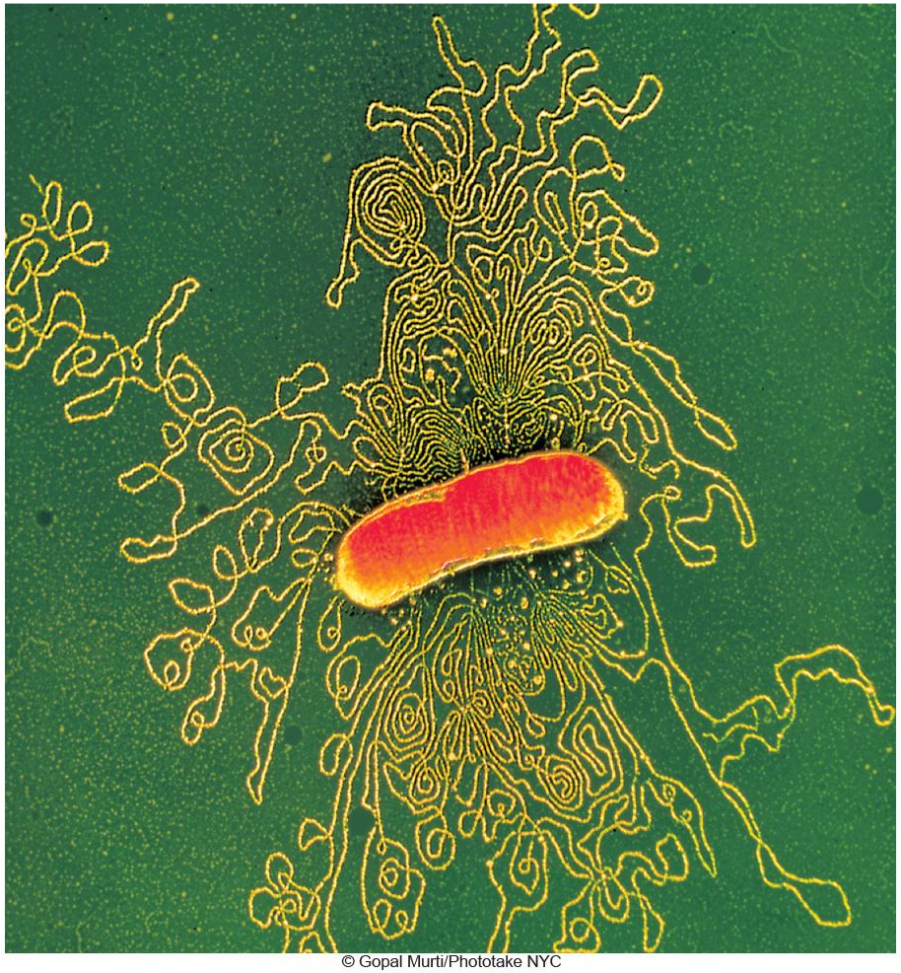

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Chapter 4

*Lecture PowerPoint

Genetics and Cellular Function

*See separate *FlexArt PowerPoint* slides for all figures and tables preinserted into PowerPoint without notes.

Introduction

- Necessary to have some familiarity with DNA and genes in order to study genetic disorders that effect hereditary traits
  - Color blindness, cystic fibrosis, diabetes mellitus, hemophilia
- Mendelian genetics helps us realize the correlation between chromosome behavior and his laws of heredity

DNA and RNA—The Nucleic Acids

- **Expected Learning Outcomes**
  - Describe the structure of DNA and relate this to its function.
  - Explain how DNA and proteins are organized to form the chromosomes.
  - Describe the types of RNA, their structural and functional differences, and how they compare with DNA.

DNA and RNA—The Nucleic Acids

- **Johann Friedrich Miescher (1844–95)**
  - Swiss biochemist, studied the nuclei of white blood cells from pus extracted from bandages
  - Coined term *nuclein,* now called DNA, repository for genes
- By 1900, components of DNA were name (sugar, phosphate groups, nitrogenous bases)

DNA Structure and Function

- **Deoxyribonucleic acid (DNA)**—a long, threadlike molecule with uniform diameter, but varied length
  - **46** DNA molecules in the nucleus of most human cells
    - Total length of 2 meters
    - Average DNA molecule 2 inches long

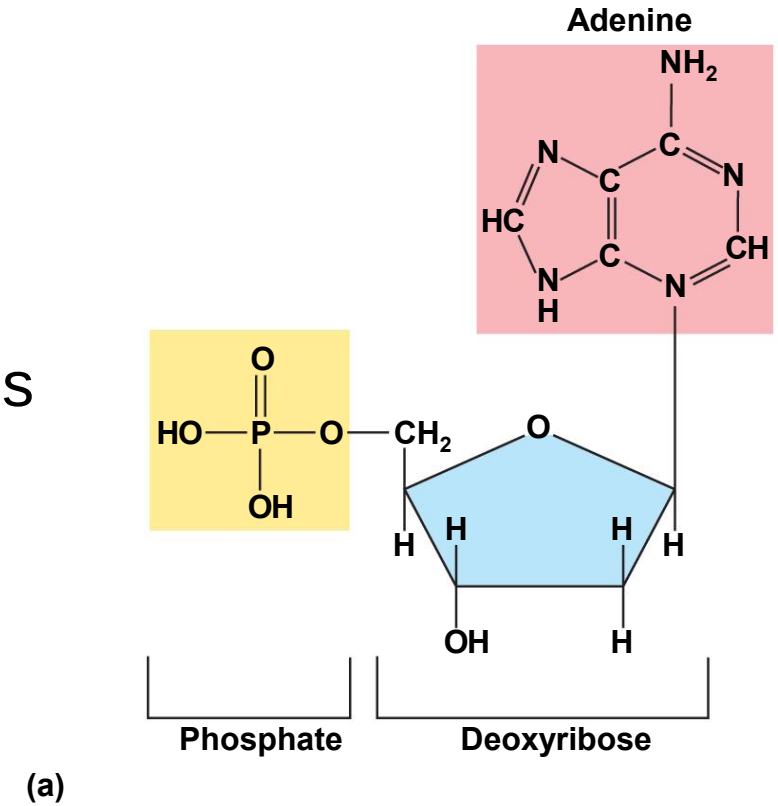
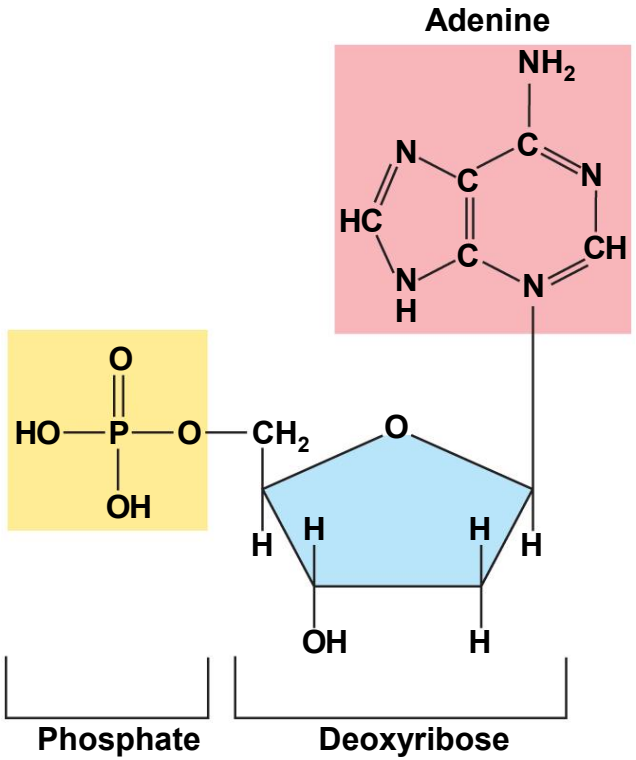


Figure 4.1a

DNA Structure and Function

- DNA and other nucleic acids are **polymers of nucleotides**
- Each **nucleotide** consists of
  - One sugar—deoxyribose
  - One phosphate group
  - One nitrogenous base
    - Either pyrimidine (single carbon–nitrogen ring) or purine (double ring)



(a)

Figure 4.1a

DNA Structure and Function

- **Purines**—double ring
  - **Adenine (A)**
  - **Guanine (G)**
- **Pyrimidines**—single ring
  - **Cytosine (C)**
  - **Thymine (T)**
- **DNA bases—ATCG**

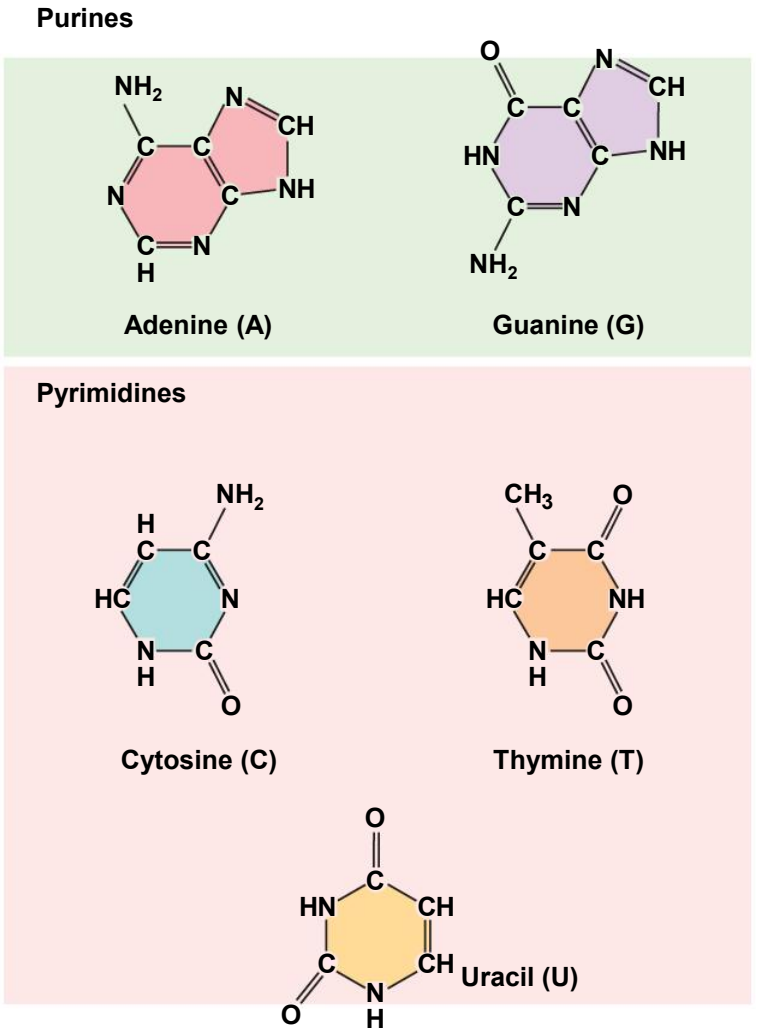


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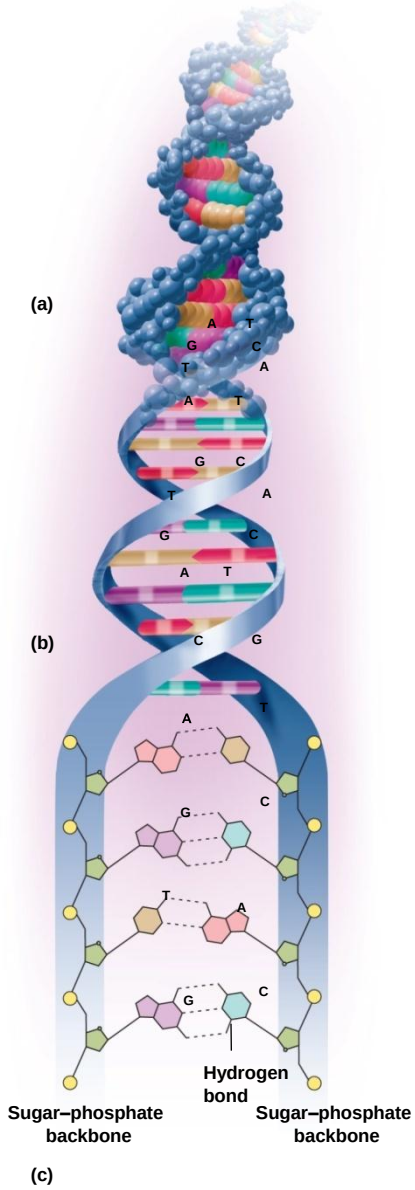
Figure 4.1b

