Chapter 12

The Cell Cycle

PowerPoint Lectures for

Biology, Seventh Edition

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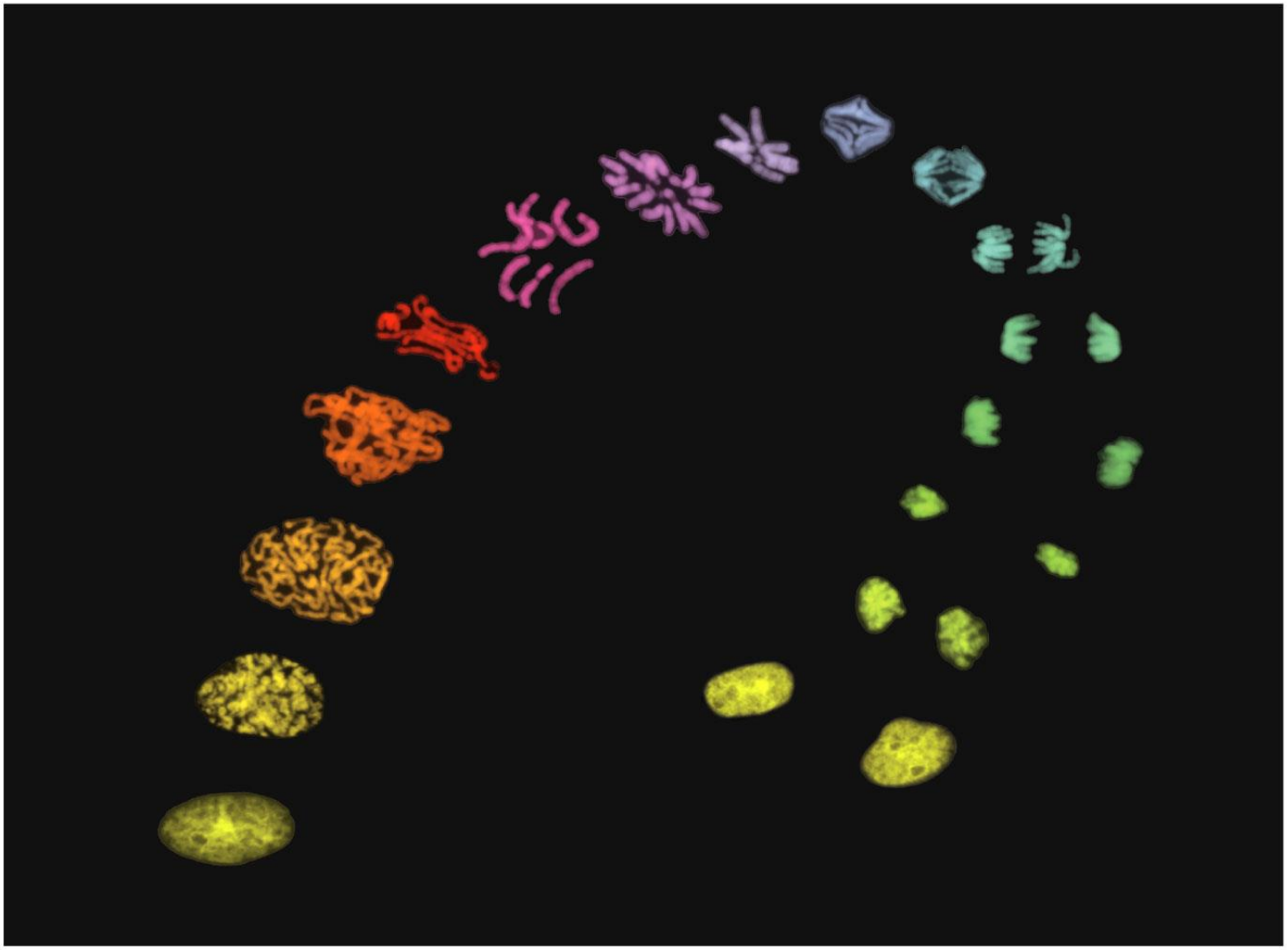
Lectures by Chris Romero

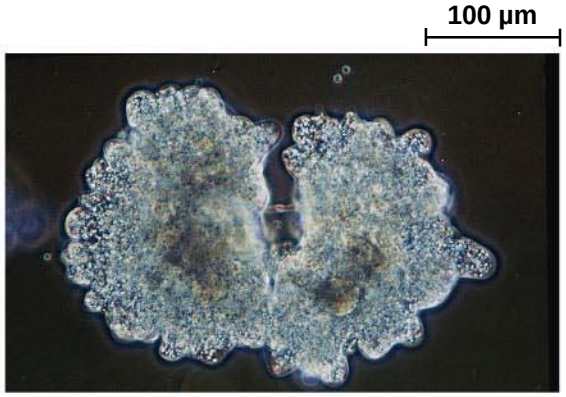
Overview: The Key Roles of Cell Division

- The ability of organisms to reproduce best distinguishes living things from nonliving matter
- The continuity of life is based upon the reproduction of cells, or cell division

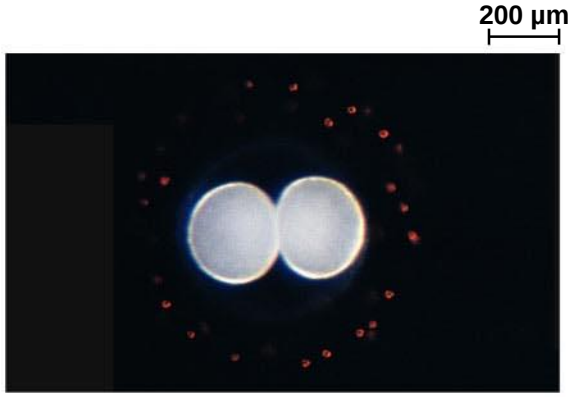


- In unicellular organisms, division of one cell reproduces the entire organism
- Multicellular organisms depend on cell division for:
  - Development from a fertilized cell
  - Growth
  - Repair
- Cell division is an integral part of the cell cycle, the life of a cell from formation to its own division

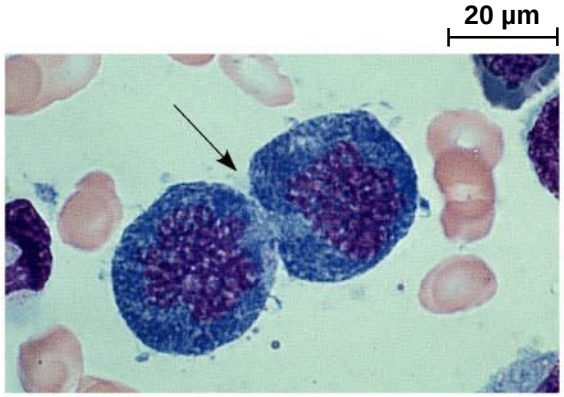
LE 12-2



(a) Reproduction



(b) Growth and development



(c) Tissue renewal

Concept 12.1: Cell division results in genetically identical daughter cells

- Cells duplicate their genetic material before they divide, ensuring that each daughter cell receives an exact copy of the genetic material, DNA
- A dividing cell duplicates its DNA, allocates the two copies to opposite ends of the cell, and only then splits into daughter cells

Cellular Organization of the Genetic Material

- A cell's endowment of DNA (its genetic information) is called its genome
- DNA molecules in a cell are packaged into chromosomes

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

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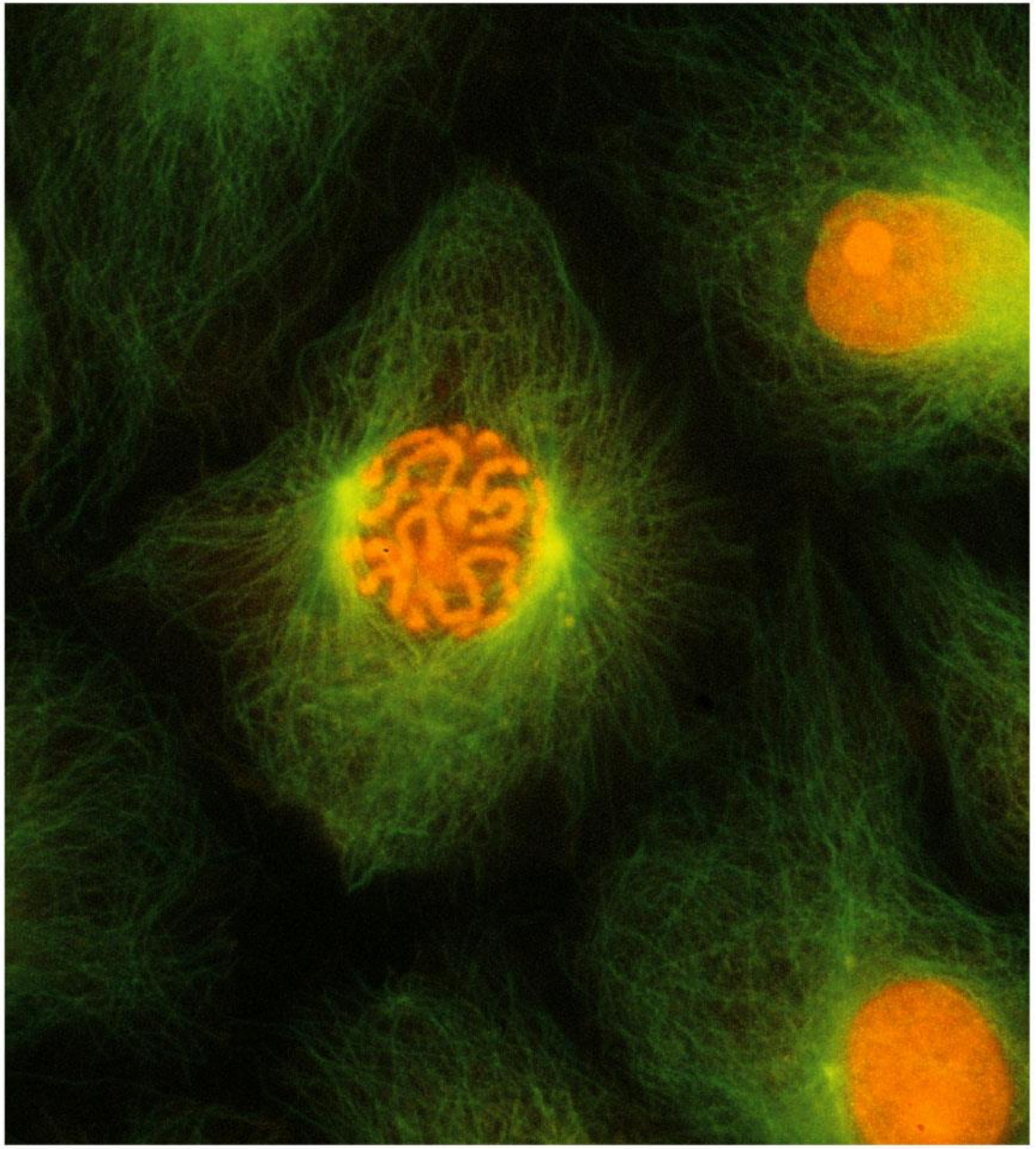
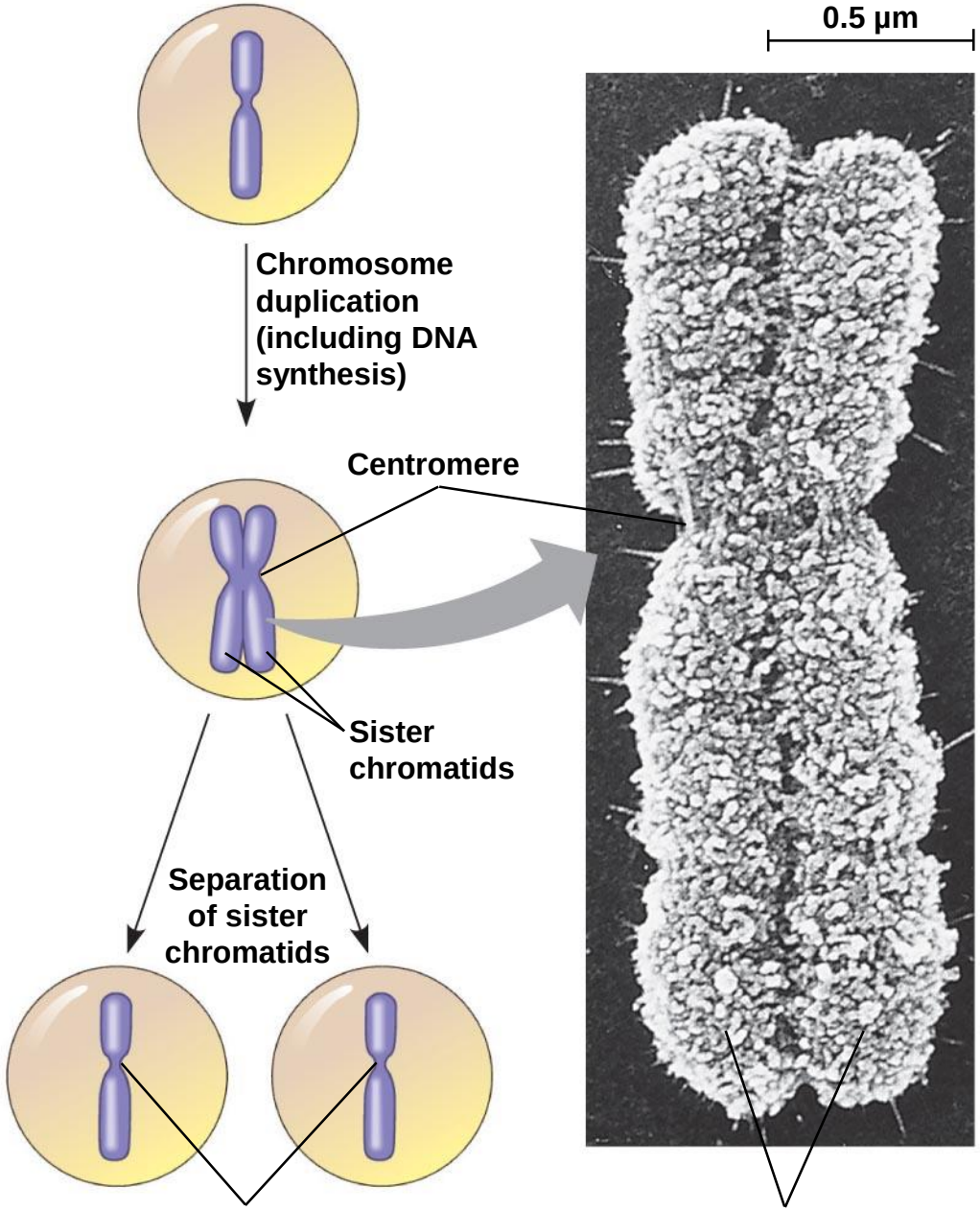


