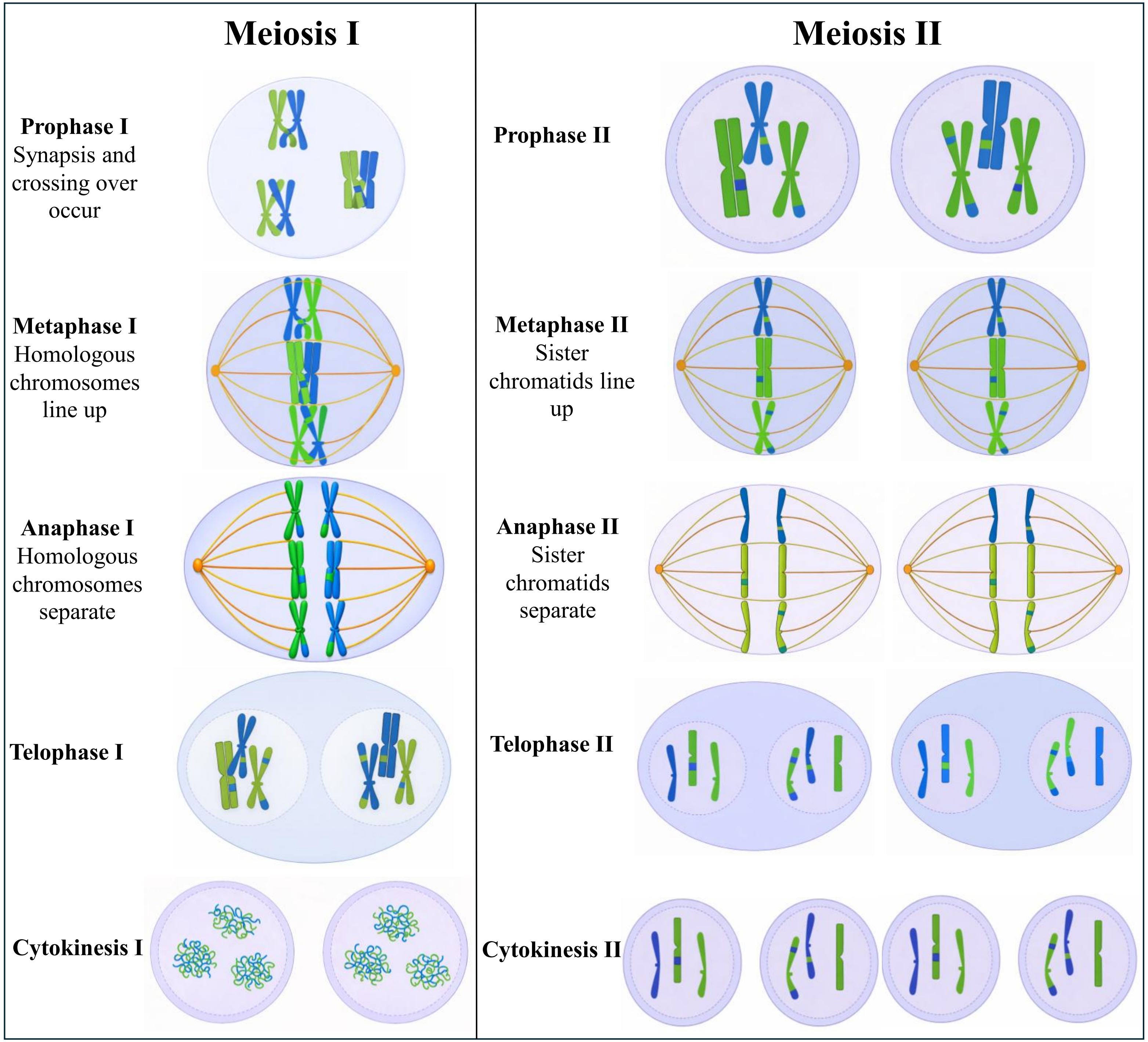
Importance of Meiosis

- ✓ Sexual reproduction
- ✓ Genetic variation
- ✓ Maintenance of chromosome number across generations

Without meiosis, chromosome numbers would double in every generation.
Meiosis ensures genetic diversity and stability.

Meiosis consists of two consecutive divisions:

- ✓ **Meiosis I** (reduction division)
- ✓ **Meiosis II** (similar to mitosis)



Meiosis I (Reduction Division)

Key Features

- ✓ Homologous chromosomes pair
- ✓ Crossing over occurs
- ✓ Chromosome number is reduced

Prophase I

- ✓ Homologous chromosomes pair (synapsis)
- ✓ Exchange of genetic material (crossing over)

↓↓↓

Prophase I is the most important stage of meiosis.
This is where genetic variation is created.

