Cell Division and Reproduction

8.1 Cell Division Plays Many Important Roles in the Lives of Organisms (1 of 2)

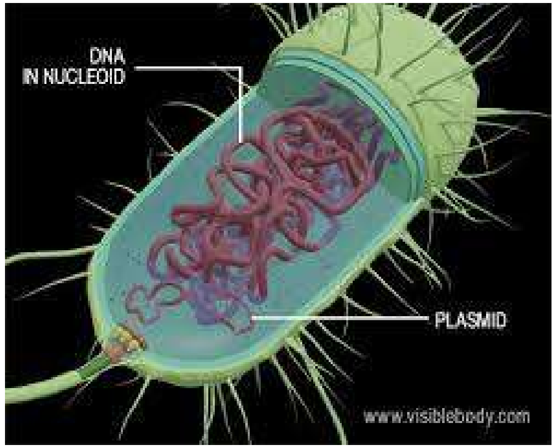
- **Cell division** is at the heart of the reproduction of cells and organisms because cells originate only from preexisting cells.
- Some organisms reproduce through **asexual reproduction**, producing offspring that are all genetic copies of the parent and identical to each other (clones).
- Other organisms reproduce through **sexual reproduction**, creating a variety of offspring.

8.1 Cell Division Plays Many Important Roles in the Lives of Organisms (2 of 2)

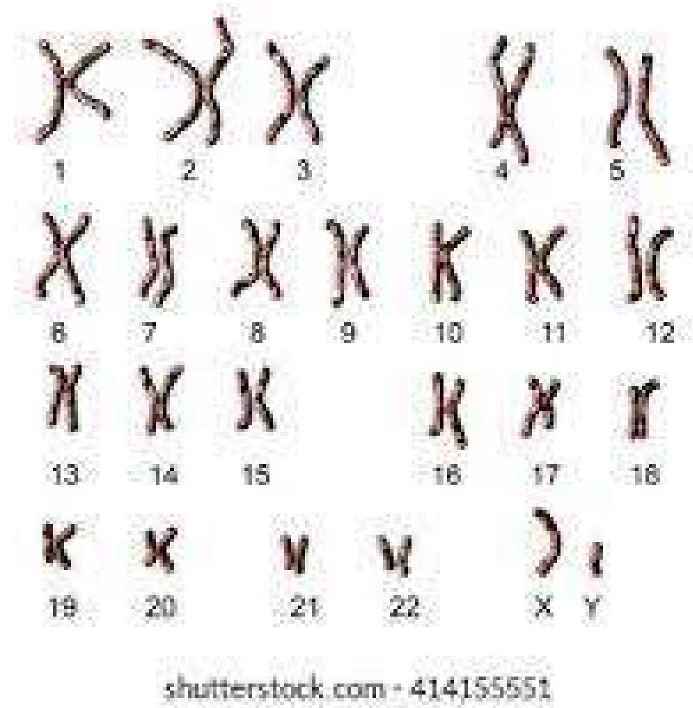
Checkpoint question What function does cell division play in an amoeba (a single-celled protist)? What functions does it play in your body?

Reproduction; development, growth, and repair

The Challenge is Genome Replication!



- Prokaryotes:
  - -small genomes
  - -one DNA polymer = 1 chromosome
  - Very little non-coding DNA
- Eukaryotes:
  - -very large genomes
  - -many DNA polymers =
  - many chromosomes
  - Mostly non-coding DNA



8.2 Prokaryotes Reproduce by Binary Fission (1 of 2)

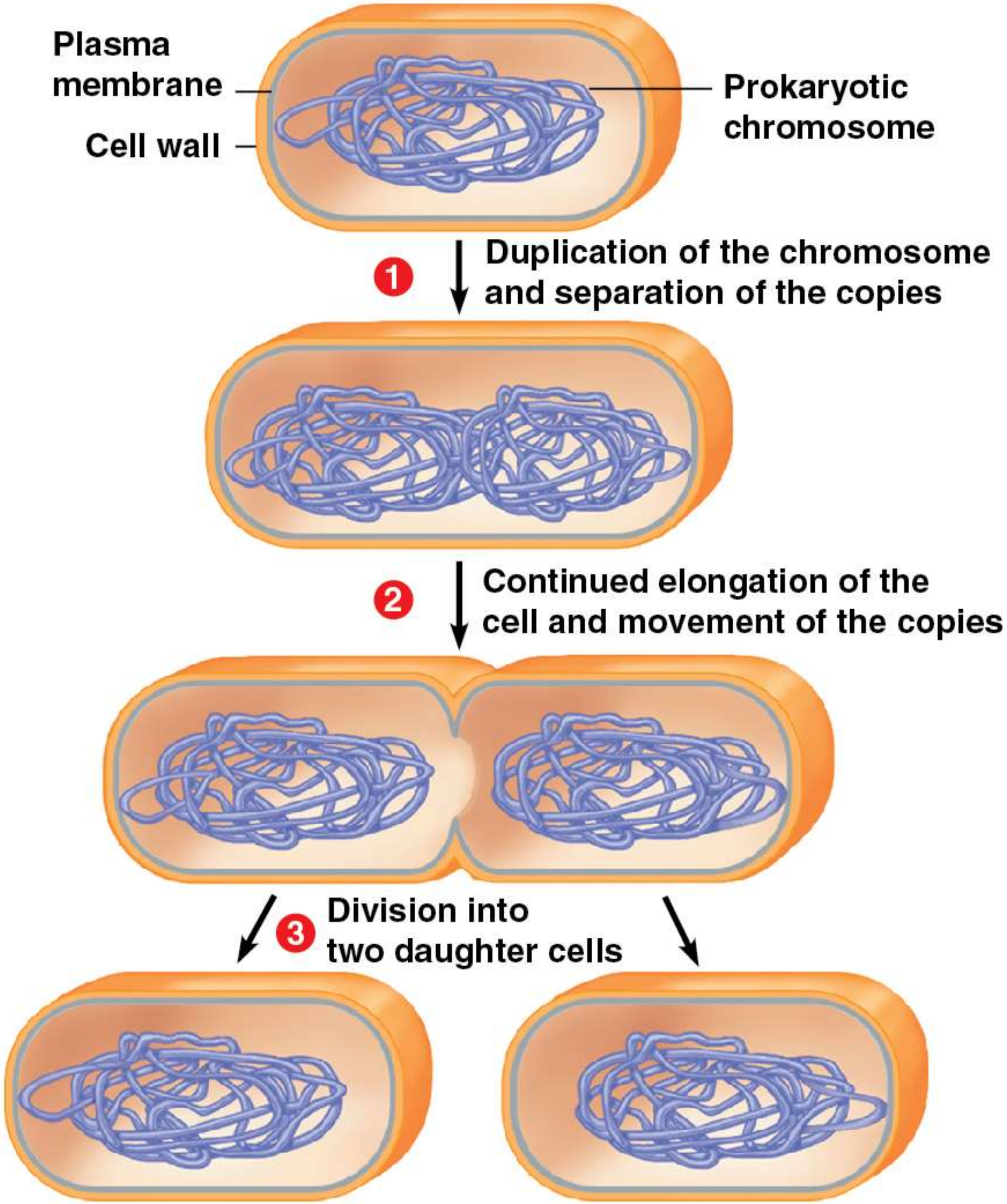
- Prokaryotic cells reproduce asexually by **binary fission**, a term that means "dividing in half."
- In typical prokaryotes, most genes are carried on one circular D N A molecule that, with associated proteins, constitutes the organism's chromosome.
- As the cell replicates its single chromosome,
  - the copies move apart,
  - the plasma membrane pinches inward, and
  - more cell wall is made, which eventually divides the parent cell into two daughter cells.

8.2 Prokaryotes Reproduce by Binary Fission (2 of 2)

Checkpoint question Why is binary fission classified as asexual reproduction?

Because the genetically identical offspring inherit their DNA from a single parent

Figure 8.2a_3



Plasma membrane
Cell wall
Prokaryotic chromosome
1 Duplication of the chromosome and separation of the copies
2 Continued elongation of the cell and movement of the copies
3 Division into two daughter cells

The Eukaryotic Cell Cycle and Mitosis

8.3 The Large, Complex Chromosomes of Eukaryotes Duplicate with Each Cell Division (1 of 3)

- A eukaryotic cell has many more genes than a prokaryotic cell, and they are grouped into multiple chromosomes in the nucleus.
  - Each eukaryotic chromosome contains one long DNA molecule.
  - Individual chromosomes are visible under a light microscope only when the cell is in the process of dividing; otherwise, chromosomes are thin, loosely packed **chromatin** fibers too small to be seen.

8.3 The Large, Complex Chromosomes of Eukaryotes Duplicate with Each Cell Division (2 of 3)

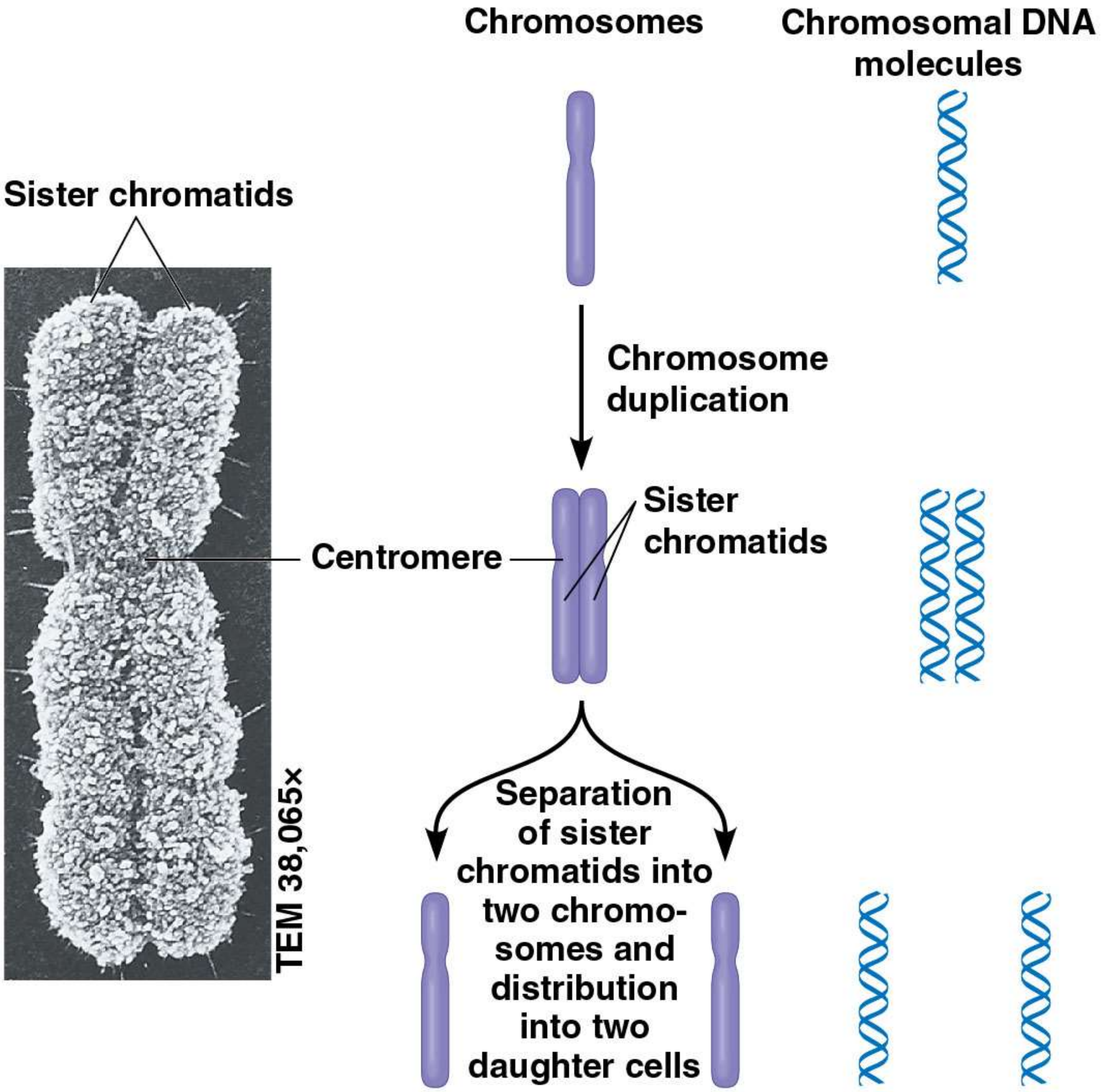
- Before a cell starts dividing, the chromosomes duplicate, producing **sister chromatids** (containing identical DNA) that are joined together along their lengths.
- Cell division involves the separation of sister chromatids and results in two daughter cells, each containing a complete and identical set of chromosomes.

