Biology

Concepts and Applications | 9e

Starr | Evers | Starr

Chapter 8

DNA Structure and Function

8.1 How Was DNA's Function Discovered?

- The substance we now call DNA was first described in 1869 by Johannes Miescher
- Miescher determined that DNA is not a protein, and that it is rich in nitrogen and phosphorus
  - He never learned of its function

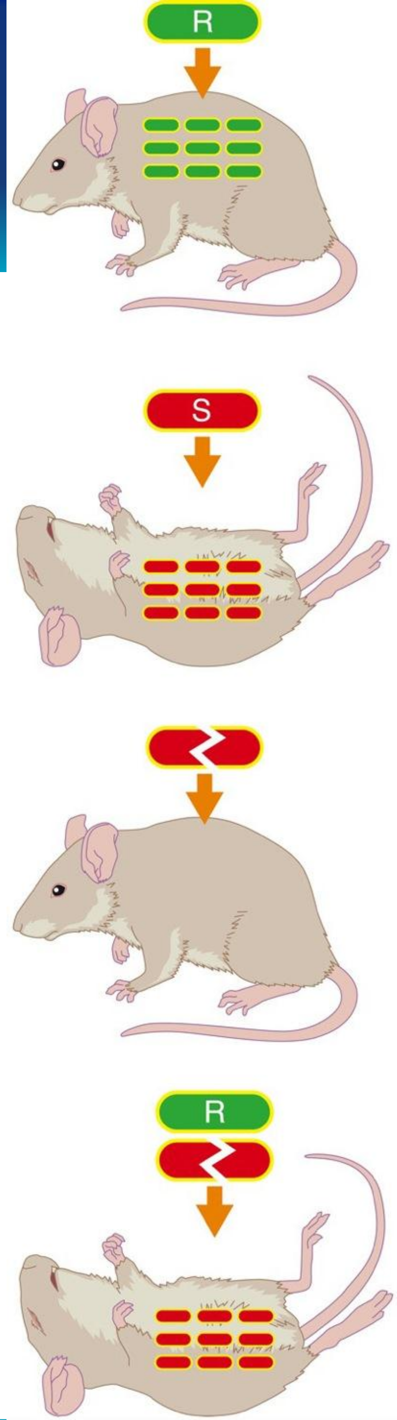
How Was DNA's Function Discovered? (cont'd.)

Patrick Landmann/Science Source

How Was DNA's Function Discovered? (cont'd.)

- Sixty years after Miescher's work, Frederick Griffith unexpectedly uncovered a clue about DNA's function
  - Heat destroyed the ability of lethal S bacteria to cause pneumonia, but it did not destroy their hereditary material
  - The hereditary material could be transferred from dead S cells to live R cells

How Was DNA's Function Discovered? (cont'd.)



A **Griffith's first experiment showed that R cells were harmless. When injected into mice, the bacteria multiplied, but the mice remained healthy.**

B **The second experiment showed that an injection of S cells caused mice to develop fatal pneumonia. Their blood contained live S cells.**

C **For a third experiment, Griffith killed S cells with heat before injecting them into mice. The mice remained healthy, indicating that the heat-killed S cells were harmless.**

D **In his fourth experiment, Griffith injected a mixture of heat-killed S cells and live R cells. To his surprise, the mice became fatally ill, and their blood contained live S cells.**

How Was DNA's Function Discovered? (cont'd.)

- In 1940, Oswald Avery and Maclyn McCarty identified that the "transforming principle" was a nucleic acid
  - Lipid- and protein-destroying enzymes did not block the S cell's transformation of R cells
  - DNA-degrading enzymes, but not RNA-degrading enzymes, prevented transformation
  - They concluded that DNA must be the transforming principle

How Was DNA's Function Discovered? (cont'd.)

- Essential properties of hereditary material:
  - A full complement of hereditary information must be transmitted along with the molecule
  - An equal amount of hereditary material must be found in each cell of a given species
  - The hereditary material must not change
  - The hereditary material must be capable of encoding the enormous amount of information required to build a new individual

How Was DNA's Function Discovered? (cont'd.)

- In the late 1940s, Alfred Hershey and Martha Chase established that DNA transmits a full complement of hereditary information
  - They established that the material bacteriophage (a virus that infects bacteria) injects into bacteria is DNA, not protein

ANIMATION: The Hershey and Chase Experiments

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How Was DNA's Function Discovered? (cont'd.)