Metaphase I

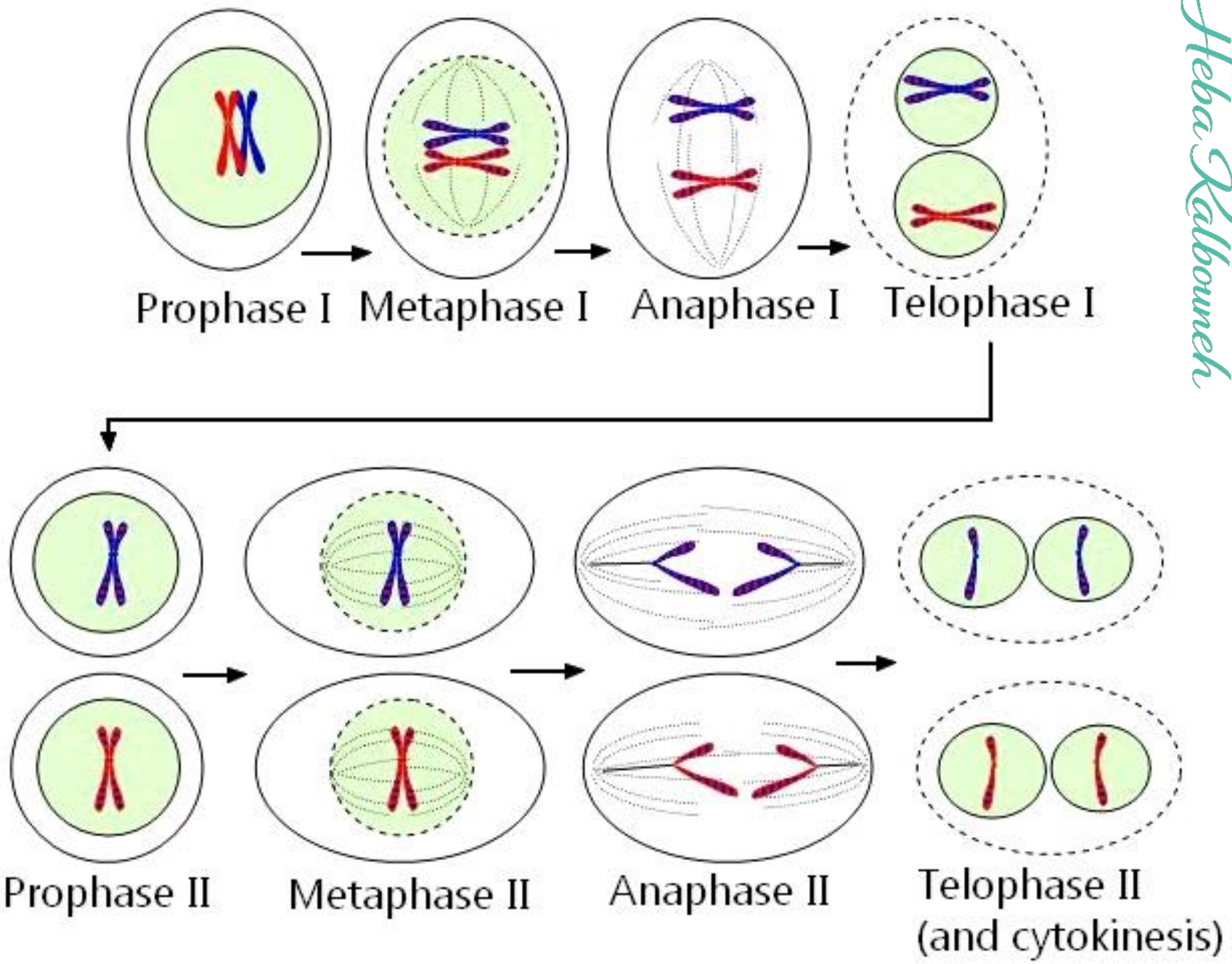
Homologous chromosome pairs align at equator

Anaphase I

Homologous chromosomes separate
Sister chromatids remain together

Telophase I

Two haploid cells are formed



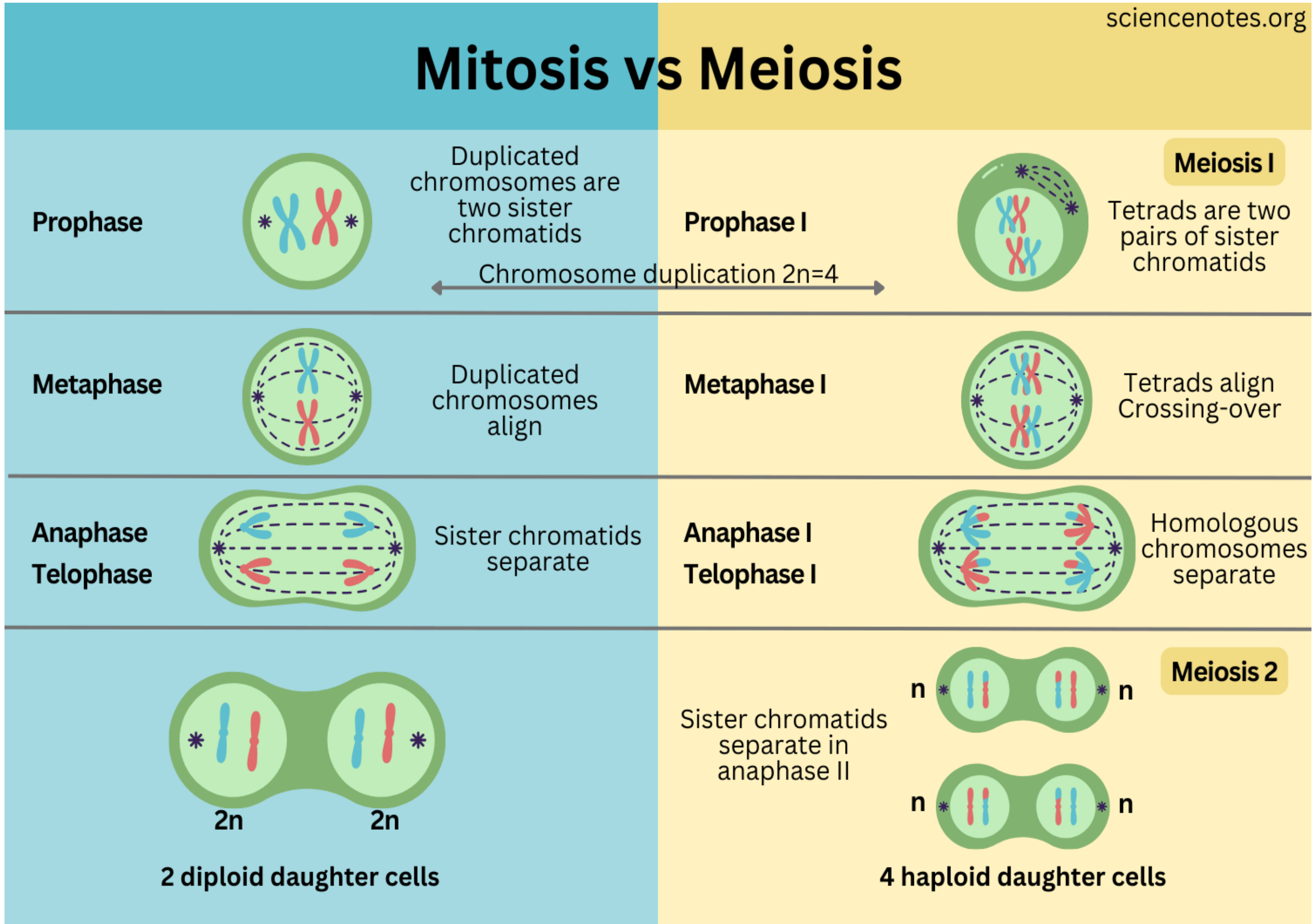
End Result

Four haploid, genetically different cells

Meiosis II

Key Features

- ✓ Similar to mitosis
- ✓ Sister chromatids separate



DNA replication occurs only once before meiosis I, and there is no chromatid duplication between meiosis I and meiosis II.

