Chapter 16

The Molecular Basis of Inheritance
In 1953, James Watson and Francis Crick introduced an elegant double-helical model for the structure of deoxyribonucleic acid, or DNA. DNA, the substance of inheritance, is the most celebrated molecule of our time. Hereditary information is encoded in DNA and reproduced in all cells of the body. This DNA program directs the development of biochemical, anatomical, physiological, and (to some extent) behavioral traits.
Concept 16.1: DNA is the genetic material

- Early in the 20th century, the identification of the molecules of inheritance loomed as a major challenge to biologists
The Search for the Genetic Material: Scientific Inquiry

- When T. H. Morgan’s group showed that genes are located on chromosomes, the two components of chromosomes—DNA and protein—became candidates for the genetic material.
- The key factor in determining the genetic material was choosing appropriate experimental organisms.
- The role of DNA in heredity was first discovered by studying bacteria and the viruses that infect them.
Evidence That DNA Can Transform Bacteria

• The discovery of the genetic role of DNA began with research by Frederick Griffith in 1928.

• Griffith worked with two strains of a bacterium, one pathogenic and one harmless.
• When he mixed heat-killed remains of the pathogenic strain with living cells of the harmless strain, some living cells became pathogenic

• He called this phenomenon transformation, now defined as a change in genotype and phenotype due to assimilation of foreign DNA
Living S cells (control)  Living R cells (control)  Heat-killed S cells (control)  Mixture of heat-killed S cells and living R cells

EXPERIMENT

RESULTS

Mouse dies  Mouse healthy  Mouse healthy  Mouse dies

Living S cells
• In 1944, Oswald Avery, Maclyn McCarty, and Colin MacLeod announced that the transforming substance was DNA
• Their conclusion was based on experimental evidence that only DNA worked in transforming harmless bacteria into pathogenic bacteria
• Many biologists remained skeptical, mainly because little was known about DNA
Evidence That Viral DNA Can Program Cells

- More evidence for DNA as the genetic material came from studies of viruses that infect bacteria.
- Such viruses, called bacteriophages (or phages), are widely used in molecular genetics research.
Animation: Phage T2 Reproductive Cycle
Right-click slide / select “Play”
• In 1952, Alfred Hershey and Martha Chase performed experiments showing that DNA is the genetic material of a phage known as T2.

• To determine this, they designed an experiment showing that only one of the two components of T2 (DNA or protein) enters an *E. coli* cell during infection.

• They concluded that the injected DNA of the phage provides the genetic information.
Animation: Hershey-Chase Experiment
Right-click slide / select “Play”
Essential Question:
How do we know DNA makes up our genetic material?

• **Griffith**: Pneumonia strains & Transformation

  - Used enzymes to destroy components of bacterial strains. Transformation occurred in the absence of all macromolecules, except DNA.

• **Oswald Avery**: Process of elimination.

• **Hershey & Chase**: T2 Bacteriophages

  - By using radioactive isotopes, it was discovered that DNA is the genetic material of viruses.
Griffith

**Transformation**: One strain of bacteria was permanently genetically altered.
**EXPERIMENT**

- **Living S cells (control)**
  - Mouse dies

- **Living R cells (control)**
  - Mouse healthy

- **Heat-killed S cells (control)**
  - Mouse healthy

- **Mixture of heat-killed S cells and living R cells**
  - Mouse dies

**RESULTS**

- Living S cells
  - Mouse healthy

- Mixture of heat-killed S cells and living R cells
  - Mouse healthy

- Living S cells
EQ: How do we know DNA makes up our genetic material?

Oswald avery

• I'm thinking of a number between 1 & 5.

1 Proteins
2 Carbs
3 Lipids
4 DNA
5 Other molecules
EQ: How do we know DNA makes up our genetic material?
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.

