THE STRUCTURE OF THE GENETIC MATERIAL
10.1 Experiments showed that DNA is the genetic material

- Frederick Griffith discovered that a “transforming factor” could be transferred into a bacterial cell
  - Disease-causing bacteria were killed by heat
  - Harmless bacteria were incubated with heat-killed bacteria
  - Some harmless cells were converted to disease-causing bacteria, a process called transformation
  - The disease-causing characteristic was inherited by descendants of the transformed cells
10.1 Experiments showed that DNA is the genetic material

- Alfred Hershey and Martha Chase used bacteriophages to show that DNA is the genetic material
  - **Bacteriophages** are viruses that infect bacterial cells
  - **Phages** were labeled with radioactive sulfur to detect proteins or radioactive phosphorus to detect DNA
  - Bacteria were infected with either type of labeled phage to determine which substance was injected into cells and which remained outside
10.1 Experiments showed that DNA is the genetic material

- The sulfur-labeled protein stayed with the phages outside the bacterial cell, while the phosphorus-labeled DNA was detected inside cells.

- Cells with phosphorus-labeled DNA produced new bacteriophages with radioactivity in DNA but not in protein.
1. Mix radioactively labeled phages with bacteria. The phages infect the bacterial cells.

2. Agitate in a blender to separate phages outside the bacteria from the cells and their contents.

3. Centrifuge the mixture so bacteria form a pellet at the bottom of the test tube.

4. Measure the radioactivity in the pellet and the liquid.

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Batch 2: Radioactive DNA

Radioactivity in the liquid

Radioactivity in the pellet
Phage attaches to bacterial cell.

Phage injects DNA.

Phage DNA directs host cell to make more phage DNA and protein parts. New phages assemble.

Cell lyses and releases new phages.
10.2 DNA and RNA are polymers of nucleotides

- The monomer unit of DNA and RNA is the **nucleotide**, containing
  - Nitrogenous base
  - 5-carbon sugar
  - Phosphate group
DNA and RNA are polymers called polynucleotides

- A sugar-phosphate backbone is formed by covalent bonding between the phosphate of one nucleotide and the sugar of the next nucleotide

- Nitrogenous bases extend from the sugar-phosphate backbone
Sugar-phosphate backbone

Phosphate group

Nitrogenous base (A, G, C, or T)

Sugar (deoxyribose)

DNA nucleotide

DNA polynucleotide

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Pyrimidines

Thymine (T)  Cytosine (C)

Purines

Adenine (A)  Guanine (G)
10.3 DNA is a double-stranded helix

- James D. Watson and Francis Crick deduced the secondary structure of DNA, with X-ray crystallography data from Rosalind Franklin and Maurice Wilkins
DNA is composed of two polynucleotide chains joined together by hydrogen bonding between bases, twisted into a helical shape

- The sugar-phosphate backbone is on the outside
- The nitrogenous bases are perpendicular to the backbone in the interior
- Specific pairs of bases give the helix a uniform shape
  - A pairs with T, forming two hydrogen bonds
  - G pairs with C, forming three hydrogen bonds
Hydrogen bond

Partial chemical structure
Hydrogen bond

Base pair

Partial chemical structure

Computer model
DNA REPLICATION
10.4 DNA replication depends on specific base pairing

- DNA replication follows a **semiconservative model**
  - The two DNA strands separate
  - Each strand is used as a pattern to produce a complementary strand, using specific base pairing
  - Each new DNA helix has one old strand with one new strand
Parental molecule of DNA
Parental molecule of DNA

Both parental strands serve as templates
Parental molecule of DNA

Both parental strands serve as templates

Two identical daughter molecules of DNA
10.5 DNA replication proceeds in two directions at many sites simultaneously

- DNA replication begins at the origins of replication
  - DNA unwinds at the origin to produce a “bubble”
  - Replication proceeds in both directions from the origin
  - Replication ends when products from the bubbles merge with each other

- DNA replication occurs in the 5’→3’ direction
  - Replication is continuous on the 3’→5’ template
  - Replication is discontinuous on the 5’→3’ template, forming short segments
10.5 DNA replication proceeds in two directions at many sites simultaneously

- Proteins involved in DNA replication
  - **DNA polymerase** adds nucleotides to a growing chain
  - **DNA ligase** joins small fragments into a continuous chain
Origin of replication

Parental strand

Daughter strand

Bubble

Two daughter DNA molecules
Parental DNA

DNA polymerase molecule

Overall direction of replication

Daughter strand synthesized continuously

Daughter strand synthesized in pieces

DNA ligase

Overall direction of replication
THE FLOW OF GENETIC INFORMATION FROM DNA TO RNA TO PROTEIN
10.6 The DNA genotype is expressed as proteins, which provide the molecular basis for phenotypic traits

