# 5.1 - DNA Structure and Organization in the Cell

Pages 204-218 (McGraw-Hill Ryerson, 2011)

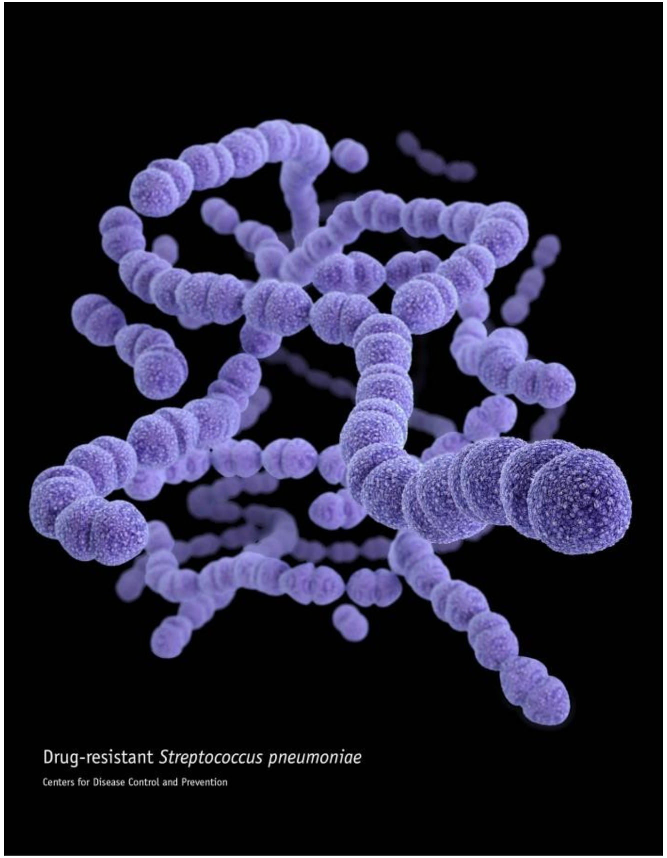
# Subtopics

- Identifying DNA as the Material of Heredity
  - Griffith - Transformation; supported by Avery et al.
  - Hershey and Chase - DNA is the Genetic Material
- Determining the Chemical Composition and Structure of DNA
  - Levene; Chargaff - Composition/Structure
- Determining the Three-Dimensional Structure of DNA
  - Watson/Crick/Pauling/Franklin - 3D Structure (Double Helix)
- The Structure and Organization of Genetic Material in:
  - Prokaryotes and Eukaryotes

# Identifying DNA as the Material of Heredity

## London, England
## 1928

Bacterial pneumonia is both common and lethal, resulting in significant fatalities world-wide.