8.3 The Large, Complex Chromosomes of Eukaryotes Duplicate with Each Cell Division (3 of 3)

Checkpoint question When does a chromosome consist of two identical chromatids?

When the cell is preparing to divide and has duplicated its chromosomes but before the duplicates actually separate

Figure 8.3b



Chromosomes
Chromosomal DNA molecules
Sister chromatids
Chromosome duplication
Centromere
Sister chromatids
TEM 38,065×
Separation of sister chromatids into two chromo- somes and distribution into two daughter cells

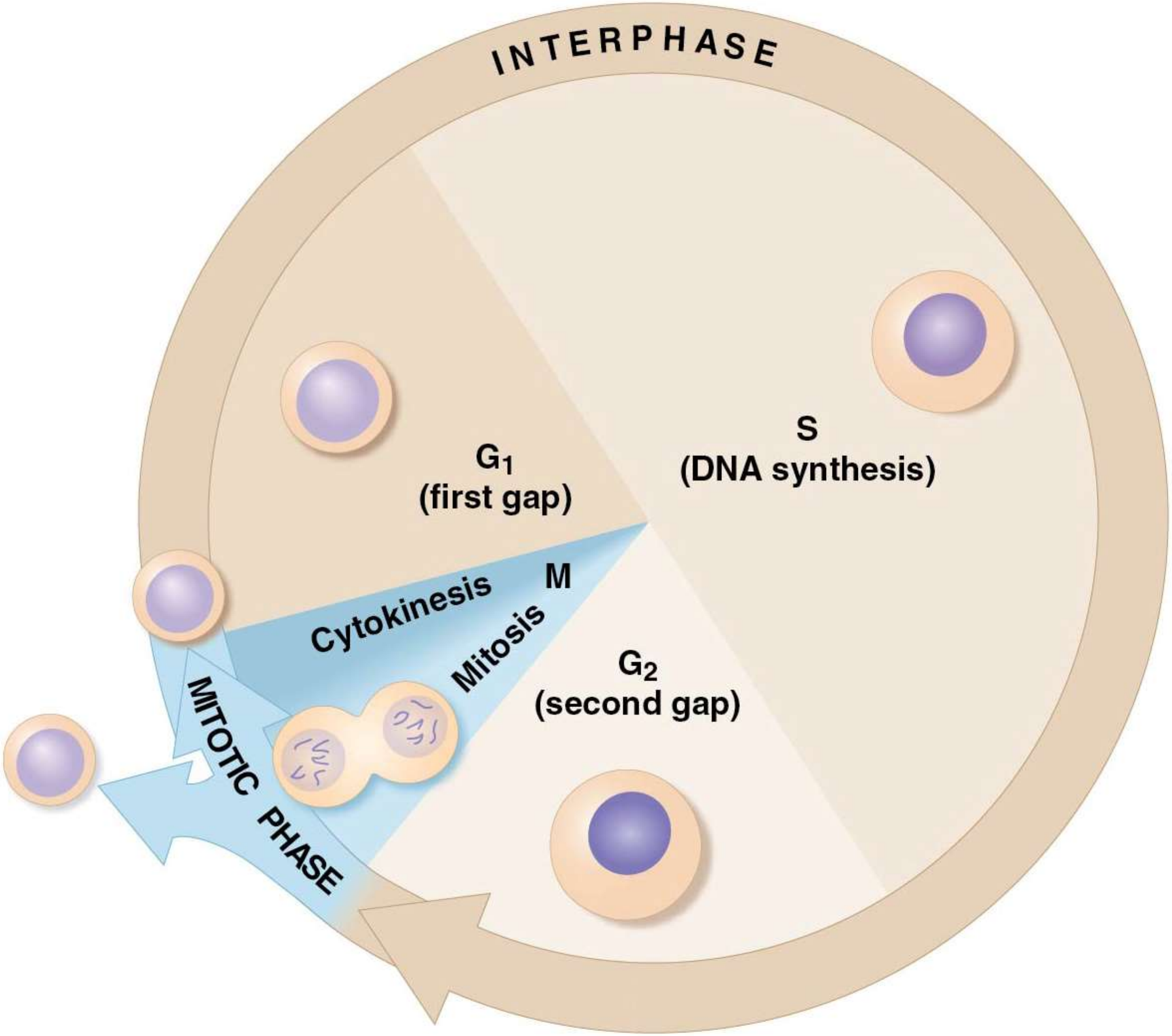
8.4 The Cell Cycle Includes Growth and Division Phases

- The **cell cycle** is an ordered sequence of events that run from the time a cell is first formed from a dividing parent cell until its own division into two cells.

Checkpoint question A researcher treats cells with a chemical that prevents DNA synthesis from starting. This treatment would trap the cells in which part of the cell cycle?

G_1

Figure 8.4



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

8.5 Cell Division Is a Continuum of Dynamic Changes (1 of 2)

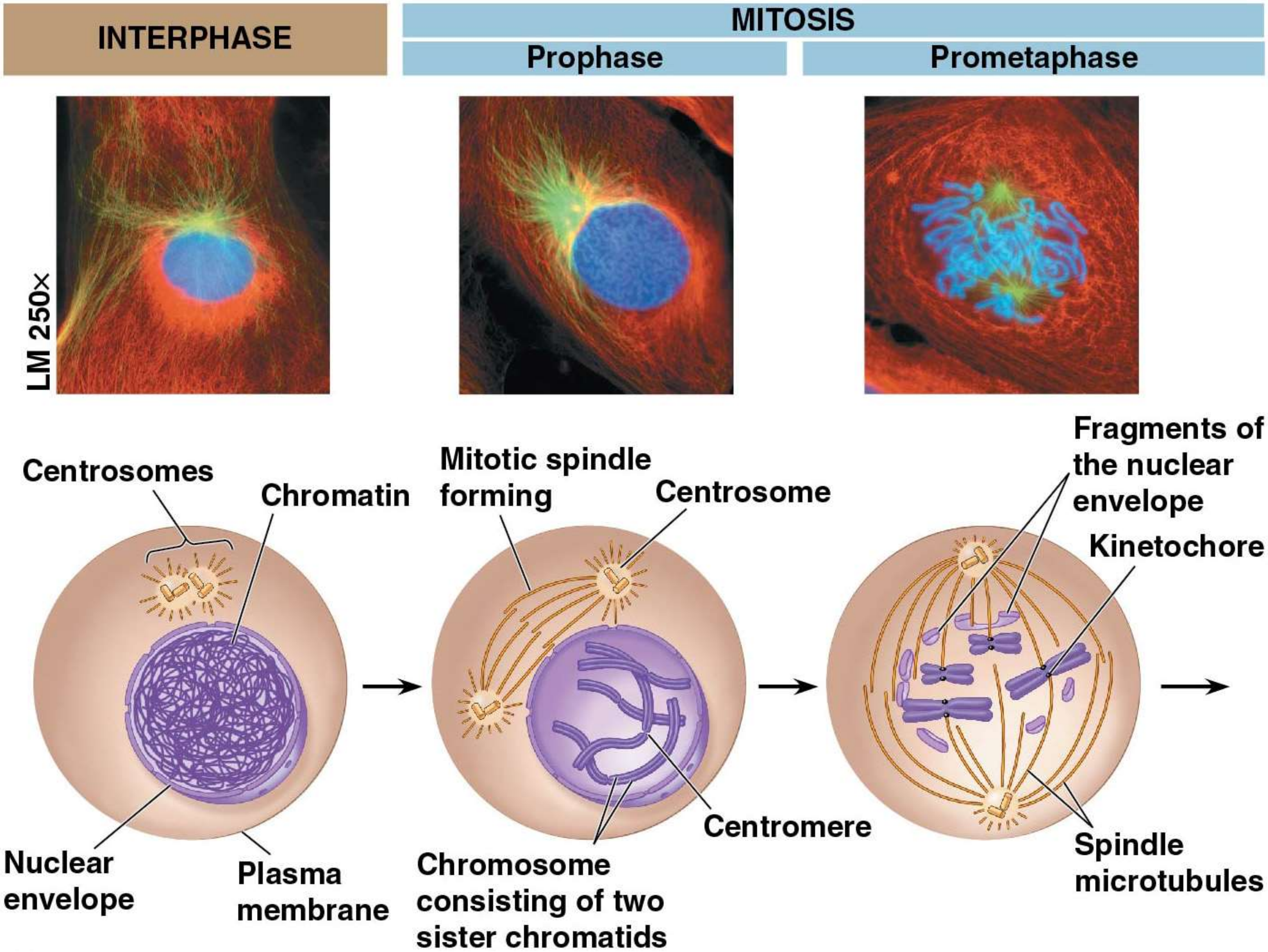
- Mitosis distributes duplicated chromosomes into two daughter nuclei.
- After the chromosomes are coiled up, a **mitotic spindle** made of microtubules moves the chromosomes to the middle of the cell.
- The sister chromatids then separate and move to opposite poles of the cell, at which point two new nuclei form.

8.5 Cell Division Is a Continuum of Dynamic Changes (2 of 2)

Checkpoint question You view an animal cell through a microscope and observe dense, duplicated chromosomes scattered throughout the cell. Which state of mitosis are you witnessing?

Prophase (because the chromosomes are condensed but not yet aligned)

Figure 8.5_1


INTERPHASE
MITOSIS
Prophase
Prometaphase
LM 250×
Centrosomes
Chromatin
Nuclear envelope
Plasma membrane
Mitotic spindle forming
Centrosome
Centromere
Chromosome consisting of two sister chromatids
Fragments of the nuclear envelope
Kinetochore
Spindle microtubules

8.6 Cytokinesis Differs for Plant and Animal Cells (1 of 2)

- Cytokinesis, in which the cell divides in two, overlaps the end of mitosis.
  - In animals, cytokinesis occurs when a cell constricts, forming a **cleavage furrow**.
  - In plants, a membranous **cell plate** forms and then splits the cell in two.

8.6 Cytokinesis Differs for Plant and Animal Cells (2 of 2)

Checkpoint question Contrast cytokinesis in animals with cytokinesis in plants.

In animals, cytokinesis involves a cleavage furrow in which contracting microfilaments pinch the cell in two. In plants, it involves formation of a cell plate, a fusion of vesicles that forms new plasma membranes and new cell walls between the cells.