- A gene is a sequence of DNA that directs the synthesis of a specific protein
  - DNA is **transcribed** into RNA
  - RNA is **translated** into protein
- The presence and action of proteins determine the phenotype of an organism
10.6 The DNA genotype is expressed as proteins, which provide the molecular basis for phenotypic traits

- Demonstrating the connections between genes and proteins
  - The one gene–one enzyme hypothesis was based on studies of inherited metabolic diseases
  - The one gene–one protein hypothesis expands the relationship to proteins other than enzymes
  - The one gene–one polypeptide hypothesis recognizes that some proteins are composed of multiple polypeptides
Cytoplasm

Nucleus

Cytoplasm
Cytoplasm

Nucleus

DNA

Transcription

RNA

Cytoplasm
DNA

Transcription

RNA

Translation

Protein
10.7 Genetic information written in codons is translated into amino acid sequences

- The sequence of nucleotides in DNA provides a code for constructing a protein
  - Protein construction requires a conversion of a nucleotide sequence to an amino acid sequence
  - Transcription rewrites the DNA code into RNA, using the same nucleotide “language”
  - Each “word” is a codon, consisting of three nucleotides
  - Translation involves switching from the nucleotide “language” to amino acid “language”
  - Each amino acid is specified by a codon
    - 64 codons are possible
    - Some amino acids have more than one possible codon
Polypeptide translation and transcription involve genes coding for RNA molecules.

- DNA molecule
- Gene 1
- Gene 2
- Gene 3

Transcription:
- DNA strand
- RNA

Translation:
- Amino acid
10.8 The genetic code is the Rosetta stone of life

- Characteristics of the **genetic code**
  - Triplet: Three nucleotides specify one amino acid
    - 61 codons correspond to amino acids
    - AUG codes for methionine and signals the start of transcription
    - 3 “stop” codons signal the end of translation
10.8 The genetic code is the Rosetta stone of life

- Redundant: More than one codon for some amino acids
- Unambiguous: Any codon for one amino acid does not code for any other amino acid
- Does not contain spacers or punctuation: Codons are adjacent to each other with no gaps in between
- Nearly universal
<table>
<thead>
<tr>
<th>First base</th>
<th>Second base</th>
<th>Third base</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>UUU</td>
<td>C</td>
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<td></td>
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<td></td>
<td>AUG</td>
<td>M or start</td>
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<td>G</td>
<td>GUU</td>
<td>U</td>
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<td></td>
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<td></td>
<td>GUG</td>
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</tbody>
</table>

- **Phe**: Phenylalanine
- **Leu**: Leucine
- **Ser**: Serine
- **Tyr**: Tyrosine
- **Cys**: Cysteine
- **His**: Histidine
- **Gln**: Glutamine
- **Lys**: Lysine
- **Asp**: Aspartic acid
- **Glu**: Glutamic acid
- **Met or start**: Methionine or start codon
- **Stop**: Stop codon

**Codon Table**
Transcription

DNA

Strand to be transcribed

RNA

Start codon

Stop codon

AUG

GAAG

UUG

UUA

UAG
Transcription produces genetic messages in the form of RNA

Overview of transcription

- The two DNA strands separate
- One strand is used as a pattern to produce an RNA chain, using specific base pairing
  - For A in DNA, U is placed in RNA
- RNA polymerase catalyzes the reaction
10.9 Transcription produces genetic messages in the form of RNA

- Stages of transcription
  - Initiation: RNA polymerase binds to a **promoter**, where the helix unwinds and transcription starts
  - Elongation: RNA nucleotides are added to the chain
  - Termination: RNA polymerase reaches a **terminator** sequence and detaches from the template
RNA polymerase

Newly made RNA

Direction of transcription Template strand of DNA

RNA nucleotides

Template strand of DNA

Newly made RNA
DNA of gene

1. Initiation

2. Elongation

Area shown in Figure 10.9A

3. Termination

Growing RNA

Completed RNA

RNA polymerase

RNA polymerase
10.10 Eukaryotic RNA is processed before leaving the nucleus

- **Messenger RNA (mRNA)** contains codons for protein sequences
- Eukaryotic mRNA has interrupting sequences called **introns**, separating the coding regions called **exons**
- Eukaryotic mRNA undergoes processing before leaving the nucleus
  - Cap added to 5’ end: single guanine nucleotide
  - Tail added to 3’ end: Poly-A tail of 50–250 adenines
  - **RNA splicing**: removal of introns and joining of exons to produce a continuous coding sequence
RNA transcript with cap and tail

