CELL DIVISION

1

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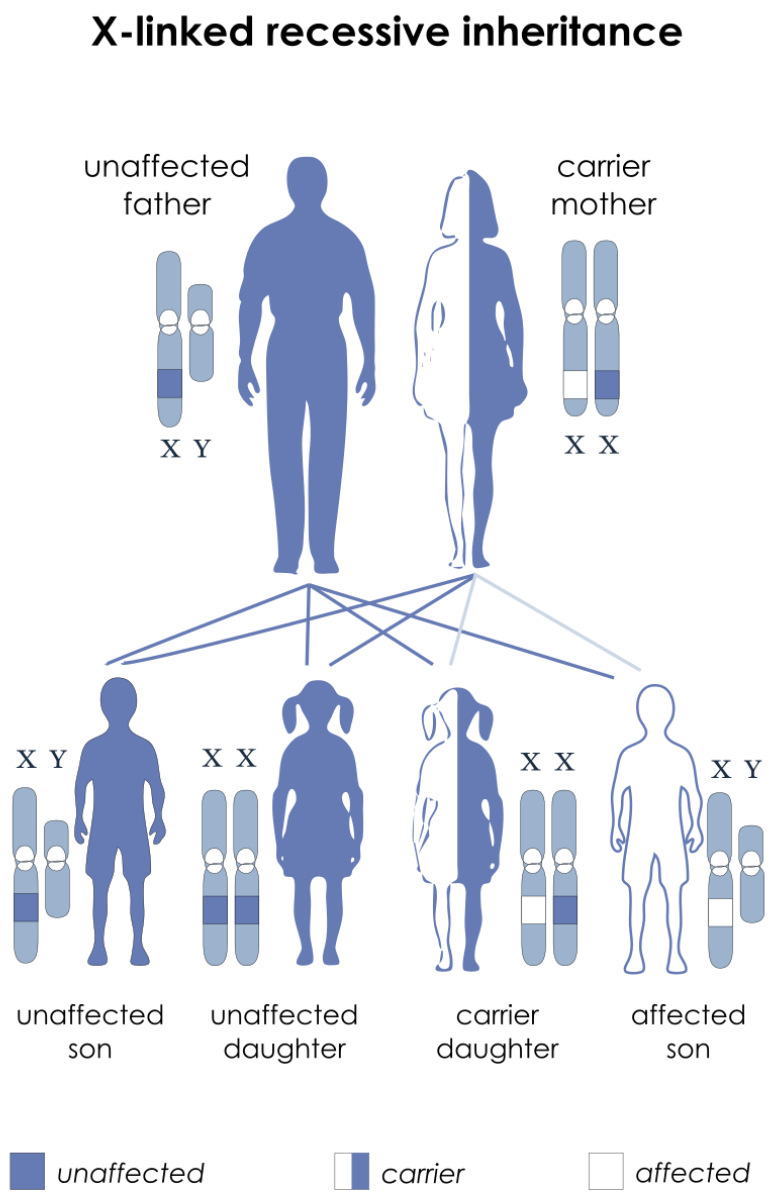
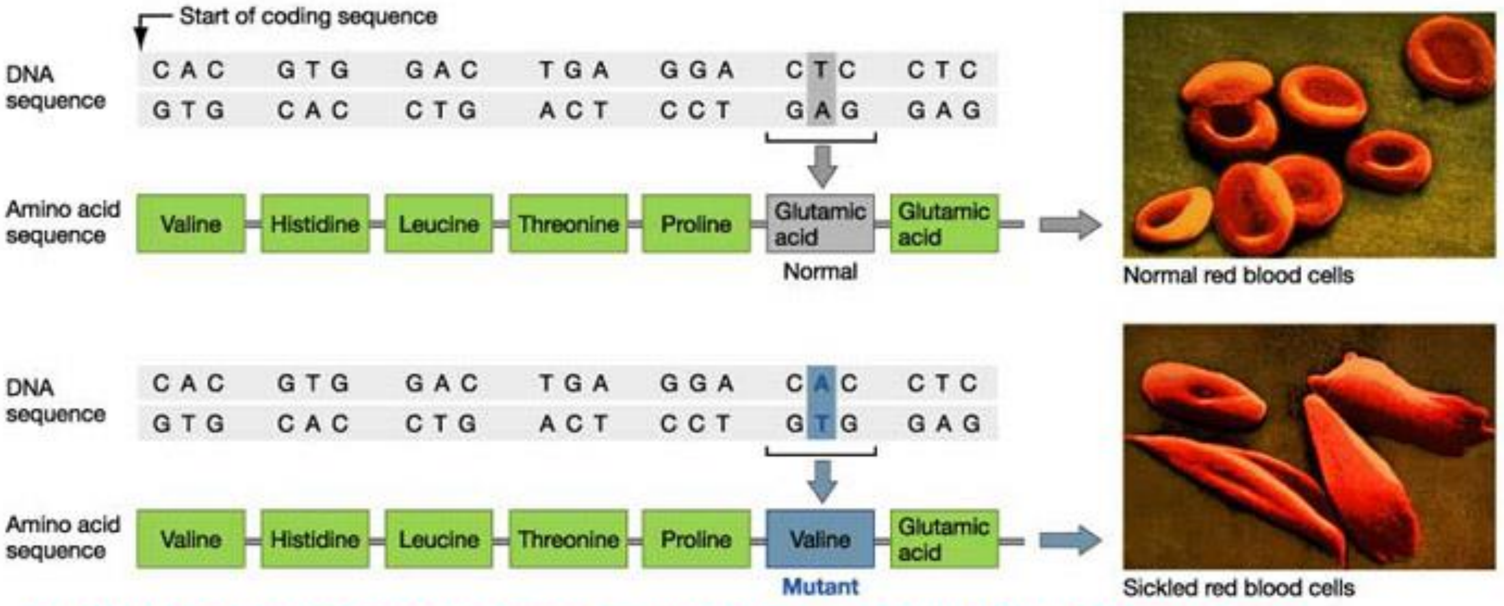
GENETIC DISORDER

Disorder prevalence (approximate)	
Autosomal dominant	
Familial hypercholesterolemia	1 in 500[10]
Polycystic kidney disease	1 in 750[11]
Neurofibromatosis type I	1 in 2,500[12]
Hereditary spherocytosis	1 in 5,000
Marfan syndrome	1 in 4,000[13]
Huntington's disease	1 in 15,000[14]
Autosomal recessive	
Sickle cell anaemia	1 in 625[15]
Cystic fibrosis	1 in 2,000
Tay–Sachs disease	1 in 3,000
Phenylketonuria	1 in 12,000
Mucopolysaccharidoses	1 in 25,000
Lysosomal acid lipase deficiency	1 in 40,000
Glycogen storage diseases	1 in 50,000
Galactosemia	1 in 57,000
X-linked	
Duchenne muscular dystrophy	1 in 5,000
Hemophilia	1 in 10,000

Duchenne Muscular Dystrophy



SICKLE CELL ANEMIA



The change in amino acid sequence causes hemoglobin molecules to crystallize when oxygen levels in the blood are low. As a result, red blood cells sickle and get stuck in small blood vessels.

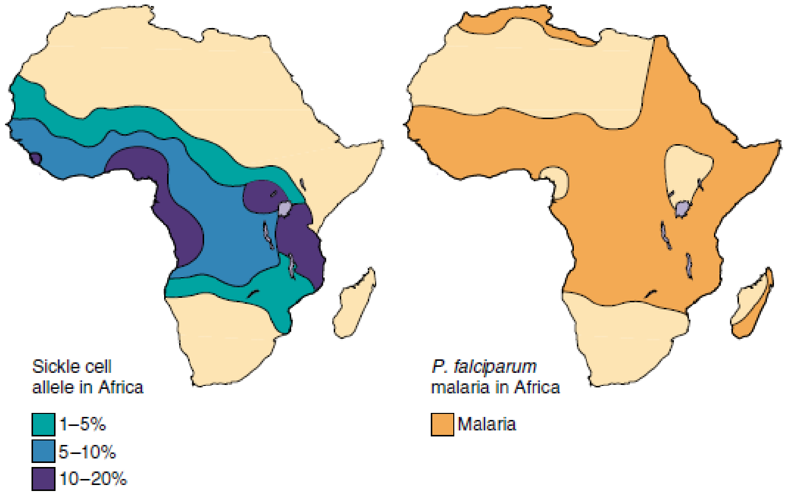


FIGURE 13.28
The sickle cell allele increases resistance to malaria. The distribution of sickle cell anemia closely matches the occurrence of malaria in central Africa. This is not a coincidence. The sickle cell allele, when heterozygous, increases resistance to malaria, a very serious disease.

NUCLEUS IS THE DECISION-MAKER

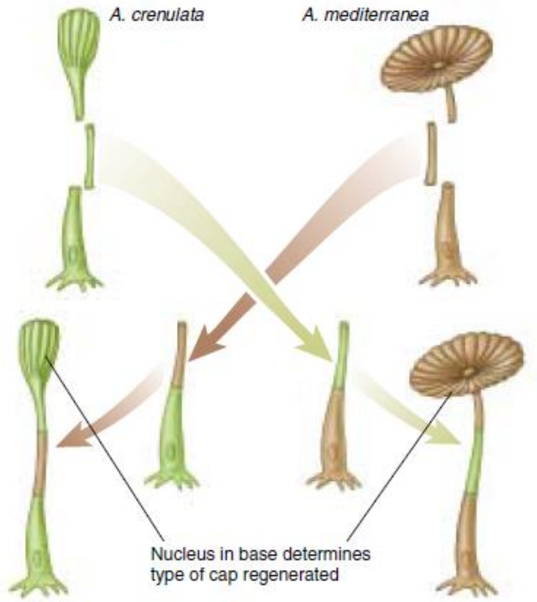


FIGURE 14.2
Hammerling's *Acetabularia* reciprocal graft experiment. Hammerling grafted a stalk of each species of *Acetabularia* onto the foot of the other species. In each case, the cap that eventually developed was dictated by the nucleus-containing foot rather than by the stalk.