Distribution of Chromosomes During Cell Division

- In preparation for cell division, DNA is replicated and the chromosomes condense
- Each duplicated chromosome has two sister chromatids, which separate during cell division
- The centromere is the narrow “waist” of the duplicated chromosome, where the two chromatids are most closely attached

LE 12-4



- Eukaryotic cell division consists of:
  - Mitosis, the division of 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
- To Flemming, it appeared that the cell simply grew larger between one cell division and the next
- Now we know that many critical events occur during this stage in a cell's life

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”)

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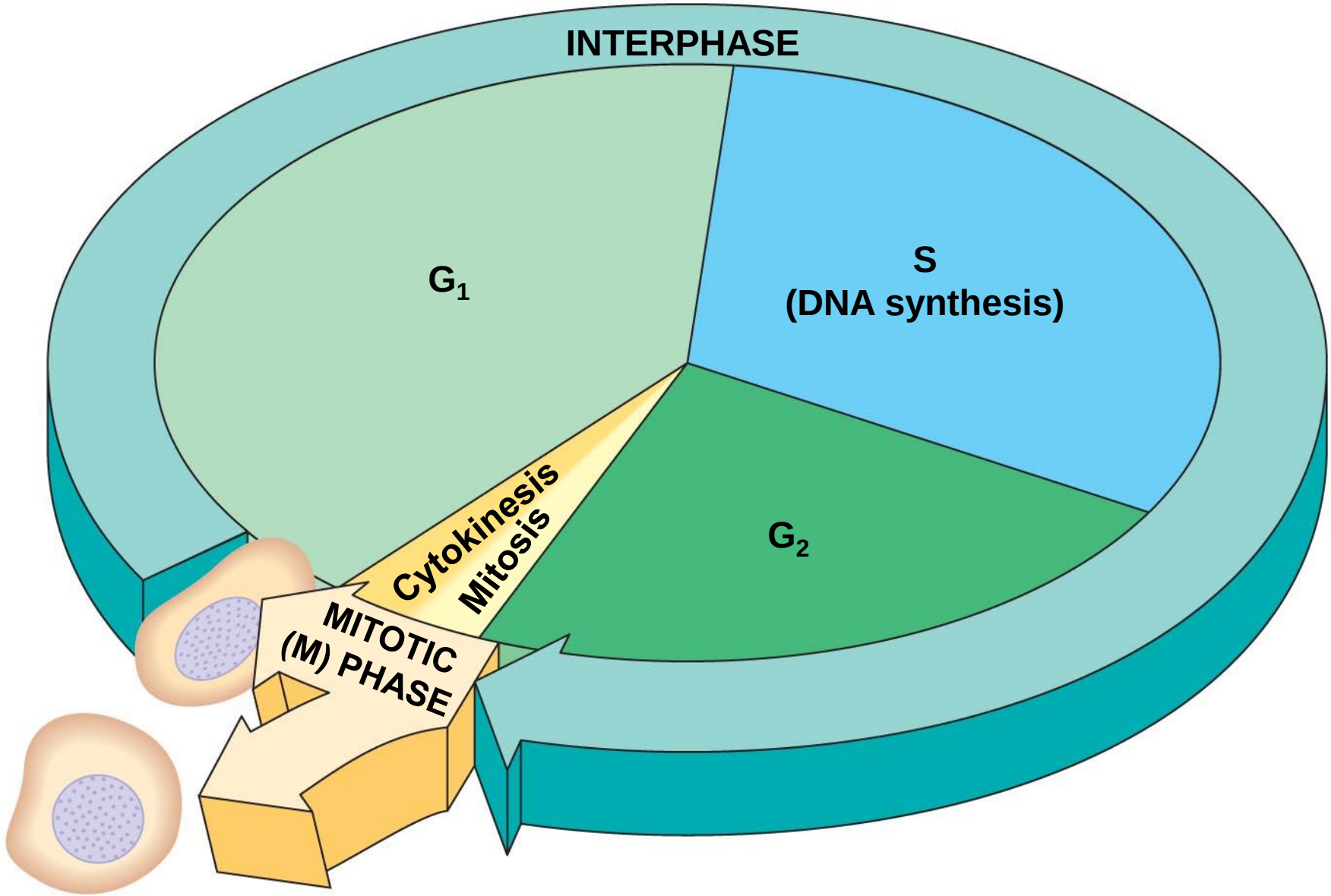

- Mitosis is conventionally divided into five phases:
  - Prophase
  - Prometaphase
  - Metaphase
  - Anaphase
  - Telophase
- Cytokinesis is well underway by late telophase

[Animations and videos listed on slide following figure]

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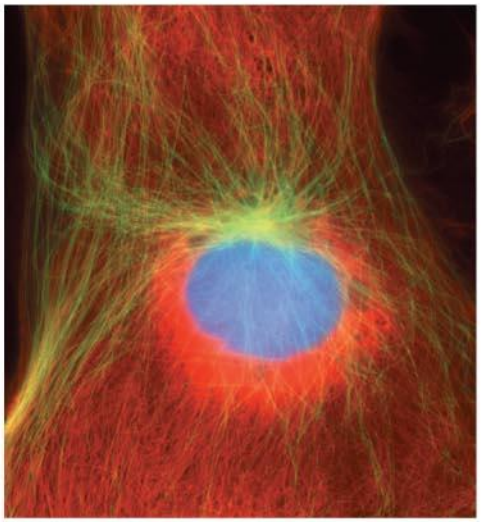
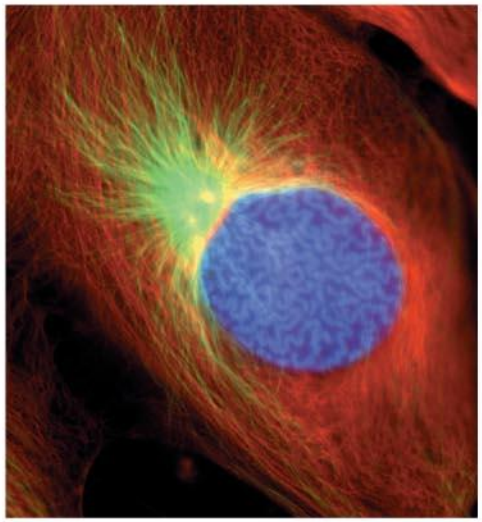
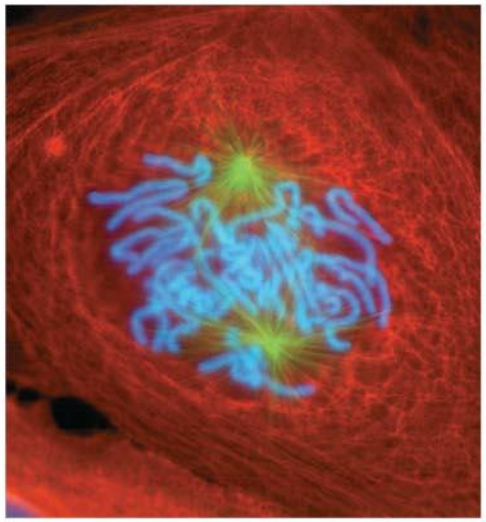


