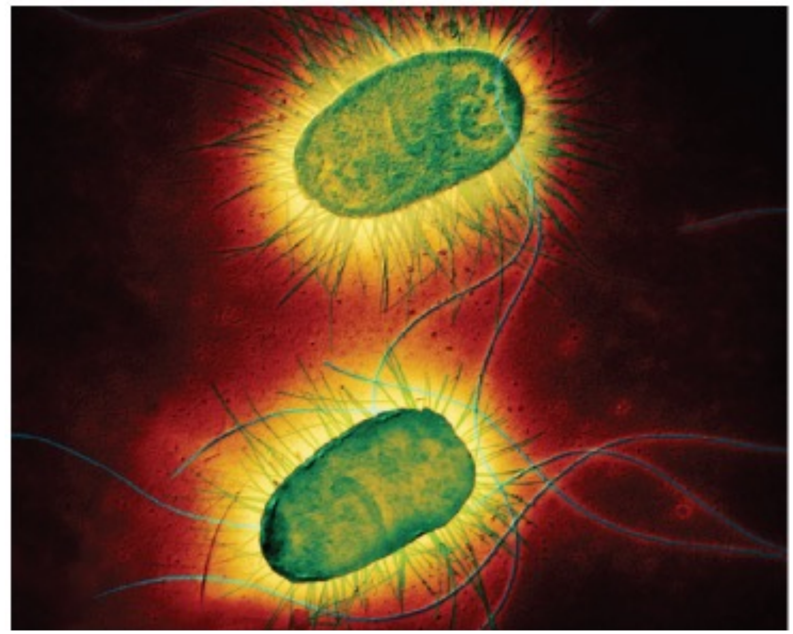
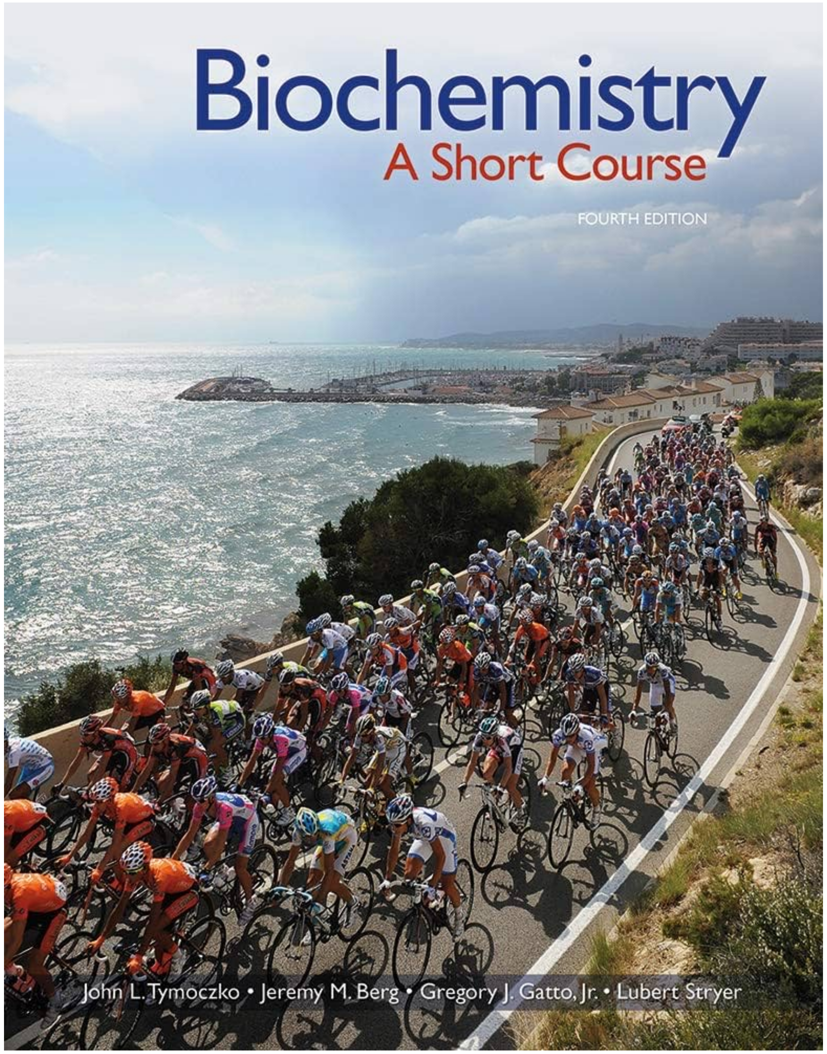
Biochemistry
helps us understand our world…



The elephant and *E. coli* are remarkably similar!



Required Textbook:
J. Tymoczko, J. Berg, L. Stryer. Biohemistry: A Short Course. 4th. ed., W.H. Freeman and Company

Lecture Schedule: This is a rough guide and may change throughout the term.

Lecture #	Week of	Subject	Book Chapter
1	Jan 6	Introduction to Biochemistry and the Unit of Life. Biochemical Interactions and pH.	1,2
2	Jan 13	Amino Acids and Protein Structure.	3,4
3	Jan 20	Enzymes and Coenzymes. Kinetics and Regulation.	6,7
4	Jan 27	Mechanisms and Inhibitors. Hemoglobin.	8,9
5	Feb 3	Carbohydrates and Lipids.	10,11
6	Feb 10	Membrane Structure and Function. Signal-Transduction Pathways.	12, 13
	Feb 17	Reading Week	
7	Feb 24	Nucleic Acid Structure and DNA Replication	33,34
8	Mar 3	RNA Synthesis and Regulations. The Genetic Code.	36,39
	Mar 4	In-class Midterm (date to be confirmed)	
9	Mar 10	Glycolysis and Glucogensis.	16,17
10	Mar 17	The Citric Acid Cycle.	18,19
11	Mar 24	Oxidative Phosphorylation (Electron transport chain and ATP synthase)	20,21
12	Mar 31	Fatty Acid and Lipid Metabolism.	27,29
		Study Break	
Winter Term Exams	April exam period	Three-hour final exam (TBA).	

DEPARTMENT OF PHYSICAL
& ENVIRONMENTAL SCIENCES

CHMB62
Introduction to Biochemistry

Lectures:

Mondays, 12:00-13:00 IA 3120

Tuesdays, 17:00-19:00 IC 208

Tutorials:

Tuesdays, 19:00-20:00 (IC200/IC208)

Office Hours:

Fridays, 14:00-16:00 (EV 566)

DEPARTMENT OF PHYSICAL
& ENVIRONMENTAL SCIENCES

Method of Evaluation

Online homework: via Achieve	**7%**
Literature Assignment: 2 marks will be assigned for peer review).	**10%**
Tutorial: 9% quizzes, 9% tutorial discussion	**18%**
Midterm Test: in-class	**25%**
Final Exam: April exam period	**40%**
TOTAL	**100%**

Achieve (Online Learning Platform)

1. LOGIN INTO THE ACHIEVE WEBSITE

2. ENROLL IN A NEW COURSE

- Once signed in, click on 'ENROLL IN A NEW COURSE'
- Next, enter the COURSE ID **k5e8k7**

3. REGISTER IN THE COURSE USING THE ACCESS CODE YOU PURCHASED.

Extra Credit Activities

- Please read our course syllabus, it has been written for you!
- You can earn up to 3 extra credits!

- Project # 1: Molecule of the week
- ➢ You will be asked to submit your ppt presentation related to the topic by the end of the term. See course syllabus for details.
- ➢ Be mentally ready to do your presentation at the end of the term.
- Project # 2: Community-engaged learning
- ➢ You will be asked to submit a <500 words summary of a Biochemistry article and create an infographic aimed at high school students.
- Project # 2: Dietary or Body Building Supplements Discovery Project
- ➢ See course syllabus for more details.

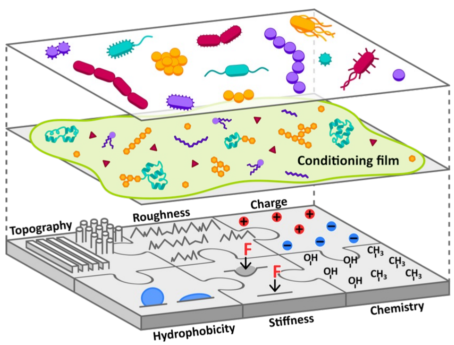
Tips for Success in Biochemistry (also in your syllabus)

1. **Skim Before Lecture**
2. **Go to Class (Yes, Every Time!)**
3. **Do Practice Problems**
4. **Ask Questions**
5. **Think Critically**

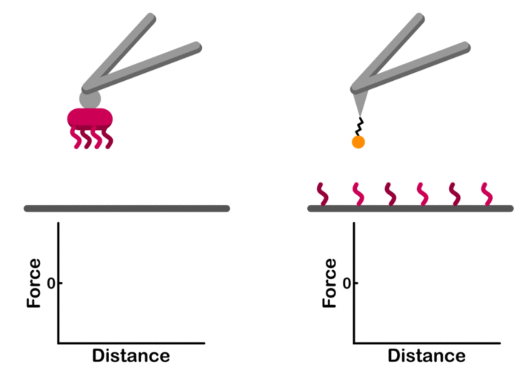
   As you study, challenge yourself with questions like:
   - **HOW** is this built or HOW does it work (structure/order)?
   - **WHY** is it built or does it work this way (function)?
   - **WHAT IF** it worked differently (order)?
   - **HOW** does this help it do its job in the cell (context)?
   - **HOW** does it interact with other molecules or processes (cross-talk)?
   - **HOW** is it activated or inhibited (regulation)?
   - **HOW** well does this work (redundancy)?
   - **HOW** can I tell this is happening (detection)?
   - **HOW** can I measure it (quantitative/qualitative analysis)?

Nano(materials)-Bio Interactions Lab

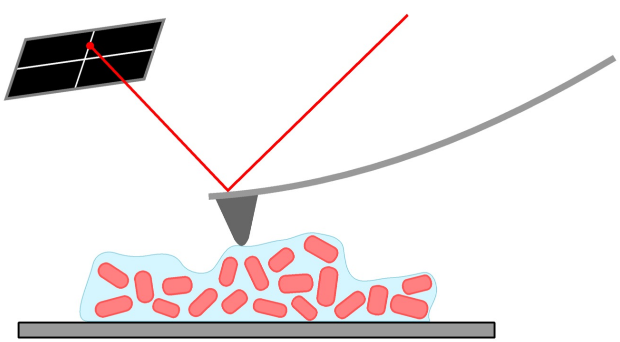
Bacteria–Surface Interactions



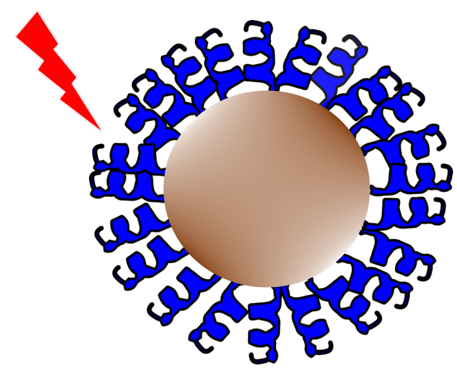
Single-molecule and Single-cell Forces



Quantitative Imaging of Biofilms



Nanomaterial-based Antimicrobials



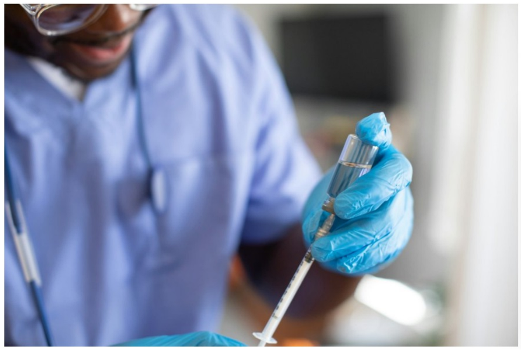
INTRODUCTION to BIOCHEMISTRY

Lecture 1

Can you get a career studying biochemistry?

Research Scientist: Conduct research in molecular biology, pharmacology, and biotechnology.

Healthcare Professional: Work in medical diagnostics or drug development.



Environmental Consultant: Address pollution, sustainability, and ecological conservation issues.

Biotech Entrepreneur: innovate products in the biopharma and agricultural sectors.

Academia and Education: Teach and inspire future scientists while conducting research.

Why bother to study biochemistry?

Understanding Life at the Molecular Level

Foundation of Life Sciences

Biochemistry underpins biology, medicine, genetics, and more → molecular perspective

Medical Advancements

- understanding diseases
- developing drugs
- improving healthcare outcomes

Biotechnology Innovation

- food production
- environmental sustainability
- industrial processes

Global Challenges

Provides solutions to issues like antibiotic resistance, malnutrition, and climate change

Biochemistry: Definition and Scope

What is Biochemistry?

- the study of chemical processes within and related to living organisms
- bridges biology and chemistry to explore the molecular basis of life

Scope of Biochemistry

- Covers areas from metabolism to genetic coding to cellular processes and biomolecular interactions

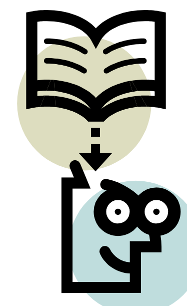
Applications in Daily Life

- Medicine, agriculture, food science, biotechnology

Biochemistry and Our World

In Lecture 1:

- Brief Overview of the Living Systems
- Major Classes of Biomolecules
- The Central Dogma
- Molecular Membranes
- Biochemical Interactions
- Hydrophobic Molecules and Their Interactions
- pH and Its Importance in Biological Systems



Readings:
Biochemistry, 2^{nd} Edition, Ch. 1 - 2, pp. 3 – 30, 4^{th} Ed., Ch. 1 – 2, pp. 4 - 30

Table 1.1 **Chemical compositions as percentage of total number of atoms**

Element	Composition in: Human beings (%)	Seawater (%)	Earth's crust (%)
Hydrogen	63	66	0.22
Oxygen	25.5	33	47
Carbon	9.5	0.0014	0.19
Nitrogen	1.4	0.1	0.1
Calcium	0.31	0.006	3.5
Phosphorus	0.22	0.1	0.1
Chloride	0.03	0.33	0.1
Potassium	0.06	0.006	2.5
Sulfur	0.05	0.017	0.1
Sodium	0.03	0.28	2.5
Magnesium	0.01	0.003	2.2
Silicon	0.1	0.1	28
Aluminum	0.1	0.1	7.9
Iron	0.1	0.1	4.5
Titanium	0.1	0.1	0.46
All others	0.1	0.1	0.1

Note: Because of rounding, total percentages do not equal 100%.
Source: After E. Frieden, The chemical elements of life, *Sci. Am.* 227(1), 1972, p. 54.

Table 1.1
Biochemistry: A Short Course, Second Edition

- Of the 90 naturally occurring elements, only three–oxygen, hydrogen, and carbon–make up 98% of the atoms in any organism.
- Hydrogen and oxygen are so prevalent because of the ubiquity of water.
- Carbon is uniquely suited to be a key atom of biomolecules. Why?