DNA Structure and Function



- Molecular shape is a **double helix** (resembles a spiral staircase)
  - Each sidepiece is a backbone composed of **phosphate groups** alternating with the sugar **deoxyribose**
  - Steplike connections between the backbones are **pairs of nitrogen bases**

Figure 4.2

DNA Structure and Function

- Nitrogenous bases united by **hydrogen bonds**
  - A purine on one backbone with a pyrimidine on the other
  - **A–T** two hydrogen bonds
  - **C–G** three hydrogen bonds
- DNA base pairing
  - **A–T**
  - **C–G**
- **Law of complementary base pairing**
  - One strand determines base sequence of other

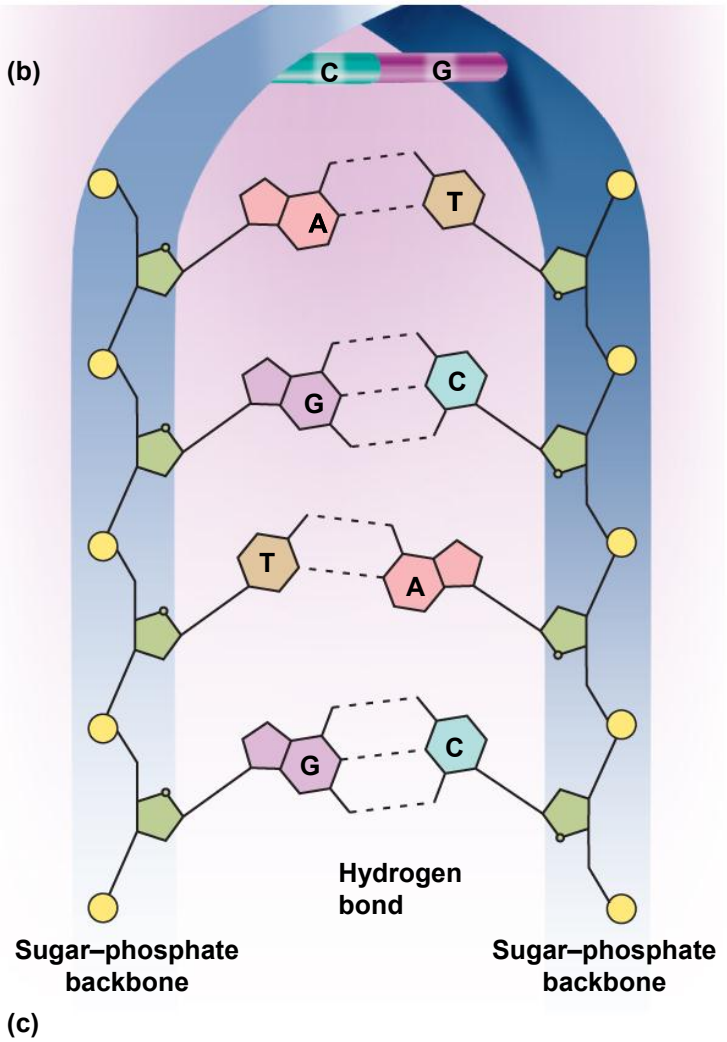


Figure 4.2b,c

Discovery of the Double Helix

- By 1900: components of DNA were known
  - Sugar, phosphate, and bases
- By 1953: X-ray diffraction determined geometry of DNA molecule
- Nobel Prize awarded in 1962 to three men: **Watson, Crick,** and **Wilkins**, but not to Rosalind Franklin, who died of cancer at 37, after discovering the X-ray data that provided the answers to the double helix

DNA Structure and Function

- **Genes**—genetic instructions for synthesis of proteins
- **Gene**—segment of DNA that codes for a specific protein
- **Genome**—all the genes of one person
  - Humans have estimated 20,000 to 25,000 genes
    - 2% of total DNA
    - Other 98% is noncoding DNA
      - Plays role in chromosome structure
      - Regulation of gene activity
      - No function at all: “junk” DNA

Chromatin and Chromosomes

- **Chromatin**—fine filamentous DNA material complexed with proteins
  - Occurs as **46** long filaments called **chromosomes**
  - 6 feet in first half of cell cycle
  - Twice that amount in preparation for cell division
  - In **nondividing cells,** chromatin is so slender it cannot be seen with light microscope
  - Granular appearance under electron microscope

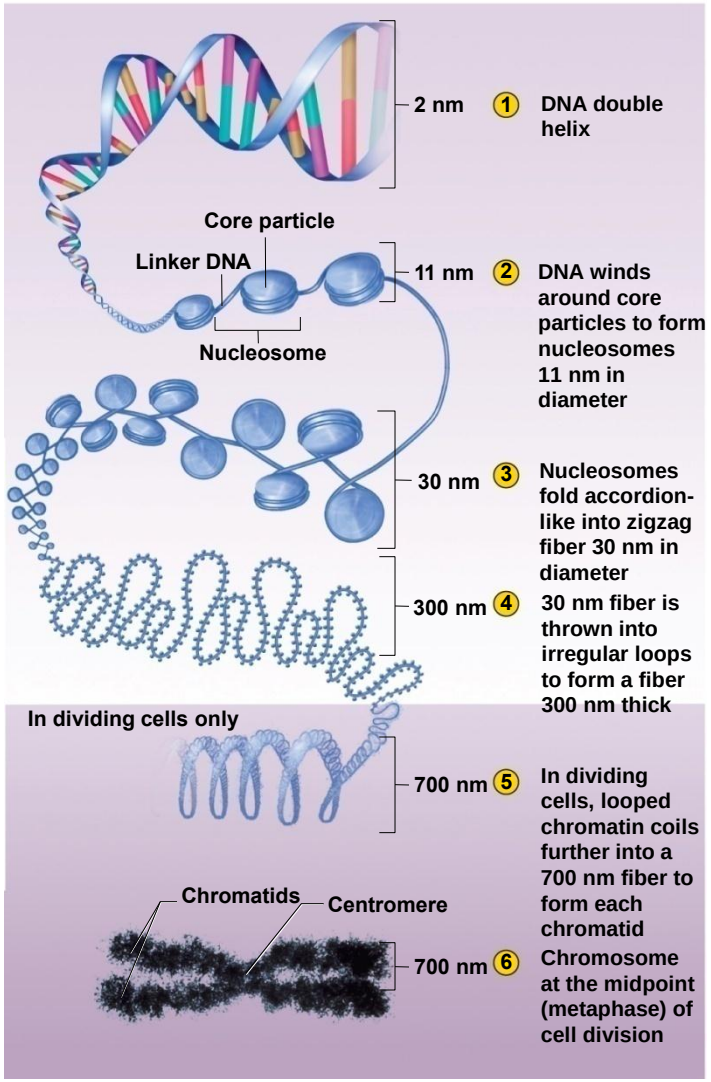


Figure 4.4b

Chromatin and Chromosomes

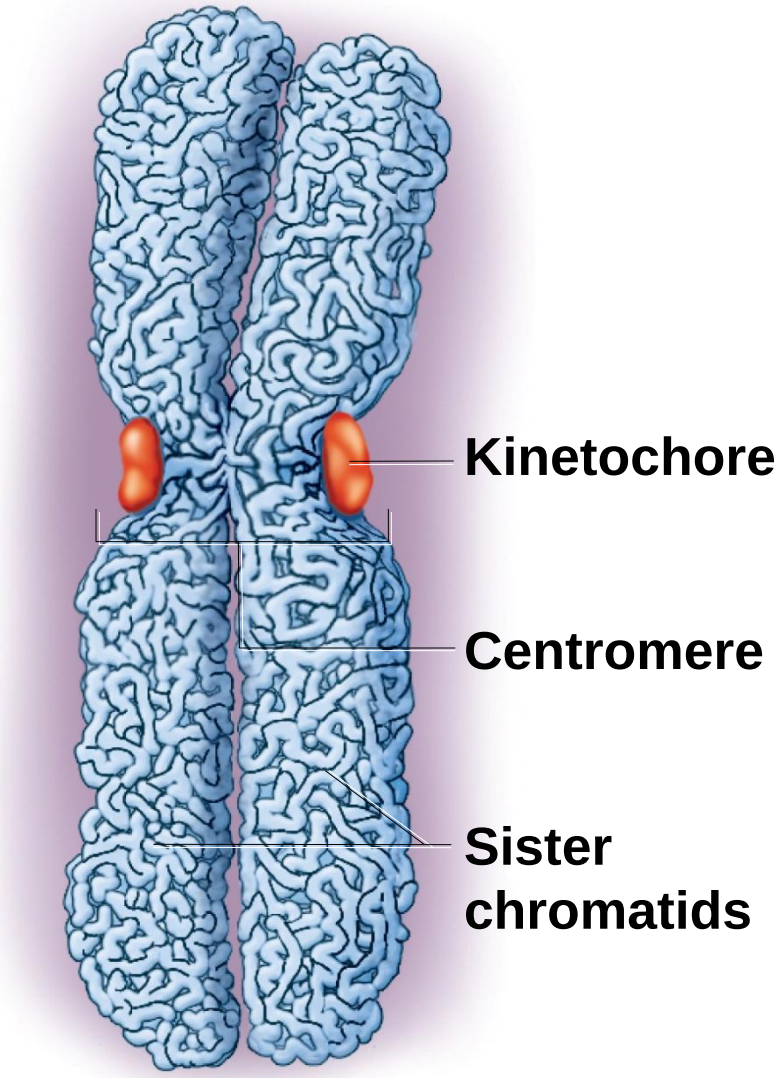
- **Histones**—disc-shaped cluster of eight proteins
  - DNA molecule winds around the cluster
  - Repeats pattern 800,000 times
  - Appears to be divided into segments: nucleosomes
- **Nucleosome** consists of:
  - **Core particle**—histones with DNA around them
  - **Linker DNA**—short segment of DNA connecting core particles
  - One-third shorter than DNA alone
- **Chromatin–protein complex** thrown into complex, irregular loops and coils
  - 1,000 times shorter than original molecule

Chromatin and Chromosomes

- Each chromosome is packed into its own spheroidal region of the nucleus—**chromosome territory**
  - Permeated with channels that allow regulatory chemicals to have access to the genes
- In nondividing cell, the chromatin is not a static structure
  - Changes moment to moment according to genetic activity of cell
  - Genes get turned off and on
  - Chromosomes migrate as cells develop, moving active genes on different chromosomes closer together
    - Allows genes to partner to bring about developmental tasks in the cell

Chromatin and Chromosomes

- Exact copies are made of all the nuclear DNA
- Each chromosome consists of two parallel filaments of identical DNA— **sister chromatids**
- In prophase, final coiling and condensing
  - Now visible with light microscope
- Final compaction enables the two sister chromatids to be pulled apart and carried to separate daughter cells without damage to the DNA
  - Joined at **centromere**
  - **Kinetochore**—protein plaques on either side of the centromere



(a) Figure 4.5a

RNA Structure and Function

- **RNA** much smaller cousin of DNA (fewer bases)
  - **Messenger RNA** (mRNA) over 10,000 bases
  - **Ribosomal RNA** (rRNA)
  - **Transfer RNA** (tRNA) 70 to 90 bases
  - DNA averages 100 million base pairs
- **One nucleotide chain** (not a double helix as DNA)
- **Ribose** replaces deoxyribose as the sugar
- **Uracil** replaces thymine as a nitrogenous base
- Essential function
  - Interprets code in DNA
  - Uses those instructions for protein synthesis
  - Leaves nucleus and functions in cytoplasm

Genes and Their Action

- **Expected Learning Outcomes**
  - Give a working definition of the *gene* and explain why new discoveries in genetics have changed our concept of what a gene is.
  - Explain what the human genome is and what relationship it has to the health sciences.
  - Define *genetic code* and describe how DNA codes for protein structure.

Genes and Their Action

Cont.

- Describe the process of assembling amino acids to form a protein.
- Explain what happens to a protein after its amino acid sequence has been synthesized.
- Describe some ways that a gene can be turned on or off.
- Explain how DNA indirectly regulates the synthesis of nonprotein molecules.

What Is a Gene?