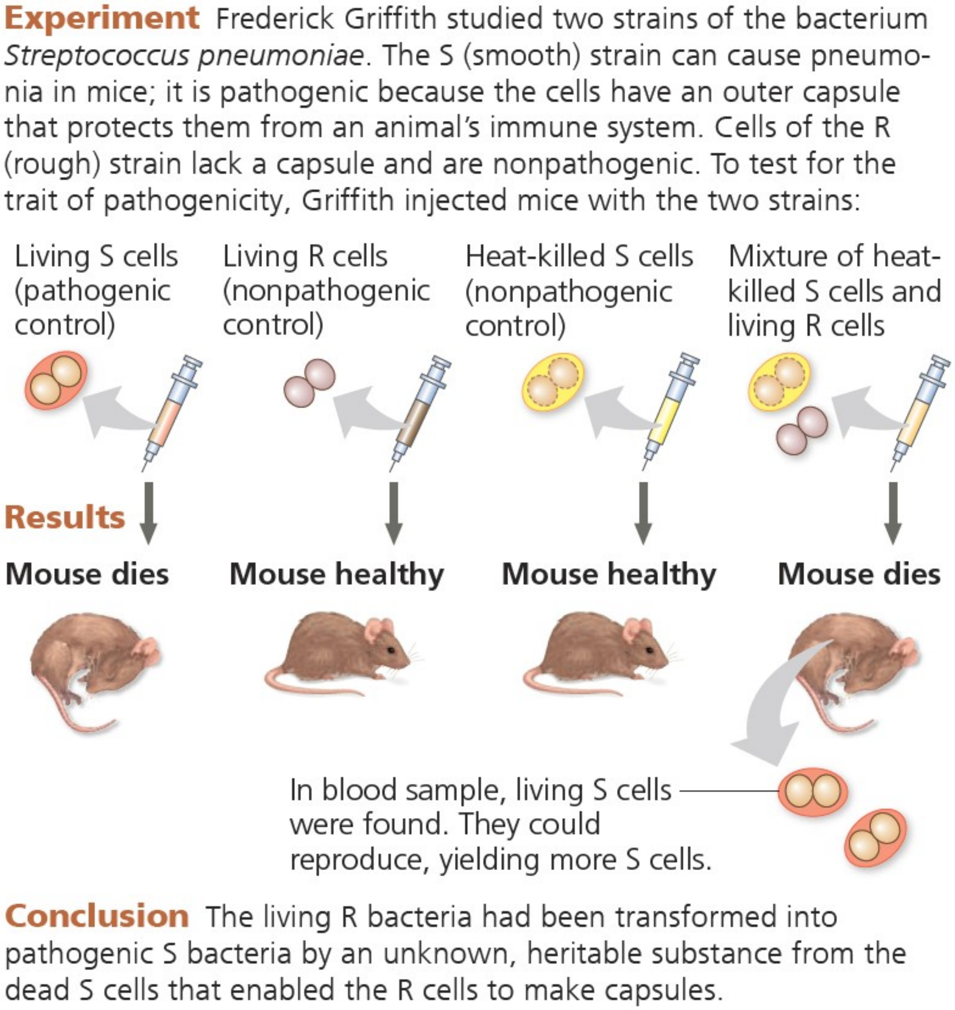

U.S. Centers for Disease Control and Prevention - Medical Illustrator

# Frederick Griffi
# microbiologist

## London, England, 192

Griffith discovery of a“transforming principle” which is some substance that can be transferred between organisms inspired Avery, MacLeod and McCarty to look further into what this substance is.

https://www.youtube.com/watch?v=ARHrYr_SqHs&ab_channel=QuickBiochemistryBasics



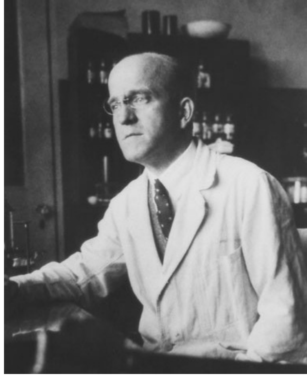

Reece et. al (2017)

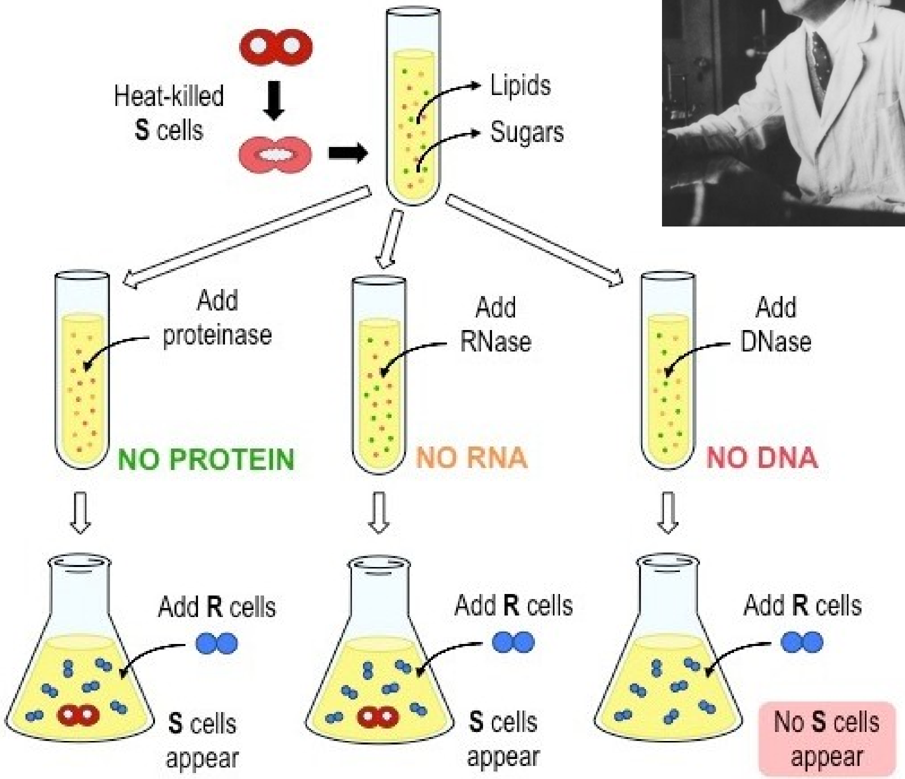
# Oswald Avery, Colin MacLeod, Maclyn McCarty