Figure 8.6a

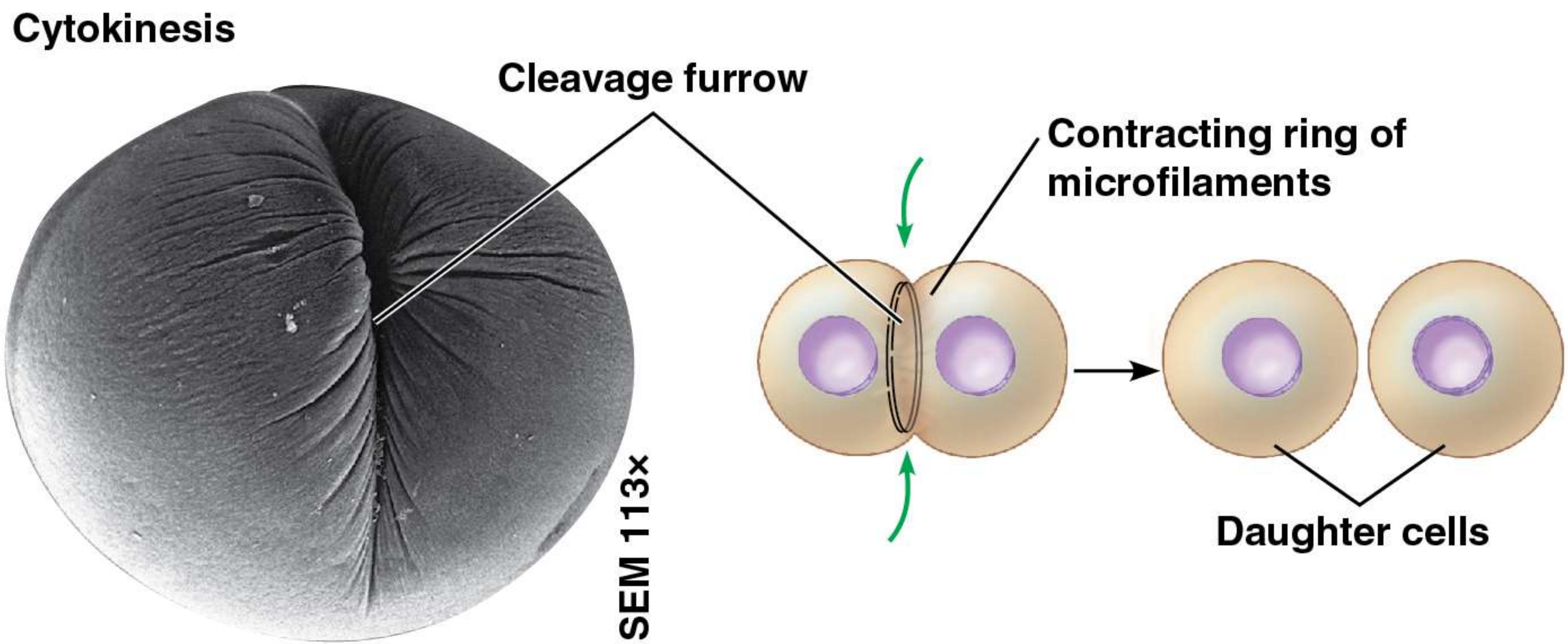
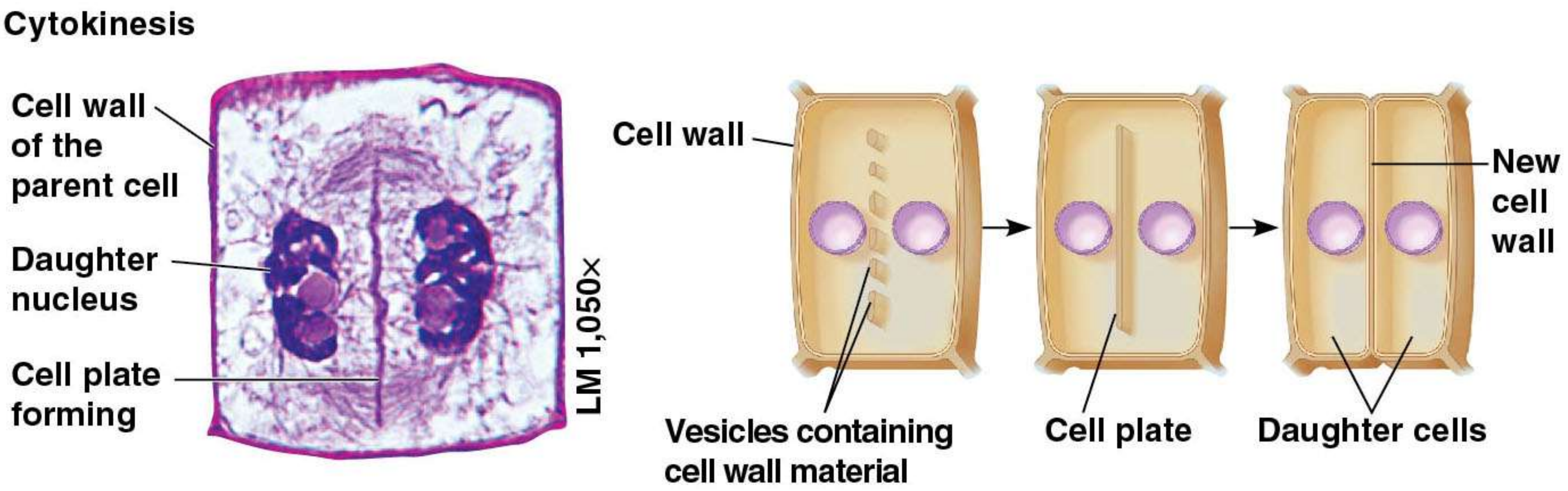

Cytokinesis
Cleavage furrow
Contracting ring of microfilaments
SEM 113×
Daughter cells

Figure 8.6b


Cytokinesis
Cell wall of the parent cell
Daughter nucleus
Cell plate forming
LM 1,050×
Cell wall
Vesicles containing cell wall material
Cell plate
Daughter cells
New cell wall

8.7 The Rate of Cell Division Is Affected by Environmental Factors (1 of 2)

- In laboratory cultures, most normal cells divide only when attached to a surface.
  - The cultured cells continue dividing until they touch one another.
  - Most animal cells divide only when stimulated by growth factors, and some do not divide at all.
  - Growth factors stimulate cells to divide.

8.7 The Rate of Cell Division Is Affected by Environmental Factors (2 of 2)

Checkpoint question Compared with a control culture, the cells in an experimental culture are fewer but much larger in size when they cover the dish surface and stop growing. What is a reasonable hypothesis for this difference?

The experimental culture is deficient in one or more growth factors.

Figure 8.7a

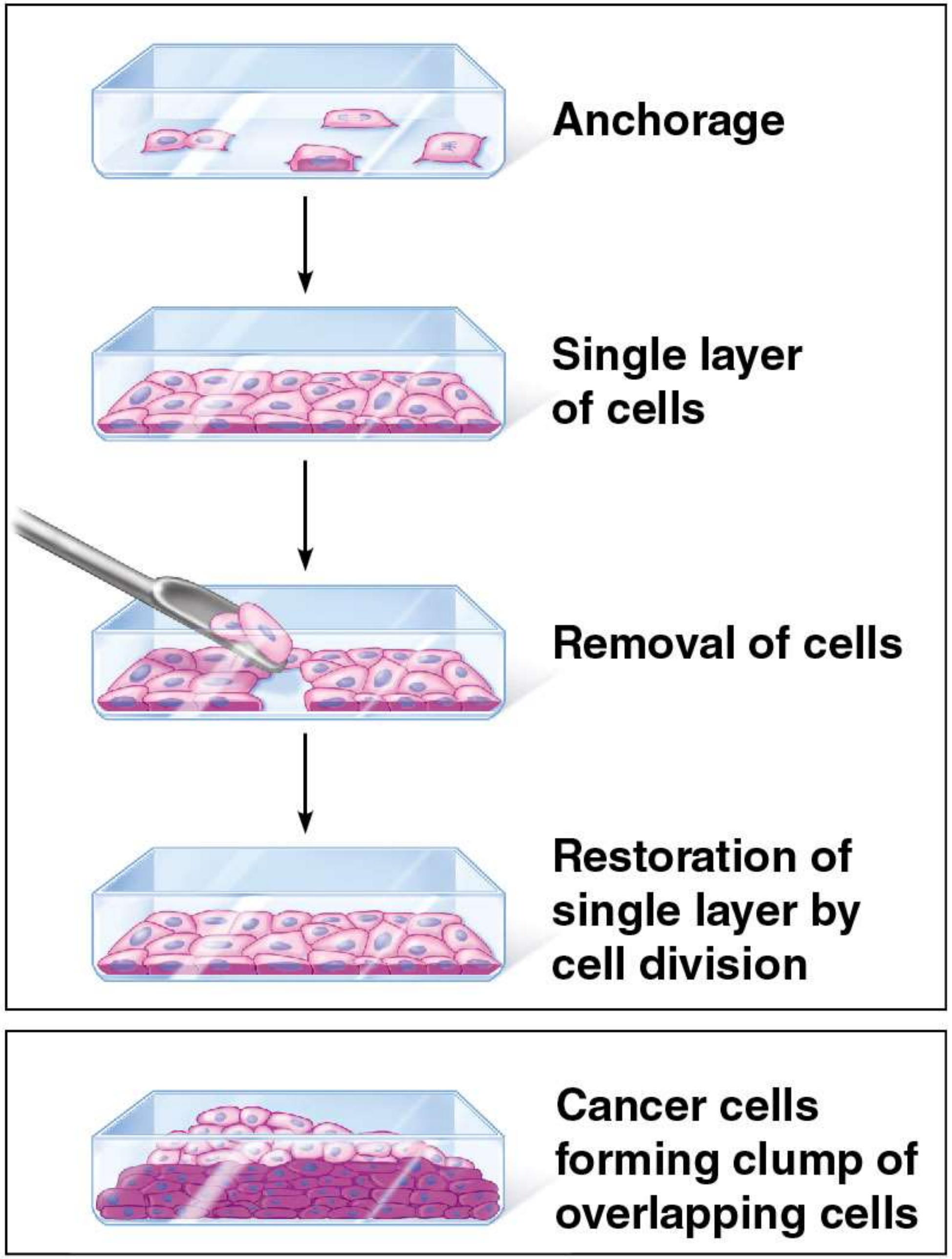
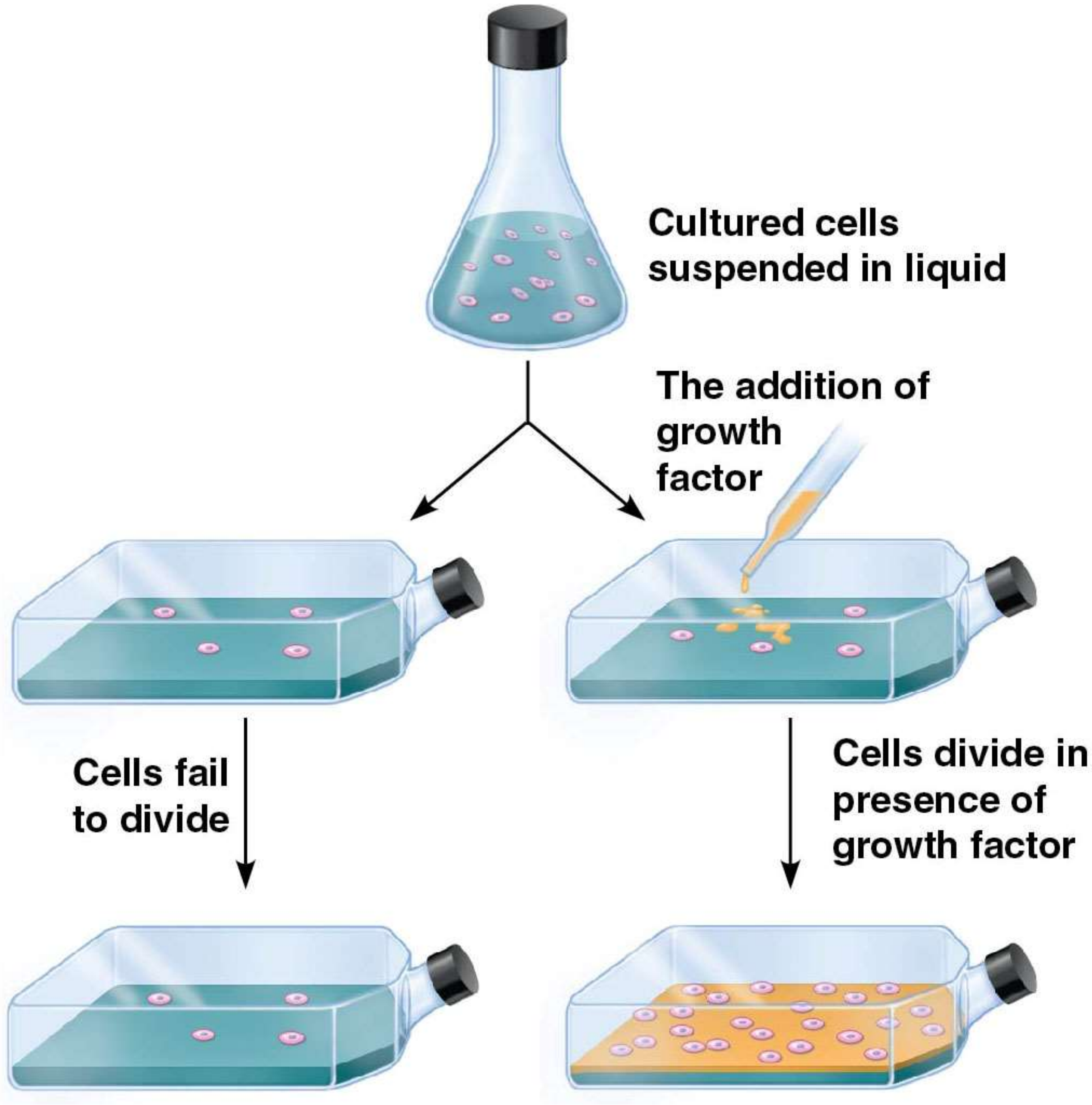

Anchorage
Single layer of cells
Removal of cells
Restoration of single layer by cell division
Cancer cells forming clump of overlapping cells

Figure 8.7b


Cultured cells suspended in liquid
The addition of growth factor
Cells fail to divide
Cells divide in presence of growth factor

8.8 Growth Factors Signal the Cell Cycle Control System (1 of 2)

- A set of proteins within the cell controls the cell cycle.
  - Signals affecting critical checkpoints in the cell cycle determine whether a cell will go through the complete cycle and divide.
  - The binding of growth factors to specific receptors on the plasma membrane is usually necessary for cell division.