G_2 OF INTERPHASE



PROPHASE



PROMETAPHASE

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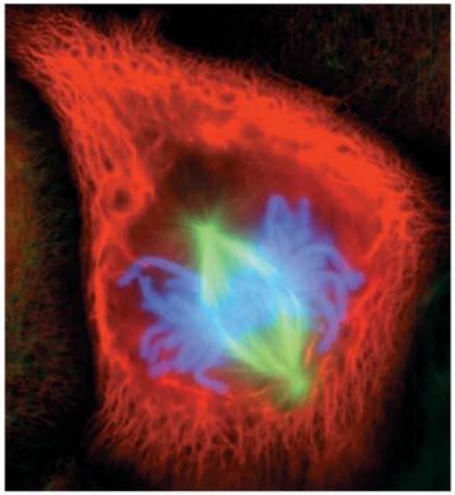
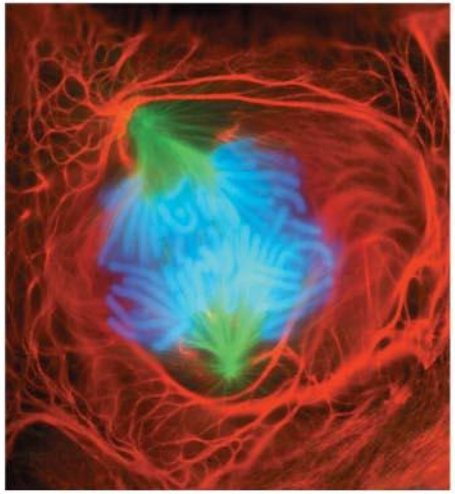
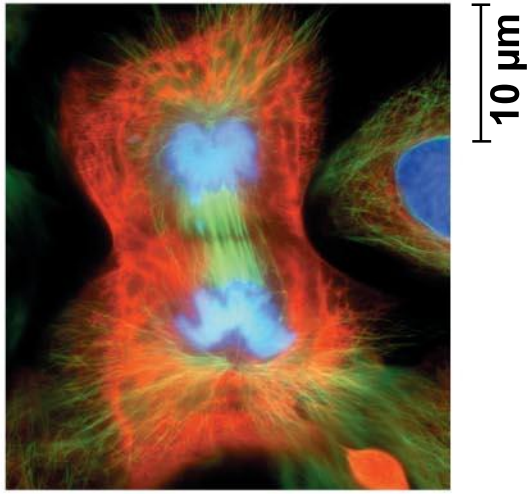


METAPHASE



ANAPHASE



TELOPHASE AND CYTOKINESIS

Video: Animal Mitosis

Video: Sea Urchin (time lapse)

Animation: Mitosis (All Phases)

Animation: Mitosis Overview

Animation: Late Interphase

Animation: Prophase

Animation: Prometaphase

Animation: Metaphase

Animation: Anaphase

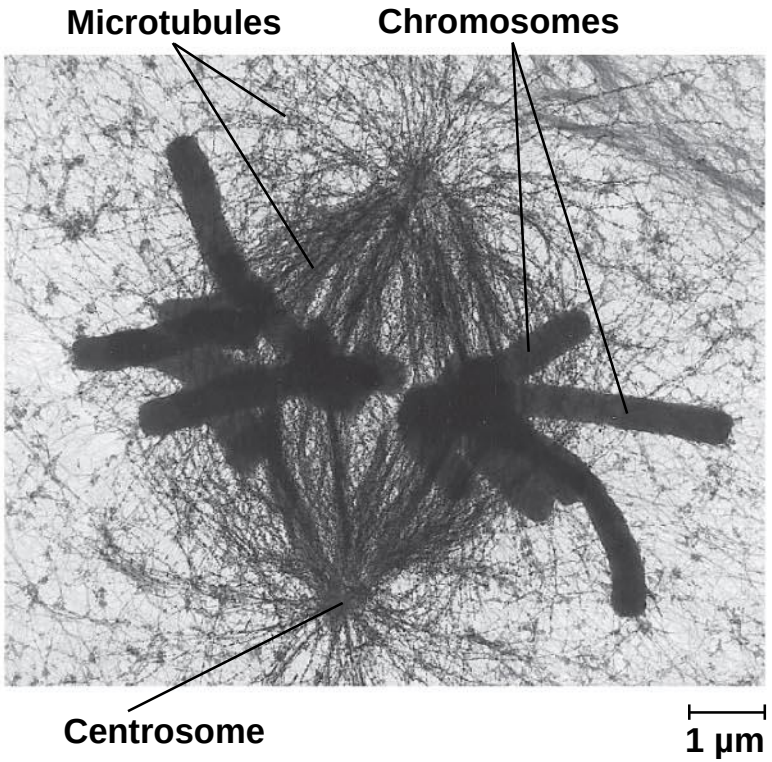
Animation: Telophase

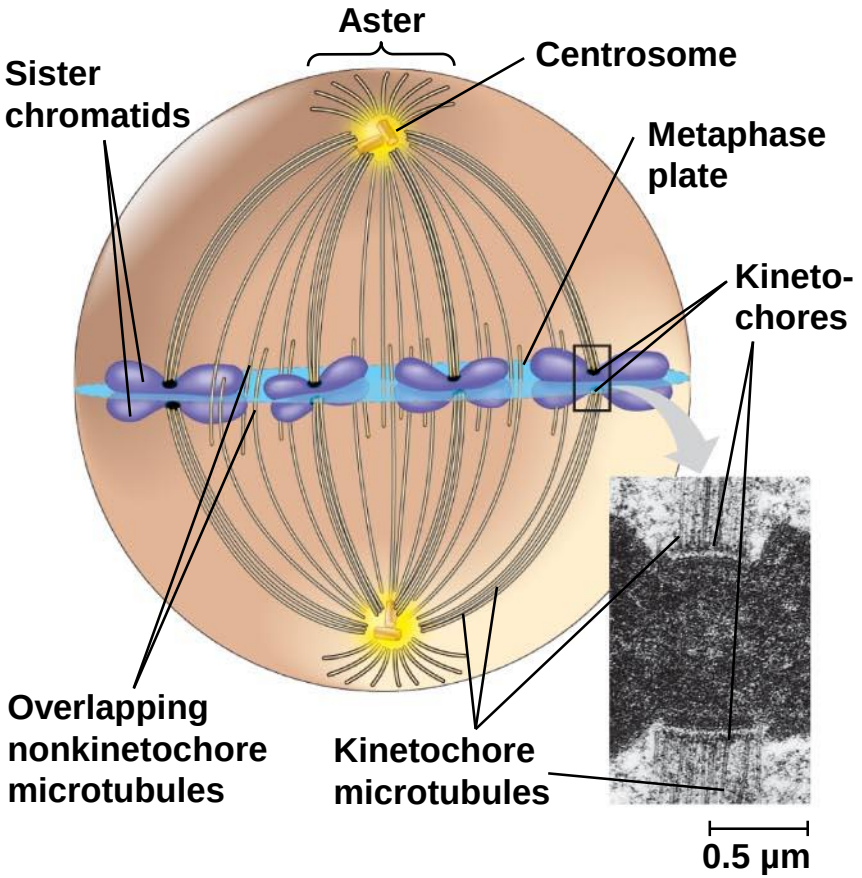
The Mitotic Spindle: *A Closer Look*

- The mitotic spindle is an apparatus of microtubules that controls chromosome movement during mitosis
- Assembly of spindle microtubules begins in the centrosome, the microtubule organizing center
- The centrosome replicates, forming two centrosomes that migrate to opposite ends of the cell, as spindle microtubules grow out from them
- An aster (a radial array of short microtubules) extends from each centrosome

- The spindle includes the centrosomes, the spindle microtubules, and the asters
- Some spindle microtubules attach to the kinetochores of chromosomes and move the chromosomes to the metaphase plate

