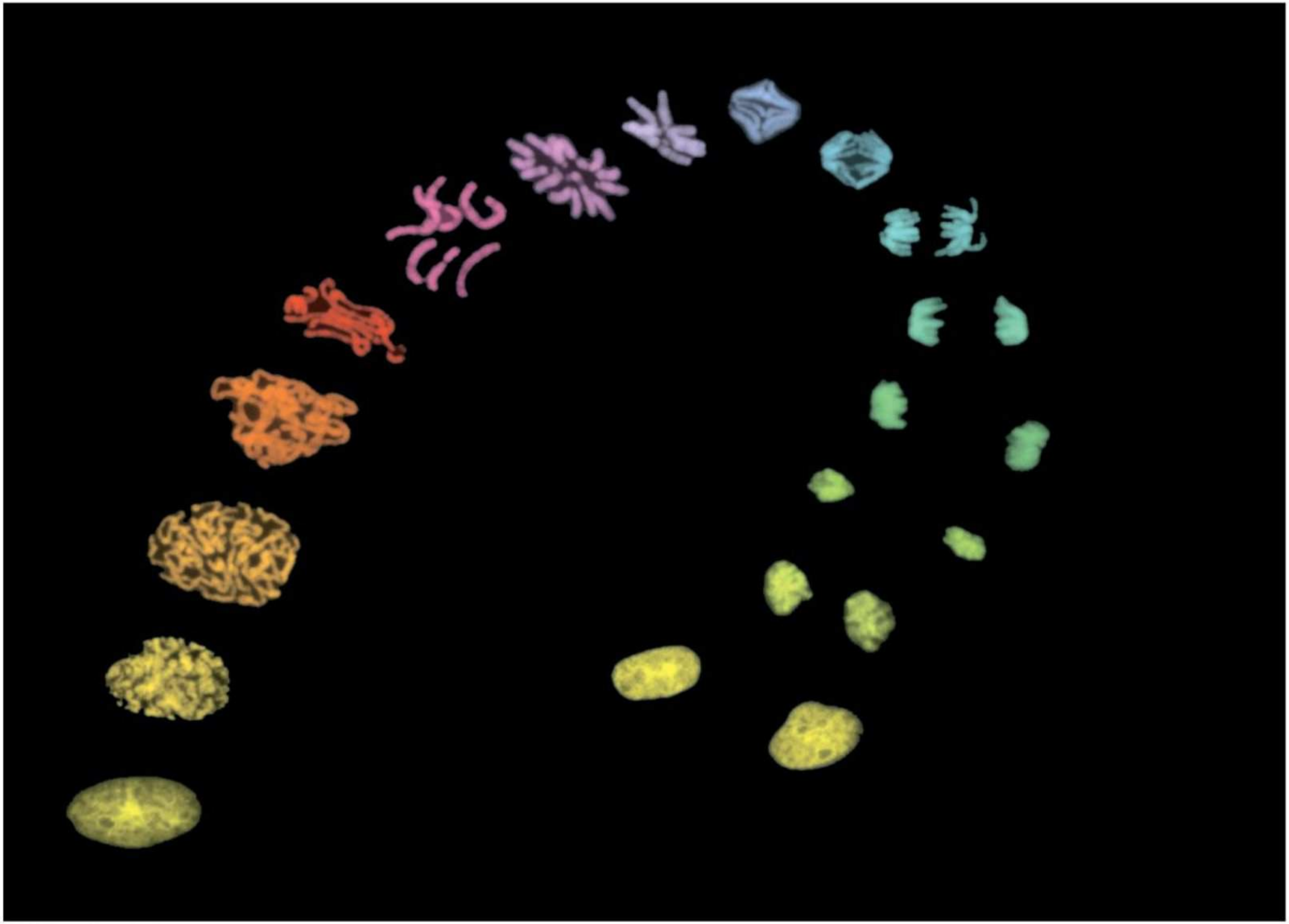
Overview: The Key Roles of Cell Division

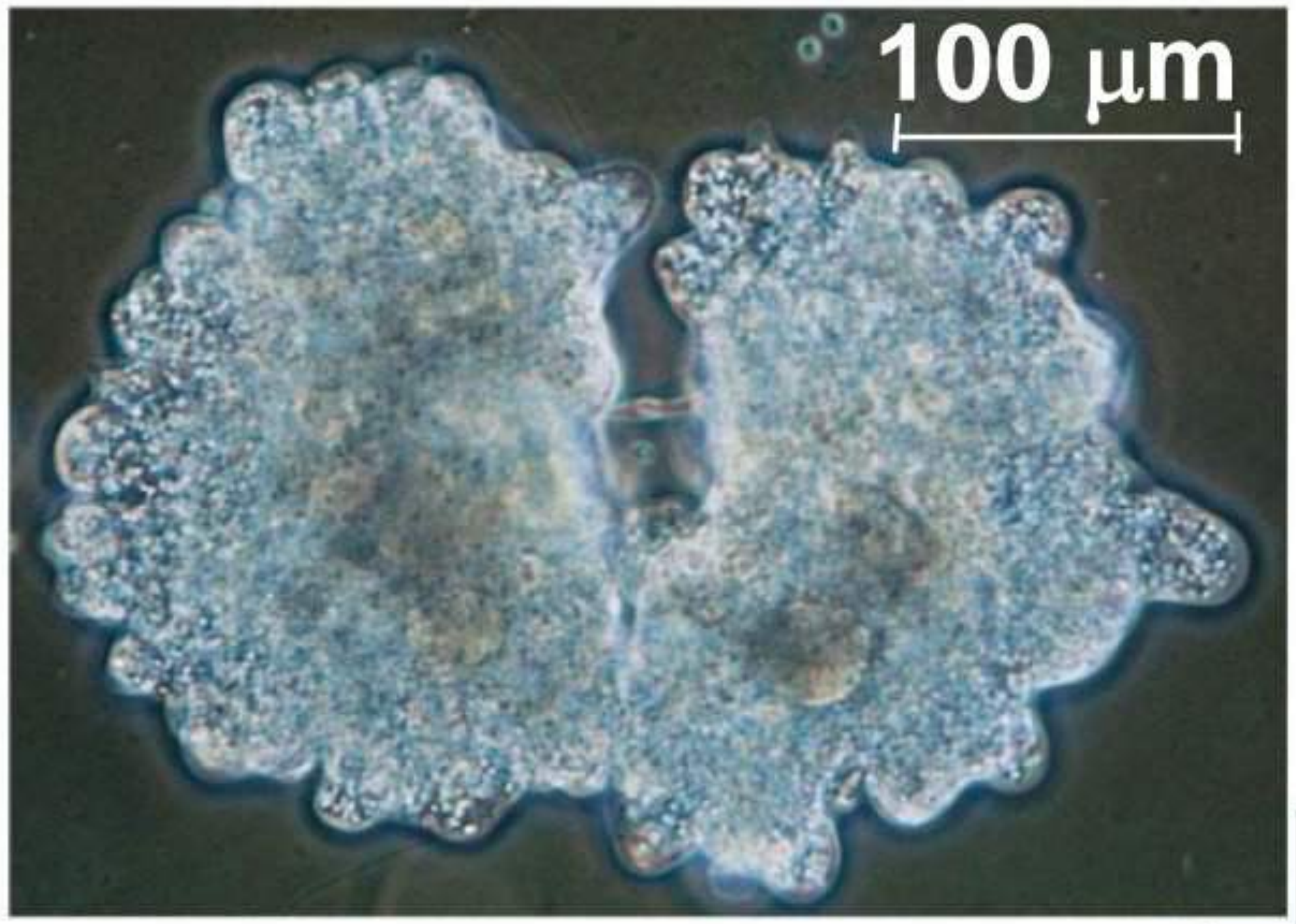
- The ability of organisms to produce more of their own kind best distinguishes living things from nonliving matter
- The continuity of life is based on the reproduction of cells, or **cell division**

Figure 12.1

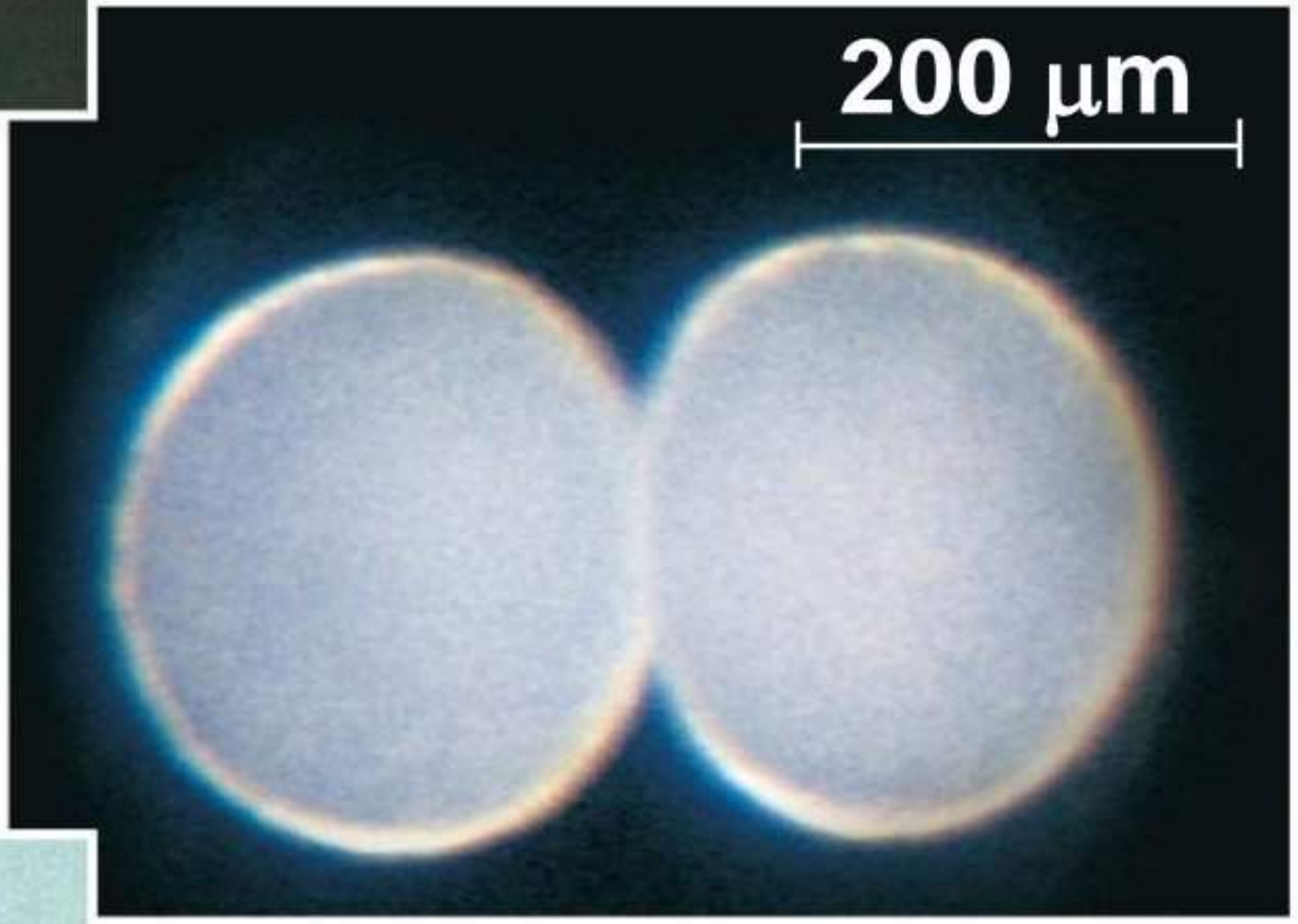


- In unicellular organisms, division of one cell reproduces the entire organism
- Multicellular organisms depend on cell division for
  - Development from a fertilized cell
  - Growth
  - Repair
- Cell division is an integral part of the **cell cycle**, the life of a cell from formation to its own division

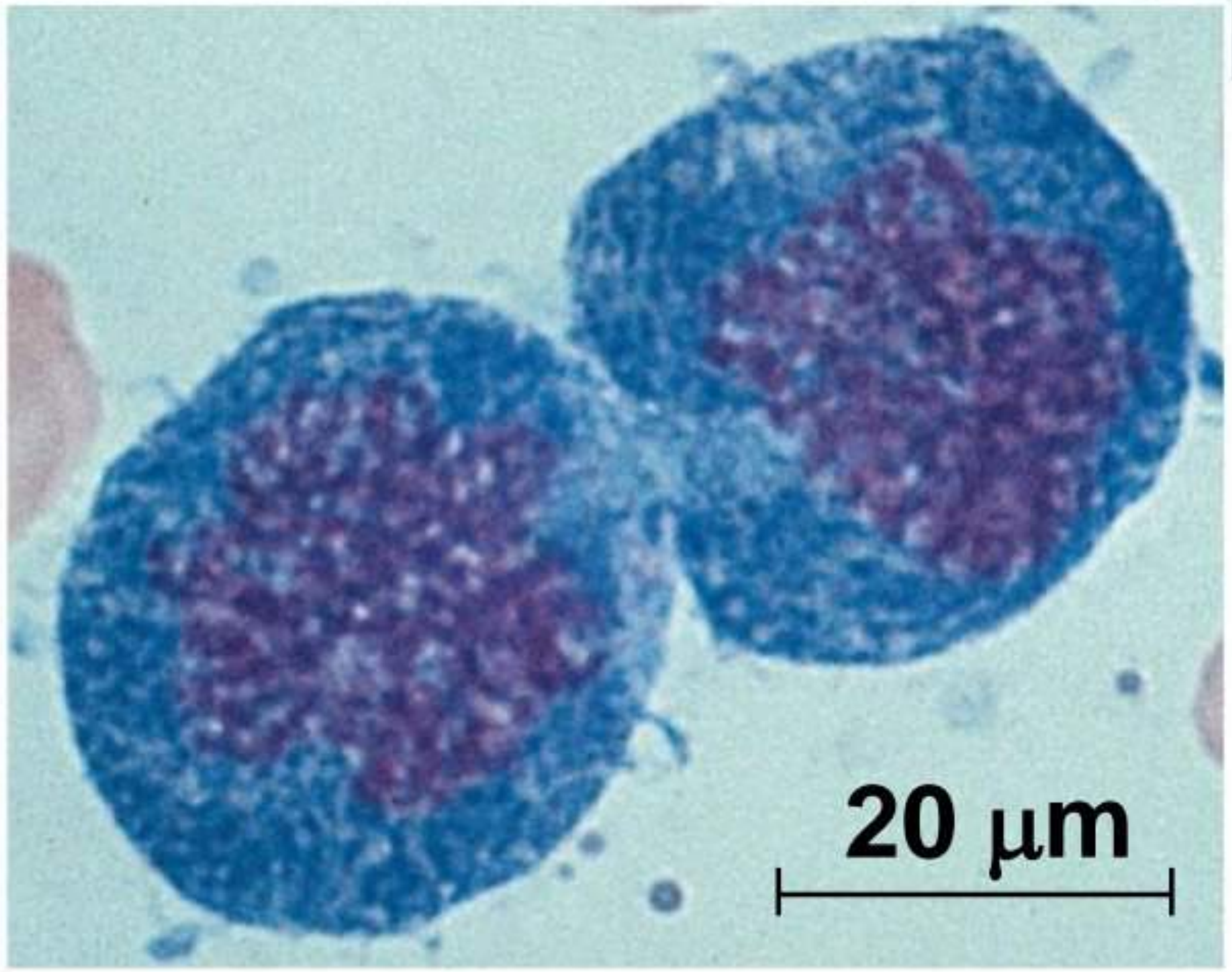
Figure 12.2



(a) Reproduction

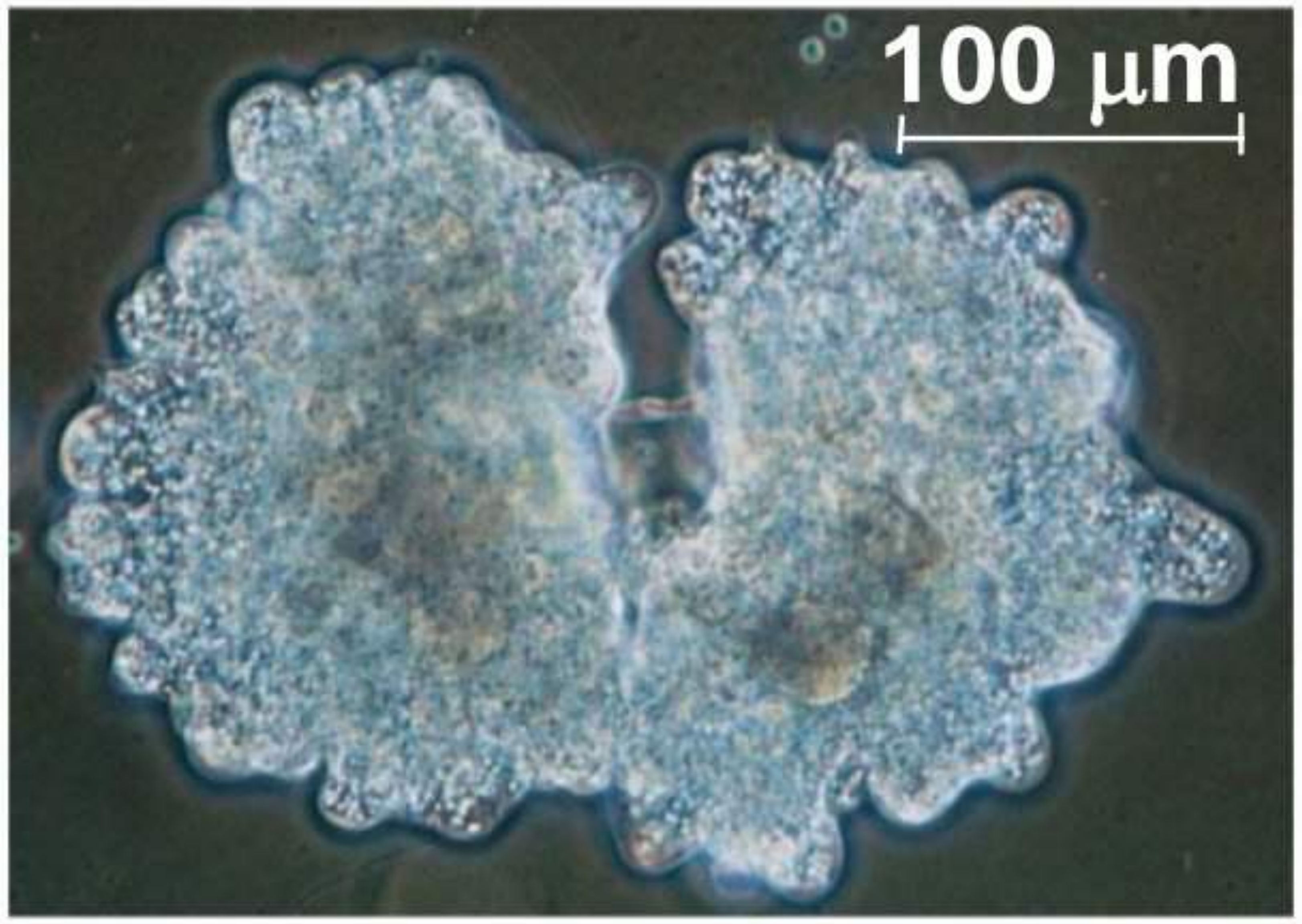


(b) Growth and development



(c) Tissue renewal

Figure 12.2a



(a) Reproduction

Figure 12.2b

▶ (b) Growth and development

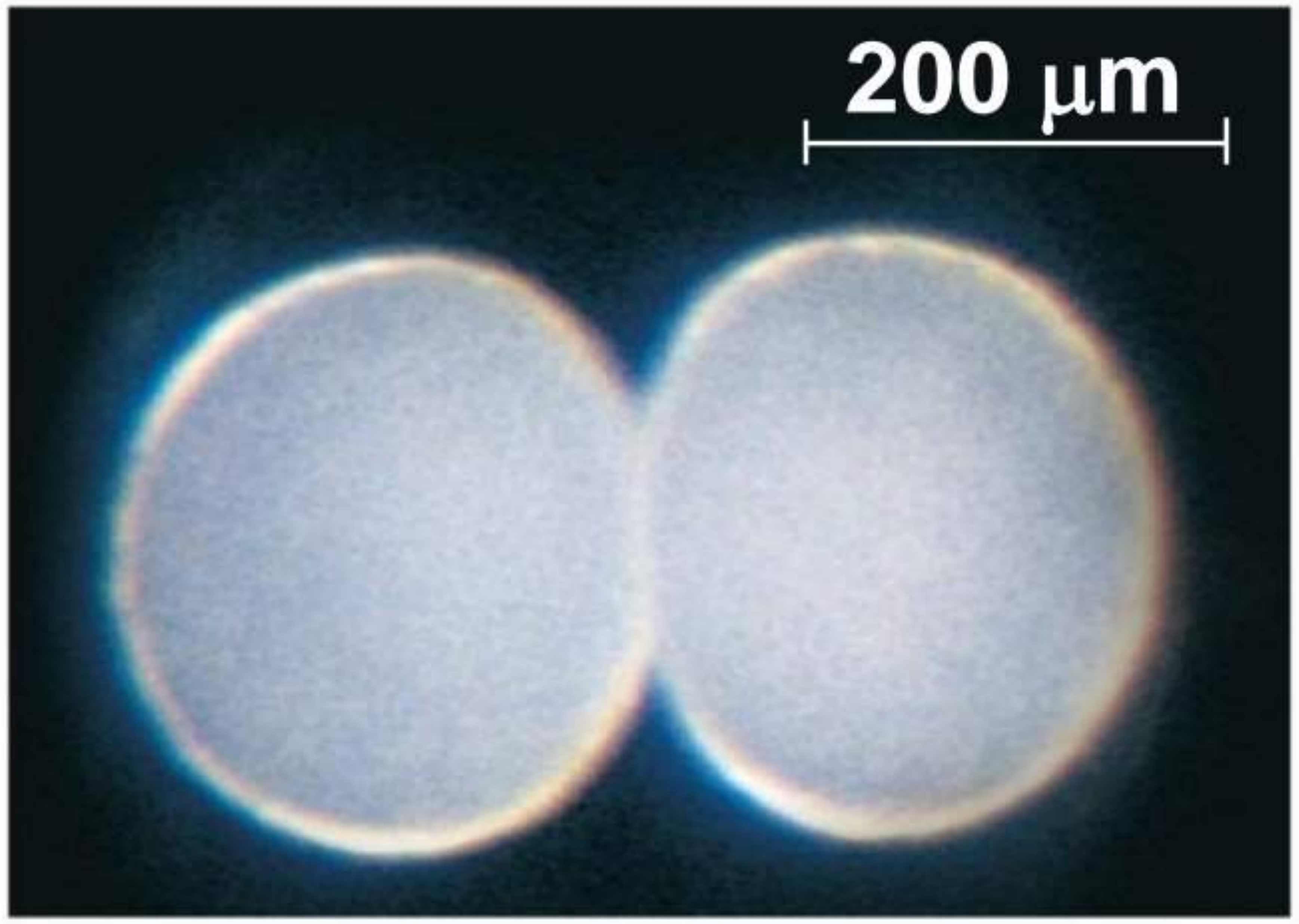
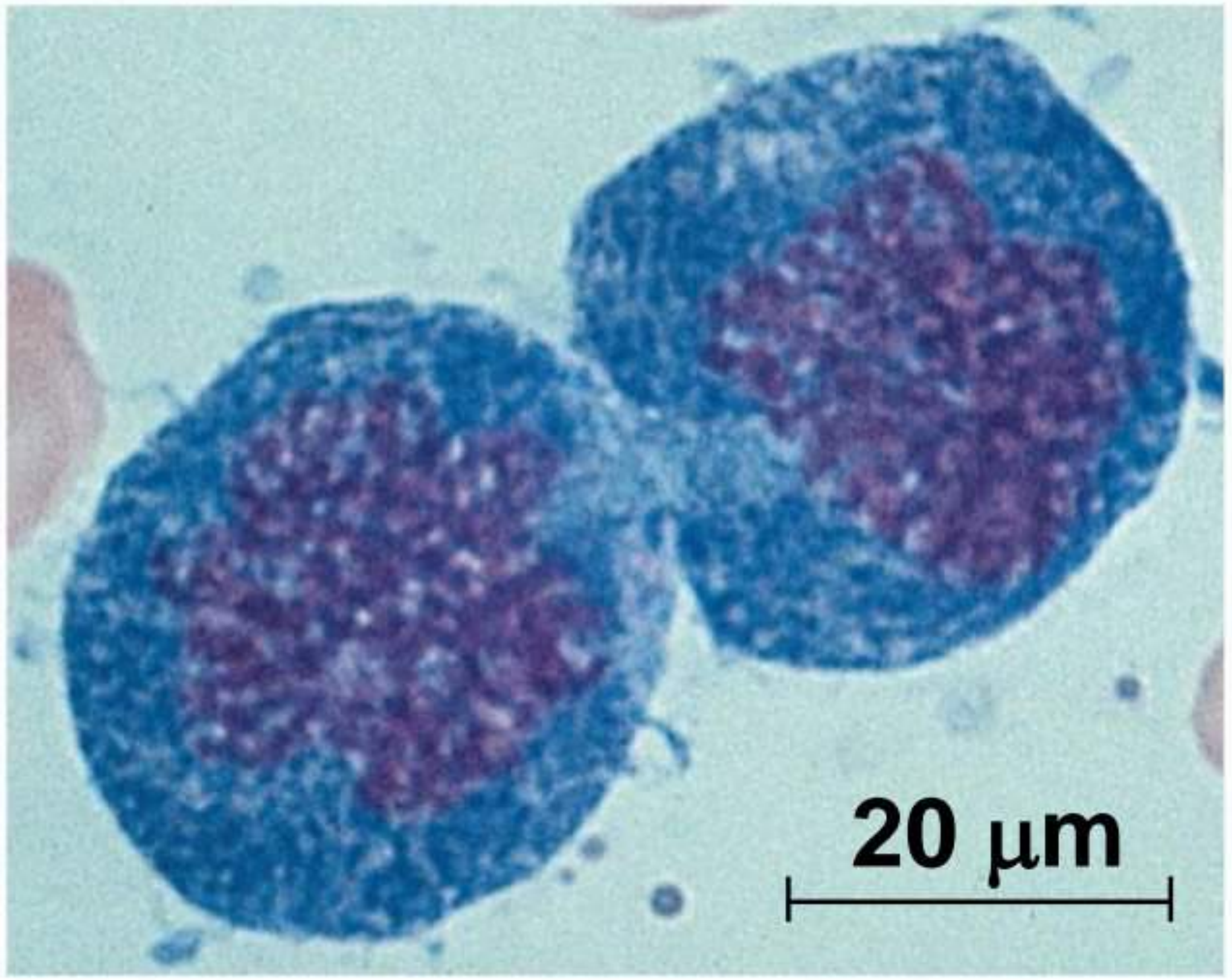


Figure 12.2c



(c) Tissue renewal

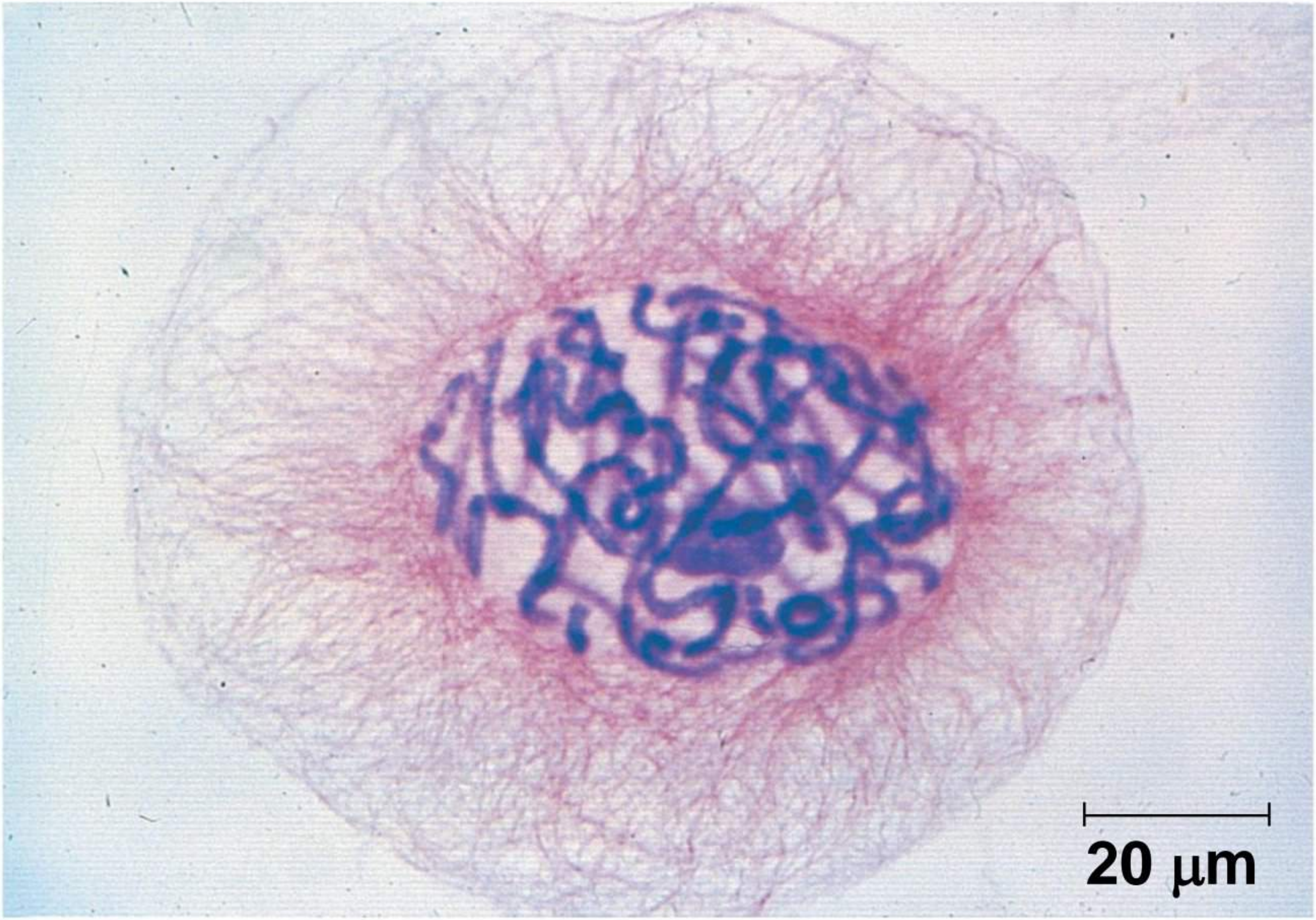
Concept 12.1: Most cell division results in genetically identical daughter cells

- Most cell division results in daughter cells with identical genetic information, DNA
- The exception is meiosis, a special type of division that can produce sperm and egg cells

Cellular Organization of the Genetic Material

- All the DNA in a cell constitutes the cell's **genome**
- A genome can consist of a single DNA molecule (common in prokaryotic cells) or a number of DNA molecules (common in eukaryotic cells)
- DNA molecules in a cell are packaged into **chromosomes**