8.8 Growth Factors Signal the Cell Cycle Control System (2 of 2)

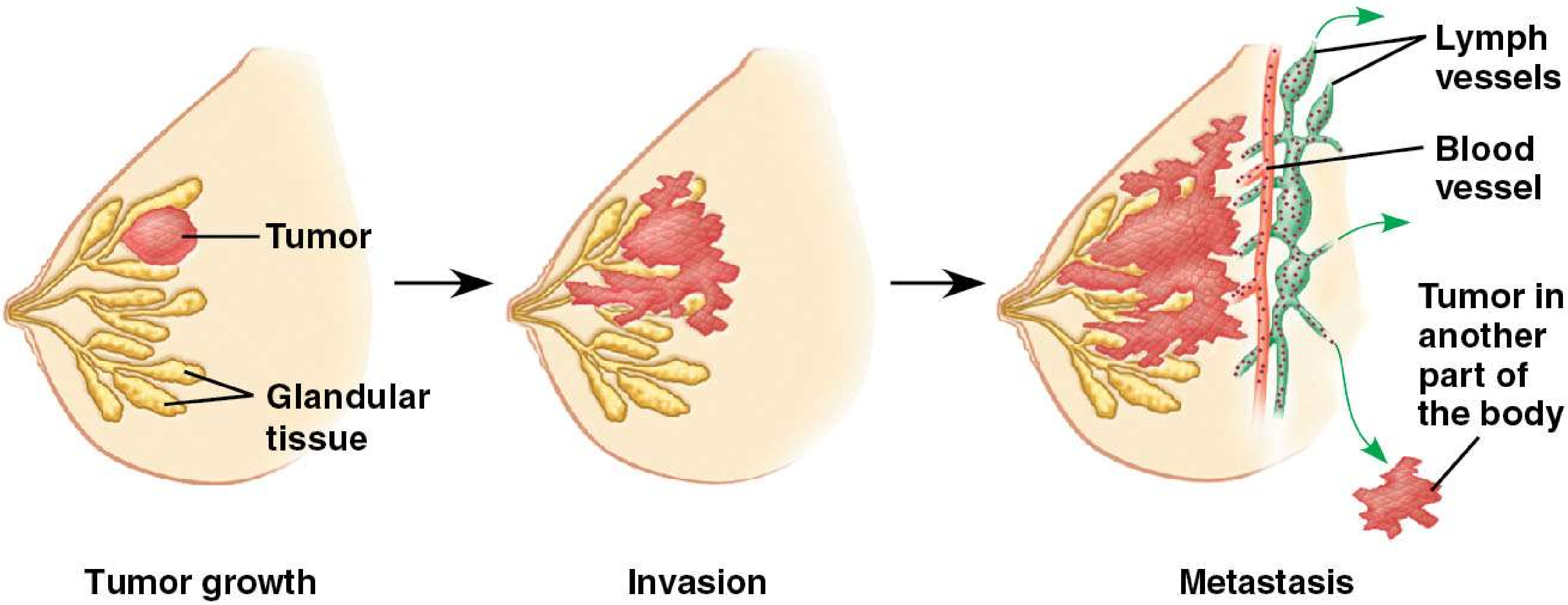
Checkpoint question At which of the three checkpoints described in this module do the chromosomes exist as duplicated sister chromatids?

G_2 and M checkpoints

8.9 Connection: Growing Out of Control, Cancer Cells Produce Malignant Tumors

- **Cancer** cells divide excessively to form masses called **tumors**.
- **Malignant tumors** can invade other tissues.
- Radiation and chemotherapy are effective as cancer treatments because they interfere with cell division.

Figure 8.9



Tumor
Glandular tissue
Lymph vessels
Blood vessel
Tumor in another part of the body
Tumor growth
Invasion
Metastasis

8.10 Scientific Thinking: The Best Cancer Treatment May Vary by Individual

- Mortality rates from cancer vary by age of diagnosis, race, and other factors.
- Taking such data into account may improve outcomes of cancer treatment.

Checkpoint question Why must human cancer research often use an observational method when controlled studies could yield more definitive results?

Meiosis and Crossing Over

8.11 Chromosomes Are Matched in Homologous Pairs

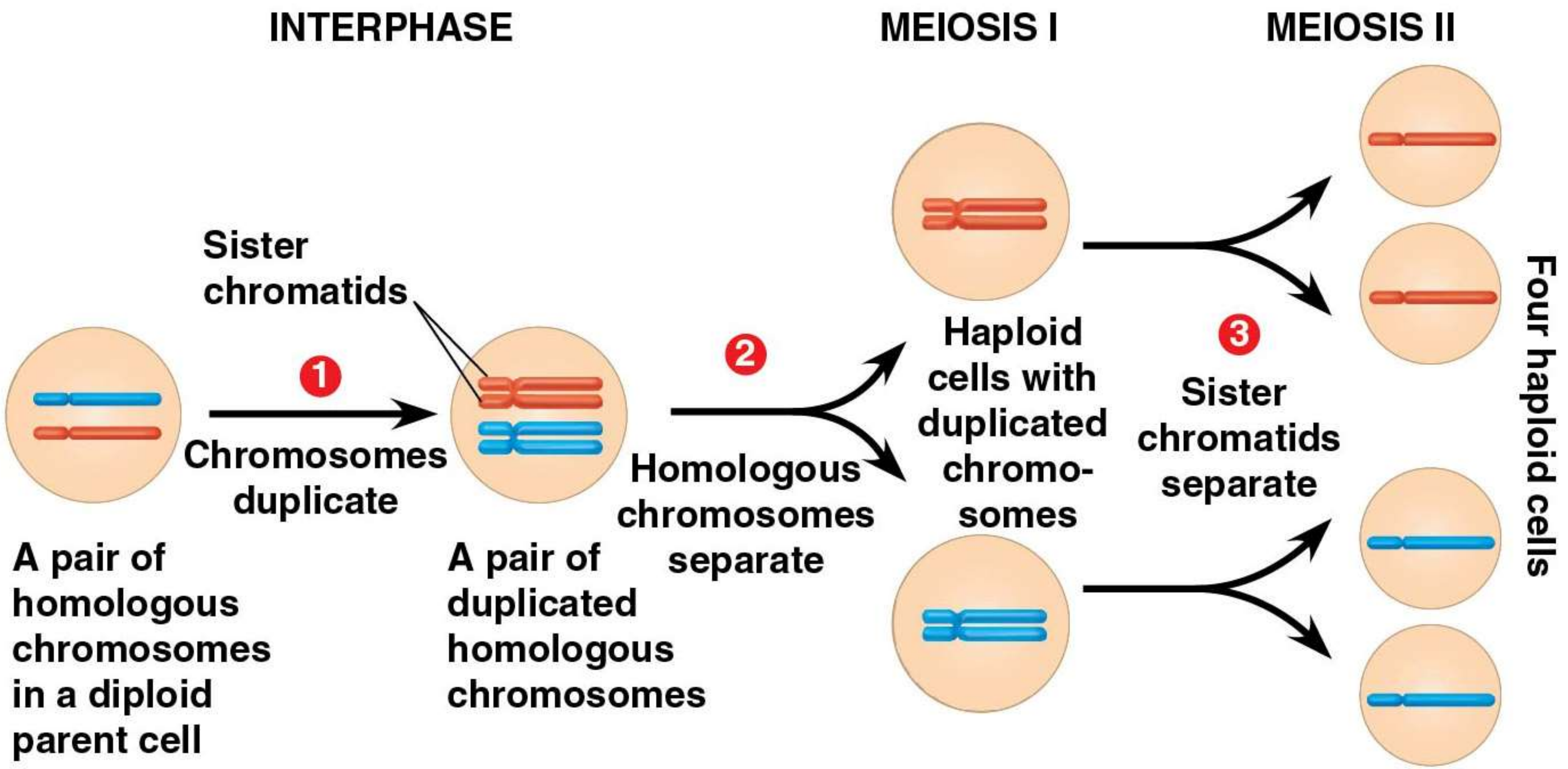
- The **somatic** (body) **cells** of each species contain a specific number of chromosomes; for example, human cells have 46, consisting of 23 pairs of **homologous chromosomes**.
- The chromosomes of a homologous pair of autosomes carry genes for the same characteristics at the same place, or **locus**.

Checkpoint question Are all of your chromosomes fully homologous?

8.12 Gametes Have a Single Set of Chromosomes

- Cells with two sets of homologous chromosomes are **diploid**.
- **Gametes**—eggs and sperm—are **haploid** cells with a single set of chromosomes.
- Sexual life cycles involve the alternation of haploid and diploid stages.

Figure 8.12b


INTERPHASE
MEIOSIS I
MEIOSIS II
Sister chromatids
1
Chromosomes duplicate
A pair of homologous chromosomes in a diploid parent cell
A pair of duplicated homologous chromosomes
2
Homologous chromosomes separate
Haploid cells with duplicated chromo- somes
3
Sister chromatids separate
Four haploid cells

8.13 Meiosis Reduces the Chromosome Number from Diploid to Haploid (1 of 3)

- **Meiosis**, like mitosis, is preceded by chromosome duplication, but in meiosis, the cell divides twice to form four daughter cells.
  - The first division, meiosis I starts with the pairing of homologous chromosomes.
  - In crossing over, homologous chromosomes exchange corresponding segments.

8.13 Meiosis Reduces the Chromosome Number from Diploid to Haploid (2 of 3)

- Meiosis I separates the members of each homologous pair and produces two daughter cells, each with one set of chromosomes.
- Meiosis II is essentially the same as mitosis:
  - In each of the cells, the sister chromatids of each chromosome separate.
  - The result is a total of four haploid cells.

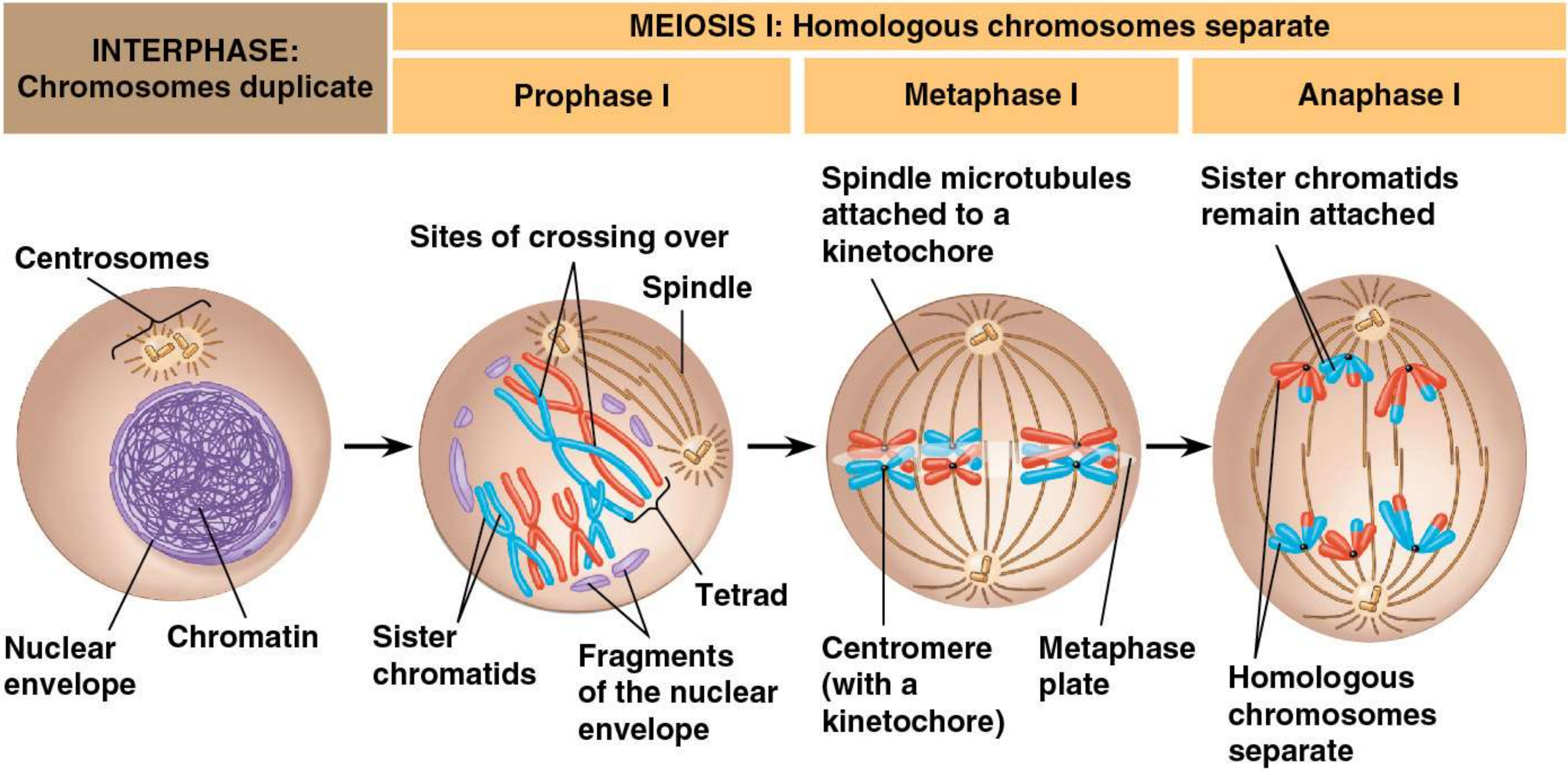
Pearson

8.13 Meiosis Reduces the Chromosome Number from Diploid to Haploid (3 of 3)

Checkpoint question A cell has the haploid number of chromosomes, but each chromosome has two chromatids. The chromosomes are arranged singly at the center of the spindle. What is the meiotic stage?