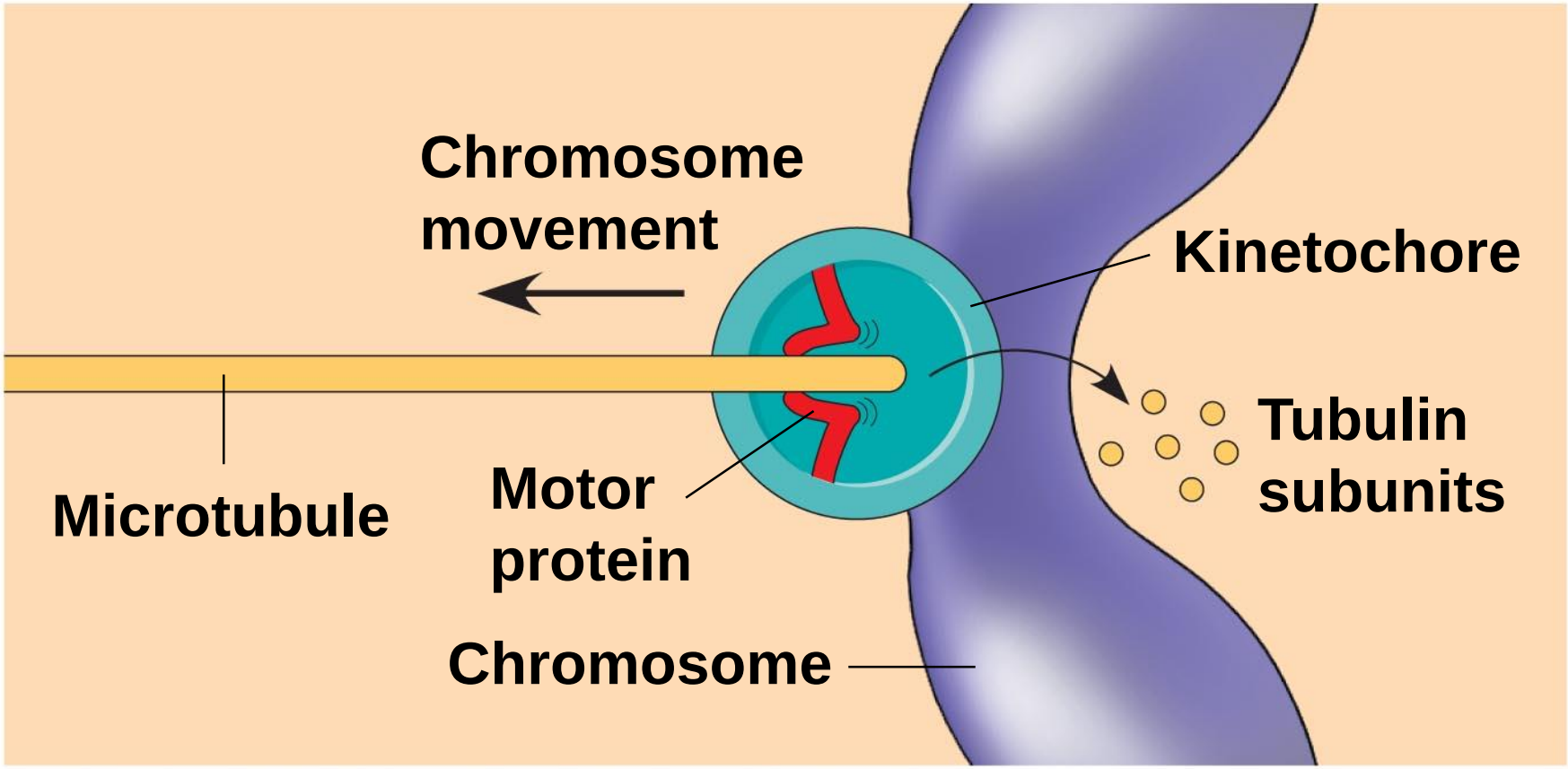
LE 12-7





- 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

LE 12-8b



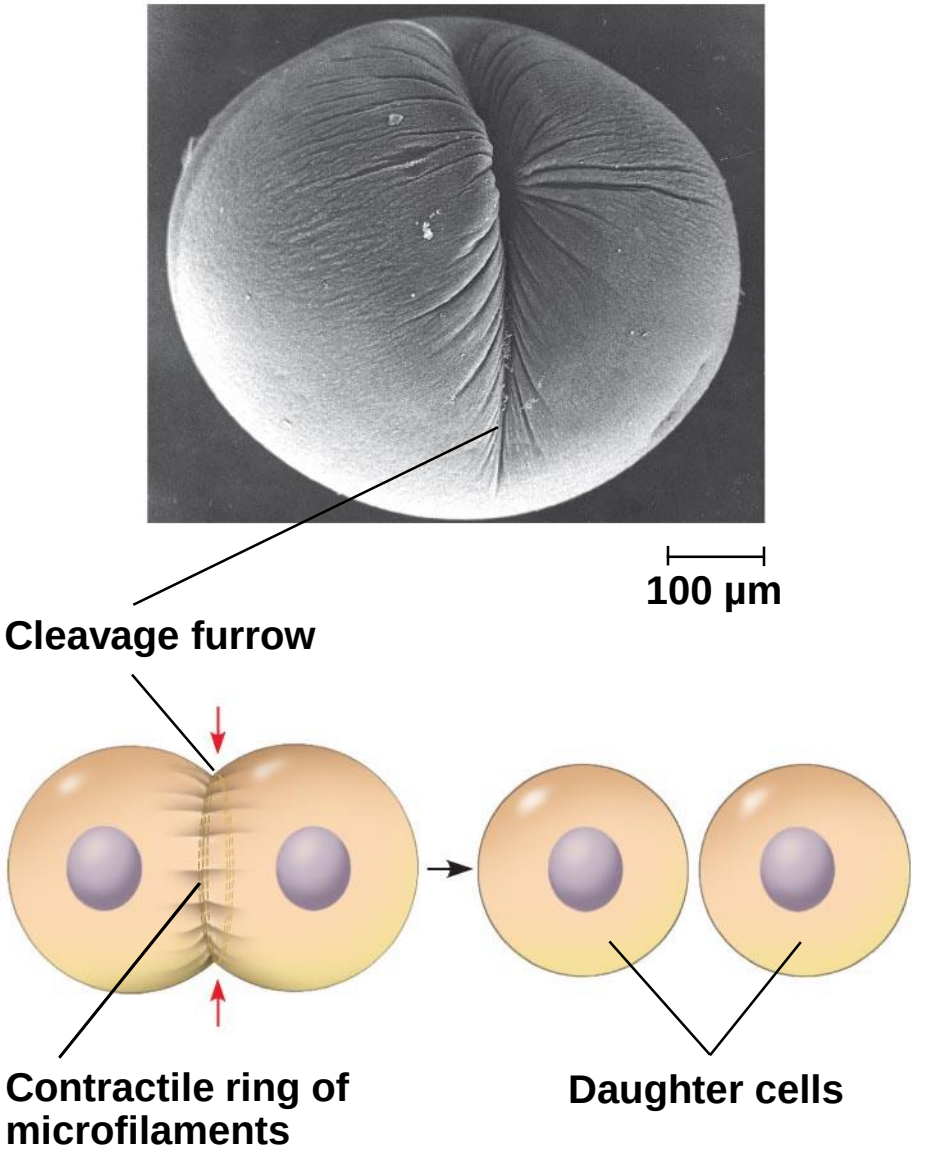
- Nonkinetochore microtubules from opposite poles overlap and push against each other, elongating the cell
- In telophase, genetically identical daughter nuclei form at opposite ends of the cell

Cytokinesis: *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

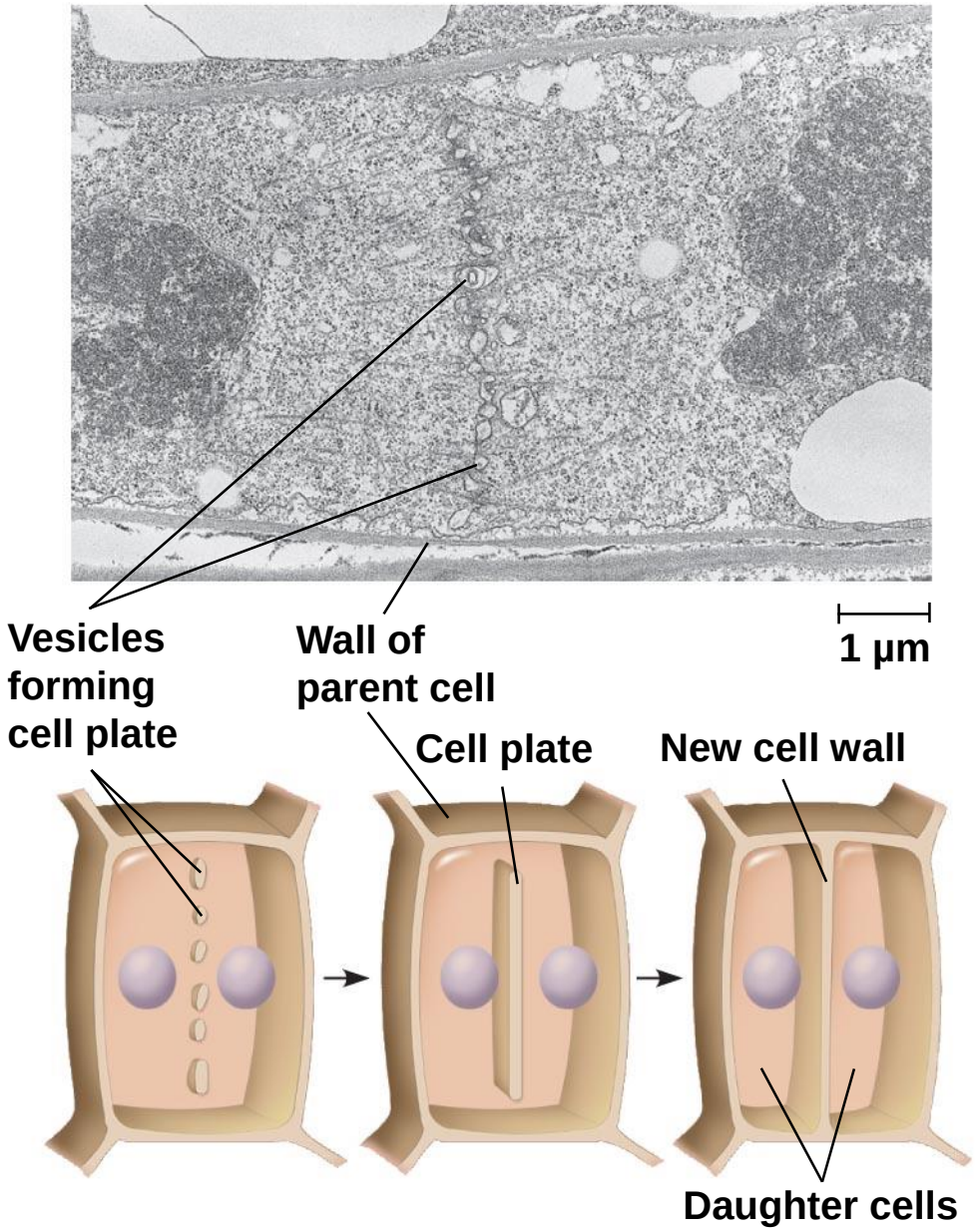
Animation: Cytokinesis

LE 12-9a



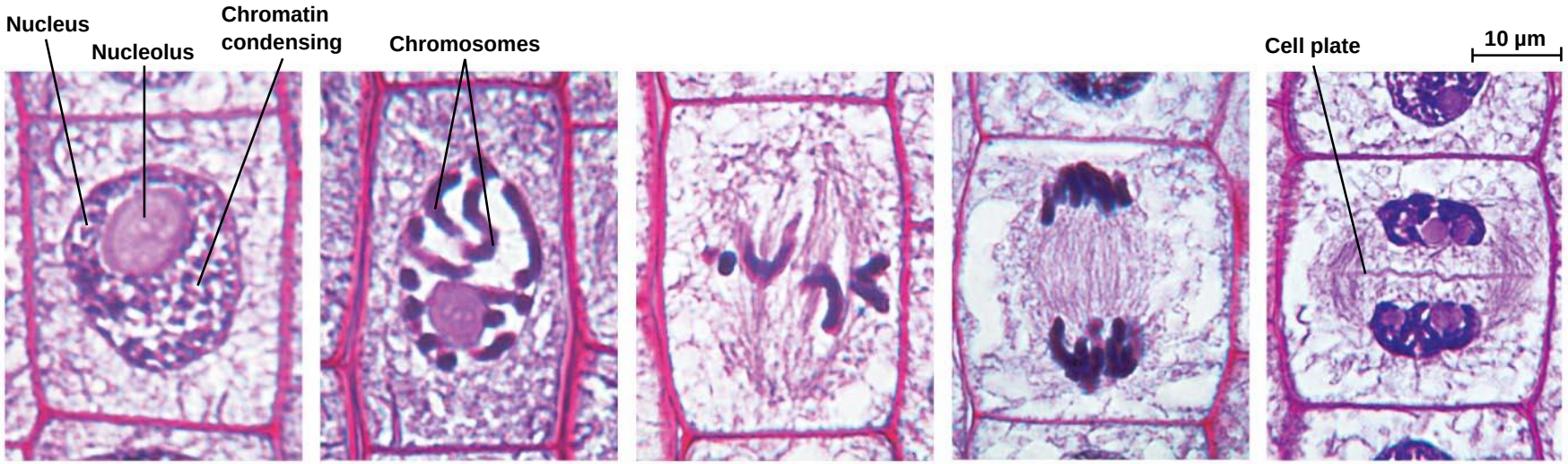
(a) Cleavage of an animal cell (SEM)

LE 12-9b



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

LE 12-10



1. Prophase. The chromatin is condensing. The nucleolus is beginning to disappear. Although not yet visible in the micrograph, the mitotic spindle is starting to form.

2. Prometaphase. We now see discrete chromosomes; each consists of two identical sister chromatids. Later in prometaphase, the nuclear envelope will fragment.

3. Metaphase. The spindle is complete, and the chromosomes, attached to microtubules at their kinetochores, are all at the metaphase plate.

4. Anaphase. The chromatids of each chromosome have separated, and the daughter chromosomes are moving to the ends of the cell as their kinetochore microtubules shorten.

5. Telophase. Daughter nuclei are forming. Meanwhile, cytokinesis has started: The cell plate, which will divide the cytoplasm in two, is growing toward the perimeter of the parent cell.