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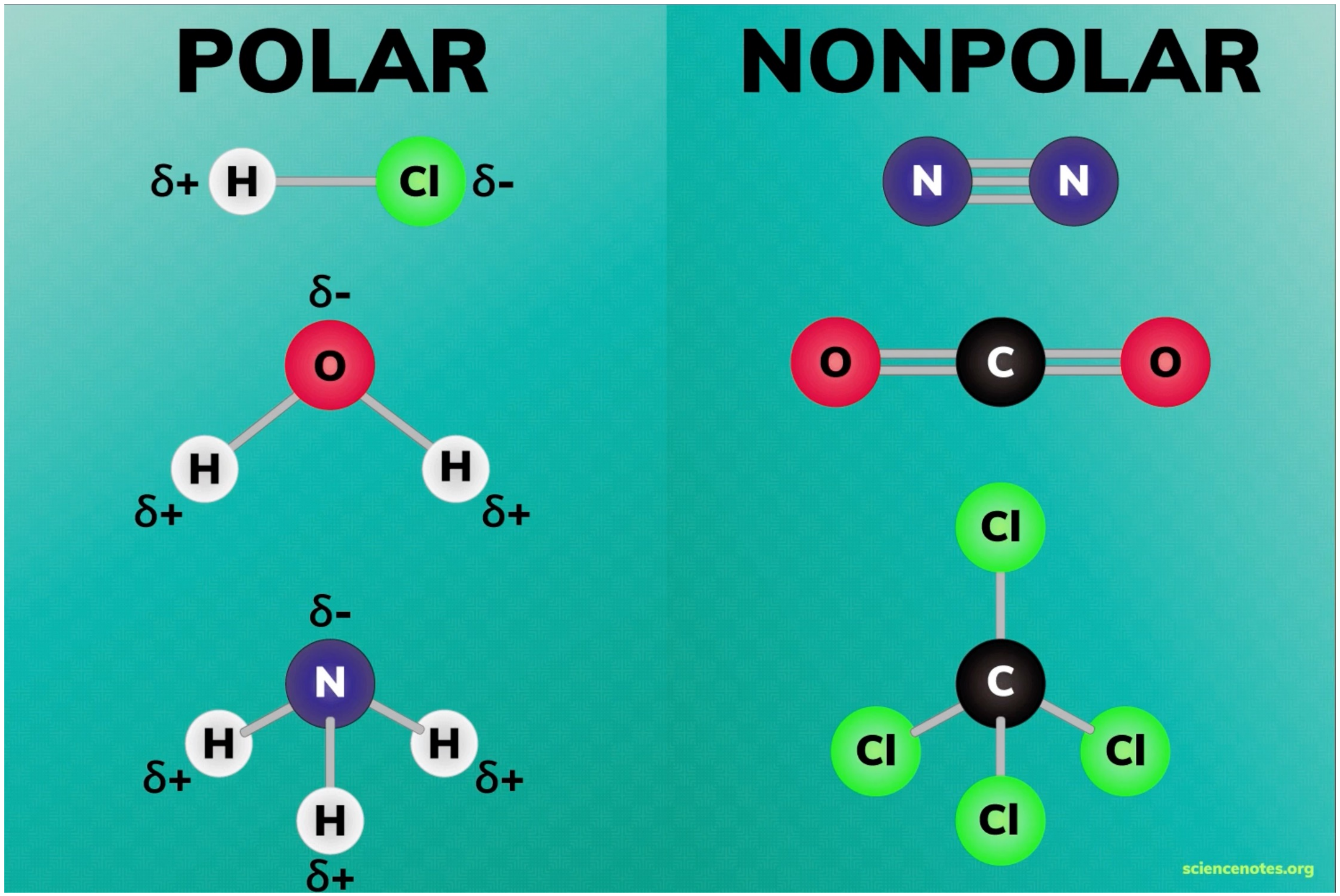
Electron dot structures of silicon and carbon

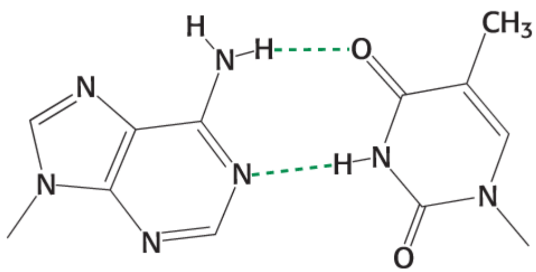
Silicon atom **carbon atom**

- Crucial to construction of large molecules!
- C-C bond strength is 348 kJ/mol and Si-Si bond strength is 226 kJ/mol
- Carbon-based molecules are stronger construction materials
- Better fuels
- CO_2 is readily soluble in water

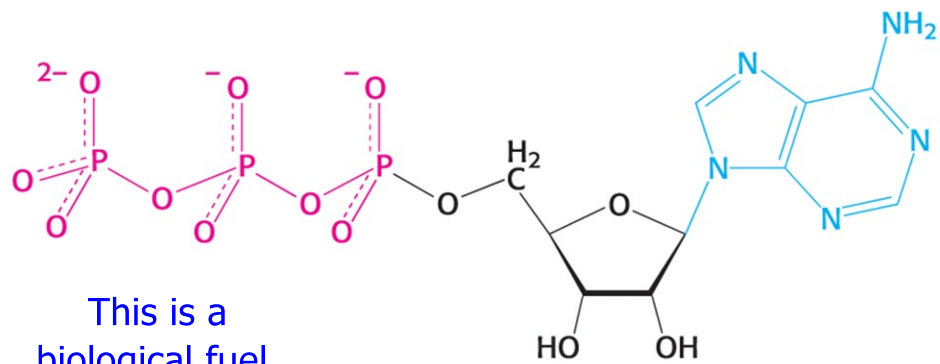
Why carbon is ubiquitous in living systems?



Living Systems Require a Limited Variety of Atoms and Molecules

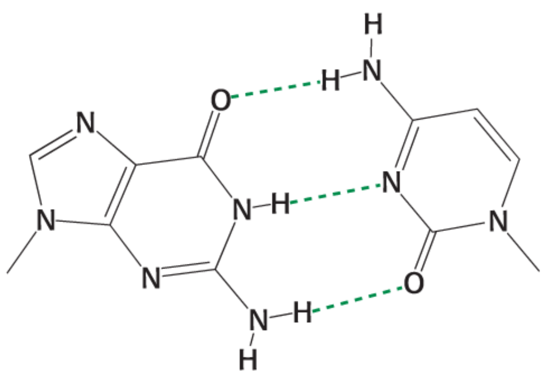


Adenine (A) Thymine (T)

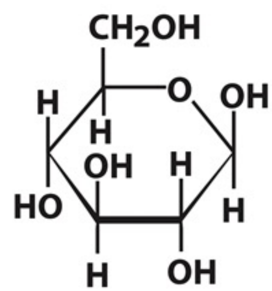


This is a biological fuel.

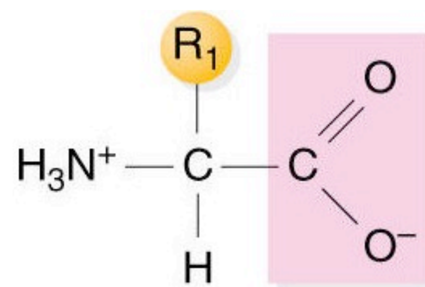
Adenosine triphosphate (ATP)



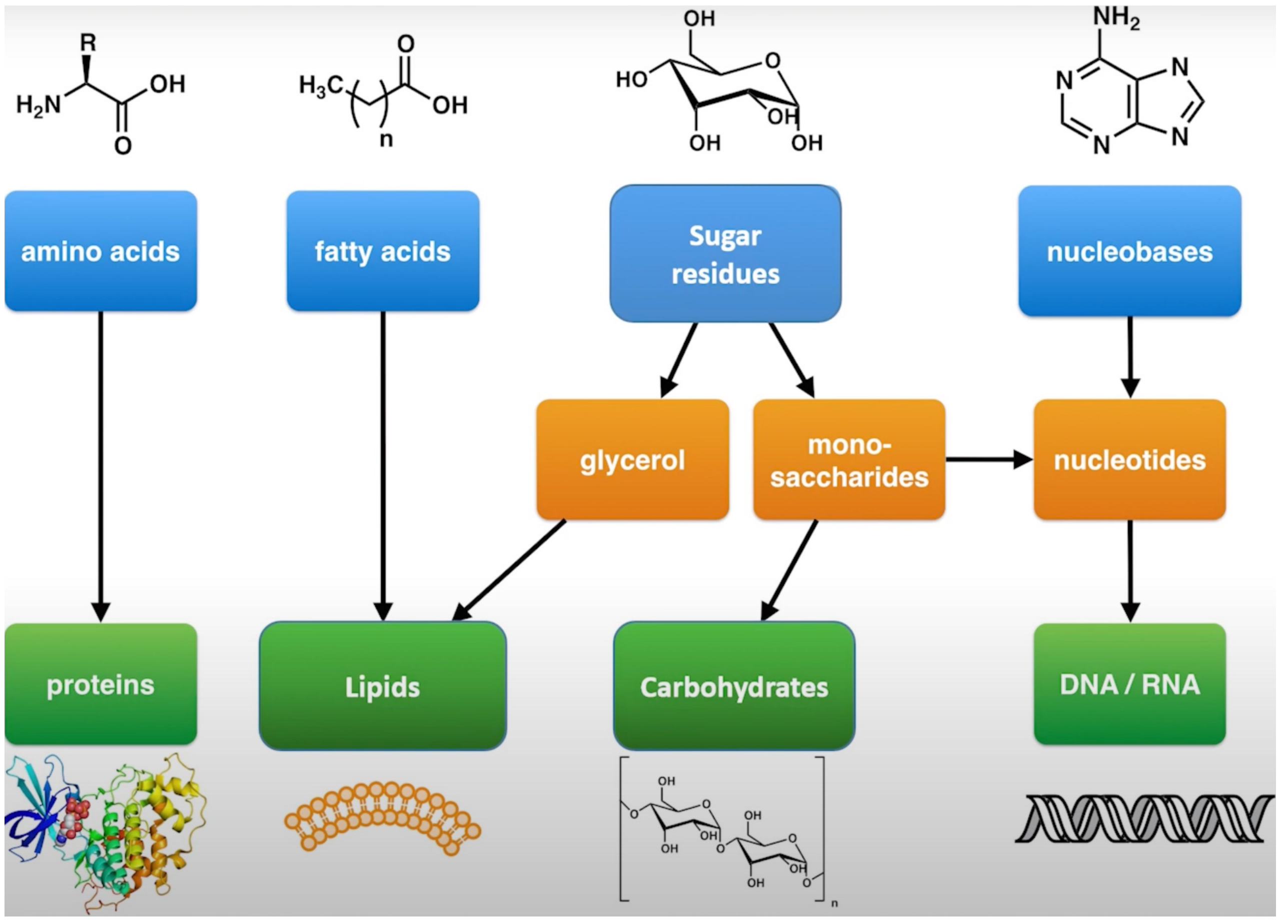
Guanine (G) Cytosine (C)



Glucose



Four Major Classes of Biomolecules

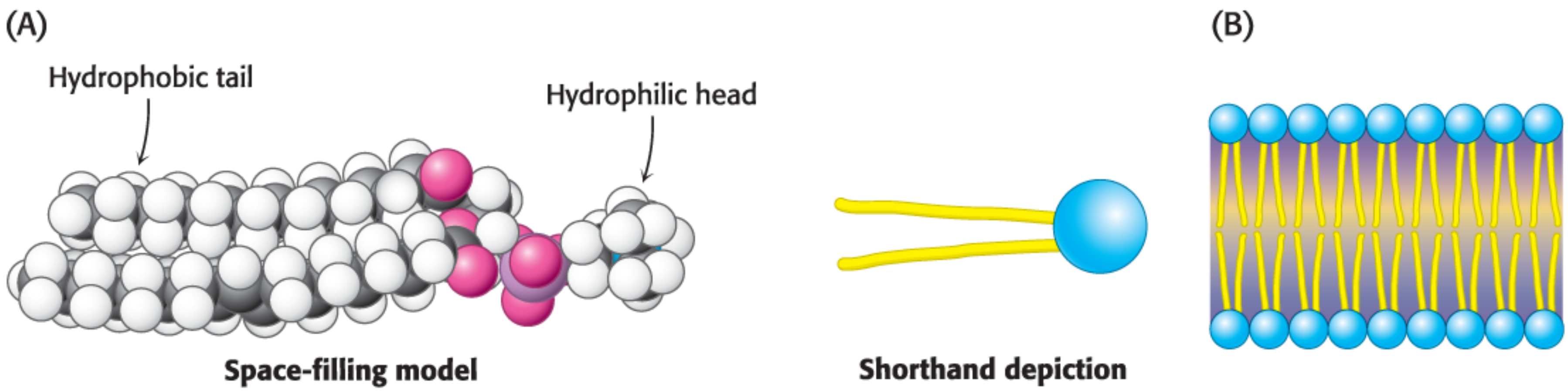


From the Science of Everything Podcast

Lipids Serve as Barrier and Storage Form of Fuel

➢ **Lipids**

- A key property of lipids is that they have hydrophilic and hydrophobic properties.
- Lipids form barriers, called membranes, that allow compartmentalization.
- Lipids also function as fuel molecules and signal molecules.



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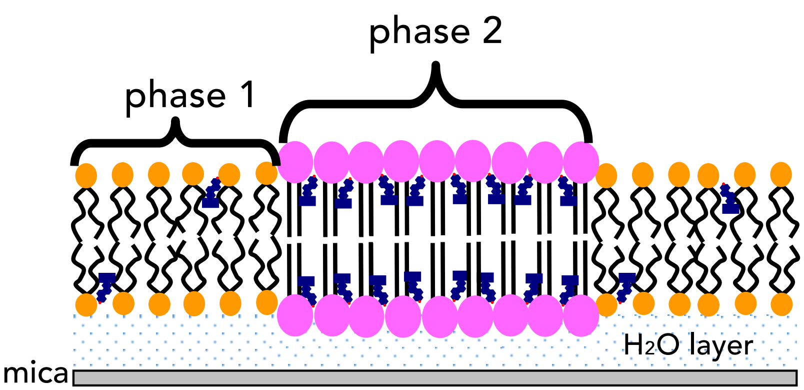
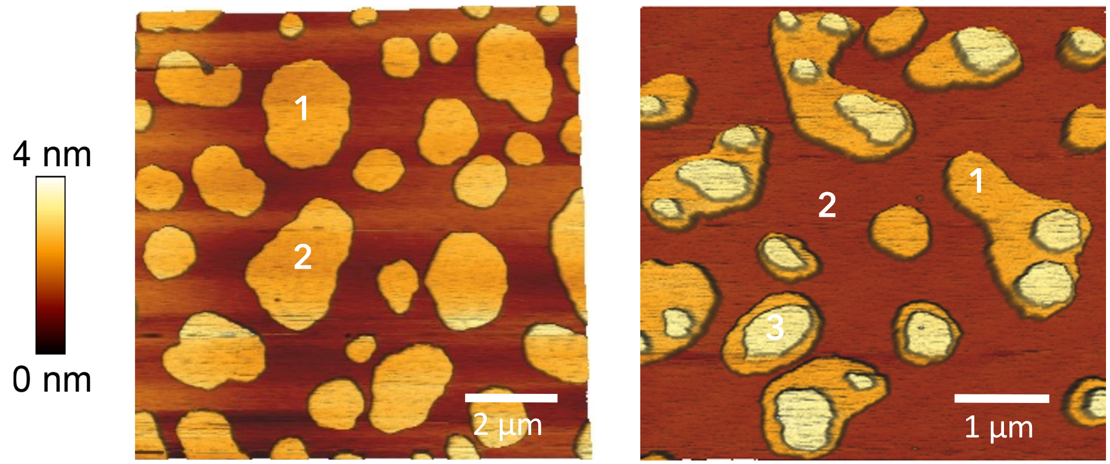
Topography images of model lipid bilayers…



schematic of a supported lipid bilayer



phase 2 — phase 1 = ~0.8 nm

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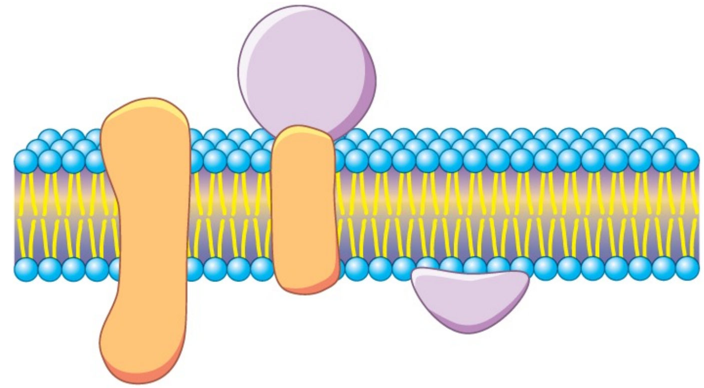
ARTICLE | March 18, 2009

