Science of Living System

BS20001

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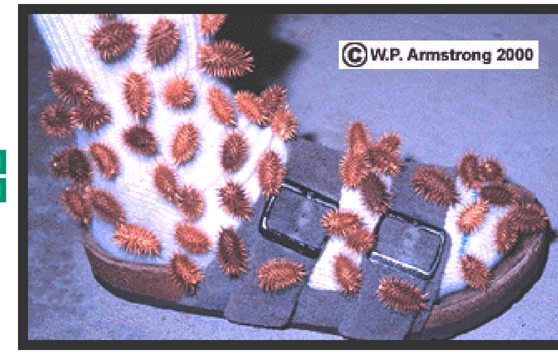
Why study Living System?

Shinkansen Bullet Train in Japan: inspired by shape of Kingfisher head

Eiji Nakatsu

Invention of Velcro®: inspired by Cockleburs

Cockleburs



George de Mestral invented Velcro®: Unique, two-sided fastener, one side with stiff **hooks** like the burs and the other side with soft **loops** like the fabric. a combination of the words velour and crochet.

Why study Living System?

STORAGE LIMITS

Estimates based on bacterial genetics suggest that digital DNA could one day rival or exceed today's storage technology.

	Hard disk	Flash memory	Bacterial DNA
Read–write speed (μs per bit)	~3,000–5,000	~100	<100
Data retention (years)	>10	>10	>100
Power usage (watts per gigabyte)	~0.04	~0.01–0.04	$<10^{-10}$
Data density (bits per cm³)	$\sim10^{13}$	$\sim10^{16}$	$\sim10^{19}$

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Microsoft Corporation – DNA Storage Research

A DNA-Based Archival Storage System Bornholt J, et. al. ASPLOS 2016 (International Conference on Architectural Support for Programming Languages and Operating Systems)

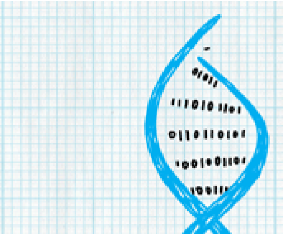
Microsoft Store Products Support

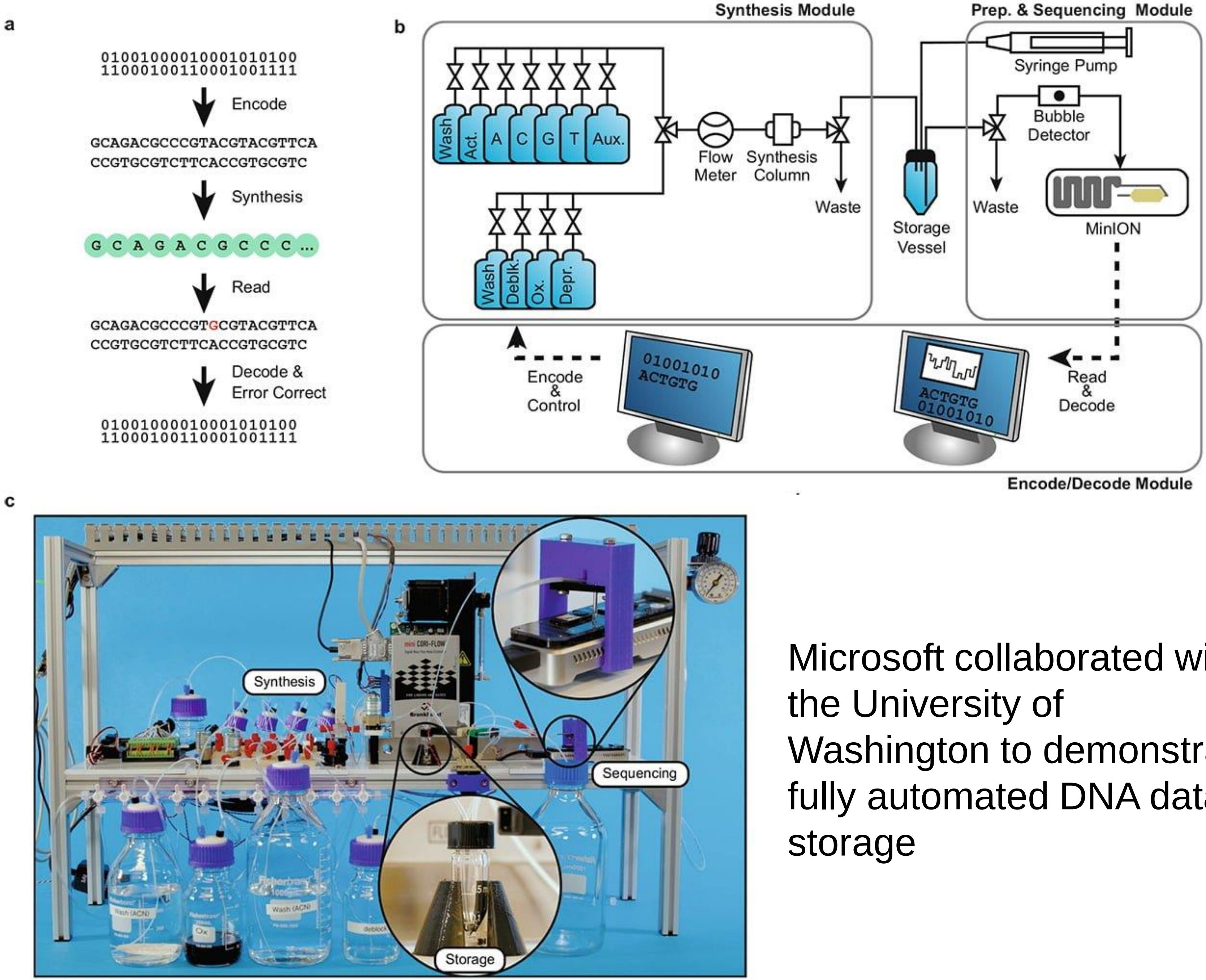
Research Research areas Products & Downloads Programs & Events People Careers About

DNA Storage

Established: January 1, 2015

The amount of digital data produced has long been outpacing the amount of storage available. This project enables molecular-level data storage into DNA molecules by leveraging biotechnology advances in synthesizing, manipulating and sequencing DNA to develop archival storage. Microsoft and University of Washington researchers are collaborating to use DNA as a high density, durable and easy-to-manipulate storage medium.





Microsoft collaborated with the University of Washington to demonstrate fully automated DNA data storage