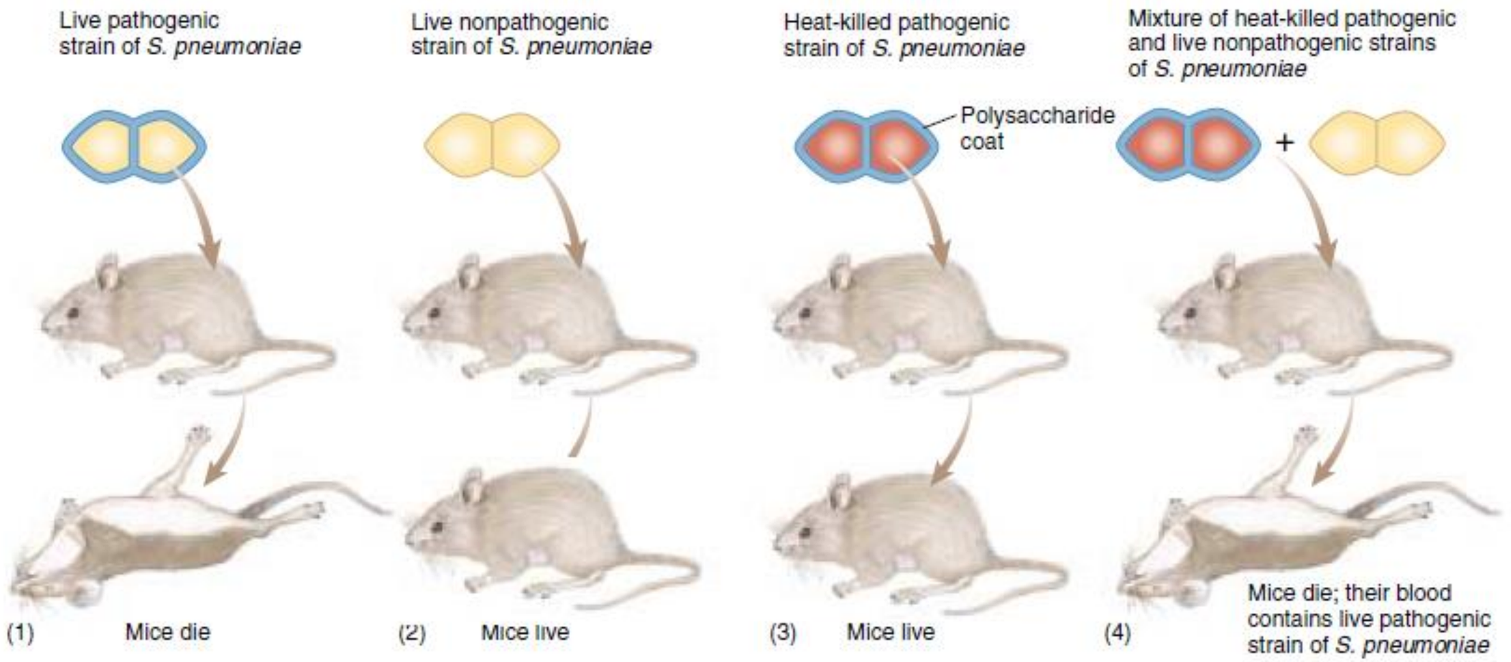
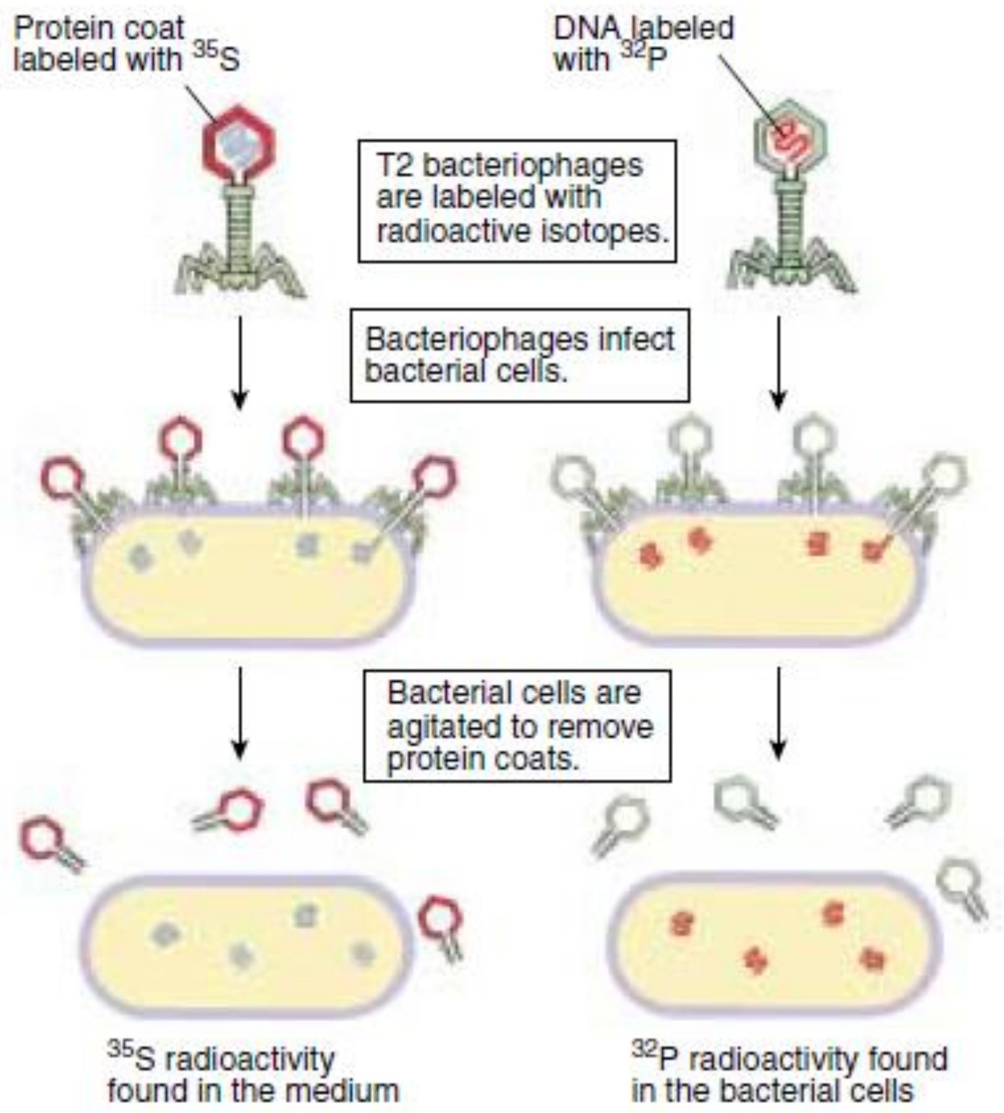


FIGURE 14.4
Griffith's discovery of transformation. (*1*) The pathogenic of the bacterium *Streptococcus pneumoniae* kills many of the mice it is injected into. The bacterial cells are covered with a polysaccharide coat, which the bacteria themselves synthesize. (*2*) Interestingly, an injection of live, coatless bacteria produced no ill effects. However, the coat itself is not the agent of disease. (*3*) When Griffith injected mice with dead bacteria that possessed polysaccharide coats, the mice were unharmed. (*4*) But when Griffith injected a mixture of dead bacteria with polysaccharide coats and live bacteria without such coats, many of the mice died, and virulent bacteria with coats were recovered. Griffith concluded that the live cells had been "transformed" by the dead ones; that is, genetic information specifying the polysaccharide coat had passed from the dead cells to the living ones.

DNA IS THE DECISION-MAKER

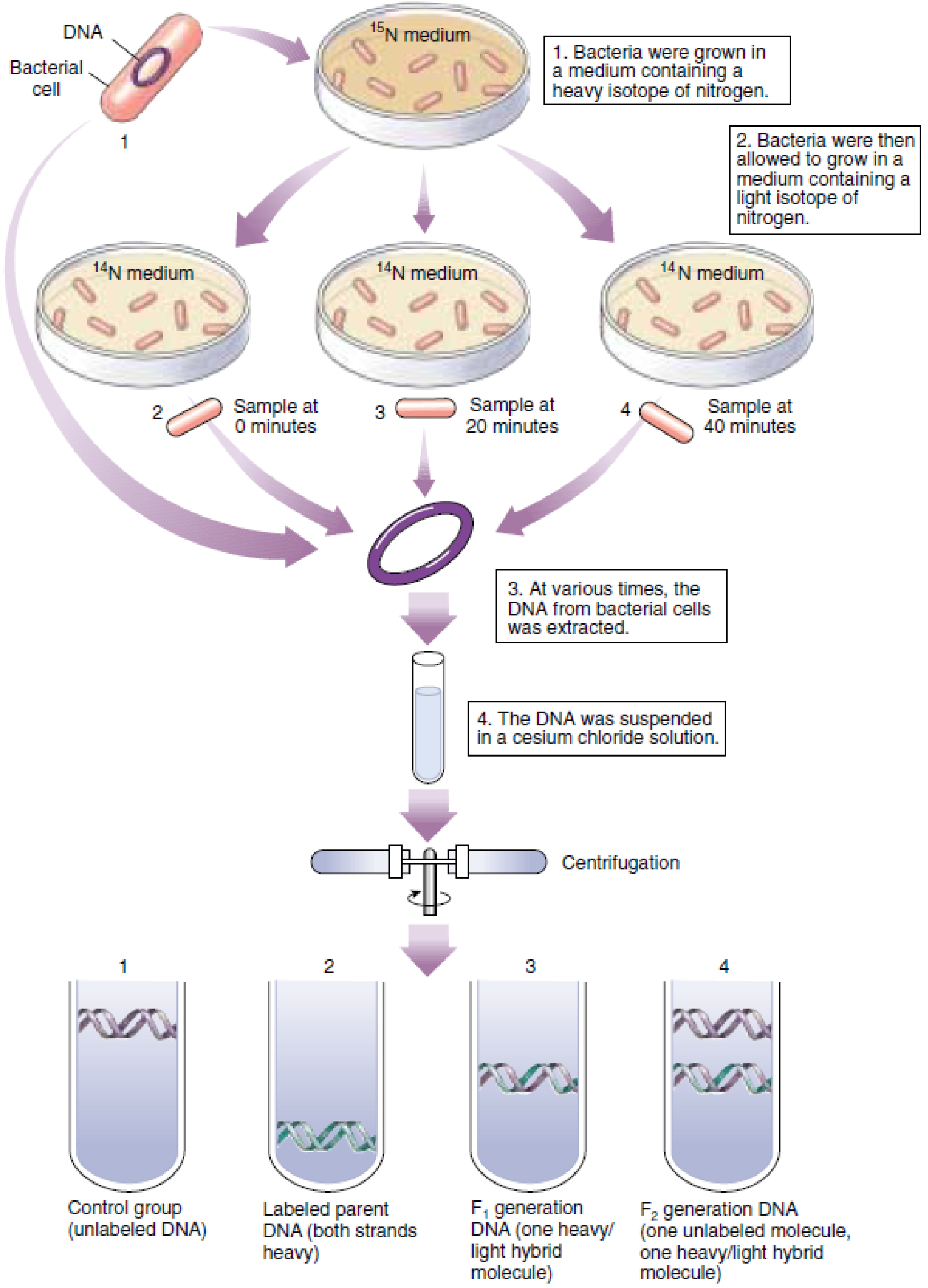
Oswald Avery, Alfred Hershey and Martha Chase

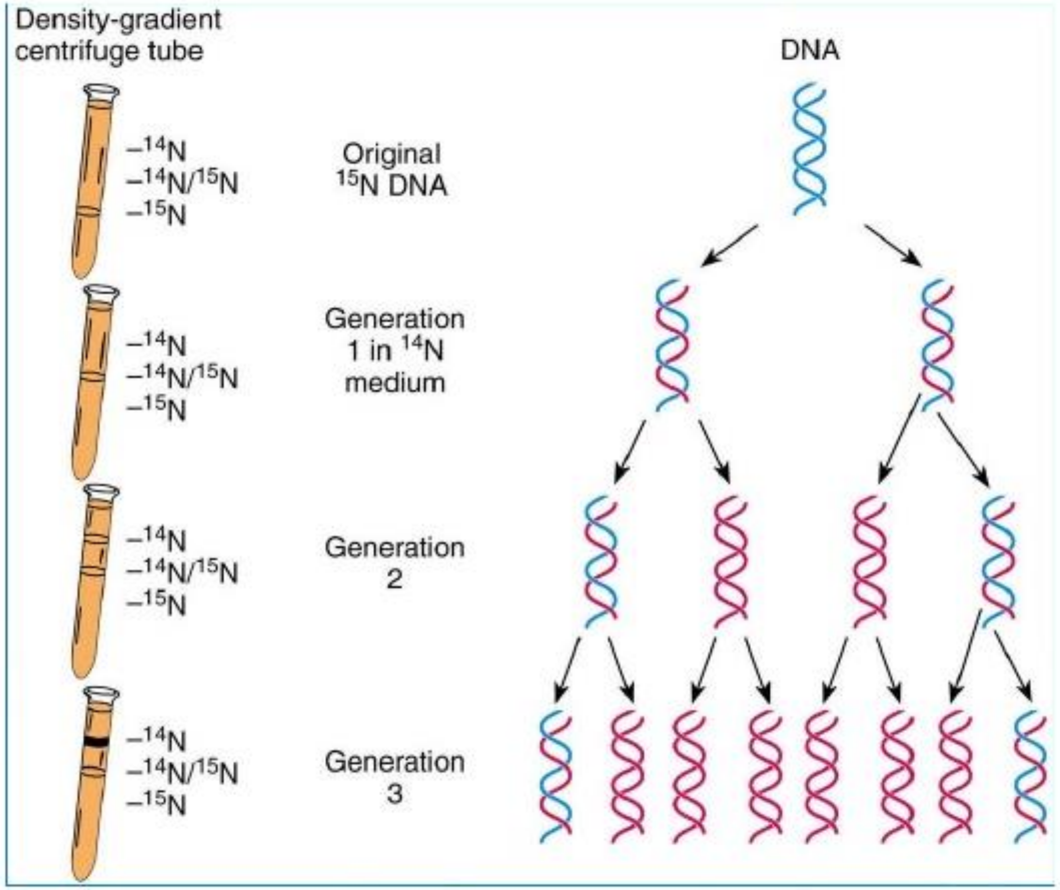
The Hershey and Chase experiment. Hershey and Chase found that ^{35}S radioactivity did not enter infected bacterial cells and ^{32}P radioactivity did. They concluded that viral DNA, not protein, was responsible for directing the production of new viruses.