Direct Correlation of Structures and Nanomechanical Properties of Multicomponent Lipid Bilayers

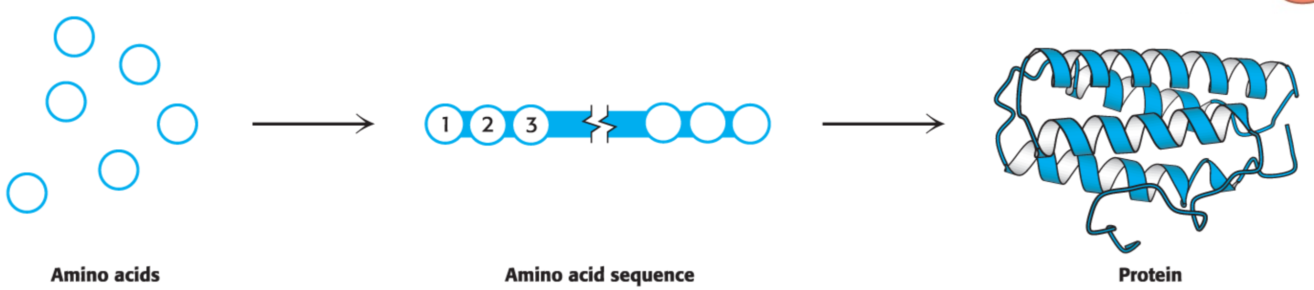
Ruby May A. Sullan[†‡], James K. Li[‡], and Shan Zou[†*]

Proteins Are Highly Versatile Biomolecules



➢ **Proteins**

- Proteins play many roles, such as signal molecules, receptors for signal molecules and enzymes (biological catalysts), and structural.



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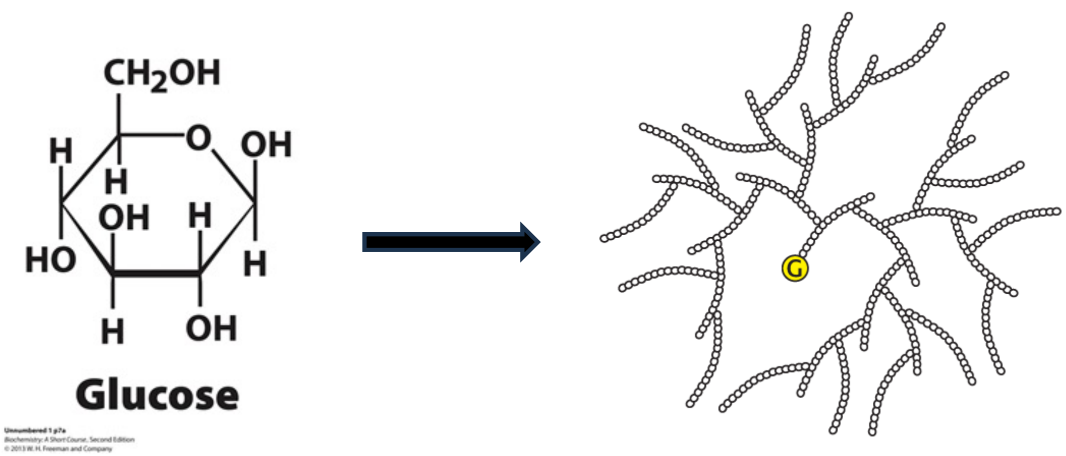
- Long unbranched polymers fold into precise 3D structures ➜ an array of biochemical functions

Carbohydrates Are Fuels and Informational Molecules

- **Carbohydrates**
  - Carbohydrates are an important fuel source.
  - Glucose is a common carbohydrate.
  - Glucose is stored as glycogen in animals (starch in plants).
  - Carbohydrates are also important signal molecules, notably in cell-cell recognition.



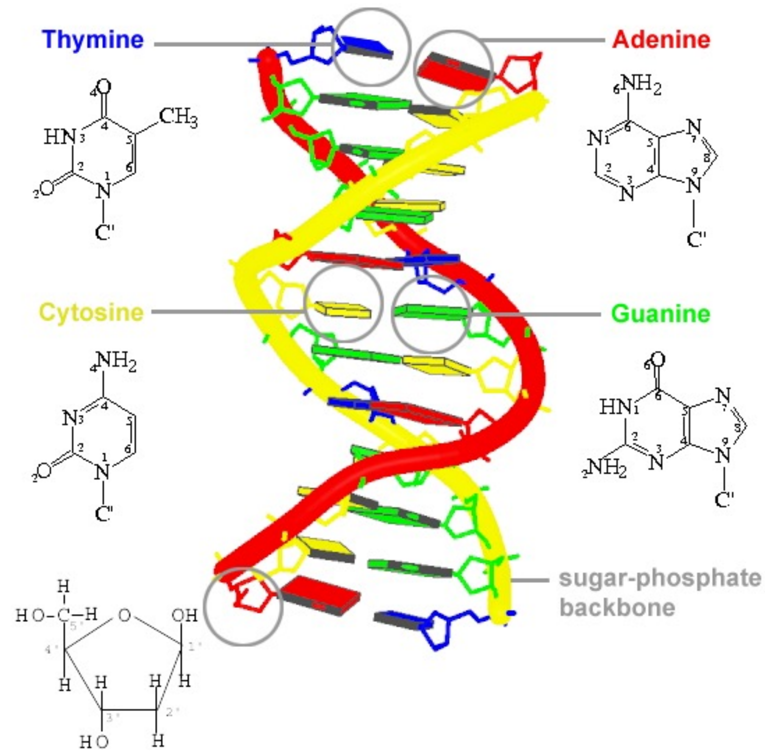
Glycogen

Nucleic Acids Store and Transfer Information

➢ **Nucleic Acids**

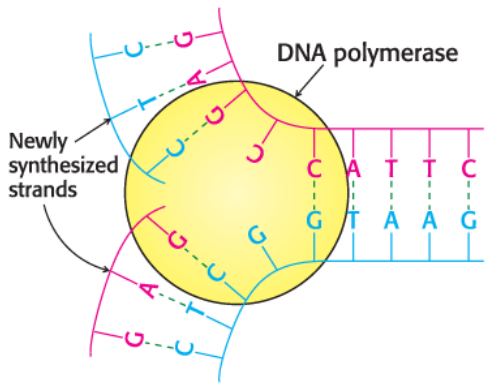
Nucleotides are the building blocks of nucleic acids.

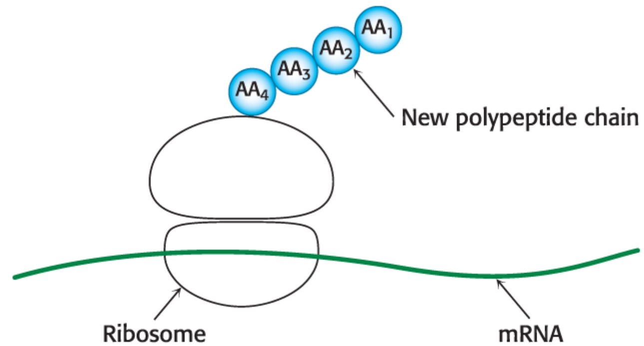
- There are two types of nucleic acids:
  - Deoxyribonucleic acid (DNA) consists of a double helix of polymers made up of deoxyribose, phosphate, and four bases: A, G, C, and T. In the double helix, A pairs with T, and G pairs with C.
  - Ribonucleic acid (RNA) is a single-stranded polymer made up of ribose; phosphate ; and the bases A, G, C and U.



The Central Dogma → Biological Information Transfer

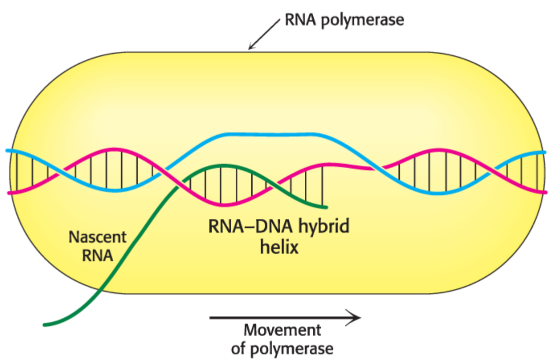
genetic information ➜ functional form





Replication (DNA → DNA)

$$\text{DNA} \xrightarrow{\textbf{Transcription}} \text{RNA} \xrightarrow{\textbf{Translation}} \text{Protein}$$

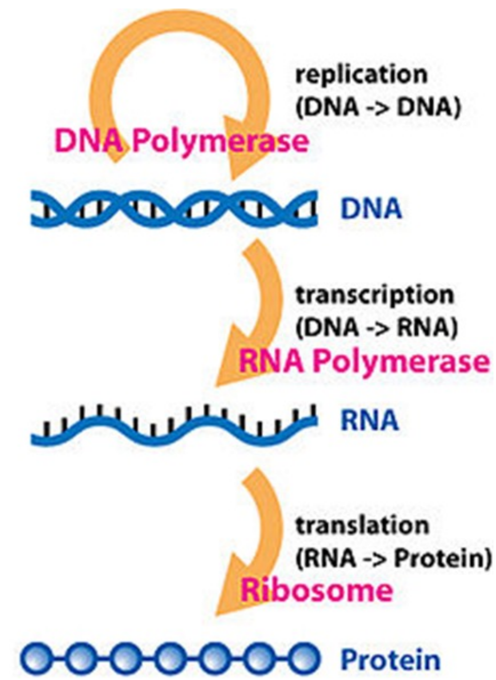


"selective expression of genetic information"

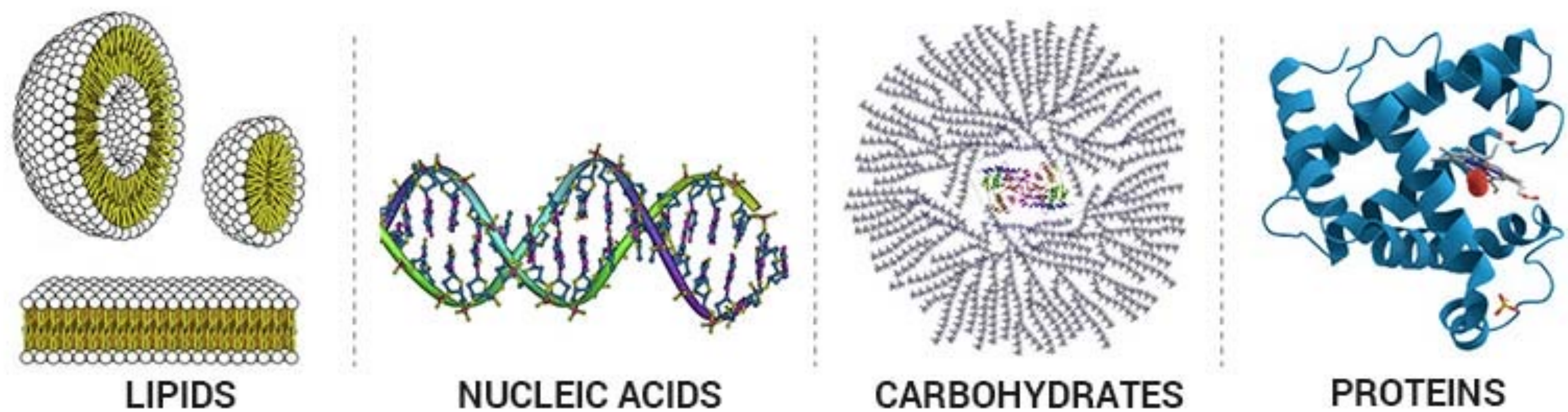
The Central Dogma → Biological Information Transfer

The Central Dogma states that information flows from DNA to RNA to protein. Moreover, DNA is replicated.

- DNA is heritable information: the genome.
- DNA is replicated by a group of enzymes collectively called **DNA polymerase**
- **RNA polymerase** catalyzes transcription: the process of copying DNA information into RNA.
- Selective **transcription** of the genome defines the function of a cell or tissue.
- **Translation** converts the nucleic acid sequence information in mRNA into protein sequence
- Translation occurs on ribosomes.