Exons spliced together

Introns removed

Transcription Addition of cap and tail

DNA

Cap

RNA transcript with cap and tail

Exons spliced together

Intron

Intron

Exon

Exon

Exon

mRNA

Coding sequence

Nucleus

Cytoplasm

Tail
Transfer RNA (tRNA) molecules match an amino acid to its corresponding mRNA codon

- tRNA structure allows it to convert one language to the other
  - An amino acid attachment site allows each tRNA to carry a specific amino acid
  - An anticodon allows the tRNA to bind to a specific mRNA codon, complementary in sequence
    - A pairs with U, G pairs with C
10.12 Ribosomes build polypeptides

- Translation occurs on the surface of the ribosome
  - Ribosomes have two subunits: small and large
  - Each subunit is composed of ribosomal RNAs and proteins
  - Ribosomal subunits come together during translation
  - Ribosomes have binding sites for mRNA and tRNAs
tRNA-binding sites

Large subunit

mRNA binding site

Small subunit
mRNA

Next amino acid to be added to polypeptide

Growing polypeptide

tRNA

mRNA

Codons
10.13 An initiation codon marks the start of an mRNA message

- Initiation brings together the components needed to begin RNA synthesis

- Initiation occurs in two steps
  1. mRNA binds to a small ribosomal subunit, and the first tRNA binds to mRNA at the start codon
     - The start codon reads AUG and codes for methionine
     - The first tRNA has the anticodon UAC
  2. A large ribosomal subunit joins the small subunit, allowing the ribosome to function
     - The first tRNA occupies the P site, which will hold the growing peptide chain
     - The A site is available to receive the next tRNA
10.14 Elongation adds amino acids to the polypeptide chain until a stop codon terminates translation

- Elongation is the addition of amino acids to the polypeptide chain

- Each cycle of elongation has three steps
  1. Codon recognition: next tRNA binds to the mRNA at the A site
  2. Peptide bond formation: joining of the new amino acid to the chain
    - Amino acids on the tRNA at the P site are attached by a covalent bond to the amino acid on the tRNA at the A site
10.14 Elongation adds amino acids to the polypeptide chain until a stop codon terminates translation

3. Translocation: tRNA is released from the P site and the ribosome moves tRNA from the A site into the P site
10.14 Elongation adds amino acids to the polypeptide chain until a stop codon terminates translation

- Elongation continues until the ribosome reaches a stop codon

- Applying Your Knowledge
  How many cycles of elongation are required to produce a protein with 100 amino acids?

- Termination
  - The completed polypeptide is released
  - The ribosomal subunits separate
  - mRNA is released and can be translated again
Codon recognition
Polypeptide

A site

Codon recognition

Codons

Amino acid

Anticodon

mRNA

P site

A site

Peptide bond formation

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Polypeptide

A site

Codon recognition

Codons

Amino acid

Anticodon

P site

mRNA

Peptide bond formation

New peptide bond

Translocation
1. **Codon recognition**
   - Polypeptide
   - mRNA
   - Codons

2. **Peptide bond formation**
   - Amino acid
   - Anticodon
   - P site
   - A site
   - mRNA movement
   - Stop codon

3. **Translocation**
   - New peptide bond

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**Legend:**
- Polypeptide
- Amino acid
- Anticodon
- Codons
- mRNA
- mRNA movement
- Stop codon
- New peptide bond
10.16 Mutations can change the meaning of genes

- **A mutation** is a change in the nucleotide sequence of DNA
  - Base substitutions: replacement of one nucleotide with another
    - Effect depends on whether there is an amino acid change that alters the function of the protein
  - Deletions or insertions
    - Alter the reading frame of the mRNA, so that nucleotides are grouped into different codons
    - Lead to significant changes in amino acid sequence downstream of mutation
    - Cause a nonfunctional polypeptide to be produced
10.16 Mutations can change the meaning of genes

- Mutations can be
  - Spontaneous: due to errors in DNA replication or recombination
  - Induced by mutagens
    - High-energy radiation
    - Chemicals
Normal hemoglobin DNA

Mutant hemoglobin DNA

mRNA

Normal hemoglobin

Sickle-cell hemoglobin

CTT

CAT

GAA

GUA

Val

Glu
Normal gene

mRNA

Protein

Met  Lys  Phe  Gly  Ala

Base substitution

mRNA

Protein

Met  Lys  Phe  Ser  Ala

Base deletion

mRNA

Protein

Met  Lys  Leu  Ala  His