- Previous definition: **gene**—a segment of DNA that carries the code for a particular protein
  - Body has millions of proteins but only about 25,000 genes
  - Small % of genes produce only RNA molecules
  - Some segments of DNA belong to two different genes
- Current definition: **gene**—an information-containing segment of DNA that codes for the production of a molecule of RNA that plays a role in synthesizing one or more proteins
- Amino acid sequence of a protein is determined by the nucleotide sequence in the DNA

The Genome

- **Genome**—all the DNA in one 23-chromosome set
  - 3.1 billion nucleotide pairs in human genome
- 46 human chromosomes come in two sets of 23 chromosomes
  - One set of 23 chromosomes came from each parent
  - Each pair of chromosomes has same genes but different versions (alleles) exist
- **Human Genome Project** (1990–2003) identified the nitrogenous base sequences of 99% of the human genome
  - **Genomics**—the comprehensive study of the whole genome and how its genes and noncoding DNA interact to affect the structure and function of the whole organism

The Genome

- **Findings of Human Genome Project:**
  - ***Homo sapiens*** has fewer genes than the 100,000 previously believed
  - Genes generate millions of different proteins
    - Not the old one gene, one protein theory
    - Single gene can code for many different proteins
  - Genes average about 3,000 bases long
    - Range up to 2.4 million bases
  - All humans are at least 99.99% genetically identical
    - 0.01% variations that we can differ from one another in more than 3 million base pairs
    - Various combinations of these **single-nucleotide polymorphisms** account for all human variation

The Genome

Cont.

- Some chromosomes are gene-rich and some gene-poor
- We now know the locations of more than 1,400 disease-producing mutations
  - Opens the door for a new branch of medical diagnosis and treatment called genomic medicine
  - Before HGP, we knew locations of fewer than 100 disease-producing mutations

The Genetic Code

- Body can make millions of different proteins, all from the same **20 amino acids,** and encoded by genes made of just **four nucleotides** (A, T, C, G)
- **Genetic code**—a system that enables these four nucleotides to code for the amino acid sequence of all proteins
- Minimum code to symbolize 20 amino acids is three nucleotides per amino acid

The Genetic Code

- **Base triplet—**a sequence of three DNA nucleotides that stands for one amino acid
  - **Codon—**the 3-base sequence in mRNA
  - **64 possible codons** available to represent the 20 amino acids
    - 61 code for amino acids
    - **Stop codons—UAG, UGA,** and **UAA:** signal “end of message,” like a period at the end of a sentence
    - **Start codon—AUG** codes for methionine, and begins the amino acid sequence of the protein

Genomic Medicine

- Application of our knowledge of the genome to the prediction, diagnosis, and treatment of disease
  - Relevant to disorders (e.g., cancer, Alzheimer disease, schizophrenia, obesity, AIDS, tuberculosis)
- Allows for early detection of diseases, more effective clinical intervention
- Expands potential for gene-substitution therapy

Protein Synthesis

- All body cells, except sex cells and some immune cells, contain identical genes
- Different genes are activated in different cells
- Any given cell uses one-third to two-thirds of its genes
  - Rest remain dormant and may be functional in other types of cells

Protein Synthesis

- **Activated gene**
  - **Messenger RNA (mRNA)**—a mirror image of the gene is made
    - Migrates from the nucleus to cytoplasm
    - Its code is read by the ribosomes
  - **Ribosomes**—cytoplasmic granules composed of ribosomal RNA (rRNA) and enzymes
  - **Transfer RNA (tRNA)**—delivers amino acids to the ribosome
  - Ribosomes assemble amino acids in the order directed by the codons of mRNA

Protein Synthesis

- Process of protein synthesis
  - **DNA** → **mRNA** → **protein**
- **Transcription**—step from **DNA** to **mRNA**
  - Occurs in the nucleus where DNA is located
- **Translation**—step from **mRNA** to **protein**
  - Most occurs in cytoplasm
  - 10% to 15% of proteins are synthesized in the nucleus

Transcription

- DNA too large to leave nucleus and participate directly in cytoplasmic protein synthesis
  - Necessary to make a small mRNA copy that can migrate through a nuclear pore into the cytoplasm
- **Transcription**—copying genetic instructions from DNA to RNA

Transcription

- **RNA polymerase—**enzyme that binds to the DNA and assembles the mRNA
  - Base sequences TATATA or TATAAA inform the polymerase where to begin
  - RNA polymerase opens up the DNA helix about 17 base pairs at a time
  - Reads base from one strand of DNA
  - Makes corresponding mRNA
    - Where it finds C on the DNA, it adds G to the mRNA
    - Where it finds A on the DNA, it adds U to the mRNA

Transcription

- RNA polymerase rewinds the DNA helix behind it
  - Gene can be transcribed by several polymerase molecules at once
  - **Terminator:** base sequence at the end of a gene which signals polymerase to stop
- Pre-mRNA—immature RNA produced by transcription
- **Exons—**"sense" portions of the immature RNA
  - Will be translated to protein
- **Introns—**"nonsense" portions of the immature RNA
  - Must be removed before translation
- **Alternative splicing—**removing the introns by enzymes and splicing the exons together into a functional RNA molecule
  - One gene can code for more than one protein

Alternative Splicing of mRNA

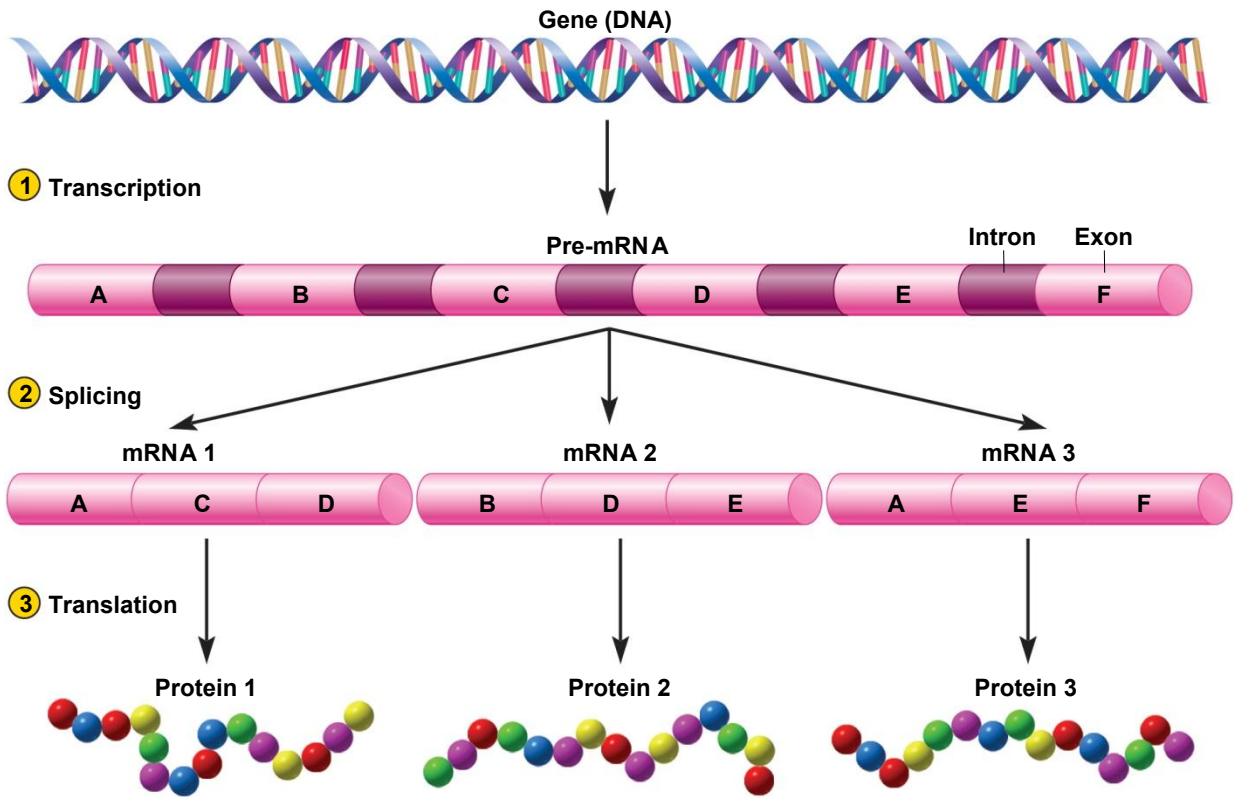


Figure 4.6

- One gene can code for more than one protein
- Exons can be spliced together into a variety of different mRNAs

Translation

- **Translation**—the process that converts the language of nucleotides into the language of amino acids

- **Ribosomes**—translate sequence of nucleotides into the sequence of amino acids
  - Occur mainly in cytosol, on surface of rough ER, and nuclear envelope
  - Consists of two granular subunits, large and small
    - Each made of several rRNA and enzyme molecules

Translation

- **mRNA** molecule begins with **leader sequence**
  - Acts as binding site for small ribosomal subunit
  - Large subunit attaches to small subunit
  - Ribosome pulls mRNA molecule through it like a ribbon, reading the bases as it goes
  - When start **codon (AUG)** is reached, protein synthesis begins
  - All proteins begin with **methionine** when first synthesized

Transfer RNA

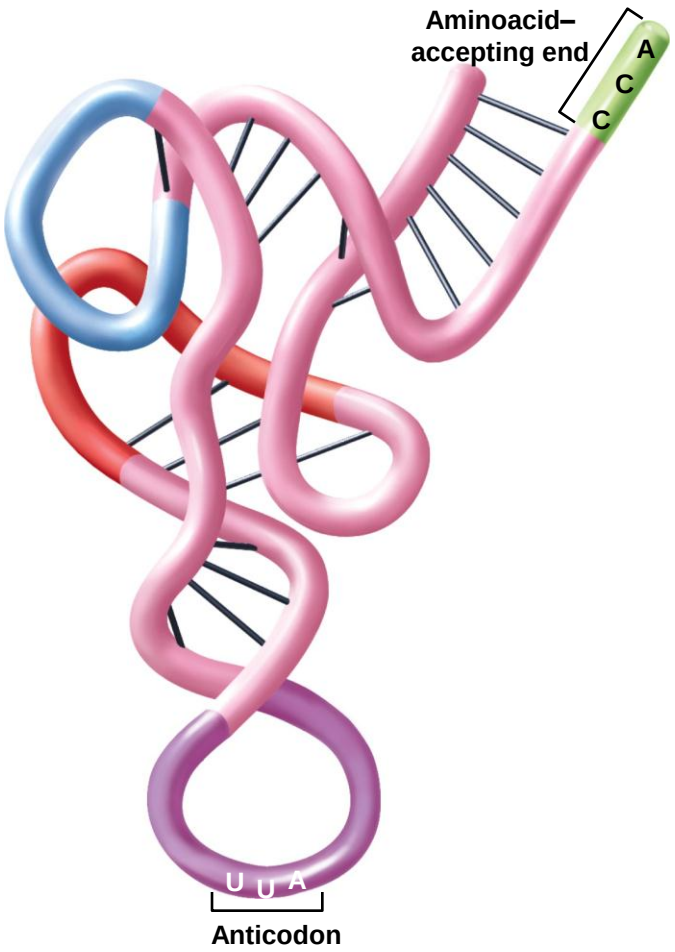


Figure 4.7

- Requires the participation of **transfer RNA** (tRNA)
  - Small RNA molecule
  - Coils on itself to form an angular L shape
  - One end of the L includes three nucleotides called an **anticodon**
  - Other end has binding site specific for one amino acid
  - Each tRNA picks up specific amino acids from pool of free amino acids in cytosol
    - One ATP molecule is used to bind amino acid to site
    - Provides energy for peptide bond formation

Translation

- Some imprecision in codon-anticodon pairing
  - Takes only 48 different tRNAs to pair with 61 different codons
- Ribosome binds and holds tRNA with its specific amino acid
- Large ribosomal subunit contains an enzyme that forms **peptide bond** that links amino acids together
- First tRNA released from ribosome
- Second tRNA temporarily anchors growing peptide chain
- Ribosome shifts and third tRNA brings its amino acid to the site