- ✓ **Mitosis** maintains the body
- ✓ **Meiosis** enables reproduction
- ✓ **Mitosis** produces identical cells
- ✓ **Meiosis** produces genetically diverse gametes

Feature	Mitosis	Meiosis
Occurs in	Somatic cells	Germ cells
Number of divisions	One	Two
Daughter cells	Two	Four
Genetic makeup	Identical	Different
Chromosome number	Diploid	Haploid
Function	Growth & repair	Reproduction

Clinical Relevance

- ✓ Errors in mitosis → cancer
- ✓ Errors in meiosis → chromosomal abnormalities (e.g., nondisjunction)
- ✓ Meiosis explains inheritance patterns
- ✓ Essential foundation for embryology and genetics

Normal meiosis → gametes: 23 chromosomes
Fertilization: 23 + 23 = 46

Mitosis keeps us alive every day.
***Meiosis** ensures life continues into the next generation.*
Together, they form the foundation of development, inheritance, and disease.

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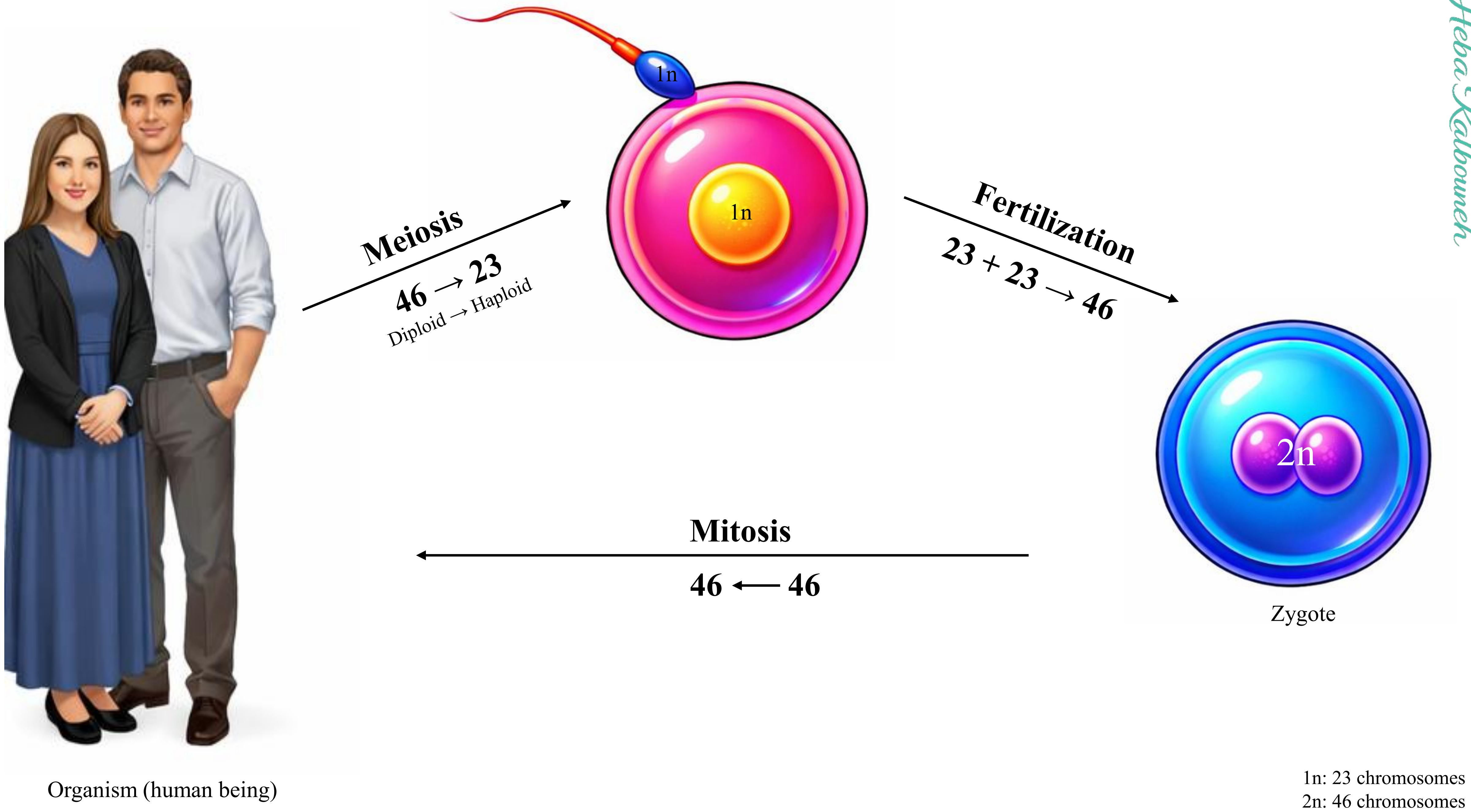
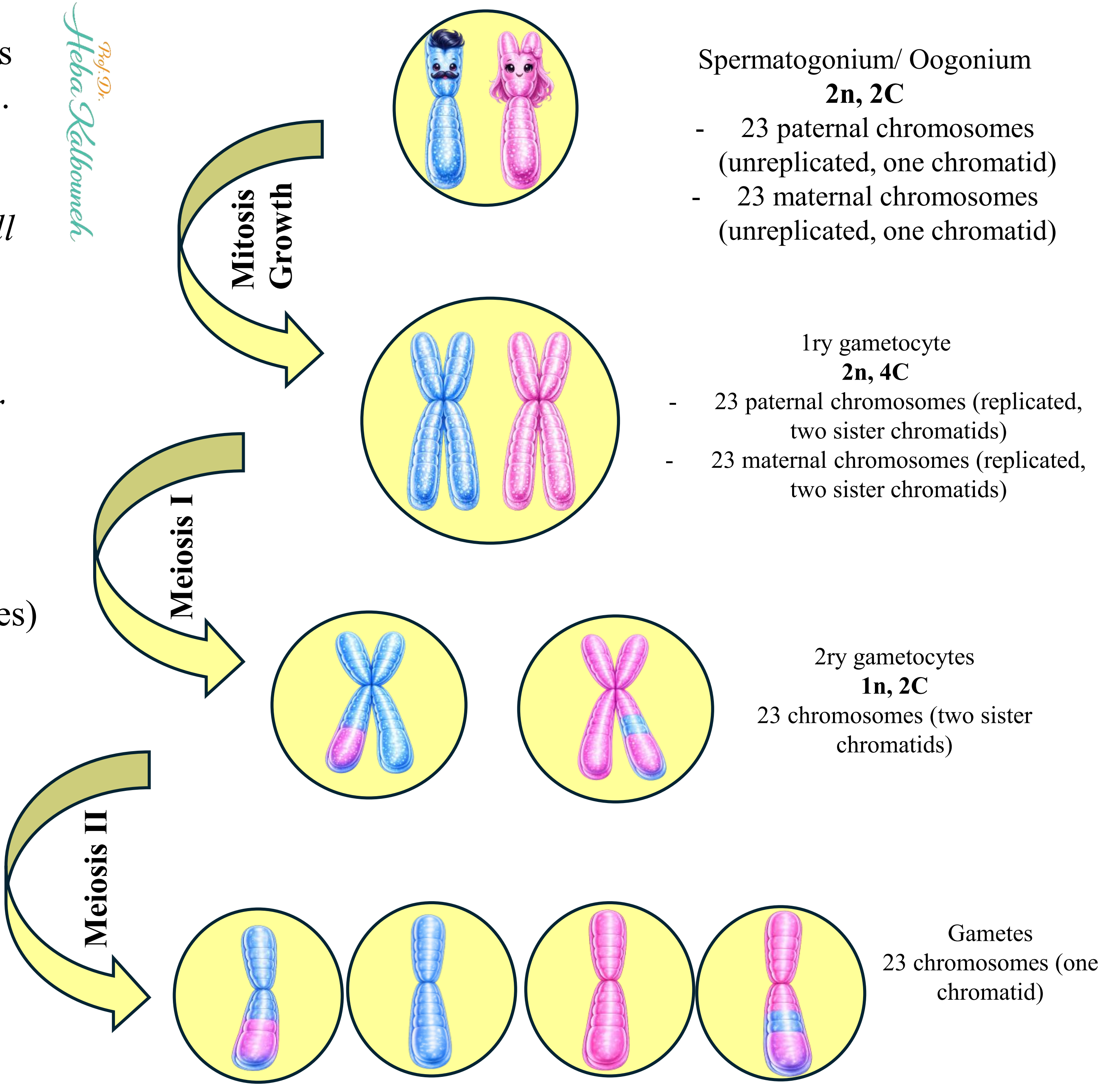