Binary Fission

- 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

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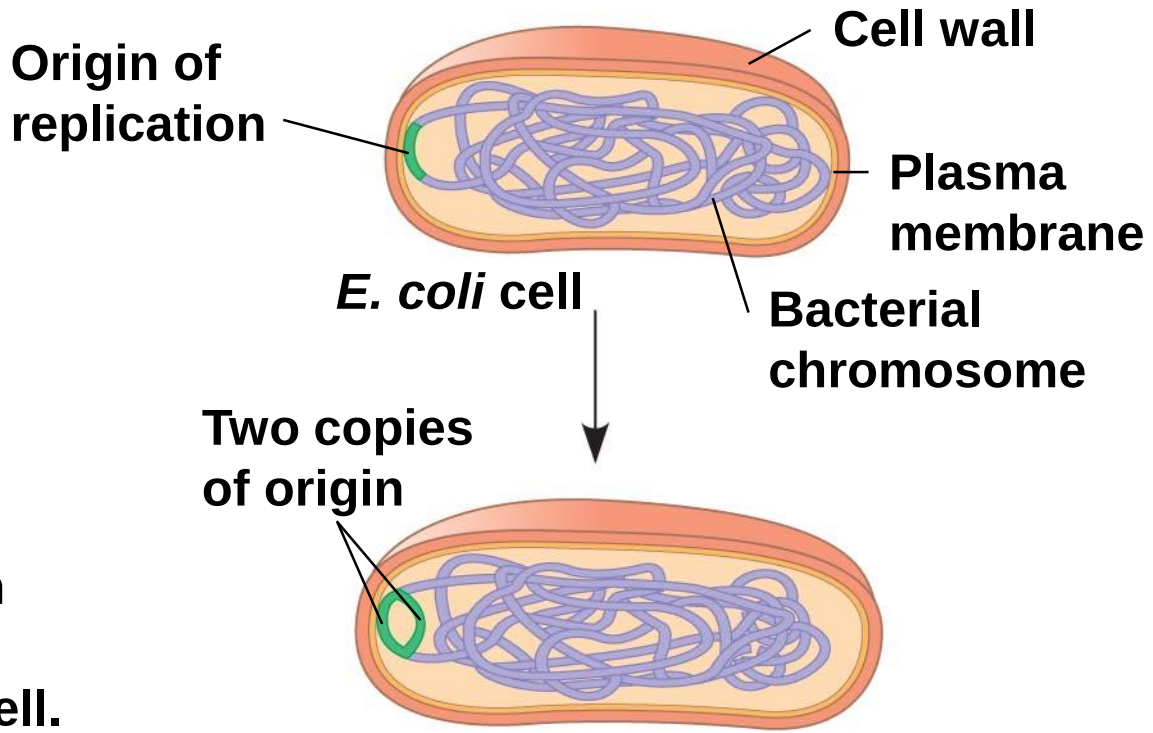

1 Chromosome replication begins. Soon thereafter, one copy of the origin moves rapidly toward the other end of the cell.

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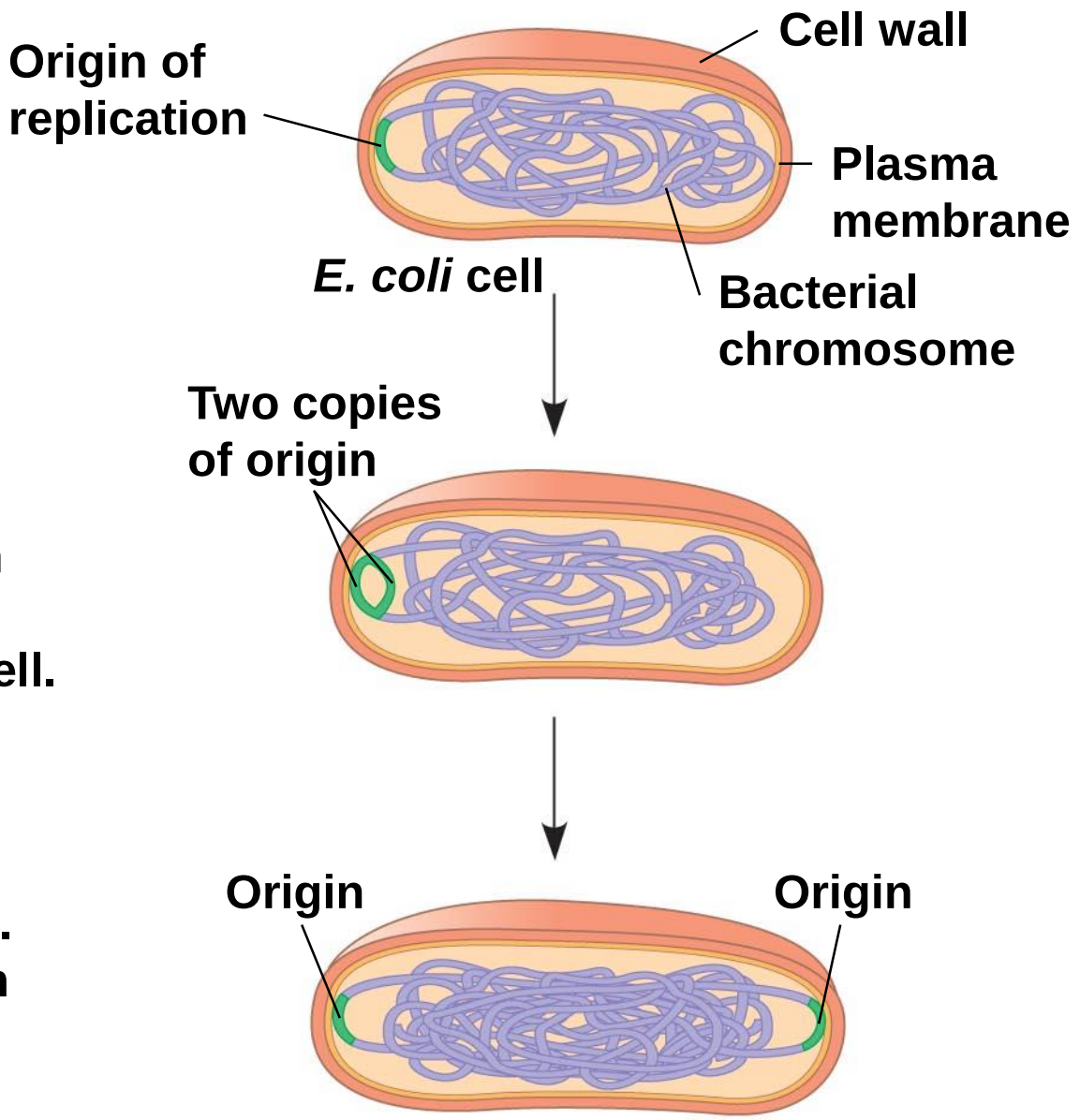

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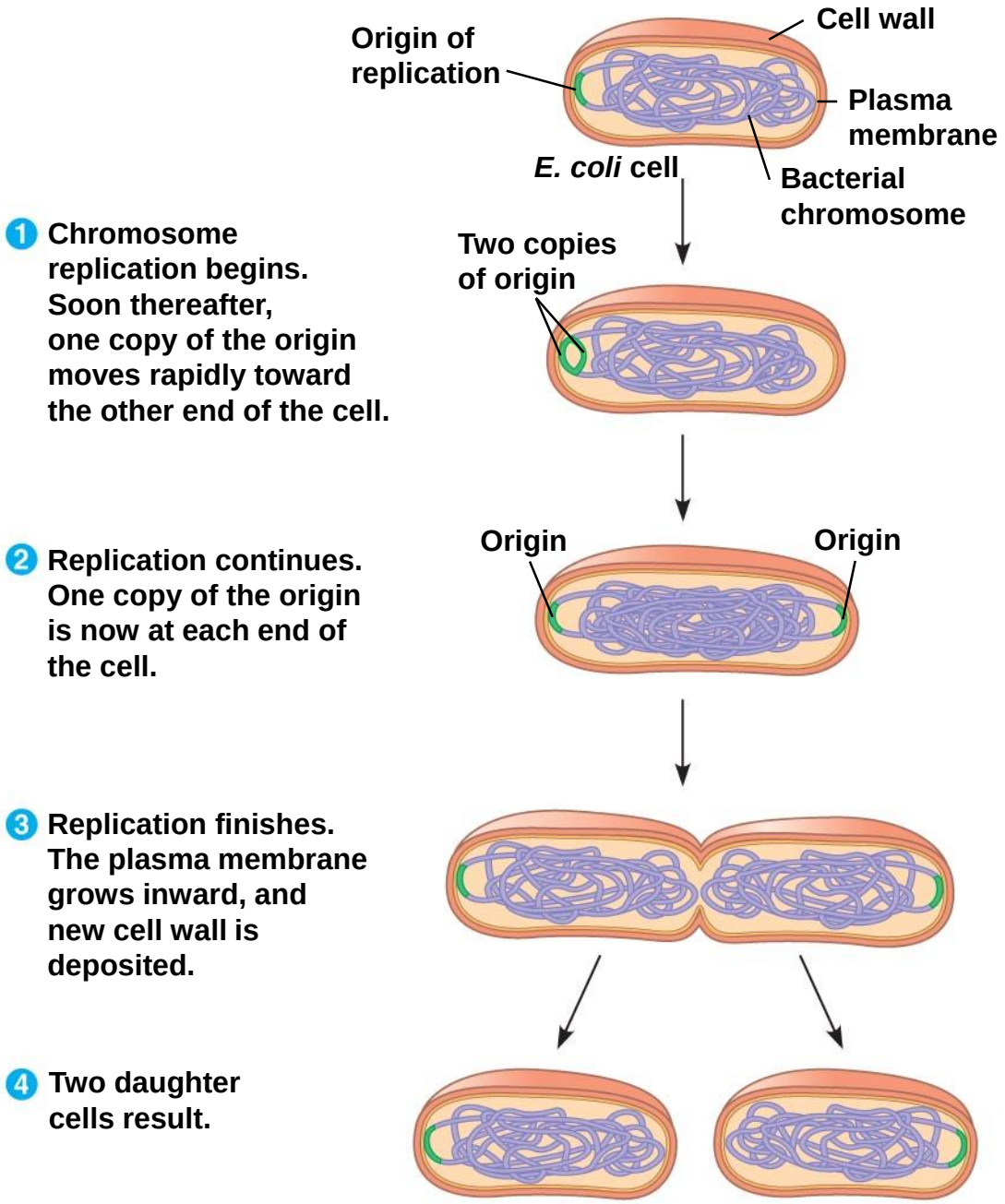