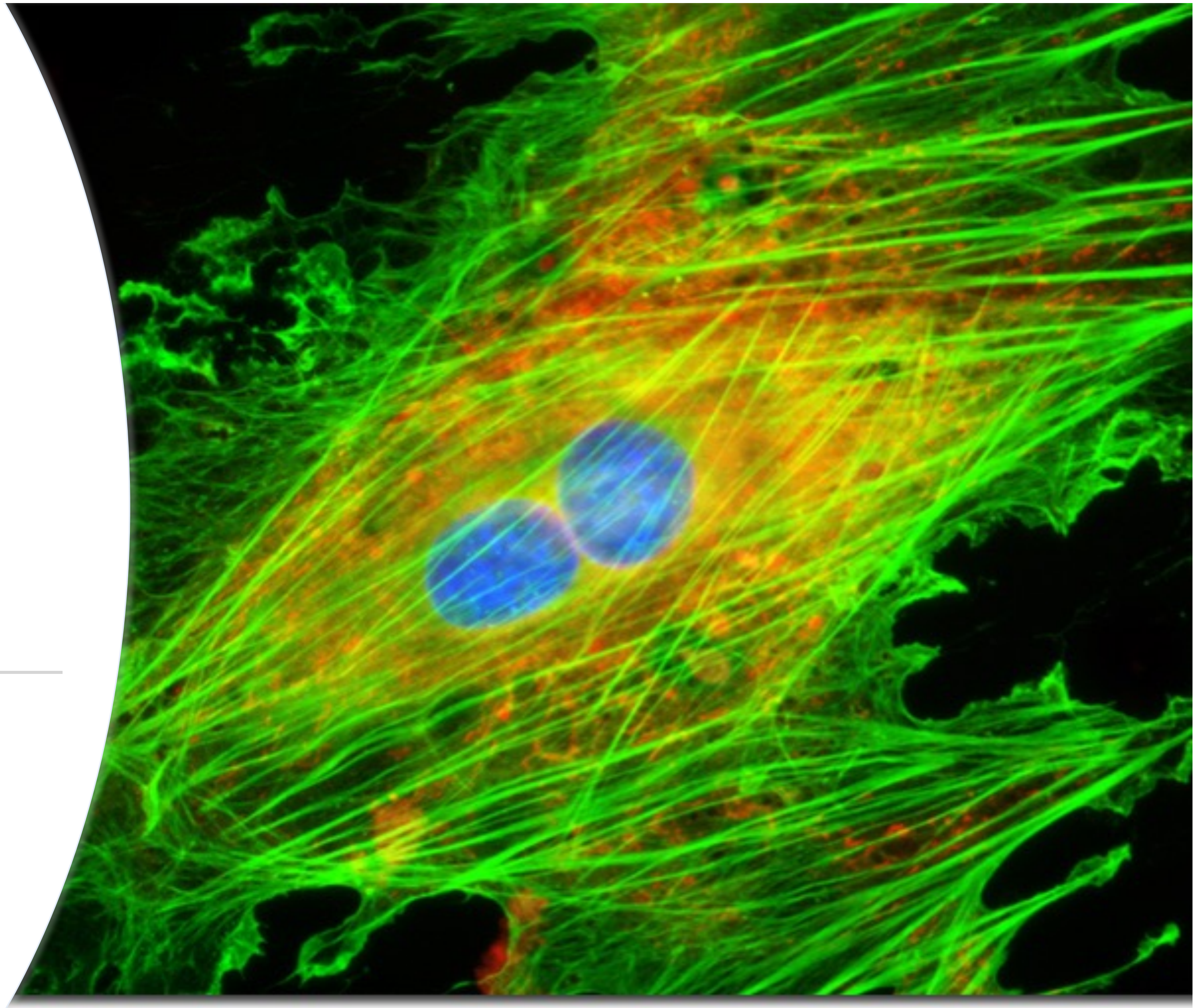
Building Blocks of Life's Complexity



https://byjus.com/biology/biomolecules/

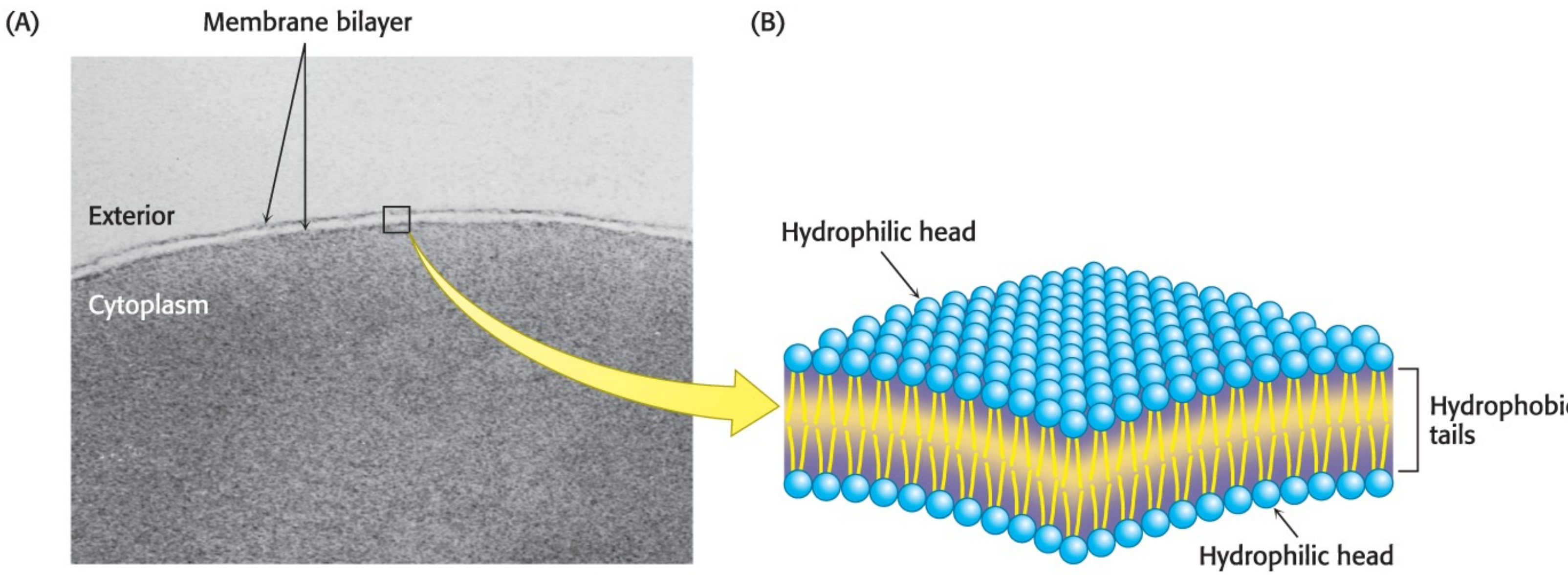
The Cell

https://micro.magnet.fsu.edu/



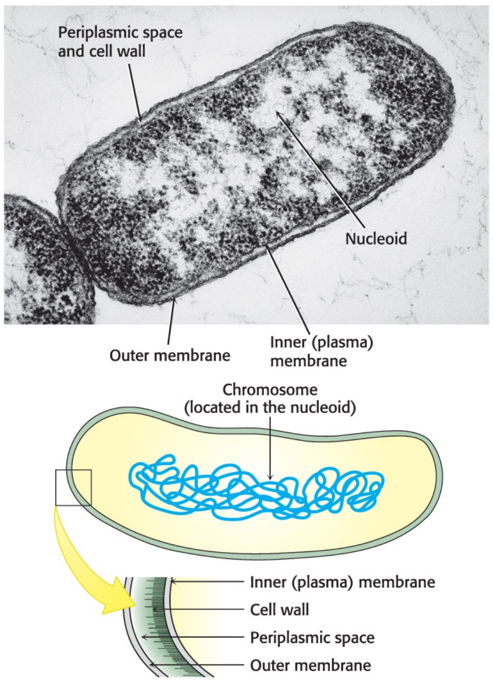
Cell Membranes and Their Function

- A membrane is a lipid bilayer.
- Eukaryotes contain membrane-enclosed compartments inside the cell.
- Prokaryotes lack intracellular membranes.

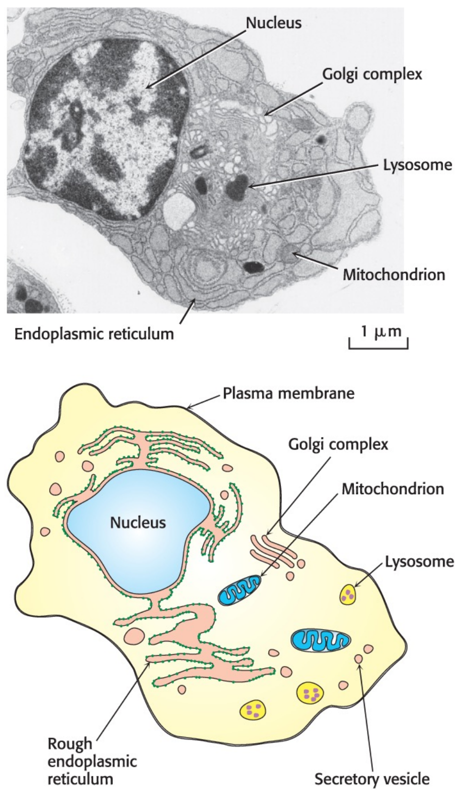


Membranes Define the Cell and Carry Out Cellular Functions

Prokaryotic cell



Eukaryotic cell

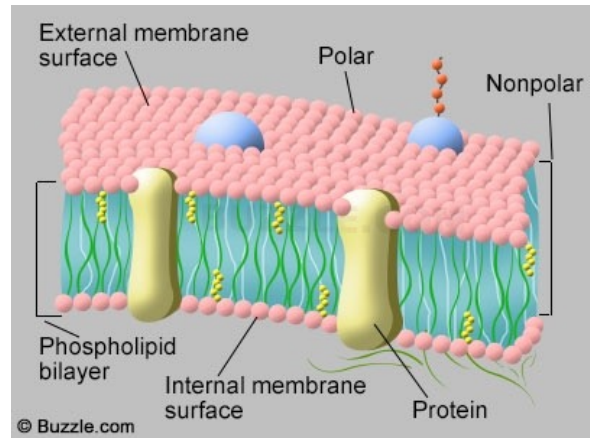


- Eukaryotic cells display more internal structure than do prokaryotic cells.
- Components within the interior of a eukaryotic cell, most notably the nucleus, are defined by membranes.

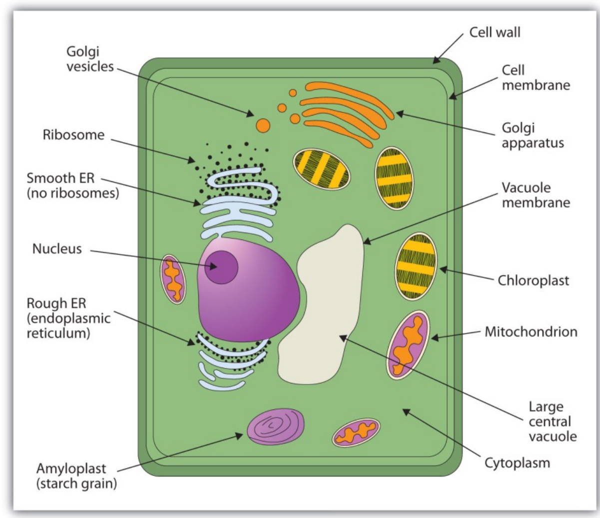
Main Features of the Cell

- **Every cell regardless of its type must have at least two main features:**

1. A barrier that separates cell from the environment: **plasma membrane ➜** impermeable to most biomolecules.
    - Selective permeability occurs because of the presence of proteins associated with the membrane.



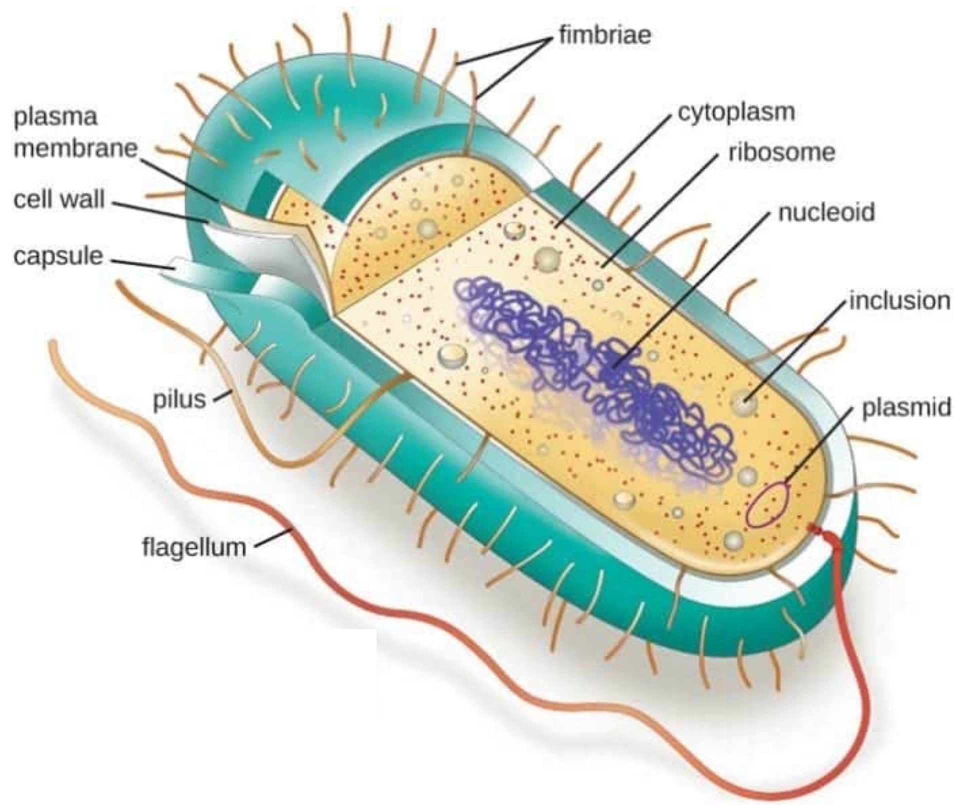
- The plasma membrane of a plant cell is surrounded by a cell wall composed largely of cellulose, a linear polymer of glucose.



Main Features of the Cell

2. Inner regions are chemically different from the environment and accommodates biochemistry of living.

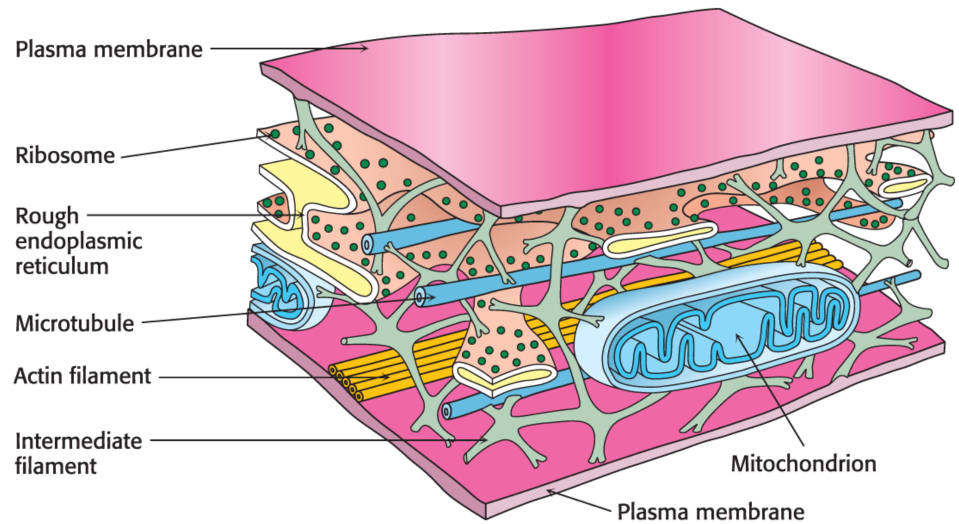
- The **cytoplasm** is the part of the cell surrounded by the plasma membrane but not enclosed by any intracellular membranes.
- The cytoplasm is organized by a series of structural filaments called the **cytoskeleton**.



https://www.bioexplorer.net/cytoplasm-functions.html/

The Cytoskeleton

- Actin filaments, intermediate filaments, and microtubules provide cell shape and facilitate cell movement.
  - These components course throughout the cytoplasm, associating with all other cellular organelles.



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Kinesin Protein Walking on a Microtubule

Cell Organelles

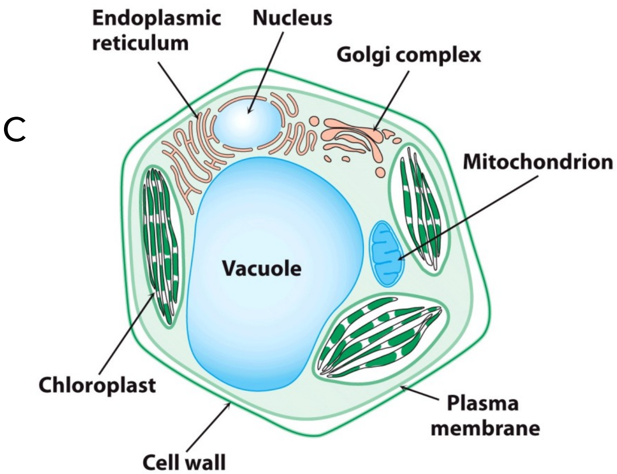

Figure 1.12b
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- A main difference between eukaryotic and prokaryotic cells is the presence of **organelles** in eukaryotes.
- Organelles are intracellular, membrane-bounded compartments such as nucleus, mitochondrion, chloroplast, etc.

➢ **Nucleus** is the information center of the cell.

➢ **Mitochondria** are the primary site of ATP generation in eukaryotic cells.

➢ **Chloroplasts**, found in plant cells, are the site of photosynthesis.