EQ: How do we know DNA makes up our genetic material?
**EXPERIMENT**

Batch 1: Radioactive sulfur ($^{35}\text{S}$)

Batch 2: Radioactive phosphorus ($^{32}\text{P}$)
EXPERIMENT

Batch 1: Radioactive sulfur ($^{35}$S)

Batch 2: Radioactive phosphorus ($^{32}$P)
**EXPERIMENT**

**Batch 1:** Radioactive sulfur ($^{35}\text{S}$)

- **Bacterial cell**
  - Phage
  - Phage protein
  - DNA

- **Radioactive sulfur**

- **Centrifuge**
  - Pellet (bacterial cells and contents)
  - Radioactivity (phage protein) in liquid

**Batch 2:** Radioactive phosphorus ($^{32}\text{P}$)

- **Bacterial cell**
  - Phage
  - Empty protein shell
  - Phage DNA

- **Radioactive phosphorus**

- **Centrifuge**
  - Pellet
  - Radioactivity (phage DNA) in pellet
Additional Evidence That DNA Is the Genetic Material

• It was known that DNA is a polymer of nucleotides, each consisting of a nitrogenous base, a sugar, and a phosphate group
• In 1950, Erwin Chargaff reported that DNA composition varies from one species to the next
• This evidence of diversity made DNA a more credible candidate for the genetic material
Two findings became known as Chargaff’s rules:
- The base composition of DNA varies between species.
- In any species the number of A and T bases are equal and the number of G and C bases are equal.

The basis for these rules was not understood until the discovery of the double helix.
The Components and Structure of DNA

- What is the overall structure of the DNA molecule?
DNA is a type of Nucleic Acid

- **Nucleic acids** are long, slightly acidic molecules originally identified in cell nuclei.
  - Nucleic acids are made up of **nucleotides**, linked together to form long chains.
The Components and Structure of DNA

- DNA is made up of nucleotides.
  - A nucleotide is a monomer (single molecule) of nucleic acids made up of:
    - A five-carbon sugar called deoxyribose
    - a phosphate group
    - & one of four nitrogenous bases.

EQ: What is the overall structure of DNA?
The Components and Structure of DNA

- The nucleotides in a strand of DNA are joined by **covalent bonds** formed between their **sugar** and **phosphate** groups.
The Components and Structure of DNA

- There are four kinds of nitrogen bases in DNA:
  1. adenine
  2. guanine
  3. cytosine
  4. thymine
• 1.) **Adenines & Guanines** belong to a class of nitrogenous base known as __________.

• 2.) **Cytosines and Thymines** belong to a class of nitrogenous base known as ________.
The Components and Structure of DNA

• The backbone of a DNA chain is formed by sugar and phosphate groups of each nucleotide.
• The nucleotides can be joined together in any order.

EQ: What is the overall structure of DNA?
Figure 16.5

Sugar–phosphate backbone

5’ end

DNA nucleotide (deoxyribose)

3’ end

Nitrogenous bases

Thymine (T)

Adenine (A)

Cytosine (C)

Guanine (G)
The Components and Structure of DNA

• Chargaff's Rules
  - Erwin Chargaff discovered that:
    • For every guanine there is a cytosine
      \[ [G] = [C] \]
    • For every adenine there is a thymine
      \[ [A] = [T] \]
Building a Structural Model of DNA: Scientific Inquiry

• After DNA was accepted as the genetic material, the challenge was to determine how its structure accounts for its role in heredity
• Maurice Wilkins and Rosalind Franklin were using a technique called X-ray crystallography to study molecular structure
• Franklin produced a picture of the DNA molecule using this technique

EQ: What is the overall structure of DNA?

EC: What led to the discovery of the structure of DNA?
Figure 16.6

(a) Rosalind Franklin

(b) Franklin’s X-ray diffraction photograph of DNA
Franklin’s X-ray crystallographic images of DNA enabled Watson to deduce that DNA was helical.

The X-ray images also enabled Watson to deduce the width of the helix and the spacing of the nitrogenous bases.

The pattern in the photo suggested that the DNA molecule was made up of two strands, forming a double helix.
The Components and Structure of DNA

• The Double Helix

Watson and Crick's model of DNA was a double helix, in which two strands were wound around each other like a twisted ladder.
• 2 sugar-phosphate “backbones” make up the two sides of the twisting ladder.
• The third component of the nucleotide, the nitrogenous bases, make up the rungs (steps) of the ladder.
The Components and Structure of DNA

- In the double-helix model, the two strands of DNA are "antiparallel"—their subunits run in opposite directions.