## New York, USA, 1944

Key Discoveries:

- DNA was the transforming principle
- Isolated and chemically characterized DNA
- Argued that protein isn't the hereditary molecule - this was a widely held belief at the time



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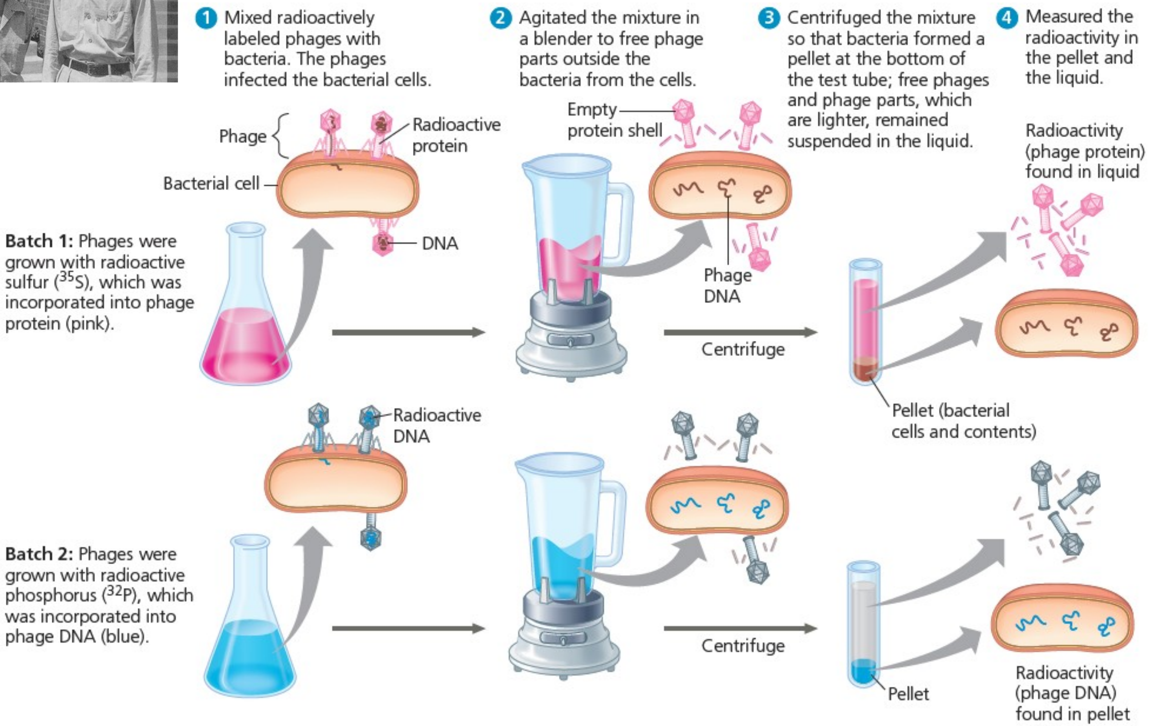
# Alfred Hershey & Martha Chase, Microbiologist

## Laurel Hollow, NY, USA, 1952

- Used T2 bacteriophage (bacterial virus)
- Used radioisotopes of sulfur (protein) and phosphorus (DNA) to determine which substance is transferred
- Ruled out protein




https://www.youtube.com/watch?v=N72Cle8xST0&ab_channel=QuickBiochemistryBasics

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Questions 1-6

# Learning Check

## Learning Check

1. Although scientists in the early 1900s had not yet identified the chemical composition of genetic material, what criteria did scientists know genetic material had to meet?
2. How did Griffith test for the existence of a transforming principle?
3. What were the results of the experiments on *S. pneumoniae* done by Avery, MacLeod, and McCarty?
4. Why did Hershey and Chase use two different radioactive isotopes in their experiments?
5. Identify the dependent and independent variables in Hershey and Chase's experiments. What were some controls?
6. If protein were the hereditary material, what would Hershey and Chase have seen in the results of their experiments?