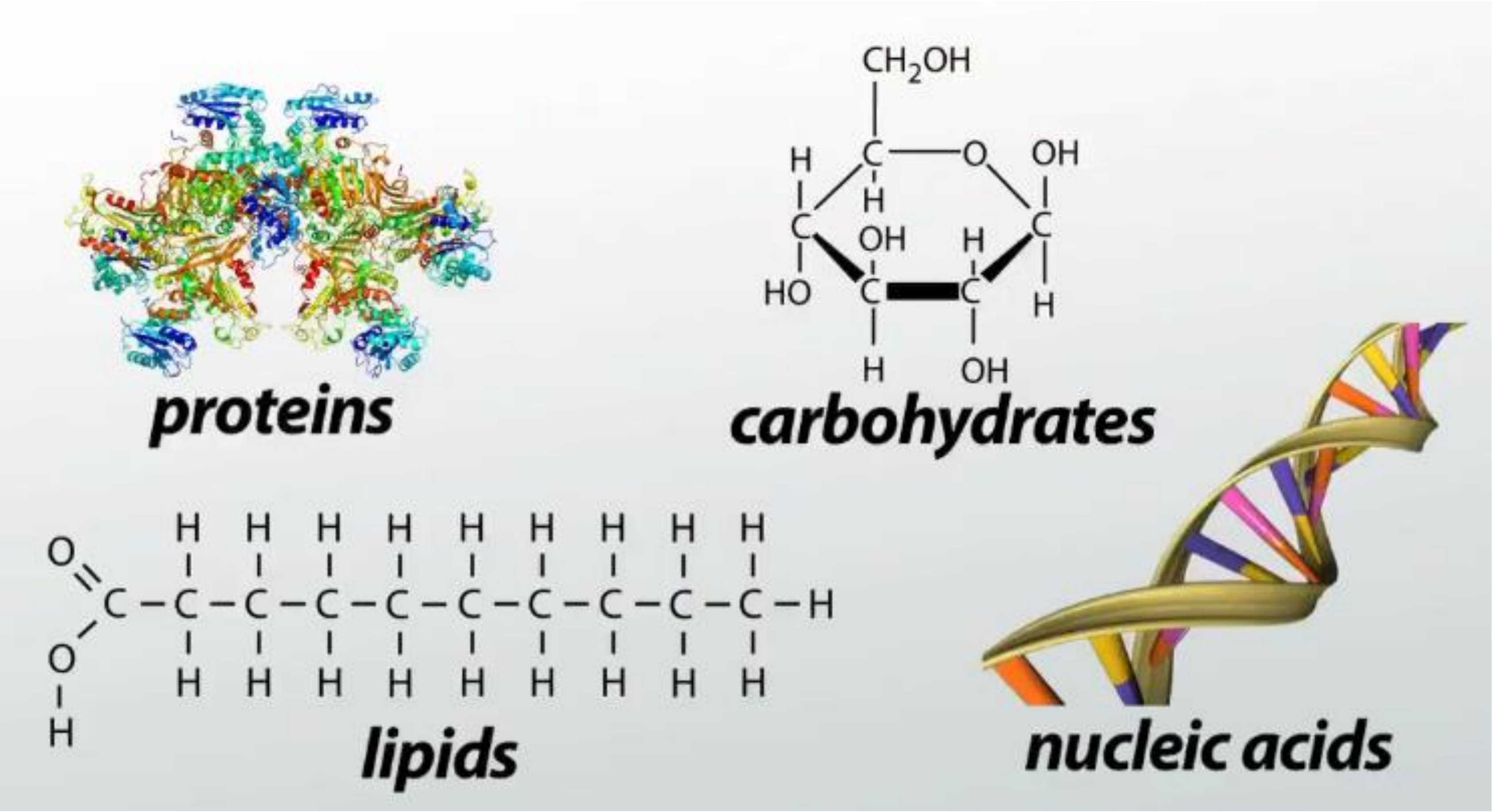
What are the characteristics of a Living System?

- High degree of **complexity**
- Mechanisms for **sensing** and **responding** to alterations in surroundings
- Systems for extracting, transforming and using **energy** from the environment
- Ability to **adapt** and **evolve**
- Ability to develop and **grow**
- Capacity for precise **self-replication** and **self-assembly**, known as reproduction

Components of Living Systems
C-H-O-N-S-P

- All life forms on Earth are composed of building blocks that are made of combinations of Carbon and other elements:
- Hydrogen
- Oxygen
- Nitrogen
- Sulphur
- Phosphorus