  - Enables the nitrogenous bases on both strands to come into contact at the center of the molecule.
Anti-parallel strands

- **Nucleotides in DNA backbone are bonded from phosphate to sugar between 3’ & 5’ carbons**
  - DNA molecule has “direction”
  - **complementary strand runs in opposite direction**
EC: What led to the discovery of the structure of DNA?

EQ: What is the overall structure of DNA?

- DNA Double Helix

Key
- Adenine (A)
- Thymine (T)
- Cytosine (C)
- Guanine (G)

Hydrogen bonds
Nucleotide
Sugar-phosphate backbone

5’  3’
5’  3’
The Components and Structure of DNA

Watson and Crick discovered that **hydrogen bonds** can form between certain **nitrogenous base pairs**. This principle is called **base pairing**. **Hydrogen Bonds** hold the rungs of the latter together.

**EQ:** What is the overall structure of DNA?

**EC:** What led to the discovery of the structure of DNA?
Purine + purine: too wide

Pyrimidine + pyrimidine: too narrow

Purine + pyrimidine: width consistent with X-ray data
**Base pairing explained**

**Chargaff's rule**: why...

\[ [A] = [T] \text{ and } [G] = [C]. \]

- For every adenine in a double-stranded DNA molecule, there had to be exactly one thymine. For each cytosine, there was one guanine.
EQ: What is the overall structure of DNA?

- DNA is made up of nucleotides that consist of a 5 carbon deoxyribose sugar, a phosphate group, and 1 of 4 nitrogenous bases.

- DNA is takes a double helix shape, like a twisted ladder. Two sugar-phosphate backbones, which are held together by covalent bonds make up the sides of the twisted ladder while nitrogenous bases, held together by hydrogen bonds make up the rungs, or connect in the center.

- The strands of the double helix run antiparallel, which allows them to link up as exact opposites.

- Nitrogenous bases form hydrogen bonds with their base pair A-T, C-G.
Chargoff determined that, in a double-stranded DNA molecule, adenine & thymine are present in equal proportions, as are guanine and cytosine.

Franklin's X-Ray revealed the spiral structure of DNA.

Both contributed to Watson & Crick's understanding of DNA's double helix and complementary base pairing, which led to their double helix model of DNA.
Figure 16.7

(a) Key features of DNA structure

(b) Partial chemical structure

(c) Space-filling model

Hydrogen bond

5’ end

3’ end

© 2011 Pearson Education, Inc.
3.4 nm

1 nm

0.34 nm

(a) Key features of DNA structure

(b) Partial chemical structure

Figure 16.7a
Figure 16.8

Adenine (A)  Thymine (T)

Guanine (G)  Cytosine (C)
What your should know

• The scientific path that led to the discovery of DNA being the material of heredity.
• The structure of DNA.
• How Watson & Crick used Franklin’s work supported Chargoff’s Rules.
Concept 16.2: Many proteins work together in DNA replication and repair

- The relationship between structure and function is manifest in the double helix
- Watson and Crick noted that the specific base pairing suggested a possible copying mechanism for genetic material
The Basic Principle: Base Pairing to a Template Strand

- Since the two strands of DNA are complementary, each strand acts as a template for building a new strand in replication.
- In DNA replication, the parent molecule unwinds, and two new daughter strands are built based on base-pairing rules.
Animation: DNA Replication Overview
Right-click slide / select “Play”
(a) Parent molecule
Figure 16.9-2

(a) Parent molecule  
(b) Separation of strands
(a) Parent molecule

(b) Separation of strands

(c) “Daughter” DNA molecules, each consisting of one parental strand and one new strand
DNA Replication: A Closer Look

• The copying of DNA is remarkable in its speed and accuracy
• More than a dozen enzymes and other proteins participate in DNA replication
Copying DNA

- Replication of DNA is Semiconservative
  - base pairing allows each strand to serve as a **template** for a new strand
  - new strand is 1/2 parent template & 1/2 new DNA
DNA Replication

- Large team of enzymes coordinates replication

(a) In eukaryotes, DNA replication begins at many sites along the giant DNA molecule of each chromosome.