1. Genetic material must contain information that regulates the production of proteins. It also must be able to accurately replicate itself to maintain continuity in future generations. Genetic material must allow for some mutations so that there is variation within a species.

2. Griffith used two forms of *S. pneumoniae*: a pathogenic S-strain and a non-pathogenic R-strain. After injecting mice with a mixture of heat-killed S-strain and live R-strain, the mice died. Griffith concluded that something from the heat-killed S-strain transferred to the R-strain to transform it into a pathogenic form.

3. Avery, MacLeod, and McCarty conducted a series of experiments and discovered the following:
   - When they treated heat-killed pathogenic bacteria with a protein-destroying enzyme, transformation still occurred.
   - When they treated heat-killed pathogenic bacteria with a DNA-destroying enzyme, transformation did not occur.

   These results provided strong evidence for DNA's role in transformation.

4. Two different radioactive isotopes were used to trace each type of molecule. One sample of T2 virus was tagged with radioactive phosphorus ($^{32}P$), since phosphorus is present in DNA and not protein. The other sample of T2 virus was tagged with radioactive sulfur ($^{35}S$), since sulfur is only found in the protein coat of the capsid.

5. The independent variable in the experiment was the type of radioactive isotope used to tag the virus. The dependent variable in the experiment was the presence of radioactivity inside the infected bacterial cells. Some of the controls include: the usage of the same type of virus in both experiments and the usage of the same protocol for infecting bacterial cells in both experiments.

6. Bacterial cells that are infected by viruses with $^{32}P$-labelled DNA would not be radioactive. Bacterial cells infected by viruses with $^{35}S$-labelled capsid proteins would be radioactive.

# Determining the Chemical Composition and Structure of DNA

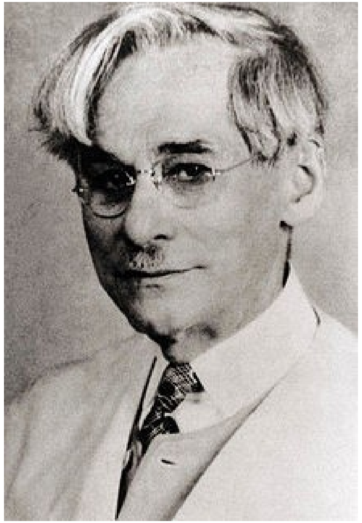
**Friedrich Miescher**

**Tübingen, Germany**
**1869-1871**

A weakly acidic substance is extracted from nuclei of white blood cells, and later other types of cells. The substance is composed of nitrogen and phosphorus. Friedrich Miescher called it **nuclein**. It later became called **nucleic acid**.