Molecules of Living Systems:
Biological Macromolecules



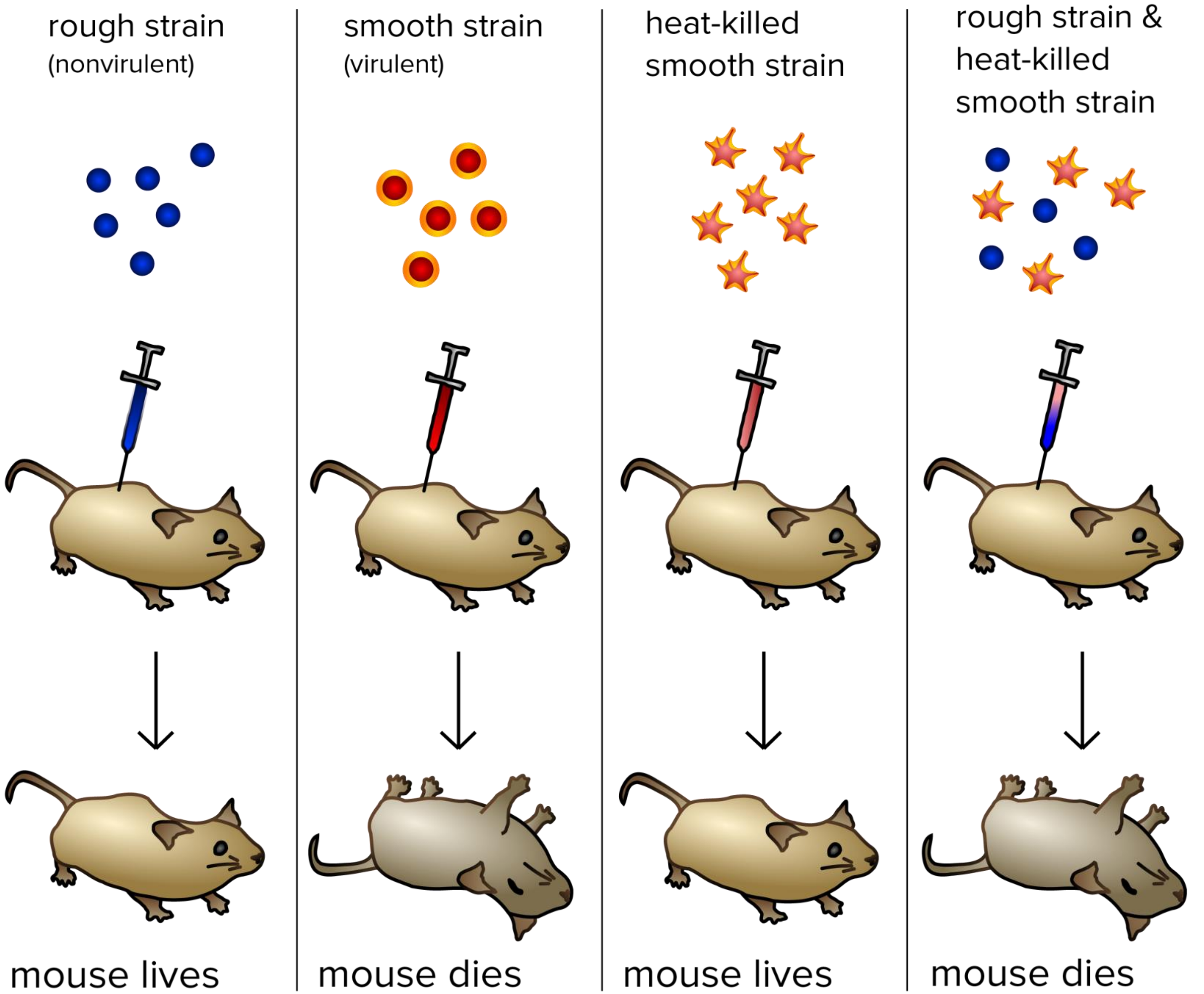
Nucleic Acid

Nucleic Acid

RNA: Ribonucleic Acid

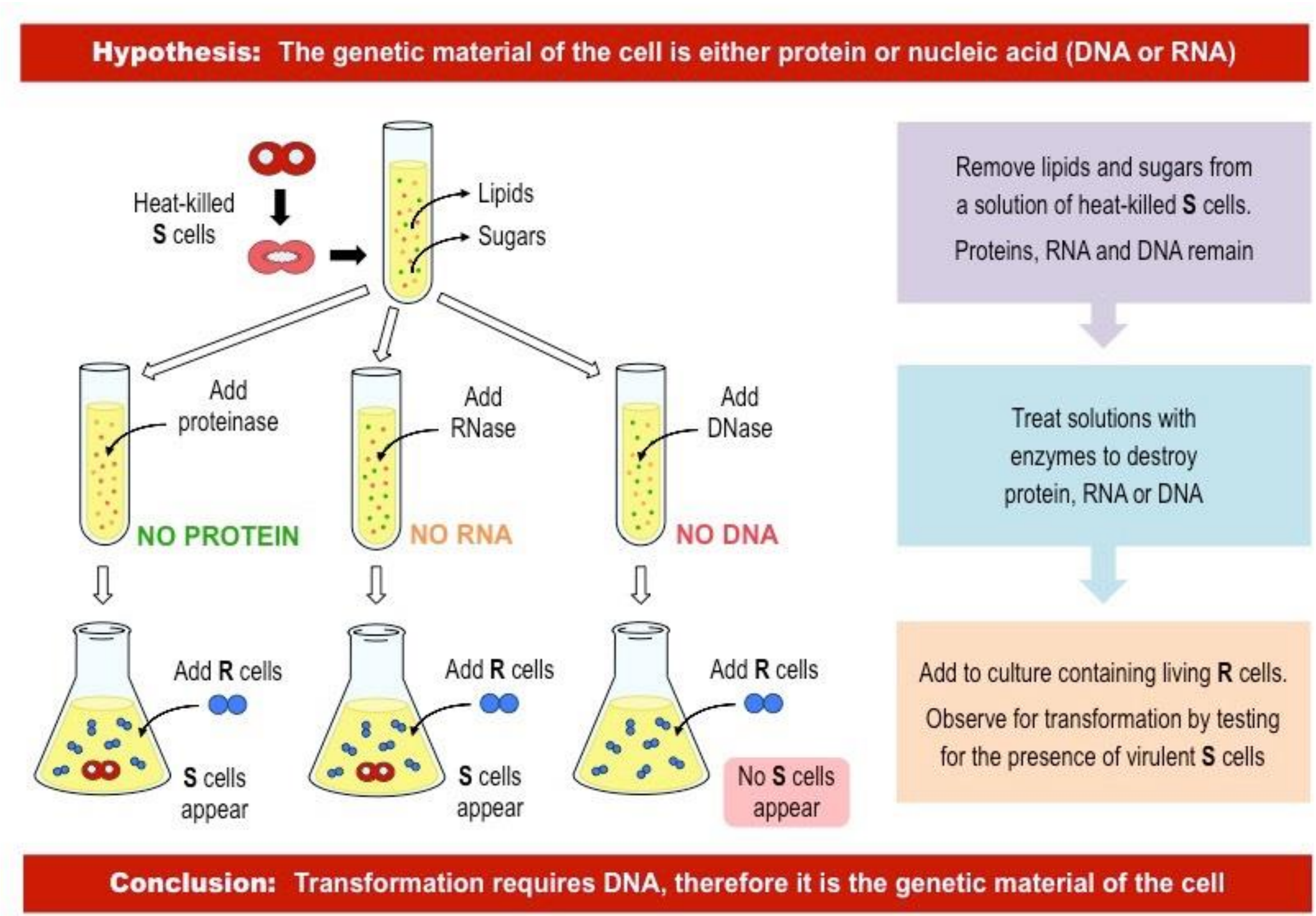
DNA: Deoxyribonucleic Acid

Experiment that Proves DNA is Our Genetic Material

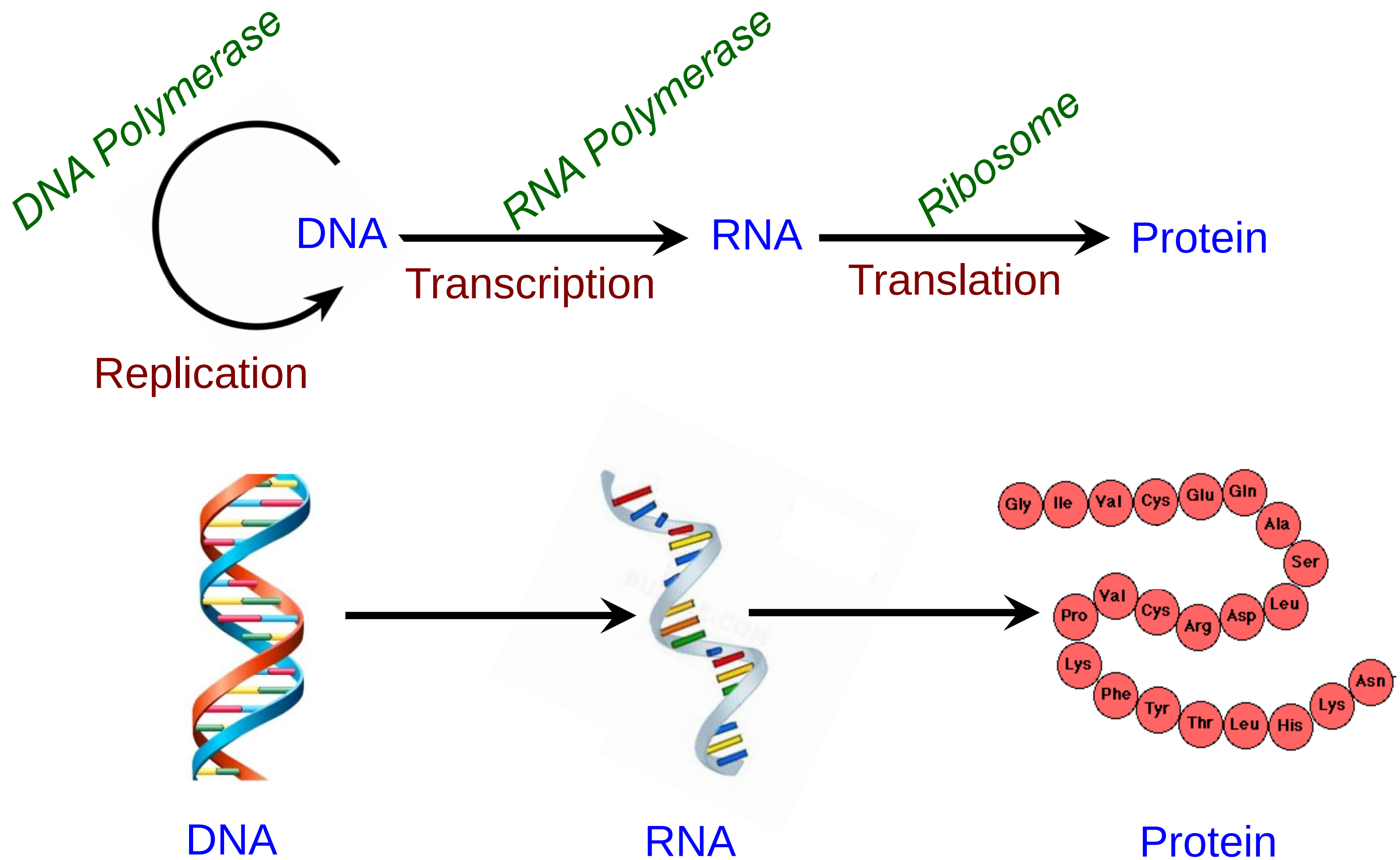


Frederick Griffith's experiment with bacteria (*Streptococcus pneumoniae*) (1928).

Experiment that Proves DNA is Our Genetic Material
Avery, MacLeod and McCarty's 1944



Flow of Genetic Information:
The Central Dogma of Molecular Biology



Polymer of nucleotides	Polymer of nucleotides	Polymer of amino acids

Nucleic Acid

- **Nucleic acids are polymers**

- **Monomer---nucleotides**
  - **Nitrogenous bases**
    - **Purines**
    - **Pyrimidines**
  - **Sugar**
    - **Ribose**
    - **Deoxyribose**
  - **Phosphates**