Figure 12.3

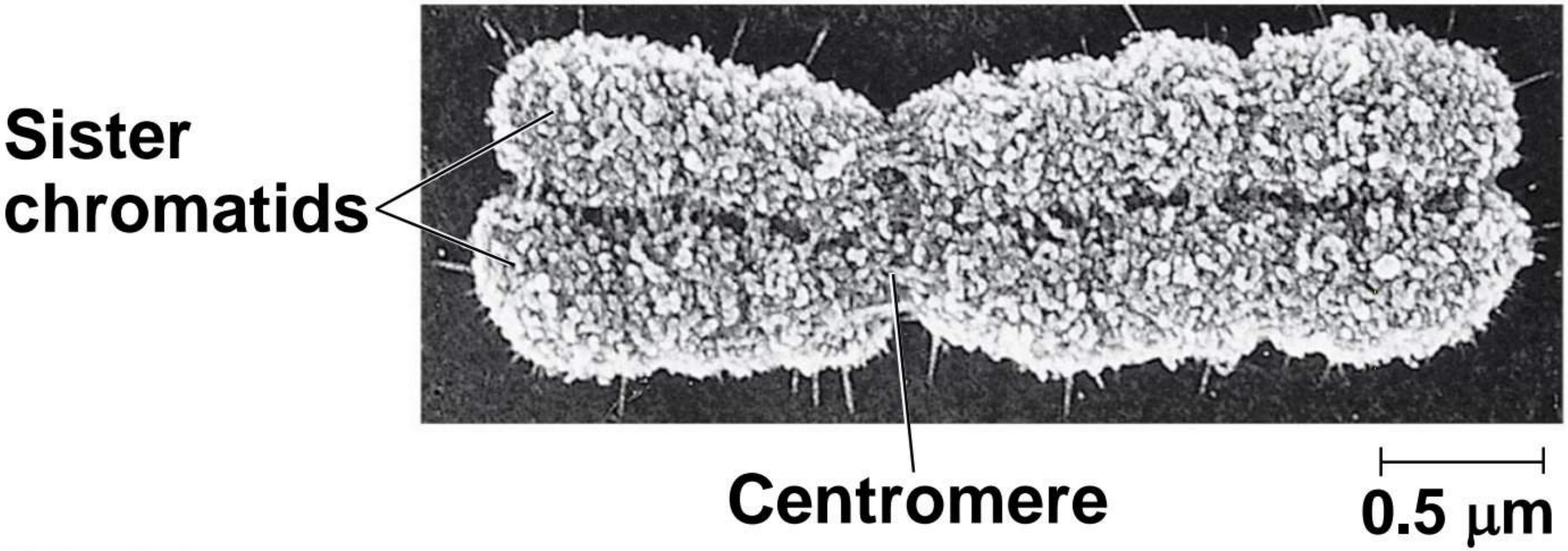


- Eukaryotic chromosomes consist of **chromatin**, a complex of DNA and protein that condenses during cell division
- Every eukaryotic species has a characteristic number of chromosomes in each cell nucleus
- **Somatic cells** (nonreproductive cells) have two sets of chromosomes
- **Gametes** (reproductive cells: sperm and eggs) have half as many chromosomes as somatic cells

Distribution of Chromosomes During Eukaryotic Cell Division

- In preparation for cell division, DNA is replicated and the chromosomes condense
- Each duplicated chromosome has two **sister chromatids** (joined copies of the original chromosome), which separate during cell division
- The **centromere** is the narrow "waist" of the duplicated chromosome, where the two chromatids are most closely attached

Figure 12.4



- During cell division, the two sister chromatids of each duplicated chromosome separate and move into two nuclei
- Once separate, the chromatids are called chromosomes

Figure 12.5-1

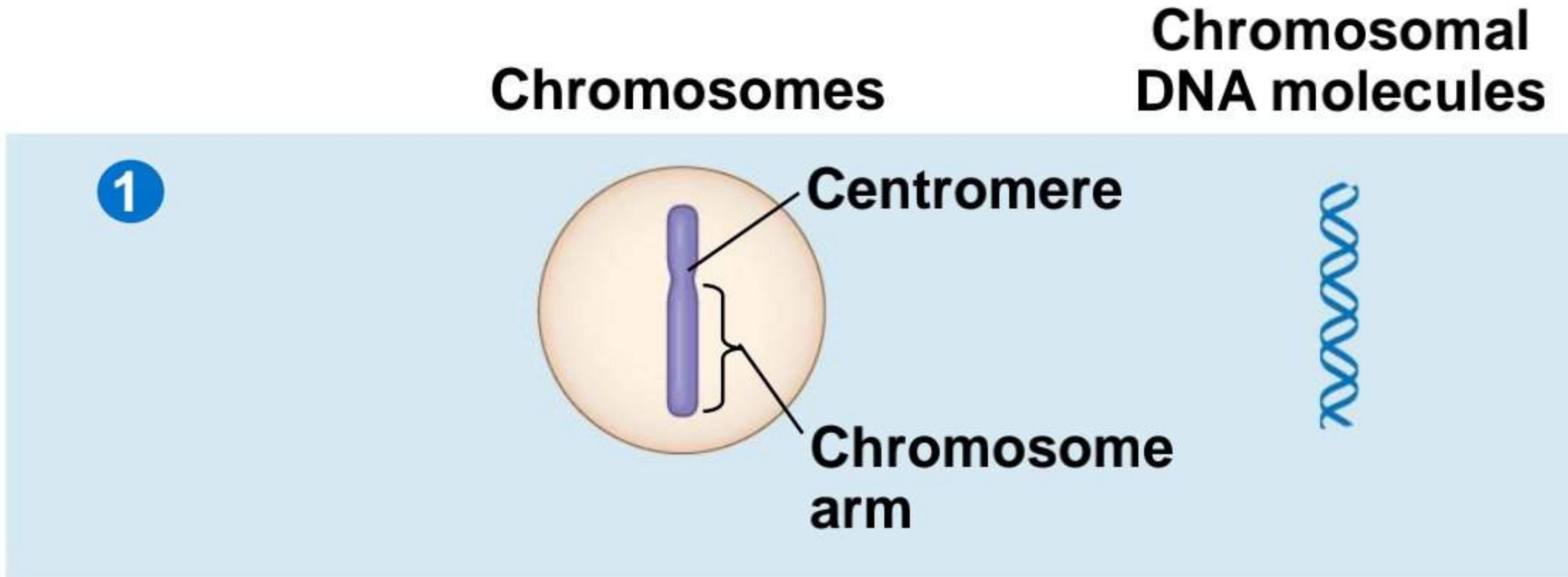
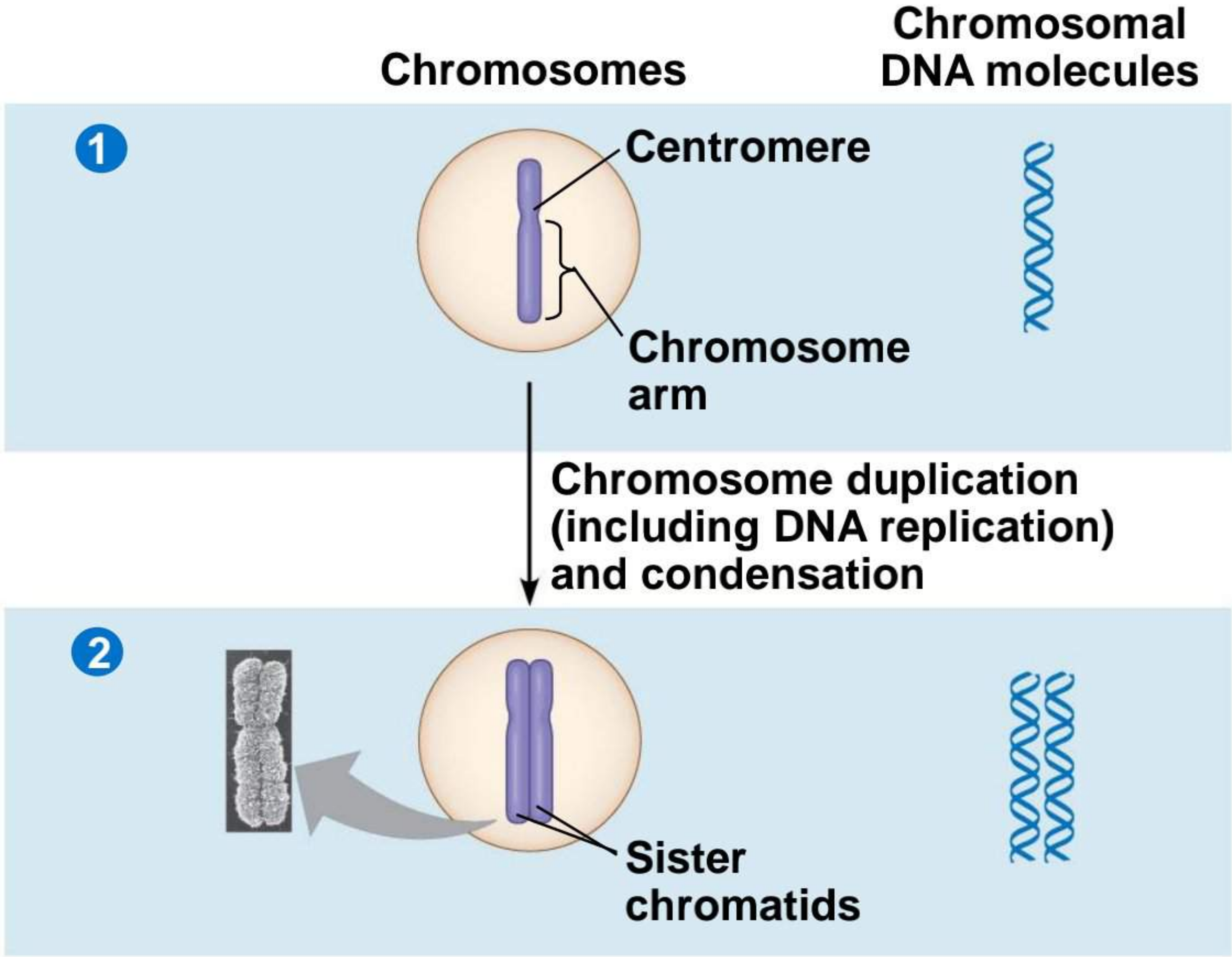
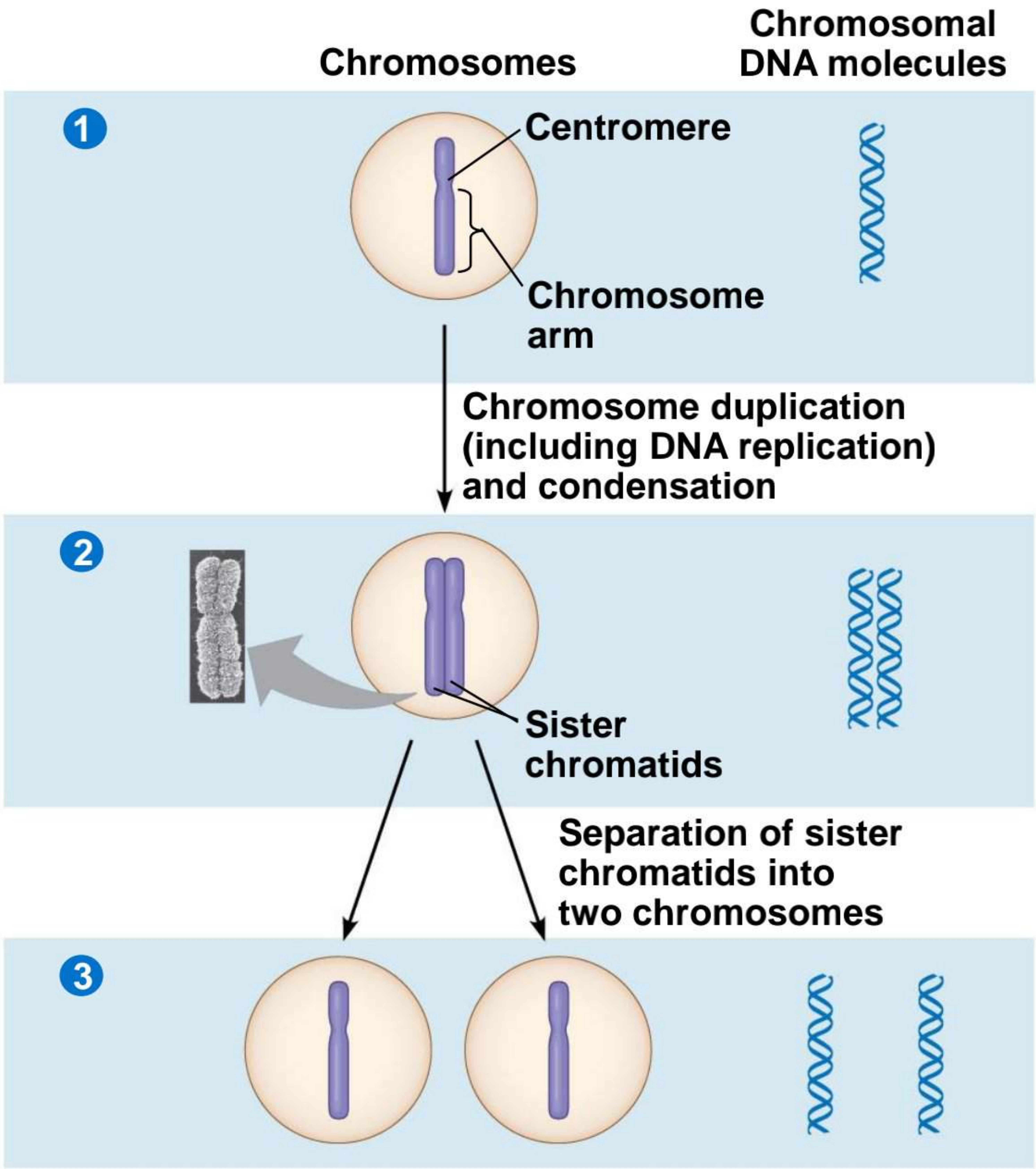

Chromosomes
Chromosomal DNA molecules
1
Centromere
Chromosome arm

Figure 12.5-2



Chromosomes
Chromosomal DNA molecules
1
Centromere
Chromosome arm
Chromosome duplication (including DNA replication) and condensation
2
Sister chromatids

Figure 12.5-3


Chromosomes
Chromosomal DNA molecules
1
Centromere
Chromosome arm
Chromosome duplication (including DNA replication) and condensation
2
Sister chromatids
Separation of sister chromatids into two chromosomes
3

- Eukaryotic cell division consists of
  - **Mitosis**, the division of the genetic material in the nucleus
  - **Cytokinesis**, the division of the cytoplasm
- Gametes are produced by a variation of cell division called **meiosis**
- Meiosis yields nonidentical daughter cells that have only one set of chromosomes, half as many as the parent cell

Concept 12.2: The mitotic phase alternates with interphase in the cell cycle

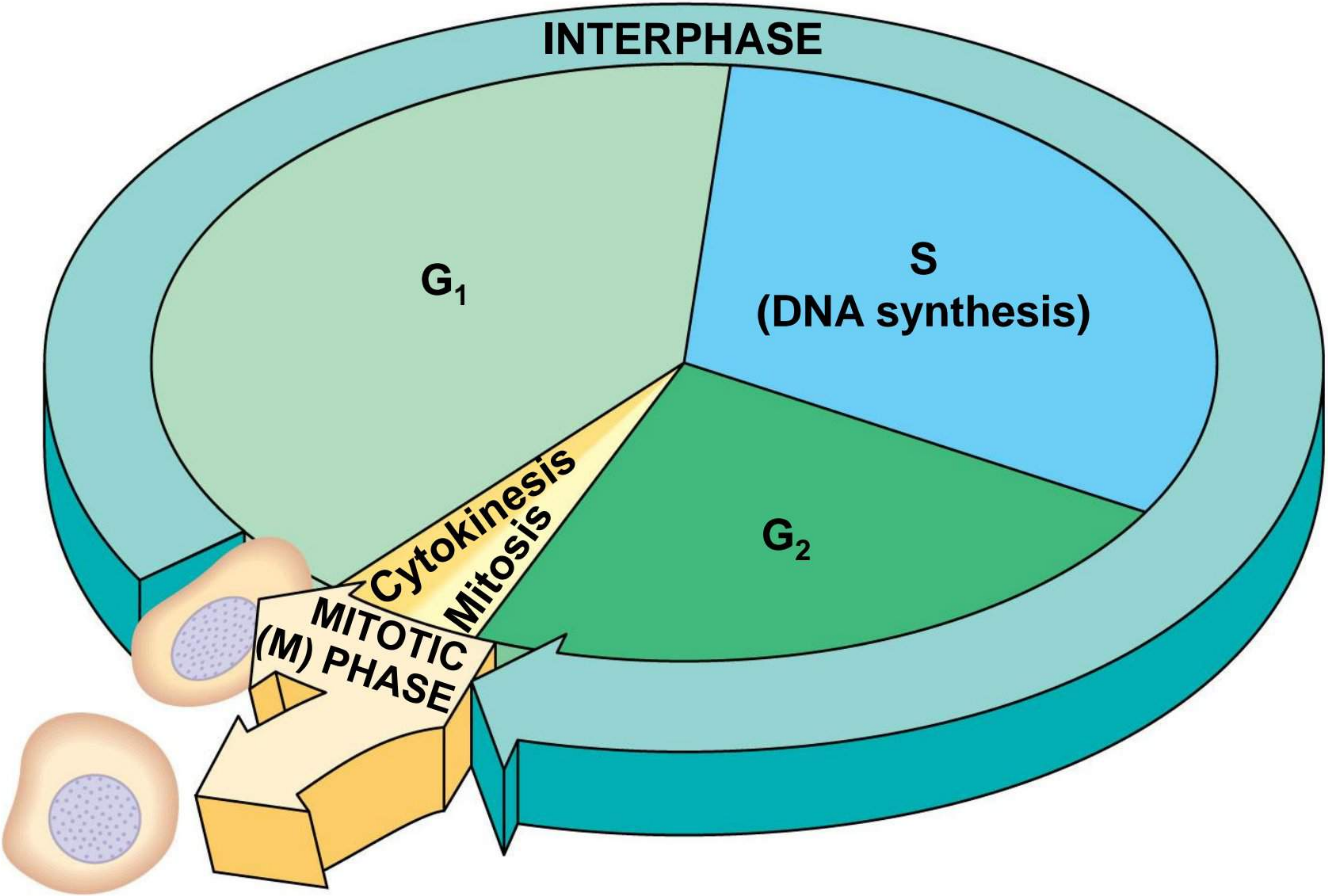
- In 1882, the German anatomist Walther Flemming developed dyes to observe chromosomes during mitosis and cytokinesis

Phases of the Cell Cycle

- The cell cycle consists of
  - **Mitotic (M) phase** (mitosis and cytokinesis)
  - **Interphase** (cell growth and copying of chromosomes in preparation for cell division)

- 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 grows during all three phases, but chromosomes are duplicated only during the S phase

Figure 12.6


INTERPHASE
G_1
S
(DNA synthesis)
G_2
Cytokinesis
Mitosis
MITOTIC
(M) PHASE

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

PLAY BioFlix: Mitosis

Figure 12.7

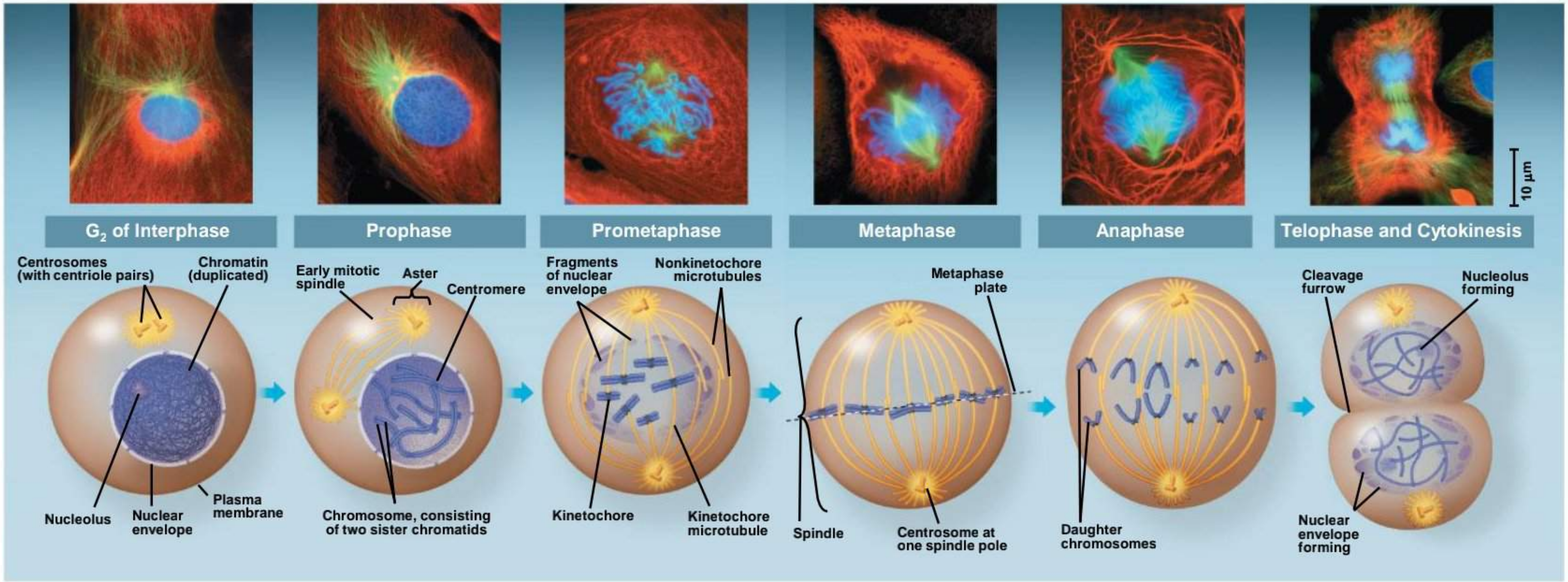
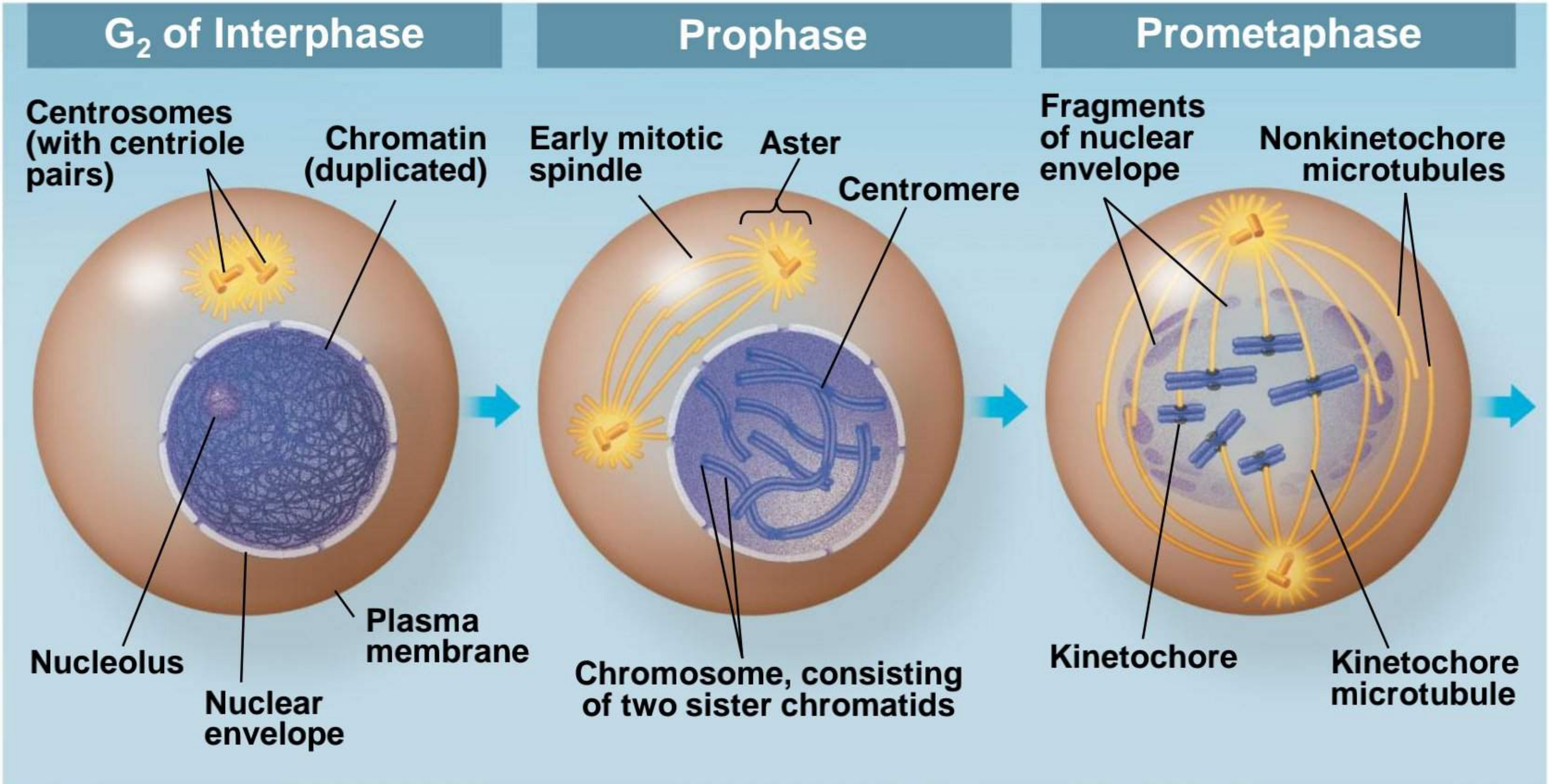
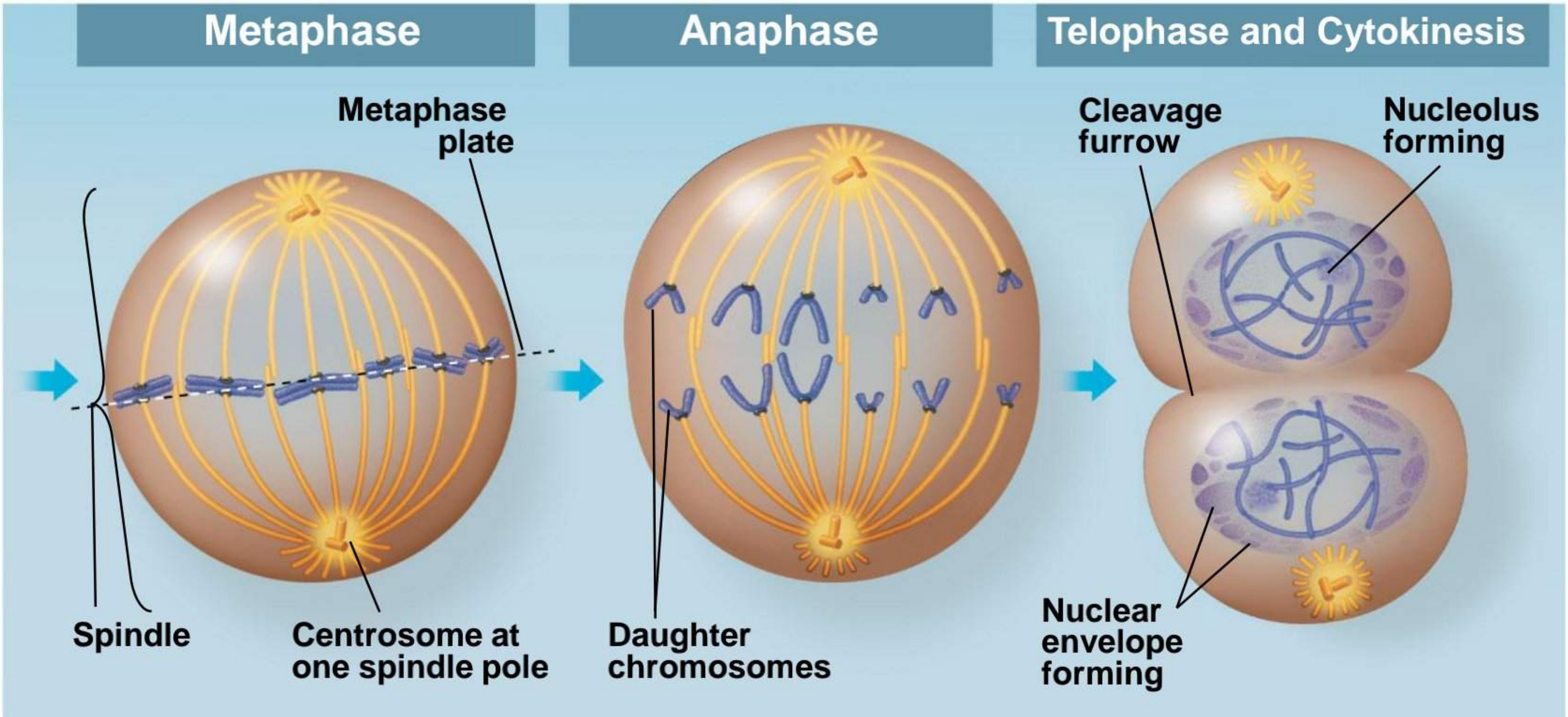

10 μm
G2 of Interphase
Prophase
Prometaphase
Metaphase
Anaphase
Telophase and Cytokinesis
Centrosomes (with centriole pairs)
Chromatin (duplicated)
Nucleolus
Nuclear envelope
Plasma membrane
Early mitotic spindle
Aster
Centromere
Chromosome, consisting of two sister chromatids
Fragments of nuclear envelope
Nonkinetochore microtubules
Kinetochore
Kinetochore microtubule
Metaphase plate
Spindle
Centrosome at one spindle pole
Daughter chromosomes
Cleavage furrow
Nucleolus forming
Nuclear envelope forming

Figure 12.7a



G$_2$ of Interphase
Prophase
Prometaphase
Centrosomes (with centriole pairs)
Chromatin (duplicated)
Early mitotic spindle
Aster
Centromere
Fragments of nuclear envelope
Nonkinetochore microtubules
Nucleolus
Nuclear envelope
Plasma membrane
Chromosome, consisting of two sister chromatids
Kinetochore
Kinetochore microtubule

Figure 12.7b



Metaphase
Anaphase
Telophase and Cytokinesis
Metaphase plate
Cleavage furrow
Nucleolus forming
Spindle
Centrosome at one spindle pole
Daughter chromosomes
Nuclear envelope forming