https://www.youtube.com/watch?v=EBL6NrF0O_M&ab_channel=AmericanMastersPBS

# Determining the Chemical Composition and Structure of DNA

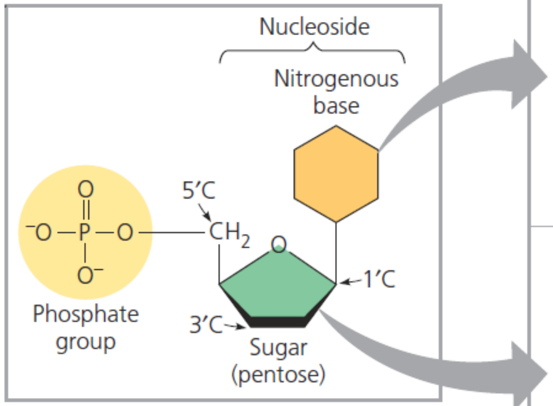


**Phoebus Levene**

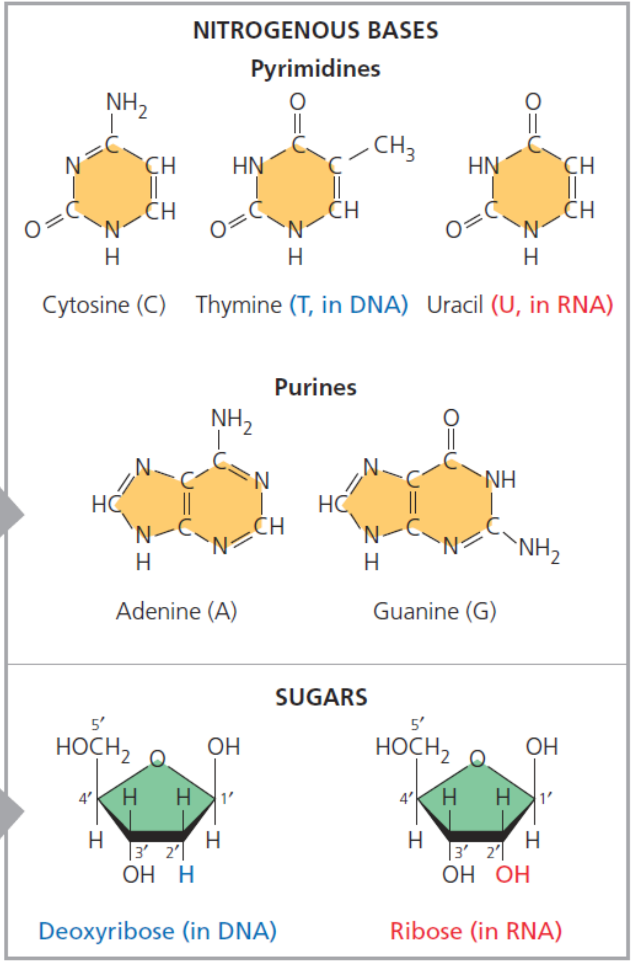
**New York, USA**
**Early 1900s**

- Ribose (1909) and Deoxyribose (1929) is identified as the sugar component of nucleic acids.

- Identified nucleotides (1919) as the monomer of nucleic acids as well as its components through hydrolysis reactions:
  - Sugar, phosphate and one of 4 nitrogen-




(b) **Nucleotide monomer in a polynucleotide**



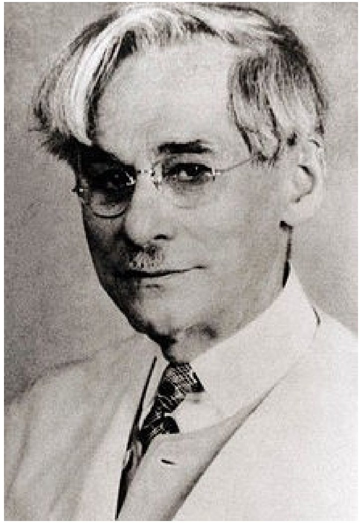

(c) **Nucleoside components**

# Determining the Chemical Composition and Structure of DNA

**Phoebus Levene**

https://www.youtube.com/watch?v=4pDtyyQgq-Q&ab_channel=RajS

**New York, USA**
**Early 1900s**



- Levene correctly proposed the polynucleotide model which describes monomers of nucleotides joined together in a long chain

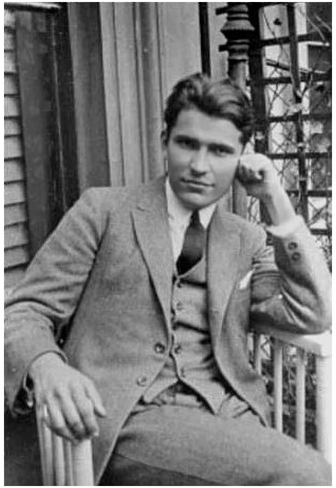
- Levene **incorrectly** proposed a model where the four bases are joined in a repeating sequence A-C-T-G-A-C-T-G-A-C-T-G. This would limit the potential for information storage and