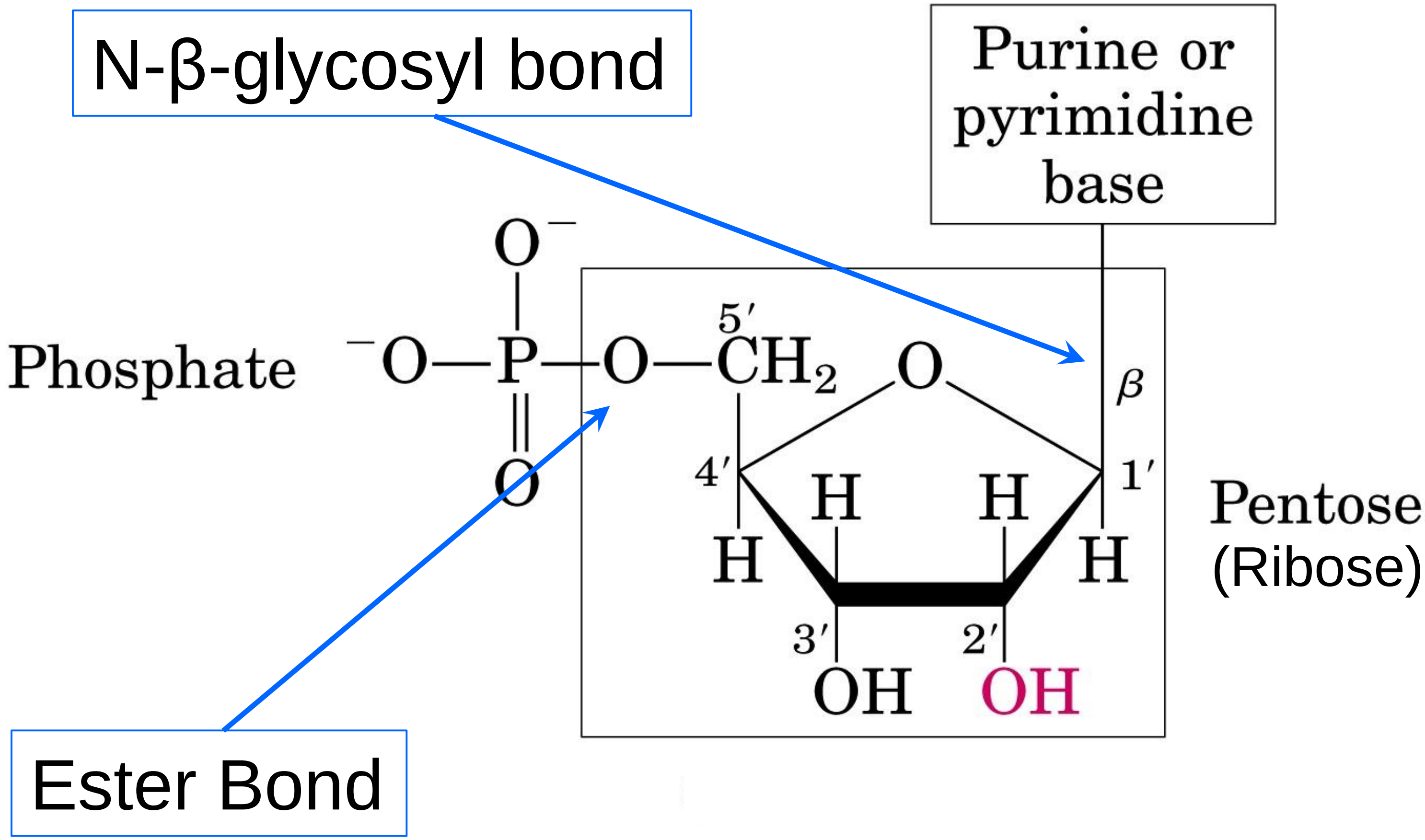
Nucleosides

Nucleotides

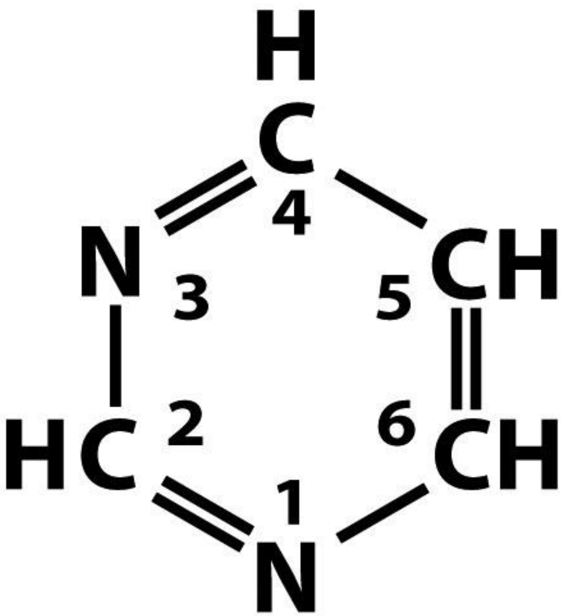
RNA vs DNA – Sugar

RNA - Ribonucleic Acid **(OH)**

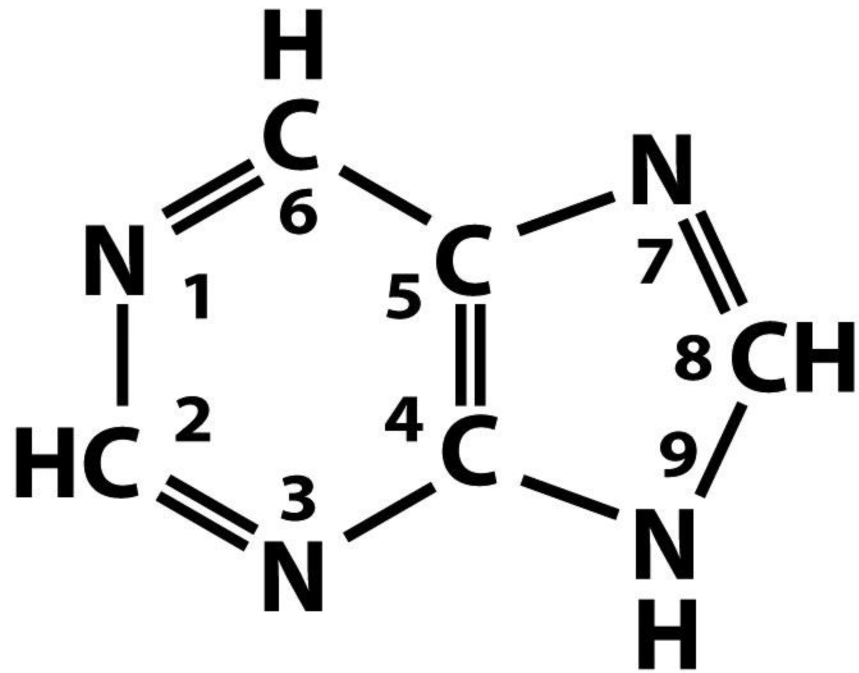
DNA - Deoxyribonucleic Acid **(H)**



Two Types of Nitrogenous Bases



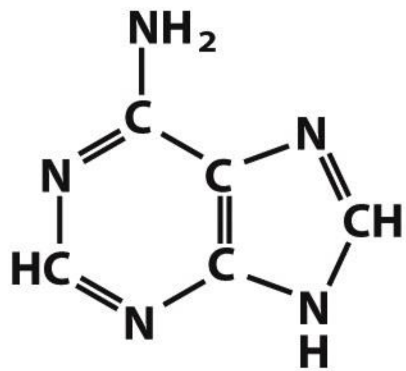
Pyrimidine



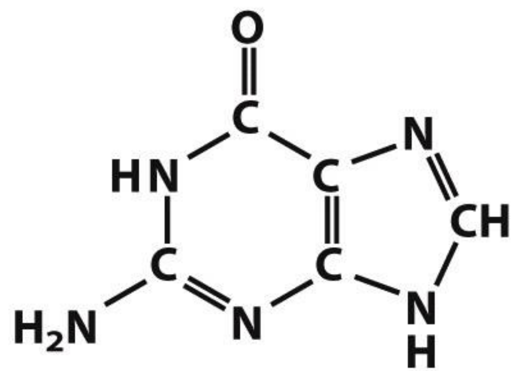
Purine

Figure 8-1b
Lehninger Principles of Biochemistry, Fifth Edition

Purine and Pyrimidine Bases

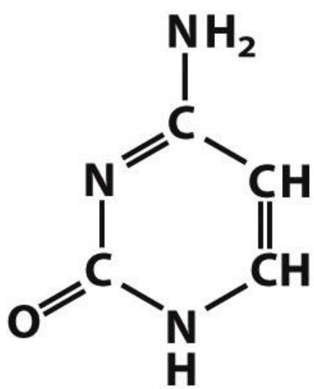


Adenine

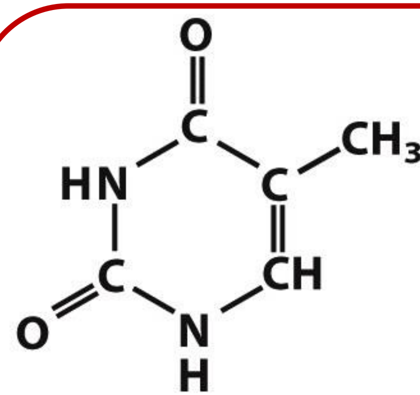


Guanine

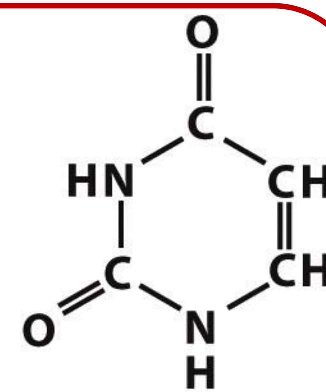
Purines



Cytosine



Thymine
(DNA)