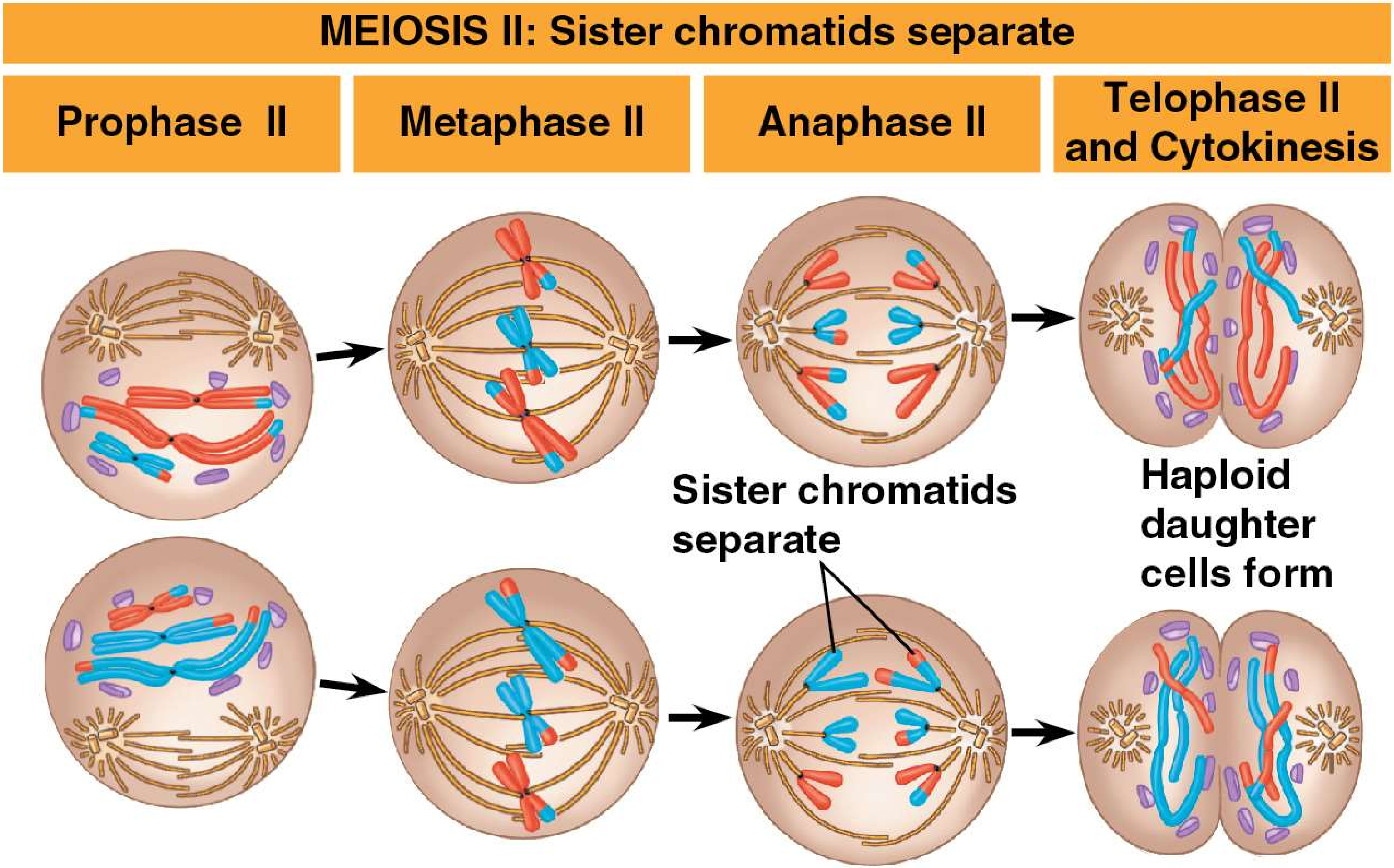
Metaphase II (because the chromosomes line up two by two in metaphase I)

Figure 8.13_1



INTERPHASE: Chromosomes duplicate
MEIOSIS I: Homologous chromosomes separate
Prophase I
Metaphase I
Anaphase I
Centrosomes
Nuclear envelope
Chromatin
Sites of crossing over
Spindle
Sister chromatids
Fragments of the nuclear envelope
Tetrad
Spindle microtubules attached to a kinetochore
Centromere (with a kinetochore)
Metaphase plate
Sister chromatids remain attached
Homologous chromosomes separate

Figure 8.13_6

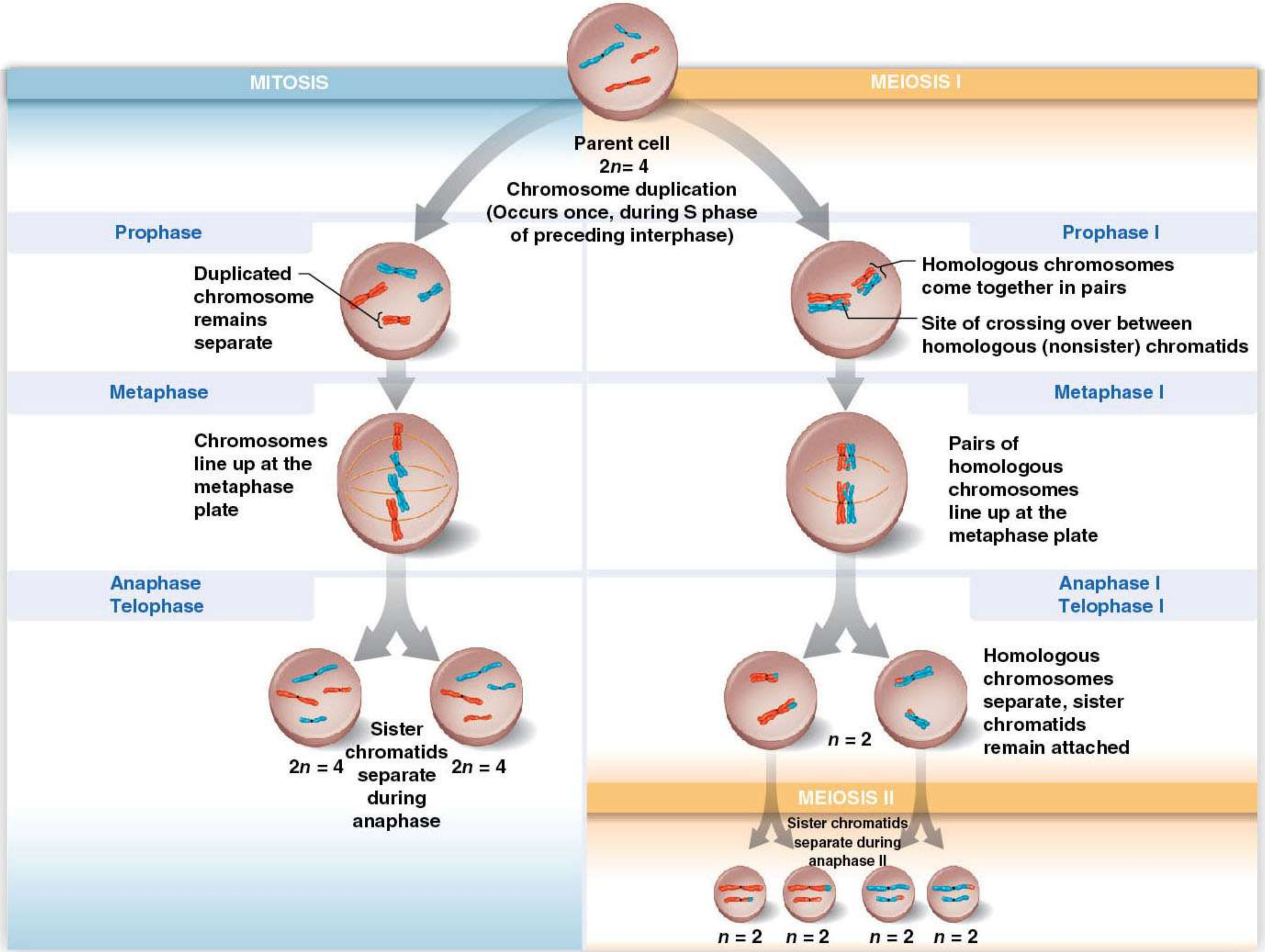


Pearson

8.14 Visualizing the Concept: Mitosis and Meiosis Have Important Similarities and Differences

- Both mitosis and meiosis begin with diploid parent cells that have chromosomes duplicated during the previous interphase.
  - Mitosis produces two genetically identical diploid somatic daughter cells.
  - Meiosis produces four genetically unique haploid gametes.

Figure 8.14_5



MITOSIS
MEIOSIS I
Parent cell
2n= 4
Chromosome duplication
(Occurs once, during S phase
of preceding interphase)
Prophase
Duplicated chromosome remains separate
Prophase I
Homologous chromosomes come together in pairs
Site of crossing over between homologous (nonsister) chromatids
Metaphase
Chromosomes line up at the metaphase plate
Metaphase I
Pairs of homologous chromosomes line up at the metaphase plate
Anaphase
Telophase
Anaphase I
Telophase I
2n = 4
Sister chromatids separate during anaphase
2n = 4
n = 2
Homologous chromosomes separate, sister chromatids remain attached
MEIOSIS II
Sister chromatids separate during anaphase II
n = 2
n = 2
n = 2
n = 2

8.15 Independent Orientation of Chromosomes in Meiosis and Random Fertilization Lead to Varied Offspring (1 of 2)

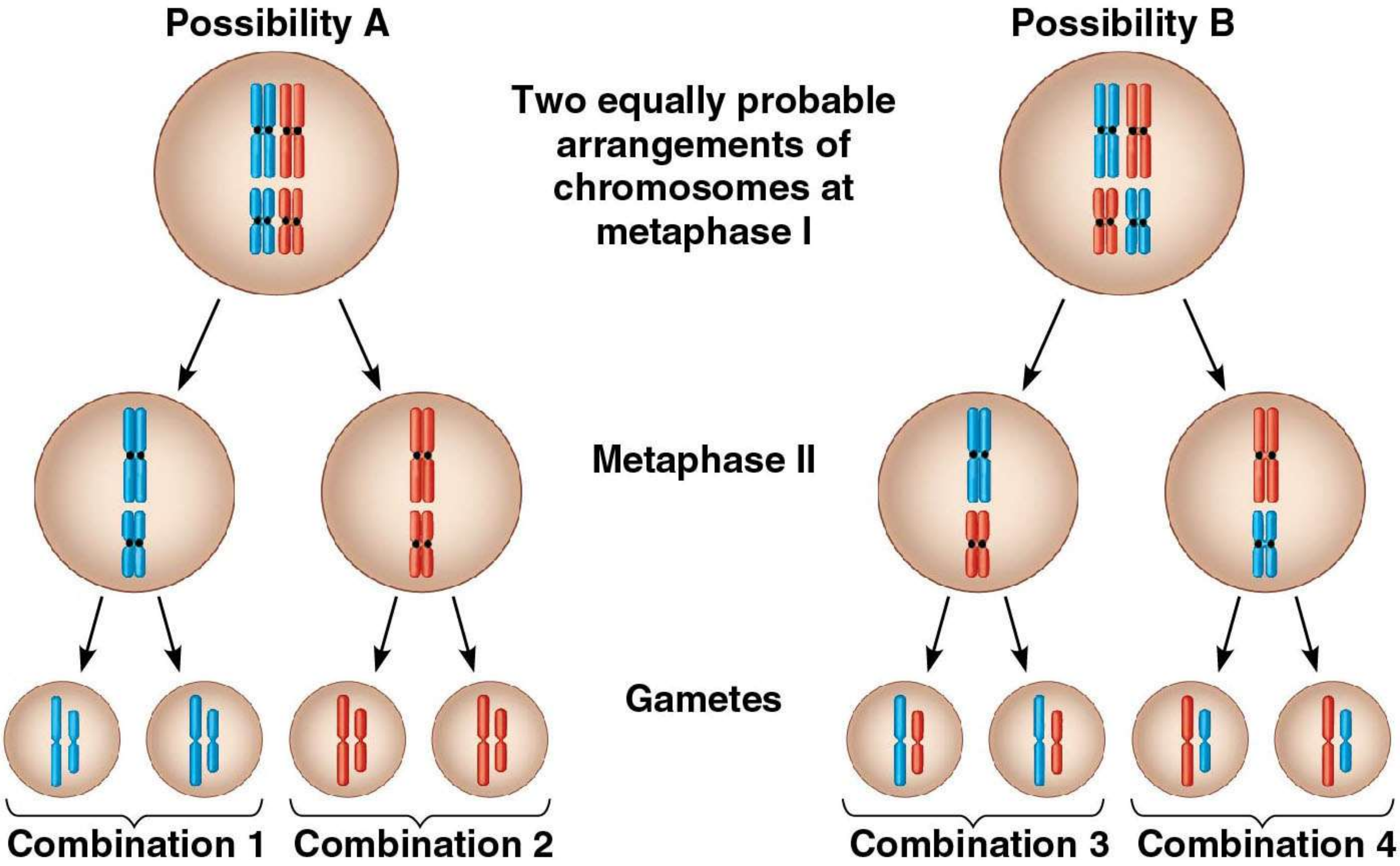
- Each chromosome of a homologous pair differs at many points from the other member of the pair.
- Random arrangements of chromosome pairs at metaphase I of meiosis lead to many different combinations of chromosomes in eggs and sperm.
- Random fertilization of eggs by sperm greatly increases this variation.