- In 1948, André Boivin and Roger Vendrely established that body cells of any individual of a species contain precisely the same amount of DNA
- Daniel Mazia's laboratory discovered that DNA content does not change over time
  - Established that DNA is not involved in metabolism

8.2 How Was DNA's Structure Discovered?

- Building blocks of DNA
  - DNA is a polymer of nucleotides, each with a five-carbon sugar, three phosphate groups, and one of four nitrogen-containing bases

Animation: Subunits of DNA

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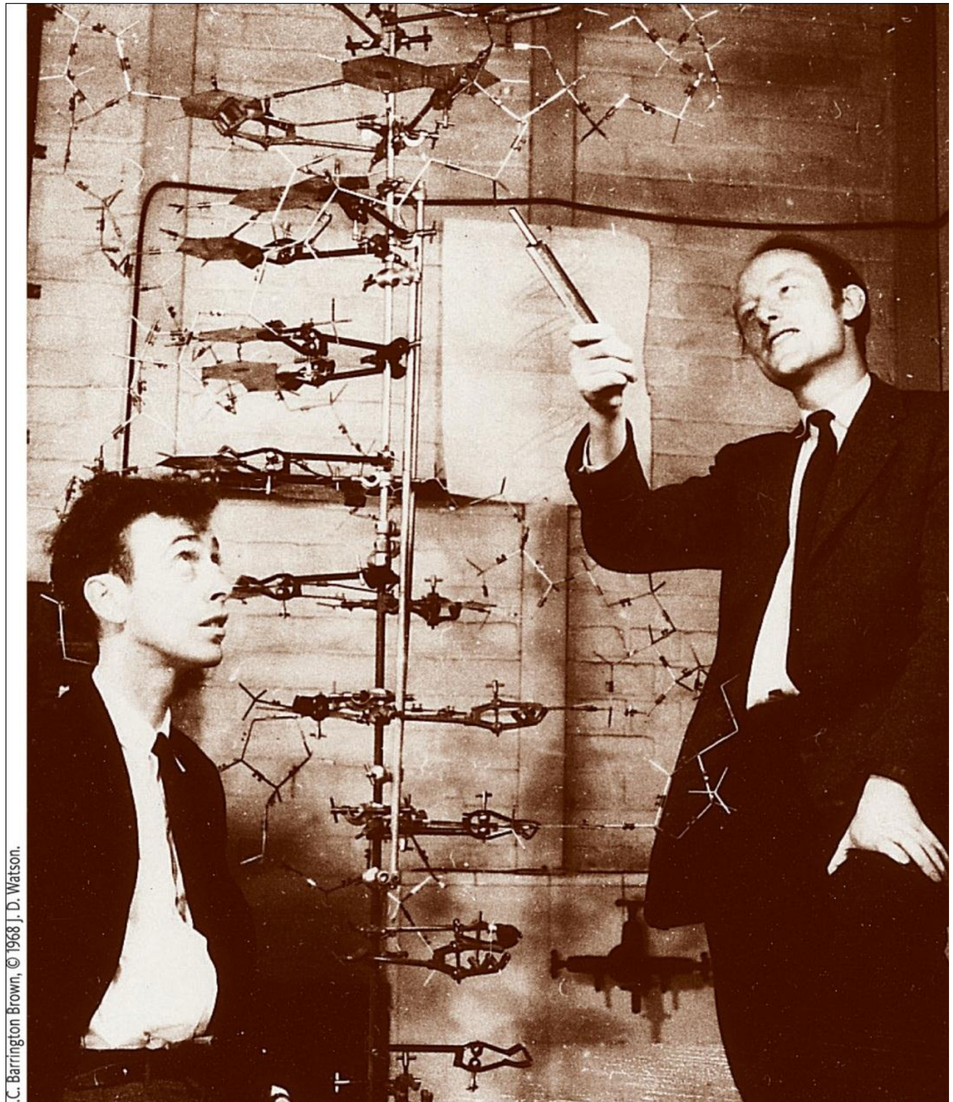
Building Blocks of DNA (cont'd.)

- 1950: Erwin Chargaff made two important discoveries about DNA
  – Chargaff 's first rule: the amounts of thymine and adenine are identical, as are the amounts of cytosine and guanine (A = T and G = C)
  – Chargaff 's second rule: DNA of different species differs in its proportions of adenine and guanine