Figure 12.7c

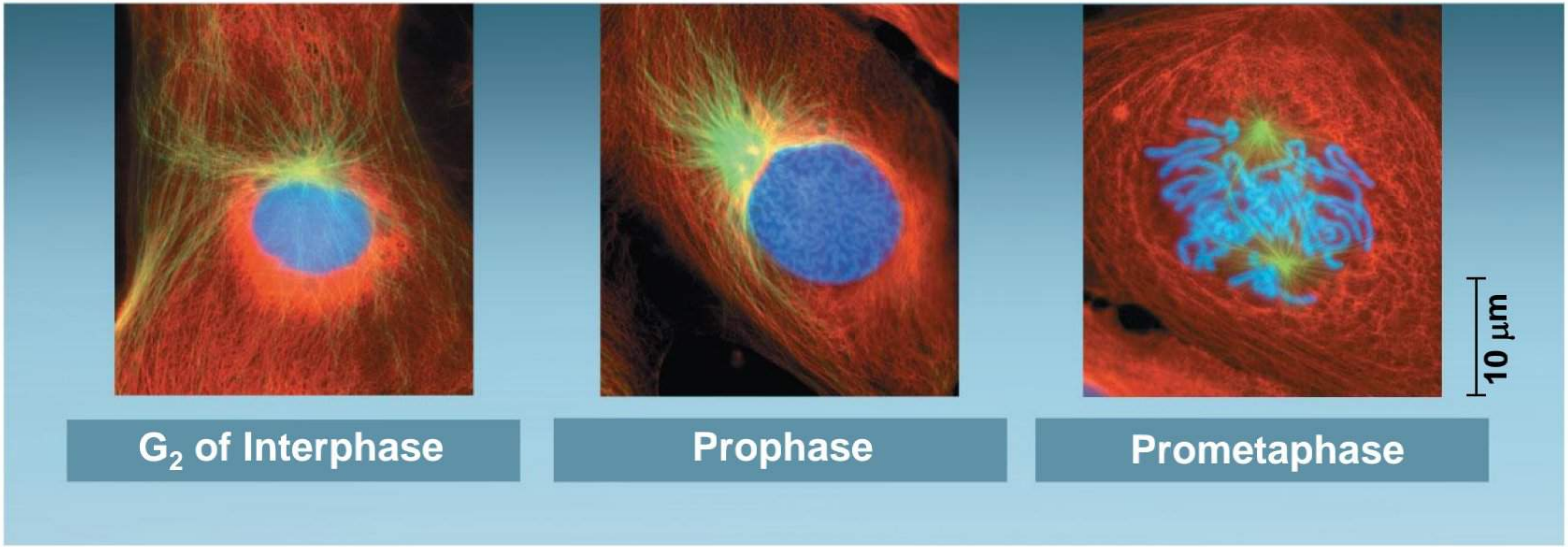


Figure 12.7d

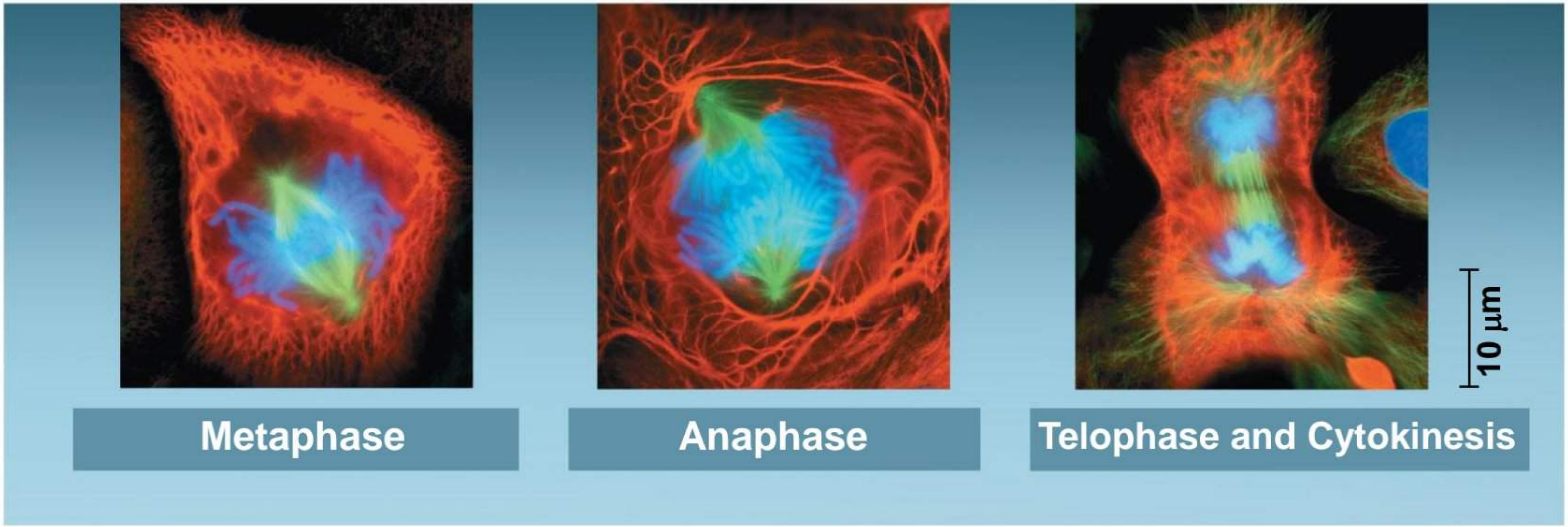


Figure 12.7e

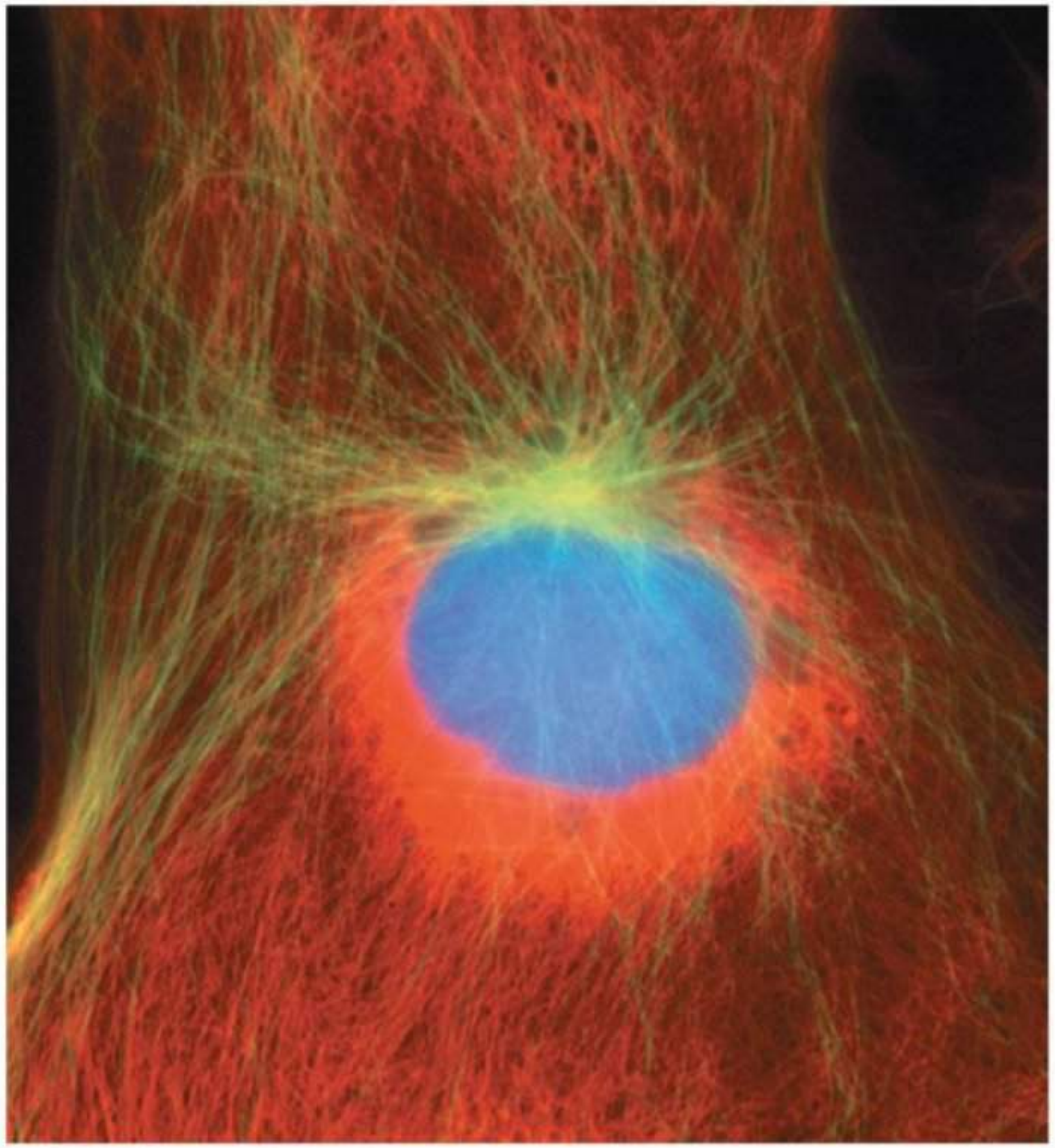


Figure 12.7f

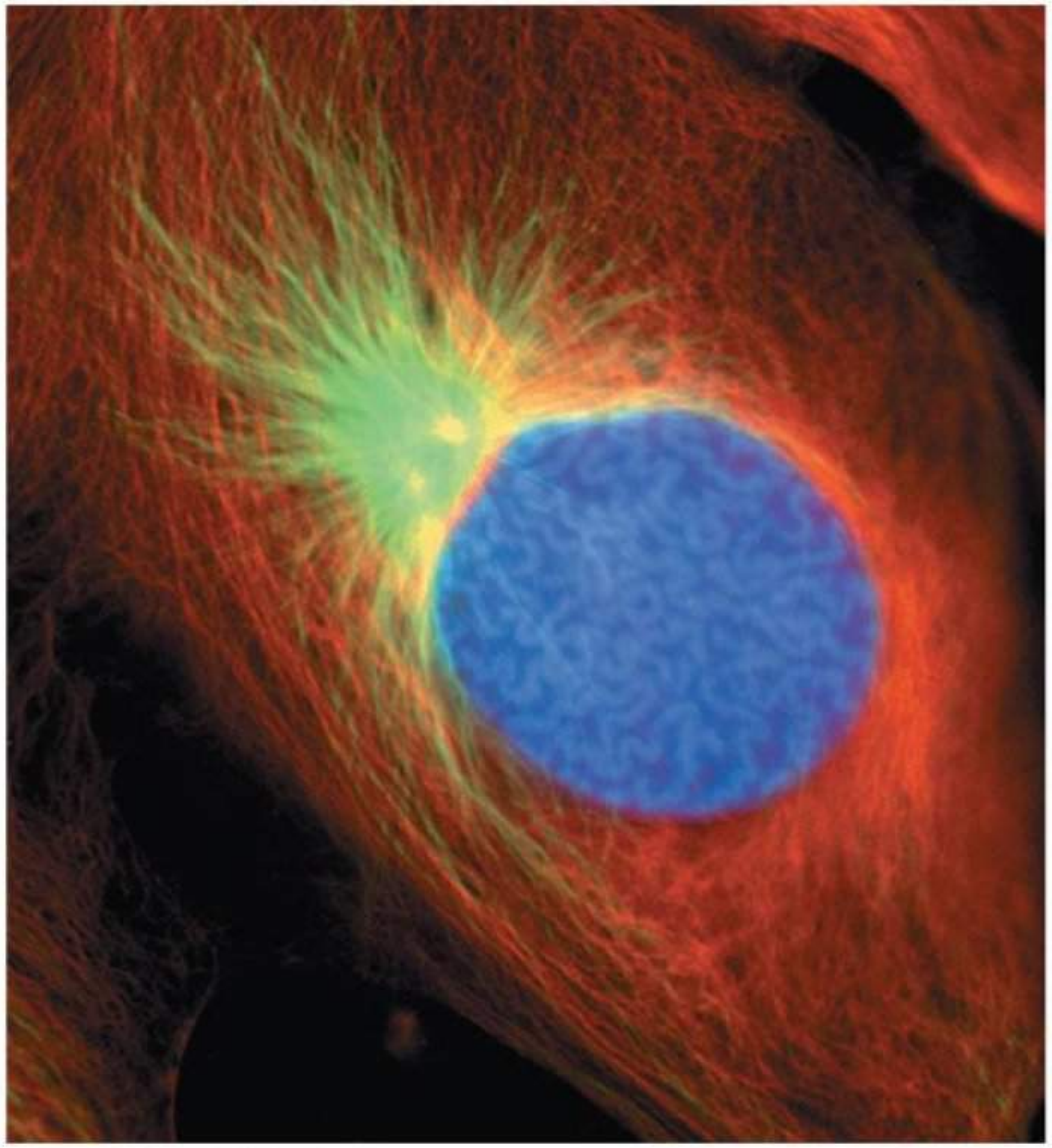


Figure 12.7g

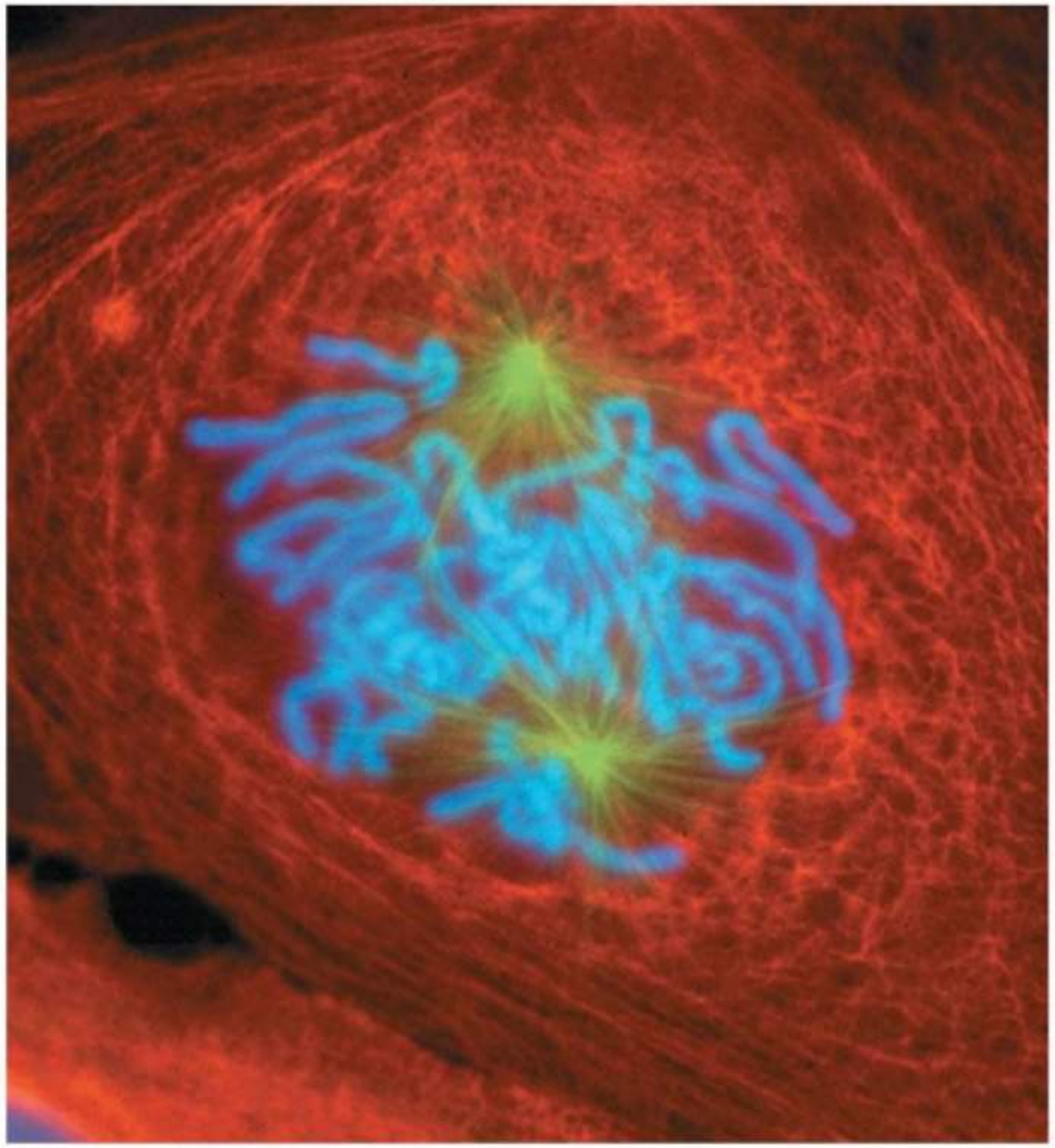


Figure 12.7h

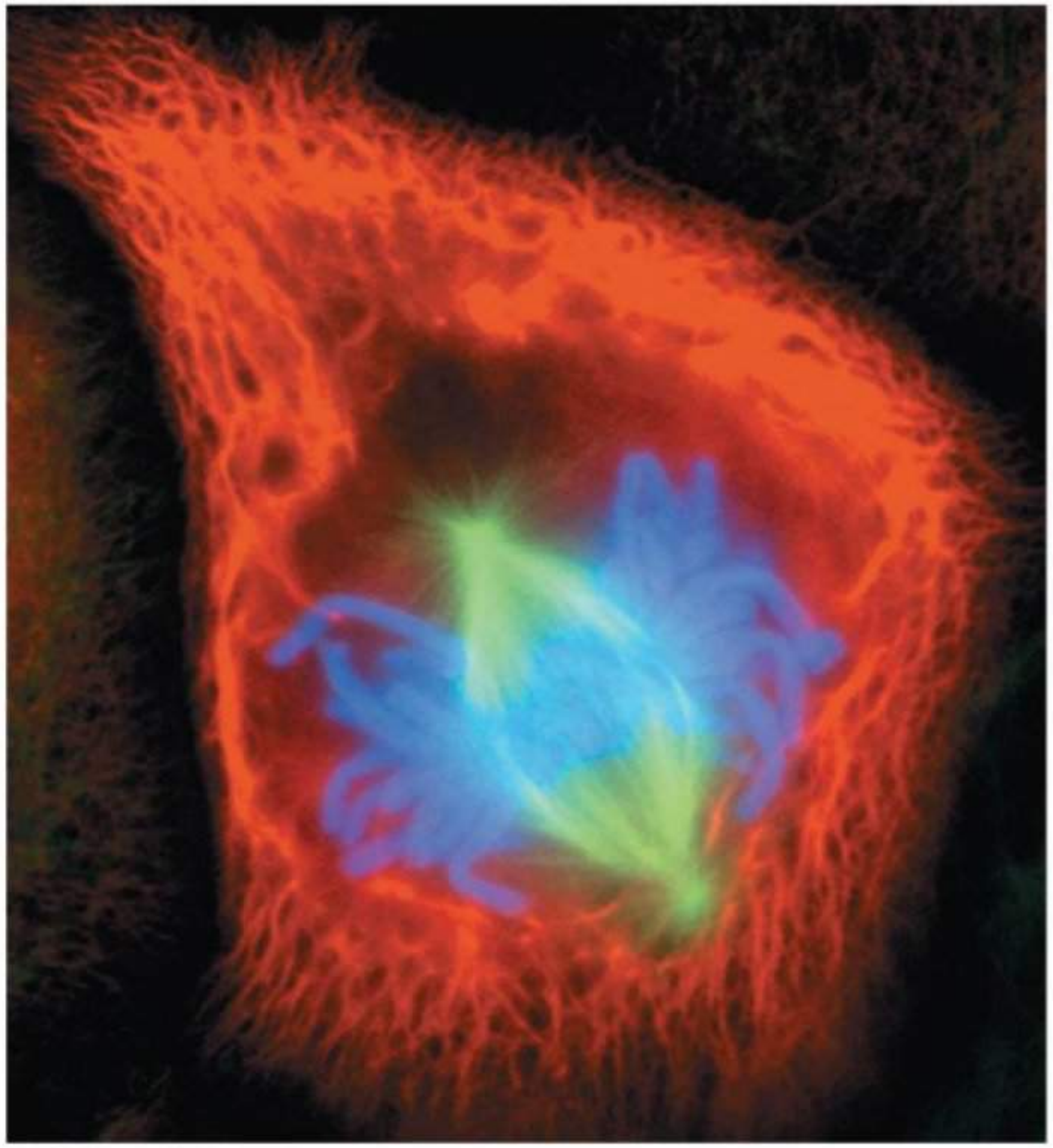


Figure 12.7i

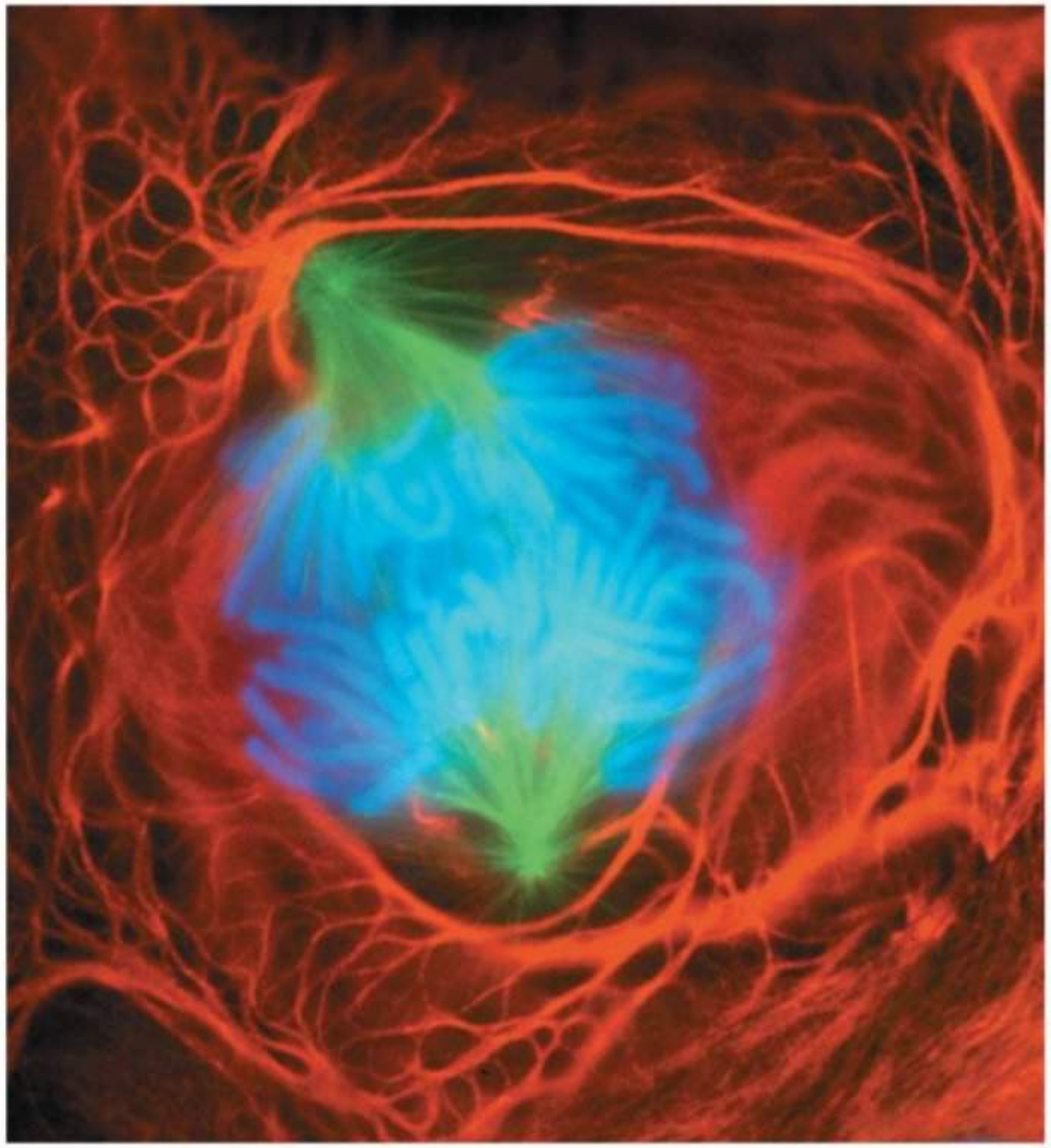
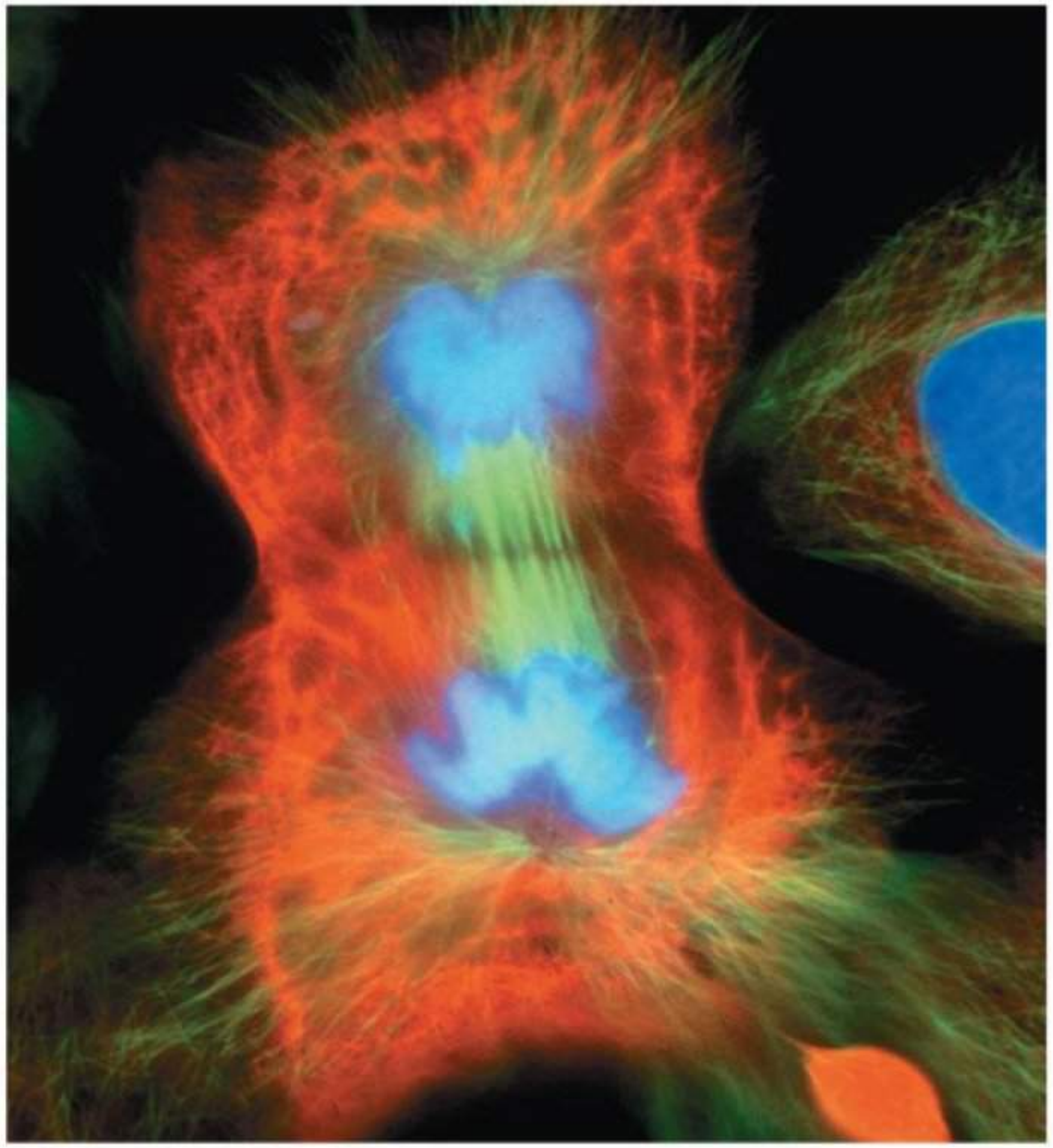


Figure 12.7j



The Mitotic Spindle: *A Closer Look*

- The **mitotic spindle** is a structure made of microtubules that controls chromosome movement during mitosis
- In animal cells, assembly of spindle microtubules begins in the **centrosome**, the microtubule organizing center
- The centrosome replicates during interphase, forming two centrosomes that migrate to opposite ends of the cell during prophase and prometaphase

- An **aster** (a radial array of short microtubules) extends from each centrosome
- The spindle includes the centrosomes, the spindle microtubules, and the asters

- During prometaphase, some spindle microtubules attach to the kinetochores of chromosomes and begin to move the chromosomes
- **Kinetochores** are protein complexes associated with centromeres
- At metaphase, the chromosomes are all lined up at the **metaphase plate**, an imaginary structure at the midway point between the spindle's two poles

Figure 12.8

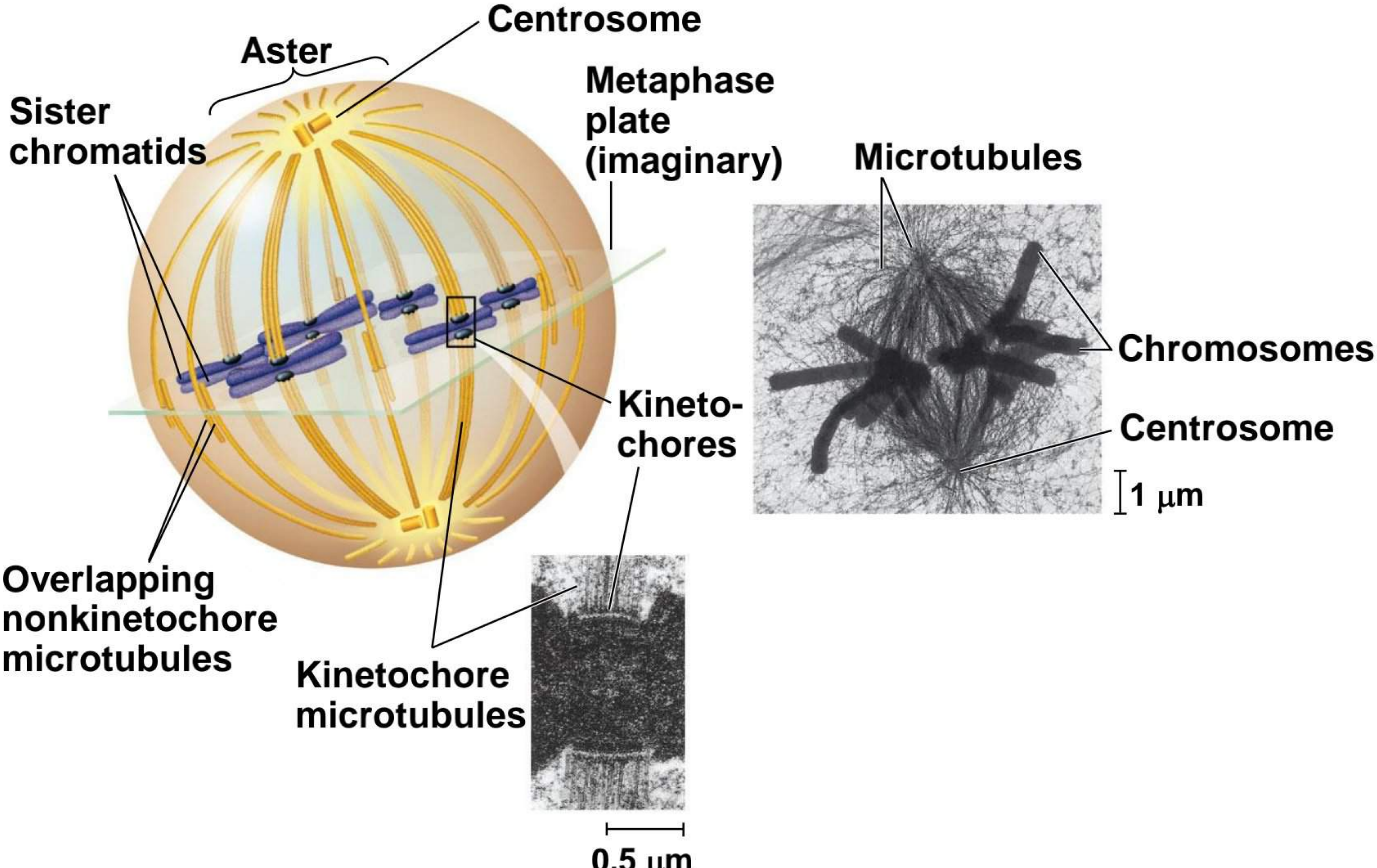

Centrosome
Aster
Sister chromatids
Metaphase plate (imaginary)
Microtubules
Chromosomes
Kineto-chores
Centrosome
1 μm
Overlapping nonkinetochore microtubules
Kinetochore microtubules
0.5 μm