The Evolution of Mitosis

- 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

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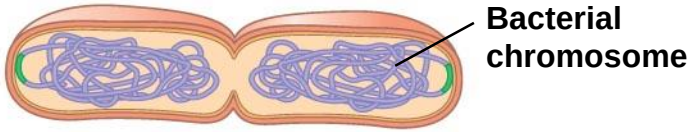
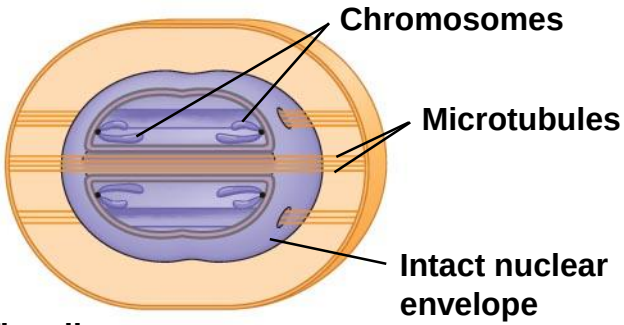
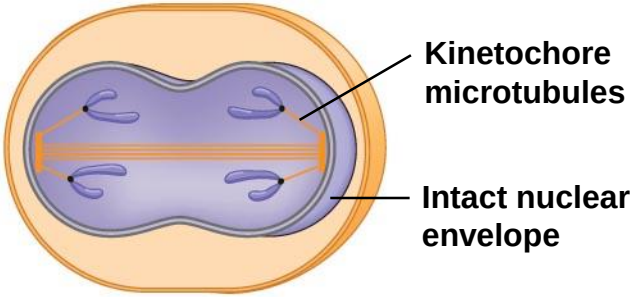


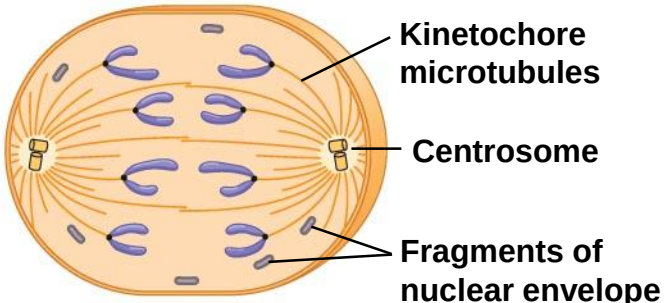
(a) Prokaryotes



(b) Dinoflagellates



(c) Diatoms



(d) Most eukaryotes

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

- The frequency of cell division varies with the type of cell
- These cell cycle differences result from regulation at the molecular level

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

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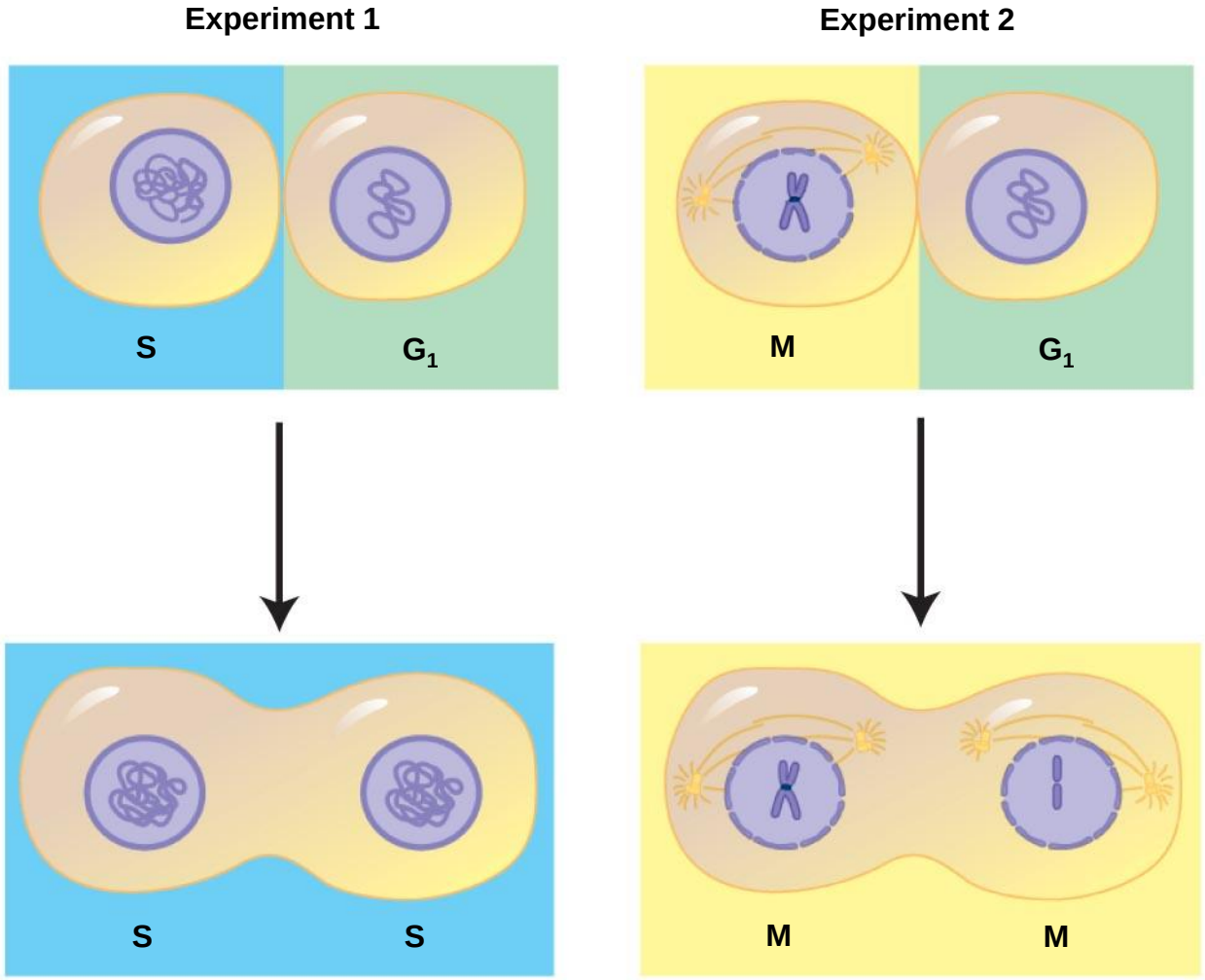

When a cell in the S phase was fused with a cell in G_1, the G_1 cell immediately entered the S phase—DNA was synthesized.

When a cell in the M phase was fused with a cell in G_1, the G_1 cell 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 clock has specific checkpoints where the cell cycle stops until a go-ahead signal is received

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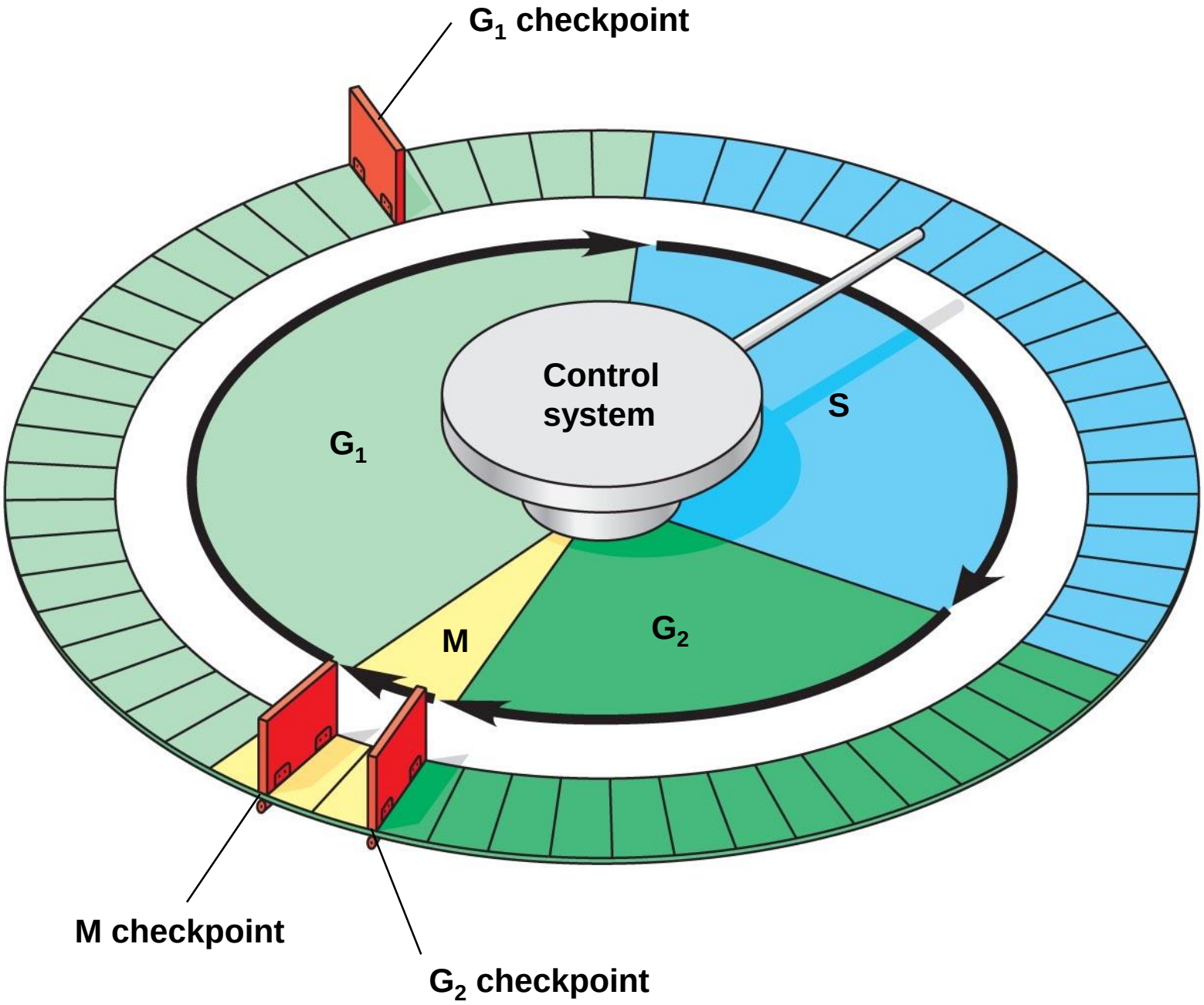

- For many cells, the G_1 checkpoint seems to be the most important one
- If a cell receives a go-ahead signal at the G_1 checkpoint, it will usually complete the S, G_2, and M phases and divide
- If the cell does not receive the go-ahead signal, it will exit the cycle, switching into a nondividing state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