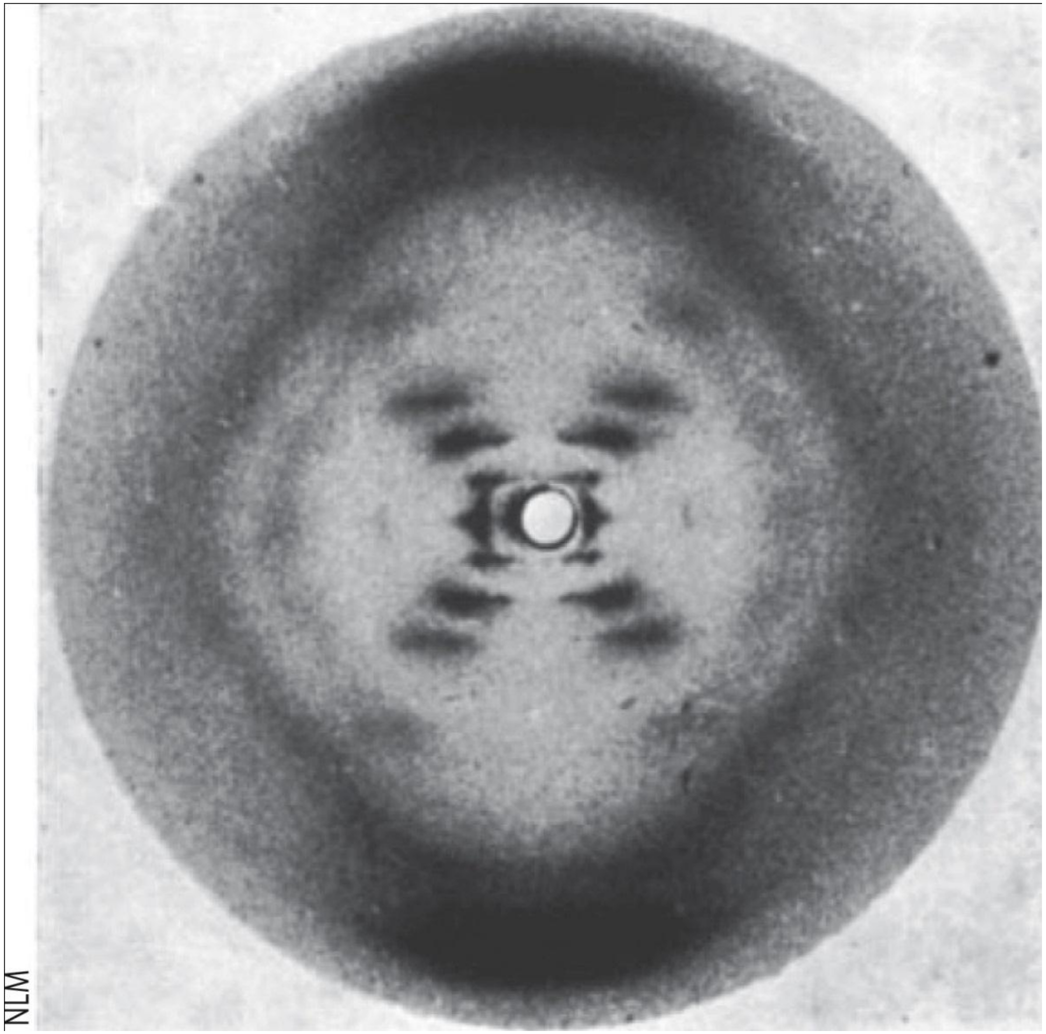
Building Blocks of DNA (cont'd.)

- 1950s: James Watson and Francis Crick suspect that DNA is a helix
  - Made models from scraps of metal connected by suitably angled "bonds" of wire
- Rosalind Franklin made the first clear x-ray diffraction image of DNA as it occurs in cells
  - She calculated that DNA is very long and identified a repeating pattern

Building Blocks of DNA (cont'd.)



Building Blocks of DNA (cont'd.)



Building Blocks of DNA (cont'd.)

- Structure of DNA helix:
  - Two sugar–phosphate chains running in opposite directions, and paired bases inside
  - Bonds between the sugar of one nucleotide and the phosphate of the next form the backbone of each chain (or strand)

Building Blocks of DNA (cont'd.)

- Structure of DNA helix (cont'd.):
  - Hydrogen bonds between the internally positioned bases hold the two strands together
  - Only two kinds of base pairings form (supports Chargaff 's first rule):
    - A to T
    - G to C

Animation: DNA close up

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DNA's Base Sequence

- The two strands of DNA match
  - The strands are complementary: the base of each nucleotide on one strand pairs with a suitable partner base on the other
  - The base-pairing patterns - A to T and G to C - is the same in all molecules of DNA

DNA's Base Sequence (cont'd.)

DNA's Base Sequence (cont'd.)

- How can just two kinds of base pairings give rise to the incredible diversity of traits we see among living things?
  - The order of nucleotides in a strand of DNA (DNA sequence) varies tremendously among species
  - Explains Chargaff 's second rule

DNA's Base Sequence (cont'd.)