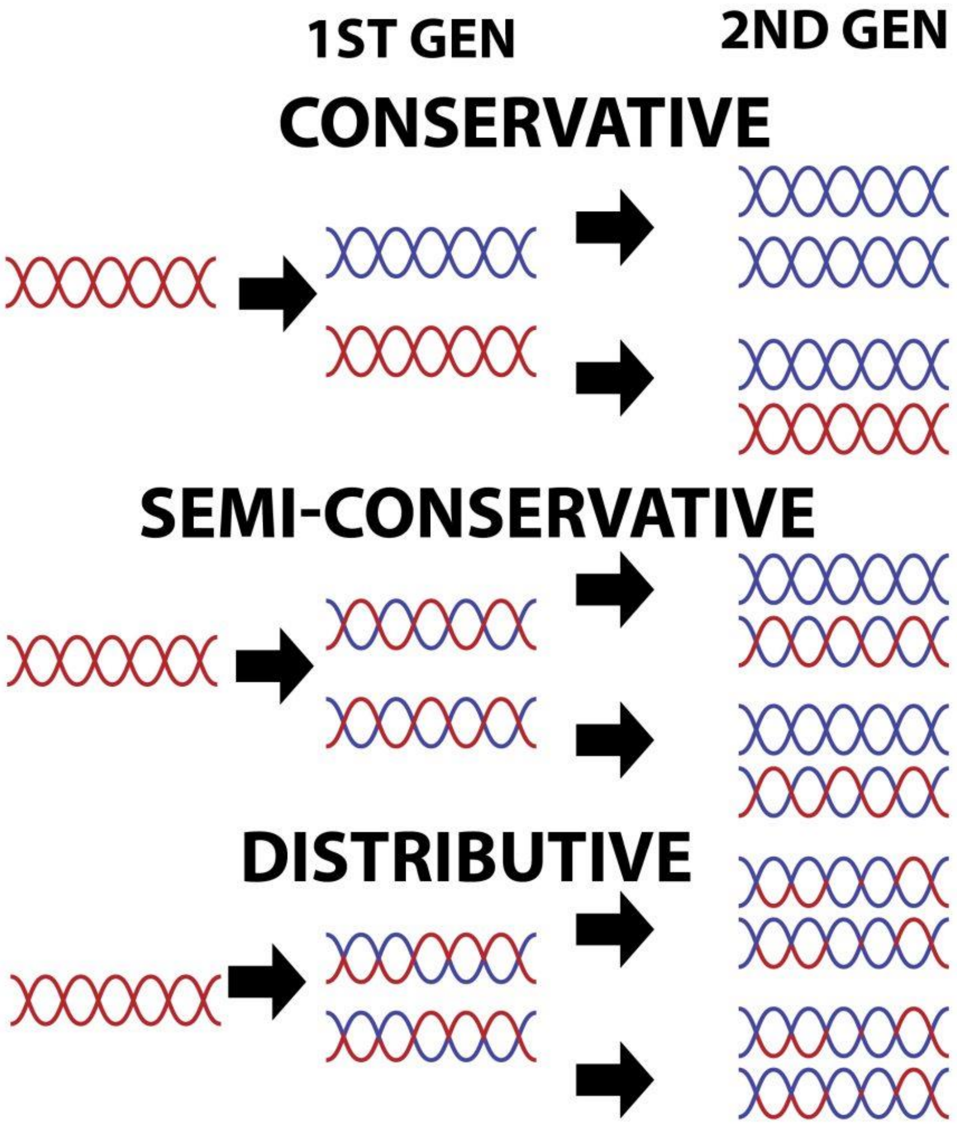


REPLICATION IS SEMICONSERVATIVE

The Meselson and Stahl experiment: Bacterial cells were grown for several generations in a medium containing a heavy isotope of nitrogen (15N) and then were transferred to a new medium containing the normal lighter isotope (14N). At various times thereafter, samples of the bacteria were collected, and their DNA was dissolved in a solution of cesium chloride, which was spun rapidly in a centrifuge. Because the cesium ion is so massive, it tends to settle toward the bottom of the spinning tube, establishing a gradient of cesium density. DNA molecules sink in the gradient until they reach a place where their density equals that of the cesium; they then "float" at that position. DNA containing 15N is denser than that containing 14N, so it sinks to a lower position in the cesium gradient. After one generation in 14N medium, the bacteria yielded a single band of DNA with a density between that of 14N-DNA and 15N-DNA, indicating that only one strand of each duplex contained 15N. After two generations in 14N medium, two bands were obtained; one of intermediate density and one of low density.




Density-gradient centrifuge tube
DNA
–14N
–14N/15N
–15N
Original 15N DNA
Generation 1 in 14N medium
Generation 2
Generation 3


1ST GEN
2ND GEN
CONSERVATIVE
SEMI-CONSERVATIVE
DISTRIBUTIVE

CELL DIVISION IN PROKARYOTES

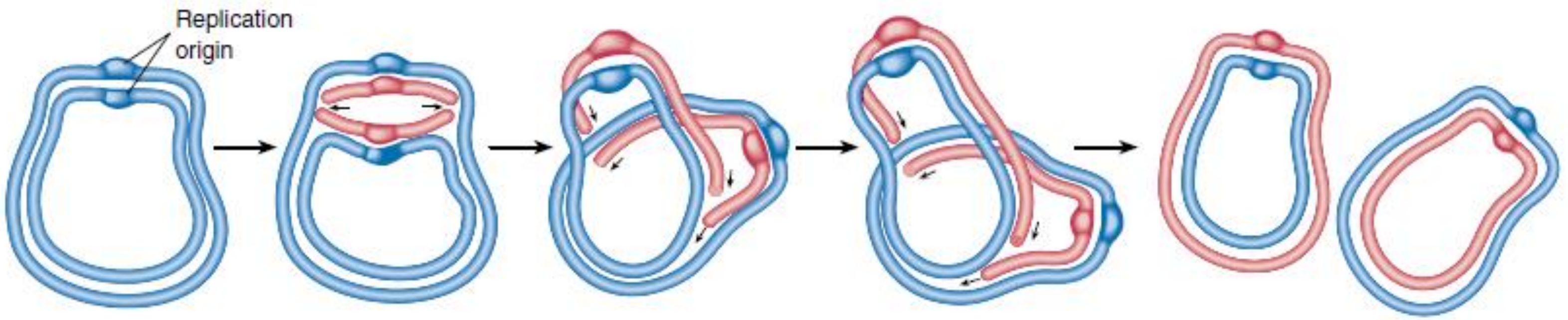


FIGURE 11.3
How bacterial DNA replicates. The replication of the circular DNA molecule (*blue*) that constitutes the genome of a bacterium begins at a single site, called the replication origin. The replication enzymes move out in both directions from that site and make copies (*red*) of each strand in the DNA duplex. When the enzymes meet on the far side of the molecule, replication is complete.

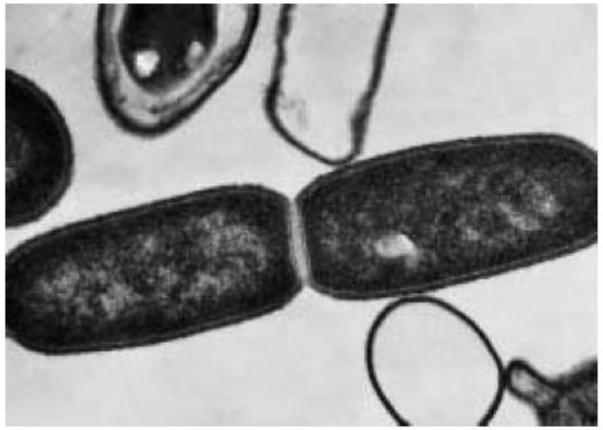


FIGURE 11.2
Fission (40,000×). Bacteria divide by a process of simple cell fission. Note the newly formed plasma membrane between the two daughter cells.

CHROMOSOMES

Table 11.1 Chromosome Number in Selected Eukaryotes

Group	Total Number of Chromosomes	Group	Total Number of Chromosomes	Group	Total Number of Chromosomes
FUNGI		PLANTS		VERTEBRATES	
Neurospora (haploid)	7	*Haplopappus gracilis*	2	Opossum	22
Saccharomyces (a yeast)	16	Garden pea	14	Frog	26
		Corn	20	Mouse	40
INSECTS		Bread wheat	42	Human	46
Mosquito	6	Sugarcane	80	Chimpanzee	48
Drosophila	8	Horsetail	216	Horse	64
Honeybee	32	Adder's tongue fern	1262	Chicken	78
Silkworm	56			Dog	78

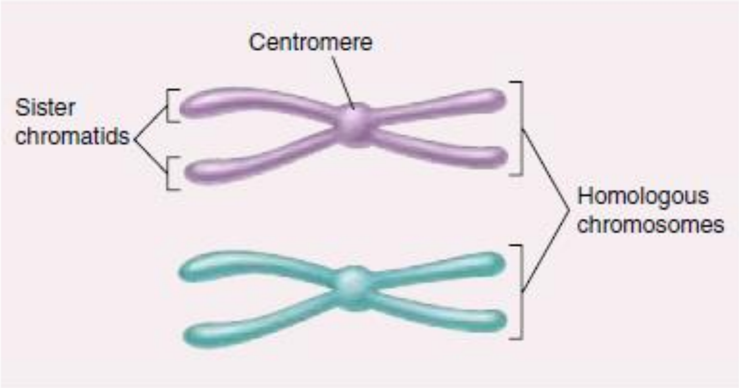


FIGURE 11.7
The difference between homologous chromosomes and sister chromatids. Homologous chromosomes are a pair of the same chromosome—say, chromosome number 16. Sister chromatids are the two replicas of a single chromosome held together by the centromeres after DNA replication.

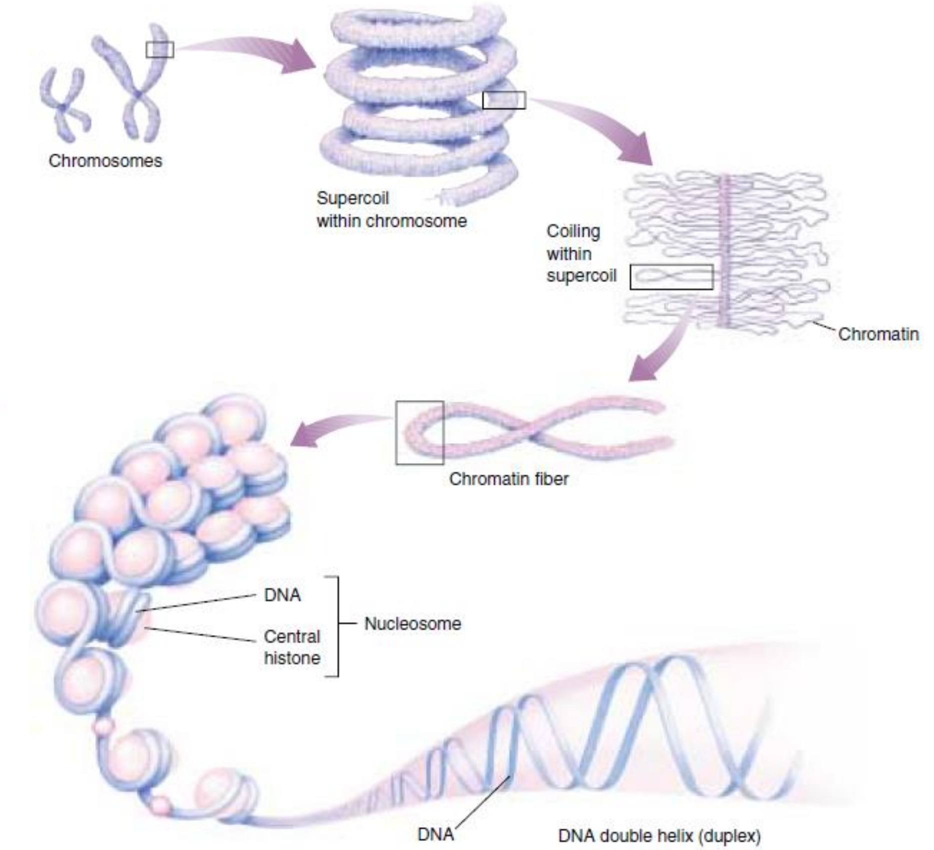
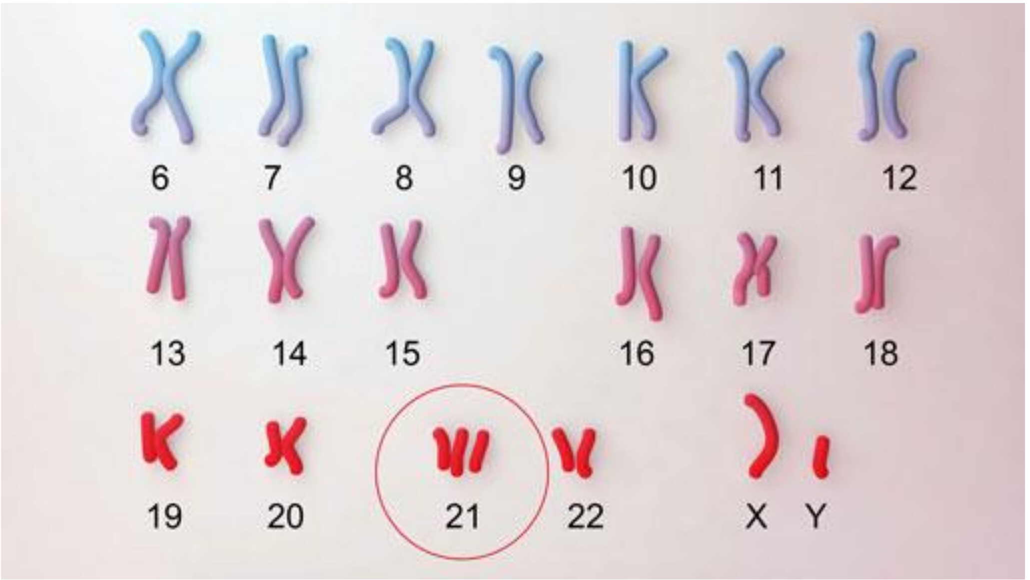


FIGURE 11.5
Levels of eukaryotic chromosomal organization. Nucleotides assemble into long double strands of DNA molecules. These strands require further packaging to fit into the cell nucleus. The DNA duplex is tightly bound to and wound around proteins called *histones.* The DNA-wrapped histones are called *nucleosomes.* The nucleosomes then coalesce into *chromatin* fibers, ultimately coiling around into *supercoils* that make up the form of DNA recognized as a *chromosome.*