(A) (B)

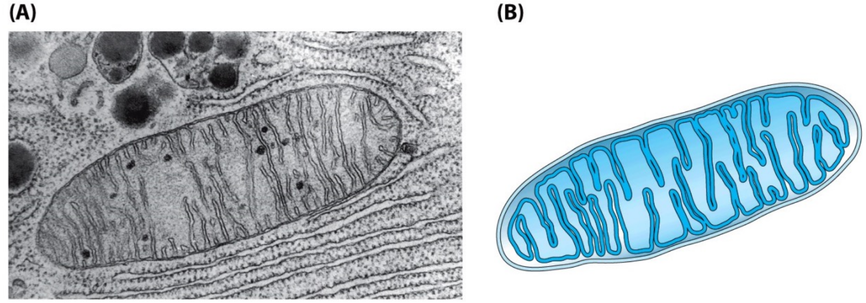

Figure 1.15
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Figure 1.14
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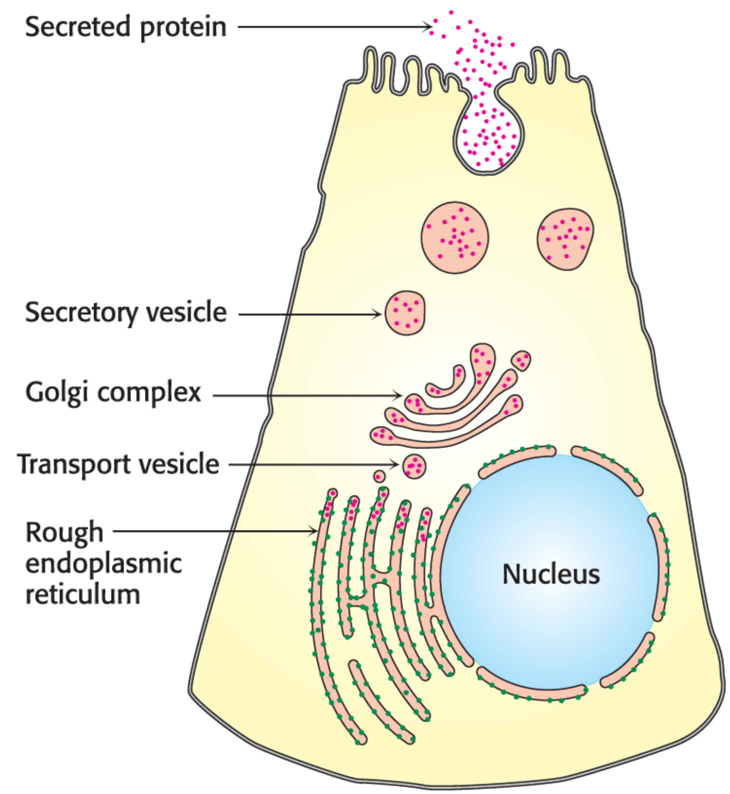
Organelles the Process and Sort Proteins (etc.)

- The **endoplasmic reticulum (ER)** is a series of membranous sacs in the cytoplasm.
- There are two types of ER:
  - Rough ER is has ribosomes associated with it and plays a role in protein processing.
  - Smooth ER lacks ribosomes and plays a role in processing exogenous chemicals (e.g., drugs).

- The **Golgi complex** is a series of stacked membranes that play a role in protein sorting. Carbohydrates are also attached to proteins in the Golgi complex.

- **Secretory granules** secrete biomolecules in the process of endocytosis and exocytosis.



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Endocytosis and Phagocytosis

- **Endocytosis** is a process of bringing crucial biomolecules into the cell.
  - An **endosome** is the structure that forms when the plasma membrane invaginates and buds off.
- Large amounts of material can be taken into the cell by the process of **phagocytosis**.

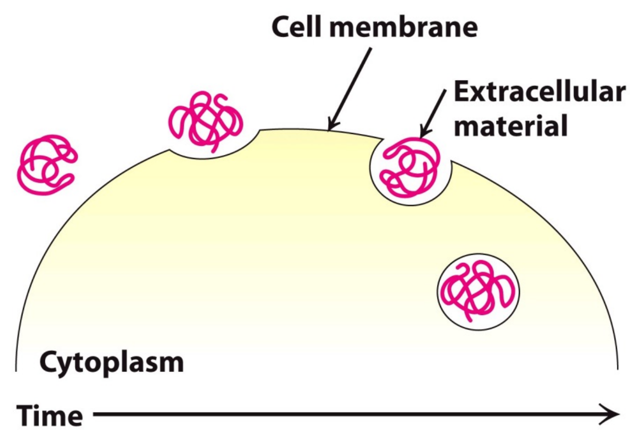

Figure 1.19
Biochemistry: A Short Course, Second Edition
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Endocytosis

Figure 1.20
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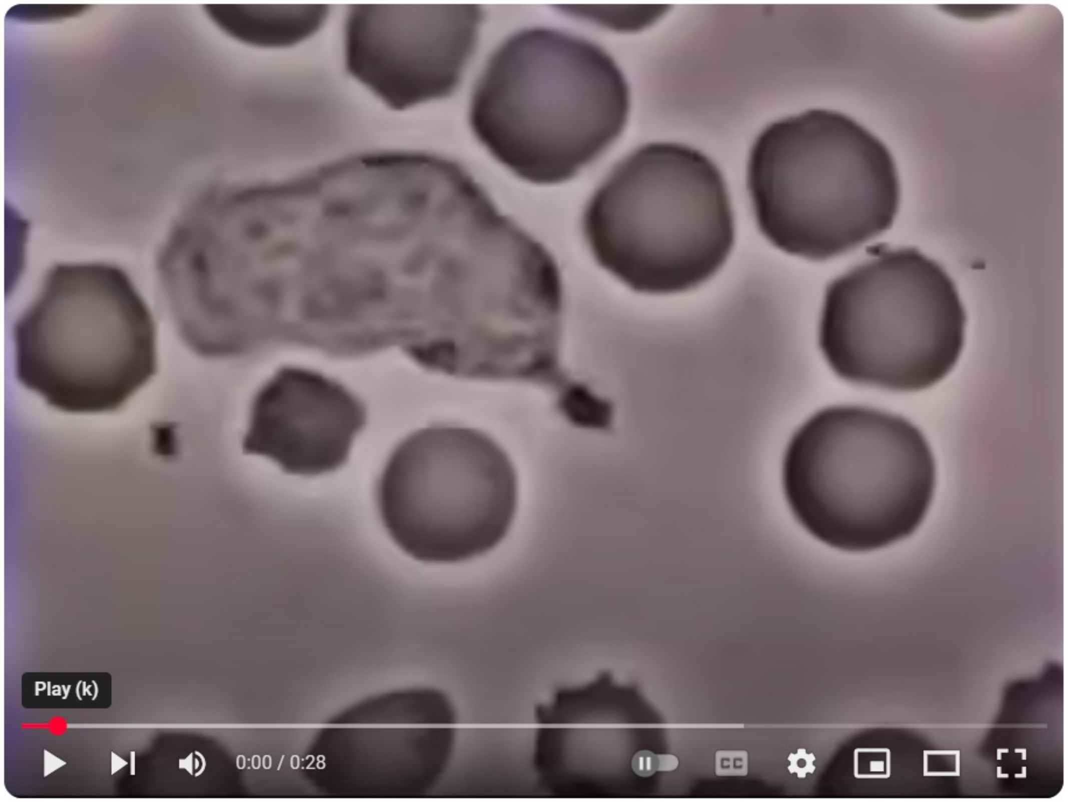
Phagocytosis

Macrophage Engulfs Foreign Cells

Human macrophage cell line engulfing red blood cells from sheep. Video by Dr. Richard Tsai.

Immune Cells Chasing Bacteria



Crawling Neutrophil Chasing a Bacterium

Taken from a 16-mm movie made in the 1950s by the late David Rogers at Vanderbilt University.

Cell Organelles

- **Lysosomes** contain a variety of digestive enzymes.
- Lysosomes fuse with endosomes to digest material brought into the cell.
- **Large vacuoles**, unique to plants, store water, ions, and various nutrients.

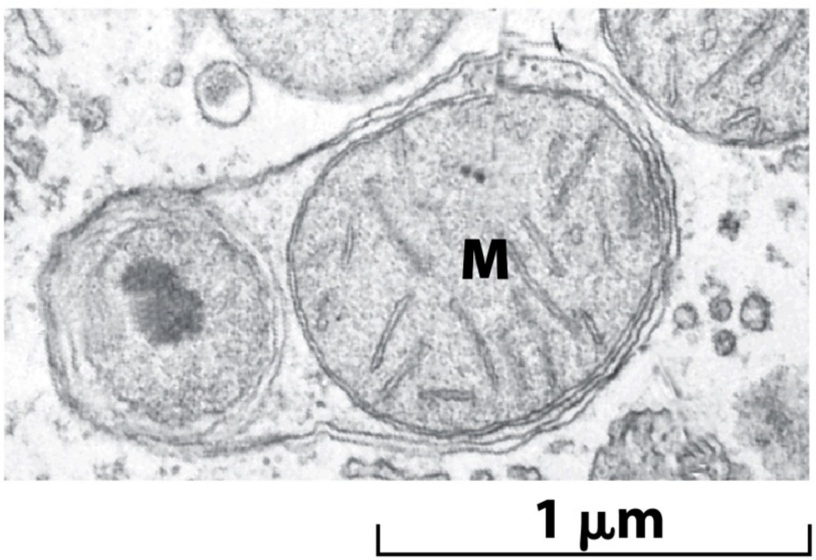


Figure 1.21
Biochemistry: A Short Course, Second Edition

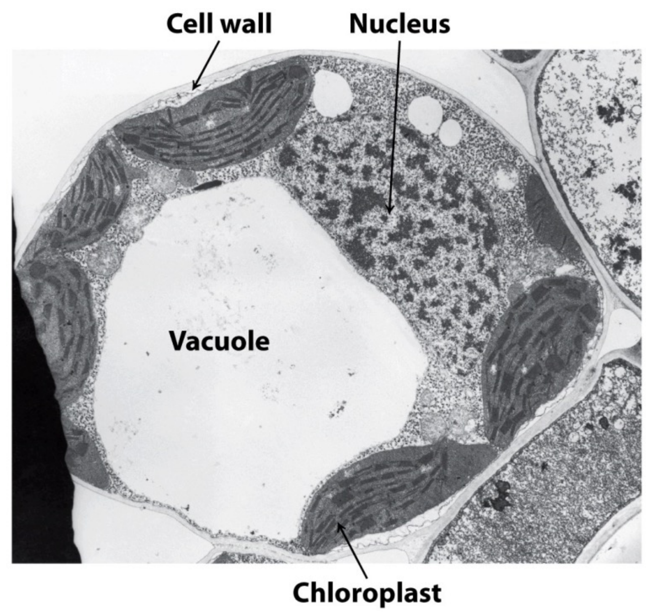


Figure 1.12a
Biochemistry: A Short Course, Second Edition

Quick Quiz 1

Which of the following is not a function attributed to proteins?

A. receptors for molecular signals
B. storage of genetic information
C. catalysis
D. structural support
E. molecular signals

Quick Quiz 2

Information in DNA is first ______into RNA. The information in RNA is then ______ to protein.

A. translated; transcribed

B. translated; translated

C. duplicated; translated

D. transcribed; transcribed

E. transcribed; translated

Quick Quiz 3

What is the main difference between a prokaryotic cell and a eukaryotic cell?

A. Prokaryotic cells do not contain membranes.
B. Eukaryotic cells have a periplasmic space.
C. Eukaryotic cells have membrane-enclosed compartments.
D. Prokaryotic cells do not contain DNA.
E. None of the above.

Quick Quiz 4

Which of the following statements is/are true?

A. Both prokaryotes and eukaryotes can have cell membrane.

B. Prokaryotes can have cell walls, but eukaryotes do not.

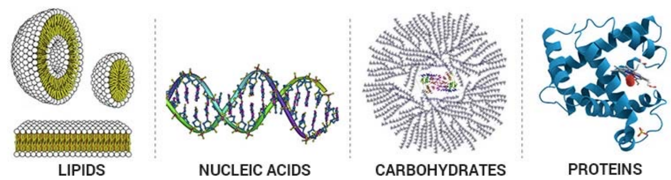
C. The hydrophobic core of the plasma membrane contains a network of fibers that provide rigidity to the cell.

D. A & C

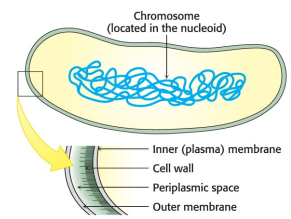
E. B & C

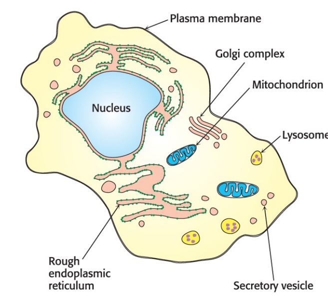
Chapter 2:
Water, Weak Bonds,
and the Generation of Order Out of Chaos

Transient chemical interactions underpin biochemistry and life



stabilized by strong covalent bonds



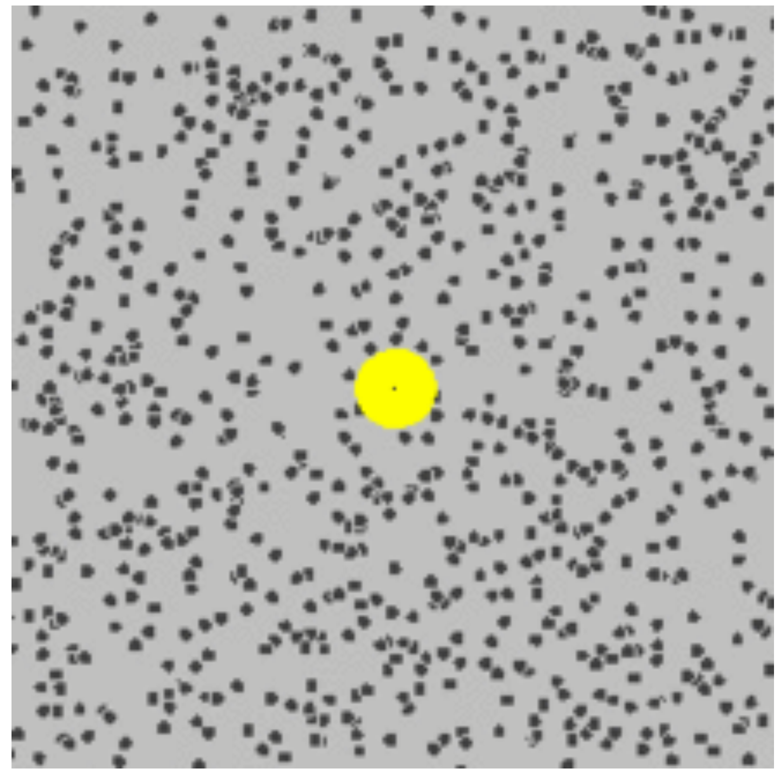


weak interactions stabilize the cell

- Strength in numbers: weak bonds in greater number create stable structures
- Dynamic interactions: allows transient binding and release (e.g., enzymes, hormones).
  - Enhance biochemical efficiency.
  - Allow rapid adaptation to changing cellular or systemic conditions.
  - Prevent prolonged activation that could harm the cell or organism.
- **Water plays a key role in influencing weak bonds.**

Thermal Motions Power Biological Interactions

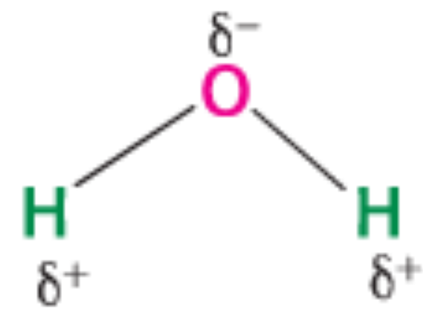
- Brownian motion (thermal noise) is essential for driving biochemical interactions.
- In cells, water serves as the main medium for Brownian motion.
  - Water acts as a lubricant, facilitating the transfer of energy and information.
- Examples of processes powered by Brownian motion:
  - Enzymes finding and binding to their substrates.
  - Fuels being broken down step-by-step to release energy.
  - Signal molecules diffusing to their target locations to trigger responses.