# Determining the Chemical Composition and Structure of DNA

**Erwin Chargaff**

https://www.youtube.com/watch?v=Nbhx94MyYkk&ab_channel=PietroDamasceno

**New York, USA**
**1944-1950**

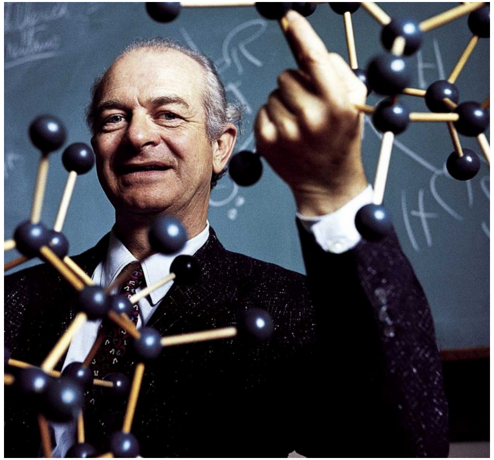


- Erwin Chargaff was inspired by Avery et al.
- Discovered that the amount of A = T and C = G and that the proportion of ACTG varies among species - DNA varies among various species!
- **Chargaff's rule** - in DNA, the % composition of adenine is the same as thymine, and the percent composition of cytosine is the same as guanine.

# Determining the Three-Dimensional Structure of DNA

- Knowledge to date:
    - Hershey and Chase confirms DNA as hereditary material
    - Levene confirms nucleotide structure using hydrolysis reactions
    - Chargaff confirms repeating units of nucleotides with fixed proportions (A-T / C-G) with variance amongst different speci

# Determining the Three-Dimensional Structure of DNA



## Linus Pauling

## California, USA, 1950s

- 2x Nobel Laureate
- Crick called him the “Father of Molecular Biology”
- Characterized sickle cell anemia as a ‘molecular disease’ ushering in a new perspective of genetically acquired mutations
- He was really good at looking at the 3d structure of molecules
- His discoveries contributed to the alpha helix and beta

# Determining the Three-Dimensional Structure of DNA

**James Watson (Biologist) & Francis Crick (Ph**

Crick (left) & Watson (right)

**Cambridge, England, 1950s**

- Watson and Crick want to go beyond identification of nucleic acids as hereditary material
- Understanding three dimensional structure is a big step towards understanding how DNA functions as hereditary material
- They relied on work done by Linus Pauling and Rosalind Franklin

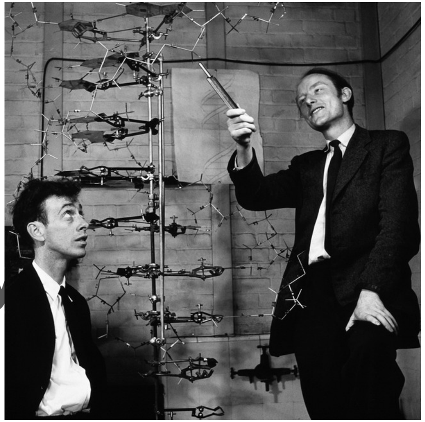
# Determining the Three-Dimensional Structure of D

**Rosalind Franklin**

**London, 1950s**

- Never won a Nobel Prize
- She was exceptionally talented at taking x-ray diffraction images
- The pattern of x-ray diffraction can be used to determine the 3D structure of a molecule exposed to the x-ray
- Her imaging suggested a helical model for DNA with repeating patterns at 0.34 nm and 3.4 nm
- She proposed a double helix model with the base pairs on

# Determining the Three-Dimensional Structure of DNA



## James Watson (Biologist) & Francis Crick (Phy

## Cambridge, England, 1950s

https://www.youtube.com/watch?v=59XnRgnkcB8&ab_channel=ThePenguinProf

- Initially Watson & Crick proposed an **incorrect** helical structure with base pairs on the exterior
- After Watson was shown Rosalind Franklin’s x-ray diffraction images (without her permission) by Maurice Wilkins, he came to the conclusion that the base pairs were on the interior of the double helix
- Pauling got stuck on the incorrect helical structure model that initially plagued Watson & Crick