8.15 Independent Orientation of Chromosomes in Meiosis and Random Fertilization Lead to Varied Offspring (2 of 2)

Checkpoint question A particular species of worm has a diploid number of 10. How many chromosomal combinations are possible for gametes formed by meiosis?

32; $2n = 10$, so $n = 5$ and $2^n = 32$

Figure 8.15_3

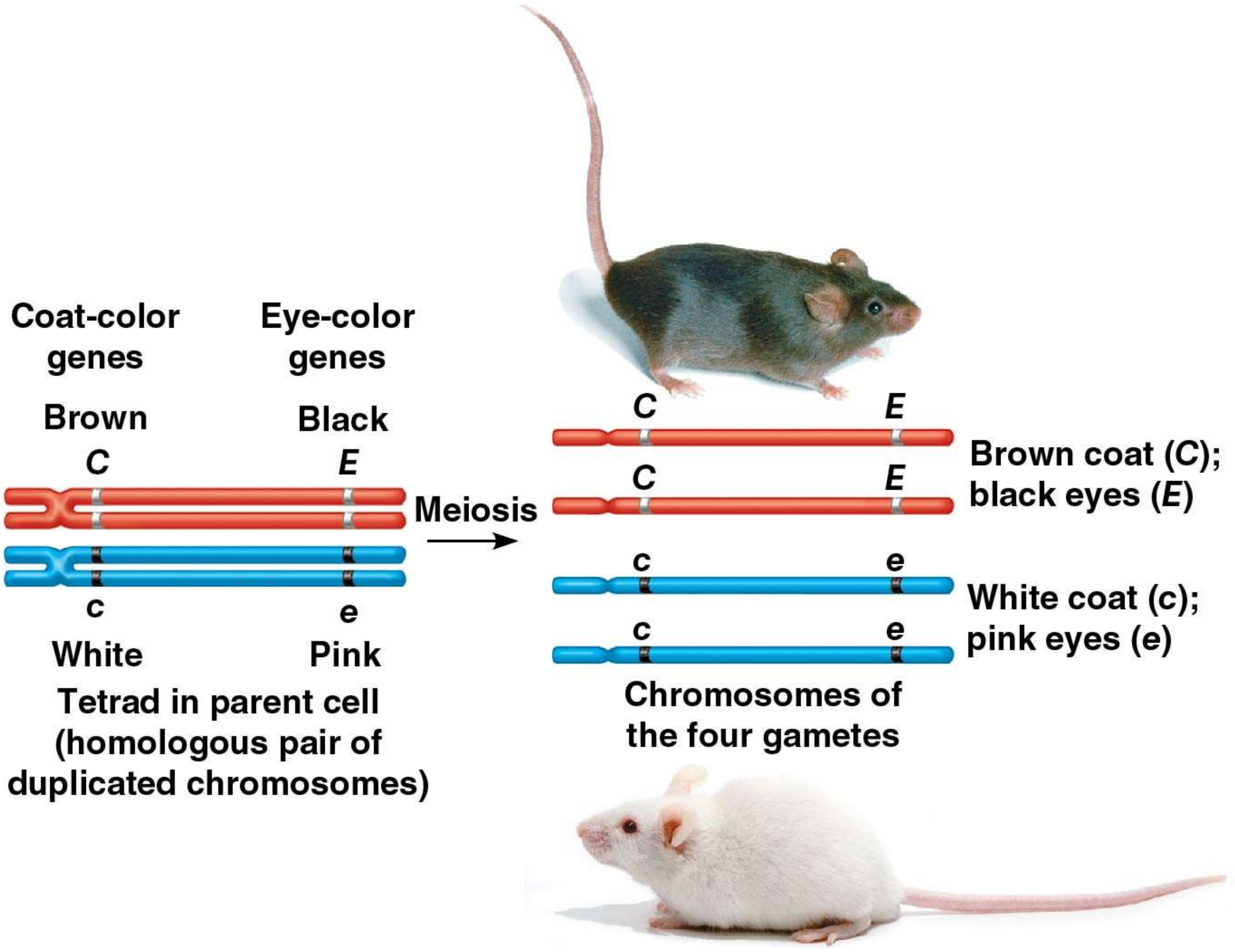


Possibility A
Possibility B
Two equally probable arrangements of chromosomes at metaphase I
Metaphase II
Gametes
Combination 1
Combination 2
Combination 3
Combination 4

8.16 Homologous Chromosomes May Carry Different Versions of Genes

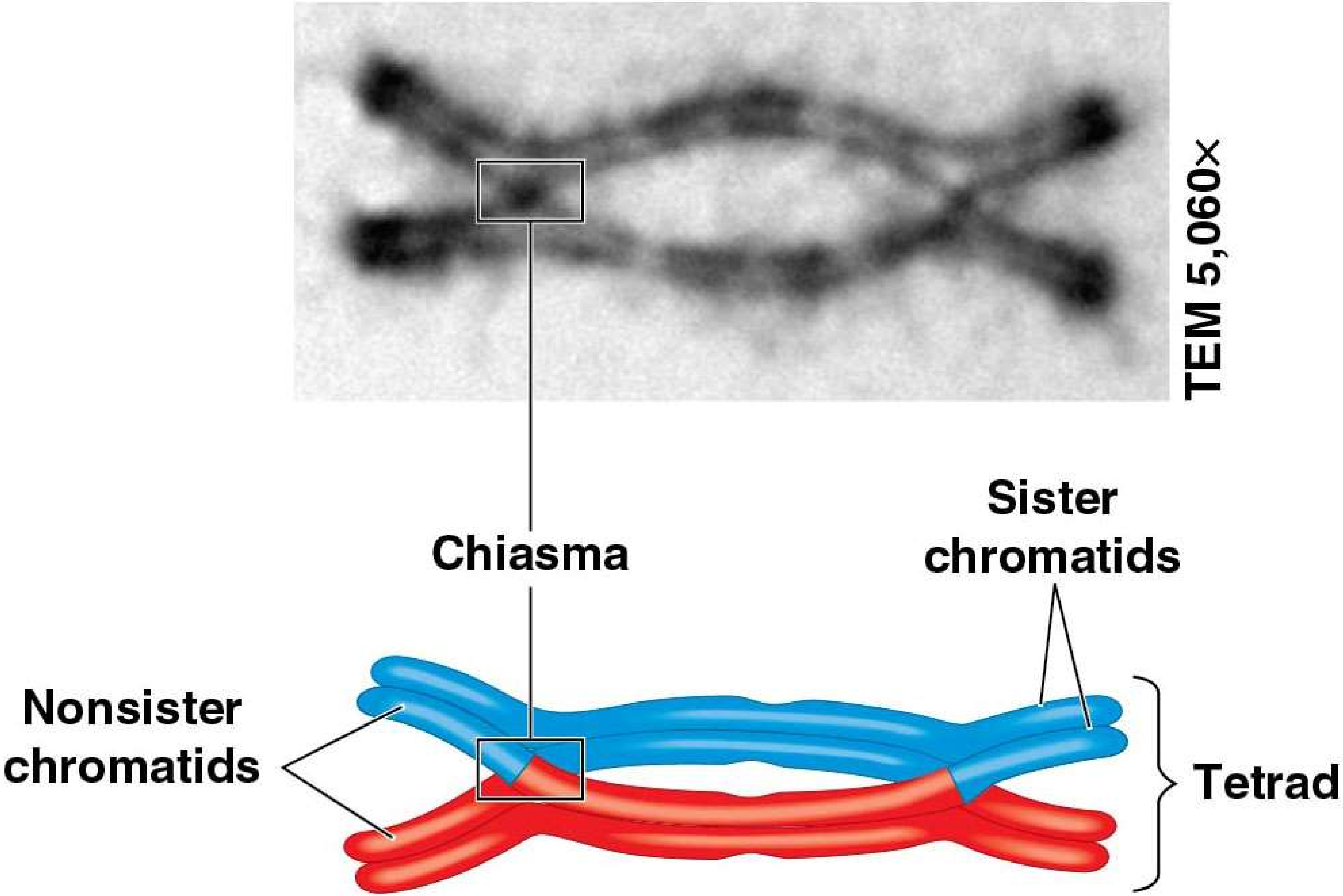
- The differences between homologous chromosomes come from the fact that they can bear different versions of genes at corresponding loci.
- **Crossing over** is an exchange of corresponding segments between nonsister chromatids of homologous chromosomes.

Figure 8.16



Coat-color genes
Eye-color genes
Brown
Black
C
E
c
e
White
Pink
Tetrad in parent cell (homologous pair of duplicated chromosomes)
Meiosis
C
E
C
E
c
e
c
e
Brown coat (C); black eyes (E)
White coat (c); pink eyes (e)
Chromosomes of the four gametes

Figure 8.16b


TEM 5,060×
Chiasma
Sister chromatids
Nonsister chromatids
Tetrad

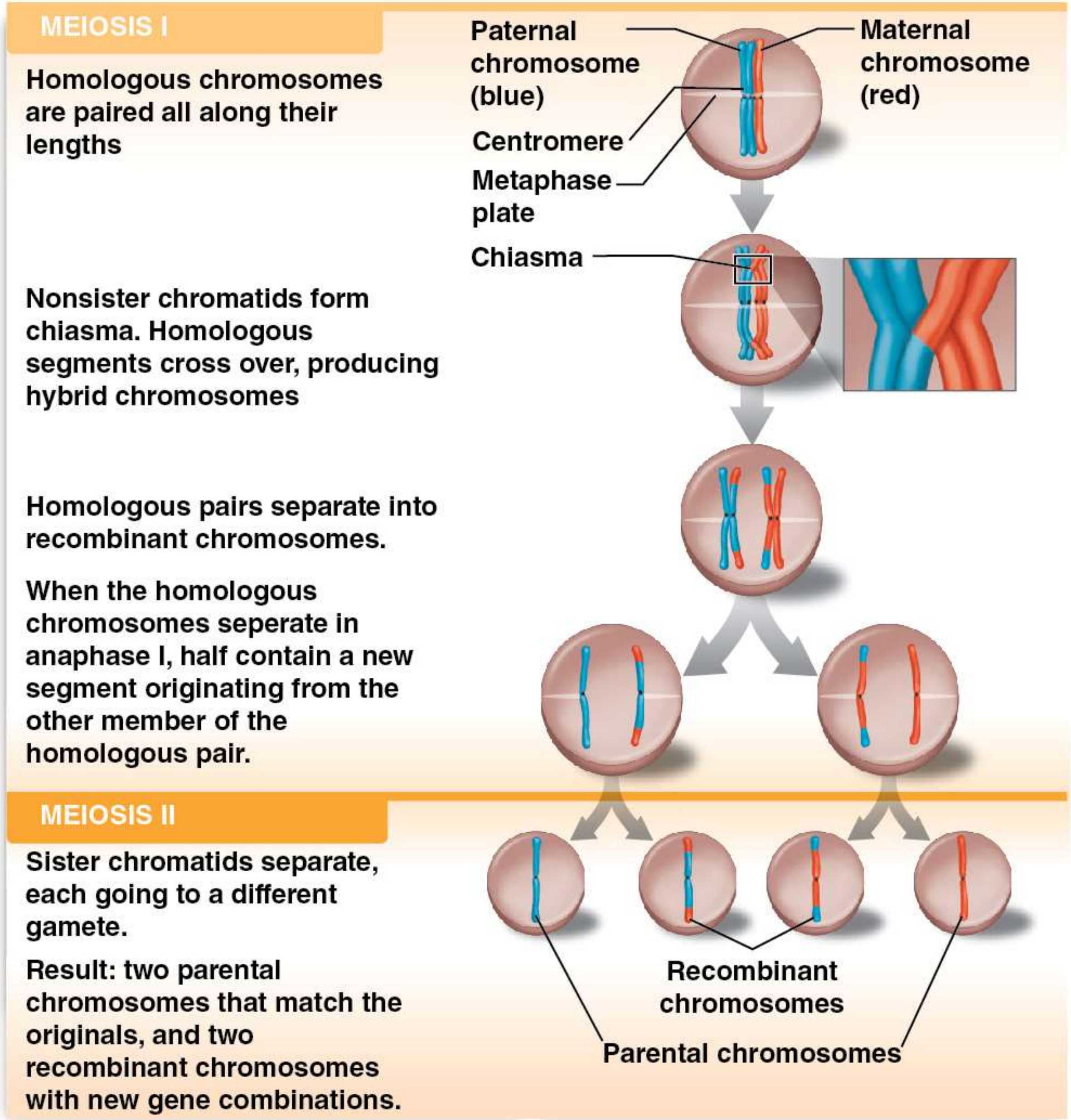
8.17 Visualizing the Concept: Crossing Over Further Increases Genetic Variability

- Genetic recombination, which results from crossing over during prophase I of meiosis, increases variation still further.