(b) In this micrograph, three replication bubbles are visible along the DNA of cultured Chinese hamster cells. The arrows indicate the direction of DNA replication at the two ends of each bubble (TEM).
Replication:

**step 1: DNA Unwinds**

- Unwind DNA
  - **helicase** enzyme
    - unwinds part of DNA helix
    - stabilized by **single-stranded binding proteins**
Getting Started

• Replication begins at particular sites called origins of replication, where the two DNA strands are separated, opening up a replication “bubble”
  - A eukaryotic chromosome may have hundreds or even thousands of origins of replication
  - Replication proceeds in both directions from each origin, until the entire molecule is copied
Animation: Origins of Replication
Right-click slide / select “Play”
(a) Origin of replication in an *E. coli* cell

Origin of replication

Parental (template) strand

Double-stranded DNA molecule

Daughter (new) strand

Replication fork

Replication bubble

Two daughter DNA molecules

0.5 μm
(b) Origins of replication in a eukaryotic cell

Origin of replication

Double-stranded DNA molecule

Parental (template) strand

Daughter (new) strand

Bubble

Replication fork

Two daughter DNA molecules

0.25 \( \mu m \)
• At the end of each replication bubble is a replication fork, a Y-shaped region where new DNA strands are elongating.

• Helicases are enzymes that untwist the double helix at the replication forks.

• Single-strand binding proteins bind to and stabilize single-stranded DNA.

• Topoisomerase corrects “overwinding” ahead of replication forks by breaking, swiveling, and rejoining DNA strands.
Figure 16.13

Topoisomerase

Primase

RNA primer

Helicase

Single-strand binding proteins

© 2011 Pearson Education, Inc.
• DNA polymerases cannot initiate synthesis of a polynucleotide; they can only add nucleotides to the 3’ end
• The initial nucleotide strand is a short RNA primer
- An enzyme called **primase** can start an RNA chain from scratch and adds RNA nucleotides one at a time using the parental DNA as a template.

- The primer is short (5-10 nucleotides long), and the 3’ end serves as the starting point for the new DNA strand.
Synthesizing a New DNA Strand

- Enzymes called DNA polymerases catalyze the elongation of new DNA at a replication fork.
- Most DNA polymerases require a primer and a DNA template strand.
- The rate of elongation is about 500 nucleotides per second in bacteria and 50 per second in human cells.
- Each nucleotide that is added to a growing DNA strand is a nucleoside triphosphate.
- dATP supplies adenine to DNA and is similar to the ATP of energy metabolism.
- The difference is in their sugars: dATP has deoxyribose while ATP has ribose.
- As each monomer of dATP joins the DNA strand, it loses two phosphate groups as a molecule of pyrophosphate.
Replication: **step 2 Adding Complementary Nucleotides**

- Build daughter DNA strand
  - add new complementary bases
- Uses **DNA polymerase III**

Where’s the **ENERGY** for the bonding!
Energy of Replication

Where does energy for bonding *usually* come from?

Modified nucleotides come with their own energy!

And we are left with a nucleotide!

You remember ATP!

Are there other energy nucleotides? You bet!

Modified nucleotide

CTP

CMP

modified nucleotide
Energy of Replication

• The nucleotides arrive as **nucleosides**
  - DNA bases with **P-P-P**
    - P-P-P = energy for bonding
  - DNA bases arrive with **their own energy** source for bonding
  - bonded by enzyme: **DNA polymerase III**
• Adding bases
  - can only add nucleotides to **3’ end** of a growing DNA strand
  - need a “starter” nucleotide to bond to
  - strand only grows **5’→3’**
Figure 16.14

New strand

Template strand

Sugar

Phosphate

Base

Nucleoside triphosphate

DNA polymerase

Pyrophosphate

Nucleoside triphosphate

© 2011 Pearson Education, Inc.
\( P = \text{phosphate} \)
\( S = 2'\text{-deoxyribose} \)
basics = T C G A

thymine cytosine guanine adenine

complementary nucleotide chain begins to form

H-bonds

unwound DNA strand
need “primer” bases to add on to

no energy to bond

ligase

energy
Antiparallel Elongation

• The antiparallel structure of the double helix affects replication

• DNA polymerases add nucleotides only to the free 3’ end of a growing strand; therefore, a new DNA strand can elongate only in the 5’ to 3’ direction
Along one template strand of DNA, the DNA polymerase synthesizes a leading strand continuously, moving toward the replication fork.
Origin of replication

Animation: Leading Strand
Right-click slide / select “Play”
Figure 16.15b

Origin of replication

RNA primer

Sliding clamp

DNA pol III

Parental DNA
• To elongate the other new strand, called the **lagging strand**, DNA polymerase must work in the direction away from the replication fork.