Translation

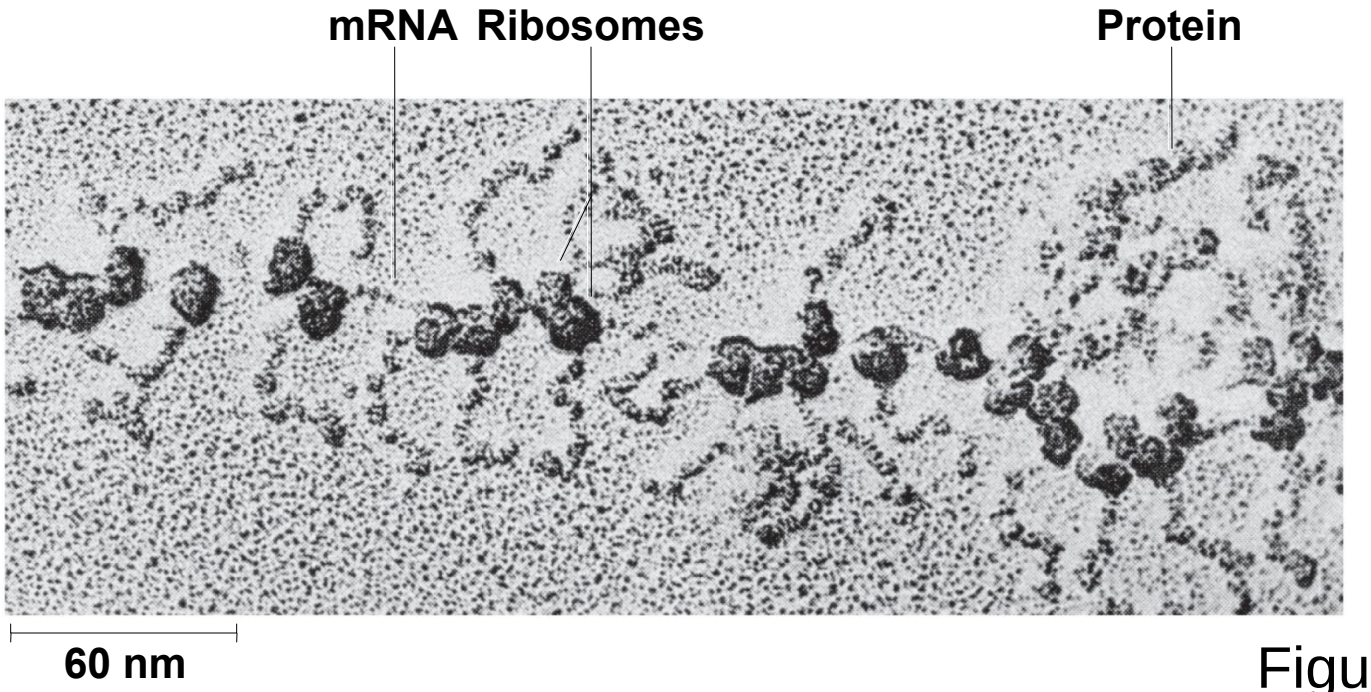


Figure 4.9

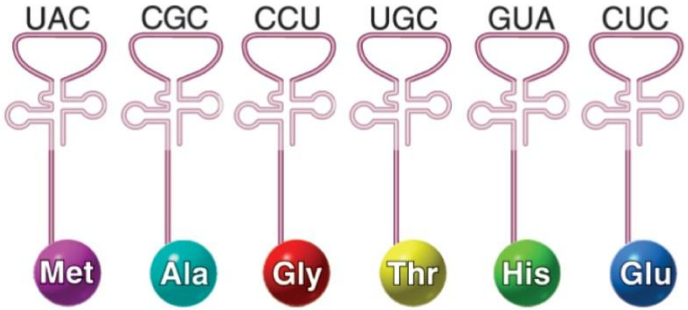
- **Polyribosome—**one mRNA holding multiple ribosomes
  - One ribosome can assemble protein of 400 amino acids in 20 seconds
  - 300,000 identical mRNA molecules may be undergoing simultaneous translation
- Cell can produce 150,000 protein molecules per second

Review of Peptide Formation

1 DNA double helix

2 Seven base triplets on the template strand of DNA

3 The corresponding codons of mRNA transcribed from the DNA triplets



4 The anticodons of tRNA that bind to the mRNA codons

5 The amino acids carried by those six tRNA molecules

6 The amino acids linked into a peptide chain

Figure 4.10

Protein Processing and Secretion

- Protein synthesis is not finished when the amino acid sequence (**primary structure**) has been assembled
- To be functional it must coil or fold into precise

  secondary and **tertiary structure**
- **Chaperone proteins**
  - Older proteins that pick up new proteins and guide the new proteins in folding into the proper shapes
  - Helps to prevent improper association between different proteins
  - Also called **stress proteins** or **heat-shock proteins**
    - Chaperones produced in response to heat or stress
    - Help damaged proteins fold back into correct functional shapes

Protein Processing and Secretion

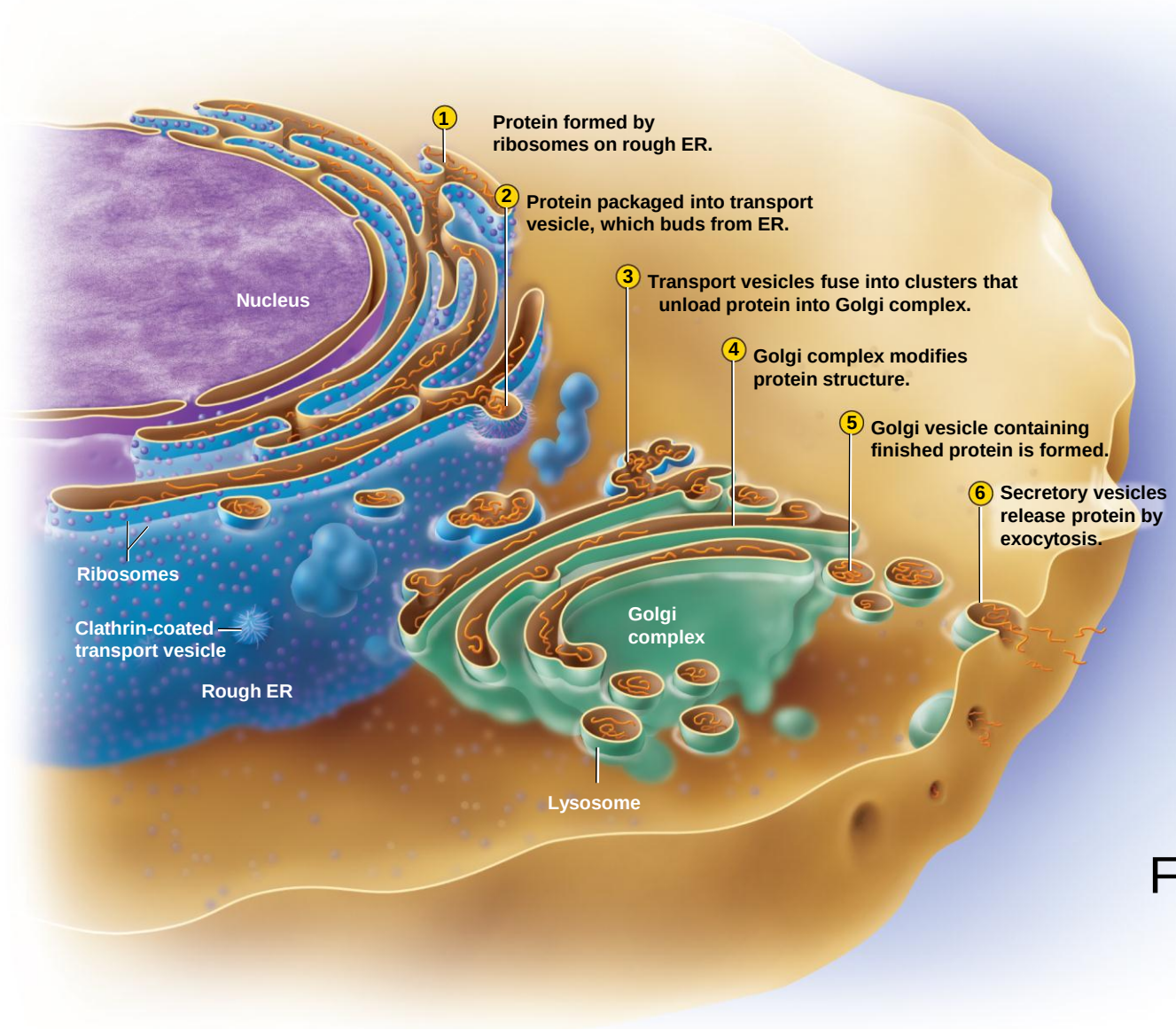


Figure 4.11

Protein Processing and Secretion

- Proteins to be used in the cytosol are likely to be made on free ribosomes in the cytosol
- Proteins destined for packaging into lysosomes or secretion from the cell are assembled on rough ER and sent to Golgi complex for packaging
  - Entire polyribosome migrated to the rough ER and docks on its surface
  - Assembled amino acid chain completed on rough ER
  - Sent to Golgi for final modification

Protein Processing and Secretion

- Proteins assembled on ER surface, threads itself through a pore in the ER membrane into cisterna
- ER modifies protein by **posttranslational modification**
  - Removing some amino acid segments; folding the protein; stabilizing protein with disulfide bridges; adding carbohydrates
- When rough ER is finished with protein
  - Pinches off bubblelike **transport vesicle** coated with **clathrin**
  - Clathrin helps select the proteins to be transported in vesicles and helps mold forming vesicle
  - Vesicles detach from ER and carry protein to the nearest cisterna of Golgi complex

Protein Processing and Secretion

- Vesicles fuse and unload proteins into Golgi cisterna
- Golgi complex further modifies the protein
  - Passes from cisterna closest to ER to cisterna farthest from ER
  - Buds off new coated Golgi vesicles containing finished protein
  - Some Golgi vesicles become lysosomes
  - Others become secretory vesicles and migrate to plasma membrane, fuse to it, and release their cell product by **exocytosis**

Gene Regulation

- Genes are turned on and off from day to day, hour to hour
- Their products may or may not be needed
- Many genes are permanently turned off in any given cell
  - Examples: genes for hemoglobin or digestive enzymes

Gene Regulation

- Several ways to turn genes on or off
  - Mother giving birth to first baby
  - Hormone **prolactin** stimulates cells of the mammary glands to begin synthesizing components of breast milk, including protein **casein**

1. Prolactin binds to **receptors**
   - Pair of proteins in plasma membrane of mammary cell
2. Receptors trigger the activation of a regulatory protein (**transcription activator**) in cytoplasm
3. Regulatory protein moves into the nucleus and binds to the DNA near the **casein gene**

Gene Regulation

Cont.

4. The binding enables **RNA polymerase** to bind to the gene and transcribe it, producing the **mRNA** for casein
5. The casein mRNA moves to the cytoplasm and is translated by ribosomes an the rough endoplasmic reticulum
6. The Golgi complex packages casein into secretory vesicles
7. The secretory vesicles release the casein by exocytosis, and it becomes part of the milk