Checkpoint question If you were to examine a chromosome from one of your gametes, is it likely to look exactly like that same chromosome from one of your skin cells?

No. Each chromosome probably looks like a cut-and-paste hybrid of segments derived from a pair of homologous chromosomes.

Figure 8.17_6



Pearson

Alterations of Chromosome Number and Structure

8.18 Accidents During Meiosis Can Alter Chromosome Number

- An abnormal chromosome count is the result of **nondisjunction**, which can result from
  - the failure of a pair of homologous chromosomes to separate during meiosis I or
  - the failure of sister chromatids to separate during meiosis II

Checkpoint question Explain how nondisjunction could result in a diploid gamete.

A diploid gamete would result if the nondisjunction affected all the chromosomes during one of the meiotic divisions.

Figure 8.18_1_3

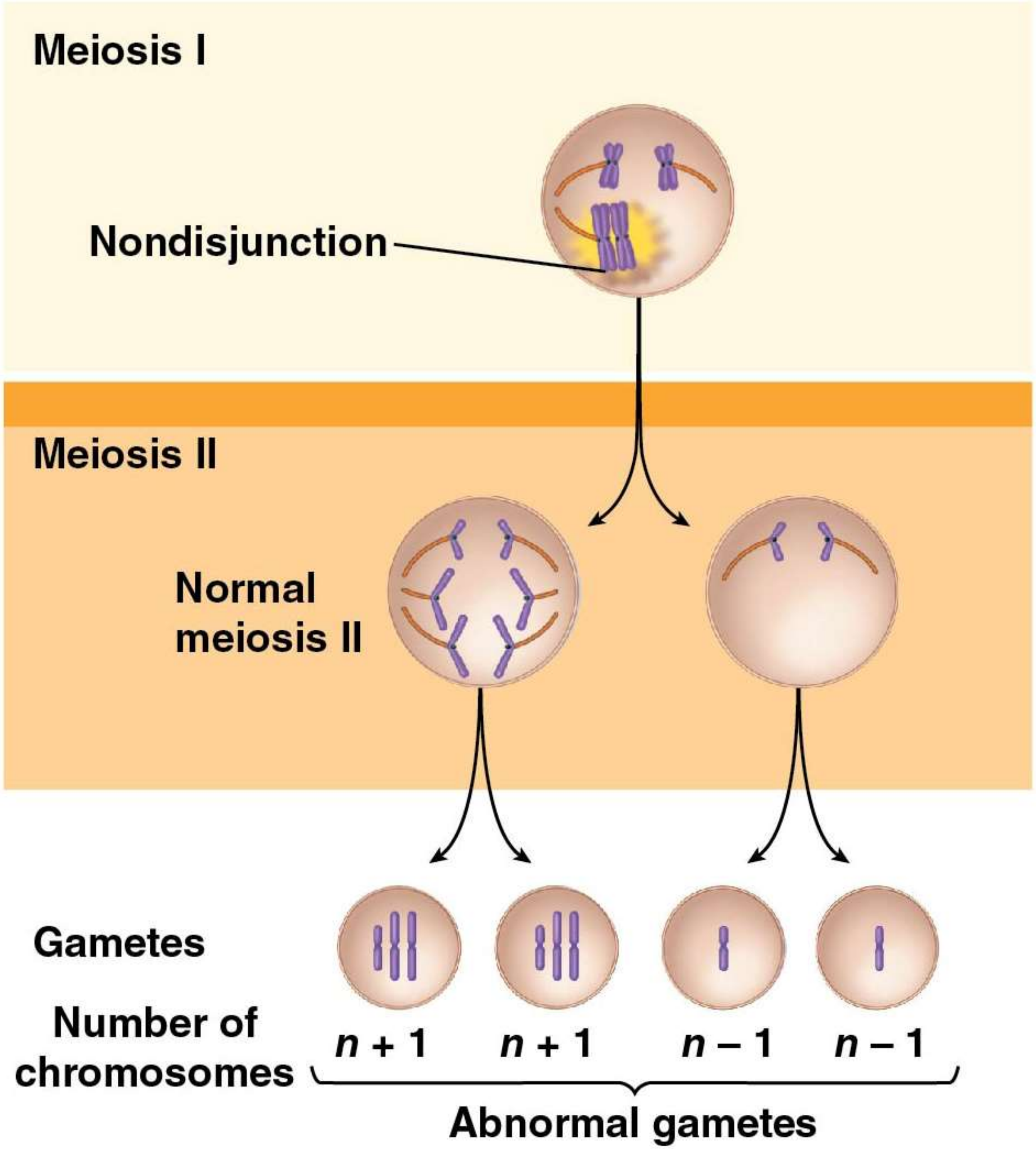
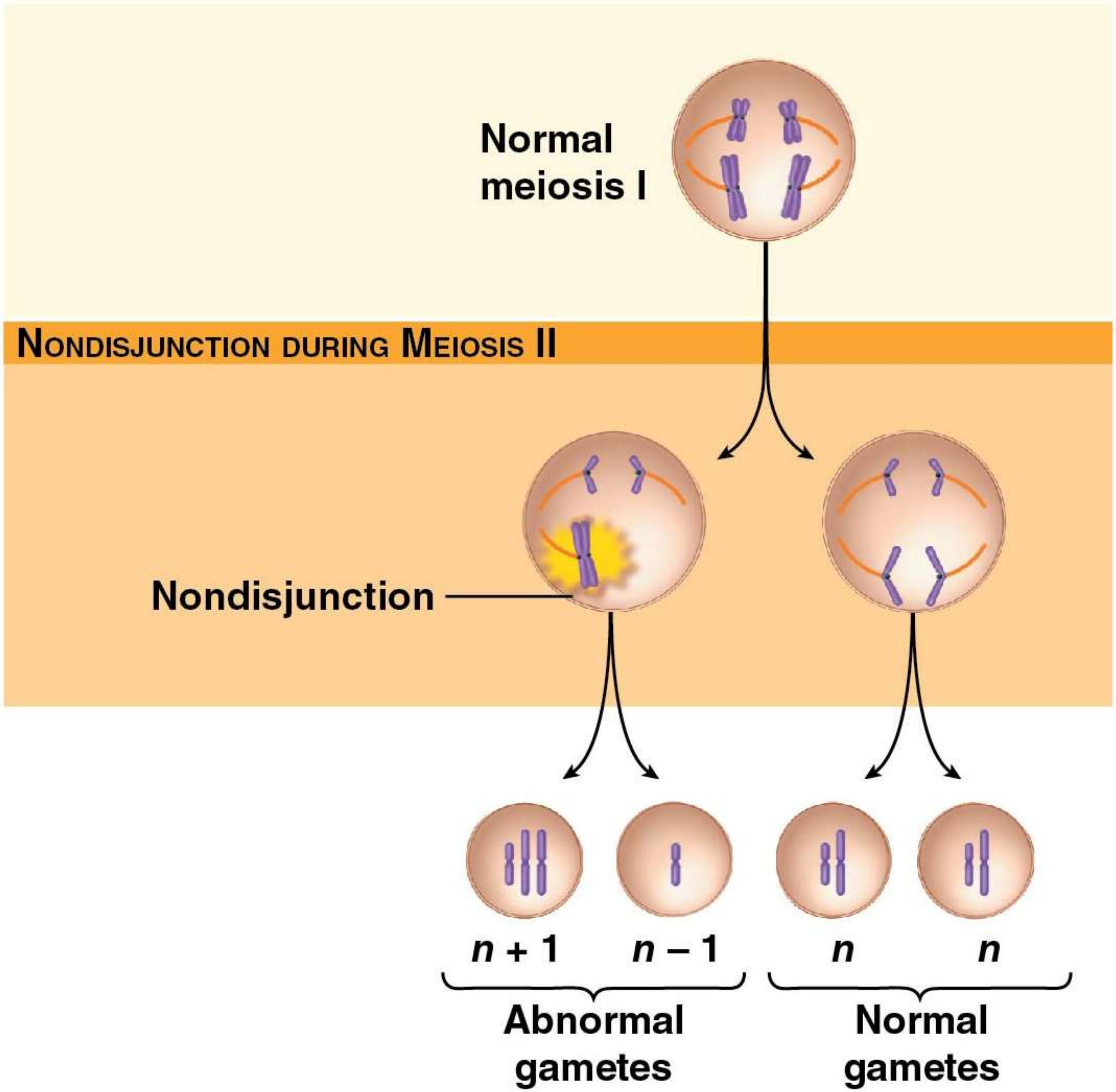