CHROMOSOMES

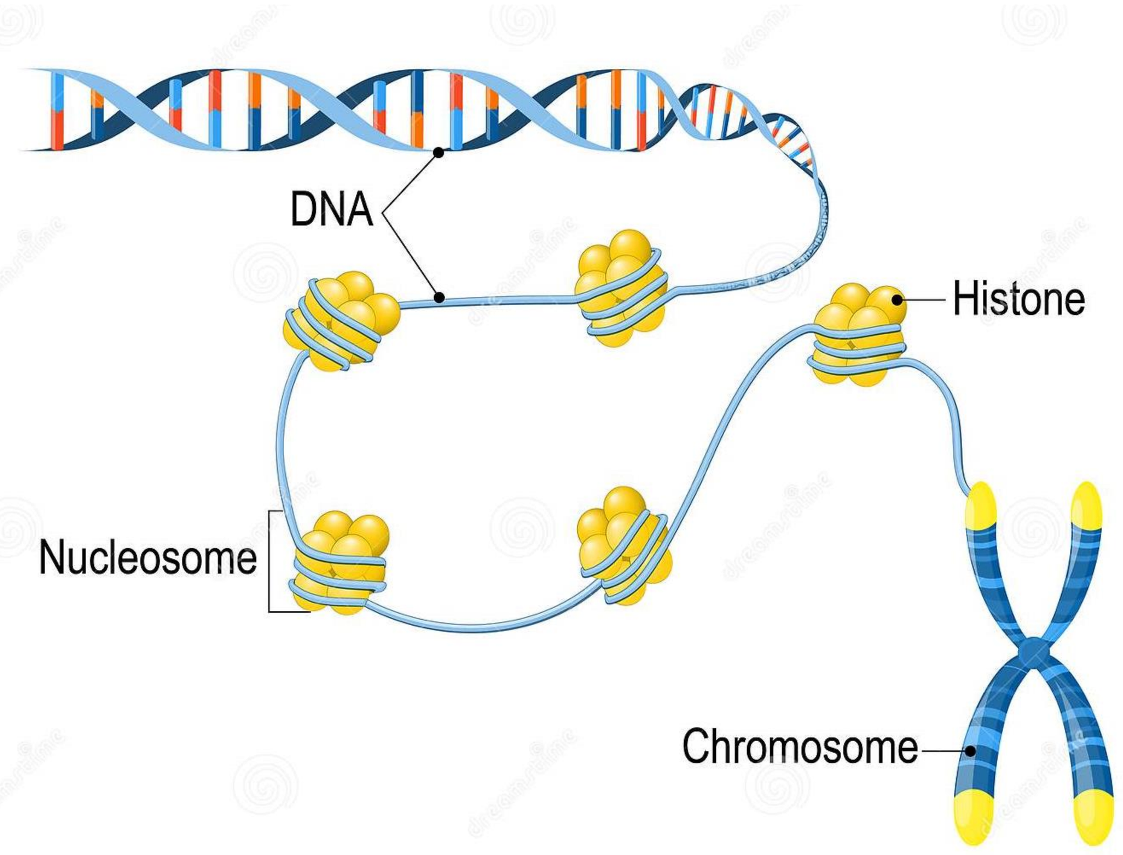


Trisomy of 21: Down's Syndrome

The Peanut Butter Falcon

It occurs in about 1 in 1,000 babies born each year. In 2015, Down syndrome was present in 5.4 million individuals globally and resulted in 27,000 deaths.

CHROMOSOME COILING



- Every 200 nucleotides, the DNA duplex is coiled around a core of eight histone proteins, forming a complex known as a **nucleosome.**
- Unlike most proteins, which have an overall negative charge, histones are positively charged, due to an abundance of the basic amino acids arginine and lysine.
- They are strongly attracted to the negatively charged phosphate groups of the DNA.

Nucleosome The basic packaging unit of eukaryotic chromosomes, in which the DNA molecule is wound around a cluster of histone proteins. Chromatin is composed of long strings of nucleosomes that resemble beads on a string.

CHROMOSOME

- Chromosomes are composed of **chromatin:** about 40% DNA and 60% protein.
- A significant amount of RNA is also associated with chromosomes because chromosomes are the sites of RNA synthesis.
- The DNA of a chromosome is one very long, double-stranded fiber that extends unbroken through the entire length of the chromosome.
- A typical human chromosome contains about 140 million (1.4×10^8) nucleotides in its DNA.
- The amount of information one chromosome contains would fill about 280 printed books of 1000 pages each, if each nucleotide corresponded to a "word" and each page had about 500 words on it.

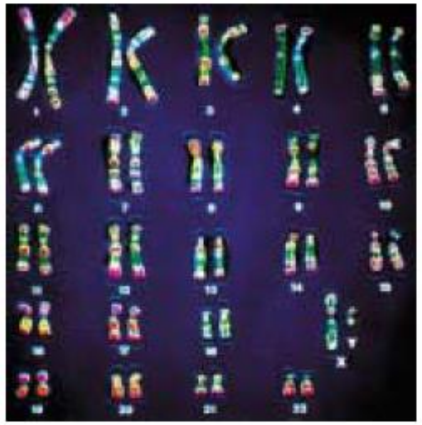
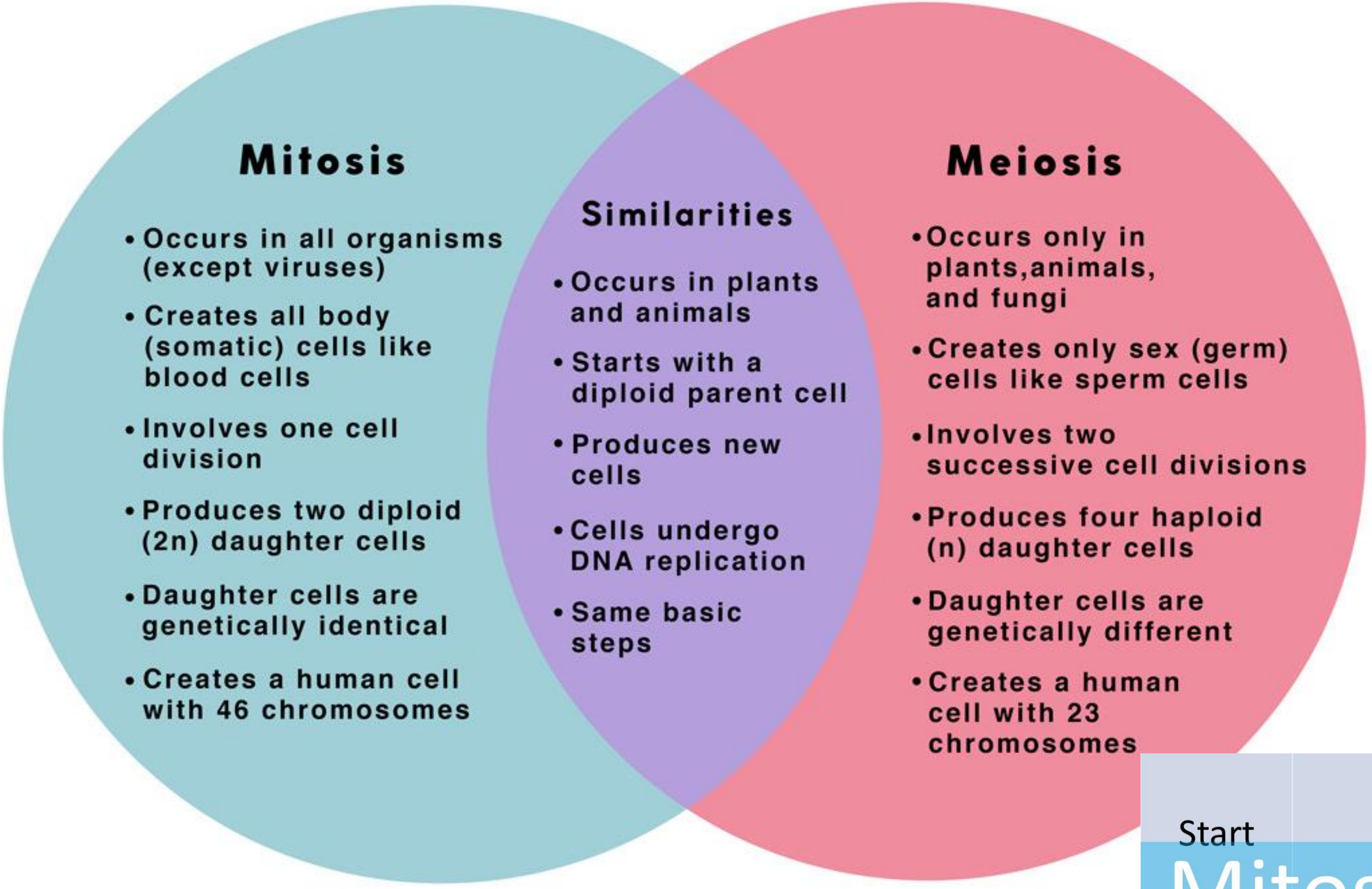
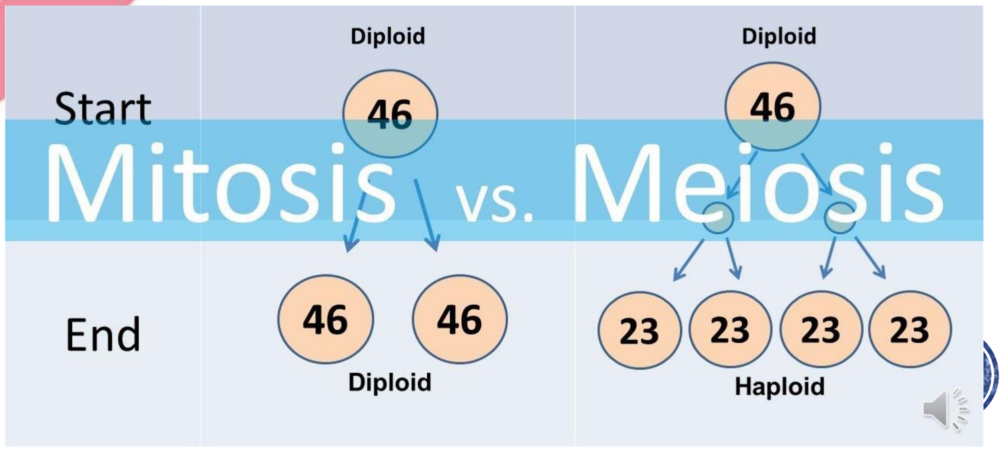
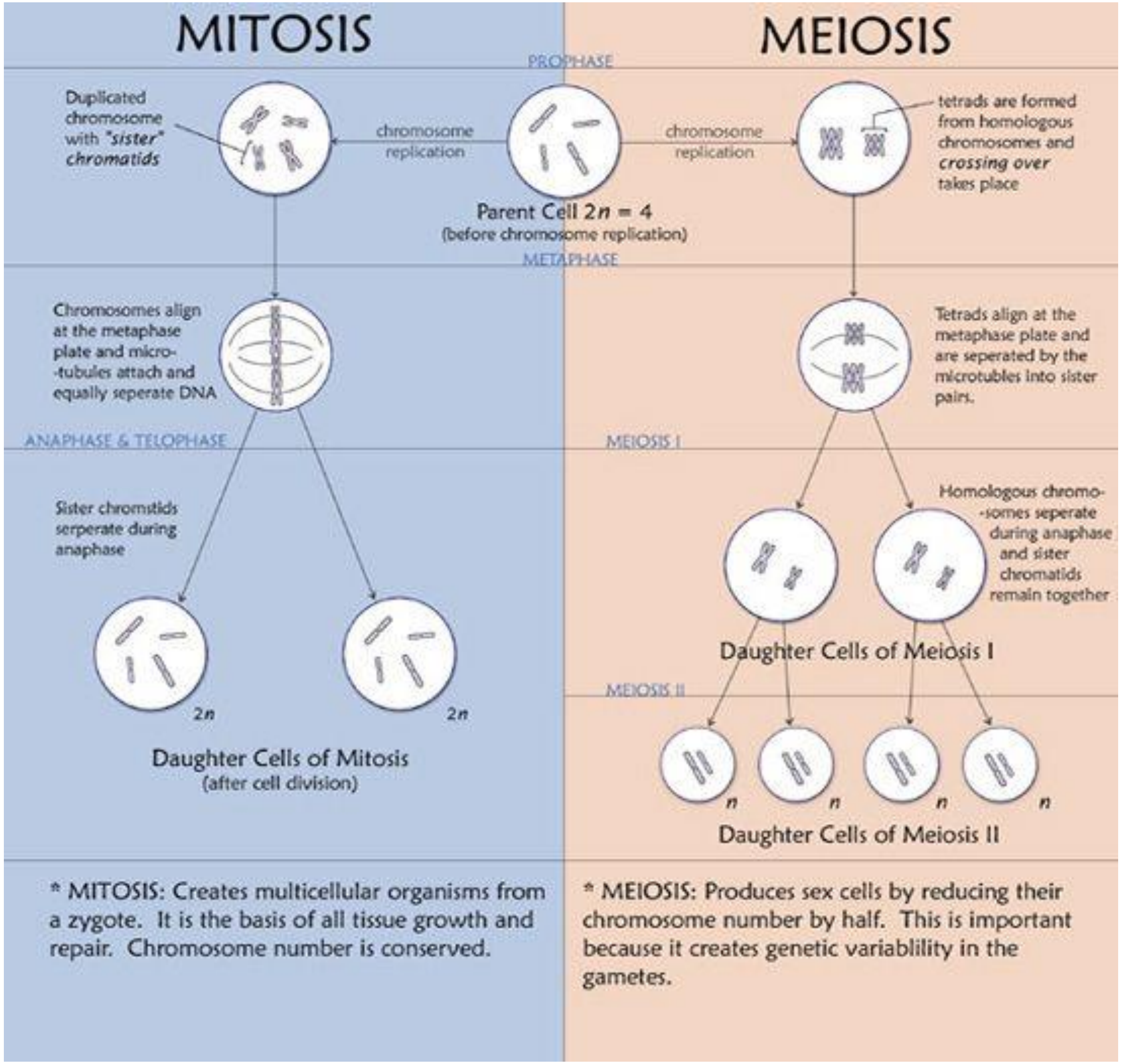


FIGURE 11.6
A human karyotype. The individual chromosomes that make up the 23 pairs differ widely in size and in centromere position. In this preparation, the chromosomes have been specifically stained to indicate further differences in their composition and to distinguish them clearly from one another.