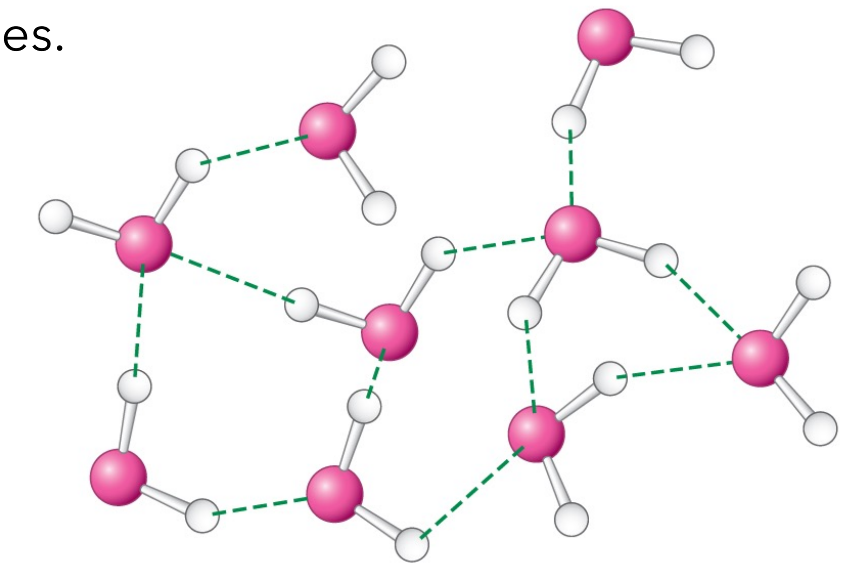


https://en.wikipedia.org/wiki/Brownian_motion

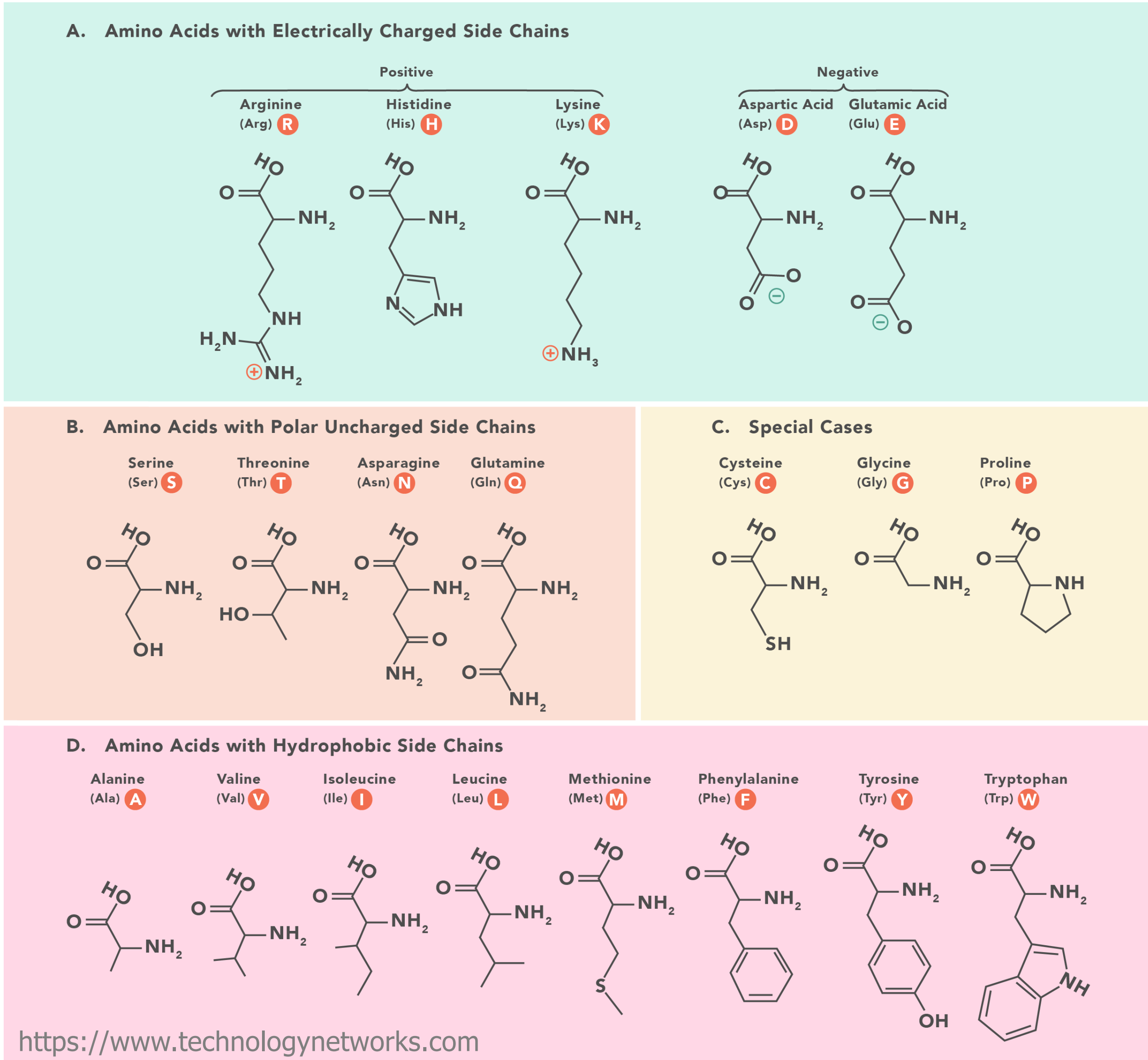
Be reminded that Water is Polar

- Hydrogen bonds, common in biomolecules, are not unique to water.
- Liquid water has a dynamic, partly ordered structure where hydrogen-bonded clusters form and break continuously, making it cohesive.
- Water's polarity and hydrogen-bonding ability allow it to dissolve charged and polar molecules.



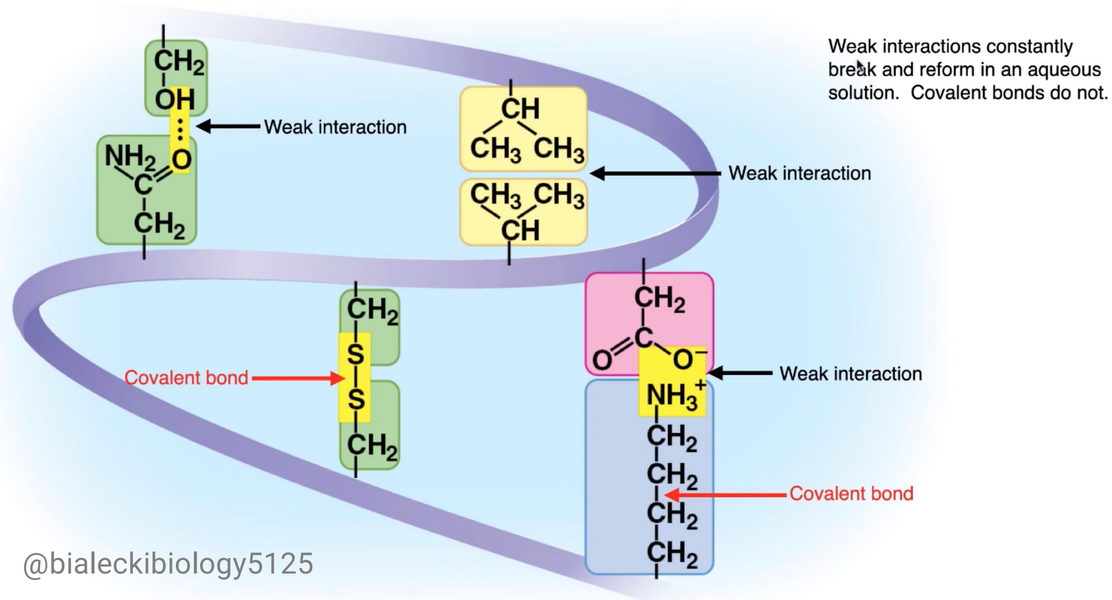


- Water's ability to dissolve many biochemicals is crucial, but its inability to dissolve certain compounds is equally significant.
- Nonpolar, or **hydrophobic**, molecules cannot dissolve in water, which plays a key role in biological processes.


A. Amino Acids with Electrically Charged Side Chains
Positive
Arginine (Arg) R
Histidine (His) H
Lysine (Lys) K
Negative
Aspartic Acid (Asp) D
Glutamic Acid (Glu) E
B. Amino Acids with Polar Uncharged Side Chains
Serine (Ser) S
Threonine (Thr) T
Asparagine (Asn) N
Glutamine (Gln) Q
C. Special Cases
Cysteine (Cys) C
Glycine (Gly) G
Proline (Pro) P
D. Amino Acids with Hydrophobic Side Chains
Alanine (Ala) A
Valine (Val) V
Isoleucine (Ile) I
Leucine (Leu) L
Methionine (Met) M
Phenylalanine (Phe) F
Tyrosine (Tyr) Y
Tryptophan (Trp) W
https://www.technologynetworks.com

Weak Interactions are Important in Biological Systems

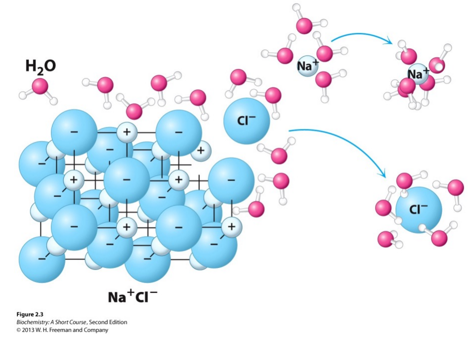
- Readily reversible, noncovalent interactions are essential for energy and information flow.
- 10-40× weaker than covalent bonds
- **Weak forces are key to processes such as:**
  - DNA replication
  - Protein folding into 3D structures
  - Enzyme-substrate recognition
  - Molecular signal detection

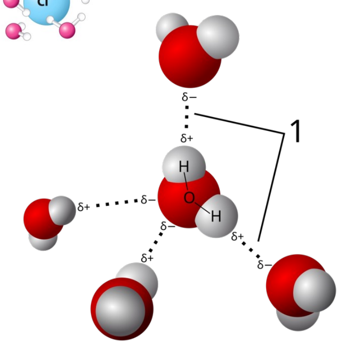


Weak interactions constantly break and reform in an aqueous solution.

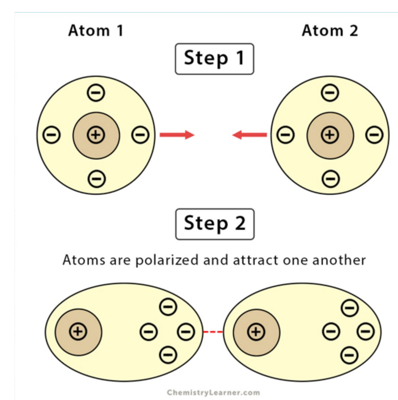
Three main types of noncovalent bonds

- **The three main types of noncovalent bonds are:**
  - ➢ Ionic bonds (electrostatic interactions)
  - ➢ Hydrogen bonds
  - ➢ Van der Waals interactions

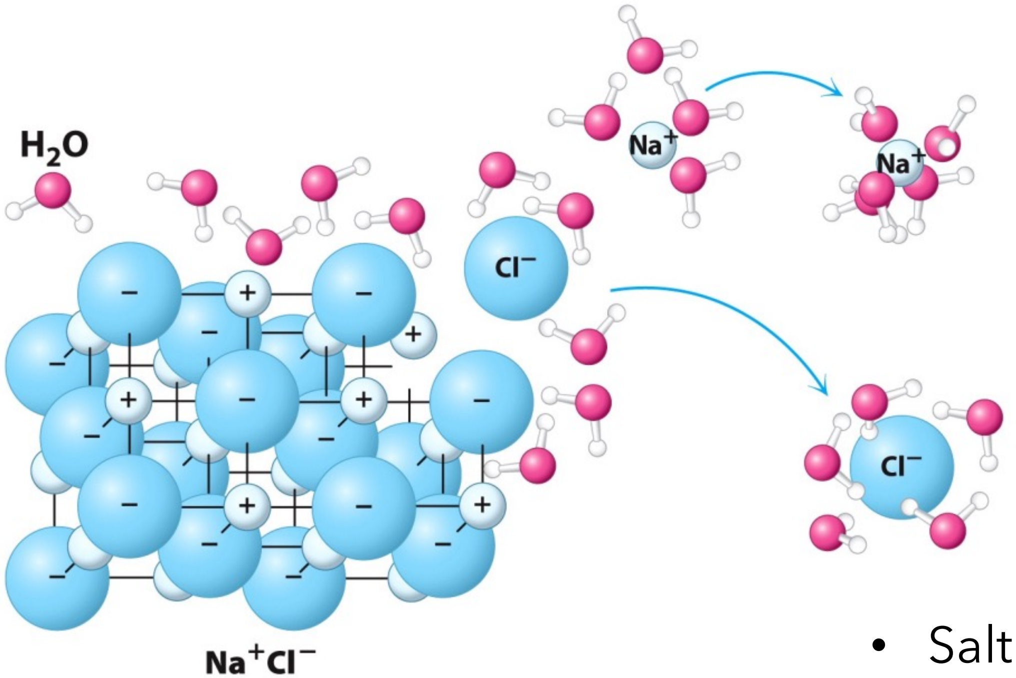




- These bonds differ in geometry, strength, and specificity, and their behavior is significantly influenced by water.
- These bonds work together to create stable yet dynamic interactions that are essential for biological function.
- Their collective strength often exceeds that of a single covalent bond, allowing for flexibility and adaptability in biochemical systems.



Ionic Bonds / Electrostatic Interactions



The force of an electrostatic interaction between two charges is given by Coulomb's law:

$$F = \frac{kq_1q_2}{Dr^2}$$

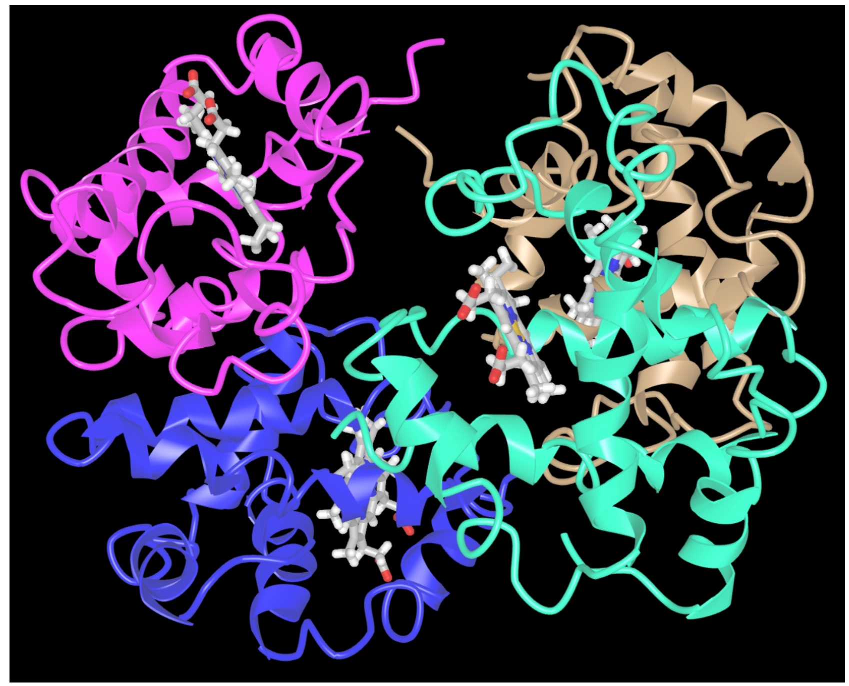
F is the force, q_1 and q_2 are the charges on the ions, *D* is the dielectric constant, *r* is the distance between the two ions, and *k* is a proportionality constant.