- DNA molecules can be hundreds of millions of nucleotides long
  - So their sequence can encode a massive amount of information
- DNA is the basis of life's unity
  - Variations in its nucleotide sequence are the foundation of life's diversity; defines species and distinguishes individuals

8.3 What Is a Chromosome?

- DNA in a single human cell is about 2 meters (6.5 feet) long
- How can that much DNA pack into a nucleus that is less than 10 micrometers in diameter?
  - Proteins associate with the DNA and help keep it organized

What Is a Chromosome? (cont'd.)

- Chromosome: structure that consists of DNA and associated proteins
  - Carries part or all of a cell's genetic information
- Histone: type of protein that structurally organizes eukaryotic chromosomes
- Nucleosome: a length of DNA wound twice around a spool of histone proteins

ANIMATION: Chromosome structural organization

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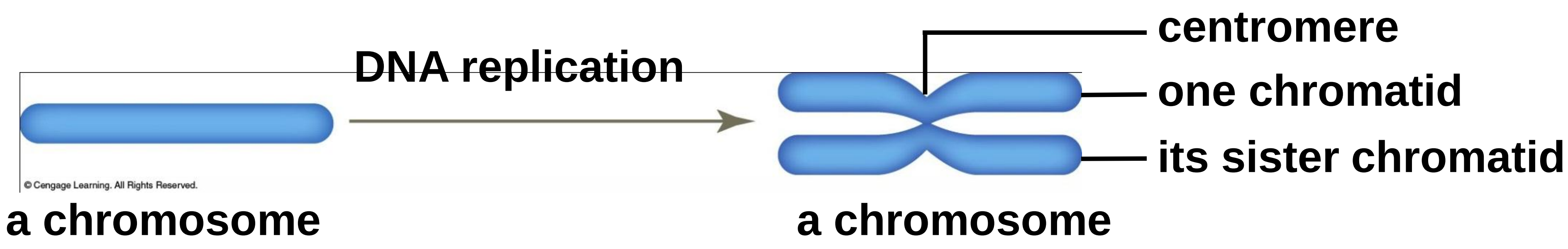
What Is a Chromosome? (cont'd.)

- During most of a cell's life, each chromosome consists of one DNA molecule
- When the cell prepares to divide, it duplicates its chromosomes by DNA replication
  - After replication, each chromosome consists of two DNA molecules (*sister chromatids)* that attach at a *centromere* region

What Is a Chromosome? (cont'd.)



Chromosome Number and Type

- Each species has a characteristic *chromosome number* (number of chromosomes in its cells)
  - Examples:
    - The chromosome number of oak trees is 12
    - The chromosome number of humans is 46

Chromosome Number and Type (cont'd.)

- Human body cells have two sets of 23 chromosomes—two of each type
  - Having two sets of chromosomes means these cells are *diploid*
- Karyotype: an image of an individual's diploid set of chromosomes

ANIMATION: Karyotype preparation

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Chromosome Number and Type (cont'd.)

- Autosome: a chromosome that is the same in males and females
  - Two autosomes of a pair have the same length, shape, and centromere location
  - They hold information about the same trait

Chromosome Number and Type (cont'd.)

- Members of a pair of *sex chromosomes* differ between females and males
  - The body cells of typical human females have two X chromosomes (XX)
  - The body cells of typical human males have one X and one Y chromosome (XY)
- Environmental factors (not sex chromosomes) determine sex in some invertebrates and reptiles

Chromosome Number and Type (cont’d.)

8.4 How Does a Cell Copy Its DNA?

- In preparation for division, a cell copies its chromosomes so that it contains two sets
  - The process by which a cell copies its DNA is called *DNA replication*