Mitosis
• Occurs in all organisms (except viruses)
• Creates all body (somatic) cells like blood cells
• Involves one cell division
• Produces two diploid (2n) daughter cells
• Daughter cells are genetically identical
• Creates a human cell with 46 chromosomes
Similarities
• Occurs in plants and animals
• Starts with a diploid parent cell
• Produces new cells
• Cells undergo DNA replication
• Same basic steps
Meiosis
• Occurs only in plants,animals, and fungi
• Creates only sex (germ) cells like sperm cells
• Involves two successive cell divisions
• Produces four haploid (n) daughter cells
• Daughter cells are genetically different
• Creates a human cell with 23 chromosomes


Mitosis vs. Meiosis
Start
End
Diploid
46
46
46
Diploid
Diploid
46
23
23
23
23
Haploid


MITOSIS
MEIOSIS
PROPHASE
Duplicated chromosome with "sister" chromatids
chromosome replication
chromosome replication
tetrads are formed from homologous chromosomes and crossing over takes place
Parent Cell $2n = 4$
(before chromosome replication)
METAPHASE
Chromosomes align at the metaphase plate and micro- -tubules attach and equally seperate DNA
Tetrads align at the metaphase plate and are seperated by the microtubles into sister pairs.
ANAPHASE & TELOPHASE
MEIOSIS I
Sister chromstids serperate during anaphase
Homologous chromo- -somes seperate during anaphase and sister chromatids remain together
Daughter Cells of Meiosis I
MEIOSIS II
2n
2n
Daughter Cells of Mitosis
(after cell division)
n
n
n
n
Daughter Cells of Meiosis II
* MITOSIS: Creates multicellular organisms from a zygote. It is the basis of all tissue growth and repair. Chromosome number is conserved.
* MEIOSIS: Produces sex cells by reducing their chromosome number by half. This is important because it creates genetic variablility in the gametes.

CELL DIVISION

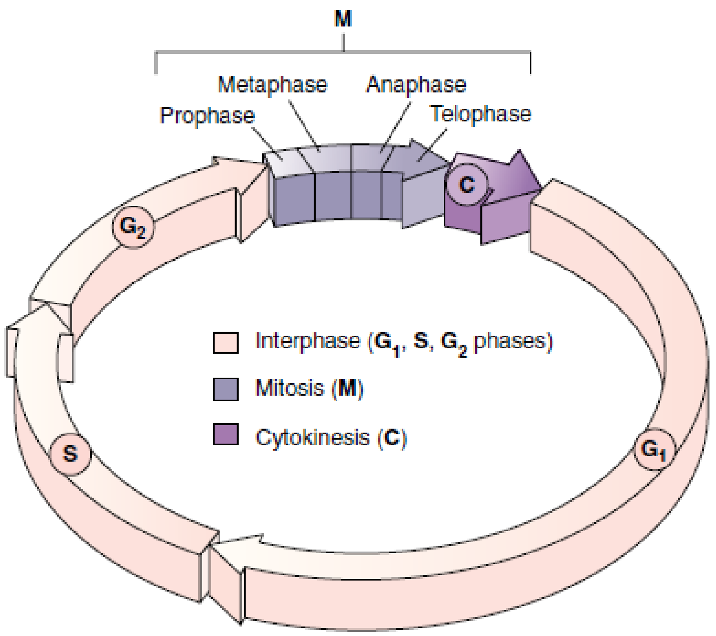


FIGURE 11.8
The cell cycle. Each wedge represents one hour of the 22-hour cell cycle in human cells growing in culture. G_1 represents the primary growth phase of the cell cycle, S the phase during which a replica of the genome is synthesized, and G_2 the second growth phase.

Mitosis comprises of 5 phases:
G1- Gap1
S- Synthesis (DNA)
G2- Gap 2
M- Mitosis
C- Cytokinesis

4 Phases:
1. Prophase
2. Metaphase
3. Anaphase
4. Telophase

INTERPHASE (G1/S/G2)

- **G_1** is the primary growth phase of the cell. For many organisms, this encompasses the major portion of the cell’s life span.
- **S** is the phase in which the cell synthesizes a replica of the genome.
- **G_2** is the second growth phase, in which preparations are made for genomic separation. During this phase, mitochondria and other organelles replicate, chromosomes condense, and microtubules begin to assemble at a spindle.
- Some cells such as nerve, muscle cells remain in G0 phase permanently.
- Liver cells can turn to G1 phase in case of liver injury.

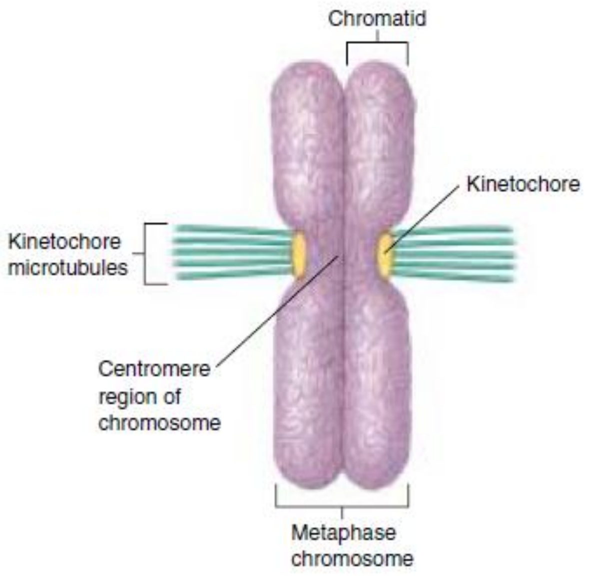
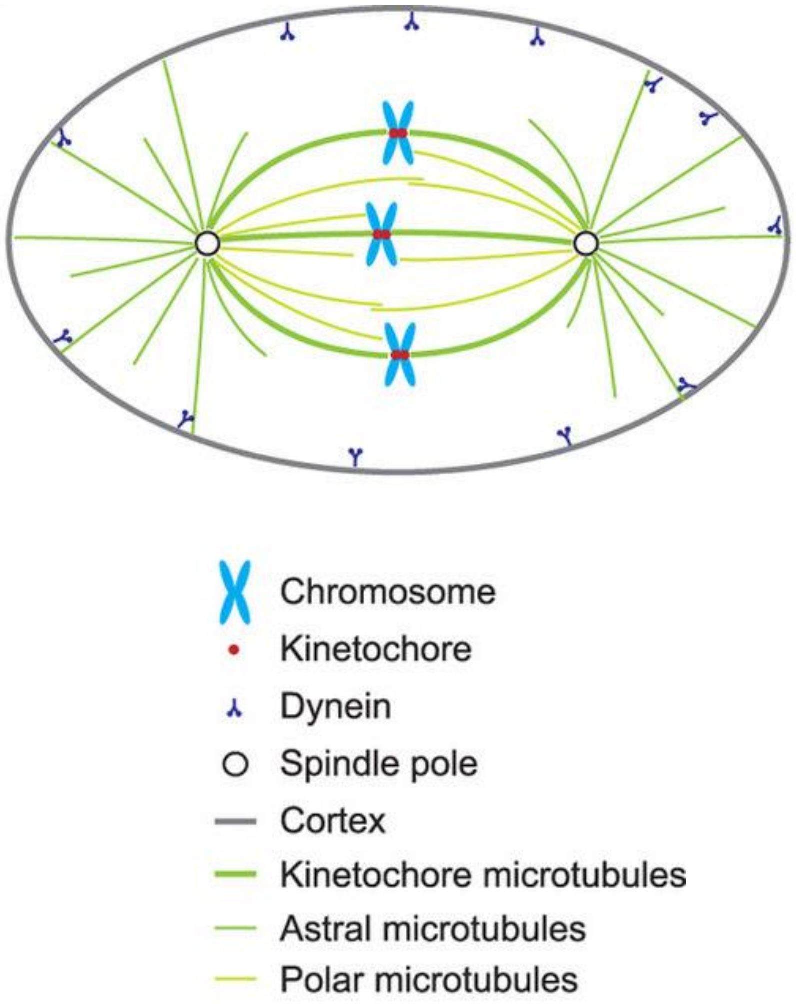


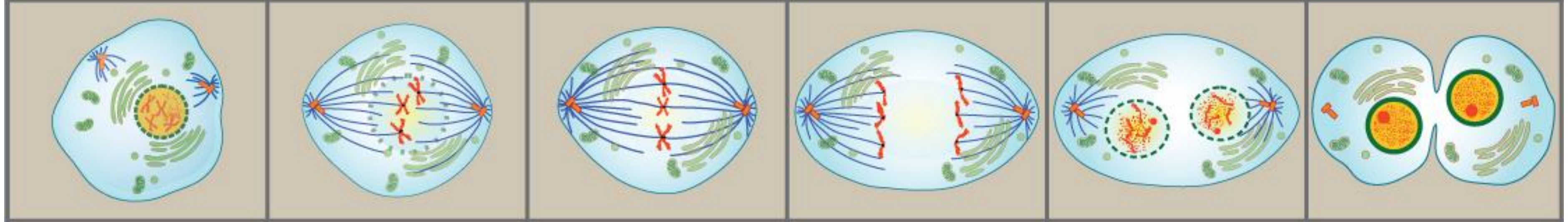
FIGURE 11.9
Kinetochores. In a metaphase chromosome, kinetochore microtubules are anchored to proteins at the centromere.

Interphase is that portion of the cell cycle in which the chromosomes are invisible under the light microscope because they are not yet condensed. It includes the G_1, S, and G_2 phases. In the G_2 phase, the cell mobilizes its resources for cell division.

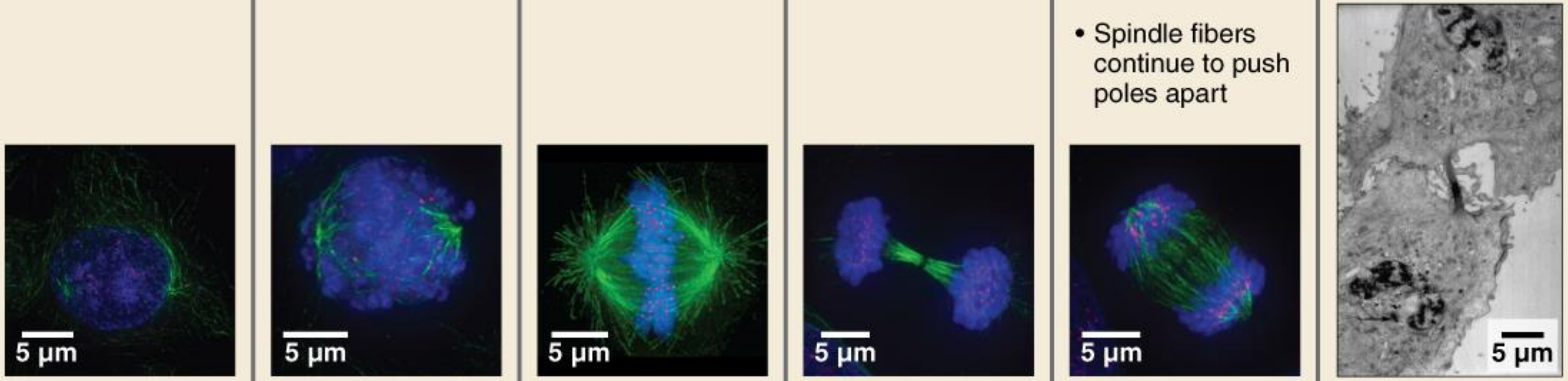
INTERPHASE: PREPARATION PHASE

Centromere: Constricted region of a chromosome about 220 nucleotides in length, composed of highly repeated DNA sequences (satellite DNA). During mitosis, the centromere joins the two sister chromatids and is the site to which the kinetochores are attached.
Chromatid: One of the two copies of a replicated chromosome, joined by a single centromere to the other strand.
Kinetochore: A disk of protein bound to the centromere and attached to microtubules during mitosis, linking each chromatid to the spindle apparatus.
Microtubule: A hollow cylinder, about 25 nanometers in diameter, composed of subunits of the protein tubulin. Microtubules lengthen by the addition of tubulin subunits to their end(s) and shorten by the removal of subunits.