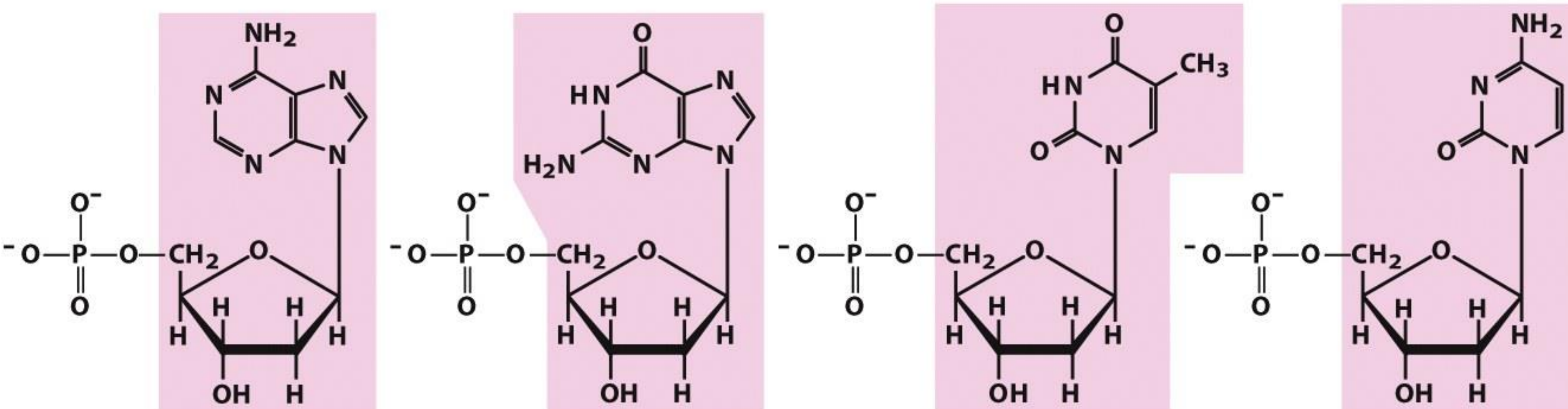


Uracil
(RNA)

Pyrimidines

Nucleotide = Nucleoside + Phosphate

(Nucleoside = Sugar + Base)



Nucleotide:	Deoxyadenylate (deoxyadenosine 5′-monophosphate)	Deoxyguanylate (deoxyguanosine 5′-monophosphate)	Deoxythymidylate (deoxythymidine 5′-monophosphate)	Deoxycytidylate (deoxycytidine 5′-monophosphate)
Symbols:	A, dA, dAMP	G, dG, dGMP	T, dT, dTMP	C, dC, dCMP
Nucleoside:	Deoxyadenosine	Deoxyguanosine	Deoxythymidine	Deoxycytidine

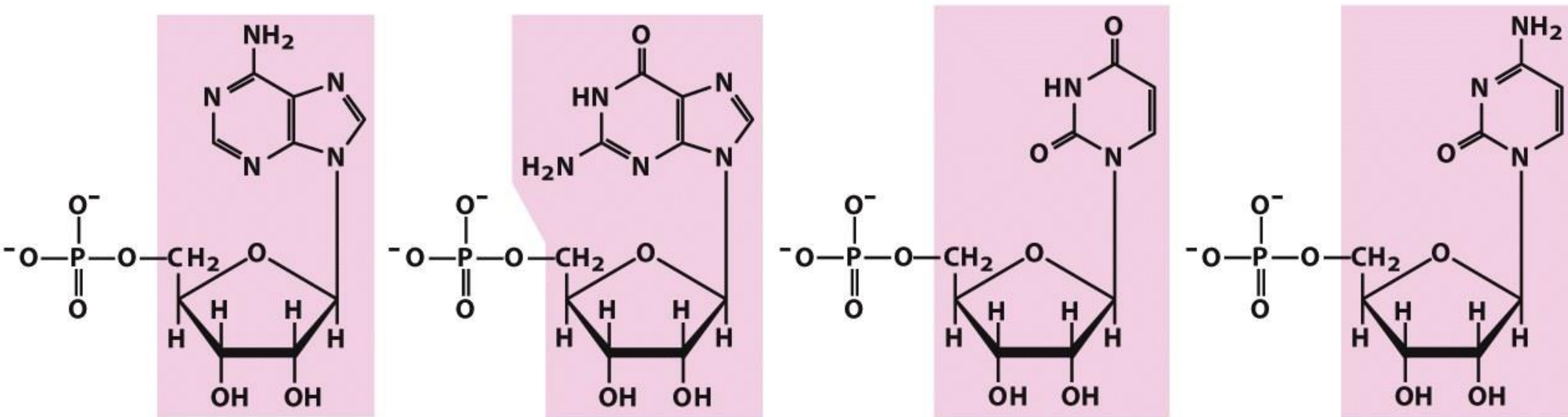
Deoxyribonucleotides

Figure 8-4a

Lehninger Principles of Biochemistry, Fifth Edition

Nucleotide = Nucleoside + Phosphate

(Nucleoside = Sugar + Base)



Nucleotide:	Adenylate (adenosine 5′-monophosphate)	Guanylate (guanosine 5′-monophosphate)	Uridylate (uridine 5′-monophosphate)	Cytidylate (cytidine 5′-monophosphate)
Symbols:	A, AMP	G, GMP	U, UMP	C, CMP
Nucleoside:	Adenosine	Guanosine	Uridine	Cytidine