• The lagging strand is synthesized as a series of segments called **Okazaki fragments**, which are joined together by **DNA ligase**.
Animation: Lagging Strand
Right-click slide / select “Play”
Figure 16.16

Overview

Leading strand

Origin of replication

Lagging strand

Overall directions of replication

Template strand

RNA primer for fragment 1

Okazaki fragment 1

RNA primer for fragment 2

Okazaki fragment 2

Overall direction of replication

© 2011 Pearson Education, Inc.
Figure 16.16a

Overview

Leading strand

Origin of replication

Lagging strand

Overall directions of replication

Leading strand

Lagging strand

1

2
Figure 16.16b-2

Template strand

RNA primer for fragment 1
Figure 16.16b-3

Template strand

RNA primer for fragment 1

Okazaki fragment 1
Figure 16.16b-4

Template strand

RNA primer for fragment 1

Okazaki fragment 1

RNA primer for fragment 2

Okazaki fragment 2
Figure 16.16b-5

RNA primer for fragment 1

RNA primer for fragment 2

Okazaki fragment 1

Okazaki fragment 2

3' Template strand 5'

3' RNA primer for fragment 1 5' 3' RNA primer for fragment 2 5'

3' Okazaki fragment 1 5'

3' Okazaki fragment 2 5'

2 1
Figure 16.16b-6

Template strand

3' → 5' → 3' → 5'

RNA primer for fragment 1

5' → 3' → 5' → 3'

Okazaki fragment 1

RNA primer for fragment 2

5' → 3' → 5' → 3'

Okazaki fragment 2

Overall direction of replication

3' → 5' → 3' → 5'
Figure 16.17

Overview

Leading strand

Origin of replication

Lagging strand

Overall directions of replication

Leading strand

Lagging strand

Leading strand

Lagging strand

Parental DNA

5’

3’

DNA pol III

3’

5’

3’

5’

Primer

Primase

DNA pol III

Lagging strand

DNA pol I

DNA ligase

1 3’

2 3’

3 3’

4 3’

5’

5’

5’

© 2011 Pearson Education, Inc.
**Limits of DNA polymerase III**
- can only build onto 3′ end of an existing DNA strand

**Leading & Lagging strands**

- **Leading strand**
  - continuous synthesis
  - DNA polymerase III

- **Lagging strand**
  - Okazaki fragments
  - joined by ligase ("spot welder" enzyme)
  - Okazaki fragments joined by ligase
Replication fork / Replication bubble

DNA polymerase III

leading strand

lagging strand

leading strand

lagging strand

growing replication fork

growing replication fork
Starting DNA synthesis: RNA primers

Limits of DNA polymerase III
- can only build onto 3’ end of an existing DNA strand

RNA primer
- built by primase
- serves as starter sequence for DNA polymerase III
Replacing RNA primers with DNA

DNA polymerase I
- removes sections of RNA primer and replaces with DNA nucleotides

But DNA polymerase I still can only build onto 3' end of an existing DNA strand
Replication fork

DNA polymerase I
DNA polymerase III
primase
Okazaki fragments
ligase
helicase
SSB
leading strand
lagging strand
3' 5' 3'
DNA polymerase III

Direction of replication
SSB = single-stranded binding proteins
The DNA Replication Complex

- The proteins that participate in DNA replication form a large complex, a “DNA replication machine”
- The DNA replication machine may be stationary during the replication process
- Recent studies support a model in which DNA polymerase molecules “reel in” parental DNA and “extrude” newly made daughter DNA molecules
Animation: DNA Replication Review
Right-click slide / select “Play”
Figure 16.18