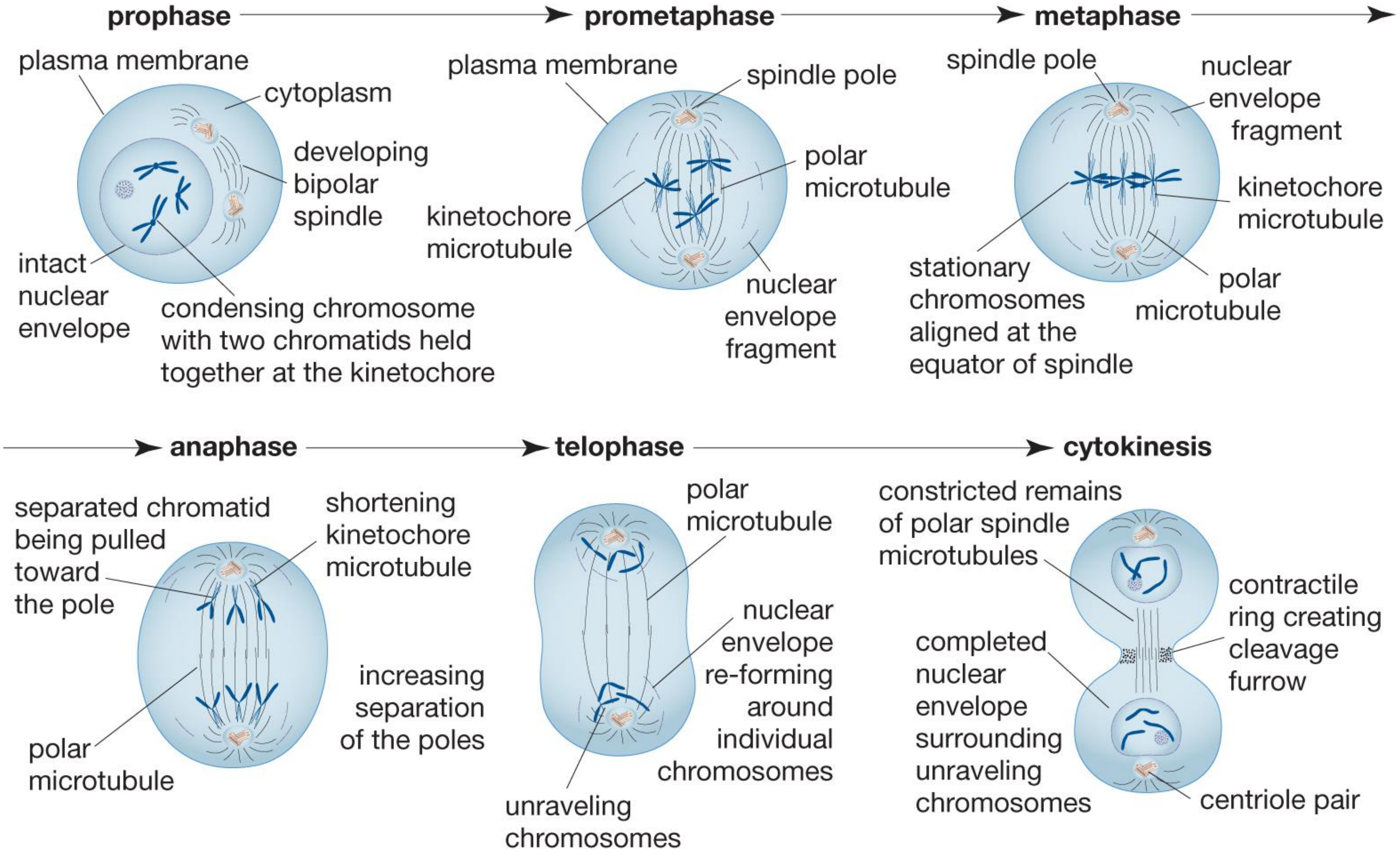


Prophase	Prometaphase	Metaphase	Anaphase	Telophase	Cytokinesis
• Chromosomes condense and become visible • Spindle fibers emerge from the centrosomes • Nuclear envelope breaks down • Centrosomes move toward opposite poles	• Chromosomes continue to condense • Kinetochores appear at the centromeres • Mitotic spindle microtubules attach to kinetochores	• Chromosomes are lined up at the metaphase plate • Each sister chromatid is attached to a spindle fiber originating from opposite poles	• Centromeres split in two • Sister chromatids (now called chromosomes) are pulled toward opposite poles • Certain spindle fibers begin to elongate the cell	• Chromosomes arrive at opposite poles and begin to decondense • Nuclear envelope material surrounds each set of chromosomes • The mitotic spindle breaks down • Spindle fibers continue to push poles apart	• Animal cells: a cleavage furrow separates the daughter cells • Plant cells: a cell plate, the precursor to a new cell wall, separates the daughter cells



MITOSIS

MITOSIS



prophase
prometaphase
metaphase
plasma membrane
cytoplasm
developing bipolar spindle
intact nuclear envelope
condensing chromosome with two chromatids held together at the kinetochore
plasma membrane
spindle pole
polar microtubule
kinetochore microtubule
nuclear envelope fragment
spindle pole
nuclear envelope fragment
kinetochore microtubule
stationary chromosomes aligned at the equator of spindle
polar microtubule
anaphase
telophase
cytokinesis
separated chromatid being pulled toward the pole
shortening kinetochore microtubule
increasing separation of the poles
polar microtubule
polar microtubule
nuclear envelope re-forming around individual chromosomes
unraveling chromosomes
constricted remains of polar spindle microtubules
contractile ring creating cleavage furrow
completed nuclear envelope surrounding unraveling chromosomes
centriole pair

METAPHASE CHROMOSOME

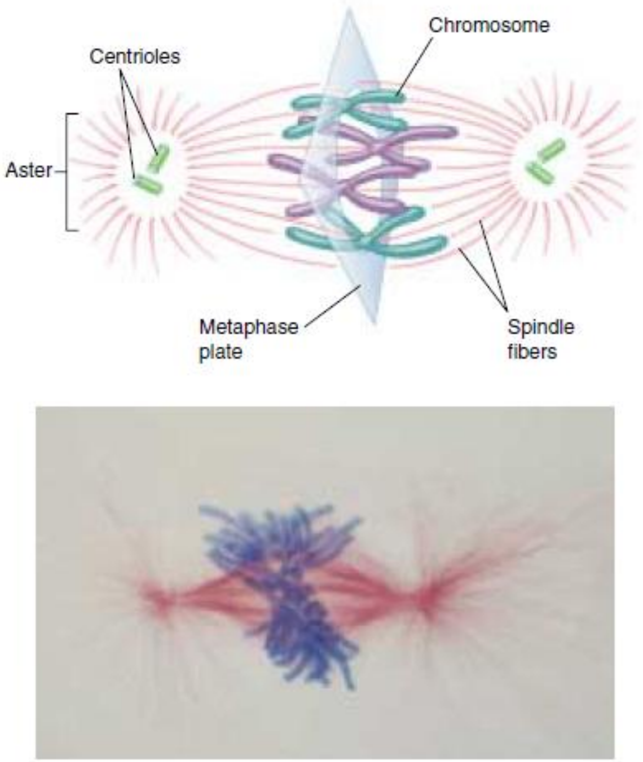


FIGURE 11.10
Metaphase. In metaphase, the chromosomes array themselves in a circle around the spindle midpoint.

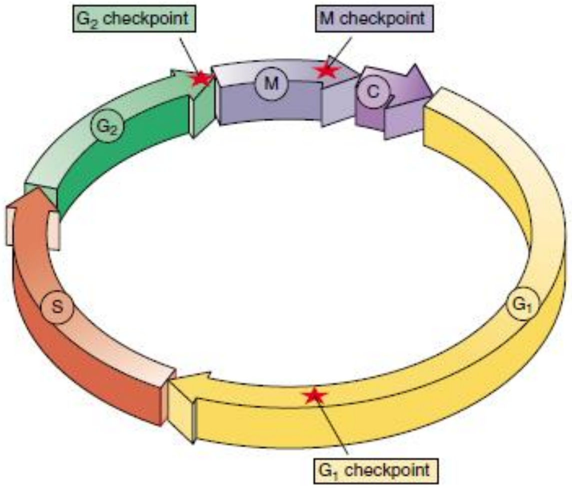


FIGURE 11.15
Control of the cell cycle. Cells use a centralized control system to check whether proper conditions have been achieved before passing three key "checkpoints" in the cell cycle.

FIGURE 11.16
The G_1 checkpoint. Feedback from the cell determines whether the cell cycle will proceed to the S phase, pause, or withdraw into G_0 for an extended rest period.

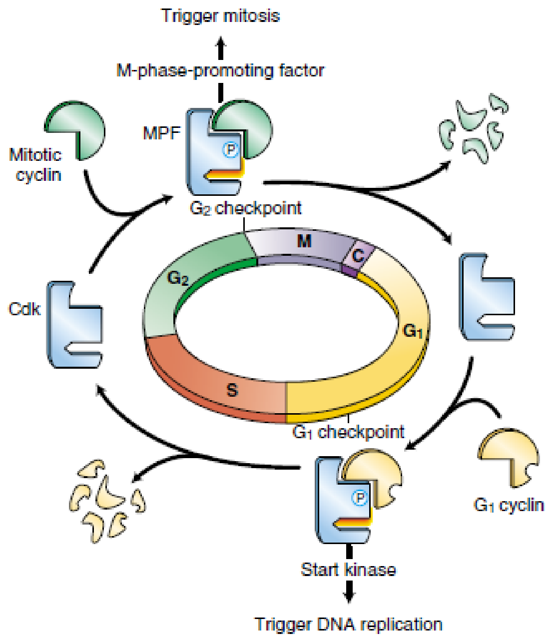


FIGURE 11.18
How cell cycle control works. As the cell cycle passes through the G_1 and G_2 checkpoints, Cdk becomes associated with different cyclins and, as a result, activates different cellular processes. At the completion of each phase, the cyclins are degraded, bringing Cdk activity to a halt until the next set of cyclins appears.

CANCER CELL CHECK

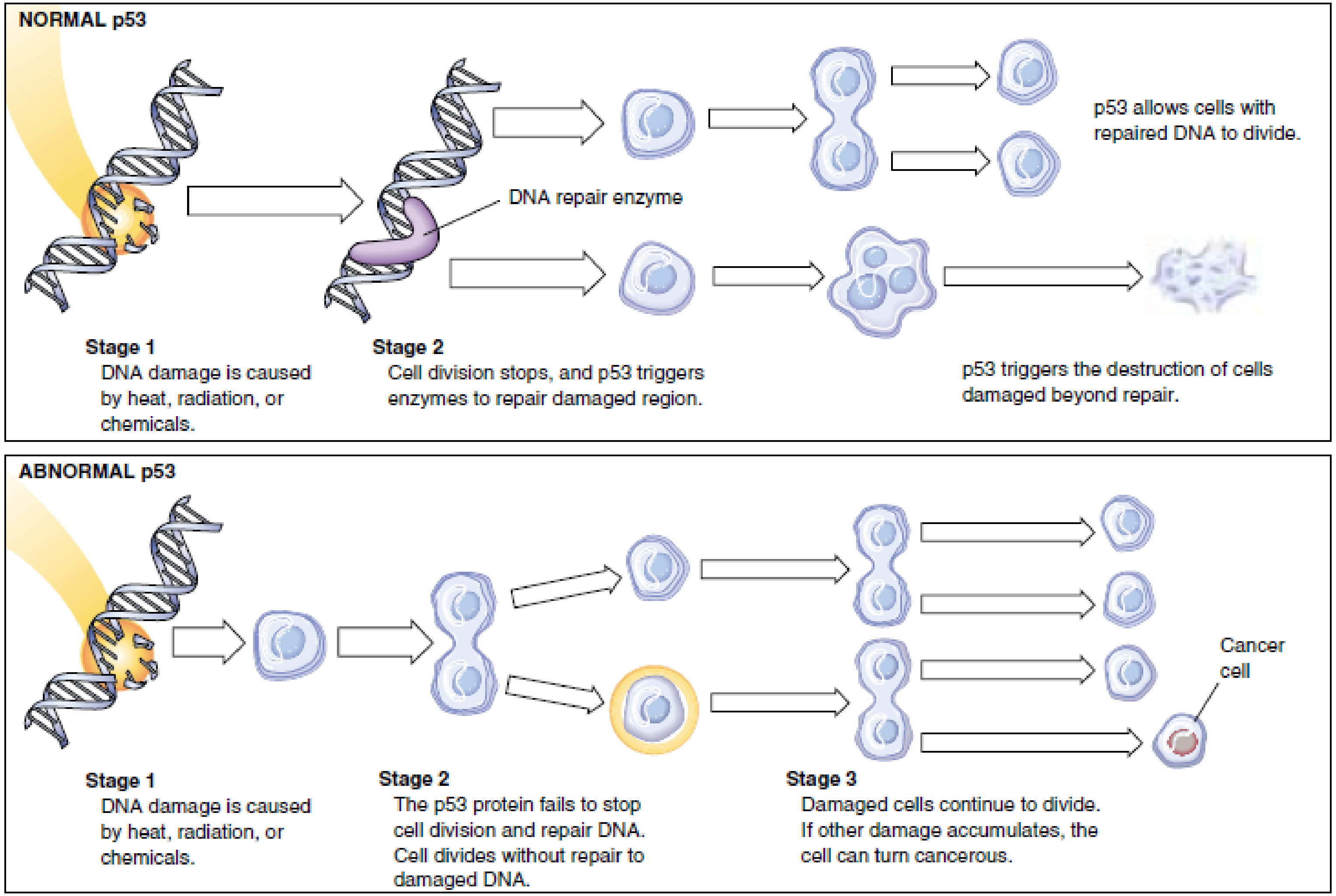


FIGURE 11.20
Cell division and p53 protein. Normal p53 protein monitors DNA, destroying cells with irreparable damage to their DNA. Abnormal p53 protein fails to stop cell division and repair DNA. As damaged cells proliferate, cancer develops.