Mechanism of Gene Activation

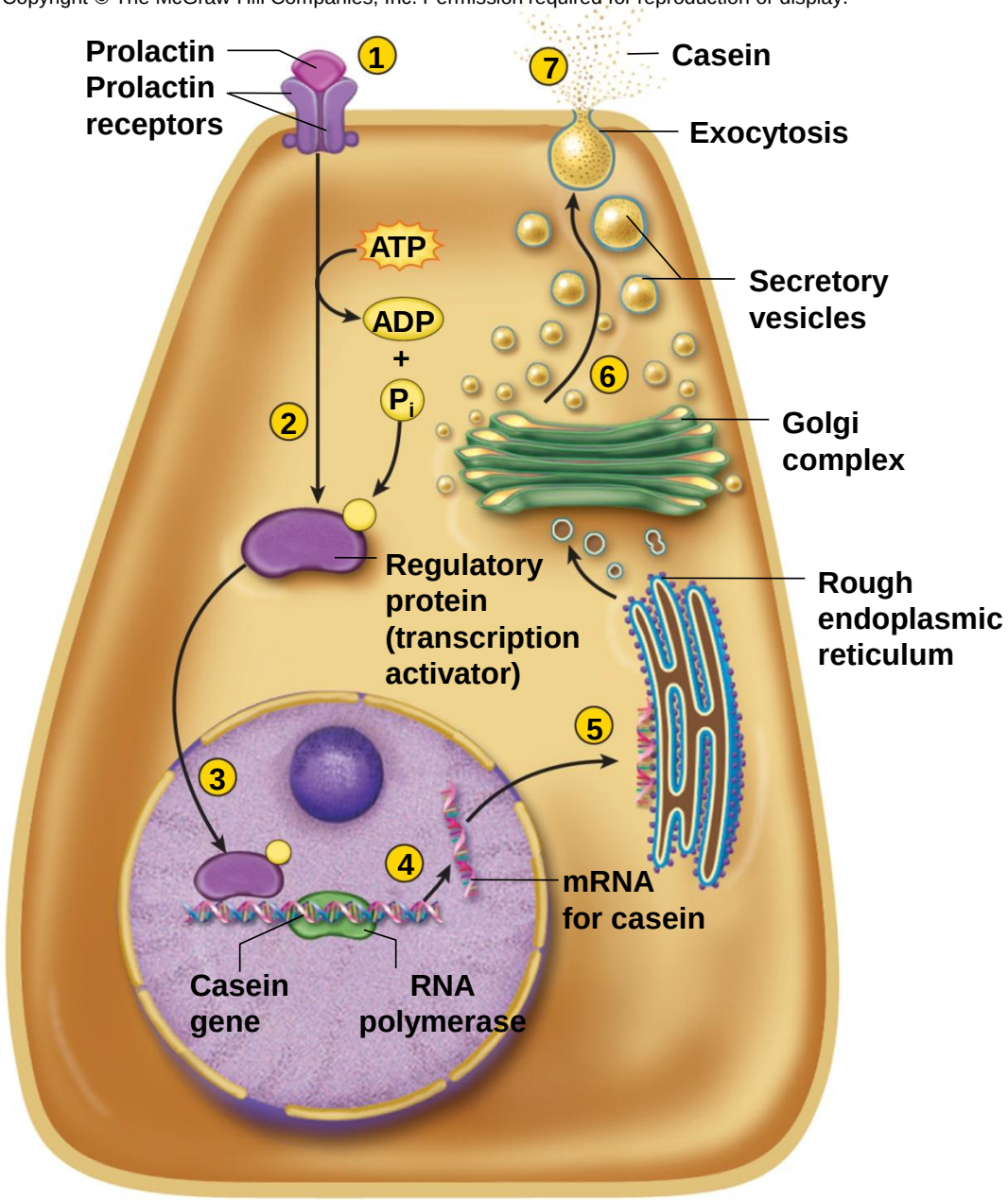


Figure 4.12

Synthesizing Compounds Other Than Proteins

- Cells synthesize glycogen, fat, steroids, phospholipids, pigments, and other compounds
  - No genes for these
  - Synthesis under indirect genetic control
  - Produced by enzymatic reactions
  - Enzymes are proteins encoded by genes
- Example: testosterone production
  - A steroid
  - A cell of the testes takes in cholesterol
  - Enzymatically converts it to testosterone
  - Only occurs when genes for enzyme are activate
- Genes may greatly affect such complex outcomes as behavior, aggression, and sex drive

DNA Replication and the Cell Cycle

- **Expected Learning Outcomes**
  - Describe how DNA is replicated.
  - Discuss the consequences of replication errors.
  - Describe the life history of a cell, including the events of mitosis.
  - Explain how the timing of cell division is regulated.

DNA Replication and the Cell Cycle

- Before a cell divides, it must **duplicate its DNA** so it can give a complete copy of all its genes to each daughter cell

- Since DNA controls all cellular function, this replication process must be very exact

DNA Replication

- **Law of complementary base pairing**—we can predict the base sequence of one DNA strand if we know the sequence of the other
  - Enables a cell to reproduce one strand based on the information in another

DNA Replication

1. Double helix unwinds from **histones**

2. Enzyme **DNA helicase** opens one short segment of helix at a time exposing its nitrogenous bases
   - **Replication fork—**the point where the DNA is opened up (like two separated halves of a zipper)

DNA Replication

3. **DNA polymerase** molecules move along each strand
   - Read the exposed bases
   - Match complementary free nucleotides
   - The two separated strands of DNA are copied by separate polymerase molecules proceeding in opposite directions
   - The polymerase molecule moving toward the replication fork makes a long, continuous, new strand of DNA

DNA Replication

Cont.

- The polymerase molecule moving away from the replication fork makes short segments of DNA at a time—**DNA ligase** joins them together
- From the old **parental DNA** molecule, two new **daughter** DNA molecules are made
- **Semiconservative replication**—each daughter DNA consists of one new helix synthesized from free nucleotides and one old helix conserved from the parental DNA

DNA Replication

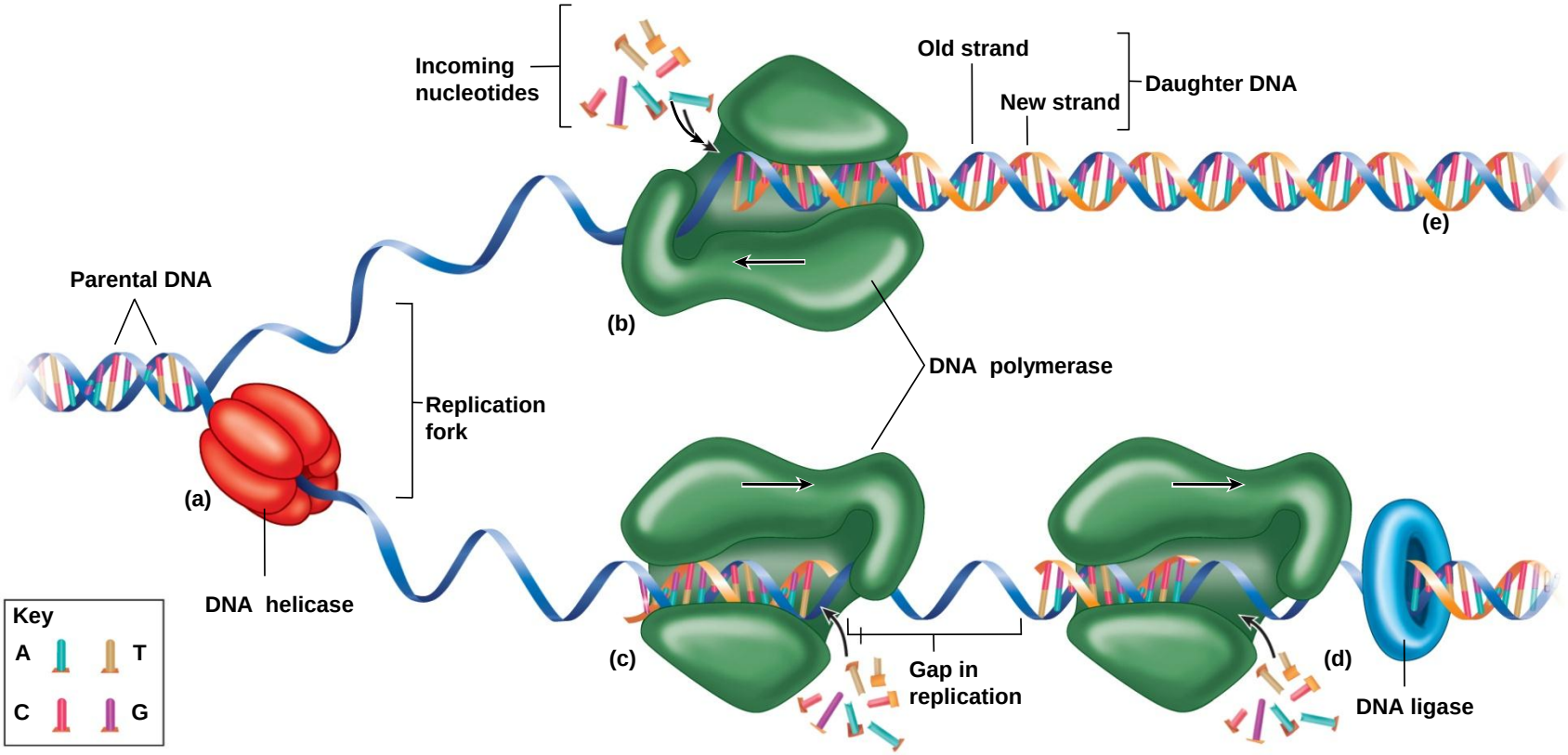


Figure 4.14

DNA Replication

4. New histones are synthesized in cytoplasm
   - Millions of histones are transported into the nucleus within a few minutes after DNA replication
   - Each new DNA helix wraps around them to make a new nucleosome
   - Each DNA polymerase works at a rate of 100 base pairs per second
   - Would take weeks for one polymerase to replicate one chromosome
   - Thousands of polymerase molecules work simultaneously on each DNA molecule
   - All 46 chromosomes are replicated in 6 to 8 hours

Errors and Mutations

- **DNA polymerase** does make mistakes
  - Multiple modes for correction of replication errors
  - Double checks the new base pair and tends to replace incorrect, biochemically unstable pairs with more stable correct pairs
  - Result is only one error per 1 billion bases replicated
- **Mutations**—changes in DNA structure due to replication errors or environmental factors (radiation, viruses, chemicals)
  - Some mutations cause no ill effects, others kill the cell, turn it cancerous, or cause genetic defects in future generations

The Cell Cycle

- **Cell cycle**—the cell's life cycle that extends from one division to the next

- **G_1 phase**—the first gap phase
  - Interval between cell division and DNA replication
  - Accumulates materials needed to replicate DNA

- **S phase**—synthesis phase
  - Duplicates centrioles
  - DNA replication occurs

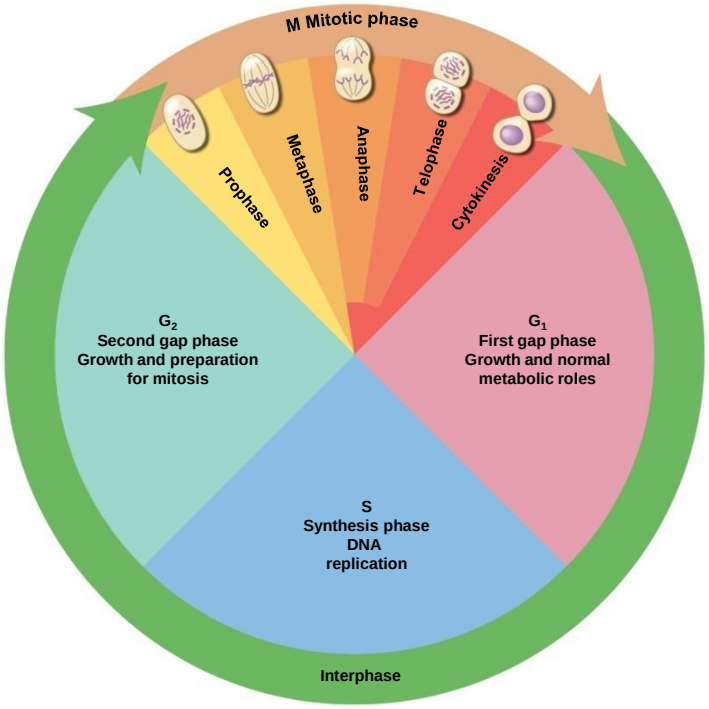


Figure 4.15

The Cell Cycle

- **G_2 phase**—second gap phase
  - Interval between DNA replication and cell division
  - Finishes centriole duplication
  - Synthesizes enzymes that control cell division
  - Repairs DNA replication errors
- **M phase**—mitotic phase
  - Cell replicates its nucleus
  - Pinches in two to form new daughter cells
- **Interphase**—collection of G_1, S, and G_2 phases
- **G_0 (G zero) phase**—cells that have left the cycle for a “rest”
  - Muscle and nerve cells
- Cell cycle duration varies between cell types

Mitosis

- Cell division in all body cells except the eggs and sperm
- Functions of mitosis
  - Development of the individual from one fertilized egg to some 40 trillion cells
  - Growth of all tissues and organs after birth
  - Replacement of cells that die
  - Repair of damaged tissues
- Four phases of mitosis
  - Prophase, metaphase, anaphase, telophase