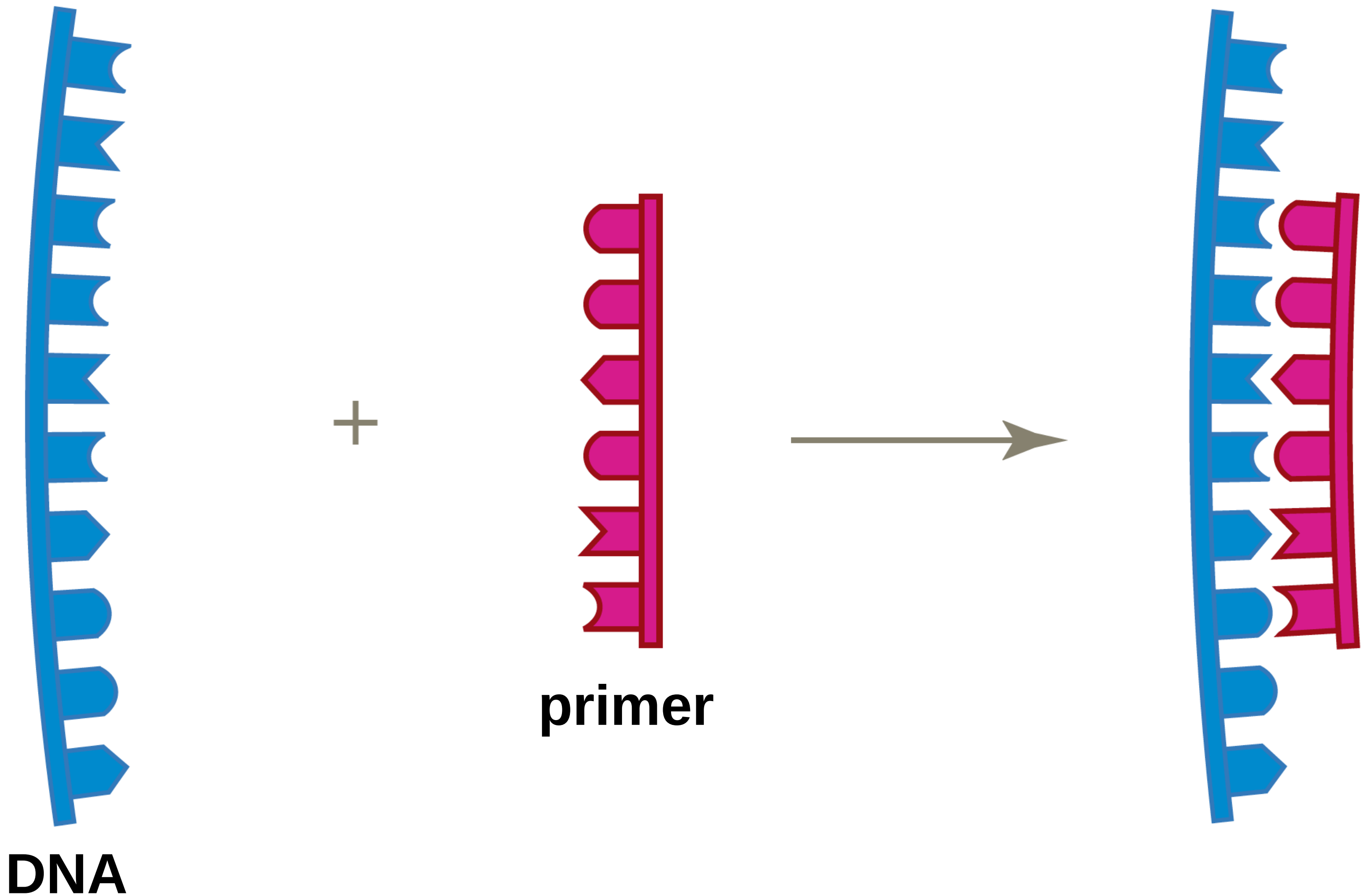
Semiconservative Replication

- Before DNA replication, a chromosome consists of one molecule of DNA (one double helix)
- As replication begins, enzymes break the hydrogen bonds that hold the double helix together
  - The two DNA strands unwind and separate

Semiconservative Replication (cont'd.)

- Another enzyme constructs *primers*: short, single strands of nucleotides
  - Primers serve as attachment points for *DNA polymerase*, the enzyme that assembles new strands of DNA
  - A primer base-pairs with a complementary strand of DNA

Semiconservative Replication (cont'd.)



Semiconservative Replication (cont'd.)

- The establishment of base-pairing between two strands of DNA is called *nucleic acid hybridization*
  - Hybridization is spontaneous, driven by hydrogen bonding between bases of complementary strands
- DNA polymerases attach to the hybridized primers and begin DNA synthesis

Semiconservative Replication (cont'd.)

- Each nucleotide provides energy for its own attachment to the end of a growing strand of DNA
  - Two of the three phosphate groups are removed when a nucleotide is added to a DNA strand
- The enzyme *DNA ligase* seals any gaps, so the new DNA strands are continuous

Semiconservative Replication (cont'd.)