Cigarette smoking

MEIOSIS

- **Reductionist division:** Belgian cytologist Pierre-Joseph van Beneden was surprised to find different numbers of chromosomes in different types of cells in the roundworm *Ascaris.*

  -Chromosome Number in sperms and eggs-2

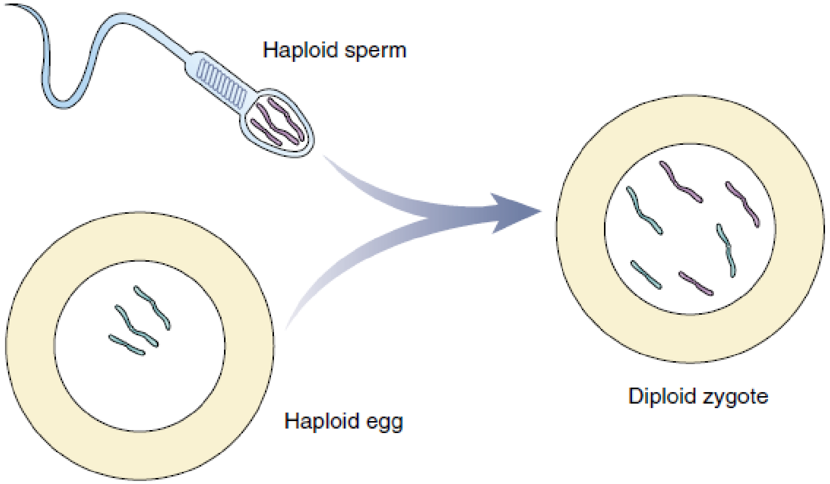
  -Chromosome Number in cells- 4

- Special form of cell division for the production of gametes

- Plays a key role in generating the tremendous genetic diversity that is the raw material of evolution.

- Fertilization- Fusion of sperms and egg to form Zygote and complete chromosome set (Diploid)

- Two kinds of cells- Somatic (2n) and Germ-line (n)



MEIOSIS

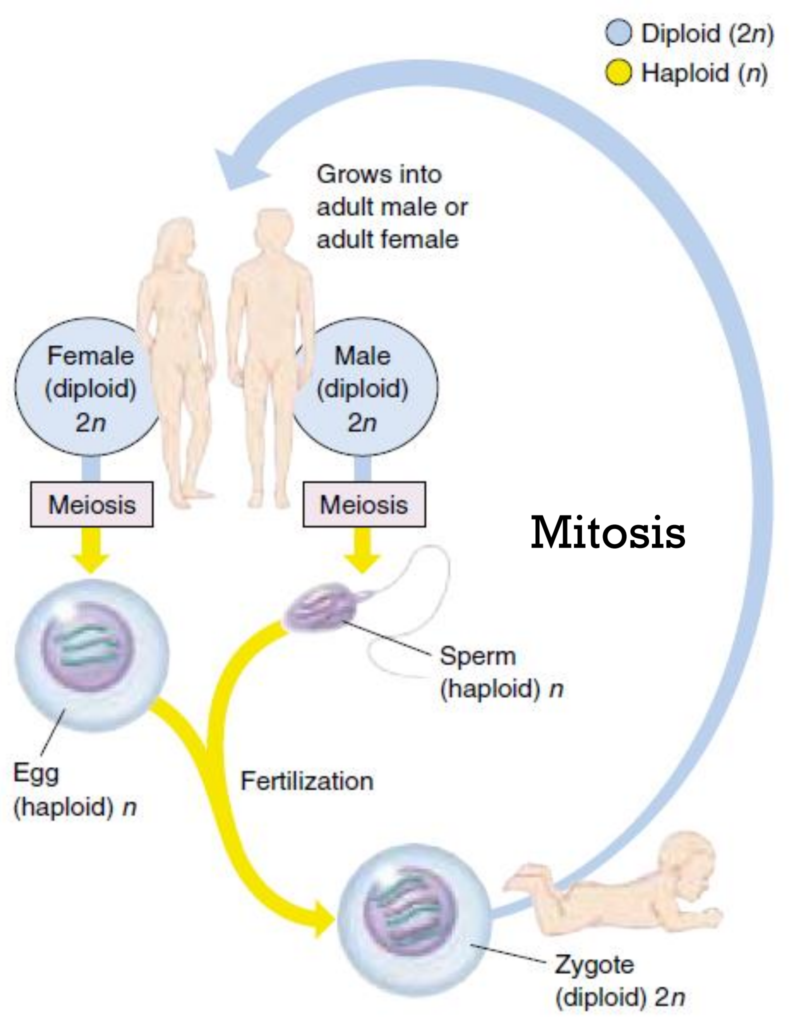
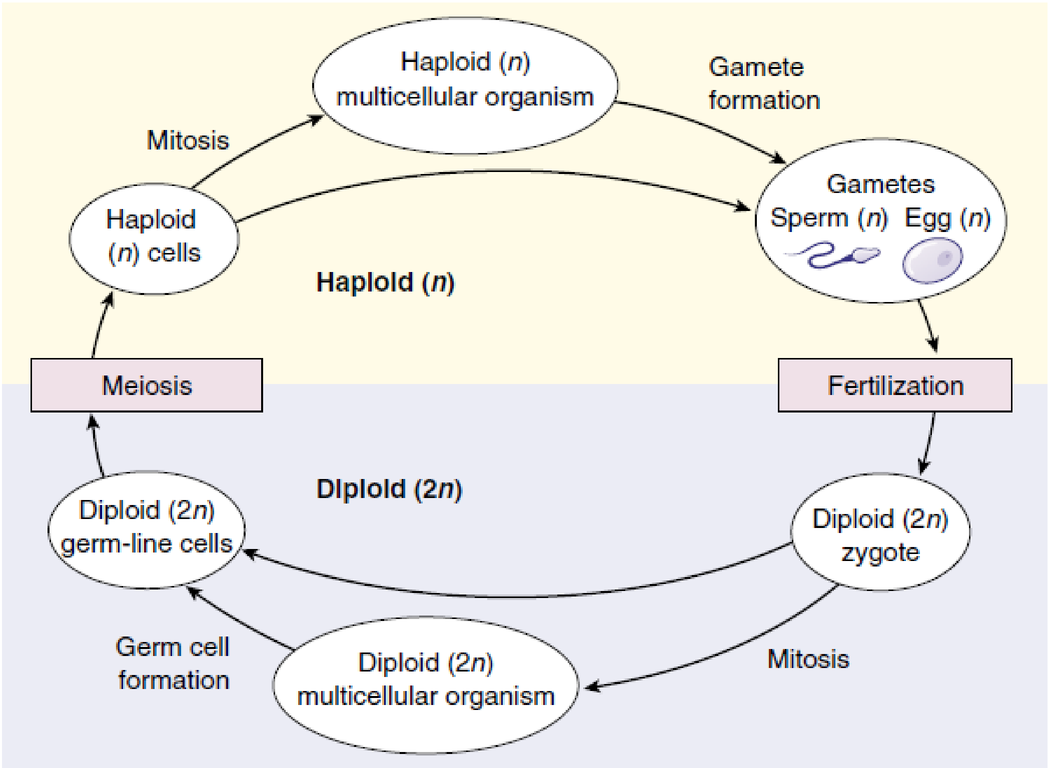
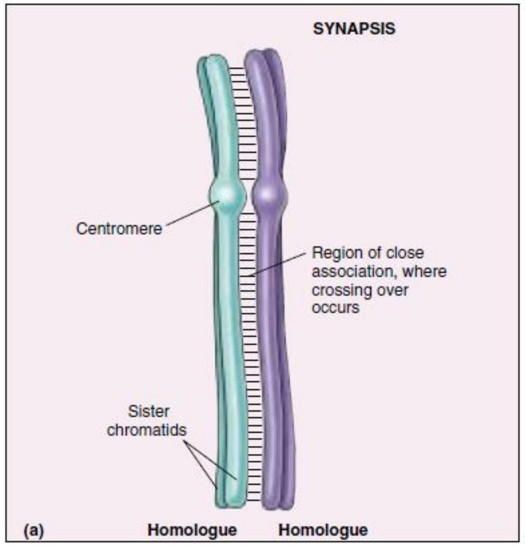
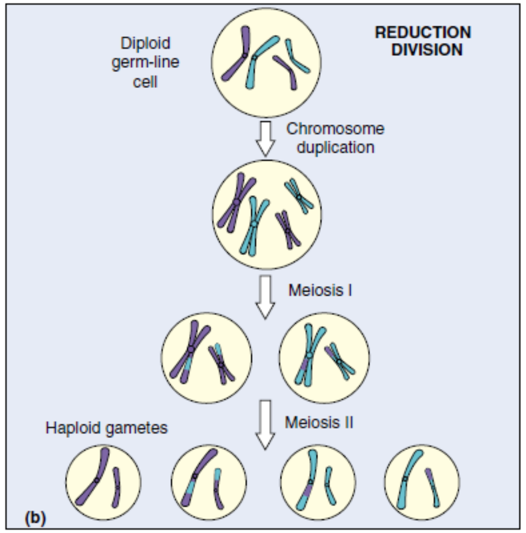


FIGURE 12.4
The sexual life cycle. In animals, the completion of meiosis is followed soon by fertilization. Thus, the vast majority of the life cycle is spent in the diploid stage.