1n
1n
Meiosis
46 → 23
Diploid → Haploid
Fertilization
23 + 23 → 46
2n
Zygote
Mitosis
46 ⟵ 46
Organism (human being)
1n: 23 chromosomes
2n: 46 chromosomes

Gametogenesis is the process by which mature gametes (Sperm or Ovum) are formed from primitive germ cells.

The production of sperm and ova (eggs), takes place through the process of meiosis. During meiosis, two cell divisions separate the paired chromosomes in the nucleus and then separate the chromatids that were made during an earlier stage of the cell's life cycle, resulting in gametes that each contain half the number of chromosomes as the parent.

It occurs in the **gonads** and includes:
Spermatogenesis → formation of spermatozoa (in testes)
Oogenesis → formation of ova (in ovaries)

Main purposes:
1. Reduction of chromosome number from diploid (2n) to haploid (1n)
2. Genetic variation (crossing over, independent assortment)
3. Production of specialized cells for fertilization



Phases of Gametogenesis (Common Framework)

Both spermatogenesis and oogenesis follow the same three fundamental phases:

A. Multiplication Phase (Mitotic proliferation)

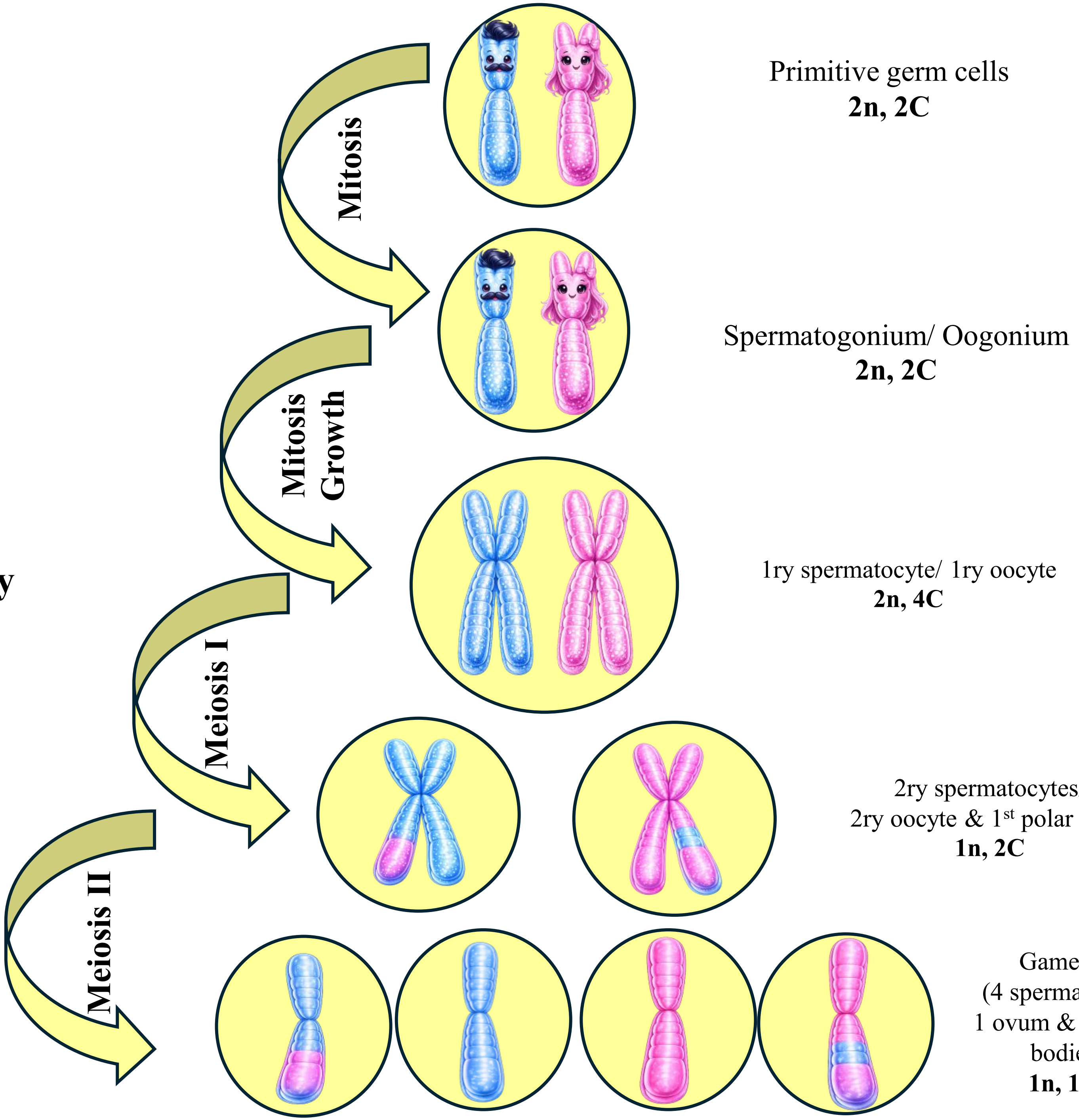
- ✓ Germ cells divide by **mitosis**
- ✓ Purpose: increase the number of germ cells
- ✓ Produces **spermatogonia** or **oogonia**