Ribonucleotides

Figure 8-4b

Lehninger Principles of Biochemistry, Fifth Edition

Phosphodiester Linkages in the Covalent Backbone of Nucleic Acid

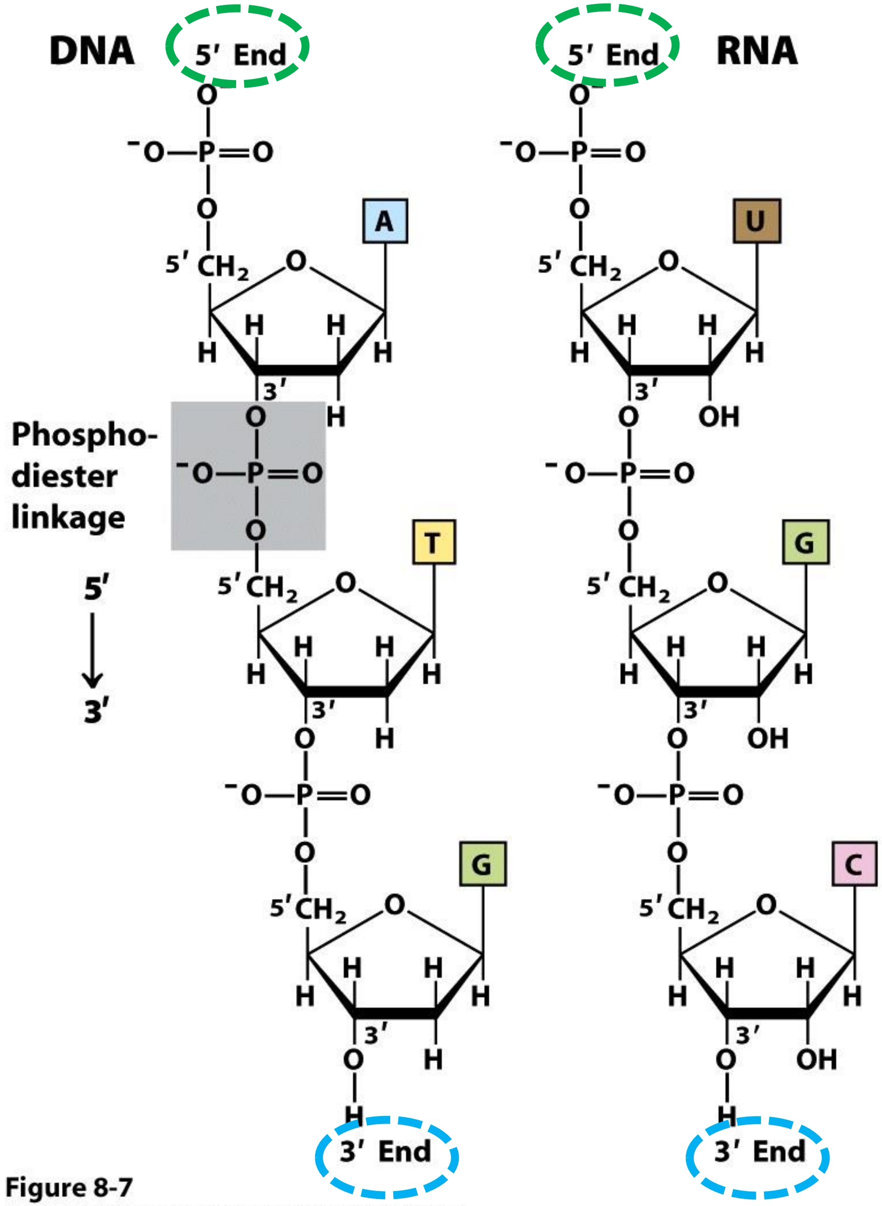
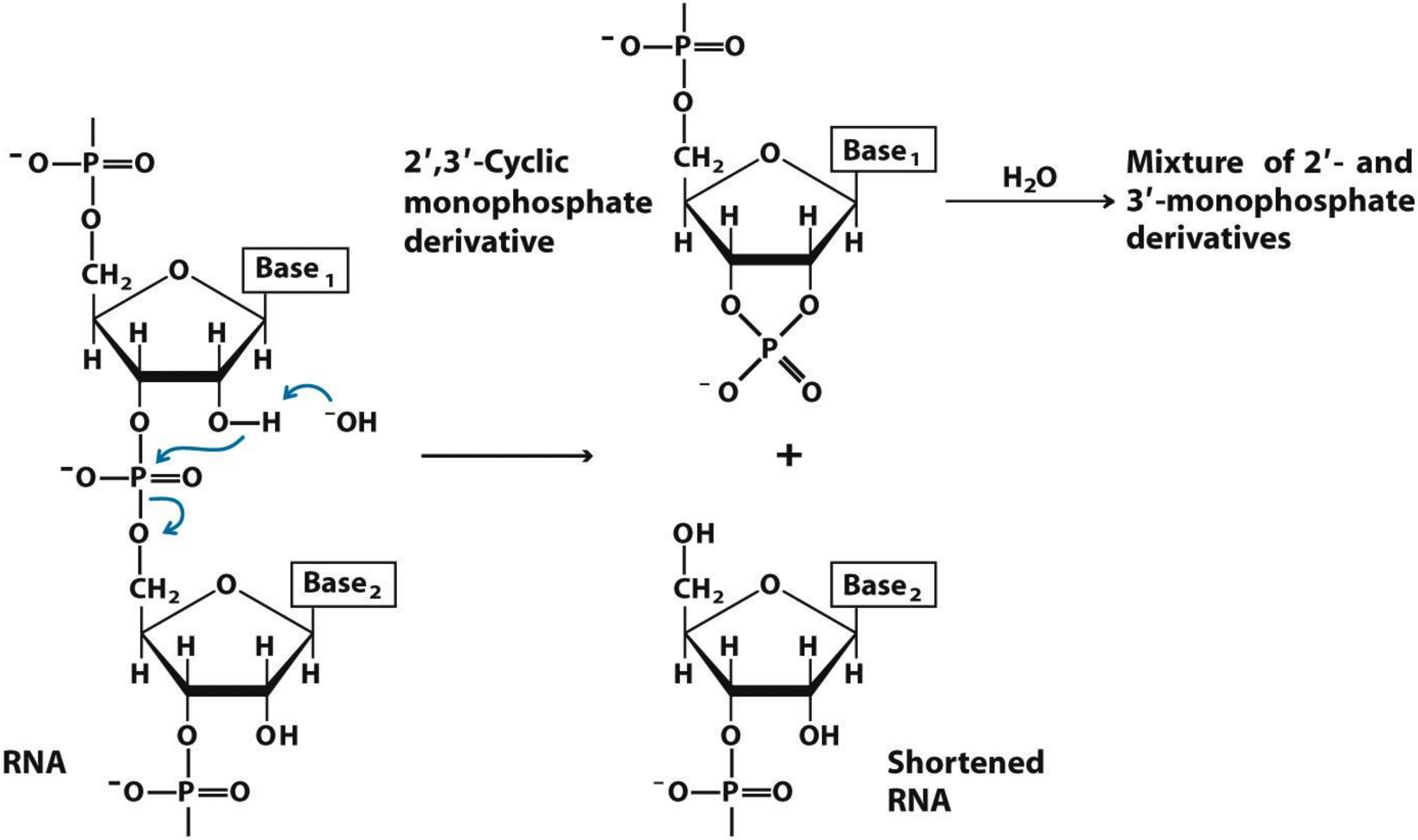
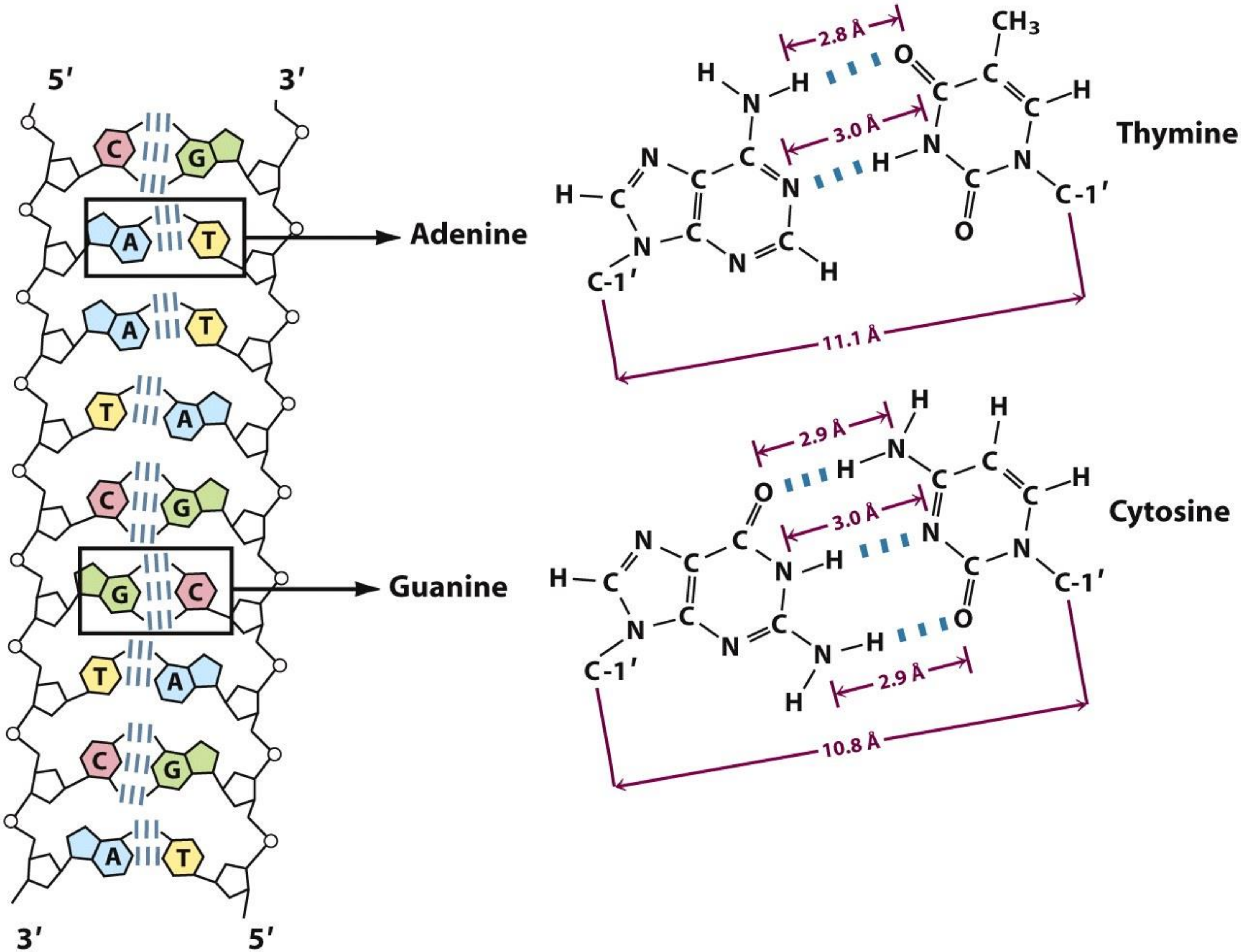