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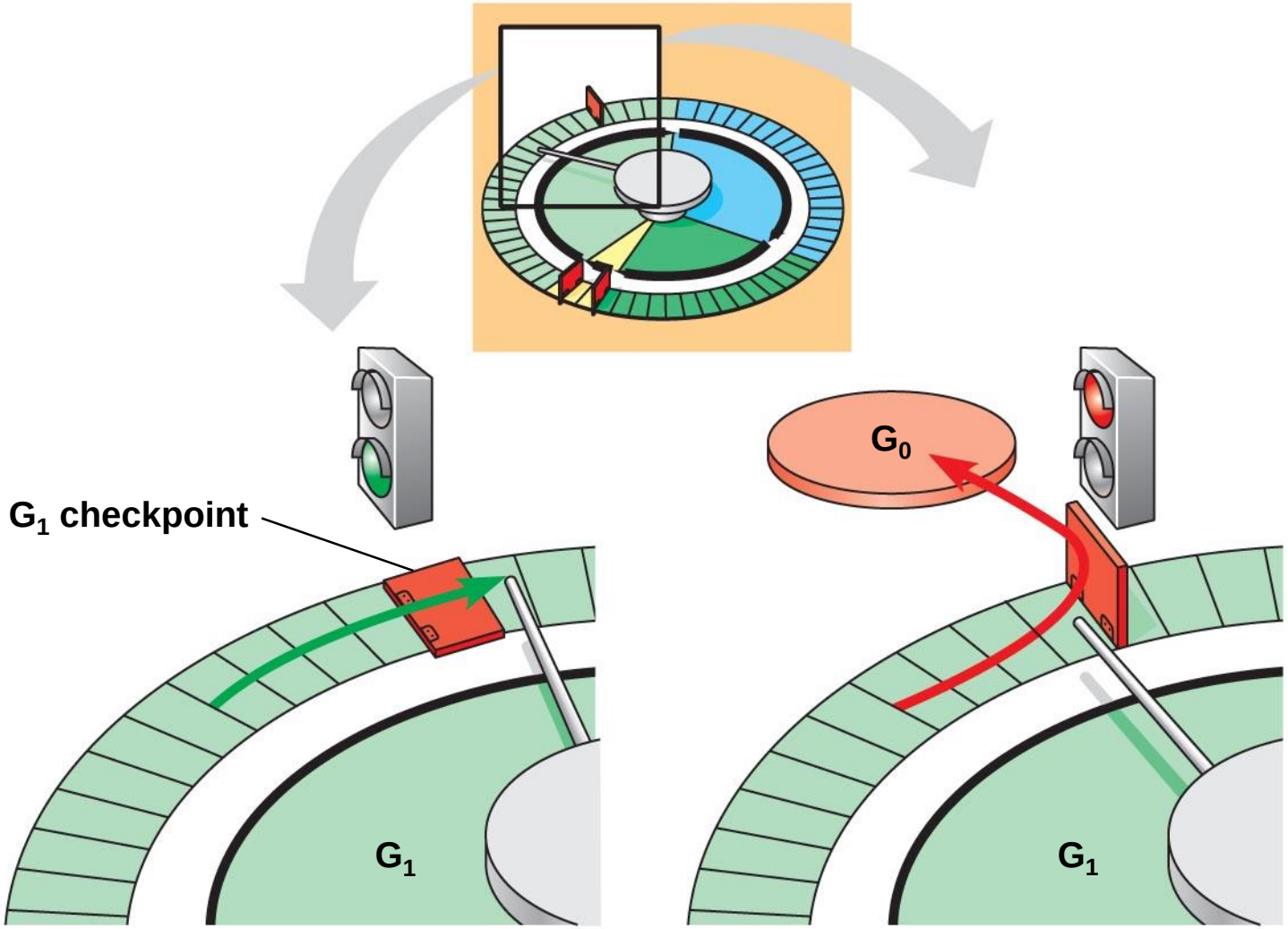

(a) If a cell receives a go-ahead signal at the G_1 checkpoint, the cell continues on in the cell cycle.

(b) If a cell does not receive a go-ahead signal at the G_1 checkpoint, the cell exits the cell cycle and goes into G_0, a nondividing state.

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)
- The activity of cyclins and Cdks fluctuates during the cell cycle

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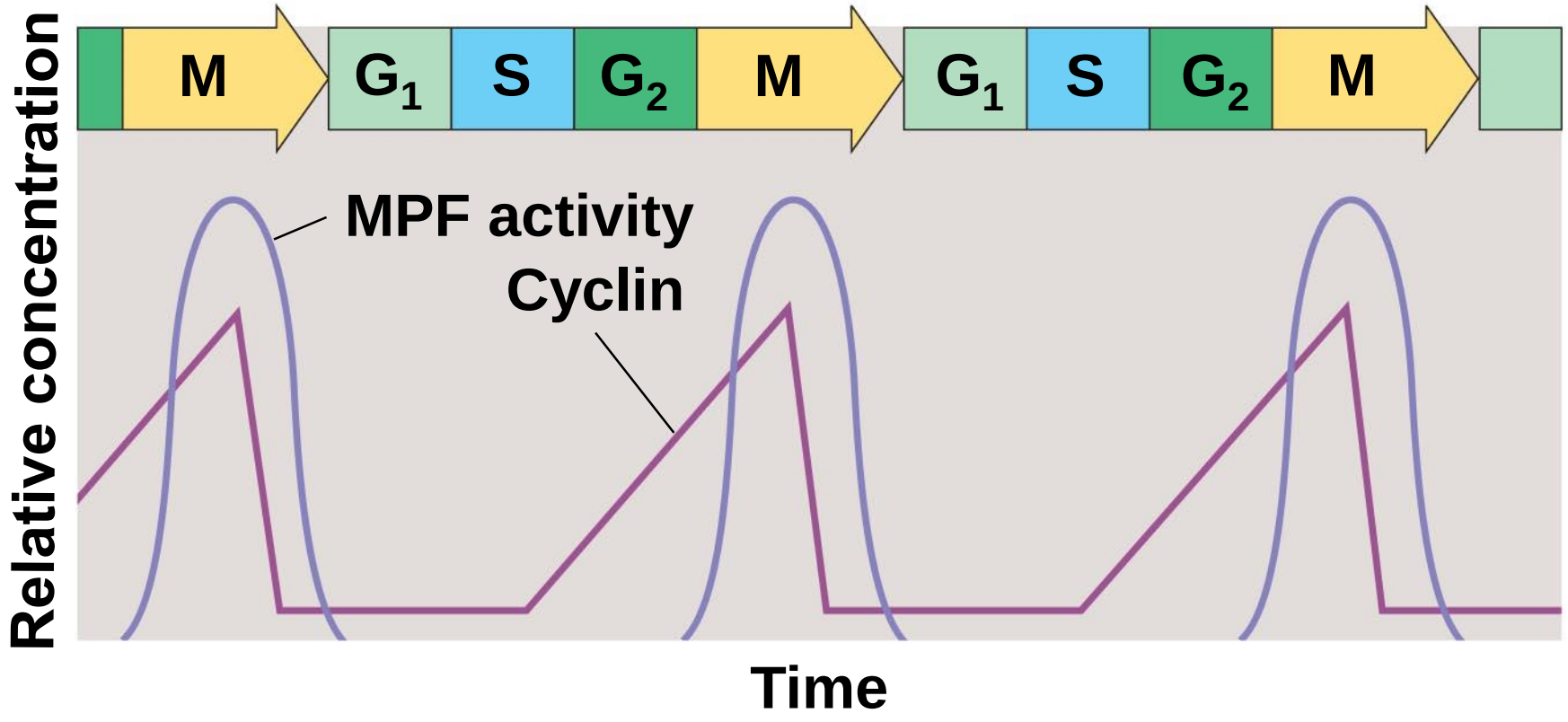

(a) Fluctuation of MPF activity and cyclin concentration during the cell cycle

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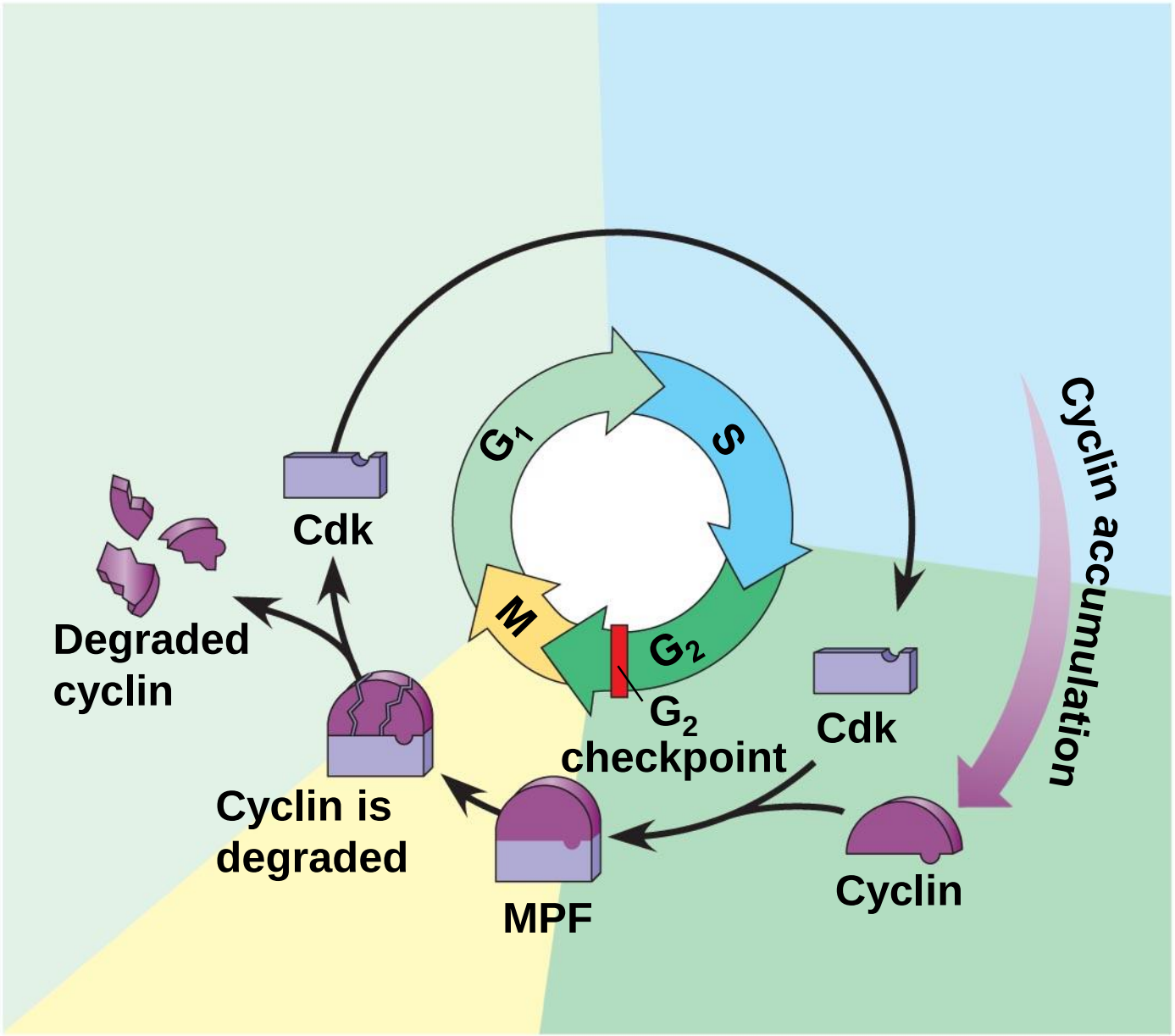