- The **dielectric constants** are strongest in a vacuum (*D*=1), water has dielectric constant of 80. Thus, water weakens electrostatic interactions.

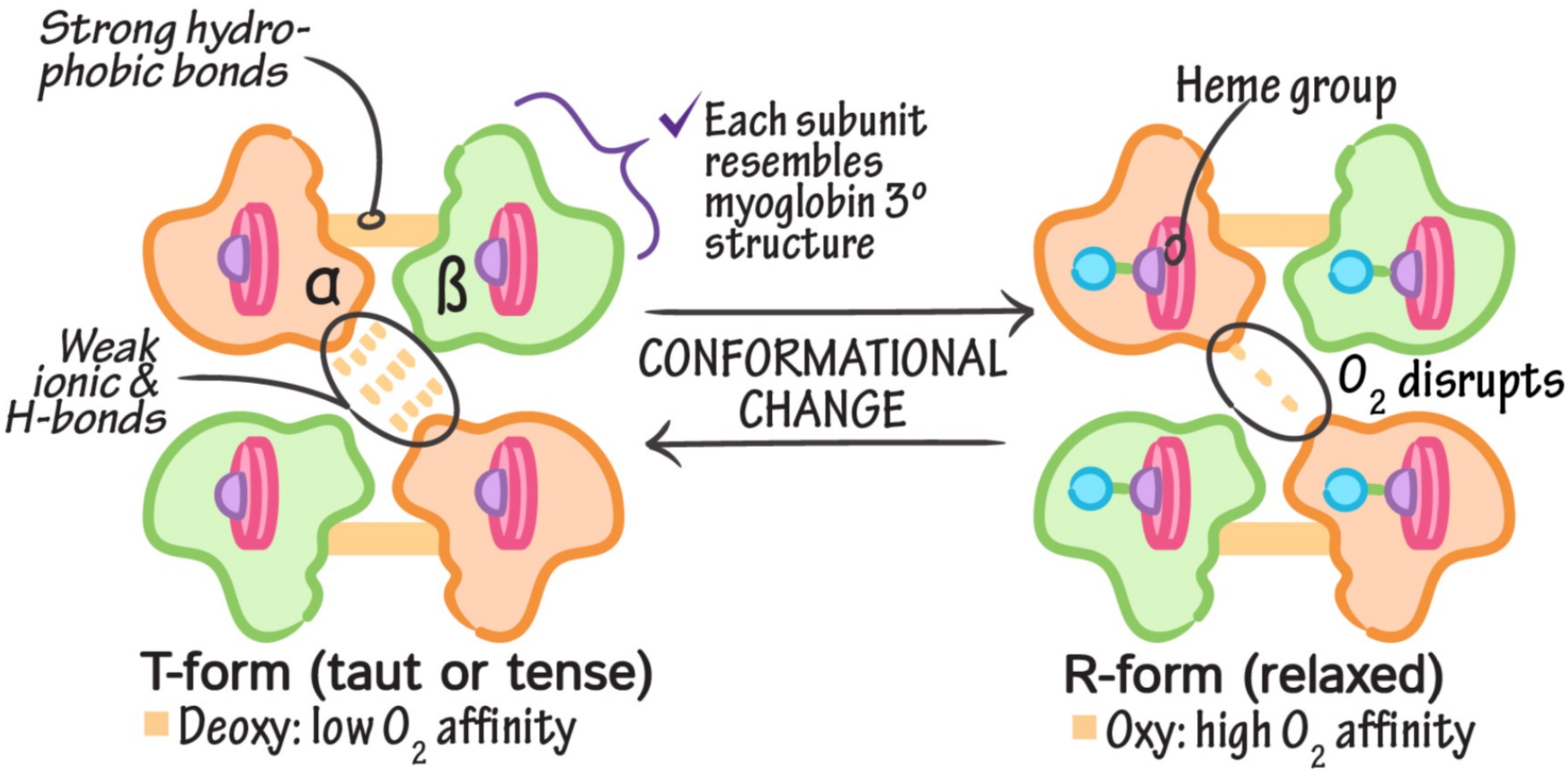
- Salt bridges in proteins are weaker in water due to its high dielectric constant, enabling flexibility and function.
- Hydrogen bonds in the double helix are stabilized in water because ionic interactions are screened.

Ionic Bonds Are Between Electrical Charges

- **Ionic Bonds or Electrostatic Interactions:**
  - •Attraction between oppositely charged ions or charged groups in molecules.
  - •Stronger than other noncovalent bonds but weaker than covalent bonds.
  - •Salt bridges in proteins, such as interactions between positively charged lysine and negatively charged glutamate side chains.
  - •Helps stabilize protein structures and mediates enzyme-substrate binding.

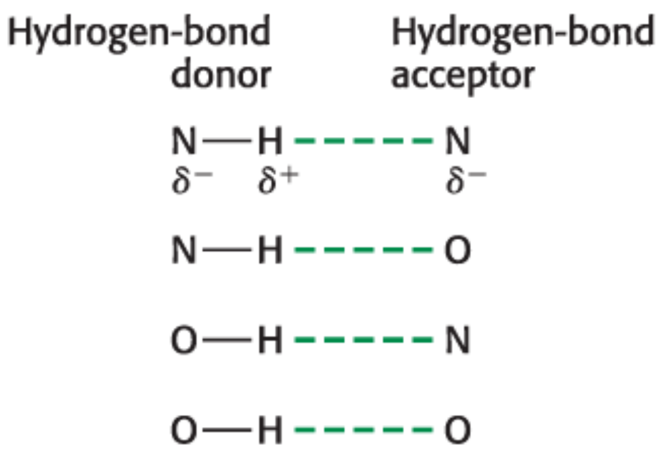


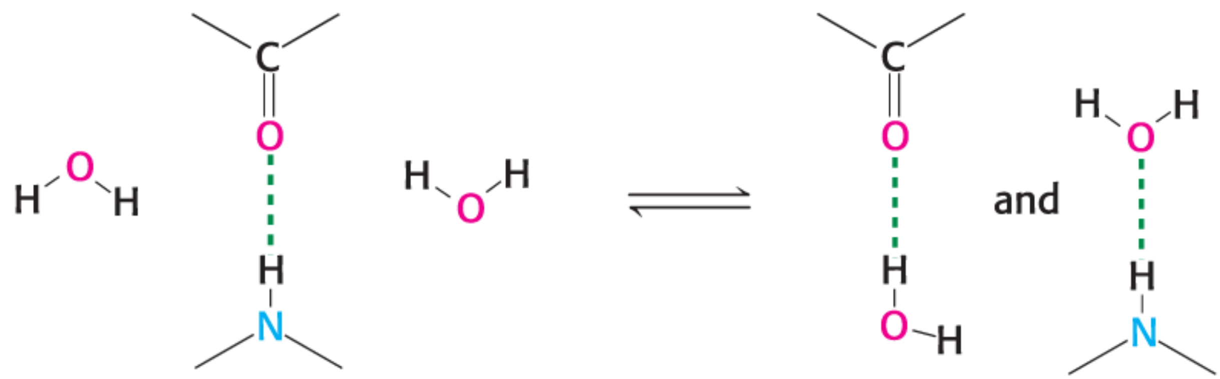
https://www.ncbi.nlm.nih.gov/Structure/pdb/2H35 https://app-web.drawittoknowit.com



The T-structure of human haemoglobin is linked by salt-bridges between its four subunits, formed by the C-terminal arginine residues of the alpha-subunits and the C-terminal histidine residues of the beta-subunits. In the R-structure, these salt-bridges are absent.

Hydrogen Bonds (H w/ an electronegative atom)



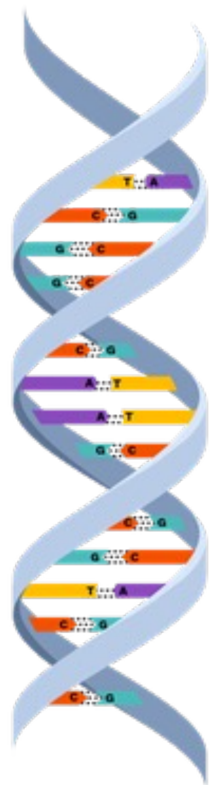


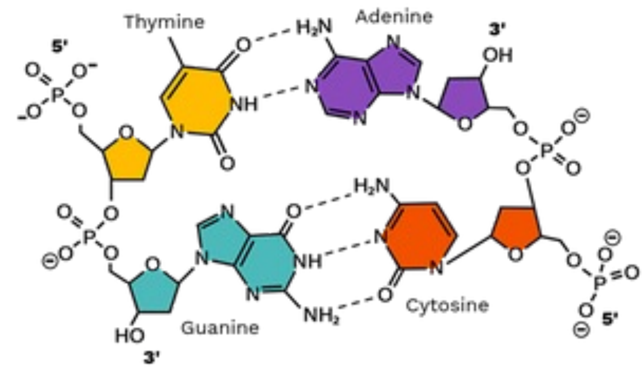
- Hydrogen bonds are not unique to water.
- H-bonds are much weaker than covalent bonds: 8-20 kJ mol^{-1} vs 418 kJ mol^{-1} (carbon–hydrogen covalent bond).
- H-bonds are also longer than covalent bonds.

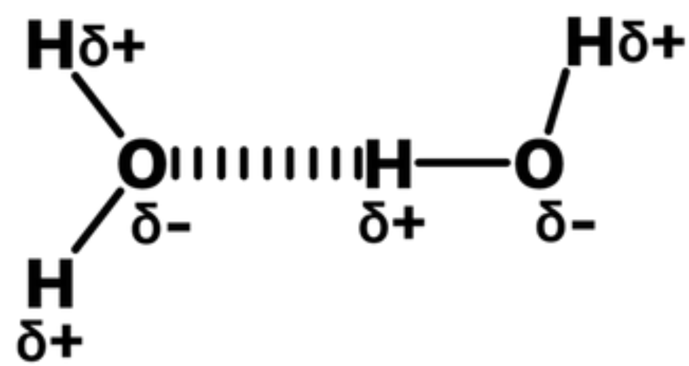
Hydrogen Bonds

Hydrogen Bonds:

- •formed when a hydrogen atom covalently bonded to an electronegative atom (O or N) is attracted to another electronegative atom
- •directional and specific
- •H-bonding between complementary bases in DNA (A-T and G-C pairs).
- •critical for DNA structure, water's unique properties, and maintaining the secondary structure of proteins (e.g., alpha-helices and beta-sheets).



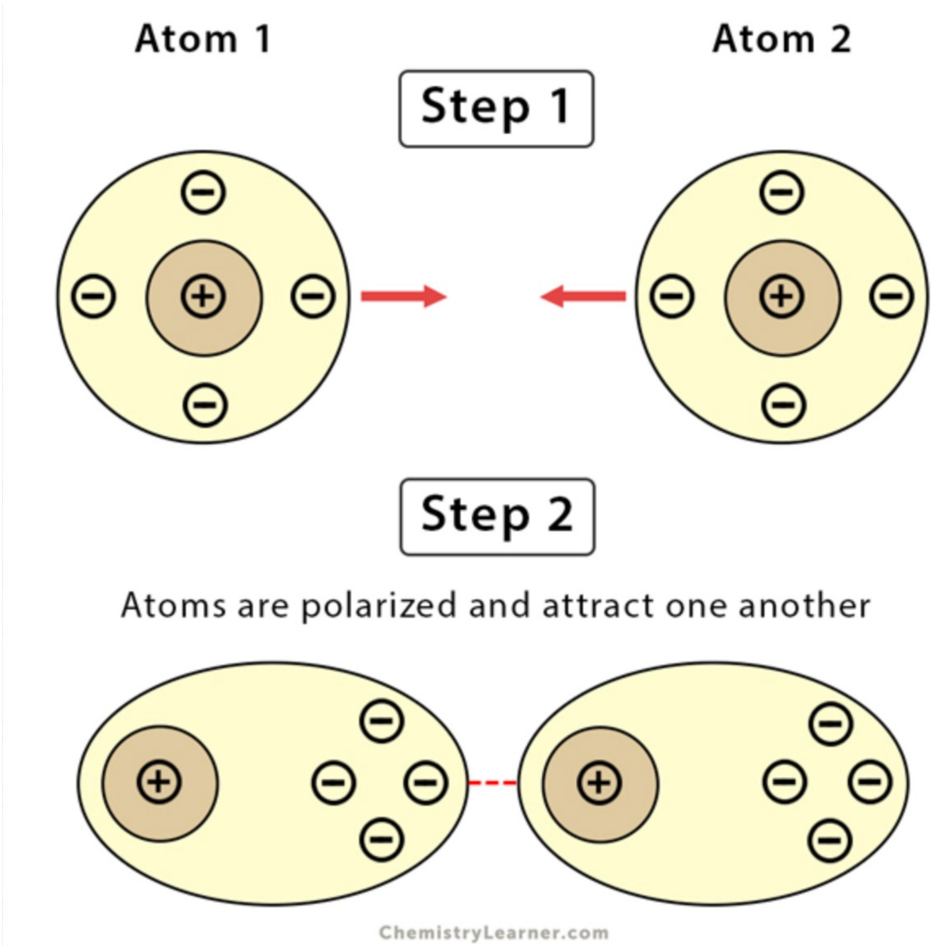




https://theory.labster.com/h-bonding-life-vdw/

What allows nonpolar and uncharged biomolecules to interact with one another effectively?

Van der Waals Interactions



- transient asymmetry in one molecule will induce complementary asymmetry in a nearby molecule.