Figure 8-7
Lehninger Principles of Biochemistry, Fifth Edition

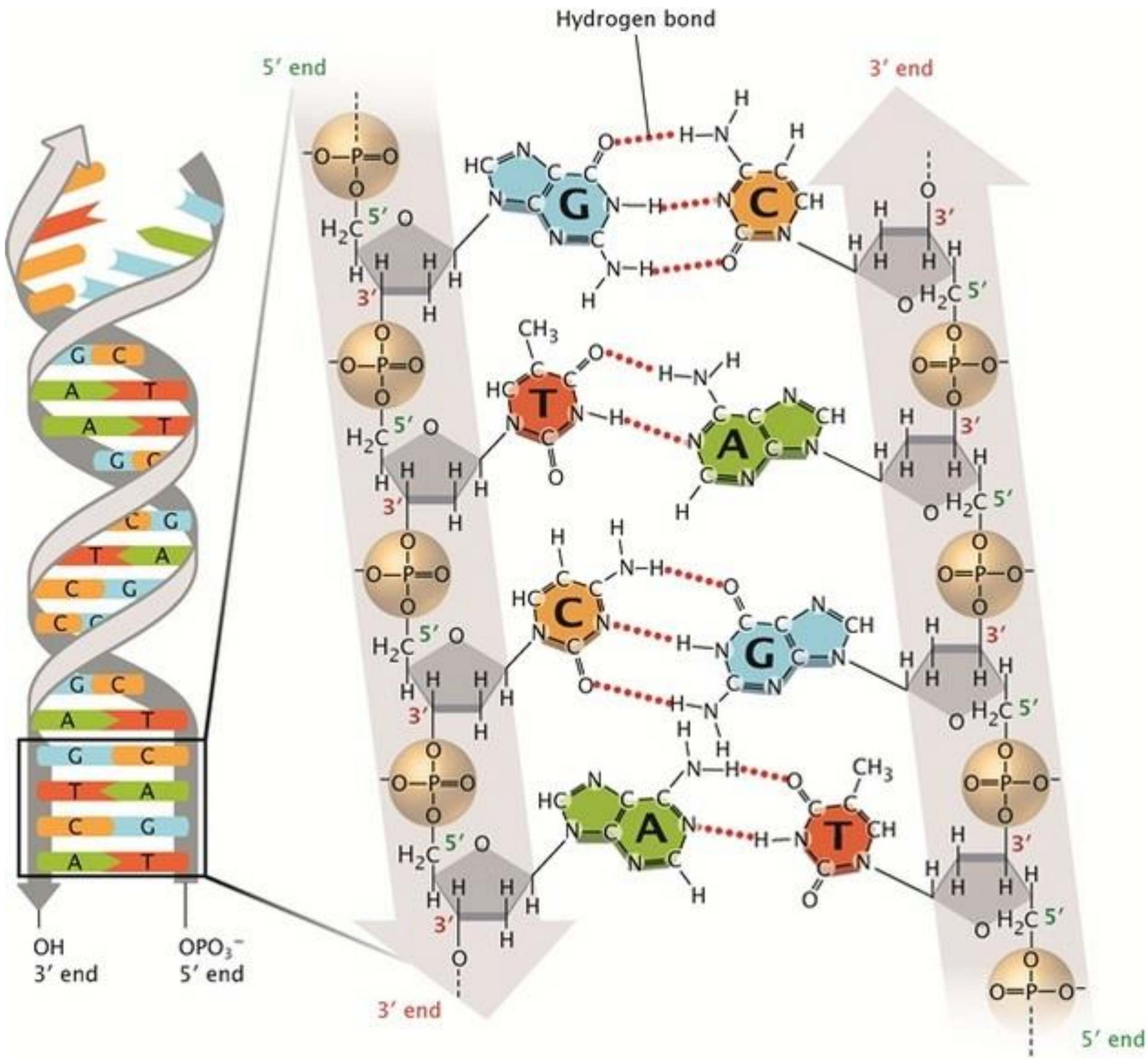
RNA is Less Stable than DNA



DNA: Deoxyribonucleic Acid



DNA: Deoxyribonucleic Acid

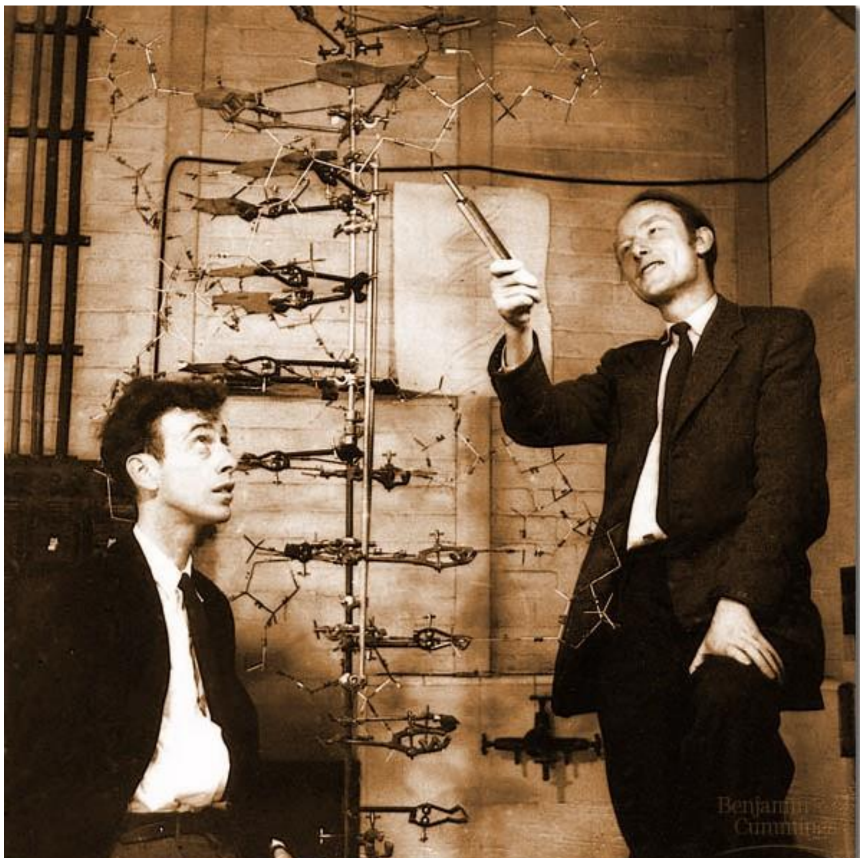


Some key features of DNA

- In **DNA,** two nucleic acid strands anneal together through extensive **inter-strand H-bonding** between the bases**.** This **base pairing** follows the rule proposed by Watson and Crick.
- **Chargaff's rule: A always pairs with T and G pairs with C**
- Hence the two strands become **complementary** to each other
- **Directionality** of two strands is **opposite:** one is **5'-3'** and another **is 3'-5'**
- Hence complementary DNA strands are **antiparallel**

Discovery of the DNA Structure

- Structure was discovered in 1953 by James Watson and Francis Crick
- Awarded **Nobel Prize in 1962**