# Modern DNA Model:
# The DNA Double Helix

- 2 polynucleotide strands forming a double helix
- Each polynucleotide has a sugar-phosphate backbone
- Strands are not identical but complementary (through A-T & C-G hydrogen bonding)
- Hydrogen bonding hold the two strands together at the nitrogenous base pairs
- The strands are anti-parallel, one strand in 5'-3' and the

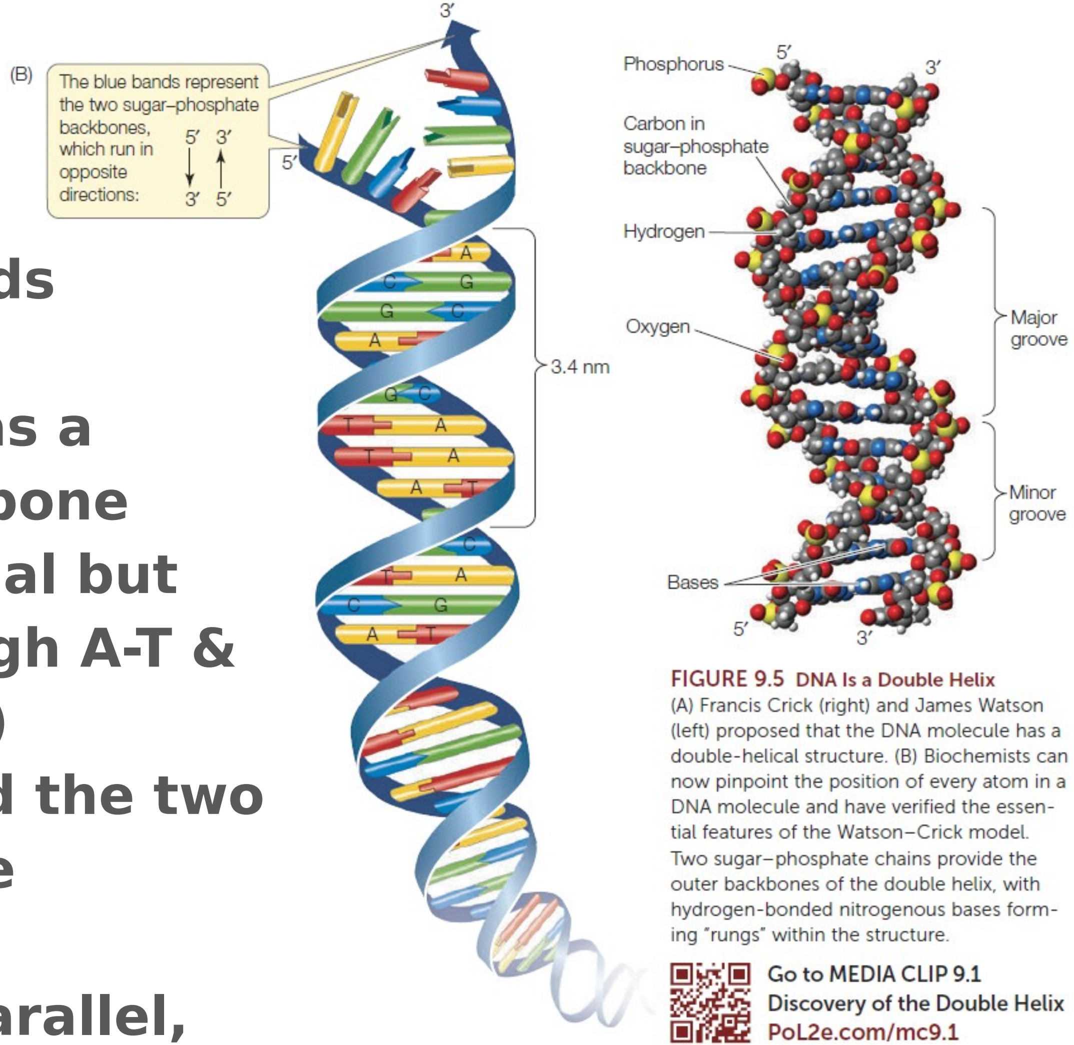



**FIGURE 9.5 DNA Is a Double Helix**
(A) Francis Crick (right) and James Watson (left) proposed that the DNA molecule has a double-helical structure. (B) Biochemists can now pinpoint the position of every atom in a DNA molecule and have verified the essential features of the Watson–Crick model. Two sugar–phosphate chains provide the outer backbones of the double helix, with hydrogen-bonded nitrogenous bases forming "rungs" within the structure.