Mitosis

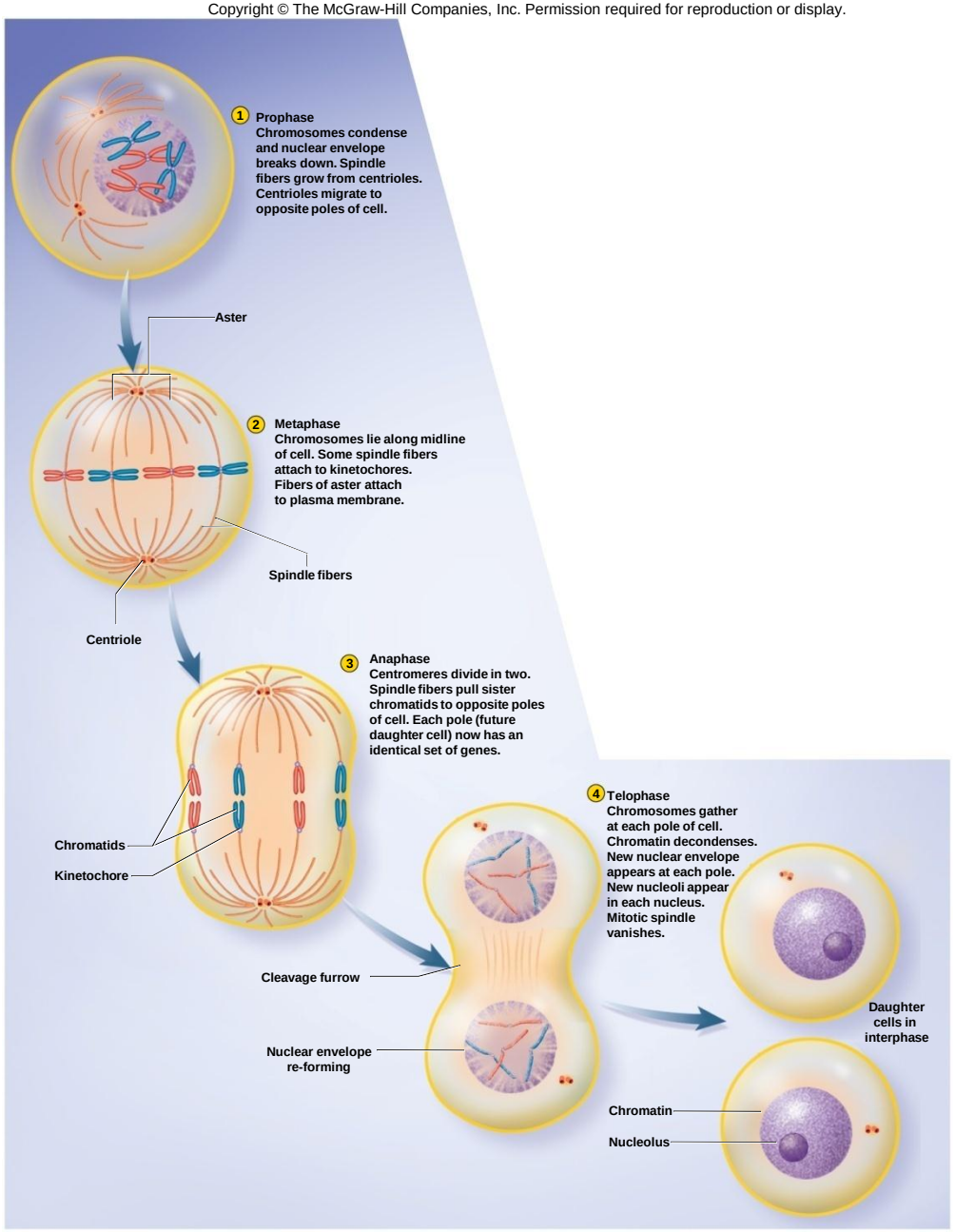


Figure 4.16

Mitosis

- **Prophase**
  - Chromosomes shorten and thicken, coiling into compact rods
  - Easier to distribute to daughter cells than chromatin
- 46 chromosomes
  - Two **chromatids** per chromosome
  - One molecule of DNA in each chromatid
- Nuclear envelope disintegrates and releases chromosomes into the cytosol
- Centrioles sprout elongated microtubules, called **spindle fibers**
  - Push centrioles apart as they grow
  - Pair of centrioles lies at each pole of the cell

Mitosis

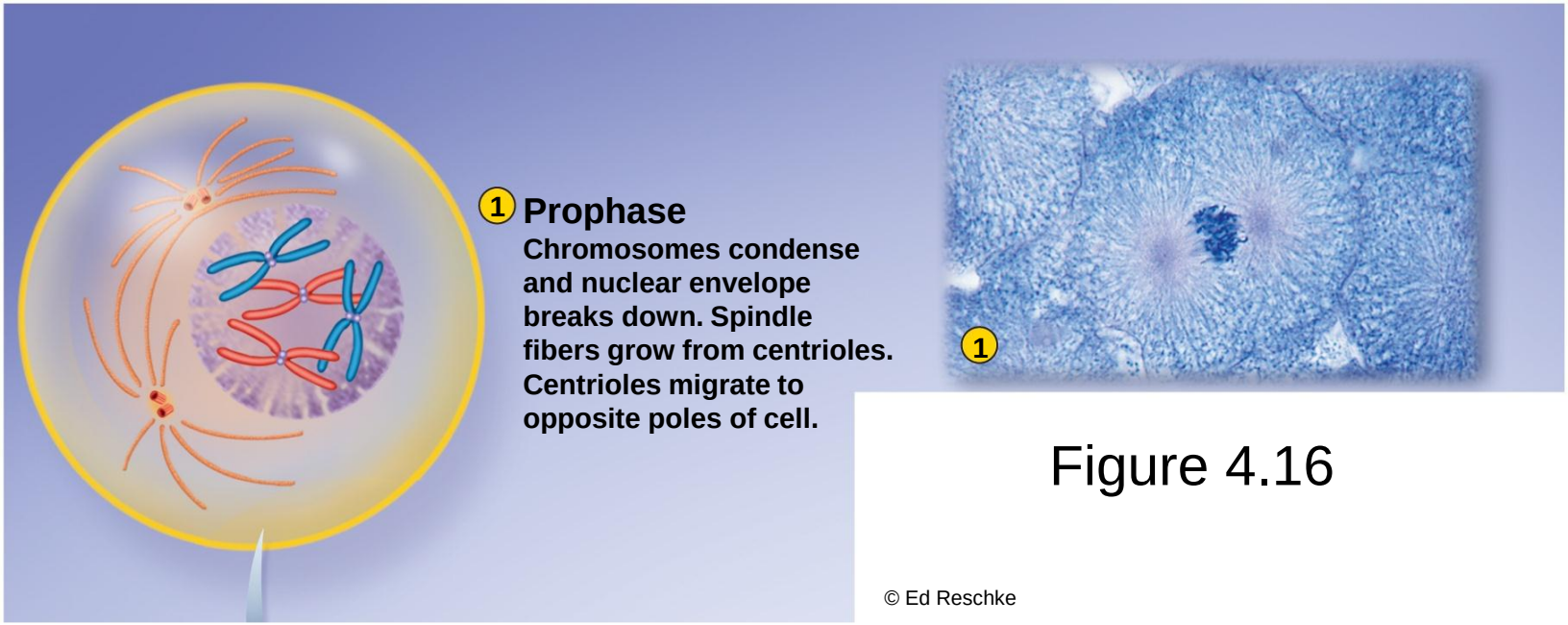


Figure 4.16

- Some spindle fibers grow toward chromosomes and attach to the kinetochore on each side of the centromere
- Spindle fibers then tug the chromosomes back and forth until they line up along the midline of the cell

Mitosis

- **Metaphase**
  - Chromosomes are aligned on **cell equator**
  - Oscillating slightly and awaiting signal that stimulates each of them to split
- **Mitotic spindle—**lemon-shaped array of spindle fibers
  - **Long spindle fibers** (microtubules) attach to chromosomes
  - **Shorter microtubules** (**aster**) anchor centrioles to plasma membrane at each end of cell

Mitosis

- **Anaphase**
  - Activation of an enzyme that cleaves two sister chromatids apart at centromere
  - Daughter chromosomes migrate toward each pole of the cell with centromere leading the way
  - Motor proteins in kinetochore crawling along the spindle fiber as the fiber itself is “chewed up” and disassembled at the chromosomal end
  - Daughter cells of mitosis are genetically identical

Mitosis

- **Telophase**
  - **Chromatids** cluster on each side of the cell
  - Rough ER produces **new nuclear envelope** around each cluster
  - Chromatids begin to uncoil and form **chromatin**
  - **Mitotic spindle** breaks up and vanishes
  - Each nucleus forms **nucleoli**
    - Indicating it has already begun making RNA and preparing for protein synthesis

Mitosis

- **Cytokinesis**—the division of cytoplasm into two cells
  - Telophase is the end of nuclear division but overlaps cytokinesis
  - Early traces of cytokinesis visible in anaphase
- Achieved by motor protein **myosin** pulling on microfilaments of **actin** in the terminal web of cytoskeleton
- Creates **cleavage furrow** around the equator of cell
- Cell eventually pinches in two

The Timing of Cell Division

Cells divide when:

- They have enough cytoplasm for two daughter cells
- They have replicated their DNA
- They have adequate supply of nutrients
- They are stimulated by **growth factor**
  - Chemical signals secreted by blood platelets, kidney cells, and other sources
- Neighboring cells die, opening up space in a tissue to be occupied by new cells

Cells stop dividing when:

- They snugly contact neighboring cells
- Nutrients or growth factors are withdrawn
- They undergo **contact inhibition**—the cessation of cell division in response to contact with other cells

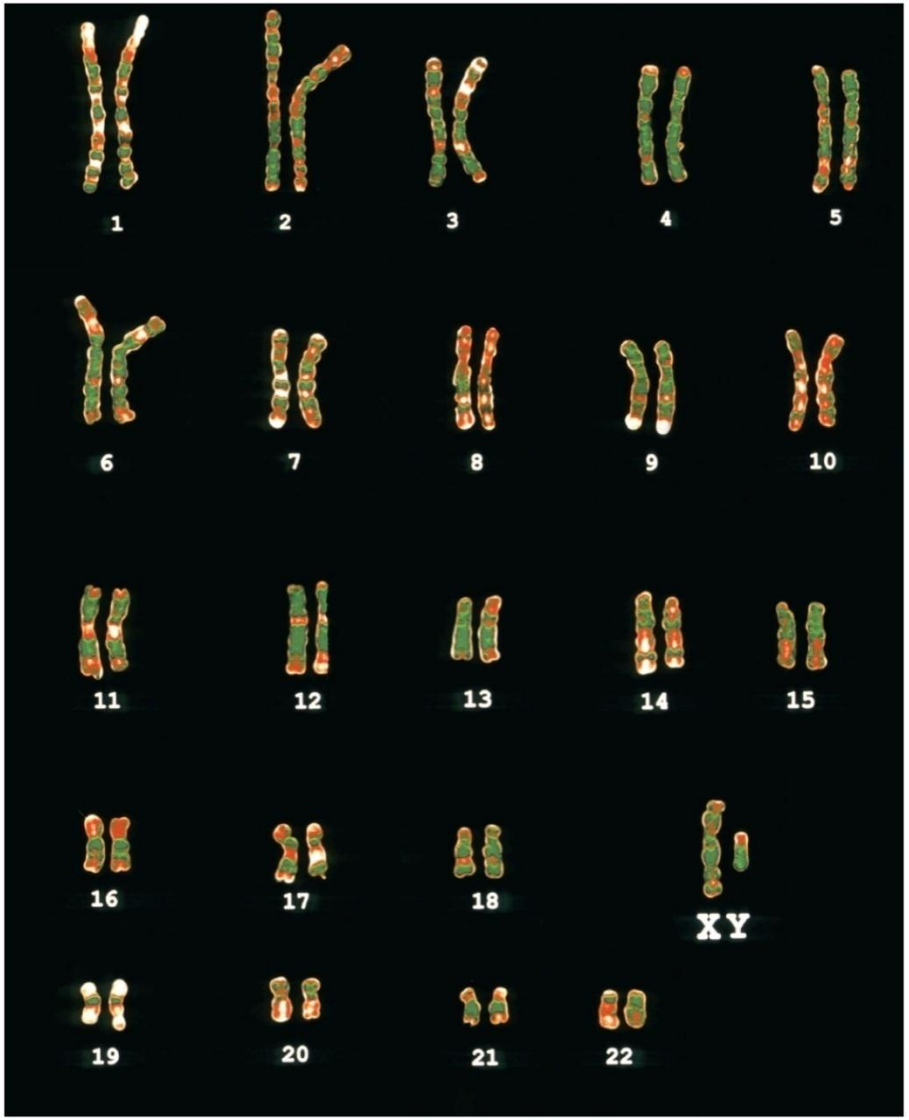
Chromosomes and Heredity

- **Expected Learning Outcomes**
  - Describe the paired arrangement of chromosomes in the human karyotype.
  - Define *allele* and discuss how alleles affect the traits of an individual.
  - Discuss the interaction of heredity and environment in producing individual traits.