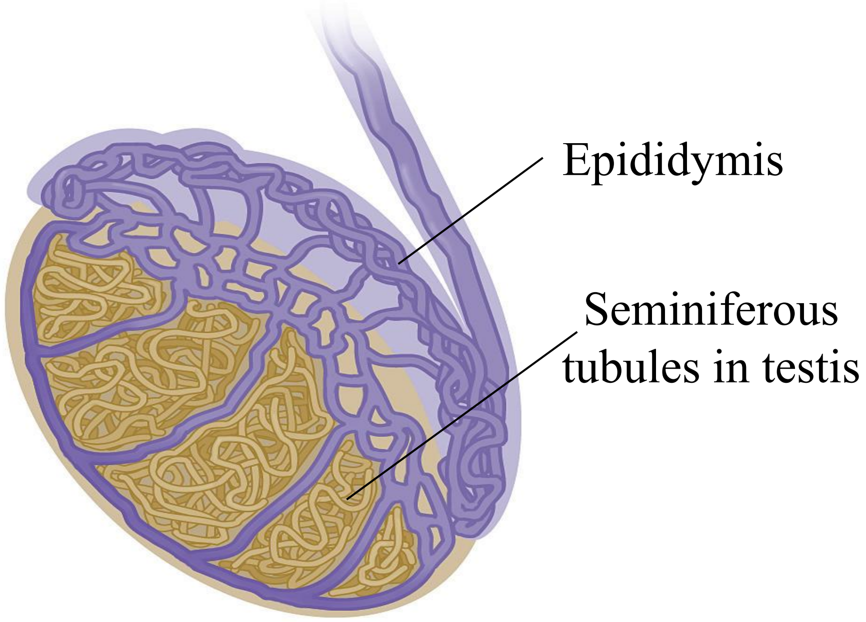
B. Growth Phase

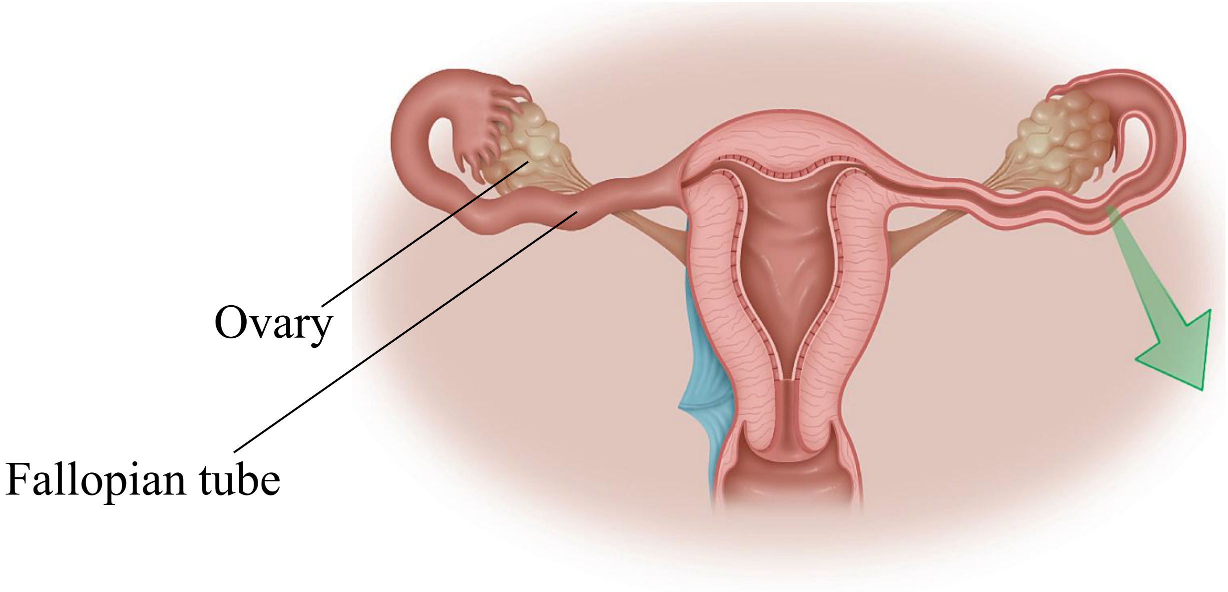
- ✓ Cells increase in size
- ✓ DNA replication occurs → cells become **primary spermatocytes** or **primary oocytes**
- ✓ Chromosomal status: 2n, 4C (diploid chromosomes, doubled DNA content)

C. Maturation Phase (Meiosis)

- ✓ Two meiotic divisions:
  - ○ **Meiosis I (reduction division) →** homologous chromosomes separate
  - ○ **Meiosis II (equational division) →** sister chromatids separate
- ✓ Final result: haploid cells (1n, 1C)







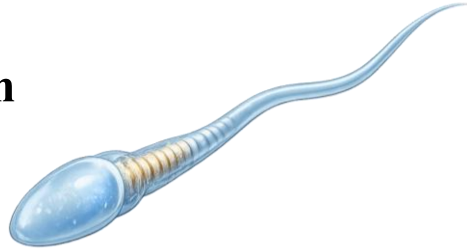
Aim of gametogenesis:

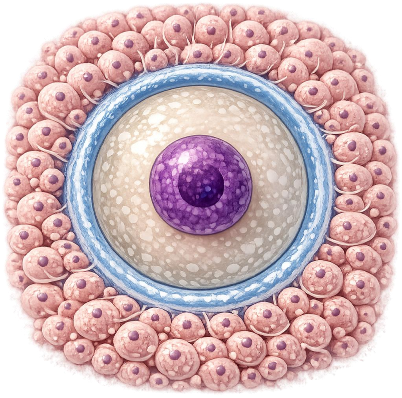
The aim of gametogenesis is to produce mature male and female gametes with the following changes:

Nucleus: Reduction of diploid number (46 chromosomes) into haploid number (23 chromosomes).