- Both of the two strands of the parent molecule are copied at the same time
- As each new DNA strand lengthens, it winds up with its template strand into a double helix
- *Semiconservative replication* produces two copies of a DNA molecule: one strand of each copy is new, and the other is parental

ANIMATION: DNA replication in detail

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Directional Synthesis

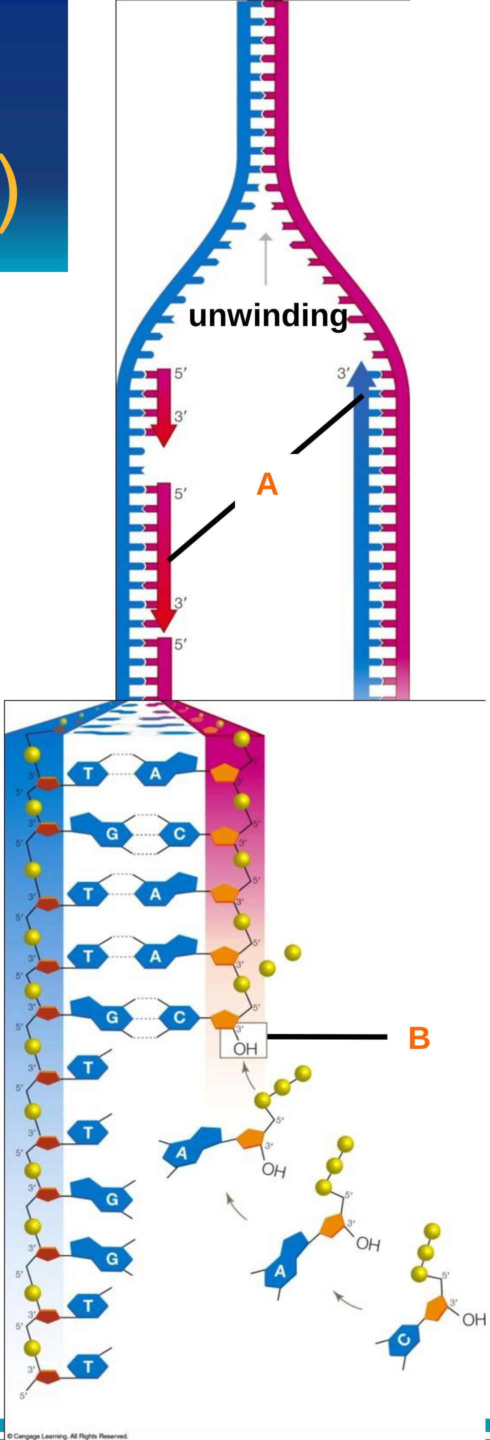
- Each strand of DNA has two ends
  - The last carbon atom on one end of the strand is a 5′ (5 prime) carbon of a sugar
  - The last carbon atom on the other end is a 3′ (three prime) carbon of a sugar

Directional Synthesis (cont'd.)

Directional Synthesis (cont'd.)

- DNA polymerase can attach a nucleotide only to a 3′ end
  - DNA synthesis proceeds only in the 5′ to 3′ direction
- One new strand of DNA is constructed in a single piece during replication
  - Synthesis of the other strand occurs in segments that must be joined by DNA ligase

Directional Synthesis (cont'd.)



8.5 What Causes Mutations?

- Mistakes can and do occur during DNA replication
- Examples:
  - The wrong base is added to a growing DNA strand
  - A nucleotide gets lost, or an extra one slips in