Figure 12.8a

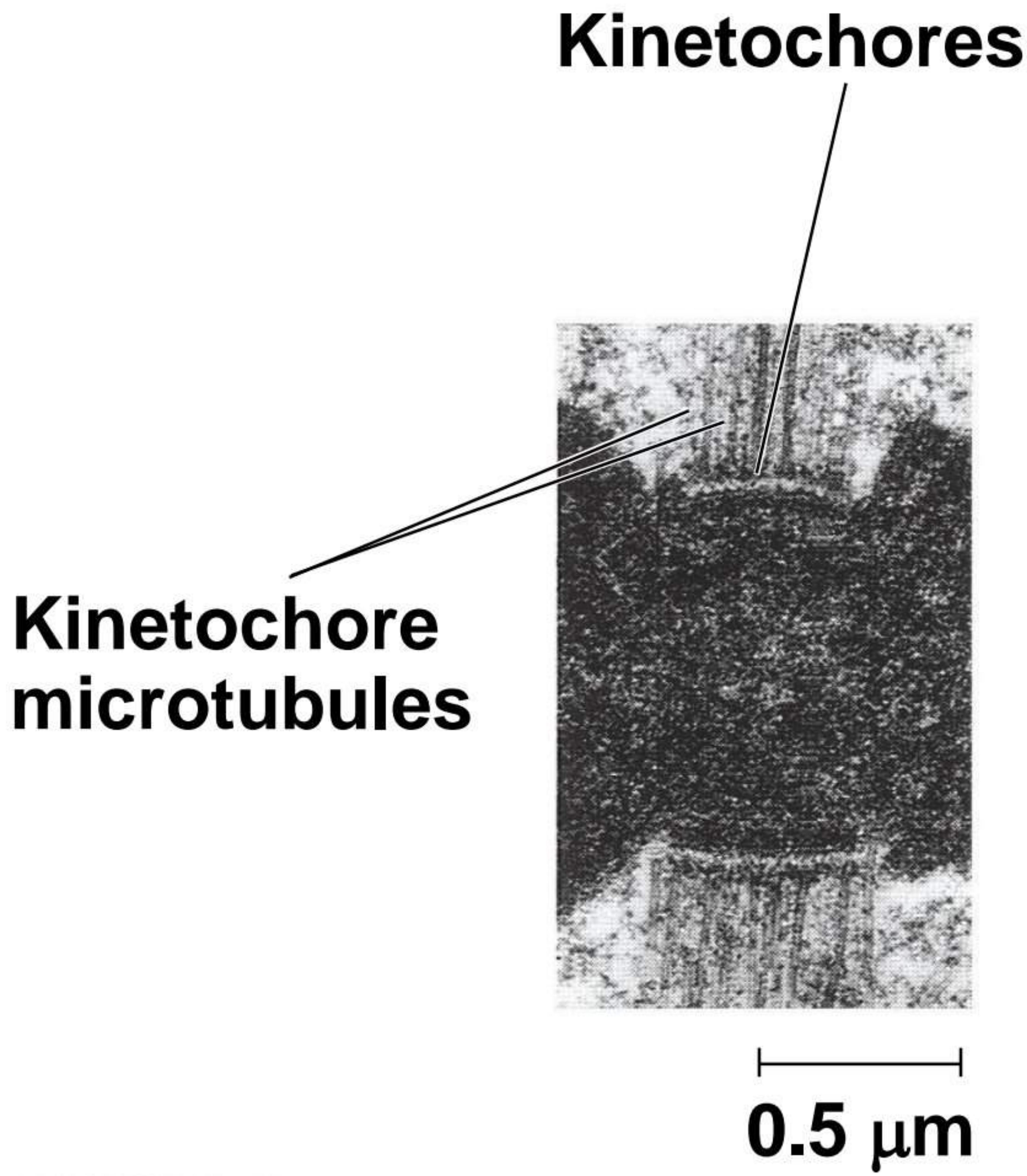
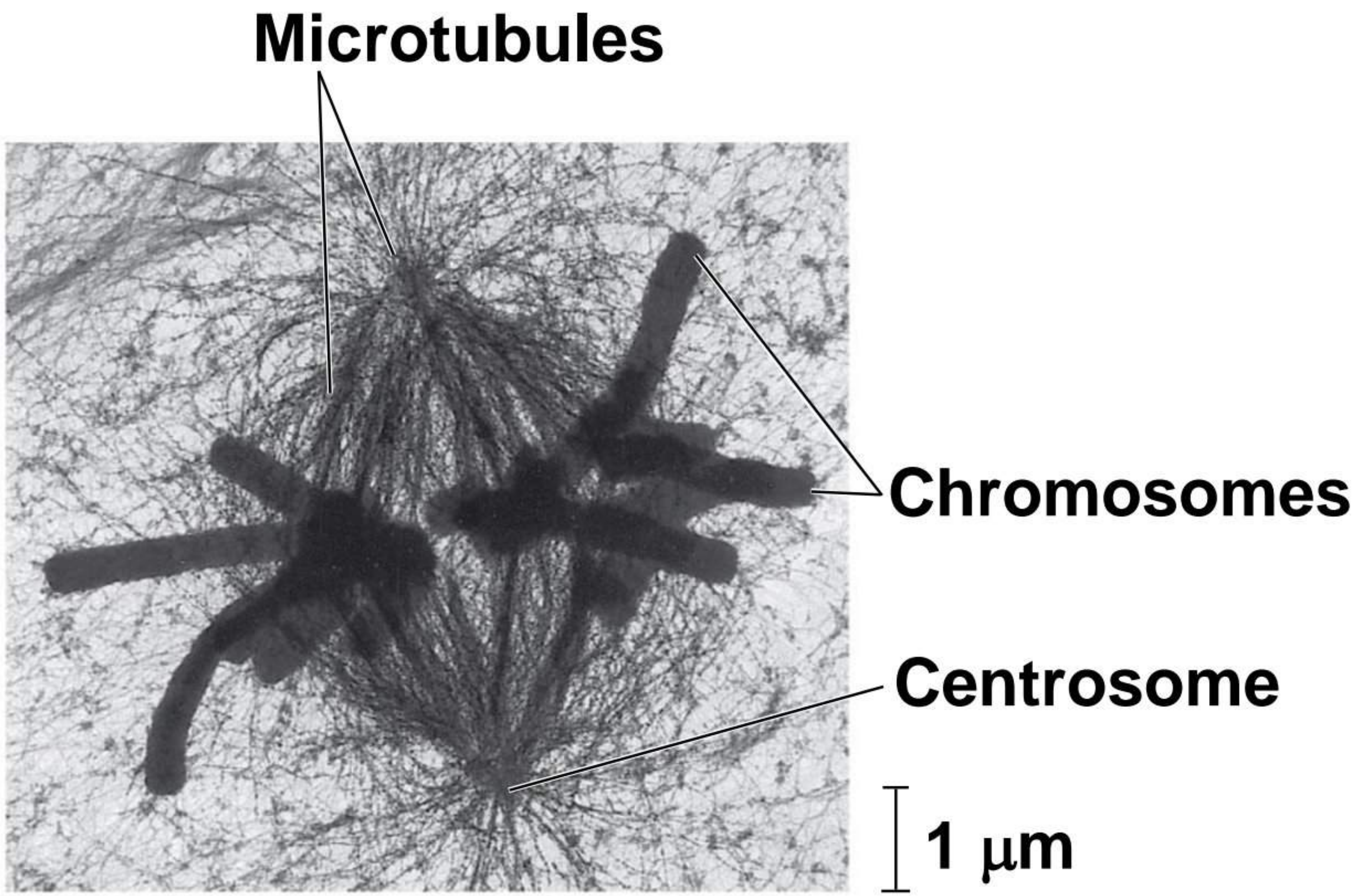
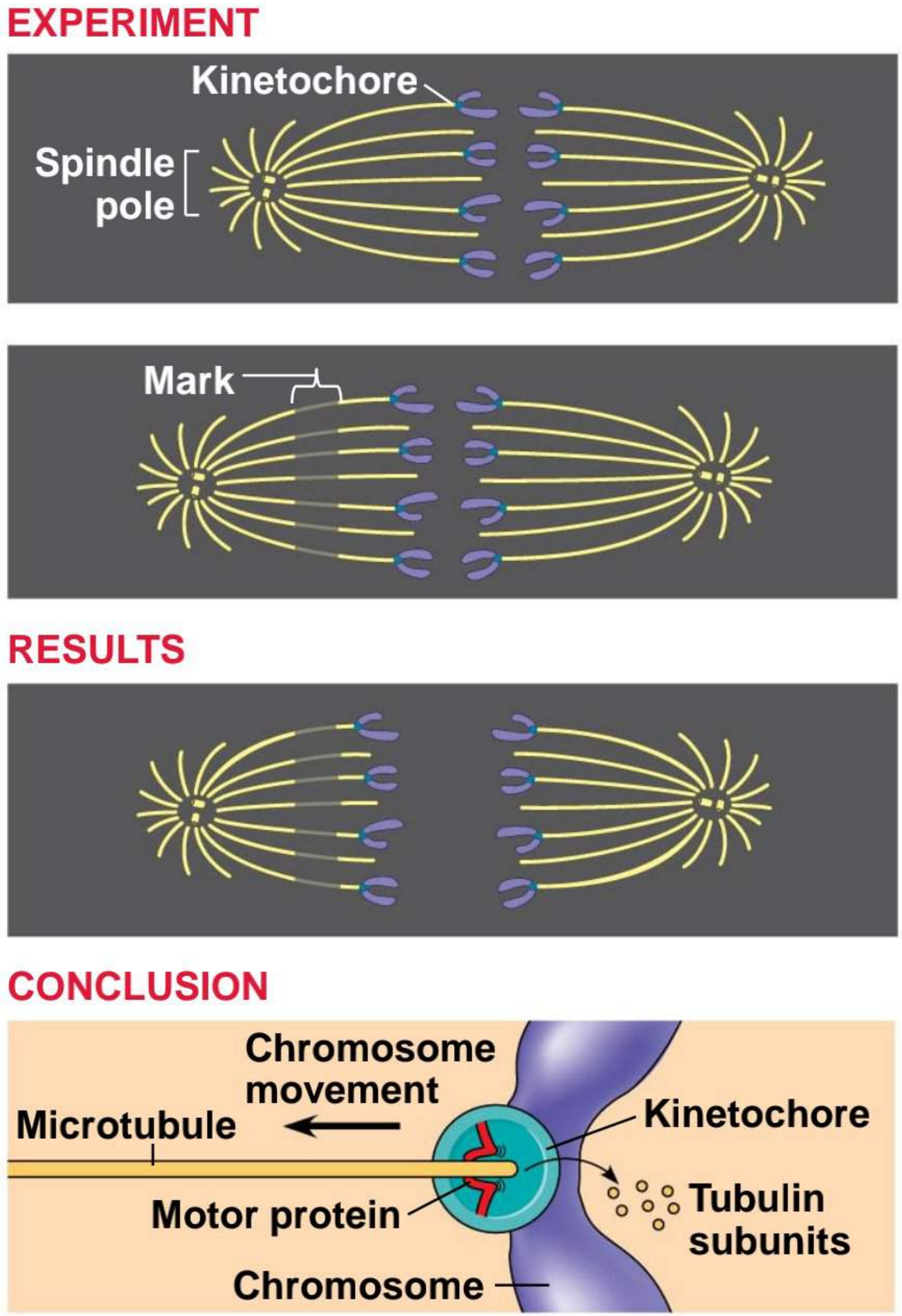


Figure 12.8b



- In anaphase, sister chromatids separate and move along the kinetochore microtubules toward opposite ends of the cell
- The microtubules shorten by depolymerizing at their kinetochore ends

Figure 12.9



EXPERIMENT
Kinetochore
Spindle pole
Mark
RESULTS
CONCLUSION
Chromosome movement
Microtubule
Kinetochore
Tubulin subunits
Motor protein
Chromosome

Figure 12.9a

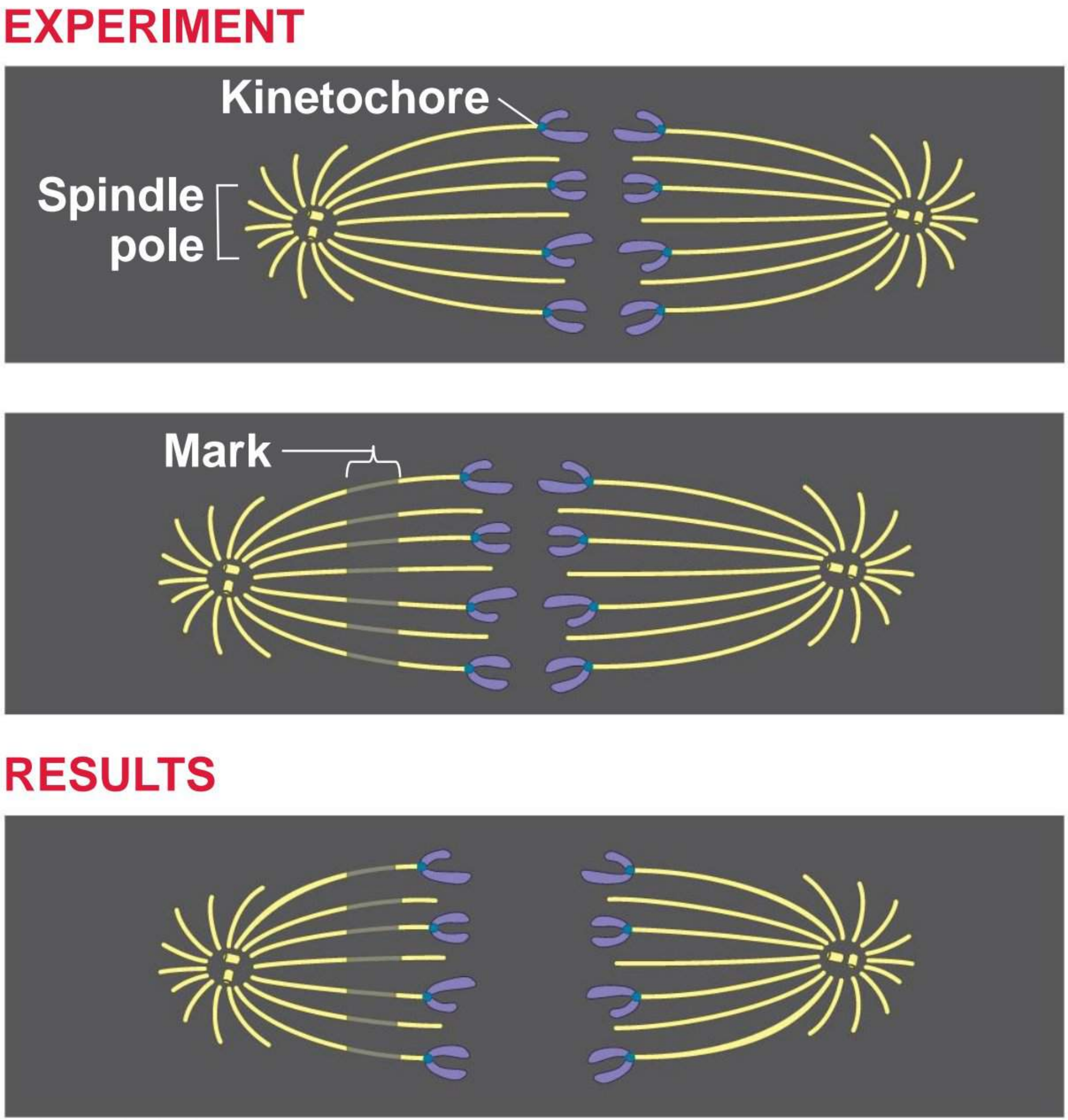
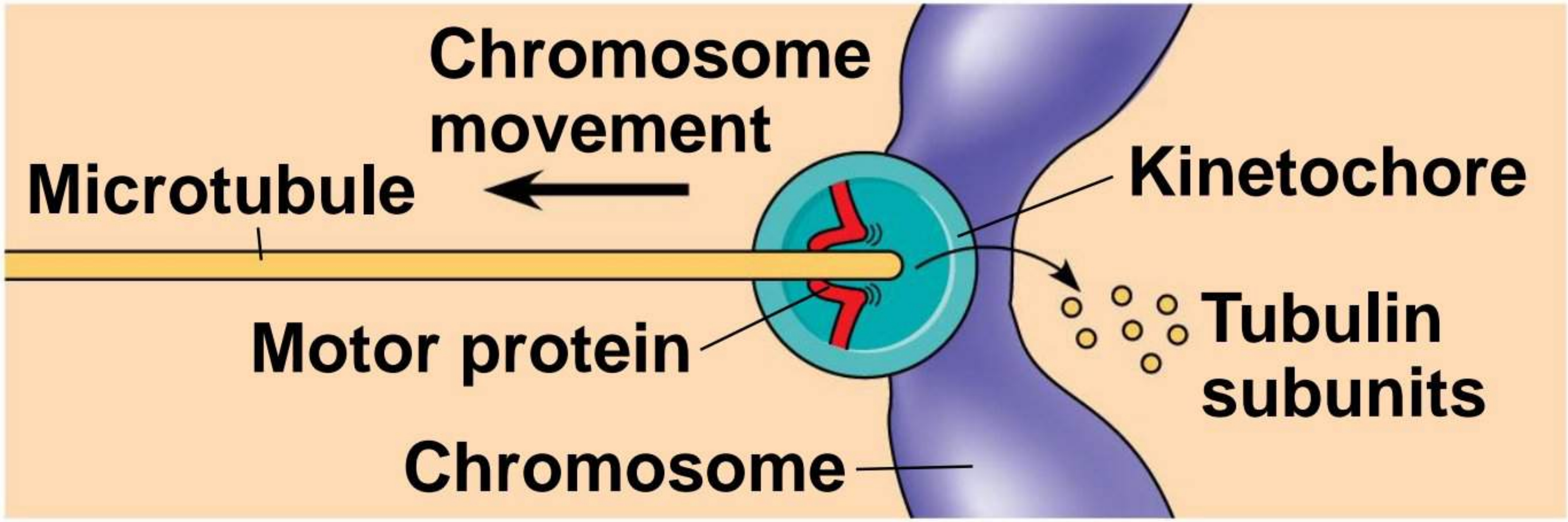


Figure 12.9b

CONCLUSION



- Nonkinetochore microtubules from opposite poles overlap and push against each other, elongating the cell
- In telophase, genetically identical daughter nuclei form at opposite ends of the cell
- Cytokinesis begins during anaphase or telophase and the spindle eventually disassembles

Cytokinesis: *A Closer Look*

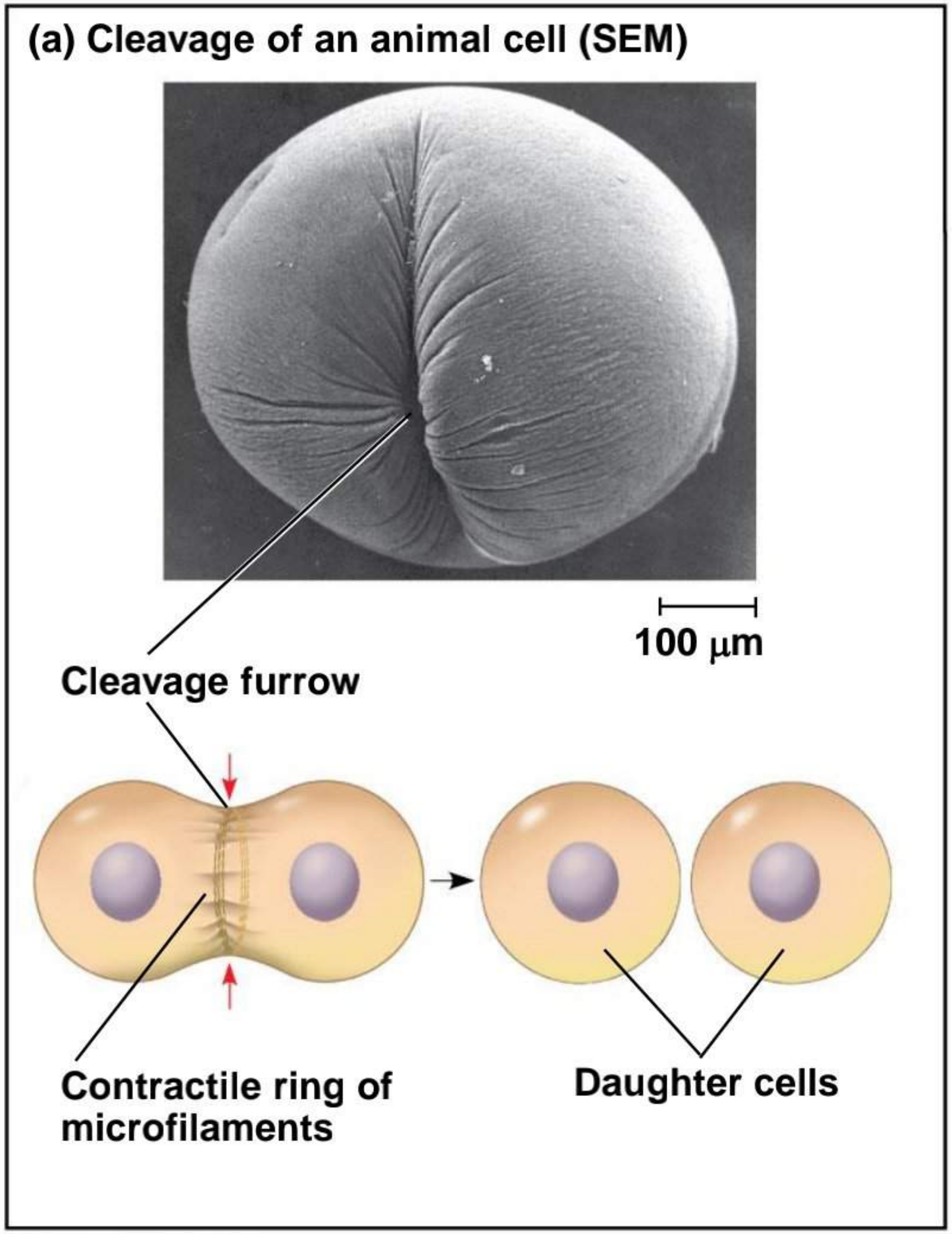
- In animal cells, cytokinesis occurs by a process known as **cleavage**, forming a **cleavage furrow**
- In plant cells, a **cell plate** forms during cytokinesis

PLAY Animation: Cytokinesis

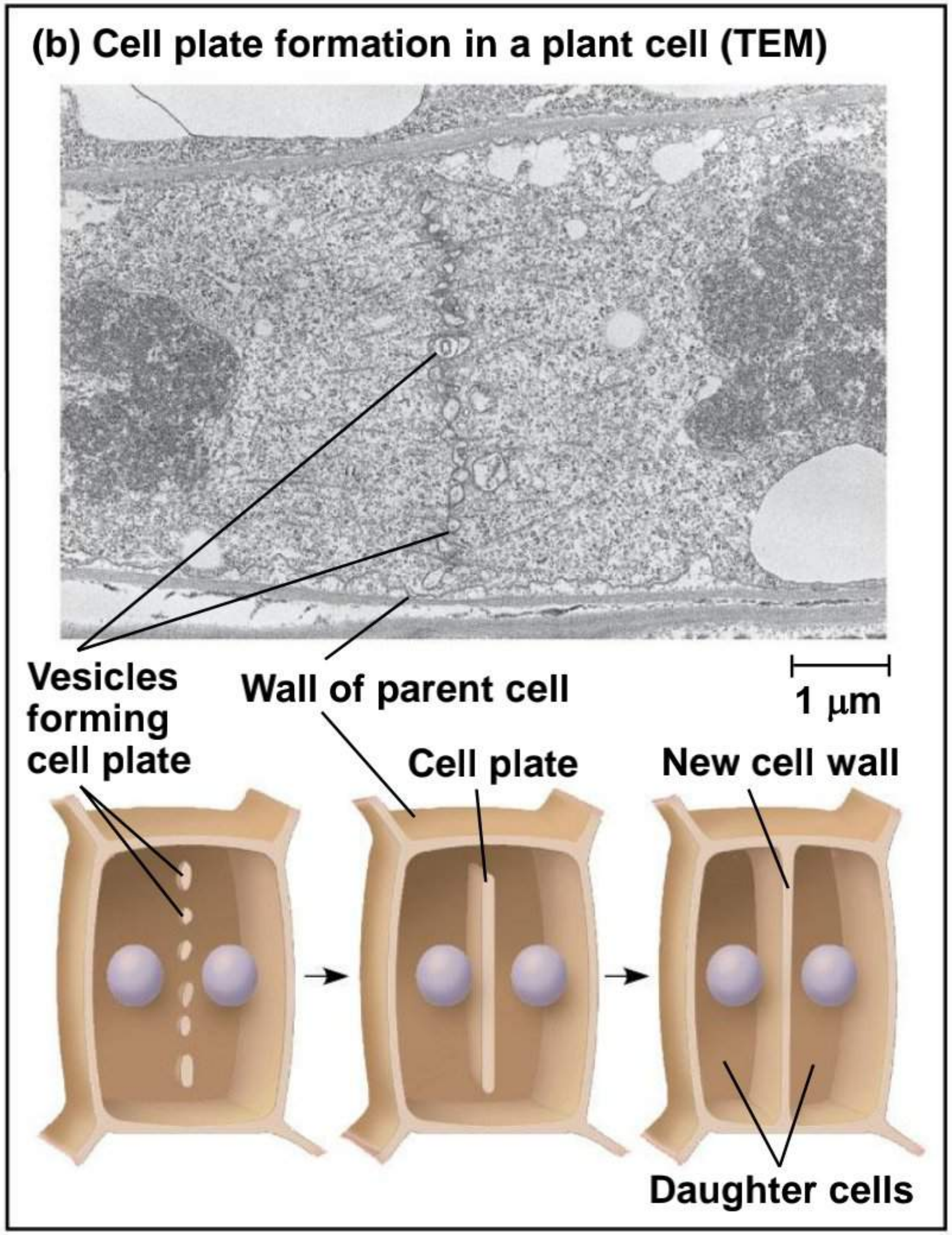
PLAY Video: Animal Mitosis

PLAY Video: Sea Urchin (Time Lapse)

Figure 12.10



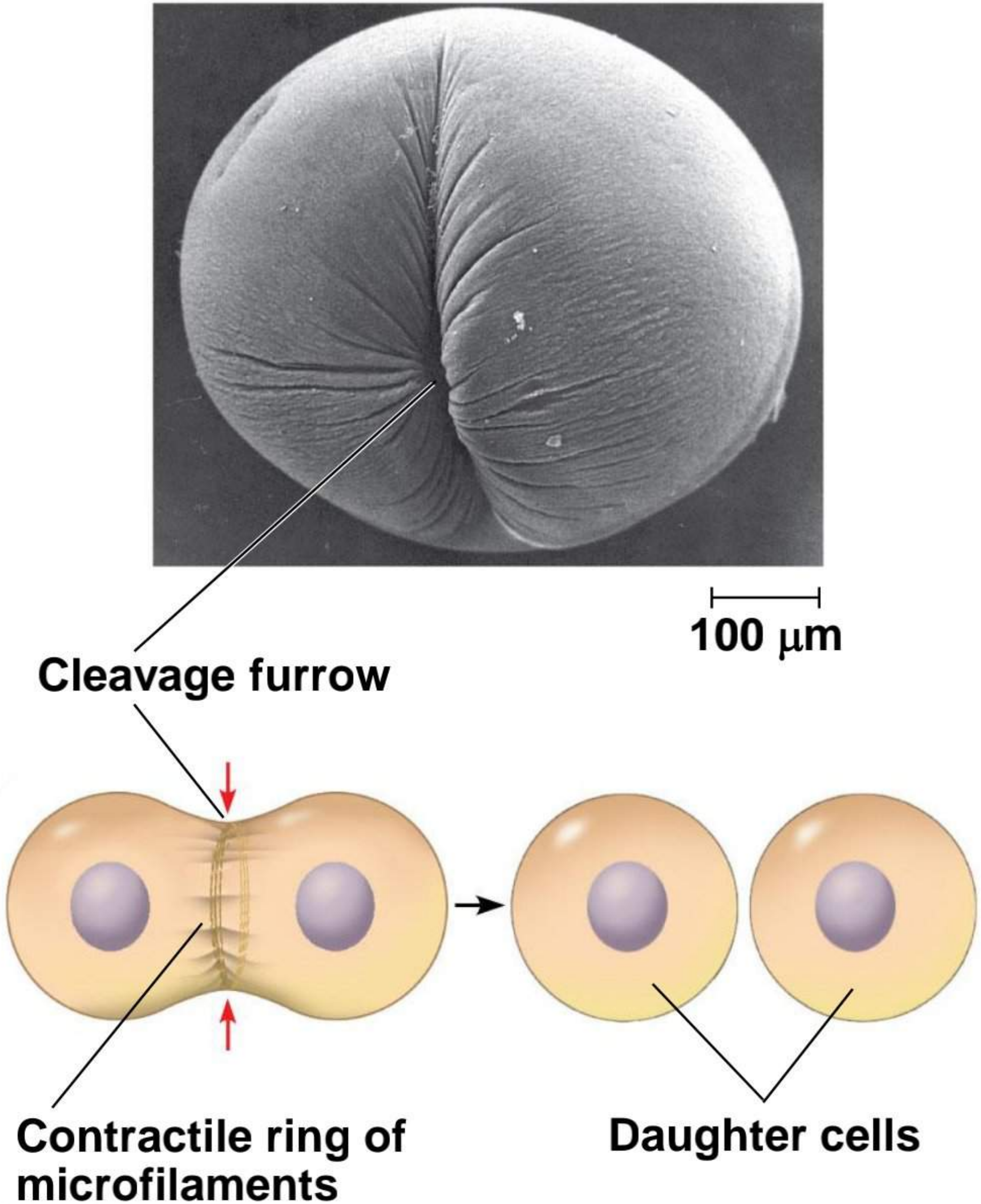
(a) Cleavage of an animal cell (SEM)
100 μm
Cleavage furrow
Contractile ring of microfilaments
Daughter cells



(b) Cell plate formation in a plant cell (TEM)
Vesicles forming cell plate
Wall of parent cell
1 μm
Cell plate
New cell wall
Daughter cells

Figure 12.10a

(a) Cleavage of an animal cell (SEM)



(b) Cell plate formation in a plant cell (TEM)