Cytoplasm: Increase in size in ova and markedly reduced in sperms.

Sperm





Ovum

Errors in Meiosis → Chromosomal Abnormalities
Example: Nondisjunction

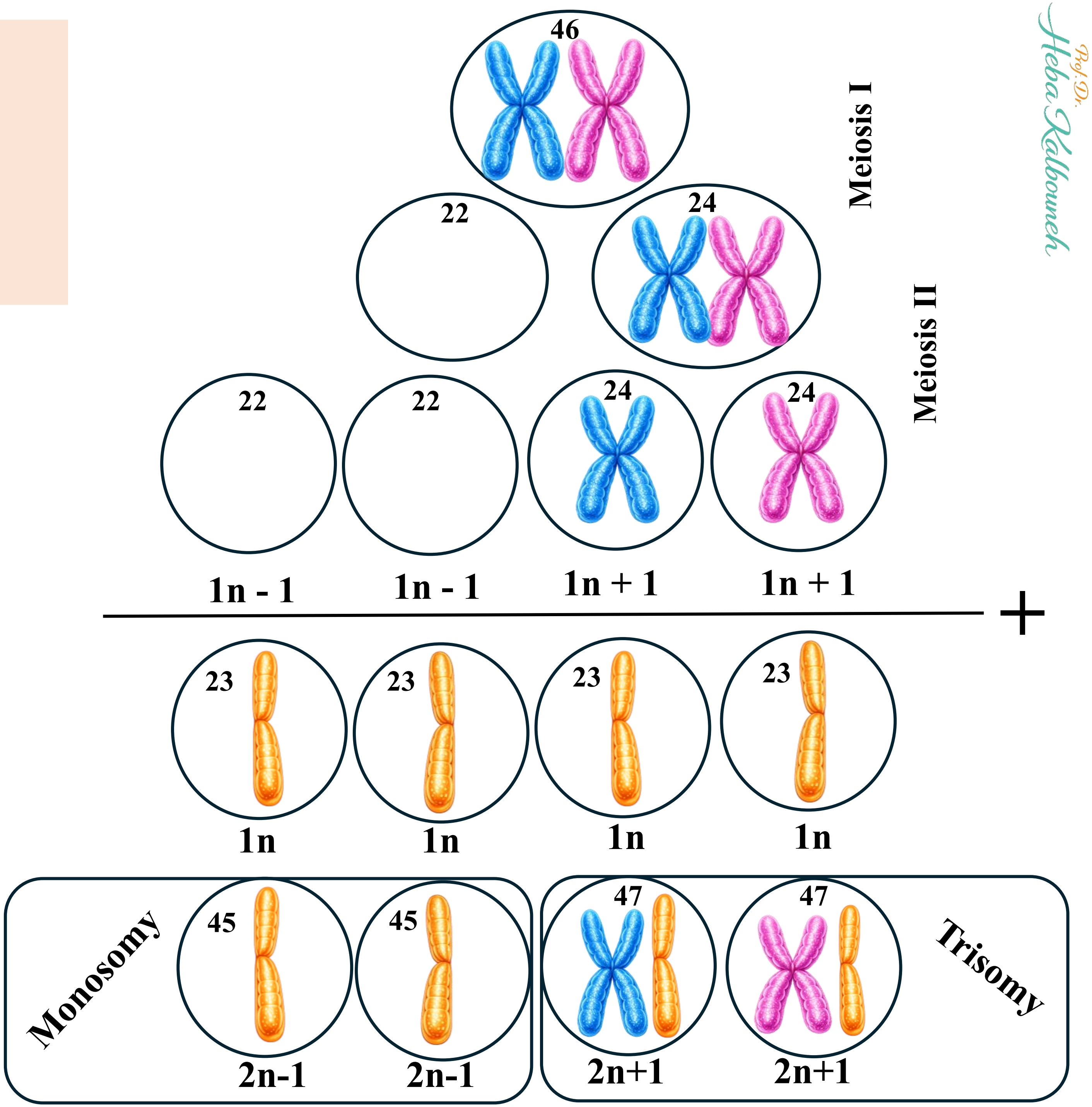
Nondisjunction: Failure of chromosomes to separate properly during meiosis, producing gametes with an abnormal chromosome number.

Nondisjunction in Meiosis I

✓ **What goes wrong:**
Homologous chromosomes fail to separate.

✓ **Resulting gametes:**
- 2 gametes with **n + 1** chromosomes
- 2 gametes with **n − 1** chromosomes

✓ **After fertilization:**
- **Trisomy (2n + 1)** or
- **Monosomy (2n − 1)**



Nondisjunction in Meiosis II

Meiosis I → normal

✓ **What goes wrong:**
Sister chromatids fail to separate.

✓ **Resulting gametes:**

- 1 n (normal)
- 1 n + 1
- 1 n − 1
- 1 n (normal)

✓ **After fertilization:**
Can still produce trisomy **(2n + 1)** or monosomy **(2n − 1)**

Clinical examples:

Down syndrome

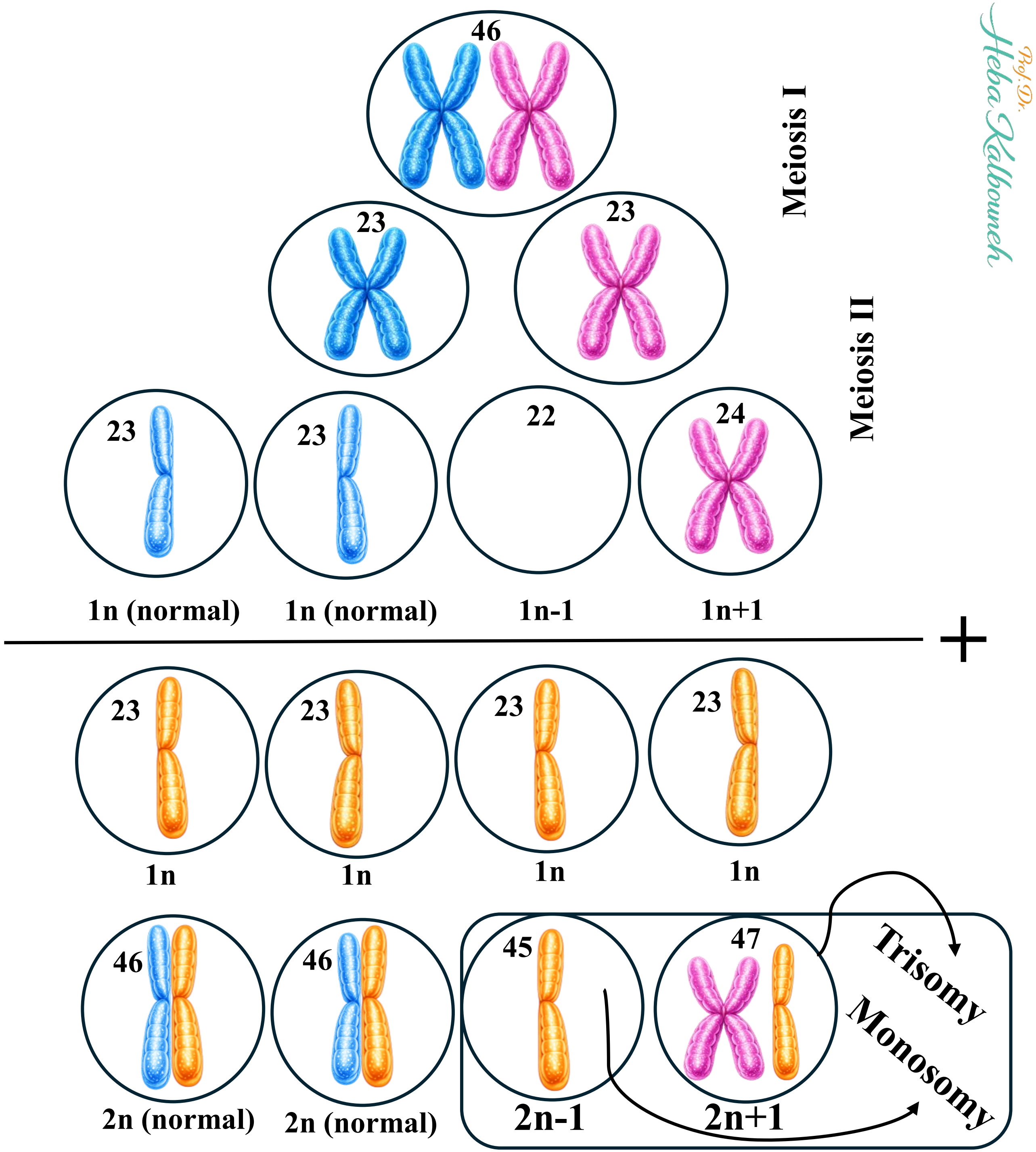
→ Caused by trisomy 21 due to nondisjunction (most commonly in maternal meiosis I)

Turner syndrome

→ Due to monosomy X from meiotic nondisjunction

Klinefelter syndrome

→ Extra X chromosome in males caused by nondisjunction



Normal meiosis → gametes: 23 chromosomes
Fertilization: 23 + 23 = 46

Gamete	After fertilization	Result
23	46	Normal
24	47	Trisomy
22	45	Monosomy

Chromosomal nondisjunction produces gametes with 24 or 22 chromosomes instead of 23, leading after fertilization to trisomy (47) or monosomy (45).

Nondisjunction in Meiosis I
(Homologous chromosomes fail to separate)

Gametes produced:
2 gametes with 24 chromosomes (n + 1)
2 gametes with 22 chromosomes (n − 1)

Instead of: 23 | 23 | 23 | 23
You get: 24 | 24 | 22 | 22

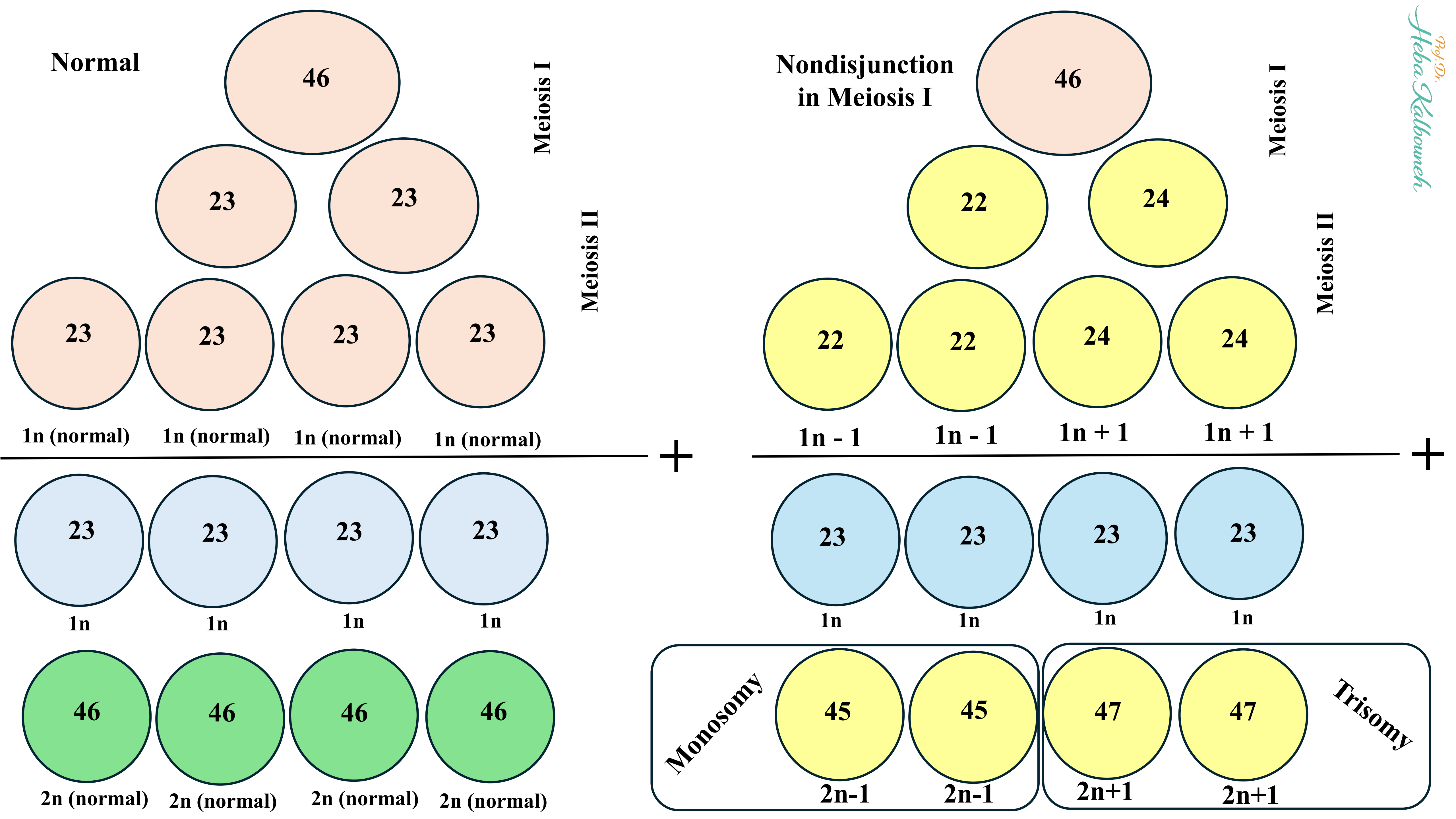
After fertilization with a normal gamete (23):
24 + 23 = 47 → ***Trisomy***
22 + 23 = 45 → ***Monosomy***