Parental DNA

Connecting protein

Helicase

DNA pol III

Leading strand

Lagging strand

5' → 3'

3' → 5'

5' → 3'

3' → 5'

Lagging strand template
Proofreading and Repairing DNA

- DNA polymerases proofread newly made DNA, replacing any incorrect nucleotides.
- In mismatch repair of DNA, repair enzymes correct errors in base pairing.
- DNA can be damaged by exposure to harmful chemical or physical agents such as cigarette smoke and X-rays; it can also undergo spontaneous changes.
- In nucleotide excision repair, a nuclease cuts out and replaces damaged stretches of DNA.
Figure 16.19

Nuclease

DNA polymerase

DNA ligase
Evolutionary Significance of Altered DNA Nucleotides

- Error rate after proofreading repair is low but not zero
- Sequence changes may become permanent and can be passed on to the next generation
- These changes (mutations) are the source of the genetic variation upon which natural selection operates
Replicating the Ends of DNA Molecules

- Limitations of DNA polymerase create problems for the linear DNA of eukaryotic chromosomes
- The usual replication machinery provides no way to complete the 5’ ends, so repeated rounds of replication produce shorter DNA molecules with uneven ends
- This is not a problem for prokaryotes, most of which have circular chromosomes
Figure 16.20

Ends of parental DNA strands

Leading strand  
Lagging strand

5’  
3’

Last fragment  
Next-to-last fragment

Lagging strand

RNA primer

5’  
3’

Parental strand

Removal of primers and replacement with DNA where a 3’ end is available

5’  
3’

Second round of replication

New leading strand

5’  
3’

New lagging strand

5’  
3’

Further rounds of replication

Shorter and shorter daughter molecules
Figure 16.20a

Ends of parental DNA strands

Leading strand

Lagging strand

Last fragment

Next-to-last fragment

Lagging strand

Parental strand

RNA primer

Removal of primers and replacement with DNA where a 3’ end is available
Figure 16.20b

- Second round of replication
- New leading strand
- New lagging strand
- Further rounds of replication
- Shorter and shorter daughter molecules
• Eukaryotic chromosomal DNA molecules have special nucleotide sequences at their ends called **telomeres**

• Telomeres do not prevent the shortening of DNA molecules, but they do postpone the erosion of genes near the ends of DNA molecules

• It has been proposed that the shortening of telomeres is connected to aging
• If chromosomes of germ cells became shorter in every cell cycle, essential genes would eventually be missing from the gametes they produce
• An enzyme called **telomerase** catalyzes the lengthening of telomeres in germ cells
Telomeres

- An enzyme called telomerase adds short, repeated DNA sequences to telomeres, lengthening the chromosomes slightly and making it less likely that important gene sequences will be lost from the telomeres during replication.
Loss of bases at 5’ ends in every replication

- chromosomes get shorter with each replication
- limit to number of cell divisions?

Chromosome erosion

All DNA polymerases can only add to 3’ end of an existing DNA strand

DNA polymerase III

DNA polymerase I

growing replication fork

RNA
**Telomeres**

Repeating, non-coding sequences at the end of chromosomes = protective cap
- limit to ~50 cell divisions

**Telomerase**
- enzyme extends telomeres
- can add DNA bases at 5’ end
- different level of activity in different cells
  - high in stem cells & cancers -- Why?
• The shortening of telomeres might protect cells from cancerous growth by limiting the number of cell divisions
• There is evidence of telomerase activity in cancer cells, which may allow cancer cells to persist
Chapter 16 DNA REVIEW

- Enzymes involved in replication:
  - Helicase
  - Single Stranded Binding Protein
  - Primase
  - DNA Polymerase III
  - Ligase
  - DNA Polymerase I
  - Telomerase

- Other stuff about Replication
  - Semiconservative Model
  - Chargaff’s Rules
  - Okazaki Fragments
  - Leading vs. Lagging strands
  - 5→3
  - Mismatch & Base-excision repair
  - Telomeres
Chapter 16 DNA REVIEW

- Griffith: Pneumonia
- Oswald Avery: Process of Elimination
- Hershey & Chase: Bacteriophage, $^{32}$P & $^{35}$S
- Erwin Chargaff
- Rosalind Franklin
- Watson & Crick
- Structure
Concept 16.3 A chromosome consists of a DNA molecule packed together with proteins