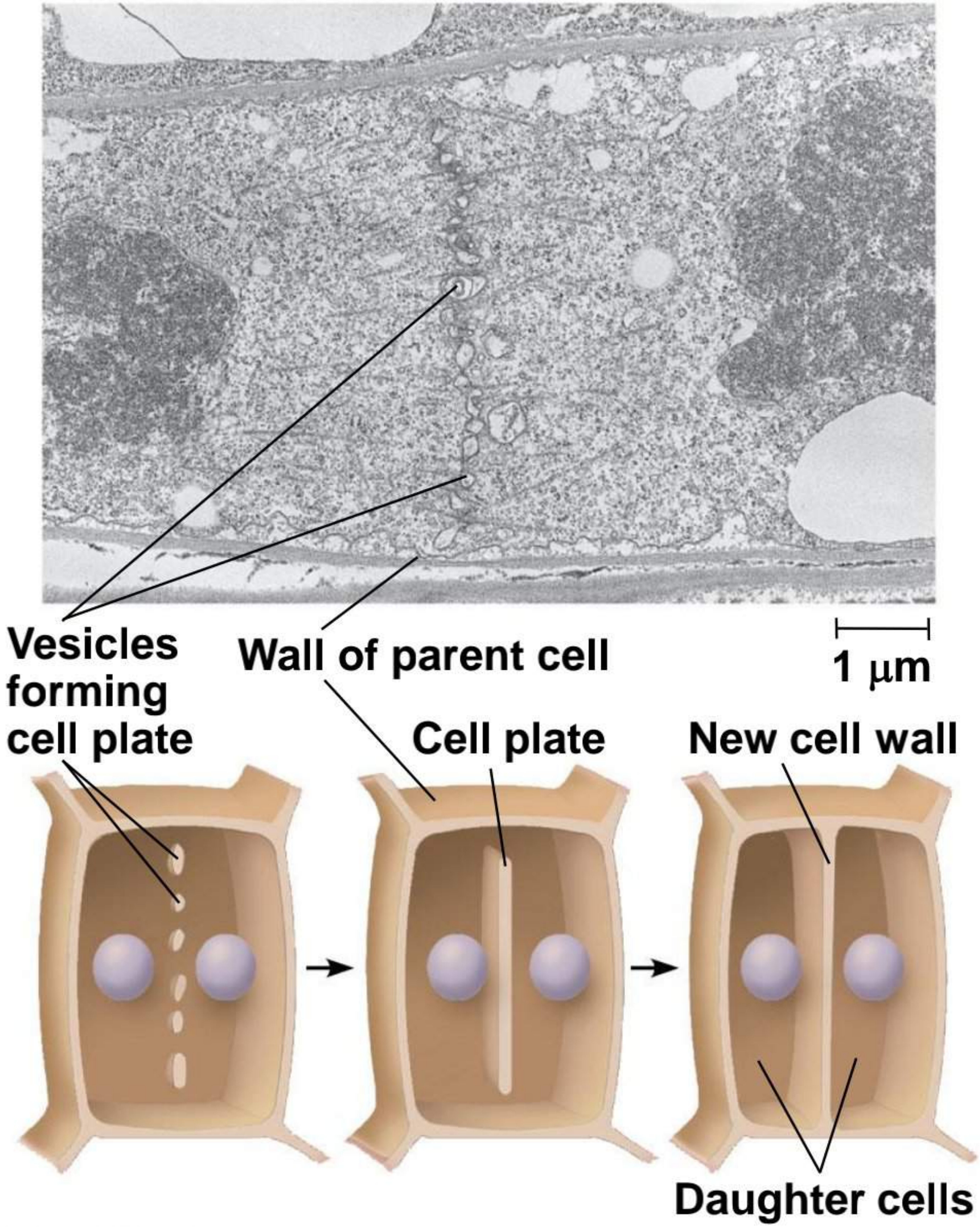


Figure 12.10c

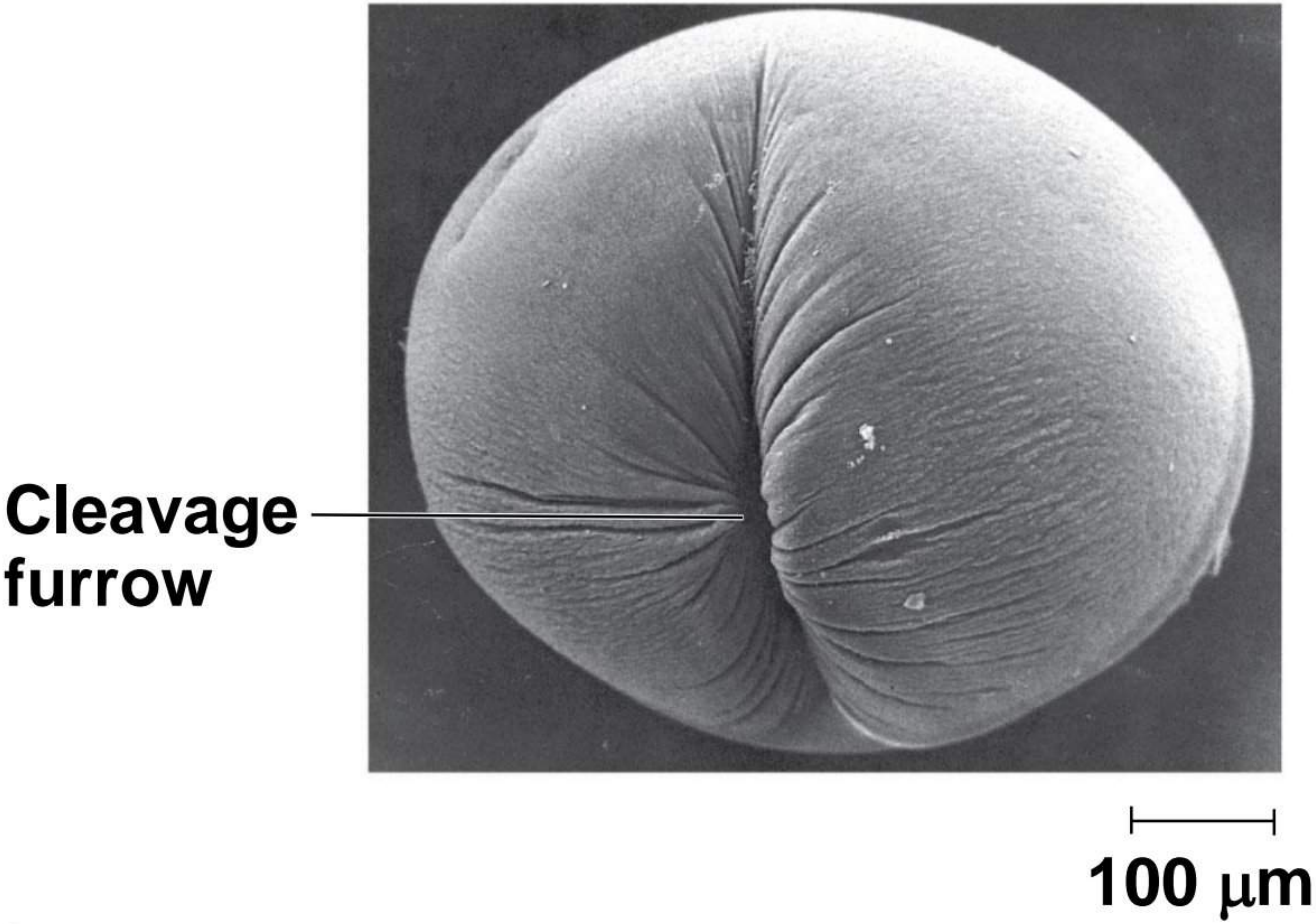


Figure 12.10d

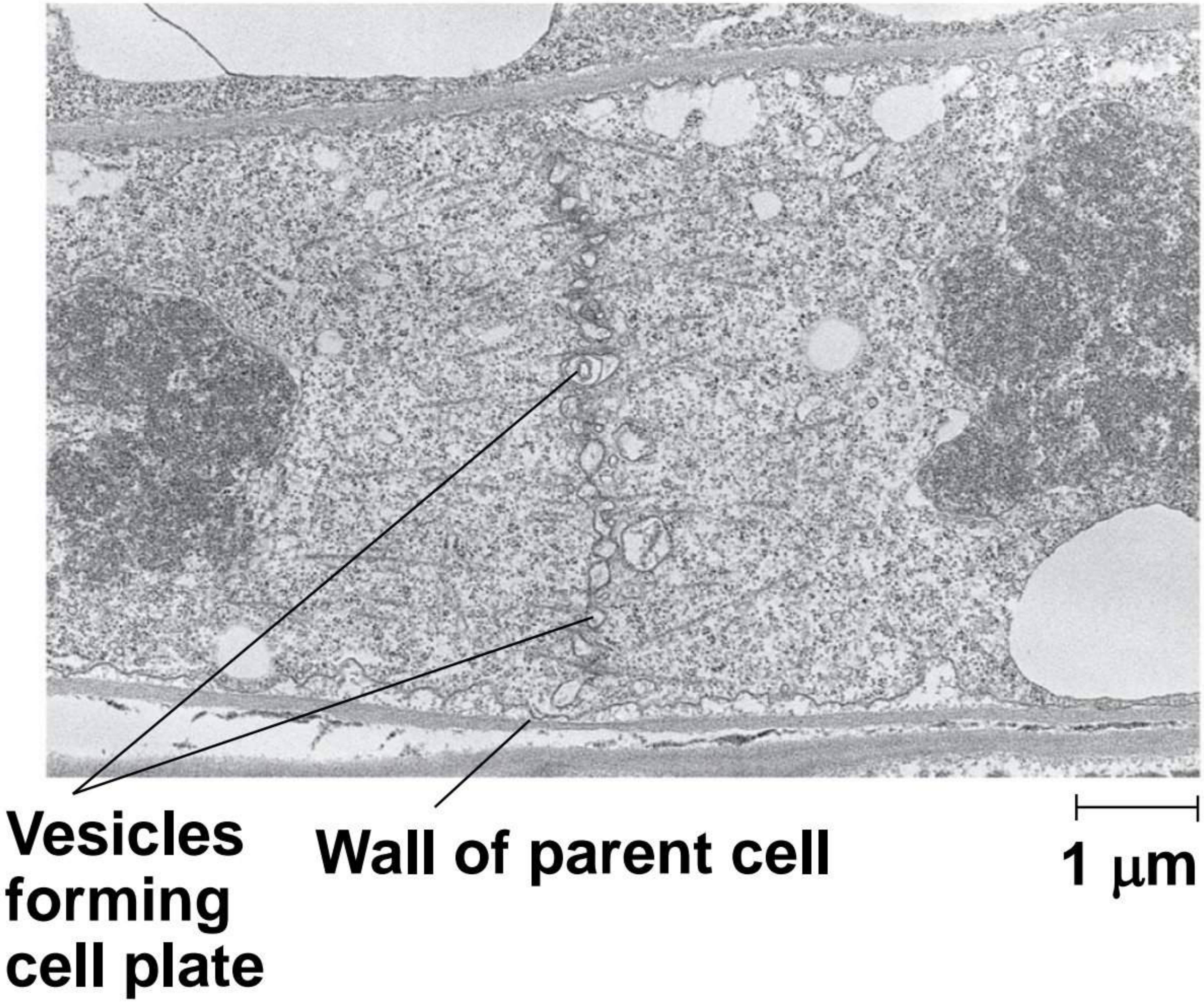
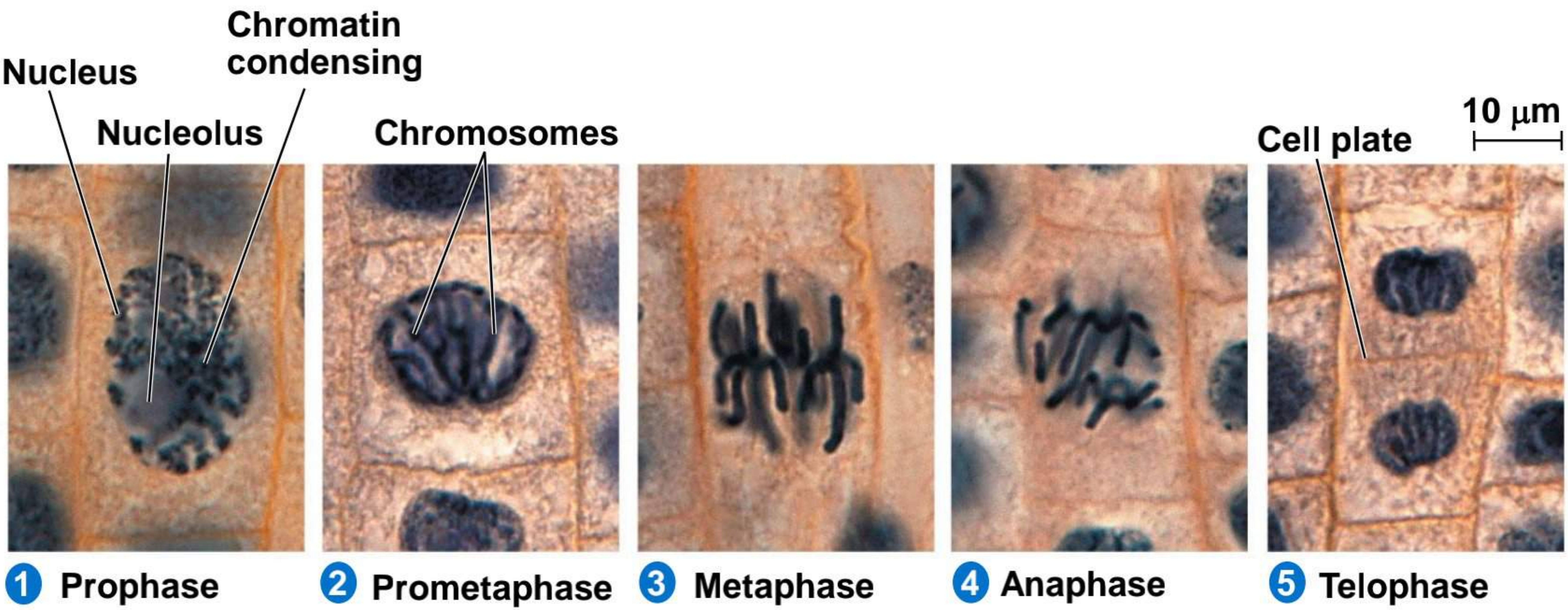
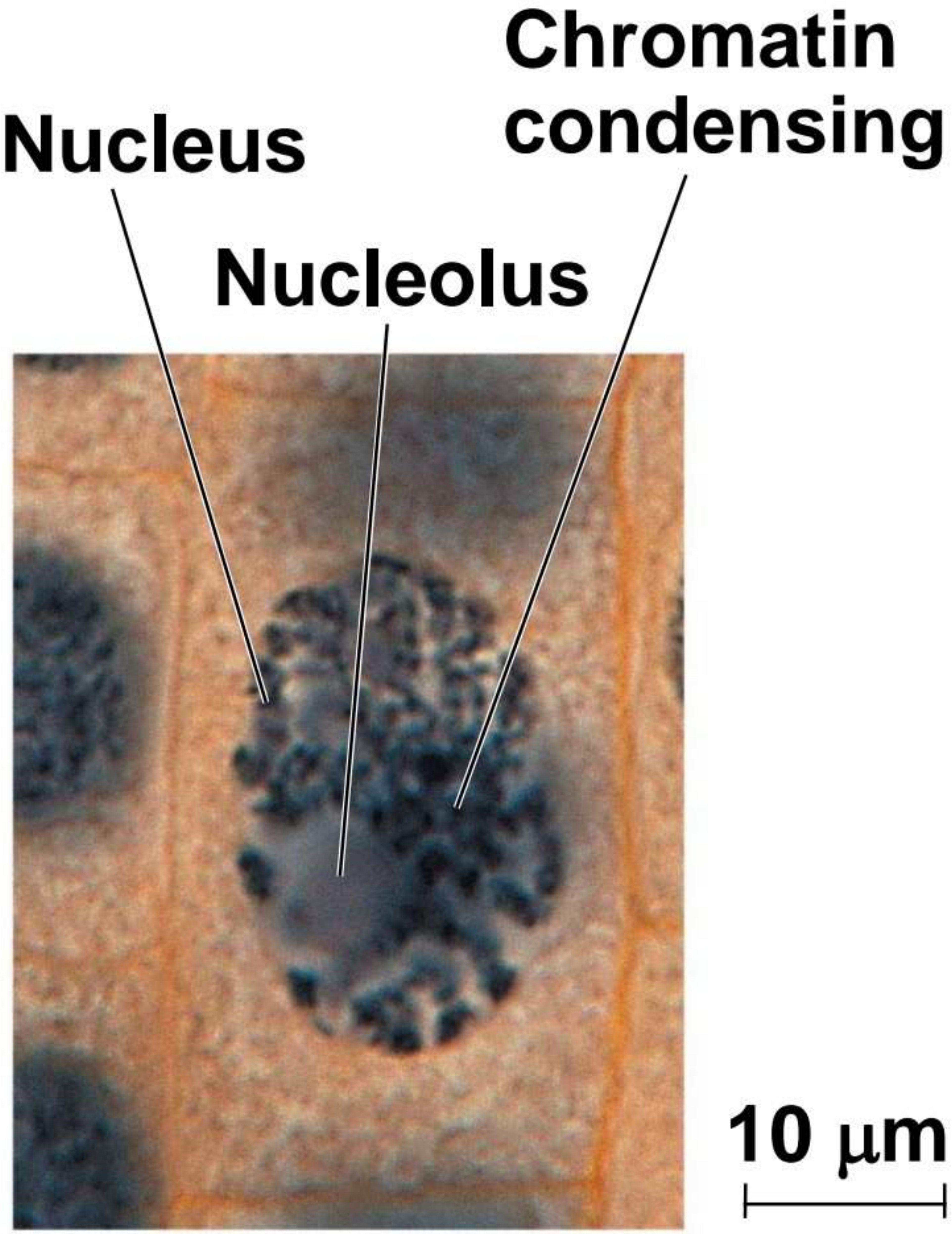


Figure 12.11



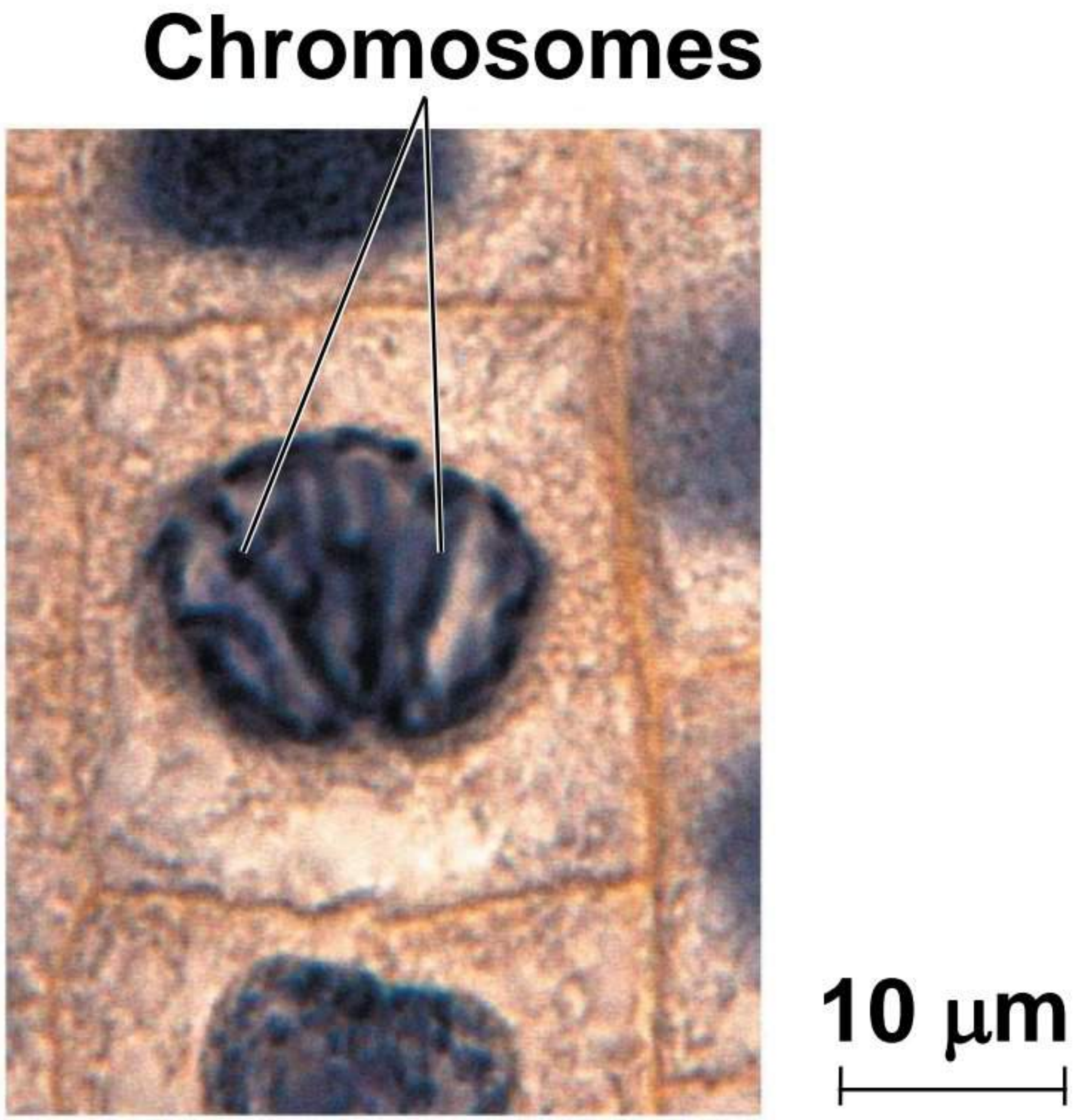
Nucleus
Nucleolus
Chromatin condensing
Chromosomes
Cell plate
10 μm
1 Prophase
2 Prometaphase
3 Metaphase
4 Anaphase
5 Telophase

Figure 12.11a



1 Prophase

Figure 12.11b



2 Prometaphase

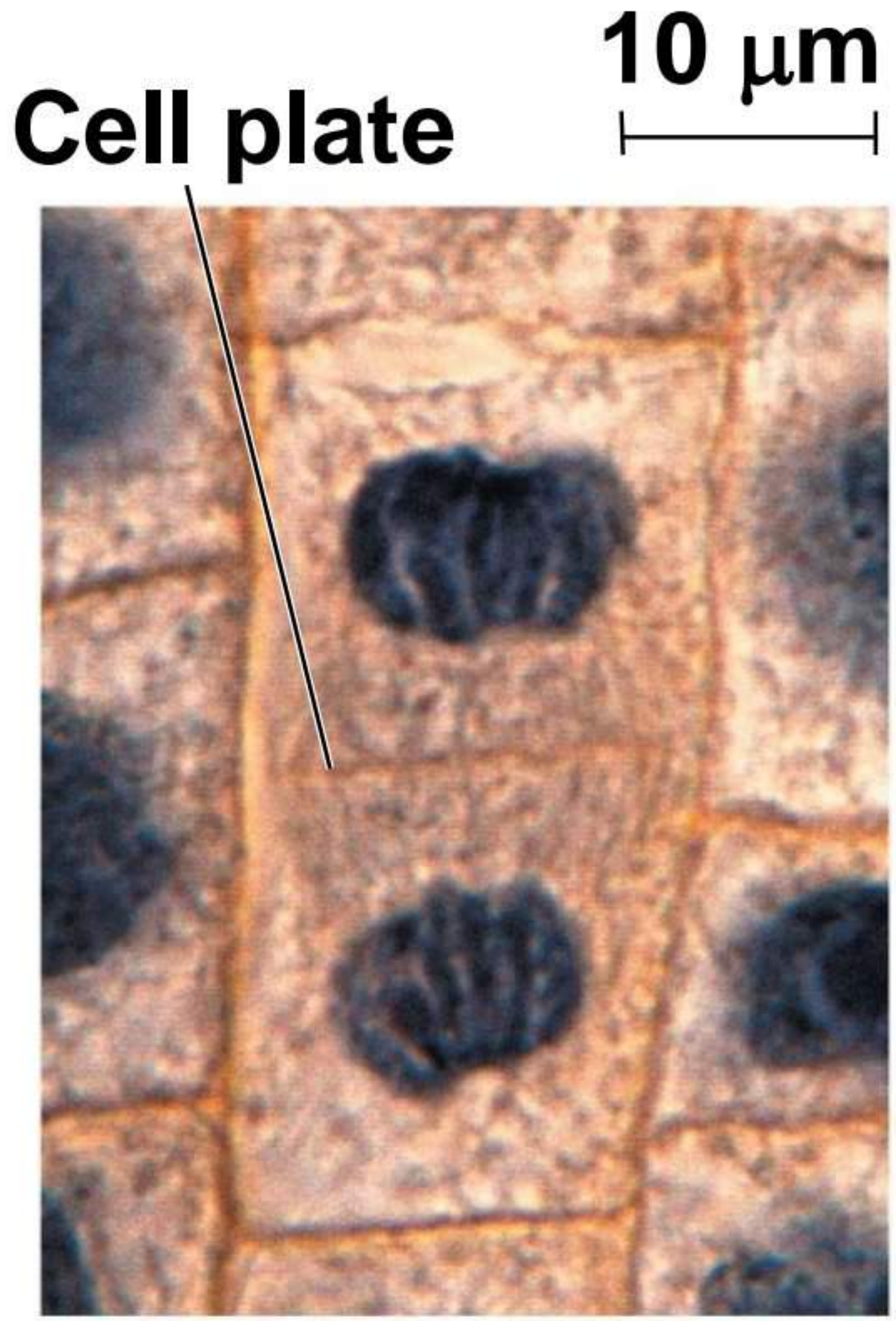
Figure 12.11c

3 Metaphase

Figure 12.11d

4 Anaphase

Figure 12.11e



5 Telophase

Binary Fission in Bacteria

- Prokaryotes (bacteria and archaea) reproduce by a type of cell division called **binary fission**
- In binary fission, the chromosome replicates (beginning at the **origin of replication**), and the two daughter chromosomes actively move apart
- The plasma membrane pinches inward, dividing the cell into two

Figure 12.12-1

1 Chromosome replication begins.

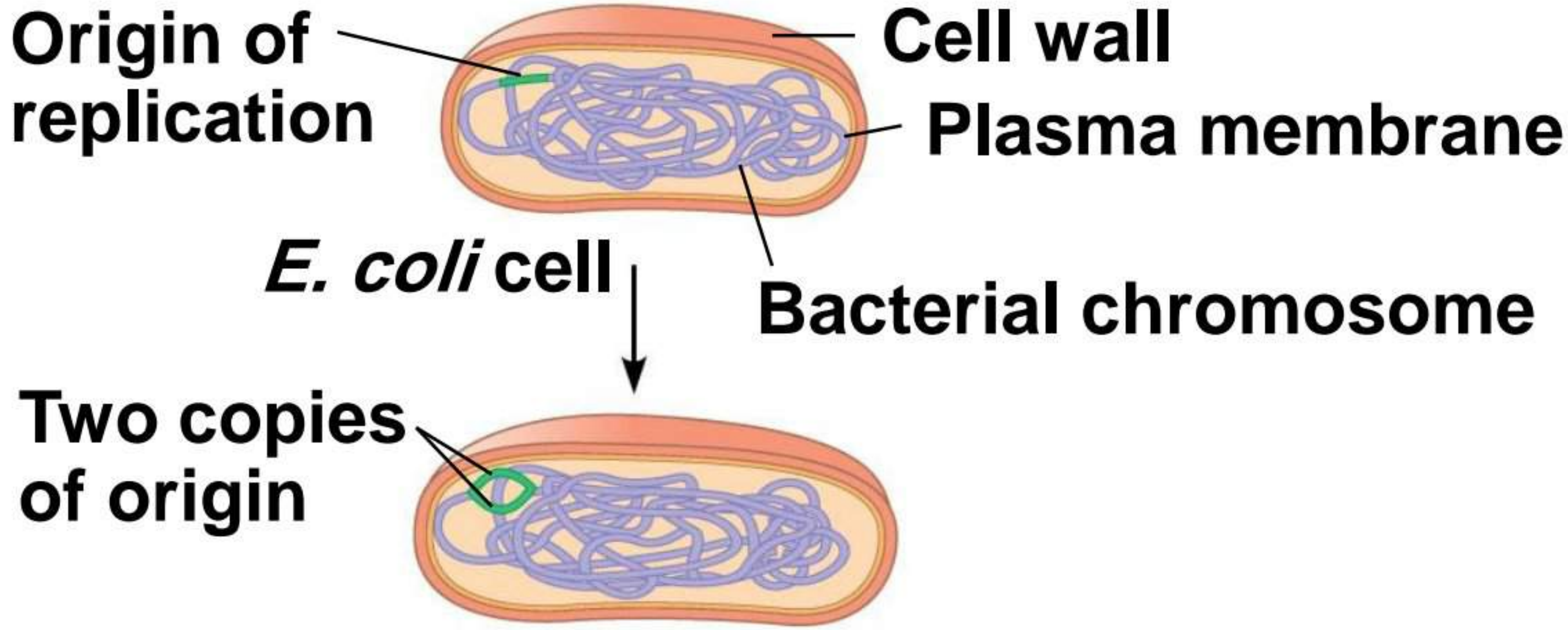
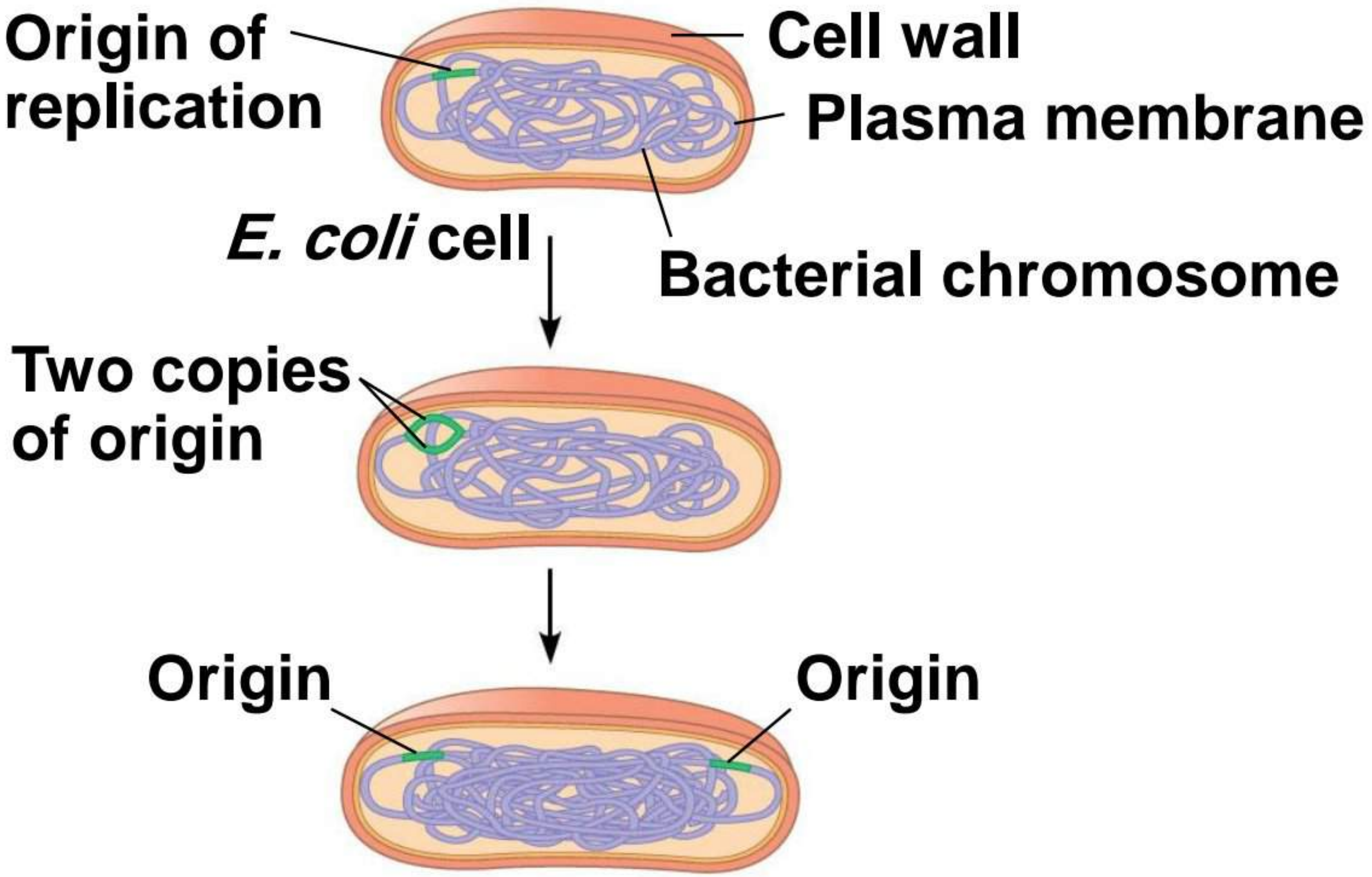