Chromosomes and Heredity

- **Heredity**—transmission of genetic characteristics from parent to offspring
- **Karyotype**—chart of 46 chromosomes laid out in order by size and other physical features
- 23 pairs—the two members of each pair are called **homologous chromosomes**
  - 1 chromosome from each pair inherited from each parent
    - 22 pairs called **autosomes**
      - Look alike and carry the same genes
    - 1 pair of **sex chromosomes** (X and Y)
      - Normal **female** has homologous pair of X chromosomes
      - Normal **male** has one X and one much smaller Y chromosome

Karyotype of Normal Male



Peter Arnold, Inc.

Figure 4.17

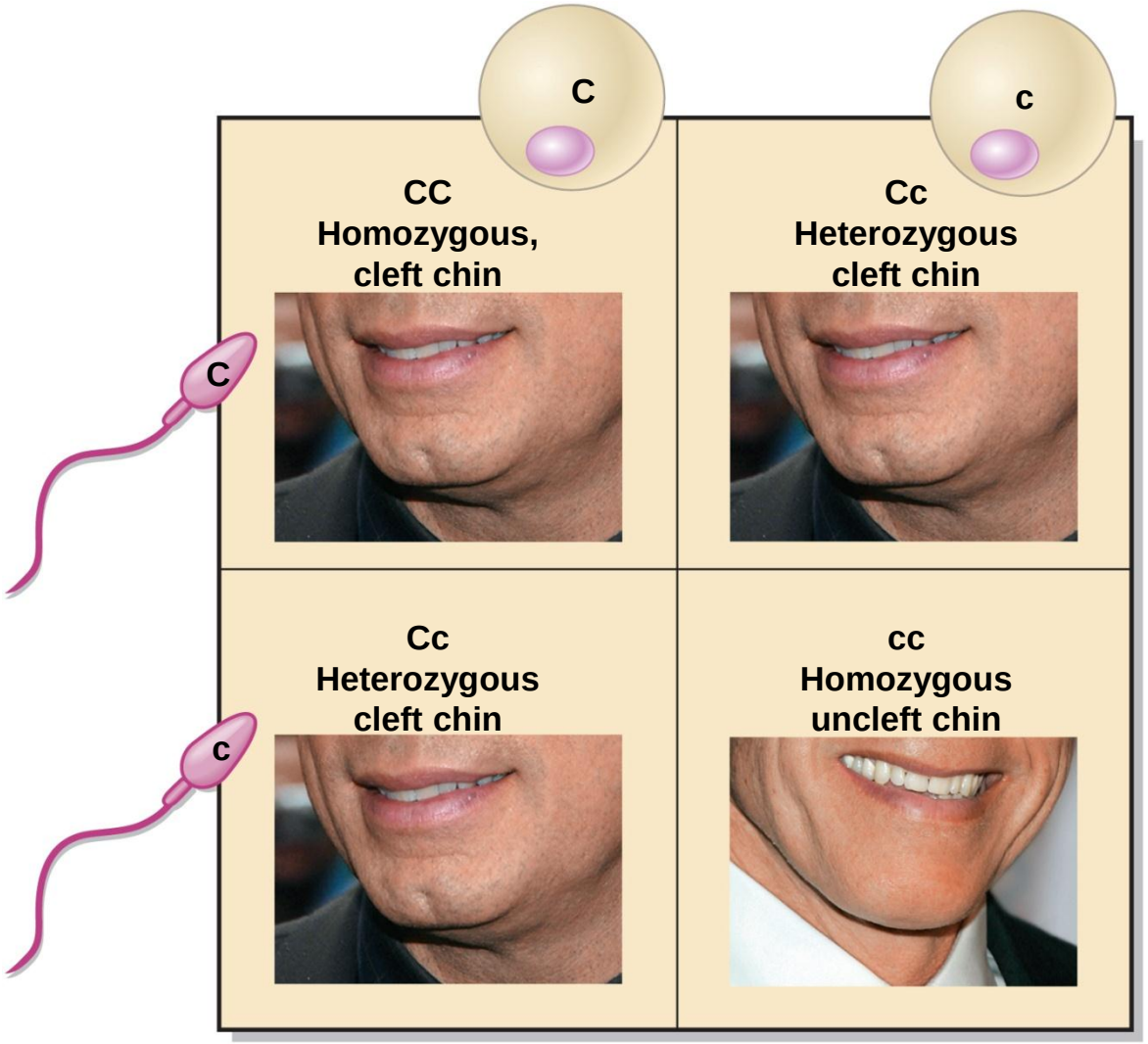
The Karyotype

- **Diploid—**any cell with 23 pairs of chromosomes (**somatic cells**)
- **Haploid—**contain half as many chromosomes as somatic cells: sperm and egg cells (**germ cells**)
- **Fertilization** restores diploid number to the fertilized egg and the somatic cells arise from it

Genes and Alleles

- **Locus**—the location of a particular gene on a chromosome
- **Alleles—**different forms of gene at same locus on two homologous chromosomes
- **Dominant allele** (represented by capital letter)
  - Corresponding trait is usually detectable in the individual
  - Masks the effect of any recessive allele that may be present
  - Produces protein responsible for visible trait
- **Recessive allele** (represented by lower case letter)
  - Expressed only when present on both of the homologous chromosomes
  - No dominant alleles at that locus

Genetics of Cleft Chin



(b)

Allele for cleft chin is dominant.

Figure 4.18 b

Genes and Alleles

- **Genotype**—the alleles that an individual possesses for a particular trait
  - **Homozygous** alleles—two identical alleles for a trait
  - **Heterozygous** alleles—different alleles for that gene
- **Phenotype**—an observable trait
  - An allele is **expressed** if it shows in the phenotype of an individual

Genes and Alleles

- **Genetic counselors**—perform genetic testing or refer clients for tests, advise couples on the probability of transmitting genetic diseases, and assist people on coping with genetic disease
- **Punnett square** shows how two heterozygous parents with cleft chins can have child with uncleft chin
  - Heterozygous **carriers** of hereditary diseases such as cystic fibrosis – Both parents healthy

Multiple Alleles, Codominance, and Incomplete Dominance

- **Gene pool—**collective genetic makeup of population as a whole
- **Multiple alleles—**more than two allelic forms for a trait
  - 100 alleles are responsible for cystic fibrosis
  - 3 alleles for ABO blood types
    - I^A, I^B, i alleles for ABO blood types

Multiple Alleles, Codominance, and Incomplete Dominance

- **Codominant—**both alleles equally dominant
  - I^AI^B = type AB blood
  - Both are phenotypically expressed

- **Incomplete dominance**
  - Phenotype intermediate between traits each allele would have produced alone

Polygenic Inheritance and Pleiotropy

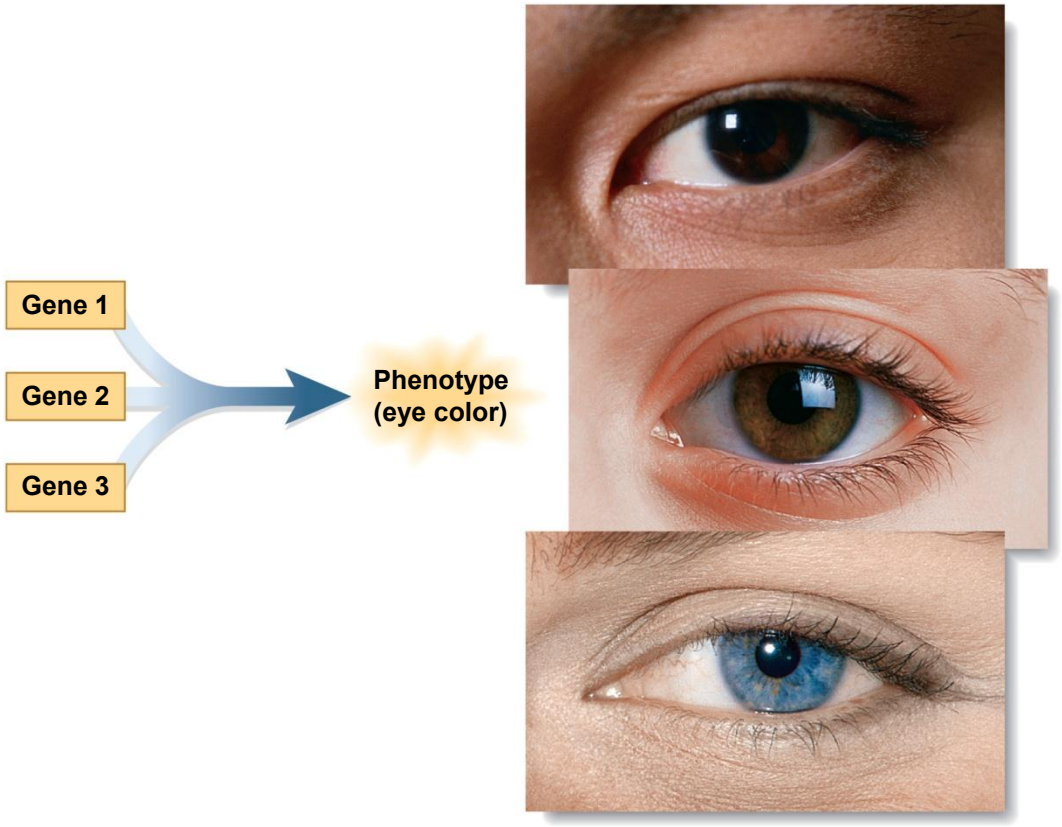


Figure 4.19

(top): Comstock/Getty Images; (middle & bottom): Photodisc Red/Getty Images

- Genes at two or more loci, or even different chromosomes, contribute to a single phenotypic trait (skin and eye color, alcoholism, mental illness, cancer, and heart disease)

Polygenic Inheritance and Pleiotropy

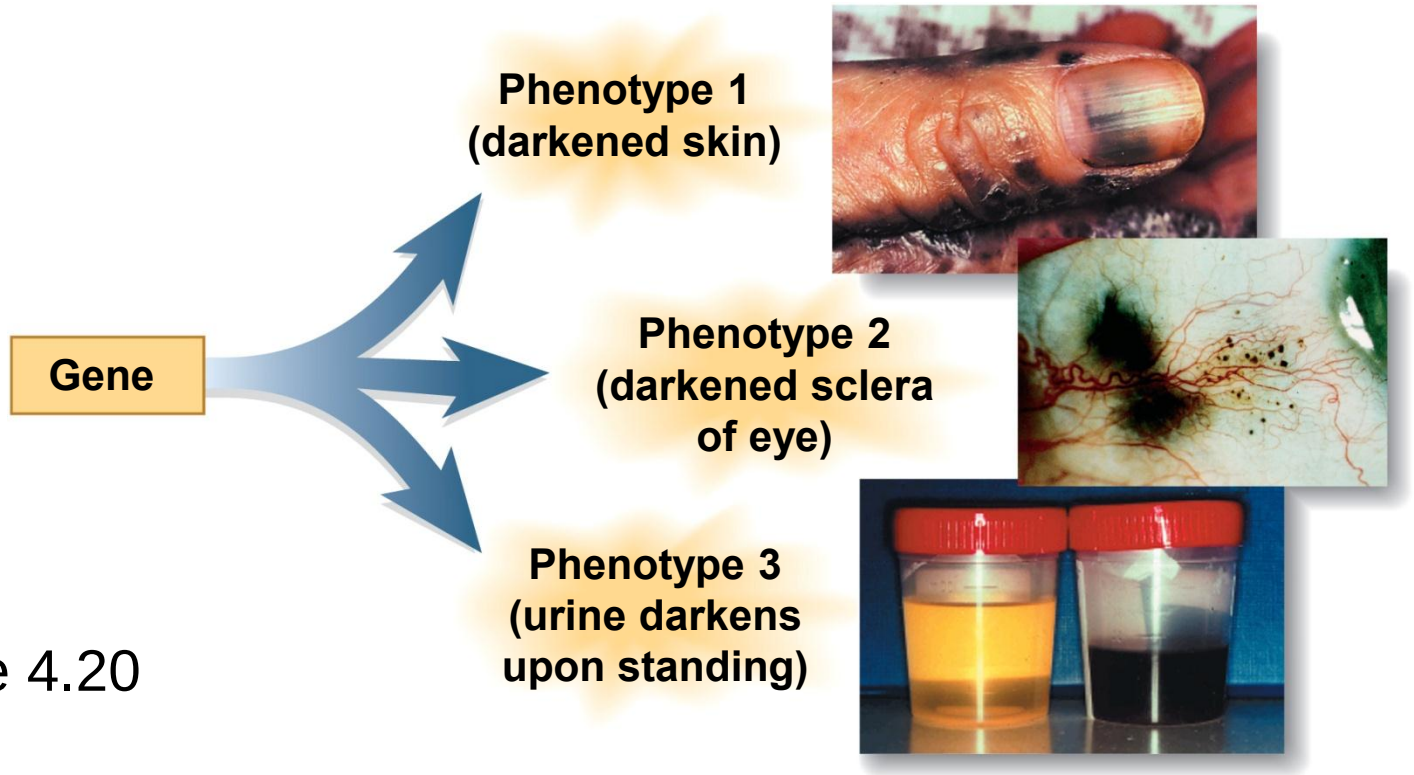


Figure 4.20

- One gene produces multiple phenotypic effects
  - **Alkaptonuria:** mutation on chromosome 3 that blocks the breakdown of tyrosine
  - **Sickle-cell disease** is another example of pleiotropy