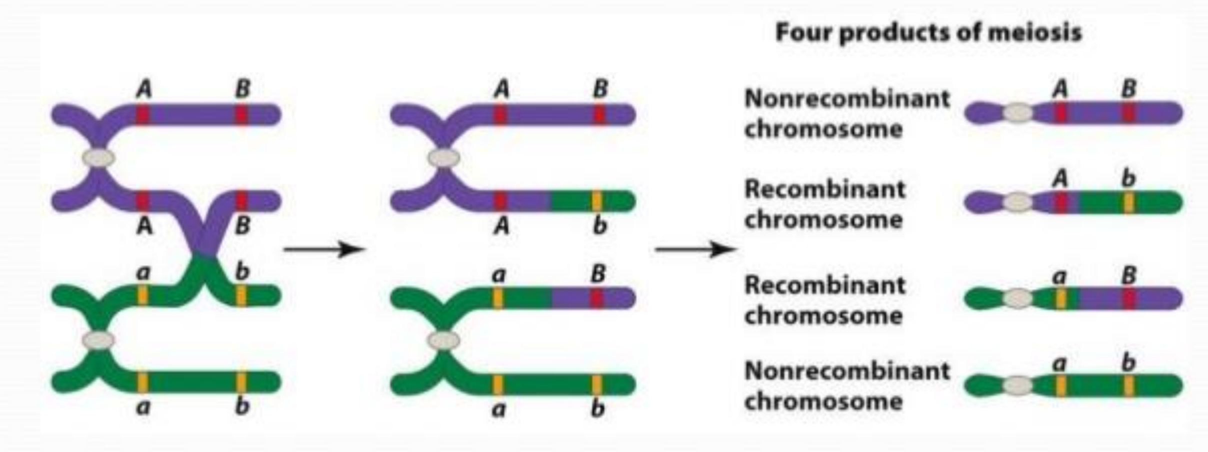


UNIQUE FEATURES





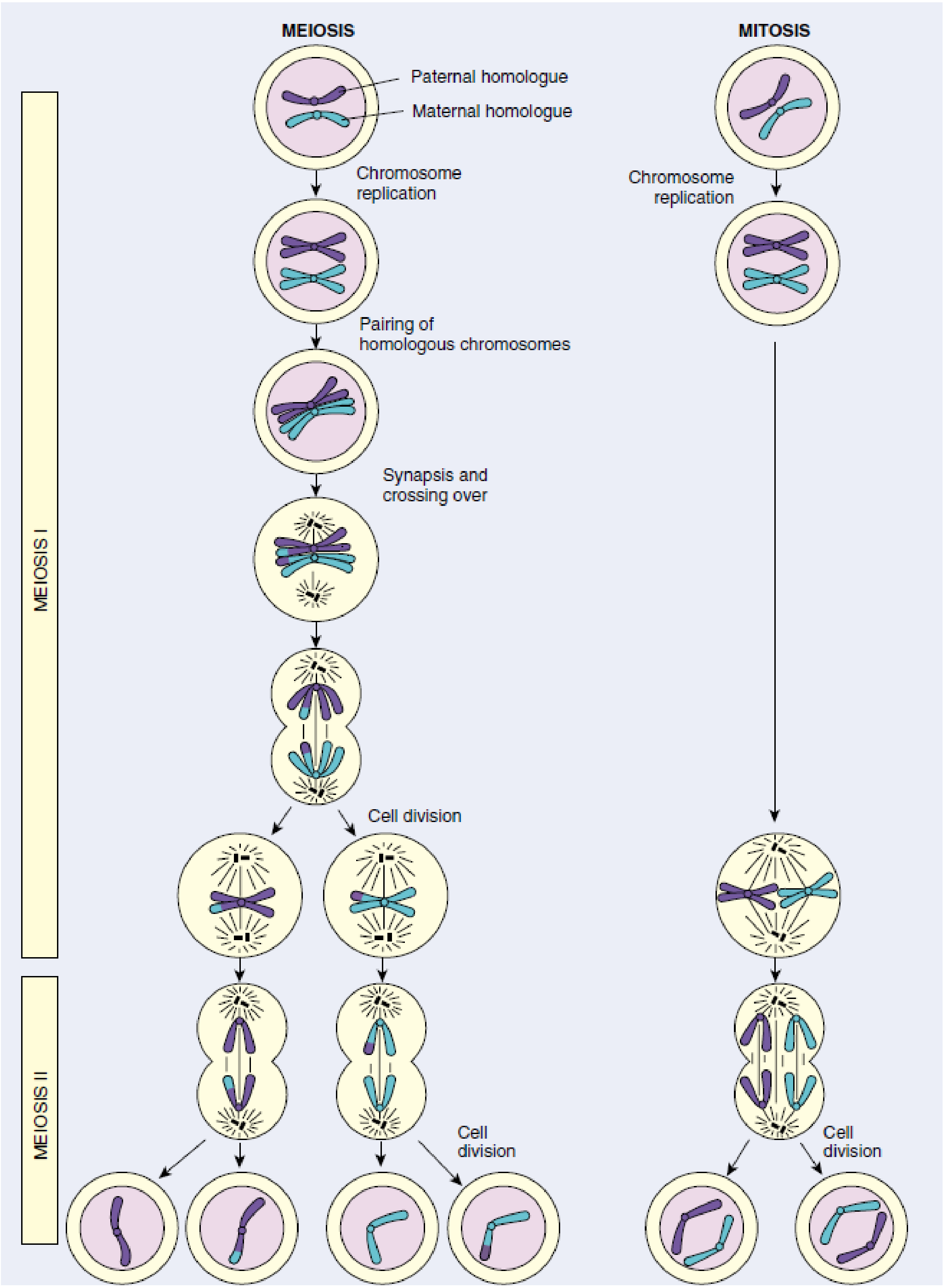
Crossing-over



(a) Synapsis- Homologous chromosomes pair along their lengths

(b) Reduction division- Only one chromosome duplication to produce haploid gametes, thus ensuring that chromosome number remains stable during the reproduction cycle.

(c) Homologous recombination- Genetic exchange between homologous chromosomes (Crossing over)



MEIOSIS

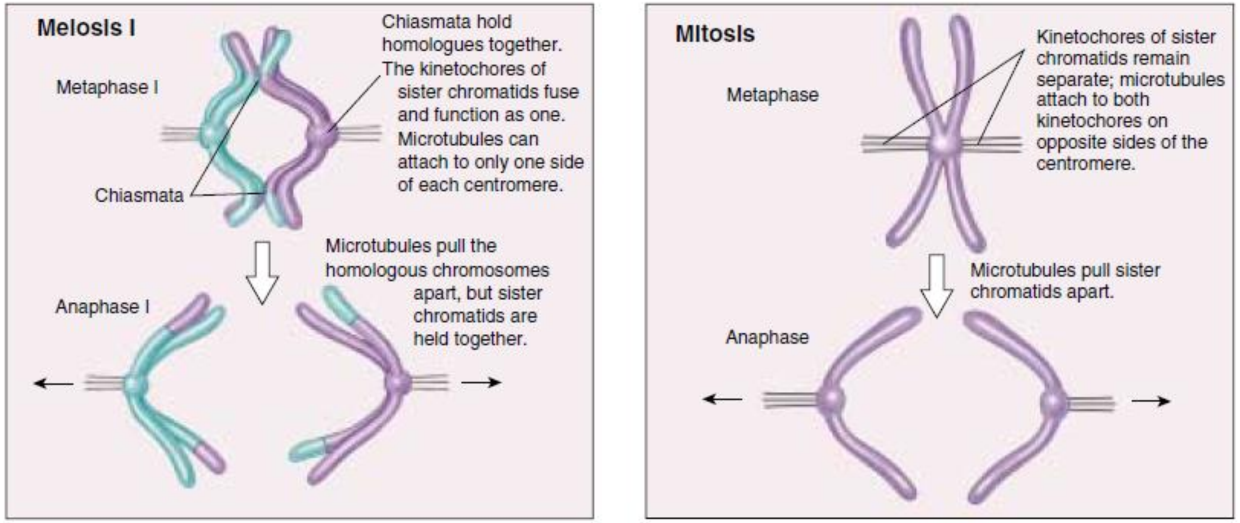
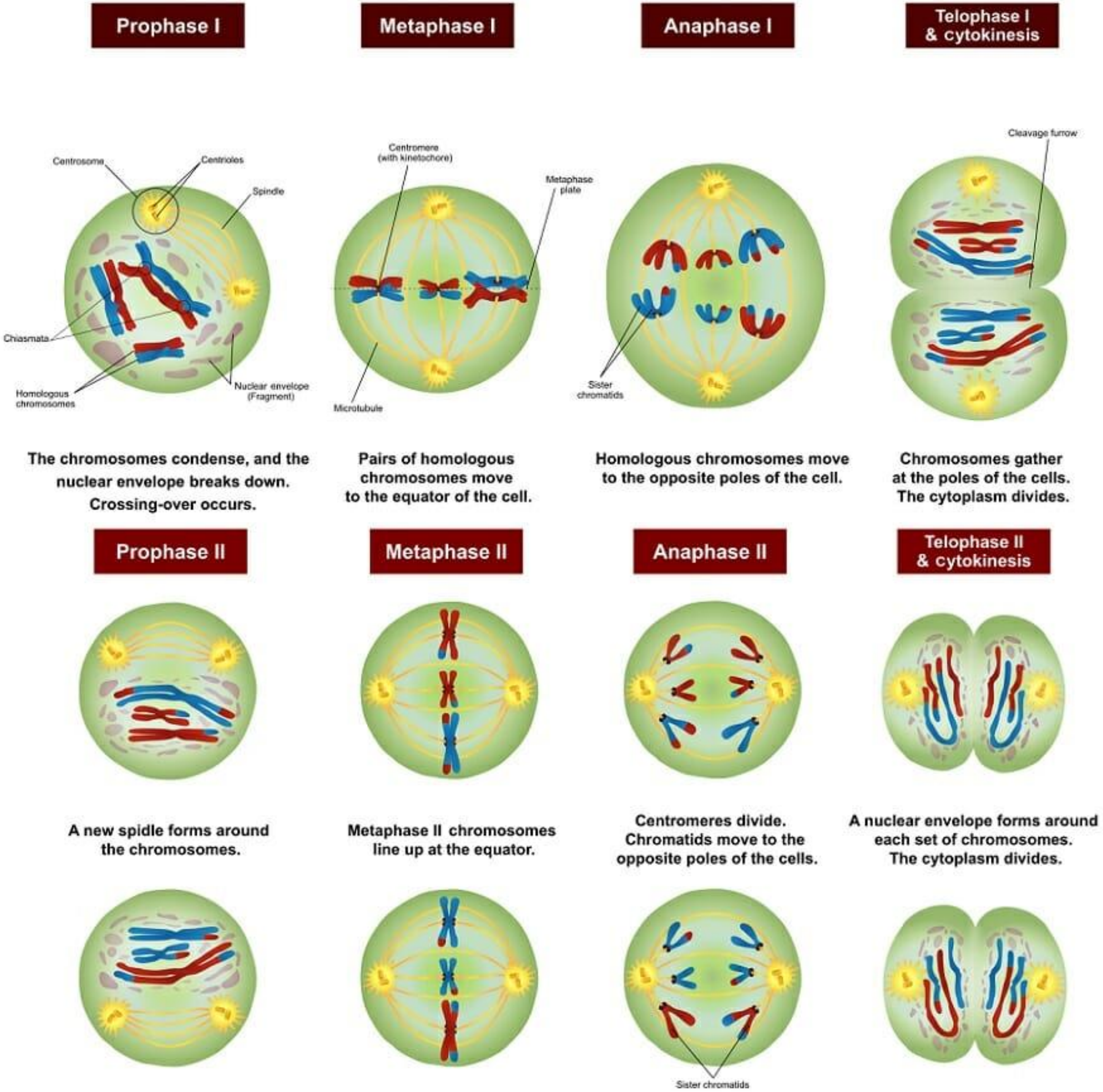
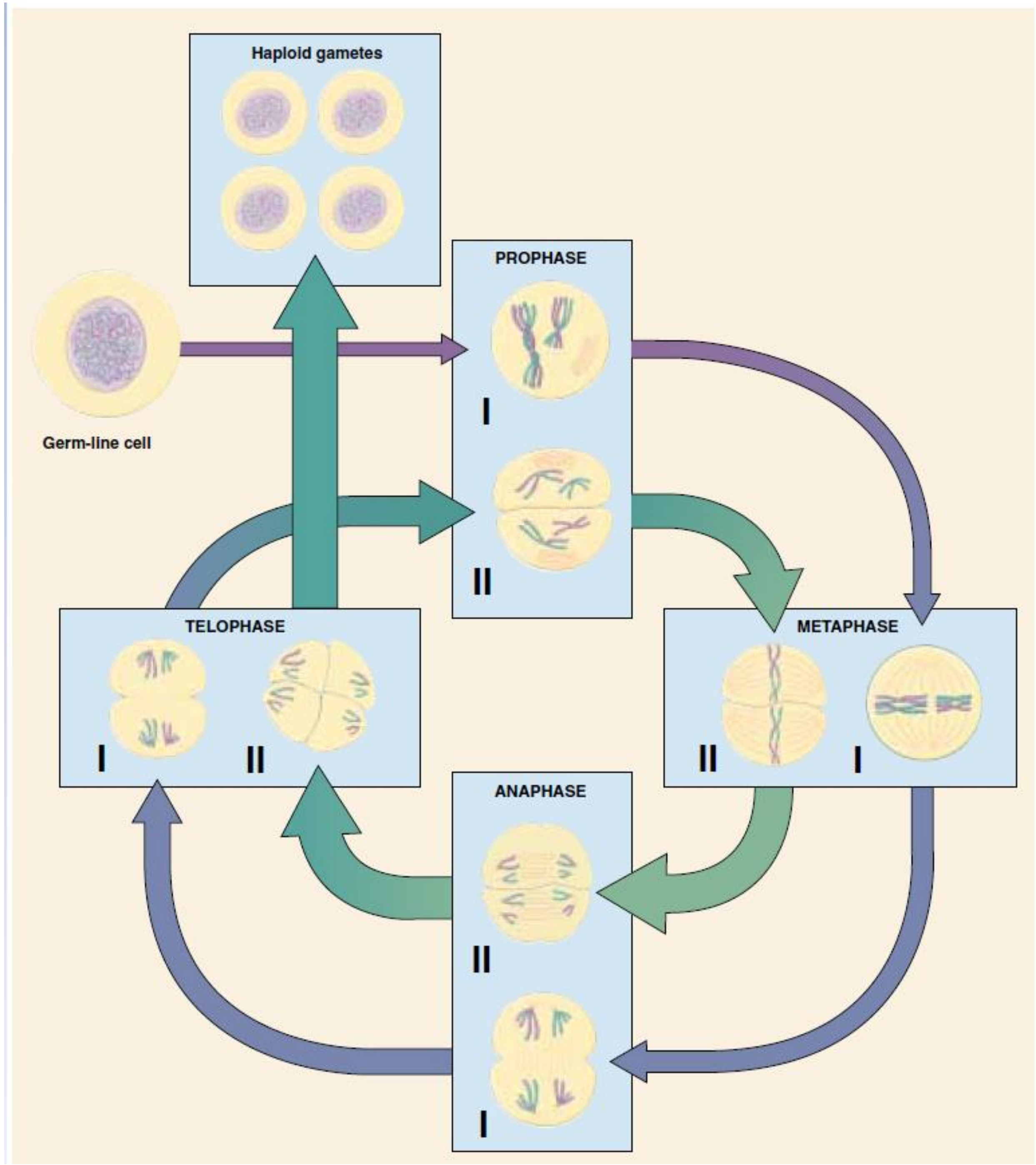


FIGURE 12.11
Chiasmata created by crossing over have a key impact on how chromosomes align in metaphase I. In the first meiotic division, the chiasmata hold one sister chromatid to the other sister chromatid; consequently, the spindle microtubules can bind to only one side of each centromere, and the homologous chromosomes are drawn to opposite poles. In mitosis, microtubules attach to *both* sides of each centromere; when the microtubules shorten, the sister chromatids are split and drawn to opposite poles.



Prophase I
Metaphase I
Anaphase I
Telophase I & cytokinesis
Centrosome
Centrioles
Spindle
Chiasmata
Homologous chromosomes
Nuclear envelope (Fragment)
Centromere (with kinetochore)
Metaphase plate
Microtubule
Sister chromatids
Cleavage furrow
The chromosomes condense, and the nuclear envelope breaks down. Crossing-over occurs.
Pairs of homologous chromosomes move to the equator of the cell.
Homologous chromosomes move to the opposite poles of the cell.
Chromosomes gather at the poles of the cells. The cytoplasm divides.
Prophase II
Metaphase II
Anaphase II
Telophase II & cytokinesis
A new spidle forms around the chromosomes.
Metaphase II chromosomes line up at the equator.
Centromeres divide. Chromatids move to the opposite poles of the cells.
A nuclear envelope forms around each set of chromosomes. The cytoplasm divides.
Sister chromatids



- Two rounds of cell division
- Meiosis II = Mitosis