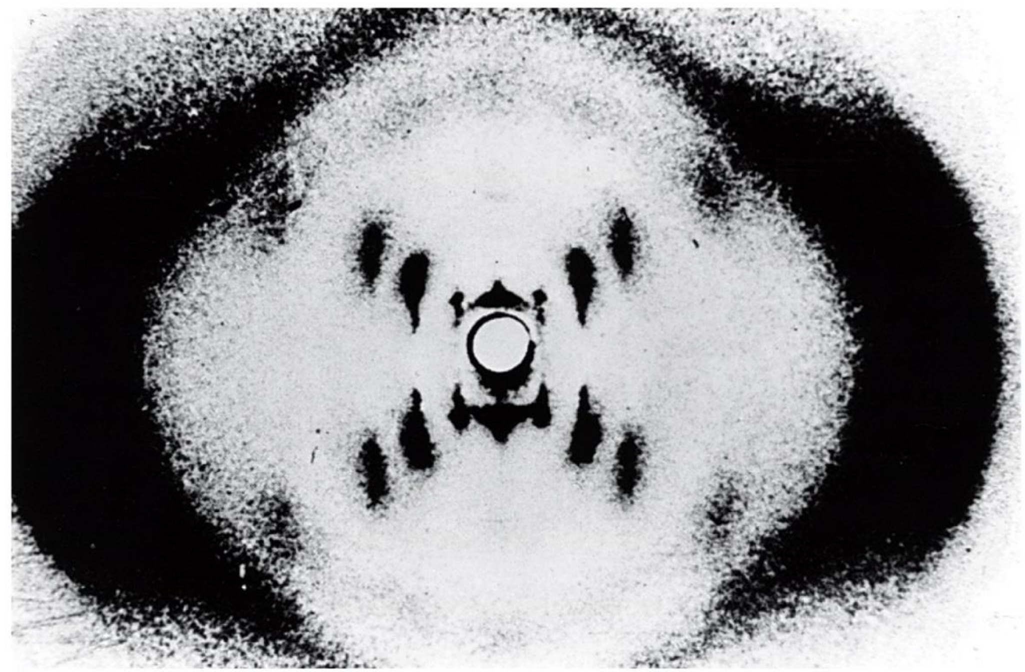
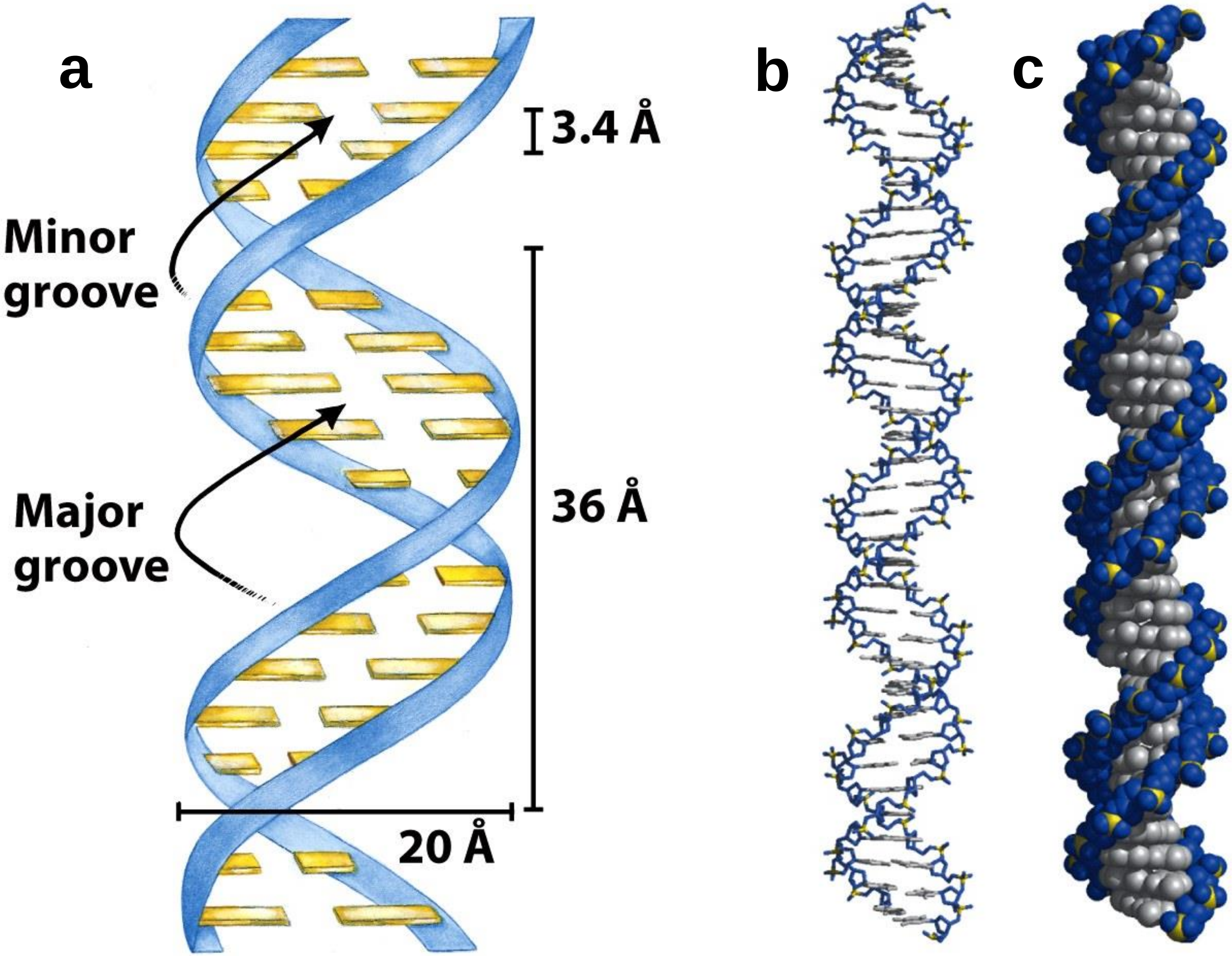


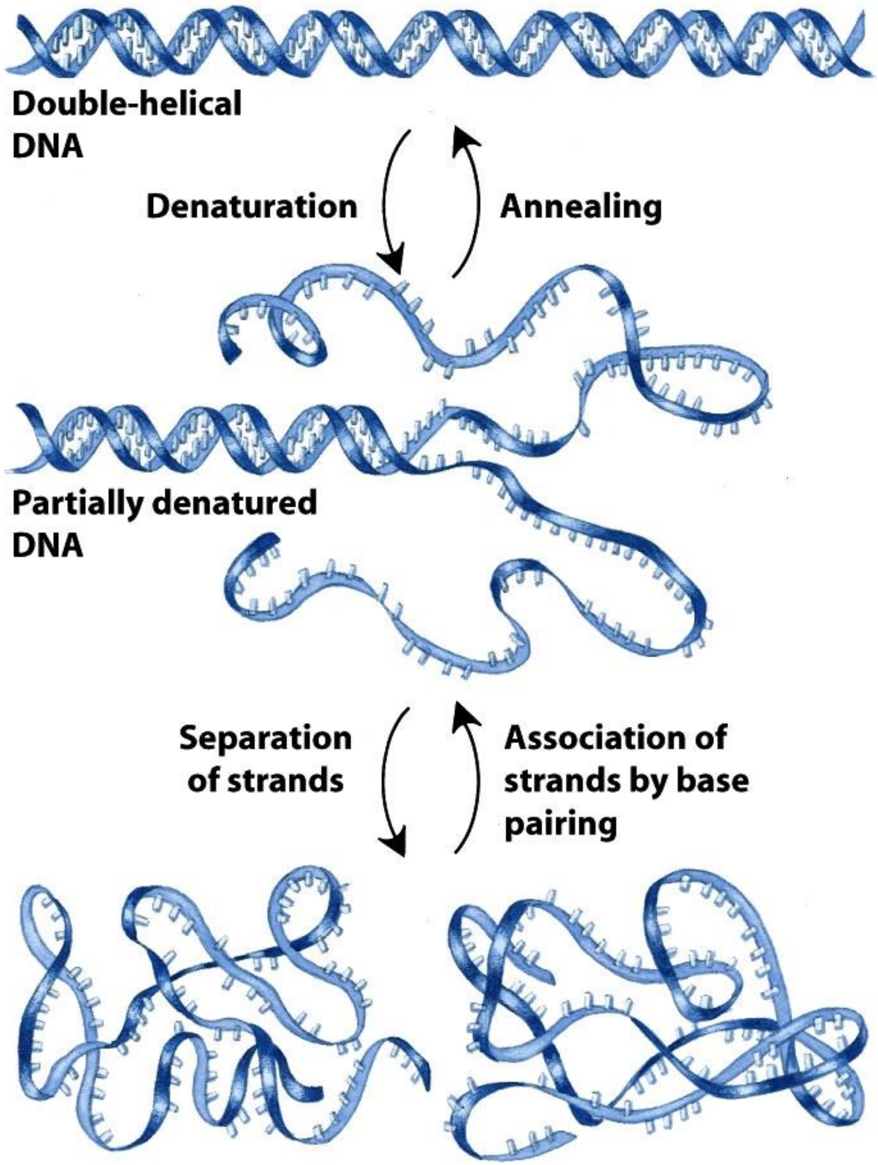
Figure 8-12
Lehninger Principles of Biochemistry, Fifth Edition

Rosalind Franklin

Watson-Crick Model for the Structure of DNA



Reversible Denaturation and Annealing (Renaturation) of DNA



Heat Denaturation of DNA