- The bacterial chromosome is a double-stranded, circular DNA molecule associated with a small amount of protein.
- Eukaryotic chromosomes have linear DNA molecules associated with a large amount of protein.
- In a bacterium, the DNA is “supercoiled” and found in a region of the cell called the nucleoid.
• **Chromatin**, a complex of DNA and protein, is found in the nucleus of eukaryotic cells

• **Chromosomes** fit into the nucleus through an elaborate, multilevel system of packing
Animation: DNA Packing
Right-click slide / select “Play”
Figure 16.22a

DNA double helix (2 nm in diameter)

DNA, the double helix

Histones

Histone tail

Nucleosome (10 nm in diameter)

H1

Nucleosomes, or “beads on a string” (10-nm fiber)
Figure 16.22b

- 30-nm fiber
- Loops
- Scaffold
- 300-nm fiber
- Replicated chromosome (1,400 nm)
- Looping domains (300-nm fiber)
- Metaphase chromosome
- Chromatid (700 nm)
DNA double helix (2 nm in diameter)
Figure 16.22d

Nucleosome (10 nm in diameter)
Figure 16.22e

30-nm fiber

© 2011 Pearson Education, Inc.
Figure 16.22f

Loops

Scaffold
Figure 16.22g

Chromatid (700 nm)
• Chromatin undergoes changes in packing during the cell cycle

• At interphase, some chromatin is organized into a 10-nm fiber, but much is compacted into a 30-nm fiber, through folding and looping

• Though interphase chromosomes are not highly condensed, they still occupy specific restricted regions in the nucleus
Figure 16.23b
Most chromatin is loosely packed in the nucleus during interphase and condenses prior to mitosis.

Loosely packed chromatin is called **euchromatin**.

During interphase a few regions of chromatin (centromeres and telomeres) are highly condensed into **heterochromatin**.

Dense packing of the heterochromatin makes it difficult for the cell to express genetic information coded in these regions.
• Histones can undergo chemical modifications that result in changes in chromatin organization
Figure 16.UN02

Sugar-phosphate backbone

Nitrogenous bases

Hydrogen bond
DNA pol III synthesizes leading strand continuously.

Parental DNA

Helicase

Primase synthesizes a short RNA primer

DNA pol III starts DNA synthesis at 3’ end of primer, continues in 5’ → 3’ direction

Lagging strand synthesized in short Okazaki fragments, later joined by DNA ligase

DNA pol I replaces the RNA primer with DNA nucleotides

Origin of replication

© 2011 Pearson Education, Inc.
<table>
<thead>
<tr>
<th>Source</th>
<th>Adenine</th>
<th>Guanine</th>
<th>Cytosine</th>
<th>Thymine</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. coli</em></td>
<td>24.7%</td>
<td>26.0%</td>
<td>25.7%</td>
<td>23.6%</td>
</tr>
<tr>
<td>Wheat</td>
<td>28.1</td>
<td>21.8</td>
<td>22.7</td>
<td>27.4</td>
</tr>
<tr>
<td>Sea urchin</td>
<td>32.8</td>
<td>17.7</td>
<td>17.3</td>
<td>32.1</td>
</tr>
<tr>
<td>Salmon</td>
<td>29.7</td>
<td>20.8</td>
<td>20.4</td>
<td>29.1</td>
</tr>
<tr>
<td>Human</td>
<td>30.4</td>
<td>19.6</td>
<td>19.9</td>
<td>30.1</td>
</tr>
<tr>
<td>Ox</td>
<td>29.0</td>
<td>21.2</td>
<td>21.2</td>
<td>28.7</td>
</tr>
</tbody>
</table>
Figure 16.UN06

DNA ligase

DNA pol I

Lagging strand

DNA pol III

DNA pol III

Primase

Primer

Parental DNA

Leading strand

© 2011 Pearson Education, Inc.
Figure 16.UN07

New DNA strand (olive)

Parental DNA strand (purple)

Sliding clamp

DNA pol III

Single-strand binding protein

Direction of replication

© 2011 Pearson Education, Inc.