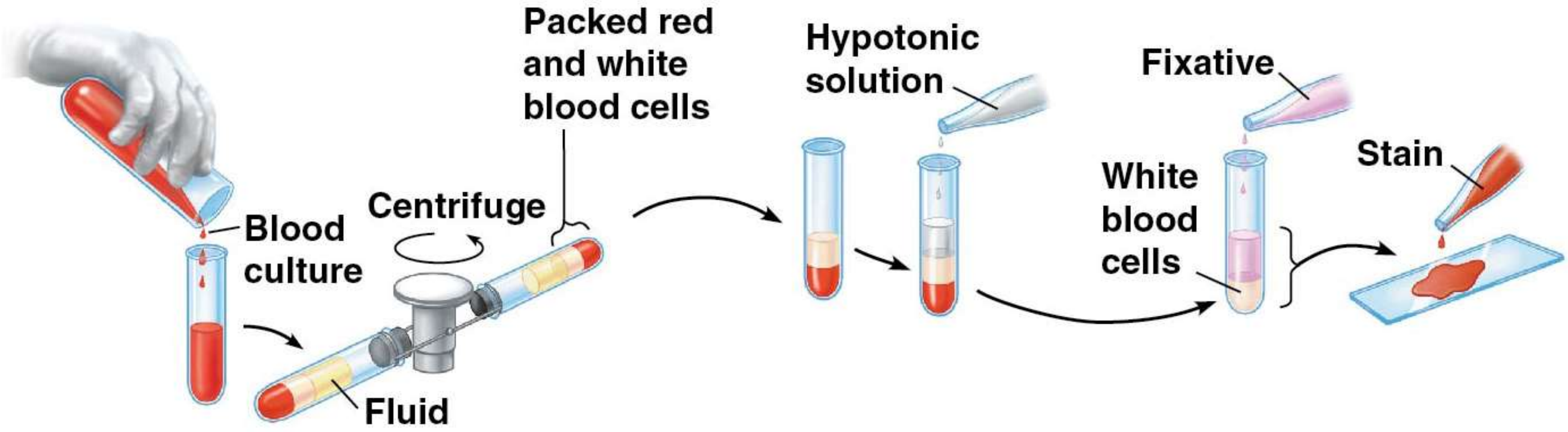
Figure 8.18_2_3



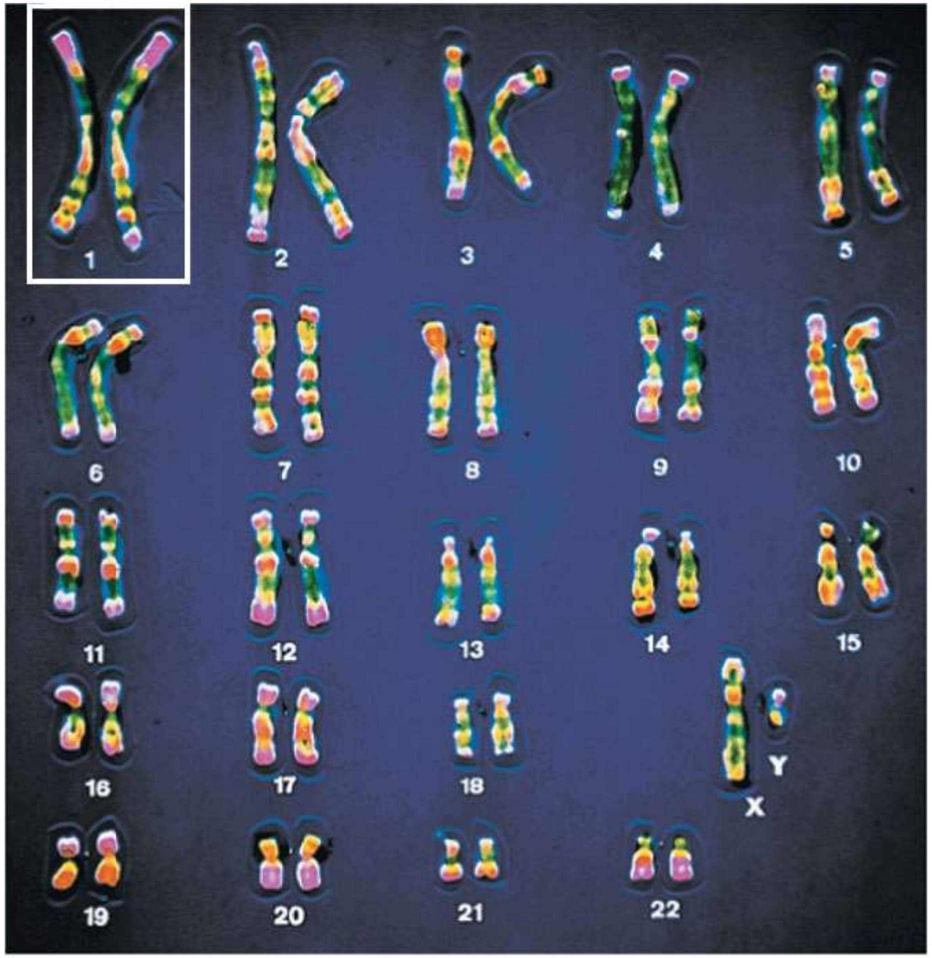
8.19 A Karyotype Is a Photographic Inventory of an Individual's Chromosomes (1 of 2)

- To prepare a **karyotype**, white blood cells are
  - isolated,
  - stimulated to grow,
  - arrested at metaphase, and
  - photographed under a microscope.
- The chromosomes are arranged into ordered pairs so that any chromosomal abnormalities can be detected.

Figure 8.19_1_3



8.19 A Karyotype Is a Photographic Inventory of an Individual’s Chromosomes (2 of 2)



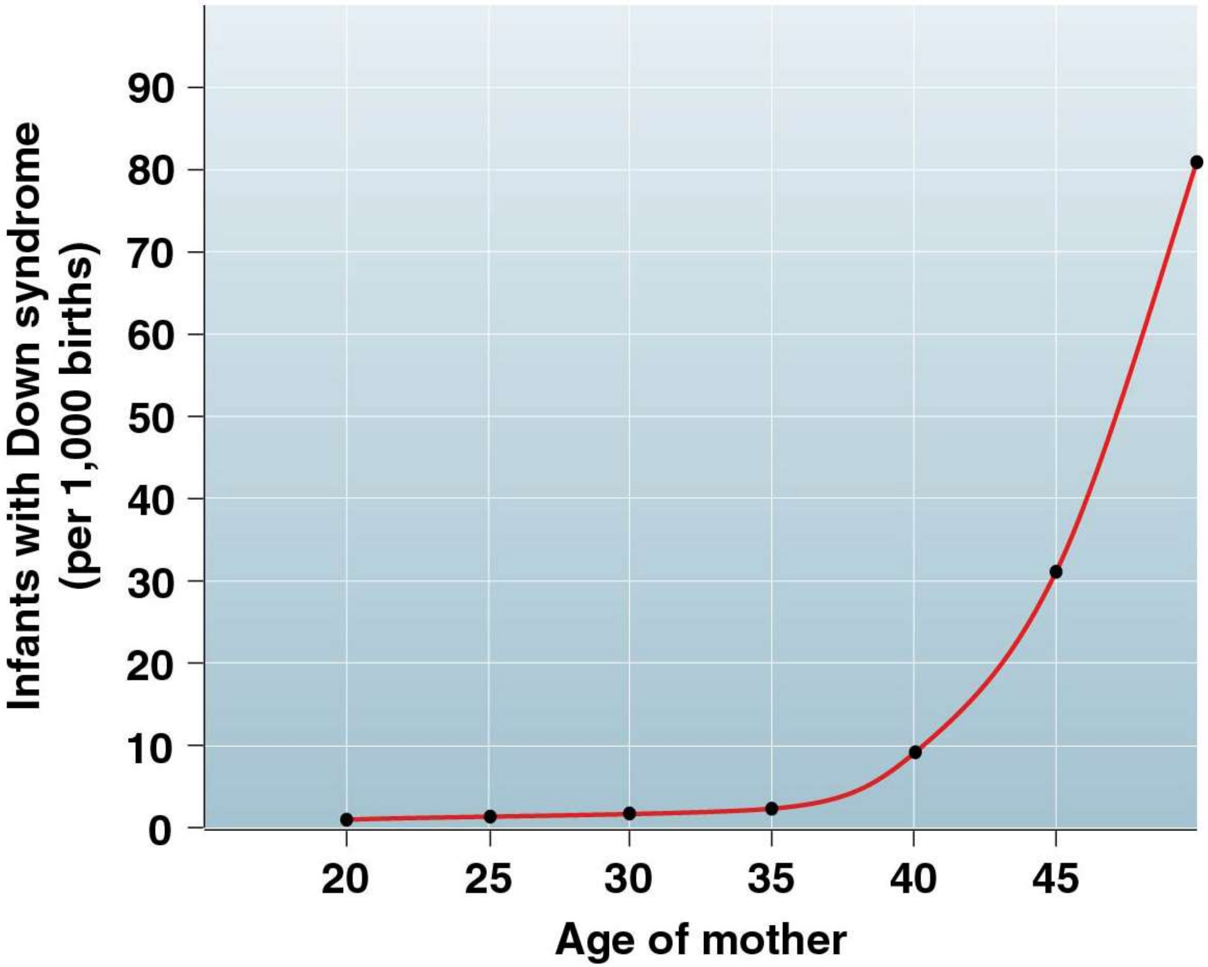
Instead of an XY combination for the sex chromosomes, there would be a homologous pair of X chromosomes (XX)

Checkpoint question How would the karyotype of a human female differ from the male karyotype in Figure 8.19?

8.20 Connection: An Extra Copy of Chromosome 21 Causes Down Syndrome

- **Trisomy 21**, the most common chromosome number abnormality, results in a condition called **Down syndrome**.

Figure 8.20b



Source: Adapted from C. A. Huether et al., Maternal age specific risk rate estimates for Down syndrome among live births in whites and other races from Ohio and Metropolitan Atlanta, 1970–1989, *Journal of Medical Genetics* 35: 482–90 (1998).

8.21 Connection: Abnormal Numbers of Sex Chromosomes Do Not Usually Affect Survival

- Nondisjunction of the sex chromosomes during meiosis can result in individuals with a missing or extra X or Y chromosome.
- In some cases (such as XXY), this leads to syndromes that can affect the health of the individual.
- In other cases (such as XXX), the body is normal.

Table 8.21 Abnormalities of Sex Chromosome Number in Humans

Sex Chromosomes	Syndrome	Origin of Nondisjunction	Symptoms
XXY	Klinefelter syndrome (male)	Meiosis in egg or sperm formation	Sterile; underdeveloped testes; secondary female characteristics
XYY	None (normal male)	Meiosis in sperm formation	None
XXX	None (normal female)	Meiosis in egg or sperm formation	Slightly taller than average
XO	Turner syndrome (female)	Meiosis in egg or sperm formation	Sterile; immature sex organs

8.22 Evolution Connection: New Species Can Arise from Errors in Cell Division

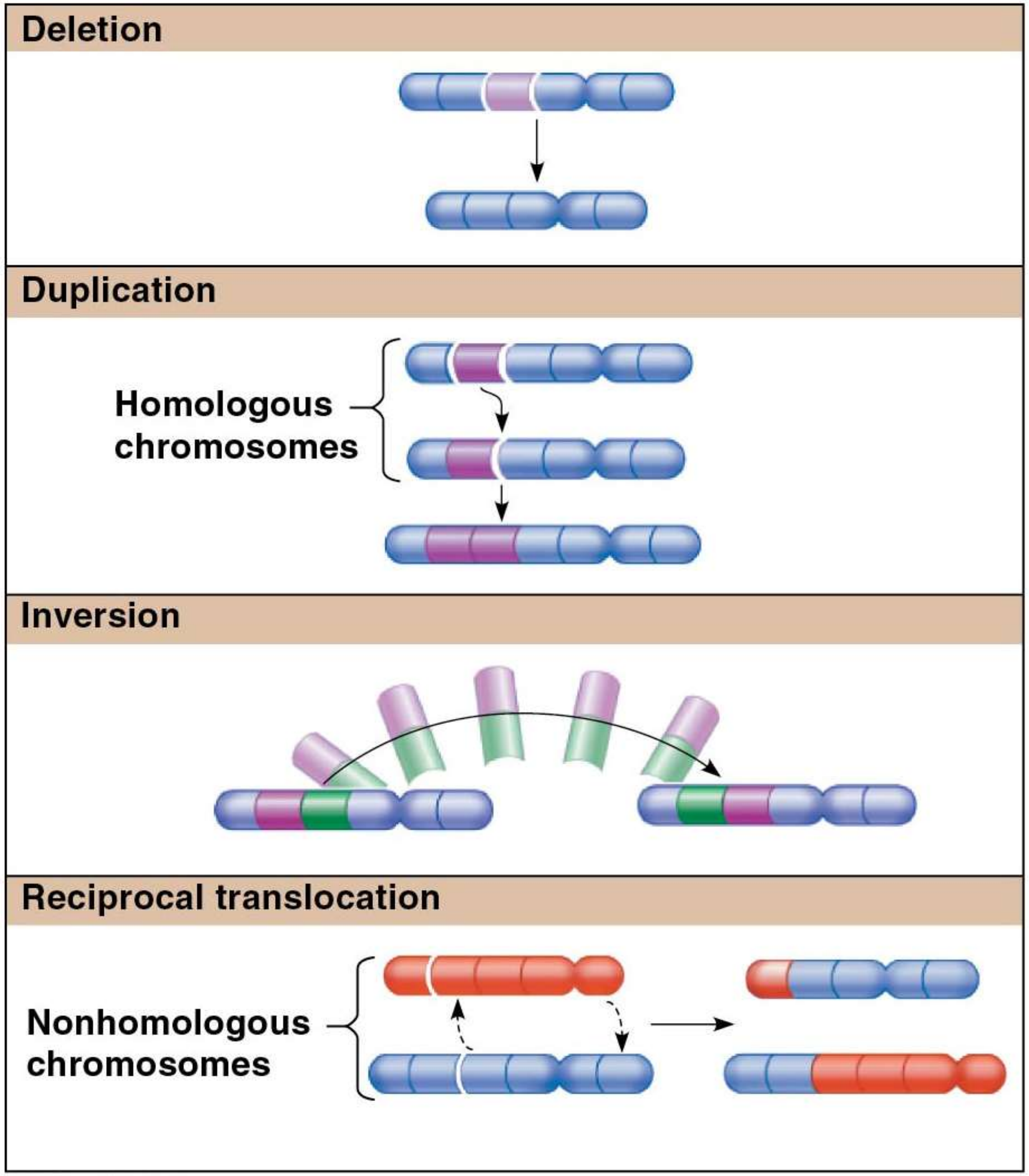
- Nondisjunction can produce polyploid organisms, organisms with extra sets of chromosomes.
- Such errors in cell division can be important in the evolution of new species.

8.23 Connection: Alterations of Chromosome Structure Can Cause Birth Defects and Cancer

- Chromosome breakage can lead to rearrangements—**deletions**, **duplications**, **inversions**, and **translocations**—that can produce genetic disorders or, if the changes occur in somatic cells, cancer.

Checkpoint question How is reciprocal translocation different from crossing over?

Figure 8.23a


Deletion
Duplication
Homologous chromosomes
Inversion
Reciprocal translocation
Nonhomologous chromosomes