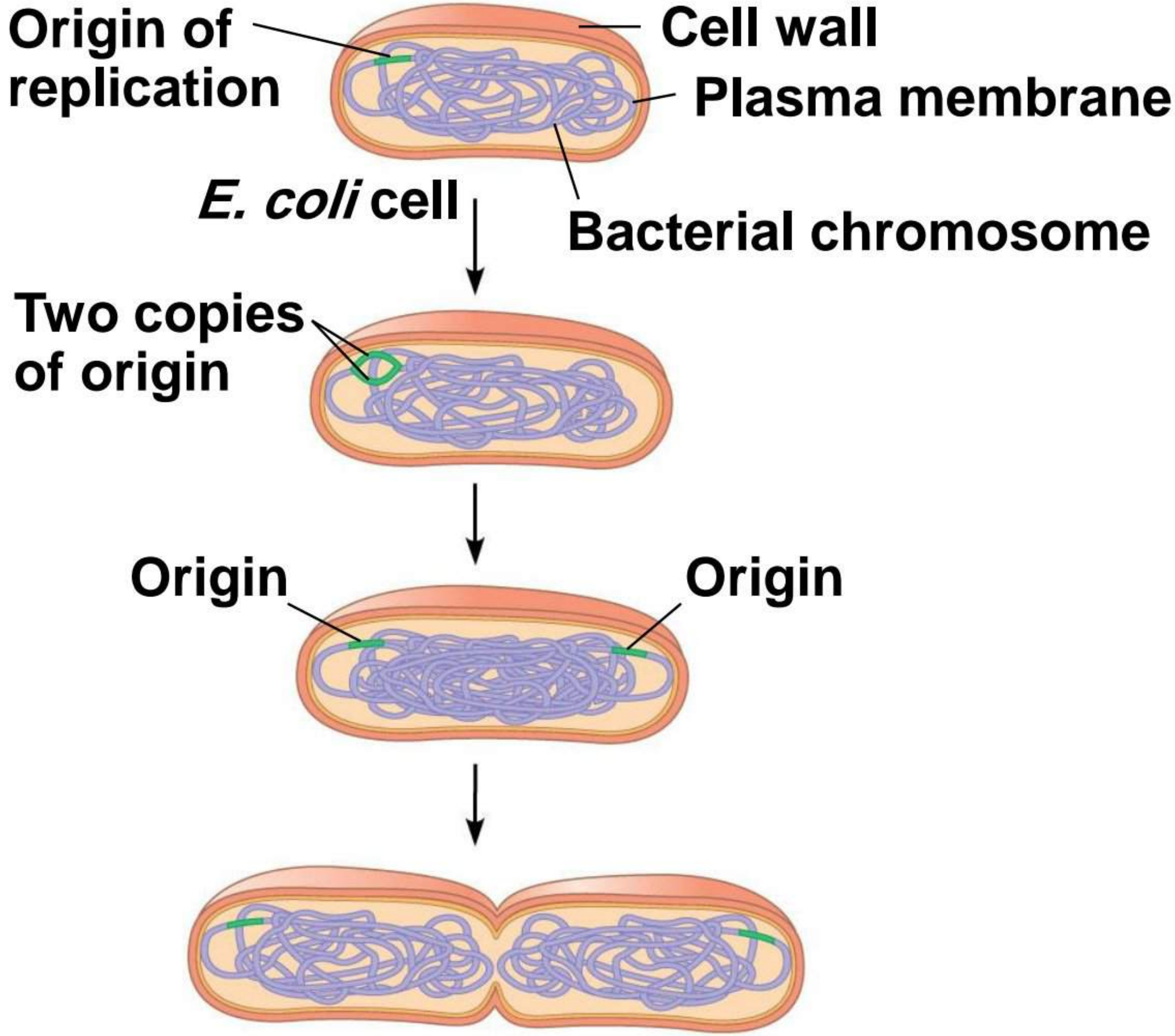
Figure 12.12-2



1 Chromosome replication begins.

2 Replication continues.

Figure 12.12-3



1 Chromosome replication begins.

2 Replication continues.

3 Replication finishes.

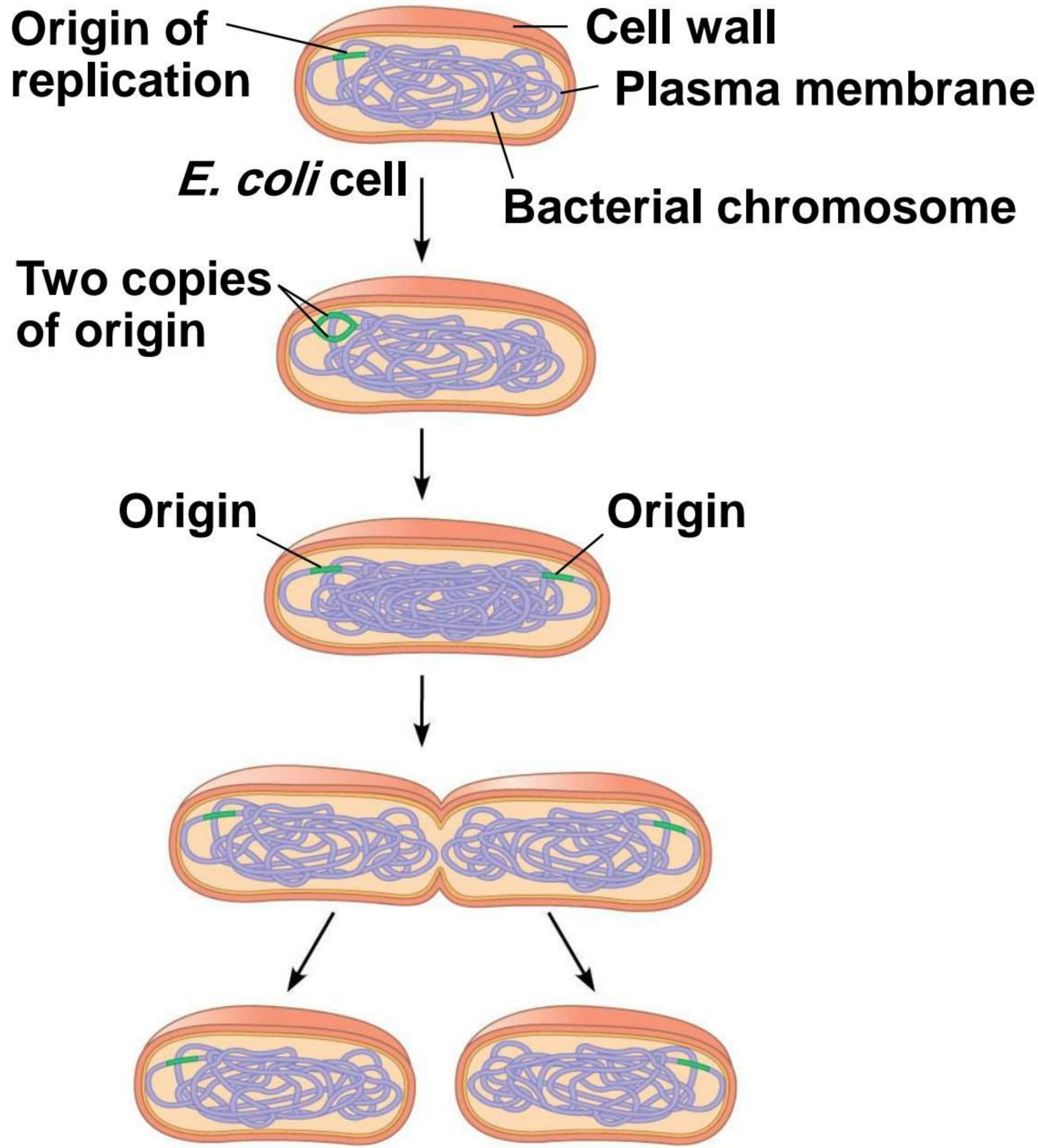
Figure 12.12-4

1 Chromosome replication begins.

2 Replication continues.

3 Replication finishes.

4 Two daughter cells result.



The Evolution of Mitosis

- Since prokaryotes evolved before eukaryotes, mitosis probably evolved from binary fission
- Certain protists exhibit types of cell division that seem intermediate between binary fission and mitosis

Figure 12.13

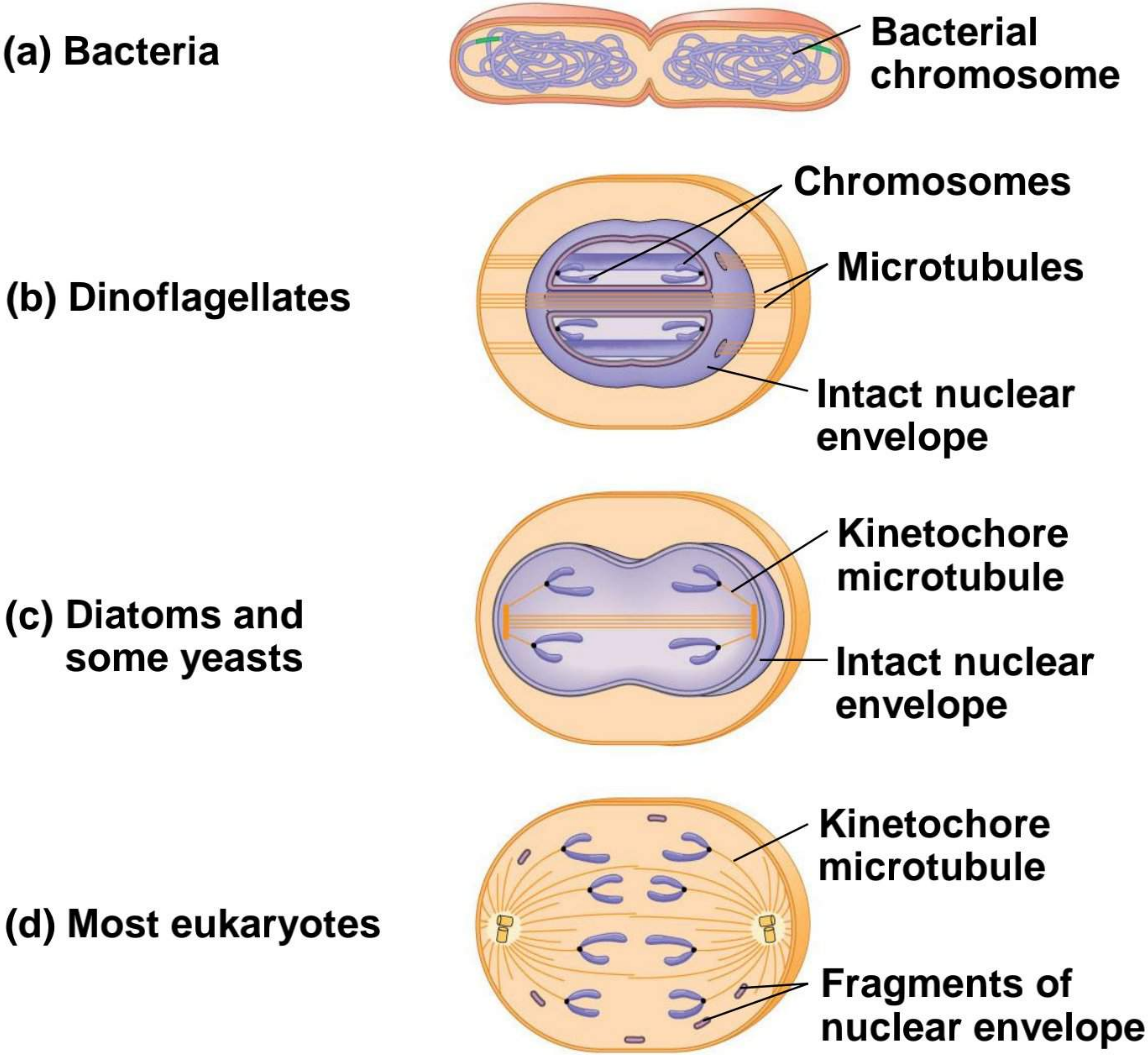
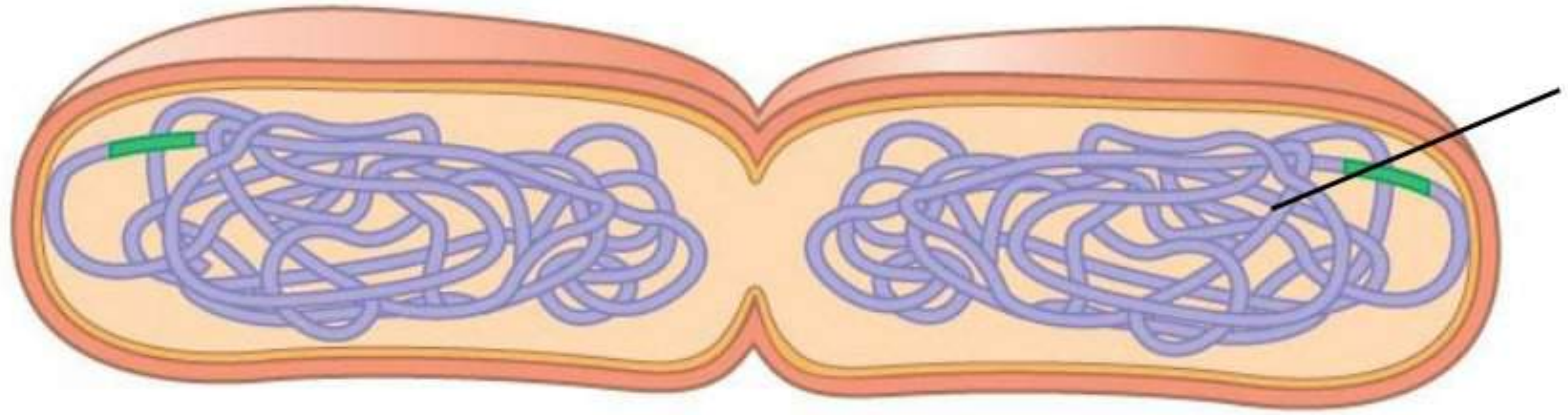
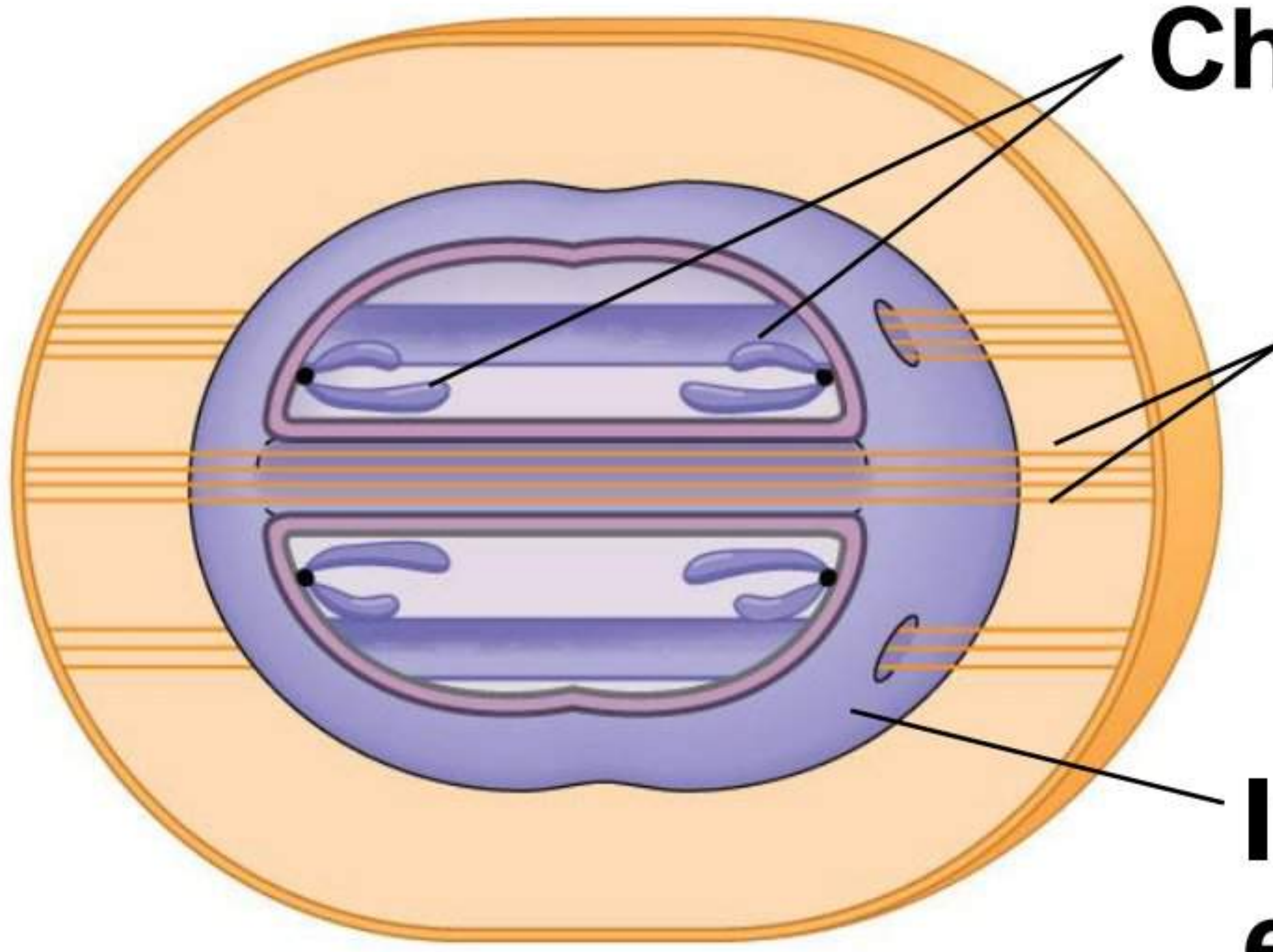

(a) Bacteria
Bacterial chromosome
(b) Dinoflagellates
Chromosomes
Microtubules
Intact nuclear envelope
(c) Diatoms and some yeasts
Kinetochore microtubule
Intact nuclear envelope
(d) Most eukaryotes
Kinetochore microtubule
Fragments of nuclear envelope

Figure 12.13a

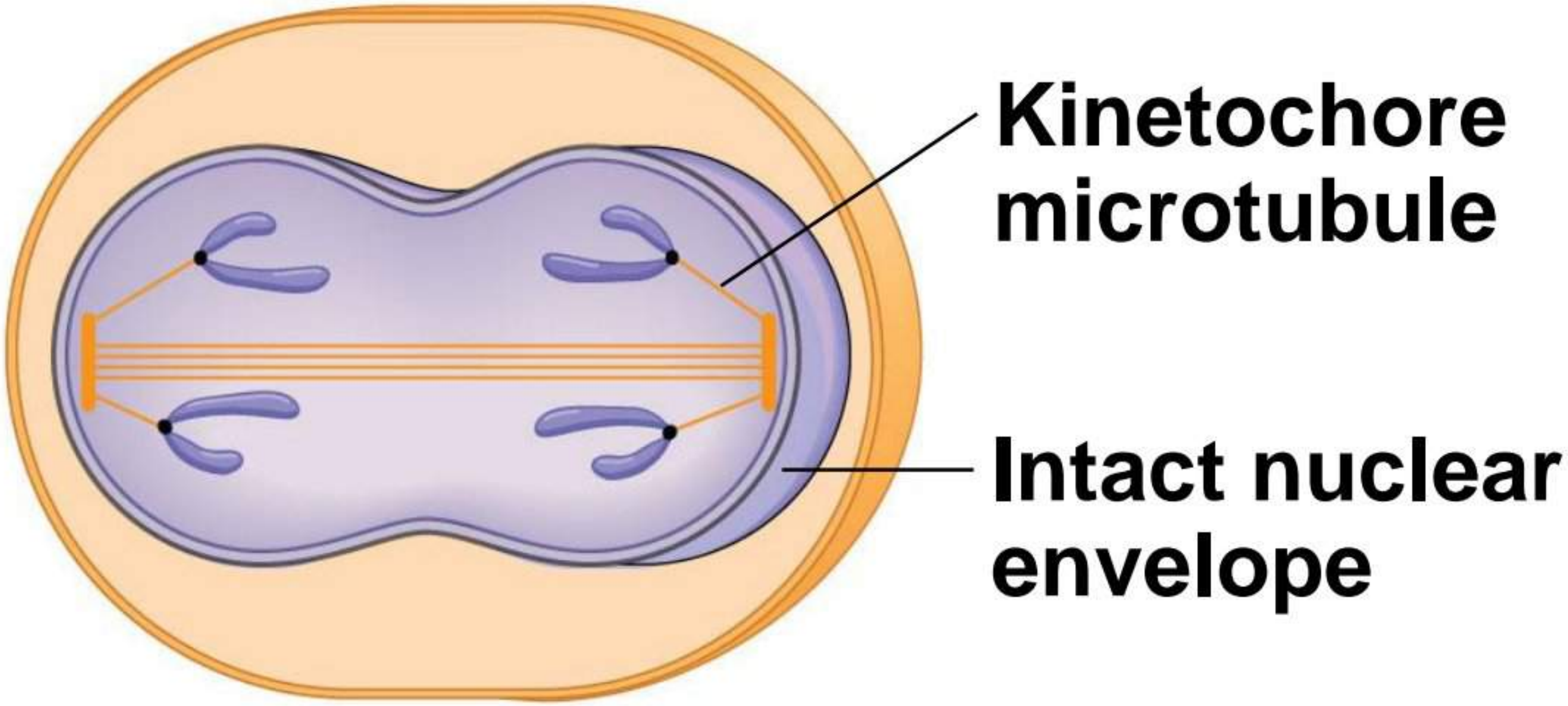


(a) Bacteria

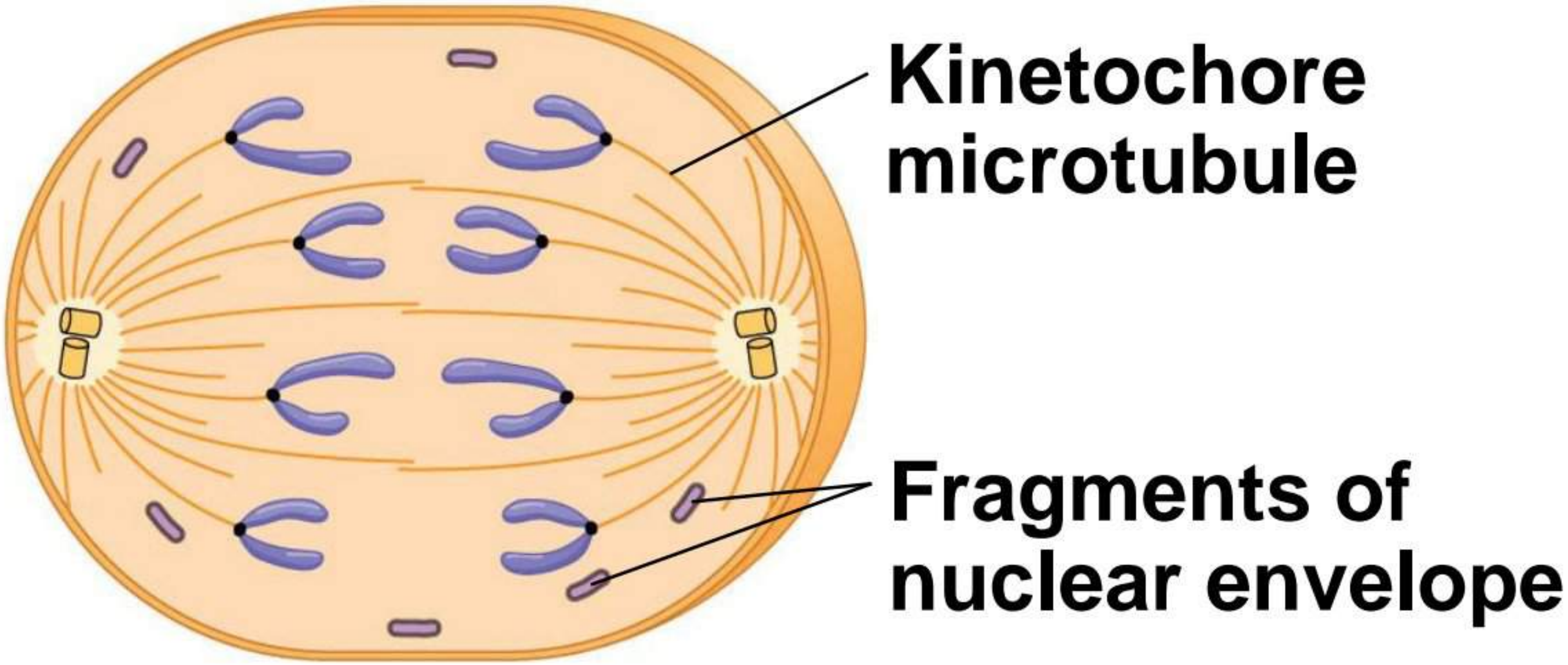


(b) Dinoflagellates

Figure 12.13b



(c) Diatoms and some yeasts



(d) Most eukaryotes

Concept 12.3: The eukaryotic cell cycle is regulated by a molecular control system

- The frequency of cell division varies with the type of cell
- These differences result from regulation at the molecular level
- Cancer cells manage to escape the usual controls on the cell cycle

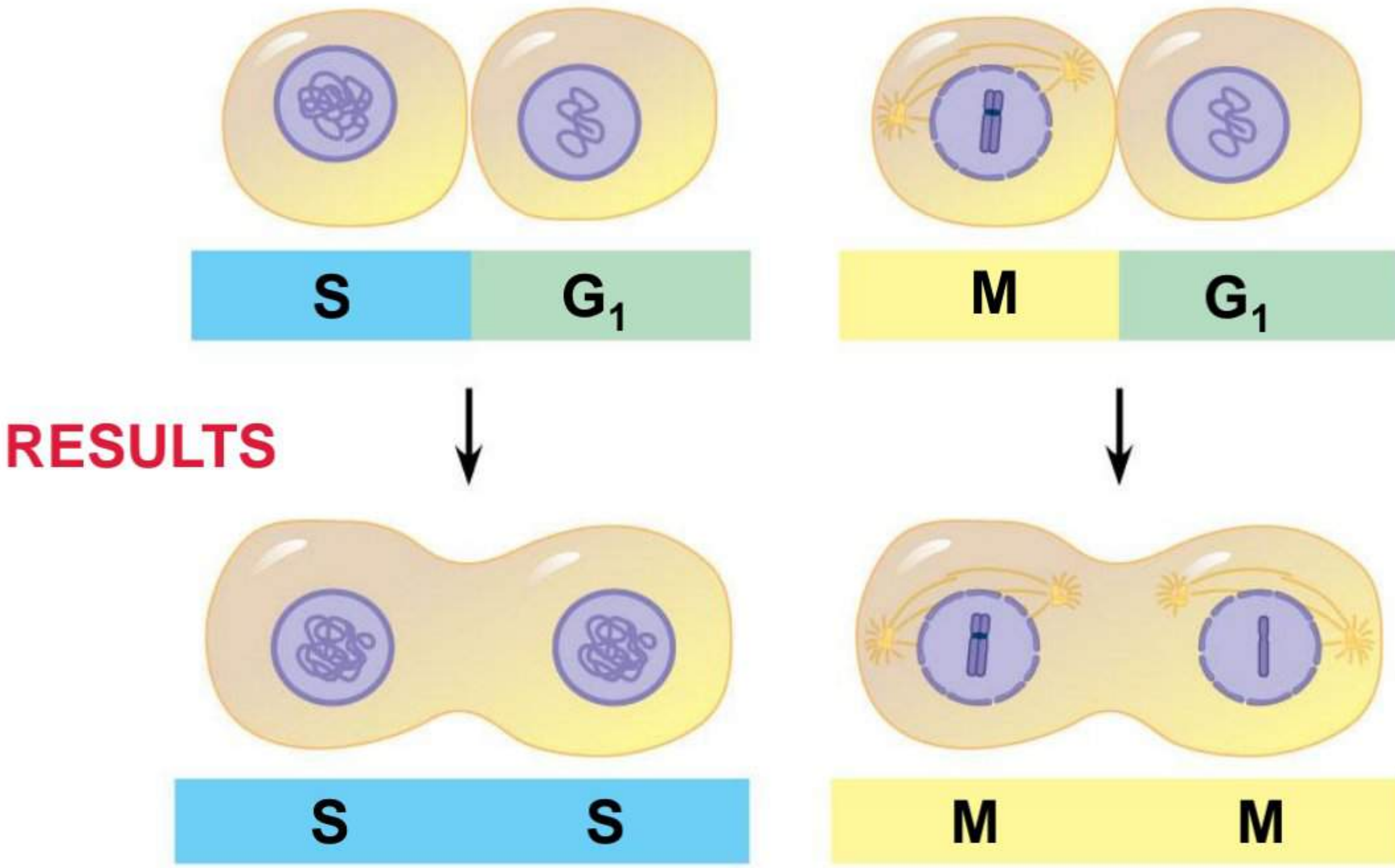
Evidence for Cytoplasmic Signals

- The cell cycle appears to be driven by specific chemical signals present in the cytoplasm
- Some evidence for this hypothesis comes from experiments in which cultured mammalian cells at different phases of the cell cycle were fused to form a single cell with two nuclei

Figure 12.14

EXPERIMENT

Experiment 1 | **Experiment 2**



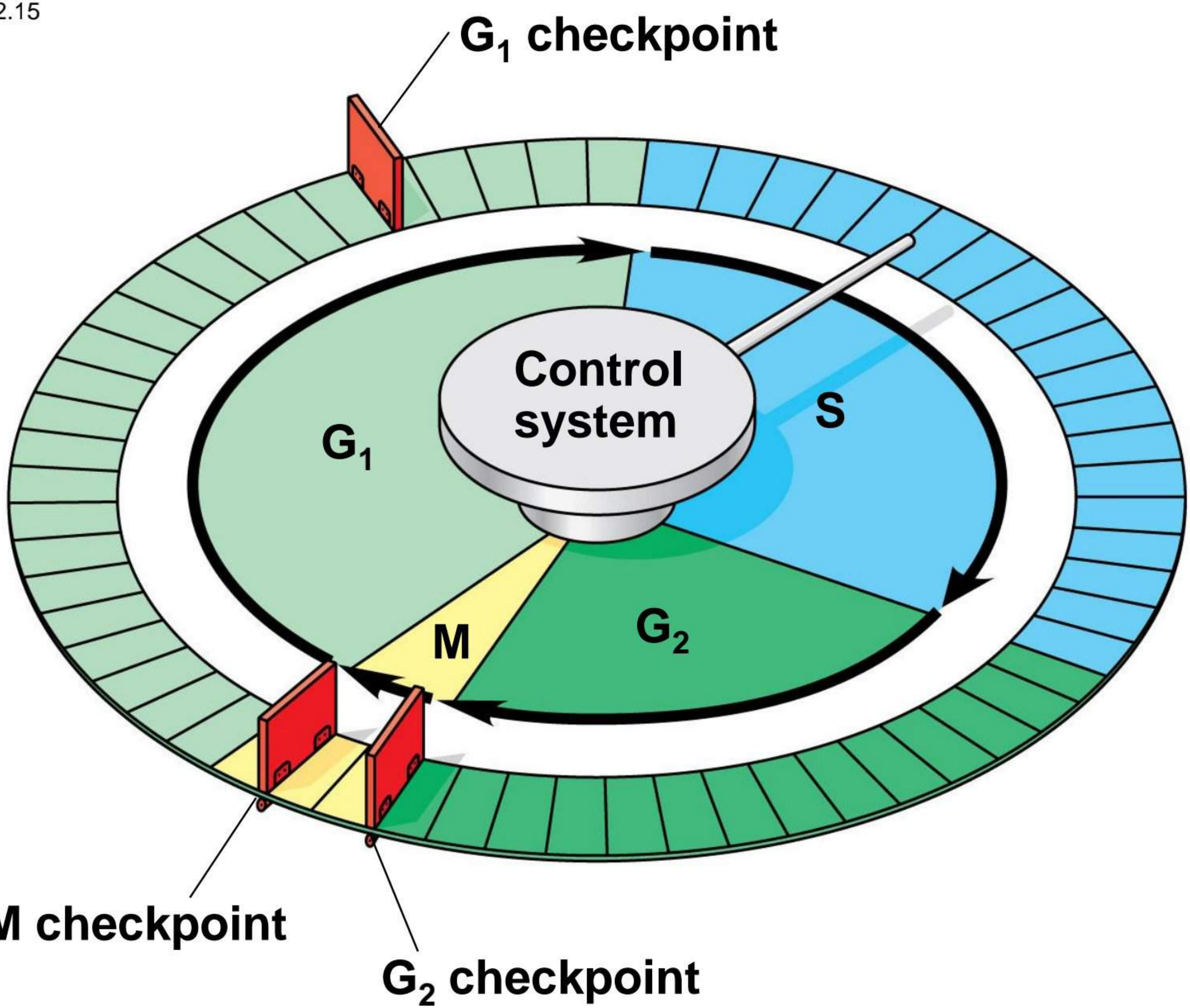
When a cell in the S phase was fused with a cell in G_1, the G_1 nucleus immediately entered the S phase—DNA was synthesized.

When a cell in the M phase was fused with a cell in G_1, the G_1 nucleus immediately began mitosis—a spindle formed and chromatin condensed, even though the chromosome had not been duplicated.