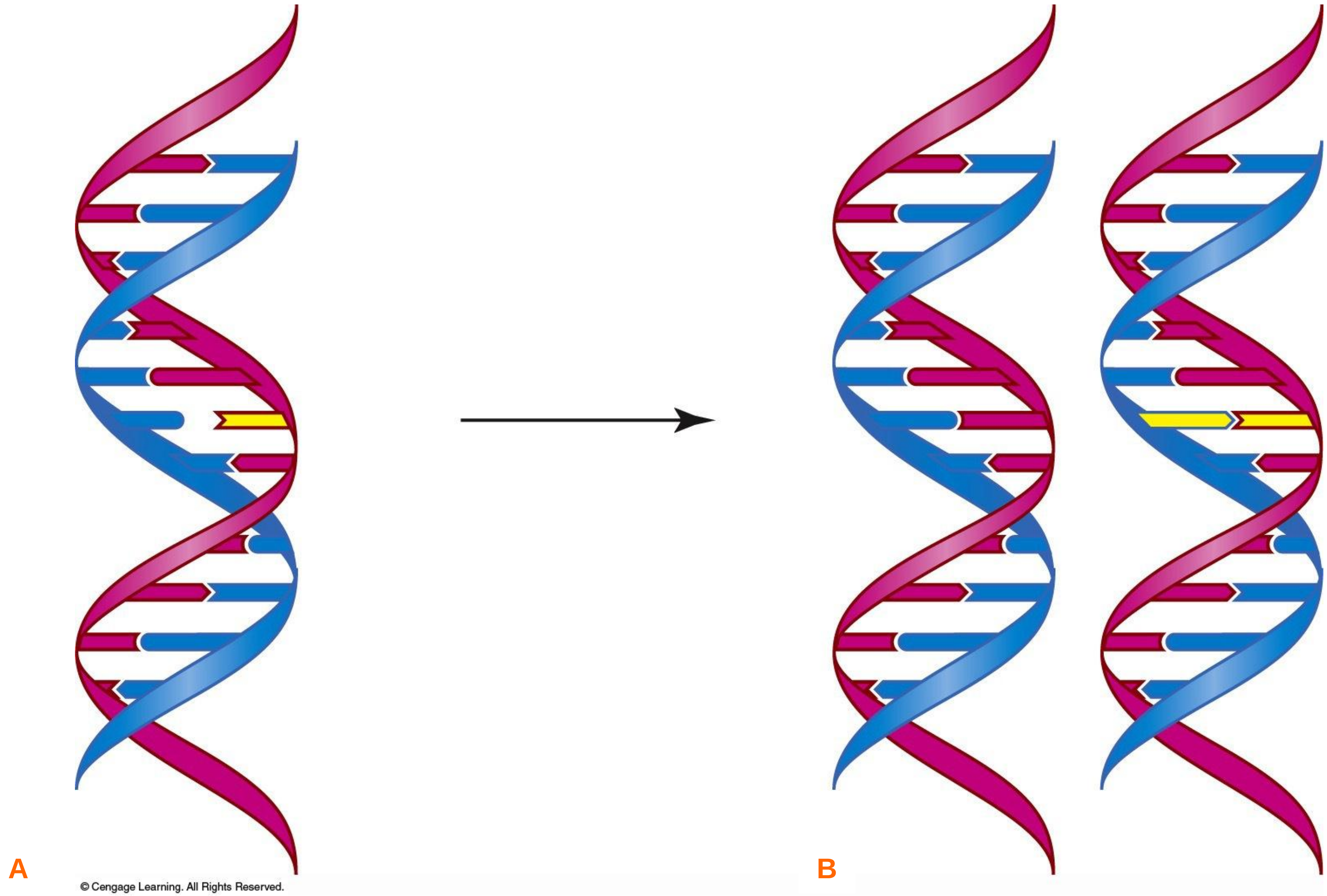
What Causes Mutations? (cont'd.)

- Most replication errors occur because DNA polymerases work very fast
- Luckily, most DNA polymerases also proofread their work
  - They can correct a mismatch by reversing the synthesis reaction to remove the mispaired nucleotide

What Causes Mutations? (cont'd.)

- Replication errors may occur after a cell's DNA gets broken or damaged
  - DNA polymerases do not copy damaged DNA very well
- When proofreading and repair mechanisms fail, an error becomes a *mutation*
  - A permanent change in the DNA sequence of a cell's chromosome

What Causes Mutations? (cont'd.)



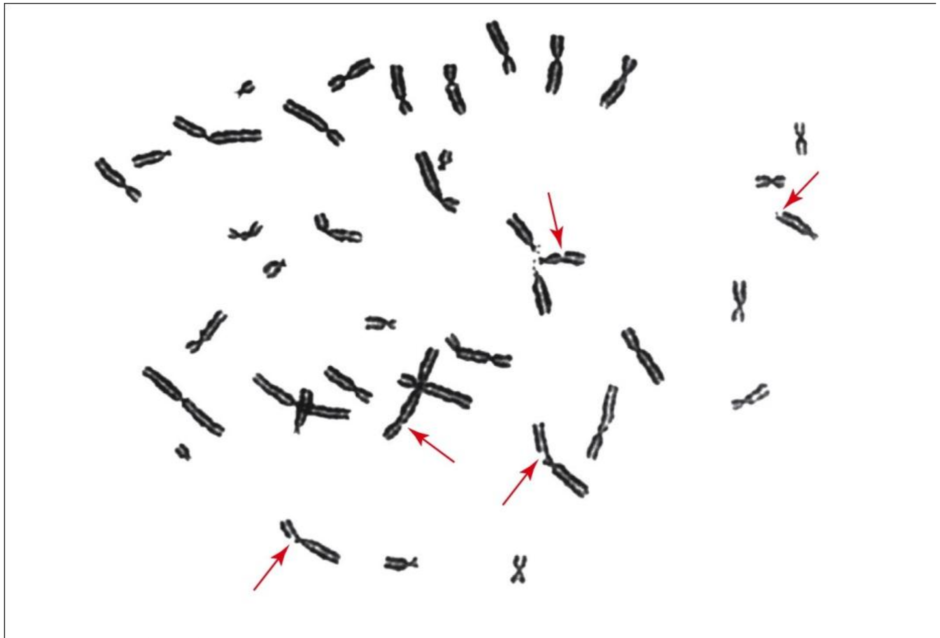
What Causes Mutations? (cont'd.)