Sex Linkage

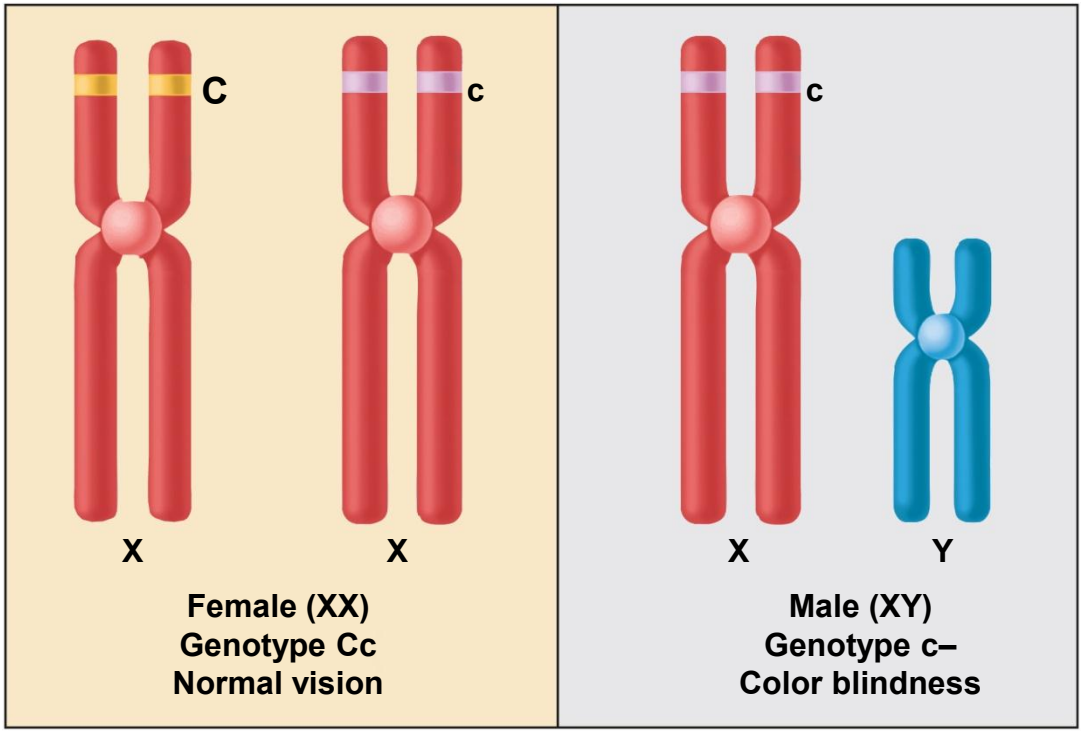


Figure 4.21

- **Sex-linked traits**—carried on the X and Y chromosomes, and therefore tend to be inherited by one sex more than the other
- Recessive color blindness allele on X, no gene locus for trait on Y, so red-green color blindness more common in men (mother is carrier)

Penetrance and Environmental Effects

- **Penetrance**—the percentage of a population with a given genotype that actually exhibits the predicted phenotype
- A dominant allele causes polydactyly
  - Presence of extra fingers or toes

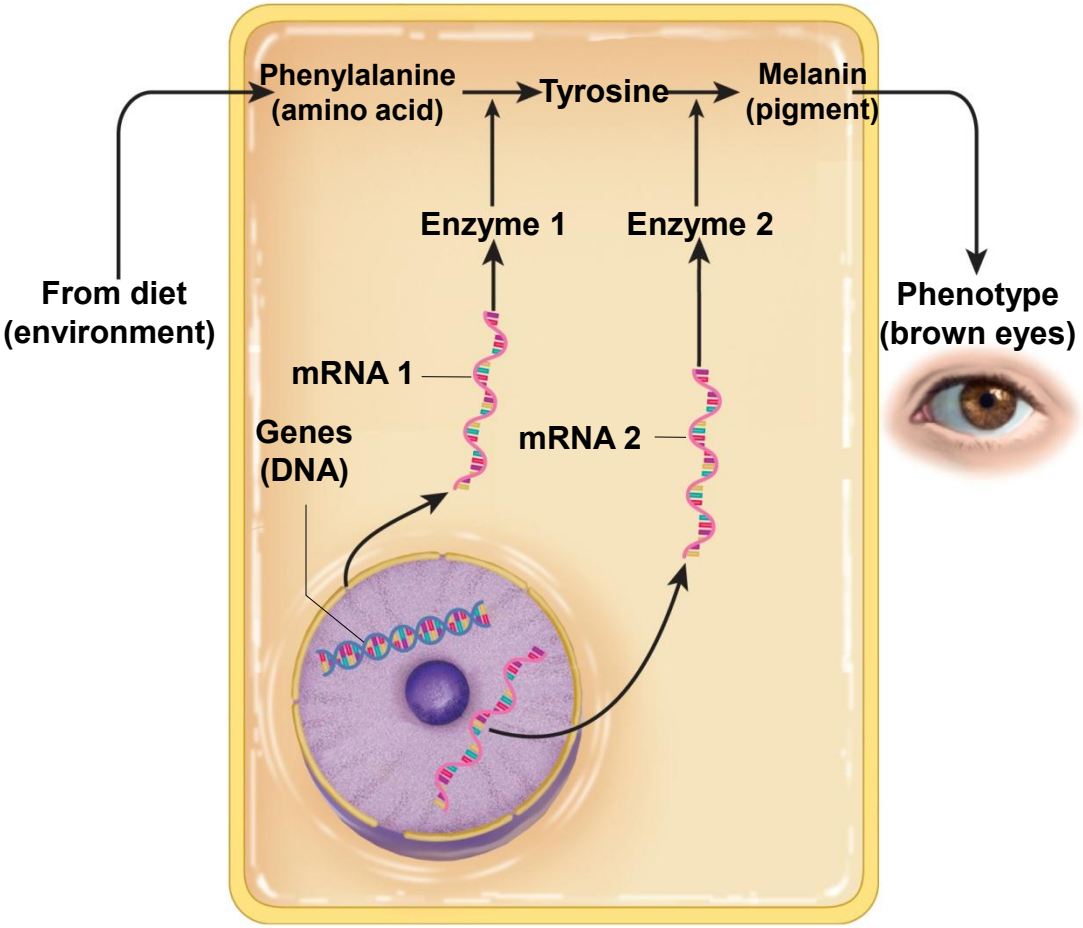


Figure 4.22

Penetrance and Environmental Effects

- **Role of environment**
  - No gene can produce a phenotypic effect without nutritional and other environmental input
  - Need both the genetic recipe and the ingredients
  - Brown eye color requires phenylalanine from diet to produce melanin pigment

Dominant and Recessive Alleles at the Population Level

- Common misconception that dominant alleles must be more common in the gene pool than recessive alleles
- Some recessive alleles, blood type O, are the most common
- Some dominant alleles, polydactyly and blood type AB, are rare in the population

Cancer

- **Benign tumor**
  - Slow growth; contained in fibrous capsule; will not metastasize; usually easy to treat
- **Malignant tumor**—called **cancer**
  - Fast growing
  - **Metastasize:** give off cells that seed the growth of multiple tumors elsewhere
- **Oncology**—medical specialty that deals with both benign and malignant tumors
- **Tumor angiogenesis**—in-growth of blood vessels stimulated by energy-hungry tumors

Cancer

- Cancers are named for the tissue of origin
  - **Carcinomas:** in epithelial tissue
  - **Lymphomas:** in lymph nodes
  - **Melanomas:** in pigment cells of epidermis (melanocytes)
  - **Leukemias:** in blood-forming tissues
  - **Sarcomas:** in bone, other connective tissue, or muscle

- **Carcinogen**—environmental cancer-causing agent

Causes of Cancer

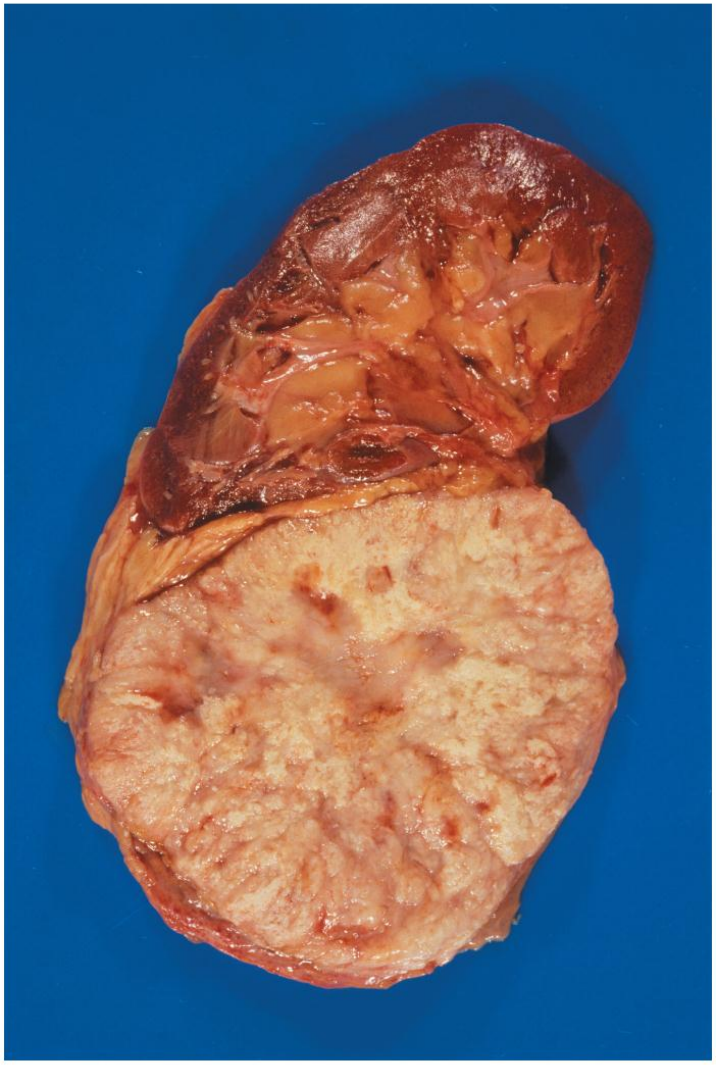
- **Carcinogens—**environmental cancer-causing agents
  - **Radiation—**ultraviolet rays, X-rays
  - **Chemical—**cigarette tar, food preservatives, industrial chemicals
  - **Viruses—**human papillomavirus, hepatitis C, and type 2 herpes simplex
- Only 5% to 10% of cancers are hereditary
- Carcinogens trigger gene mutations

Malignant Tumor Genes

- **Oncogenes**
  - Cause cell division to accelerate out of control
    - Excessive production of growth factors that stimulate mitosis
    - The production for excessive growth-factor receptors

- **Tumor-suppressor genes**
  - Inhibit development of cancer
    - Oppose action of oncogenes
    - Codes for DNA-repair enzymes

Tumor



Dr. E. Walker/Photo Researchers, Inc.

- **Wilms tumor**
  - Malignant tumor of the kidney occurring especially in children

Figure 4.23

Lethal Effects of Cancer

- Replace functional tissue in vital organs
- Steal nutrients from the rest of the body
  - **Cachexia:** severe wasting away of depleted tissues
- Weaken one's immunity
- Open the door for opportunistic infections
- Often invade blood vessels, lung tissue, or brain tissue