The Cell Cycle Control System

- The sequential events of the cell cycle are directed by a distinct **cell cycle control system**, which is similar to a clock
- The cell cycle control system is regulated by both internal and external controls
- The clock has specific **checkpoints** where the cell cycle stops until a go-ahead signal is received

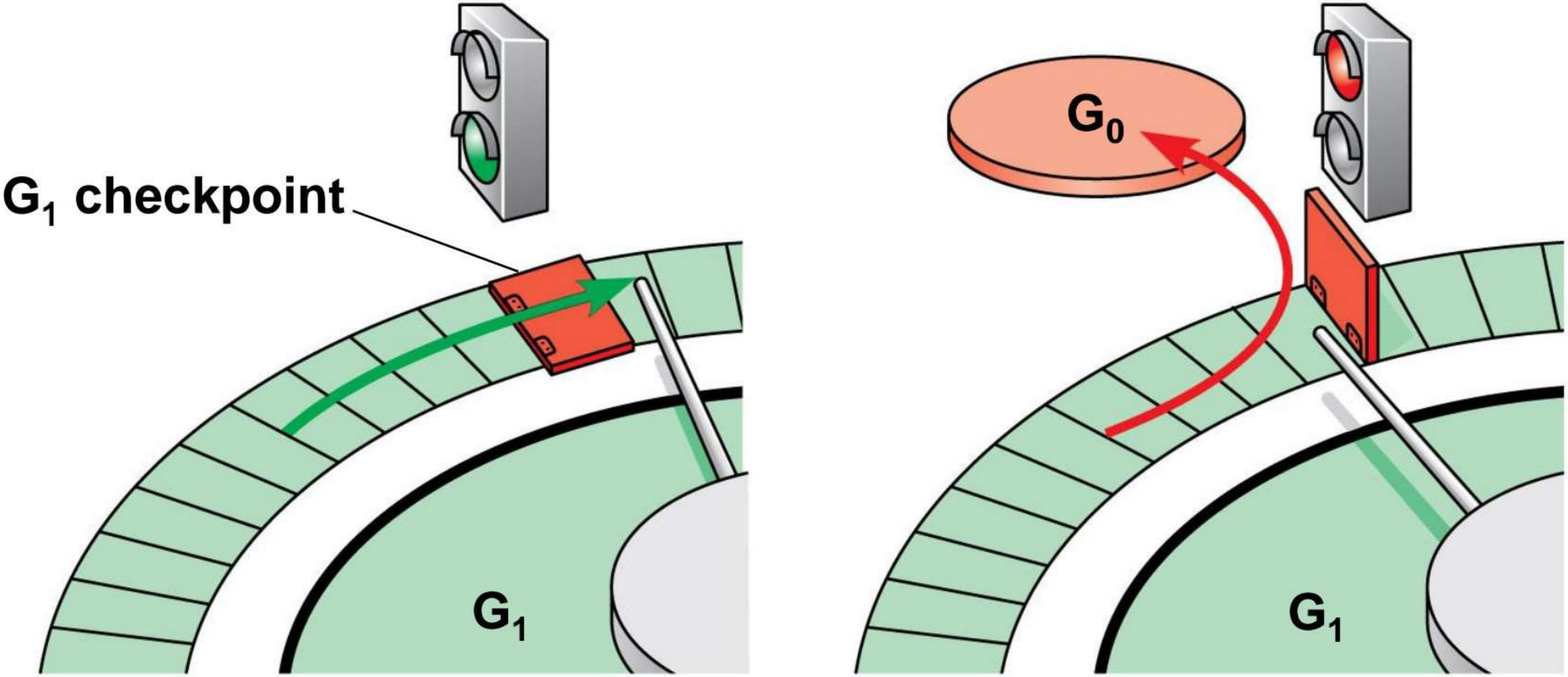
Figure 12.15



G1 checkpoint
Control system
G1
S
M
G2
M checkpoint
G2 checkpoint

- For many cells, the G_1 checkpoint seems to be the most important
- If a cell receives a go-ahead signal at the G_1 checkpoint, it will usually complete the S, G_2, and M phases and divide
- If the cell does not receive the go-ahead signal, it will exit the cycle, switching into a nondividing state called the **G_0 phase**

Figure 12.16



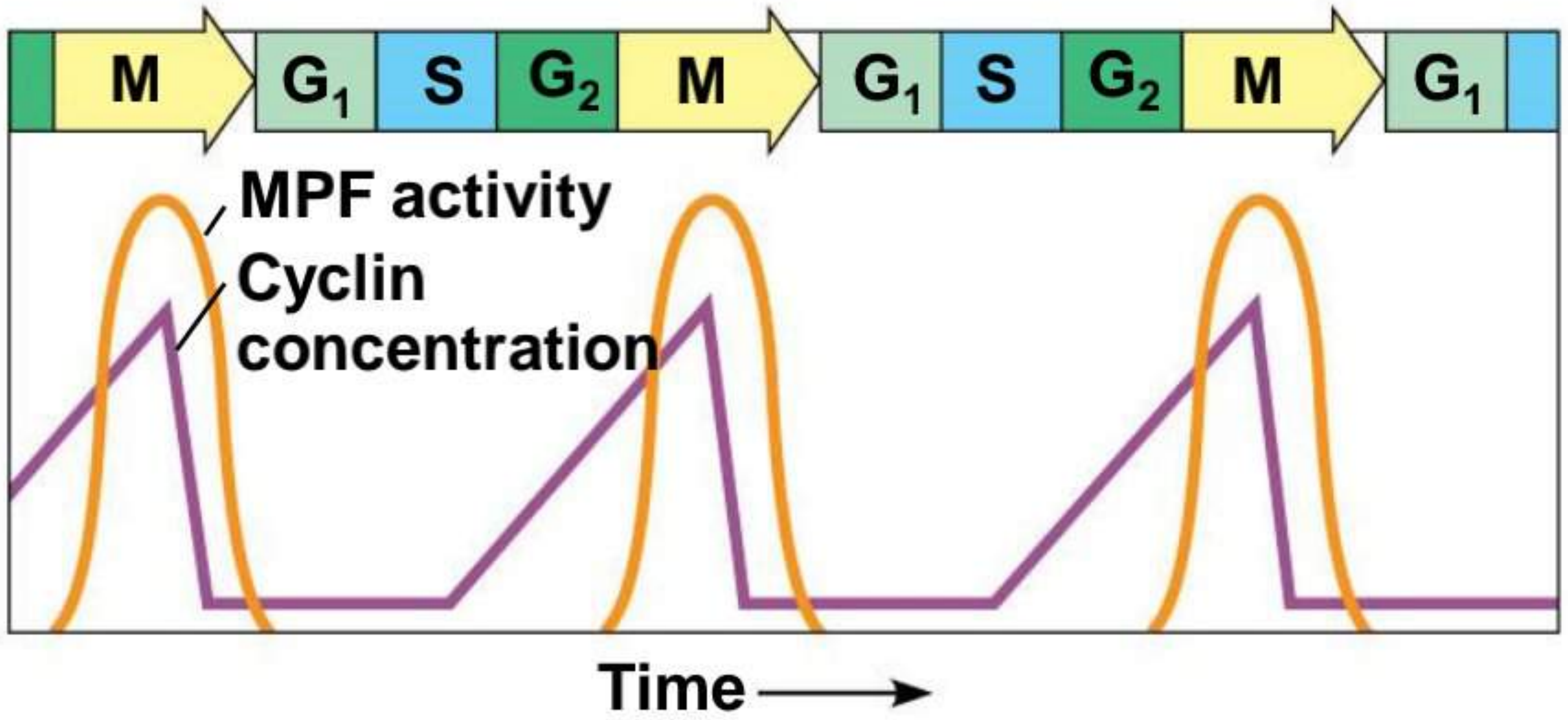
(a) Cell receives a go-ahead signal.

(b) Cell does not receive a go-ahead signal.

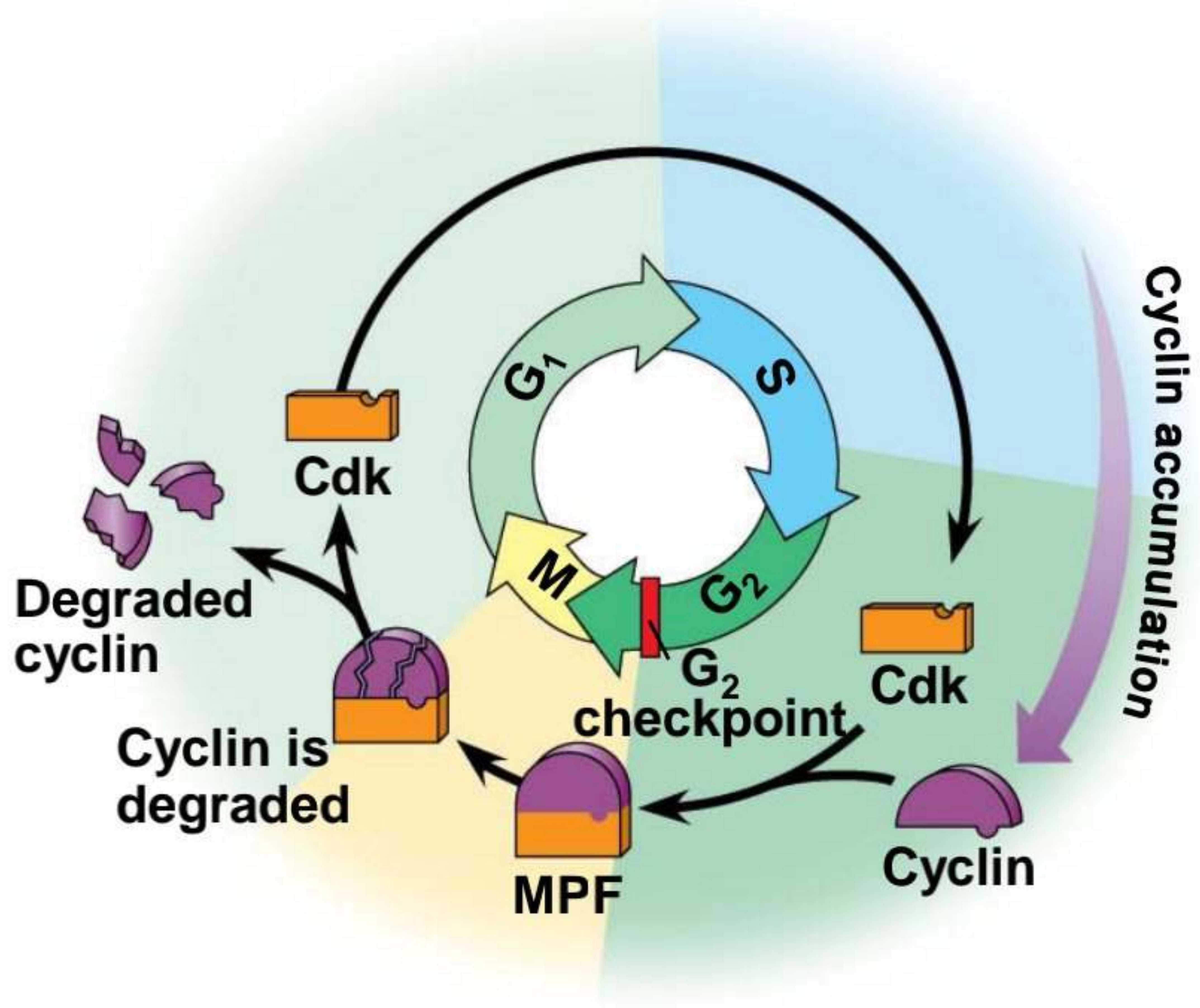
The Cell Cycle Clock: Cyclins and Cyclin-Dependent Kinases

- Two types of regulatory proteins are involved in cell cycle control: **cyclins** and **cyclin-dependent kinases (Cdks)**
- Cdks activity fluctuates during the cell cycle because it is controled by cyclins, so named because their concentrations vary with the cell cycle
- **MPF** (maturation-promoting factor) is a cyclin-Cdk complex that triggers a cell's passage past the G_2 checkpoint into the M phase

Figure 12.17

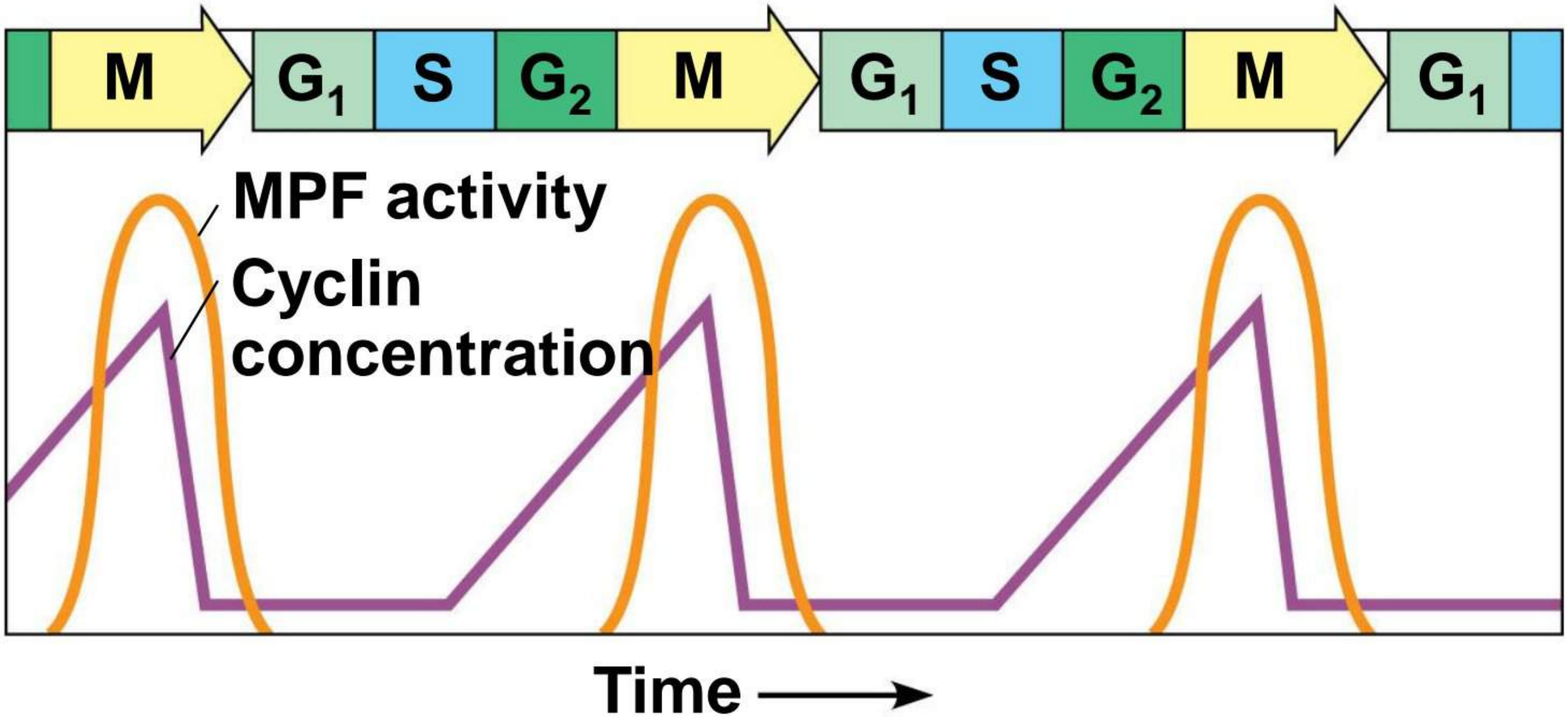


(a) Fluctuation of MPF activity and cyclin concentration during the cell cycle



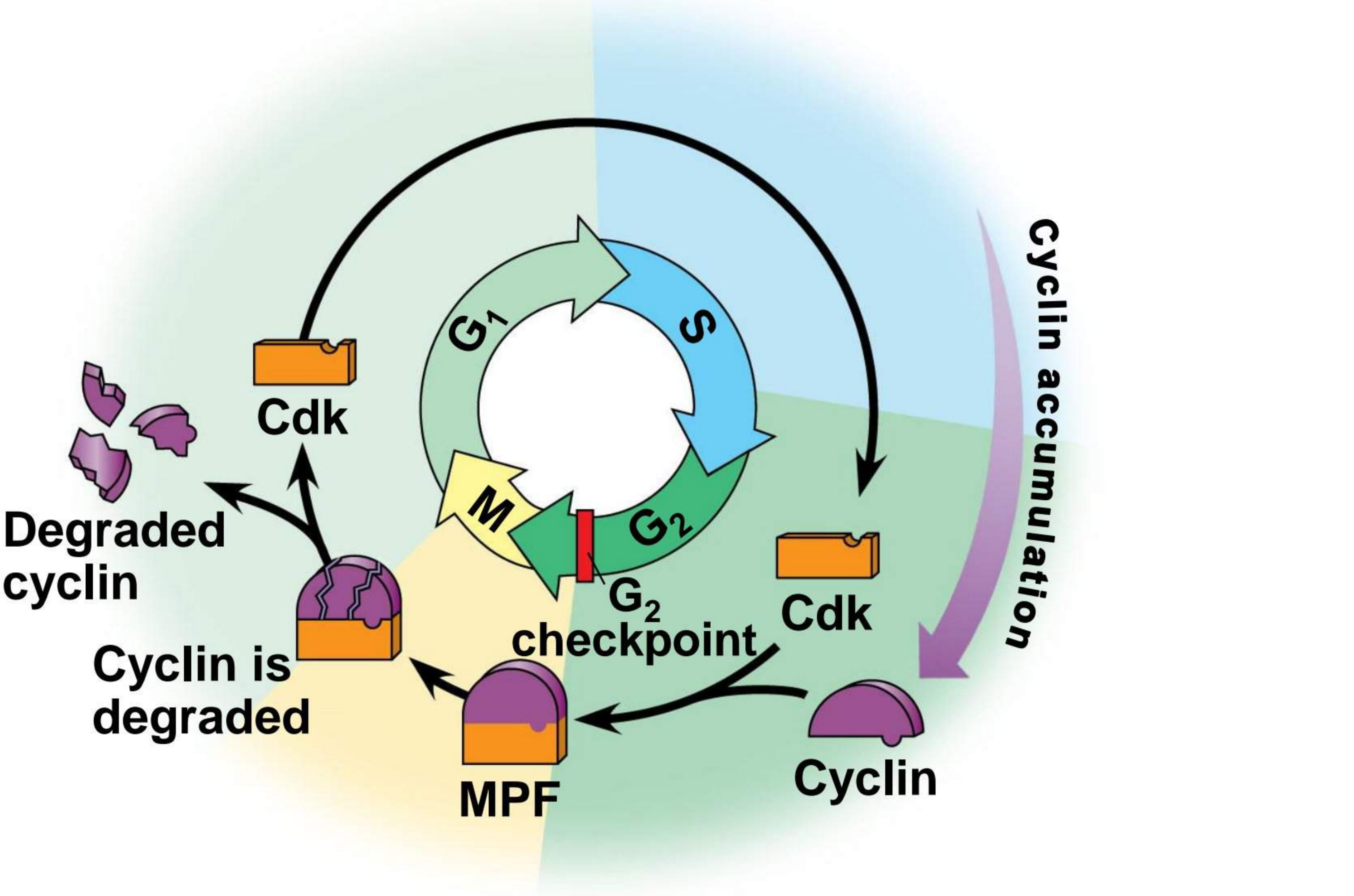
(b) Molecular mechanisms that help regulate the cell cycle

Figure 12.17a



(a) Fluctuation of MPF activity and cyclin concentration during the cell cycle

Figure 12.17b



(b) Molecular mechanisms that help regulate the cell cycle

Stop and Go Signs: Internal and External Signals at the Checkpoints

- An example of an internal signal is that kinetochores not attached to spindle microtubules send a molecular signal that delays anaphase
- Some external signals are **growth factors**, proteins released by certain cells that stimulate other cells to divide
- For example, platelet-derived growth factor (PDGF) stimulates the division of human fibroblast cells in culture

Figure 12.18

1 A sample of human connective tissue is cut up into small pieces.

2 Enzymes digest the extracellular matrix, resulting in a suspension of free fibroblasts.

3 Cells are transferred to culture vessels.

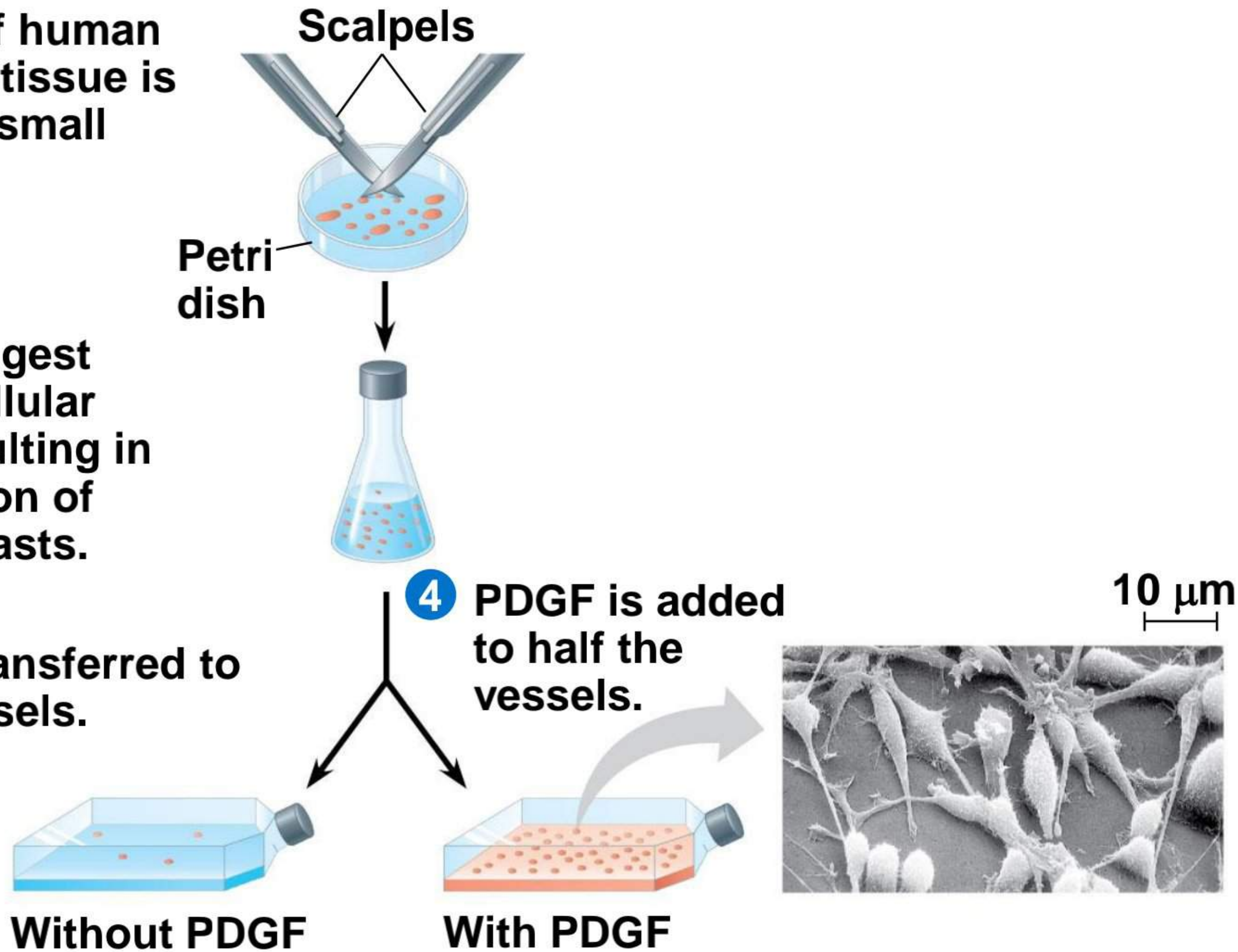
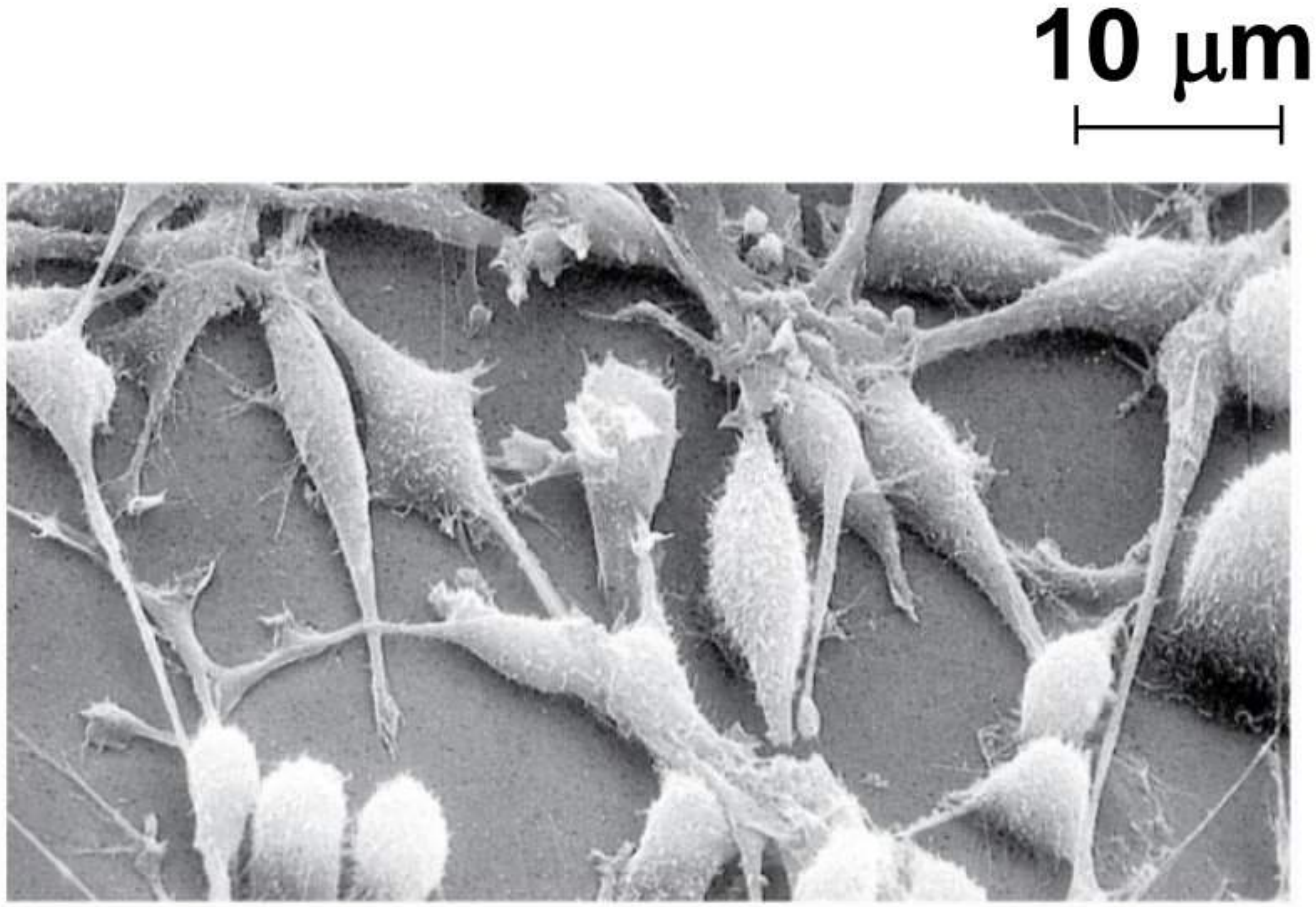
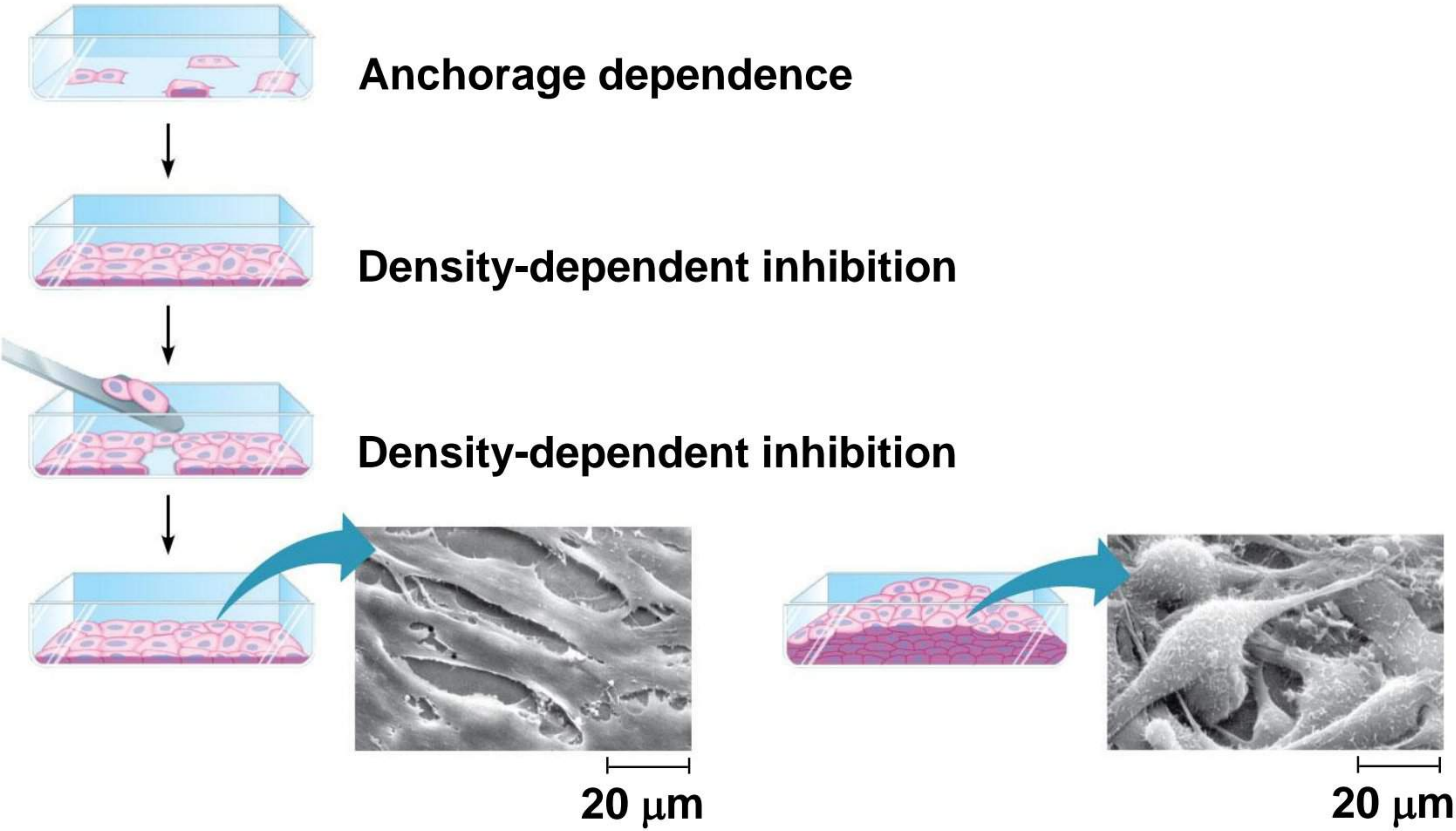


Figure 12.18a



- A clear example of external signals is **density-dependent inhibition**, in which crowded cells stop dividing
- Most animal cells also exhibit **anchorage dependence**, in which they must be attached to a substratum in order to divide
- Cancer cells exhibit neither density-dependent inhibition nor anchorage dependence