- Mutations can form in any type of cell
  - Those that occur during egg or sperm formation can be passed to offspring
- Mutations that alter DNA's instructions may have a harmful or lethal outcome
  - Most cancers begin with a mutation
- Not all mutations are dangerous
  - Some give rise to variation in traits; basis for evolution

Agents of DNA Damage

- Ionizing radiation from x-rays, most UV light, and gamma rays may cause DNA damage:
  - Breaks DNA
  - Causes covalent bonds to form between bases on opposite strands
  - Fatally alters nucleotide bases
  - Causes adjacent nucleotide dimers to form

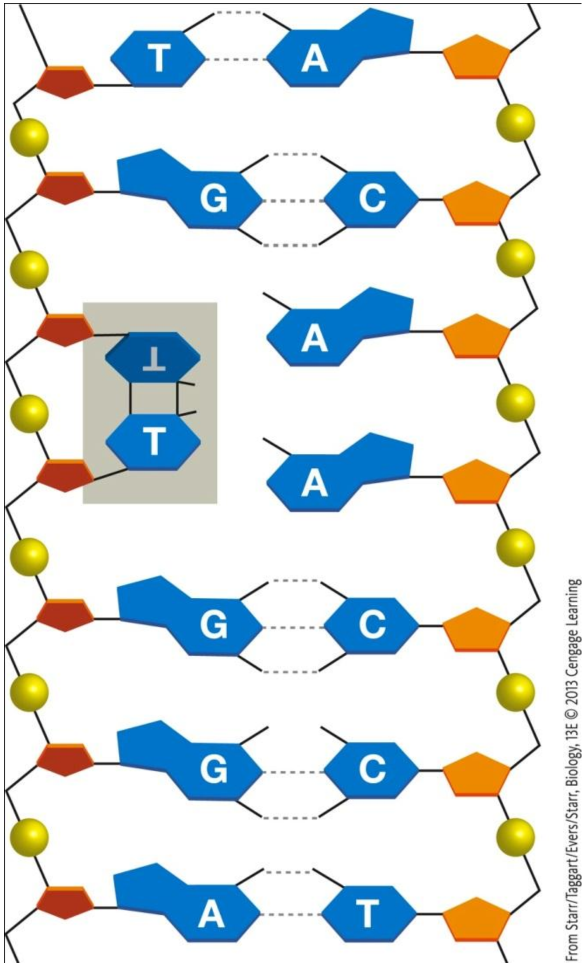
Agents of DNA Damage (cont'd.)



Olga Shovman, Andrew C. Riches, Douglas Adamson, and Peter E. Bryant. An improved assay for radiation-induced chromatid breaks using a colcemid block and calyculin-induced PCC combination. *Mutagenesis* (2008) 23(4): 267–270 first published online March 6, 2008 doi:10.1093/mutage/gen009, by permission of Oxford University Press

main, Courtesy of Janis Ruksans; inset, Frank Sommariva/image/imagebroker.net/SuperStock.

Agents of DNA Damage (cont'd.)



a thymine dimer

8.6 How Does Cloning Work?

- Cloning: making an identical copy of something
- Reproductive cloning: technology that produces genetically identical individuals
  - Example: artificial embryo splitting

How Does Cloning Work? (cont'd.)

- Animal breeders sometimes want an exact copy of a specific individual
  - Use a cloning method where a somatic cell is taken from an adult organism (contains master blueprint for new individual)
  - An adult somatic cell will not start dividing to produce an embryo because the cell has already *differentiated* (obtained specialized characteristics)

How Does Cloning Work? (cont'd.)

- *Somatic cell nuclear transfer* (SCNT) can undifferentiate a somatic cell by turning its unused DNA back on
  - An unfertilized egg's nucleus is replaced with the nucleus of a donor's somatic cell
  - The egg's cytoplasm reprograms the transplanted DNA to direct the development of an embryo, which is then implanted into a surrogate mother

ANIMATION: How Dolly was created

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How Does Cloning Work? (cont'd.)

Courtesy of Cyagra, Inc., www.cyagra.com

How Does Cloning Work? (cont'd.)

- As techniques become routine, cloning humans is no longer only within the realm of science fiction
- SCNT is already being used to produce human embryos for medical purposes, called *therapeutic cloning*
  - Example: researchers are using SCNT to study how heart defects cause developing heart cells to malfunction

8.7 A Hero Dog's Golden Clones

- Trakr, who died in 2009, was a hero dog who helped rescuers at the World Trade Center on 9/11
  - Through the Golden Clone Giveaway Trakr's DNA was used to make clones
- Cloning animals raises ethical questions about cloning humans
  - Is it acceptable to clone a lost child for a grieving parent?

A Hero Dog's Golden Clones (cont'd.)

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