(b) Molecular mechanisms that help regulate the cell cycle

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

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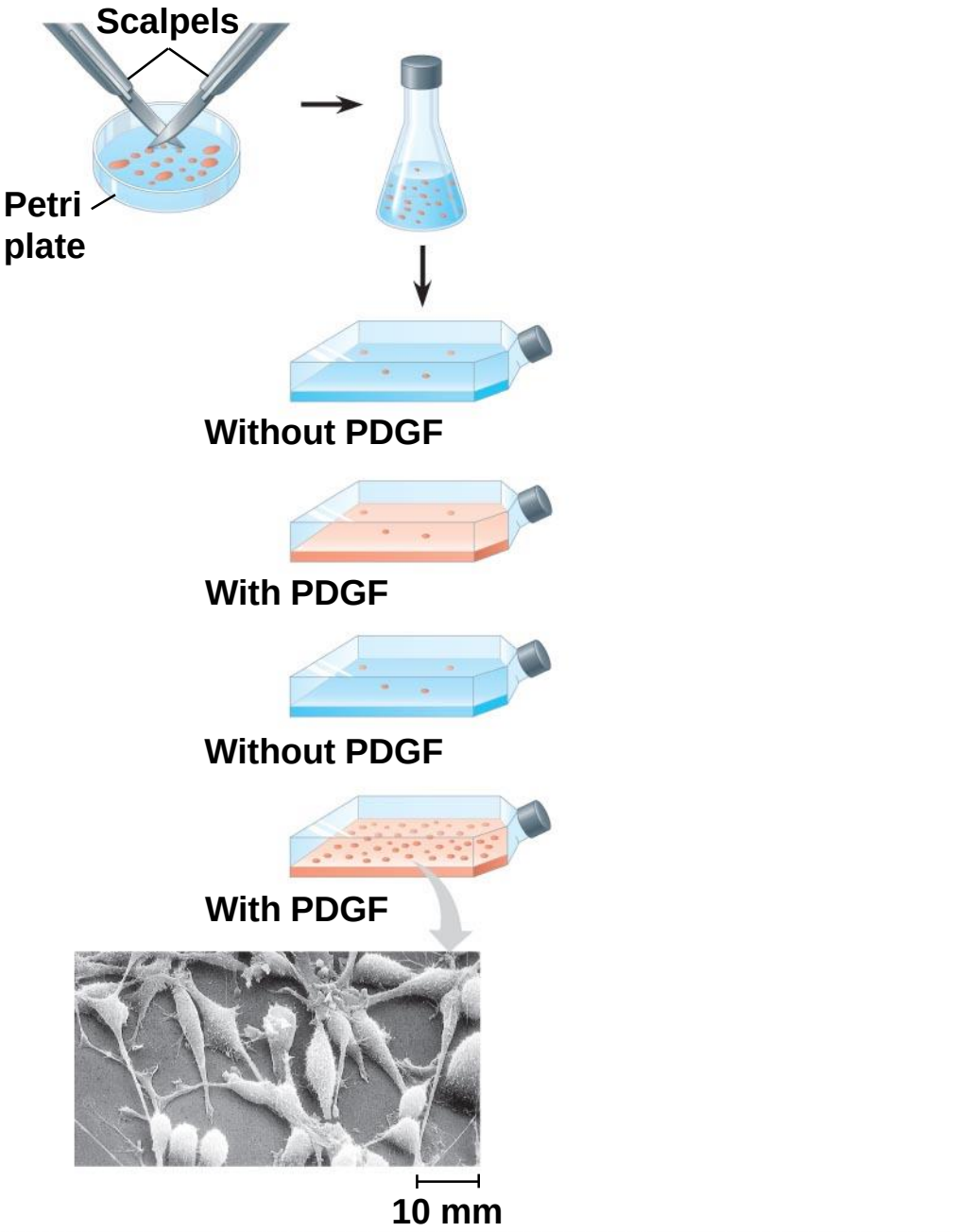

- Another example of external signals is density-dependent inhibition, in which crowded cells stop dividing
- Most animal cells also exhibit anchorage dependence, in which they must be attached to a substratum in order to divide

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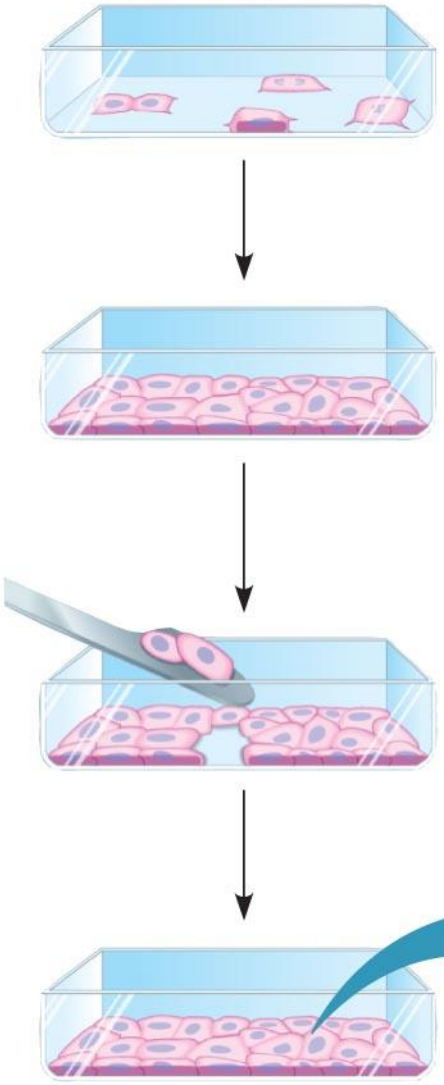
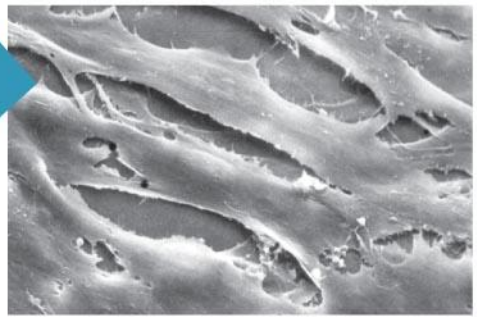


Cells anchor to dish surface and divide (anchorage dependence).

When cells have formed a complete single layer, they stop dividing (density-dependent inhibition).

If some cells are scraped away, the remaining cells divide to fill the gap and then stop (density-dependent inhibition).



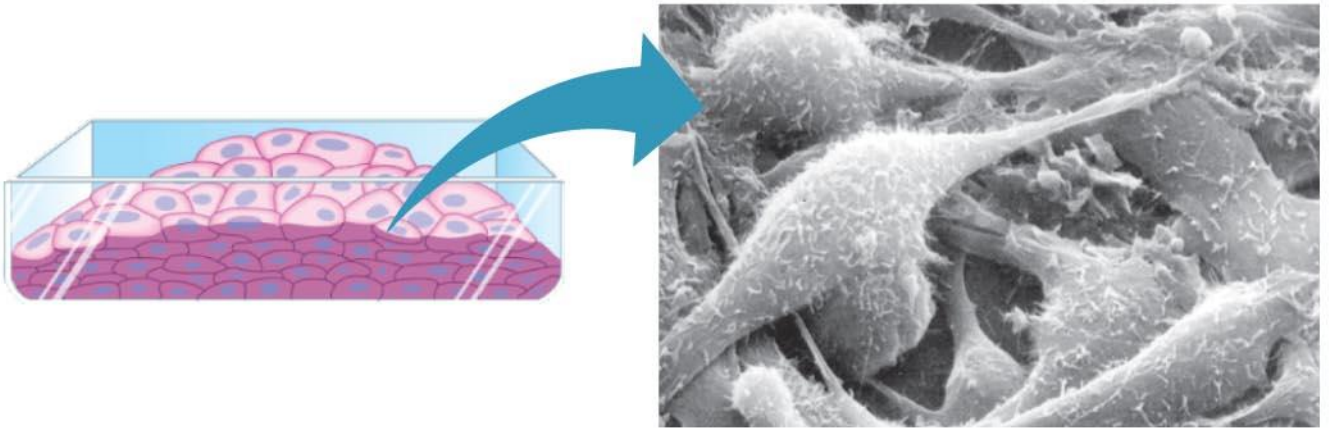
25 µm

(a) Normal mammalian cells

- Cancer cells exhibit neither density-dependent inhibition nor anchorage dependence

LE 12-18b

Cancer cells do not exhibit anchorage dependence or density-dependent inhibition.



(b) Cancer cells

Loss of Cell Cycle Controls in Cancer Cells

- Cancer cells do not respond normally to the body's control mechanisms
- Cancer cells form tumors, masses of abnormal cells within otherwise normal tissue
- If abnormal cells remain 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 secondary tumors

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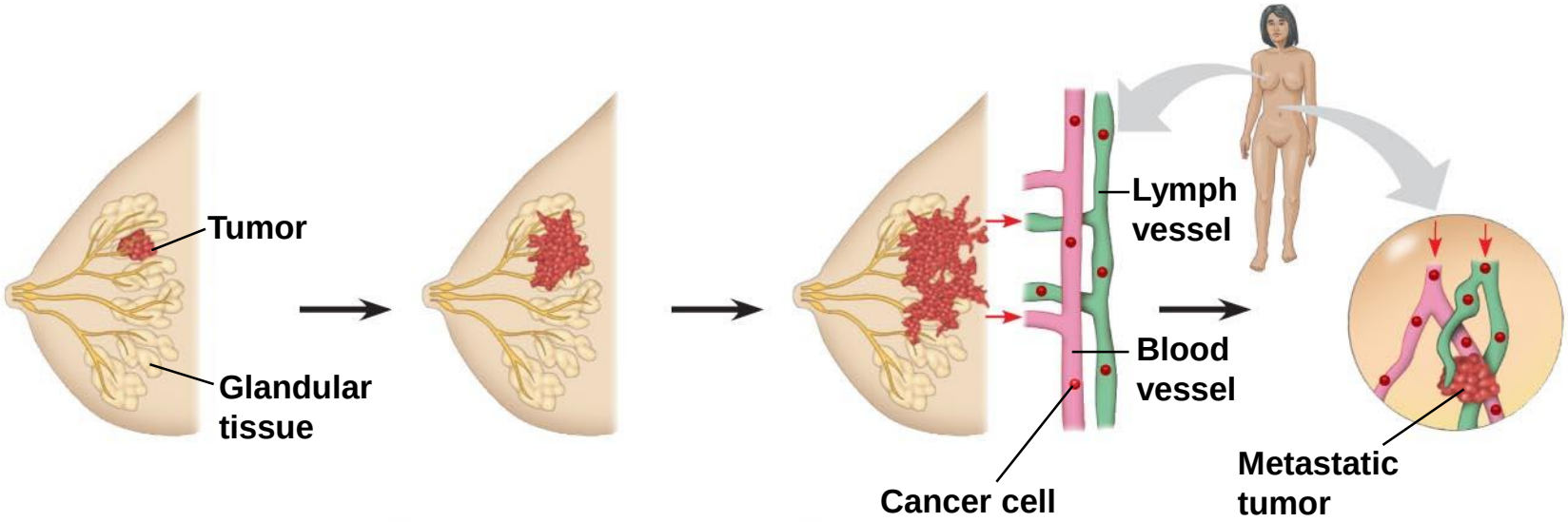

1. A tumor grows from a single cancer cell.
2. Cancer cells invade neighboring tissue.
3. Cancer cells spread through lymph and blood vessels to other parts of the body.
4. A small percentage of cancer cells may survive and establish a new tumor in another part of the body.