Nondisjunction in Meiosis II
(Sister chromatids fail to separate)

Gametes produced:
2 normal gametes: 23
1 gamete: 24
1 gamete: 22

Instead of: 23 | 23 | 23 | 23
You get: 23 | 23 | 24 | 22

After fertilization with a normal gamete (23):
23 + 23 = 46 → ***Normal***
24 + 23 = 47 → ***Trisomy***
22 + 23 = 45 → ***Monosomy***



Normal
46
Meiosis I
23
23
Meiosis II
23
23
23
23
1n (normal)
1n (normal)
1n (normal)
1n (normal)
+
23
23
23
23
1n
1n
1n
1n
46
46
46
46
2n (normal)
2n (normal)
2n (normal)
2n (normal)
Nondisjunction in Meiosis I
46
Meiosis I
22
24
Meiosis II
22
22
24
24
1n - 1
1n - 1
1n + 1
1n + 1
+
23
23
23
23
1n
1n
1n
1n
Monosomy
45
45
2n-1
2n-1
47
47
2n+1
2n+1
Trisomy
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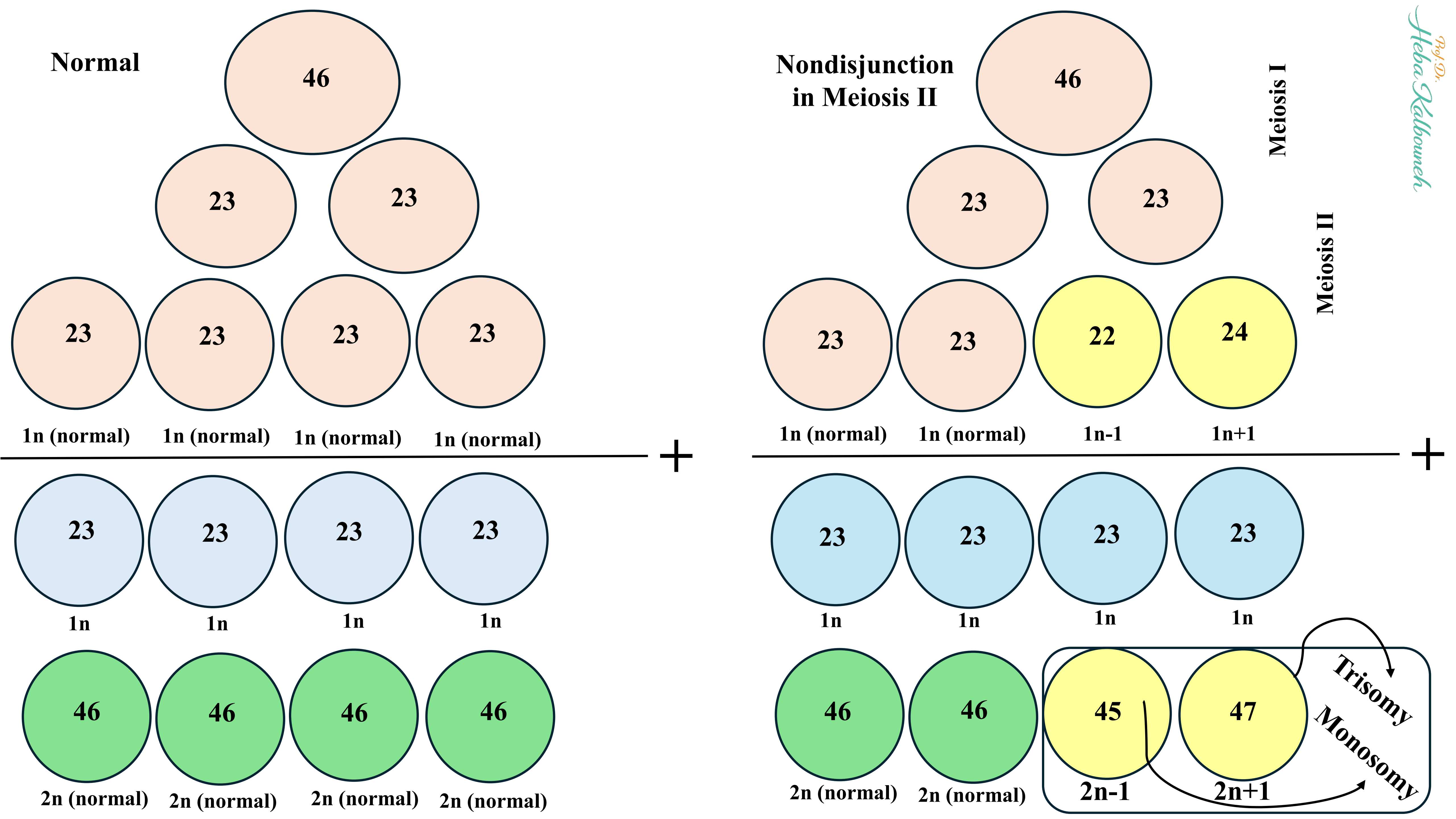
Normal
46
23
23
23
23
23
23
1n (normal)
1n (normal)
1n (normal)
1n (normal)
23
23
23
23
1n
1n
1n
1n
46
46
46
46
2n (normal)
2n (normal)
2n (normal)
2n (normal)
Nondisjunction in Meiosis II
46
Meiosis I
23
23
Meiosis II
23
23
22
24
1n (normal)
1n (normal)
1n-1
1n+1
23
23
23
23
1n
1n
1n
1n
46
46
45
47
2n (normal)
2n (normal)
2n-1
2n+1
Trisomy
Monosomy
Prof. Dr. Heba Kalbouneh