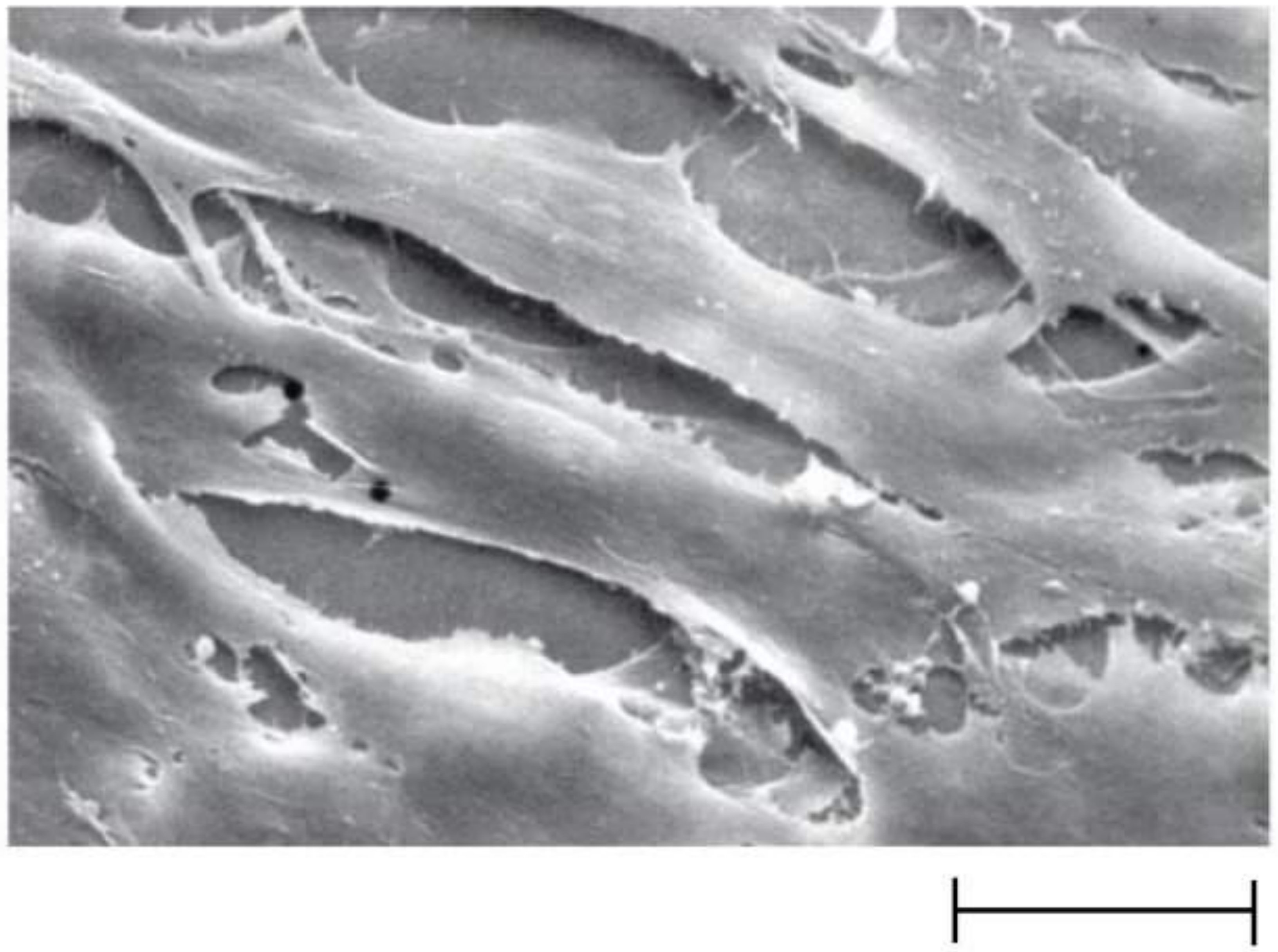
Figure 12.19



(a) Normal mammalian cells

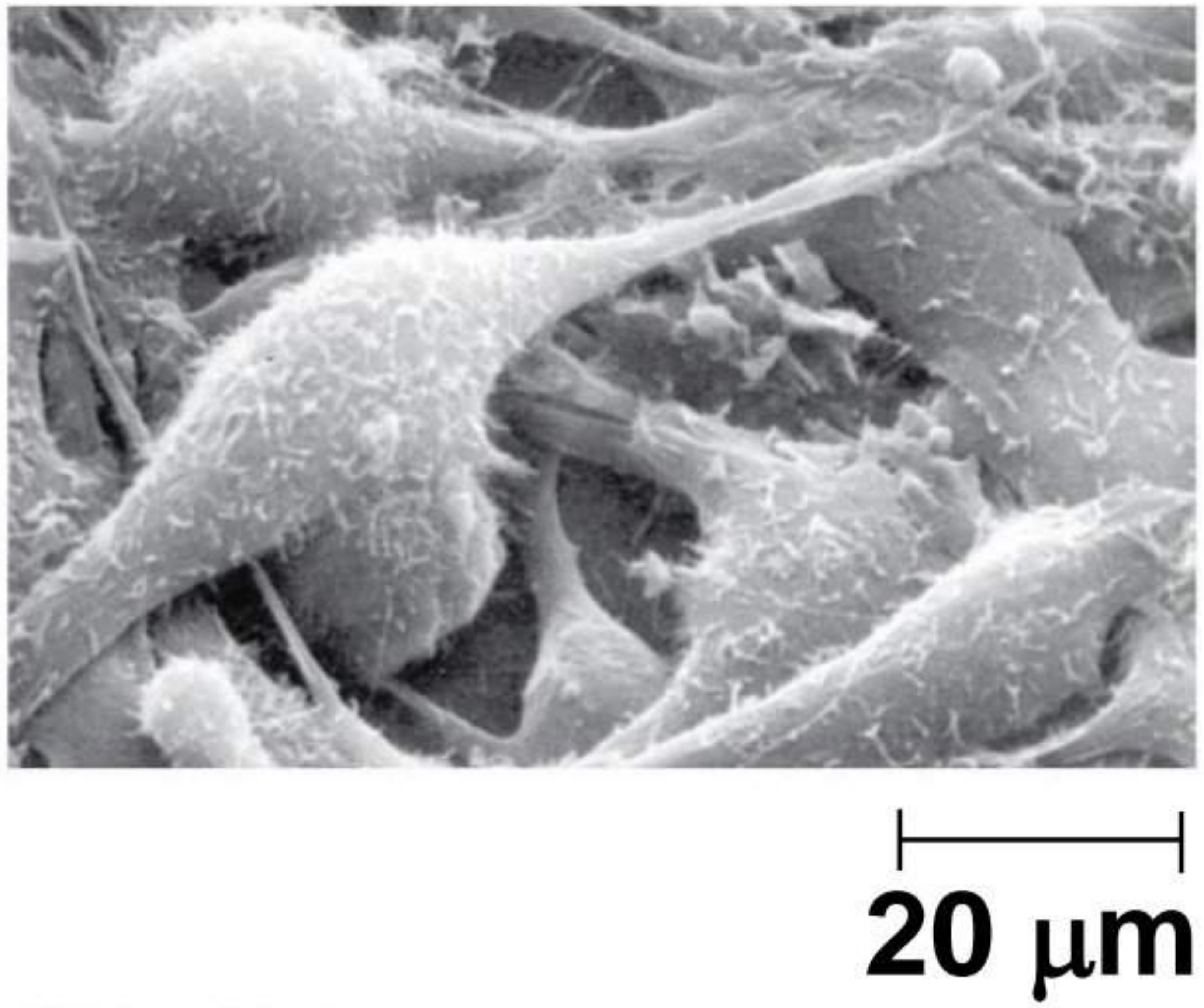
(b) Cancer cells

Figure 12.19a



20 µm

Figure 12.19b

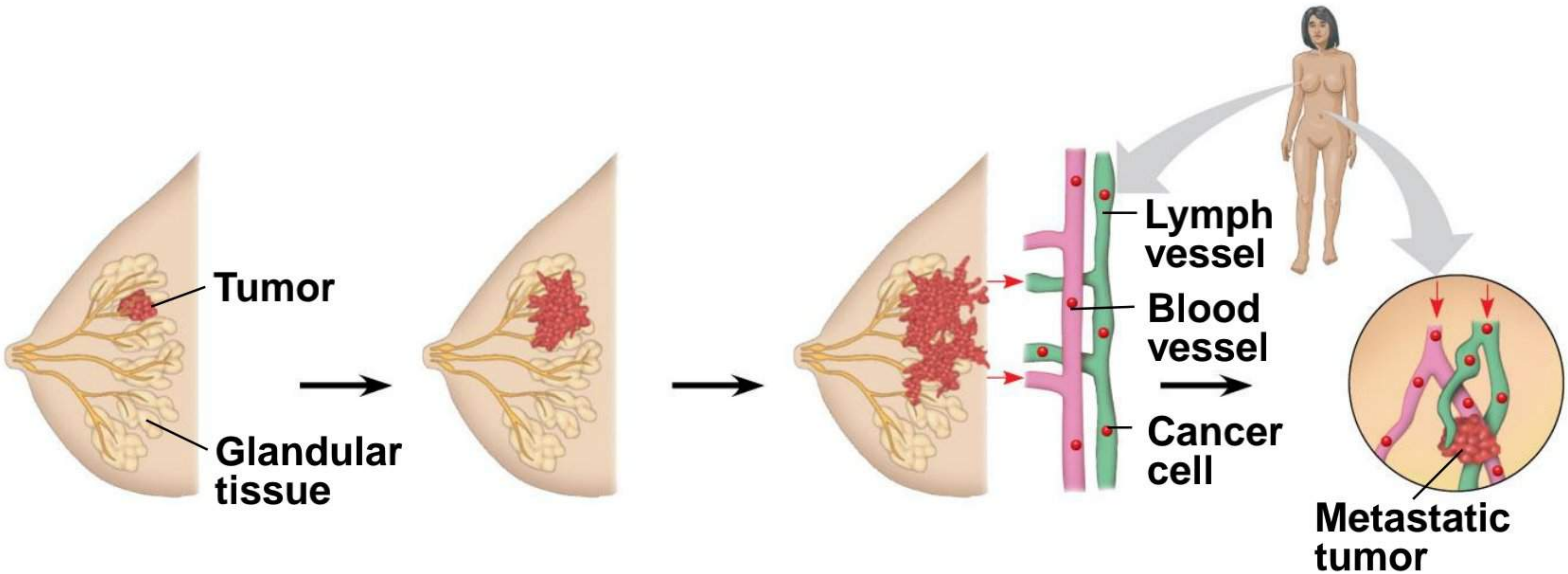


Loss of Cell Cycle Controls in Cancer Cells

- Cancer cells do not respond normally to the body's control mechanisms
- Cancer cells may not need growth factors to grow and divide
  - They may make their own growth factor
  - They may convey a growth factor's signal without the presence of the growth factor
  - They may have an abnormal cell cycle control system

- A normal cell is converted to a cancerous cell by a process called **transformation**
- Cancer cells that are not eliminated by the immune system form tumors, masses of abnormal cells within otherwise normal tissue
- If abnormal cells remain only at the original site, the lump is called a **benign tumor**
- **Malignant tumors** invade surrounding tissues and can **metastasize**, exporting cancer cells to other parts of the body, where they may form additional tumors

Figure 12.20



1. A tumor grows from a single cancer cell.
2. Cancer cells invade neighboring tissue.
3. Cancer cells spread through lymph and blood vessels to other parts of the body.
4. Cancer cells may survive and establish a new tumor in another part of the body.

- Recent advances in understanding the cell cycle and cell cycle signaling have led to advances in cancer treatment

Figure 12.21

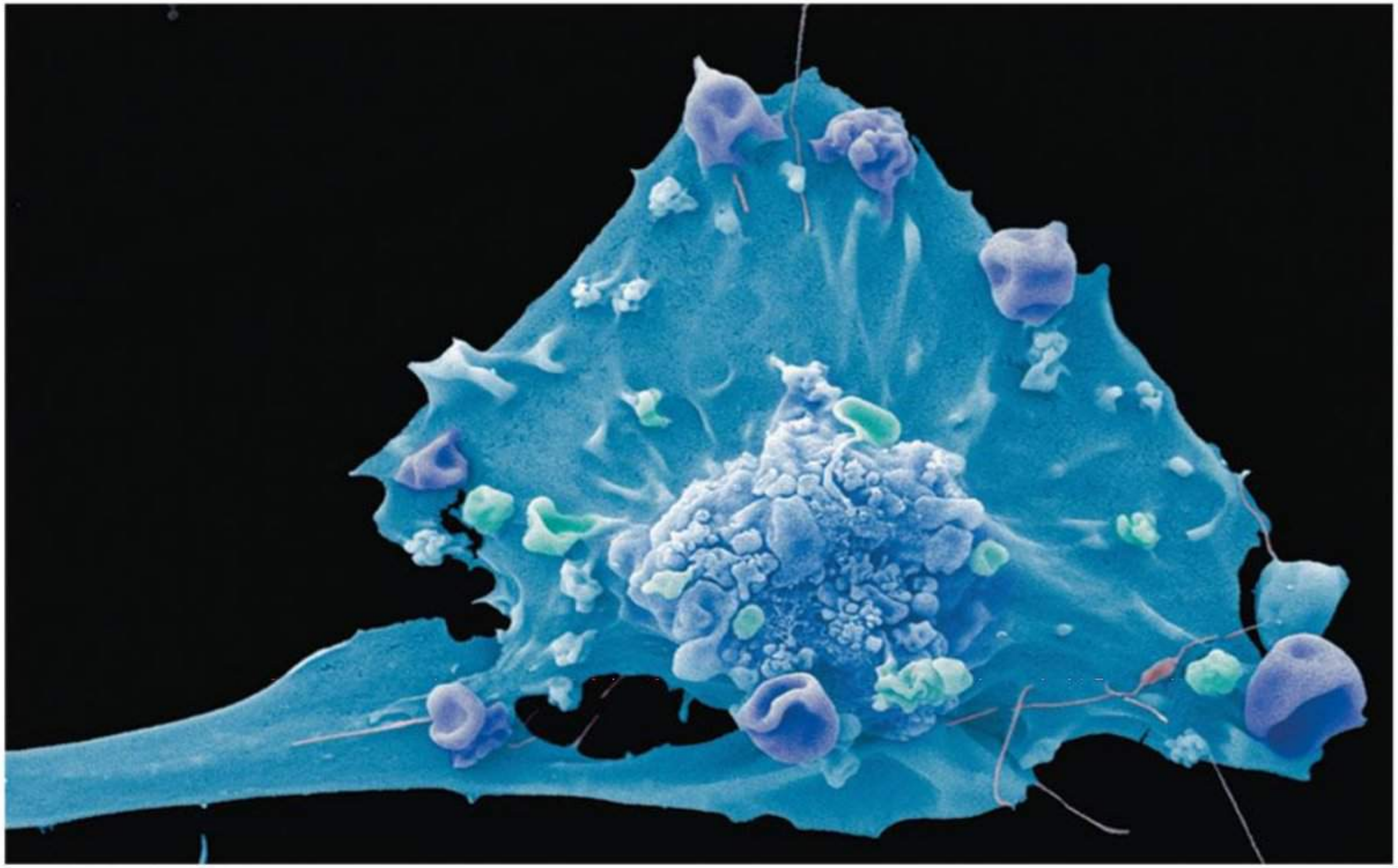


Figure 12.UN01

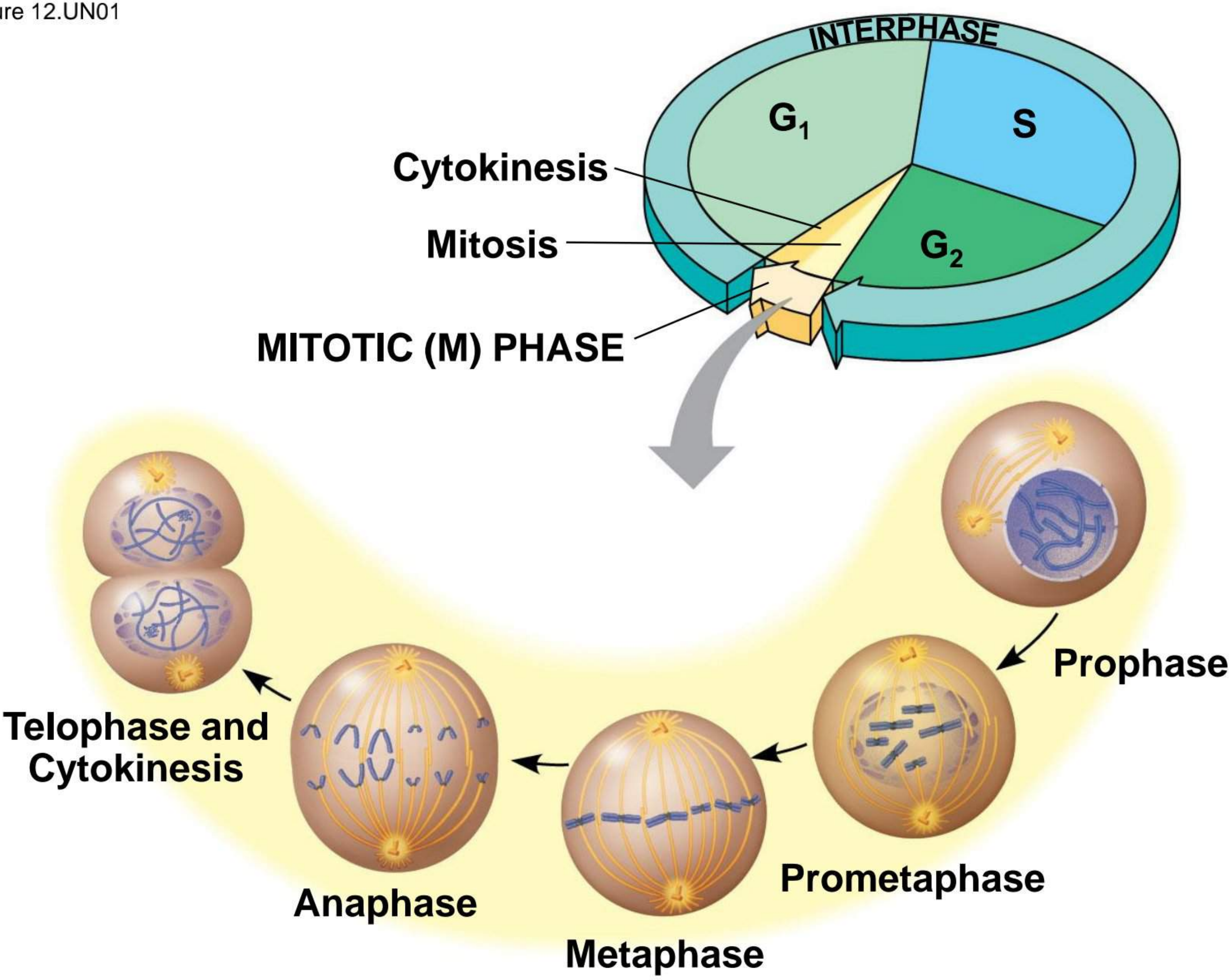


Figure 12.UN02

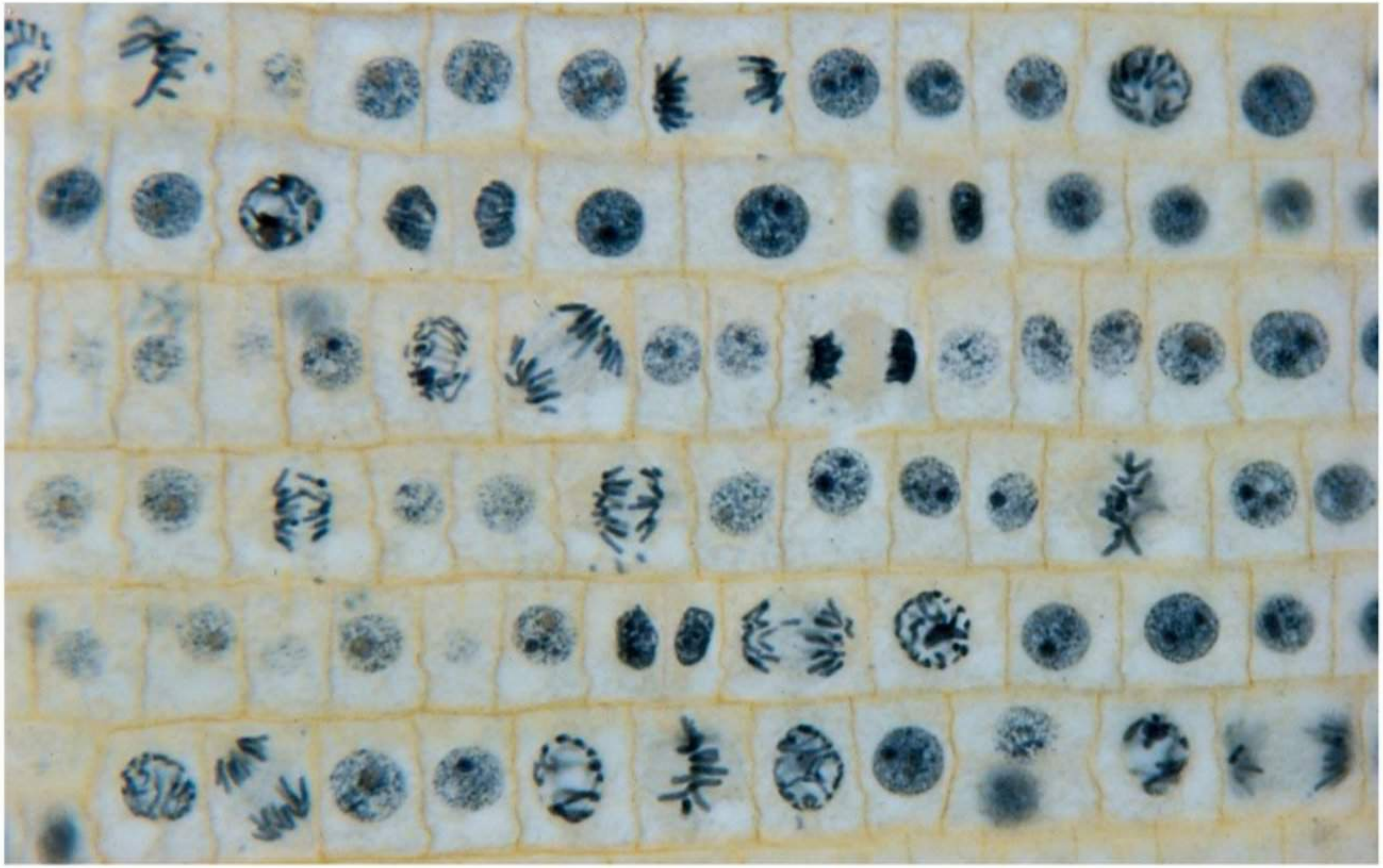


Figure 12.UN03

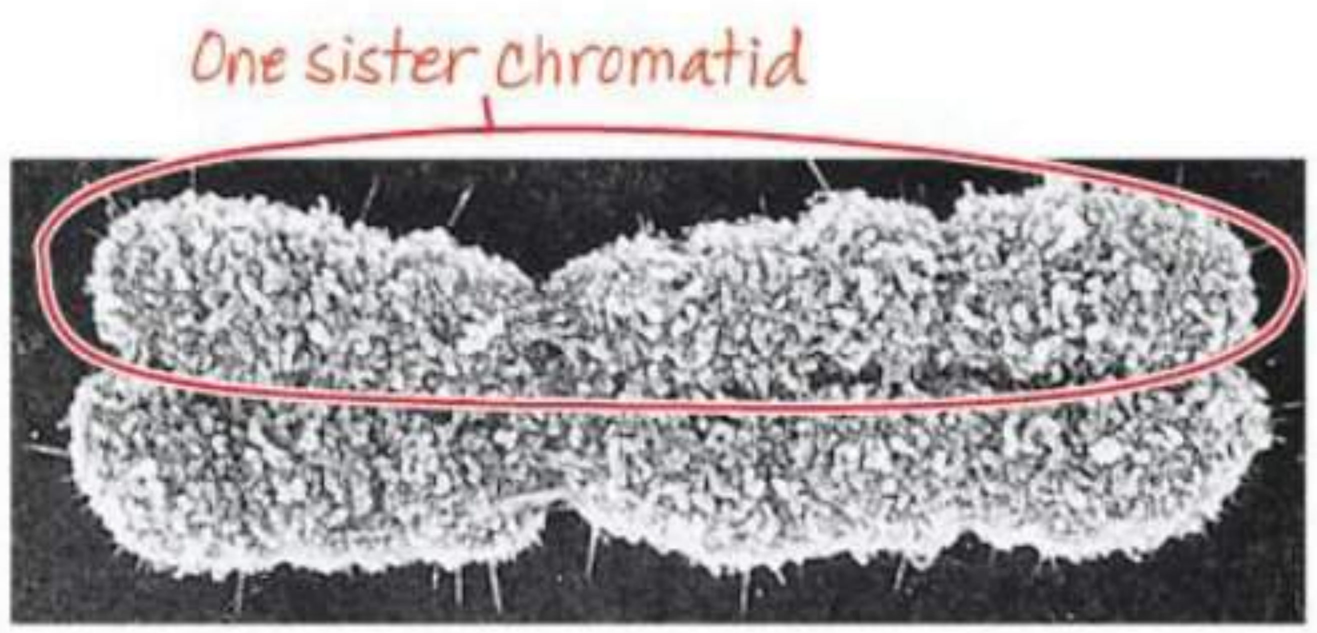


Figure 12.UN04

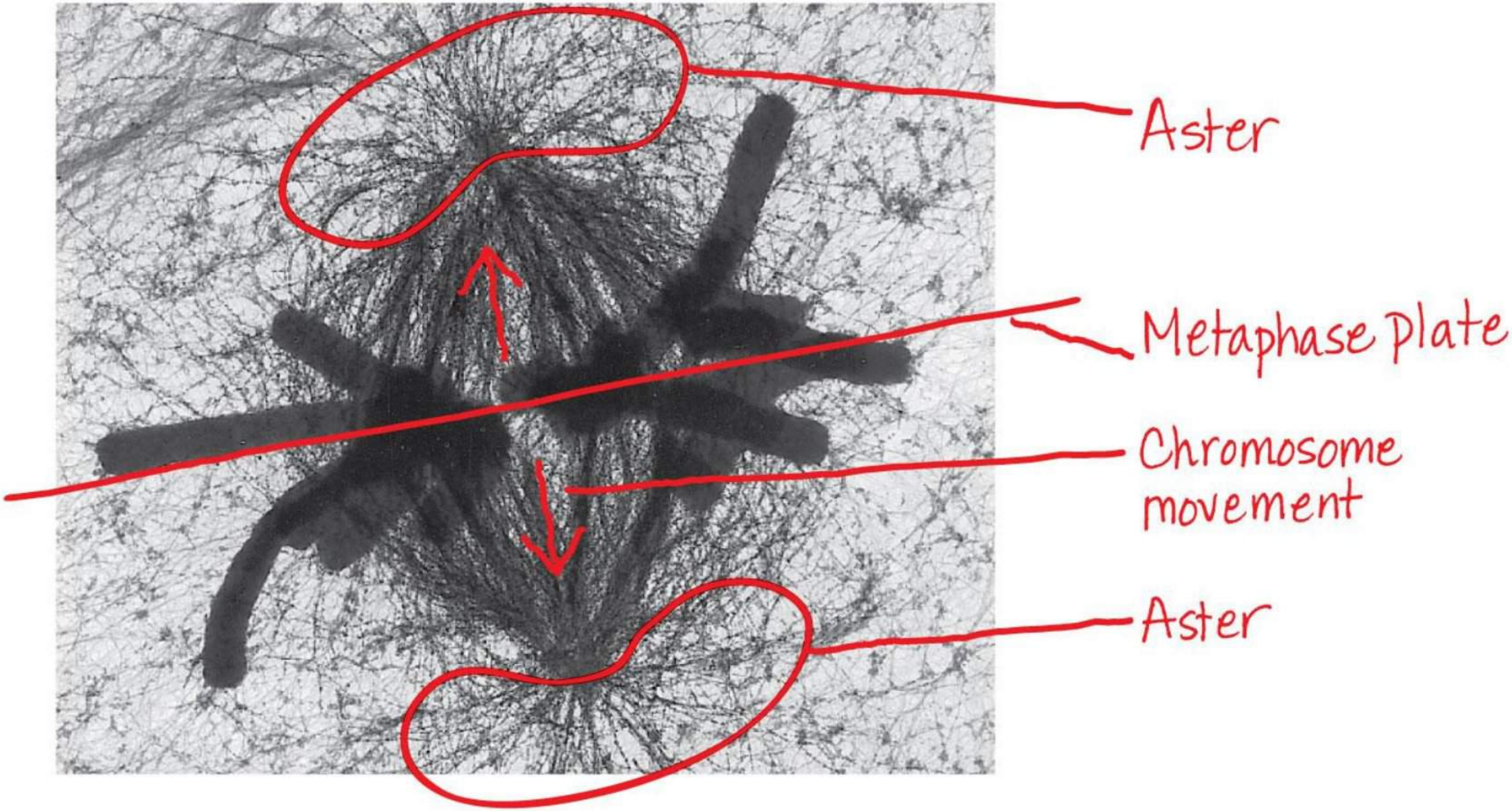


Figure 12.UN05

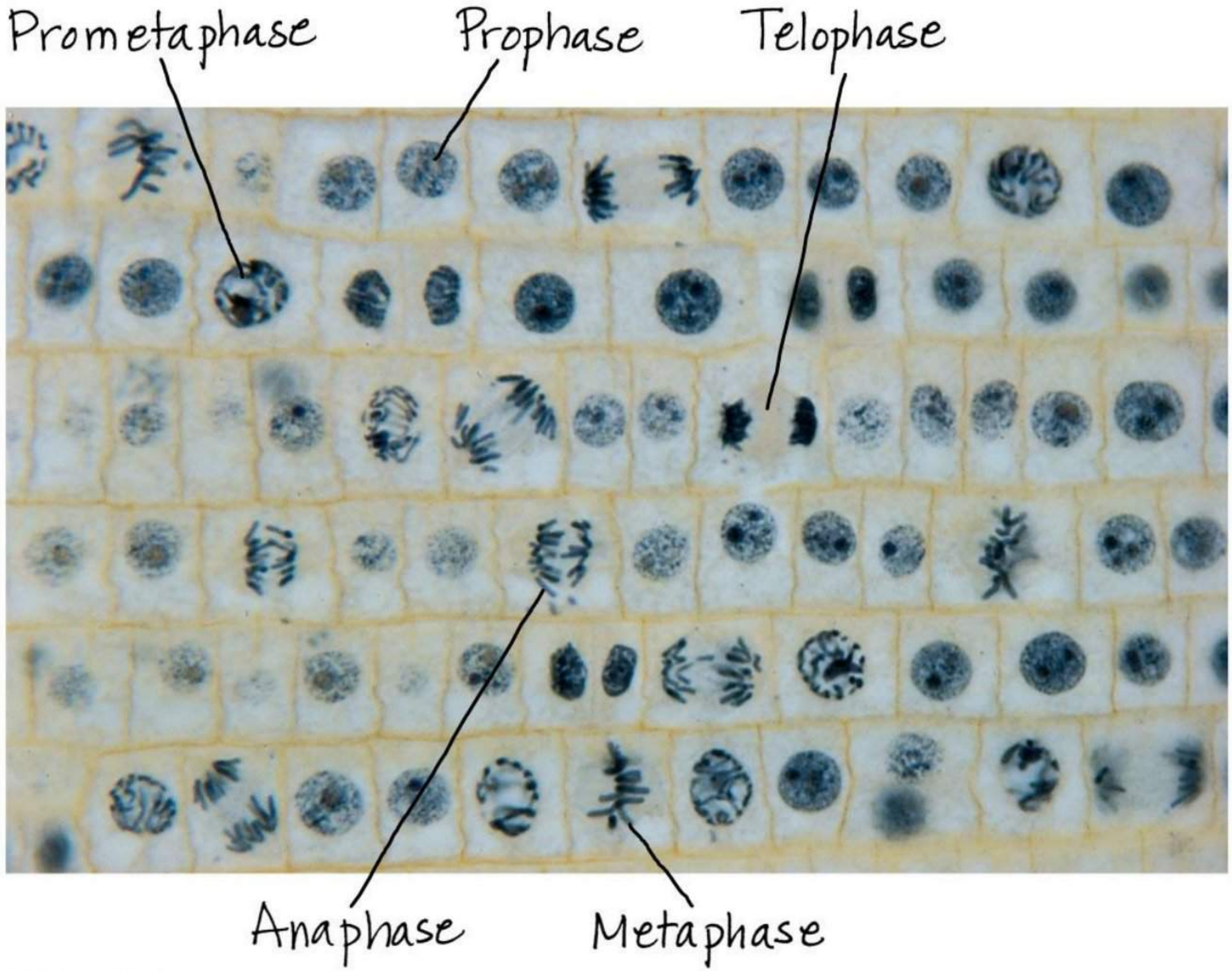


Figure 12.UN06