Go to MEDIA CLIP 9.1
Discovery of the Double Helix
PoL2e.com/mc9.1

Questions 7-12

# Learning Check

## Learning Check

7. Draw and label a diagram of the general structure of a single nucleotide.
8. How do nucleotides in DNA differ from nucleotides in RNA?
9. Define Chargaff's rule. How did Chargaff's findings overturn earlier beliefs about DNA?
10. How did the work of Franklin and Pauling contribute to the Watson and Crick model of DNA?
11. Use a labelled diagram to illustrate the following features of a DNA molecule:
    - **a.** complementary base pairing
    - **b.** antiparallel strands
12. In an early model of DNA tested by Watson and Crick, the sugar-phosphate handrails were on the inside of the helix and the nitrogenous bases protruded outward. How is this model inconsistent with experimental evidence about the structure of DNA?

7. Answers should be similar to **Figure 5.4** on page 208 of the student textbook, with labels for the following: phosphate group, sugar group, nitrogen-containing base.

8. Nucleotides in DNA have a deoxyribose sugar, while nucleotides in RNA have a ribose sugar with a hydroxyl group at carbon 2. In addition to the sugar group each nucleotide is attached to a phosphate group and a base. The bases are adenine, cytosine, guanine, and thymine in the case of DNA and adenine, cytosine, guanine, and uracil in the case of RNA.

9. Chargaff's rule states that in the DNA nucleotides, the amount of adenine will be more or less equal to the amount of thymine, and the amount of guanine will be equal to the amount of cytosine. The number of A-T nucleotides will not necessarily equal the number of C-G nucleotides. This overturned Levene's earlier hypothesis that the nucleotides occurred in equal amounts and were present in a constant and repeated sequence.

10. Franklin used X-ray photography to analyze the structure of DNA. Her observations provided evidence that DNA has a helical structure with two regularly repeating patterns. She also concluded that the nitrogenous bases were located on the inside of the helical structure, and the sugar-phosphate backbone was located on the outside, facing toward the watery nucleus of the cell. Pauling's methods of assembling three-dimensional models of compounds led to the discovery that many proteins had a helical structure. Watson and Crick also used this information to propose that DNA had a helix shape.

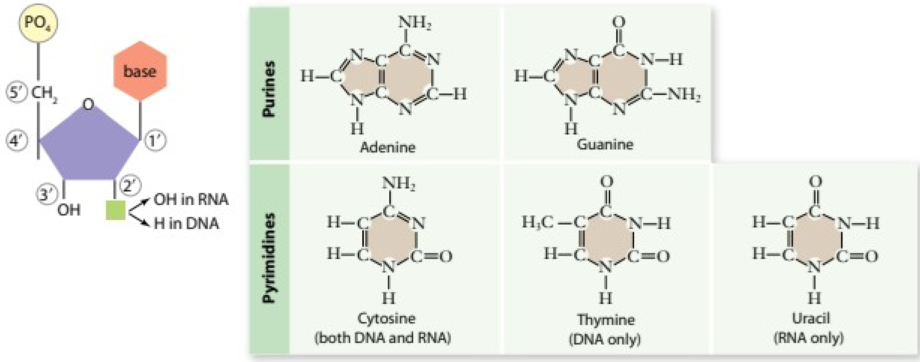



**Figure 5.4** The general structure of a DNA nucleotide includes a phosphate group, a deoxyribose sugar group, and a nitrogen-containing base. Nucleotides in RNA have the same basic structure, except a ribose sugar group is used. The sugar groups differ by a hydroxyl group at the 2′ carbon. Both DNA and RNA contain the same purine bases and the cytosine pyrimidine base. However, thymine is only present in DNA, and uracil is only present in RNA.

# References

Carter-Edwards, T., Gerards, S., Gibbons, K., McCallum, S., Noble, R., Parrington, J., Ramlochan, C., Ramlochan, S. (2011). *Biology 12*. McGraw-Hill Ryerson Limited

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