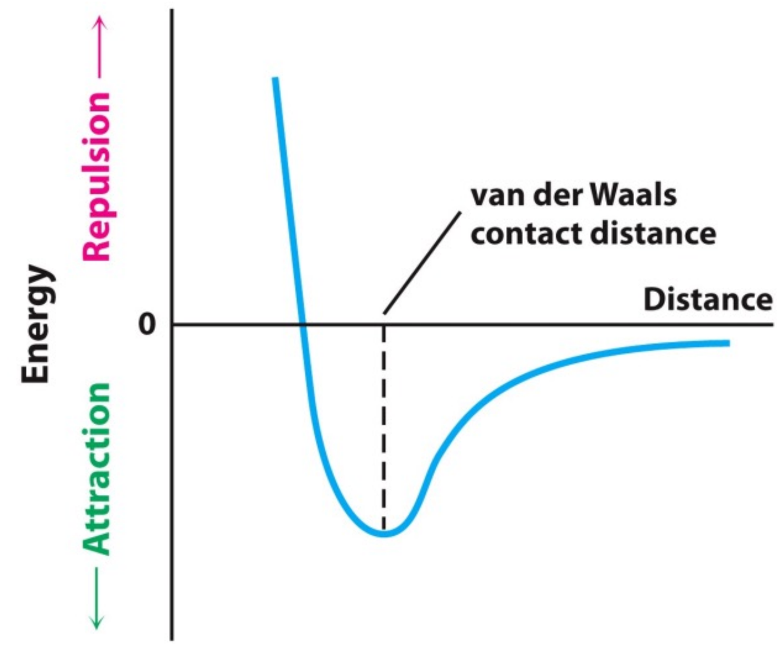
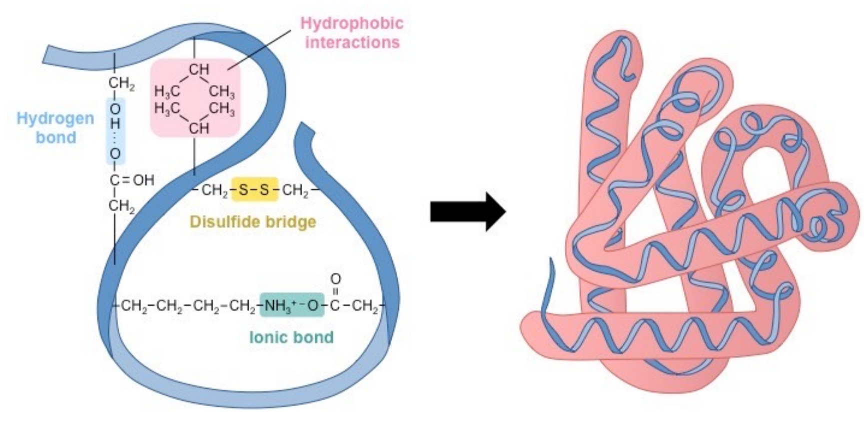


Figure 2.6
Biochemistry: A Short Course, Second Edition

Van der Waals Interactions

Van der Waals Interactions:

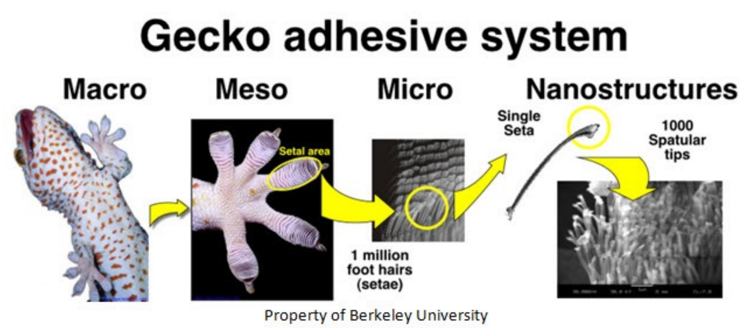
- •Weak, nonspecific forces from temporary dipoles created by fluctuating electron distributions in nearby atoms or molecules.
- •The weakest of noncovalent bonds (2-4 kJ mol^{-1}); highly distance-dependent.
- •Packing of hydrophobic amino acids in the core of globular proteins.
- •Stabilizes protein folding and helps membrane lipids aggregate.



Types of side chain interactions

Overall 3D shape (3° Structure)

https://old-ib.bioninja.com.au



http://www.livescience.com/48845-gecko-inspired-tech-climbing-walls.html

Quick Quiz 5

Within the helical structure of DNA, the bases are held together by ____________, which are relatively _________ bonds.

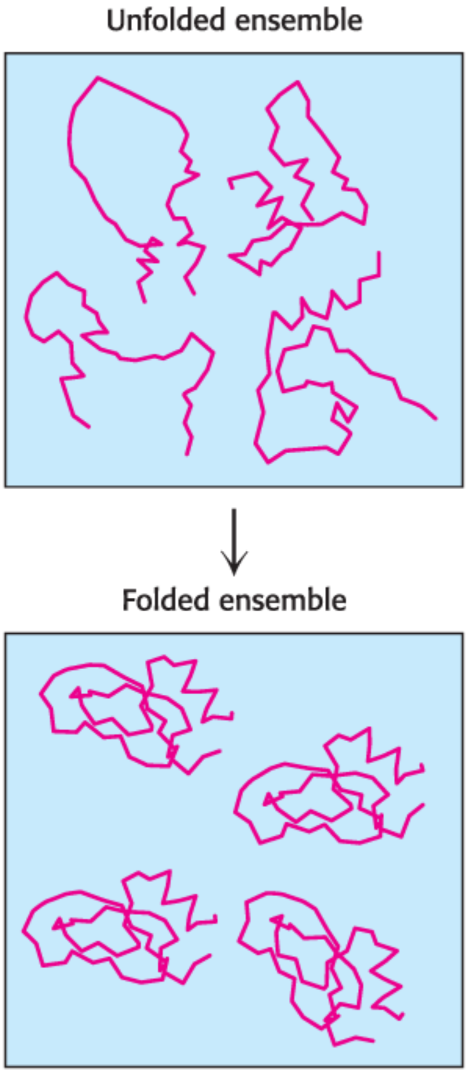
A. ionic interactions; strong

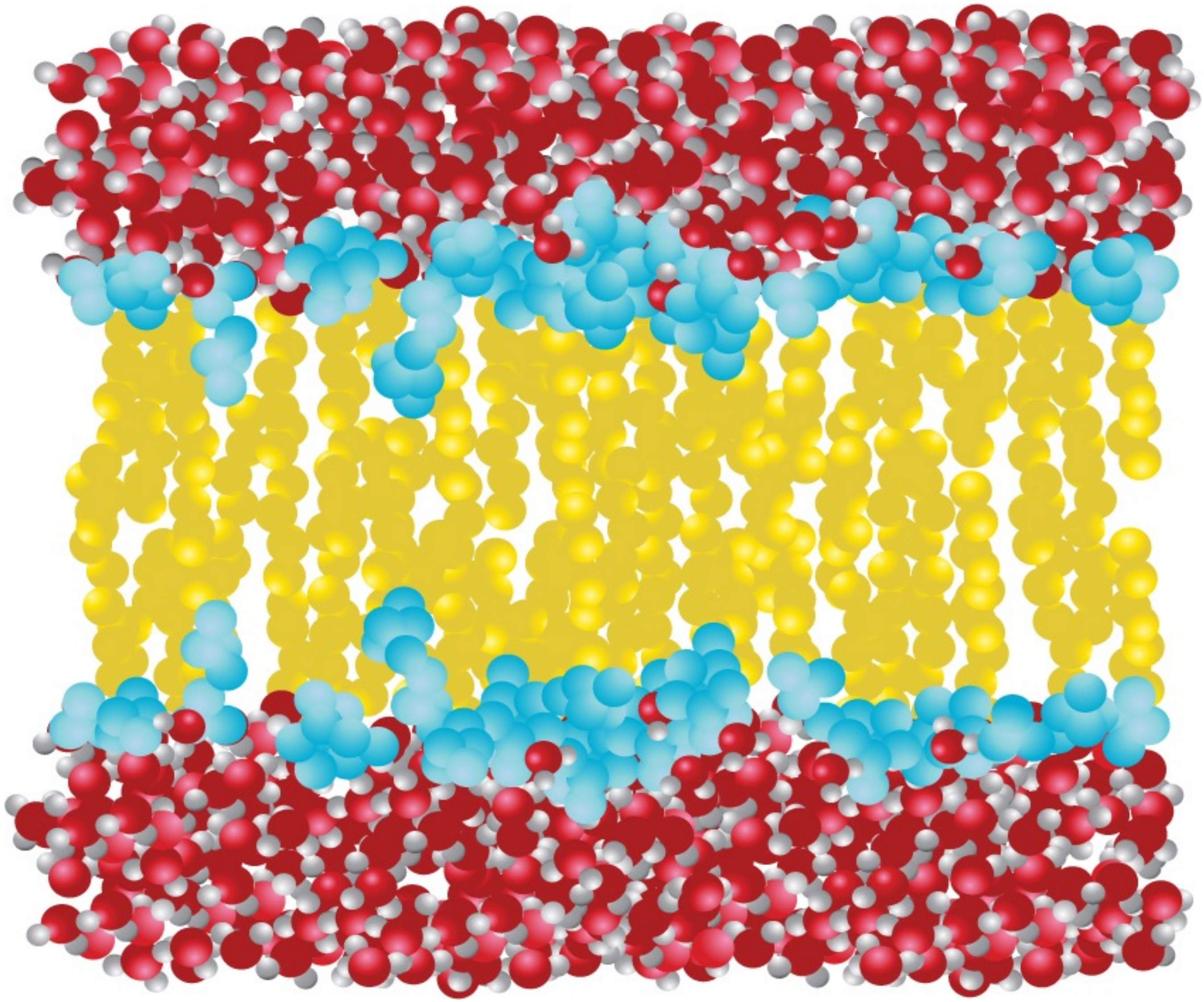
B. ionic interactions; weak

C. hydrogen bonds; strong

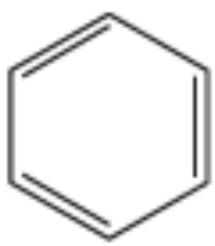
D. covalent bonds; weak

E. hydrogen bonds; weak

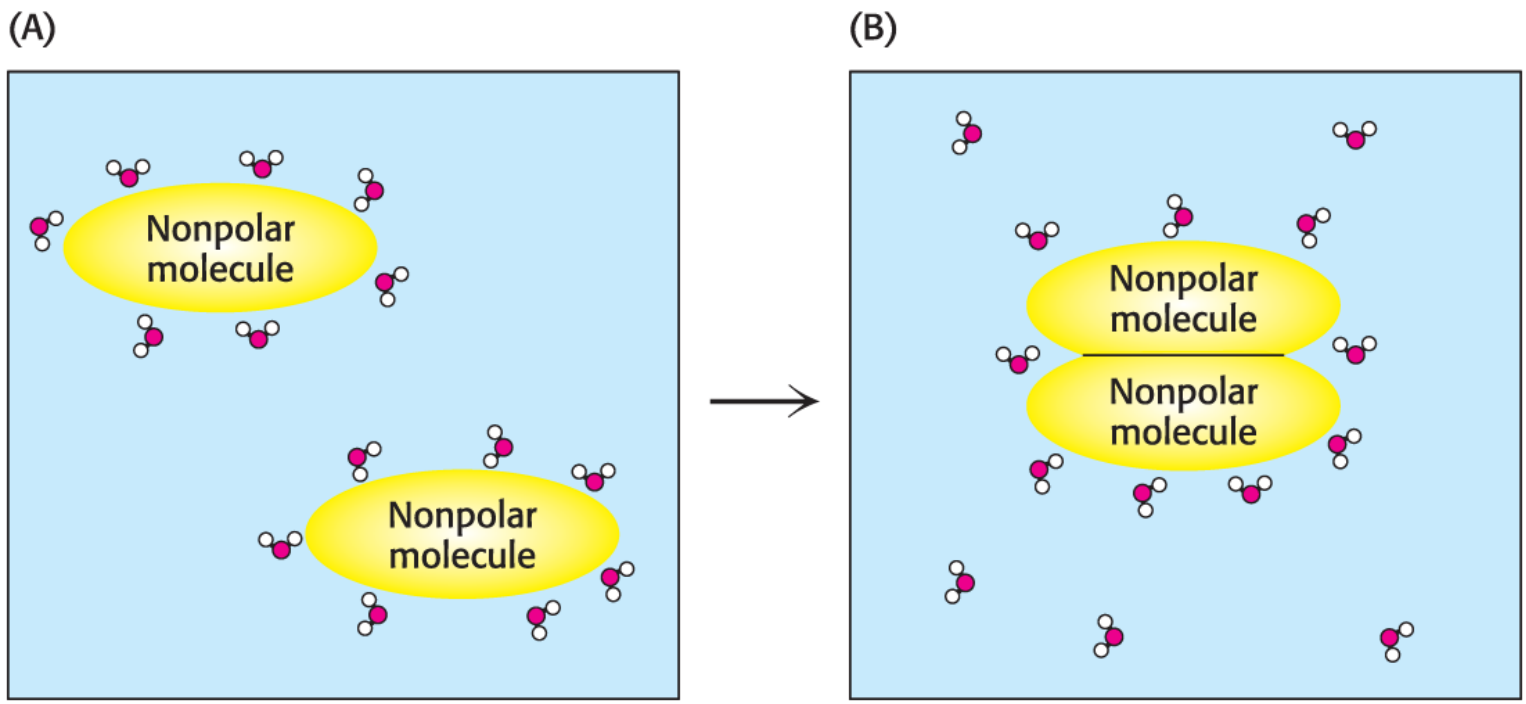

Unfolded ensemble
Folded ensemble



The Hydrophobic Effect



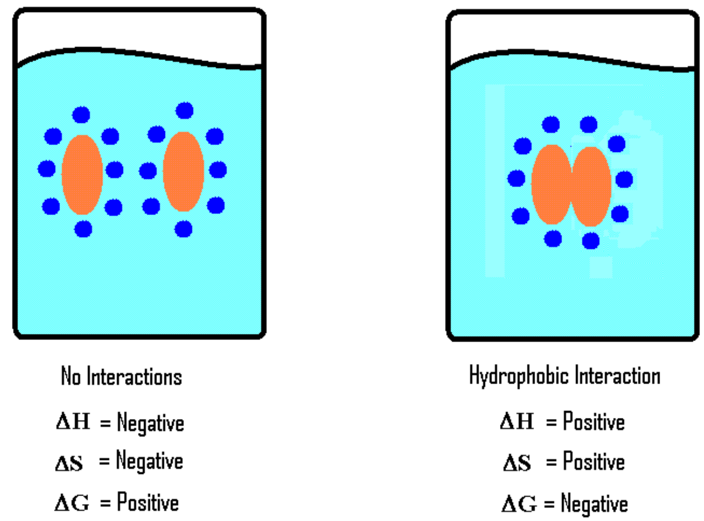
Benzene



entropically driven ➜
increases the disorder in water molecules

Hydrophobic Molecules Cluster Together

- This clustering of hydrophobic molecules in water is called the **hydrophobic effect**.
- The hydrophobic effect is powered by the increase in the entropy of water that results when hydrophobic molecules come together.
- Phospholipids have hydrophilic and hydrophobic properties. When exposed to water, phospholipids form membranes.
- Protein folding is also powered by the hydrophobic effect.



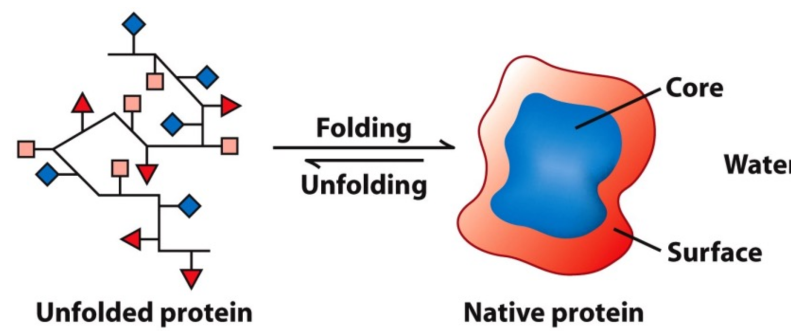
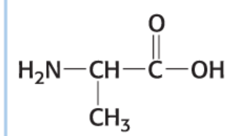
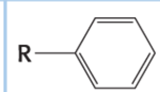
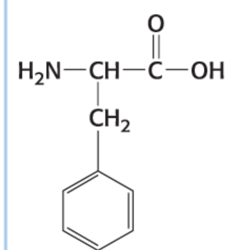
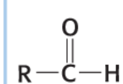
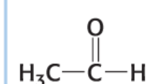
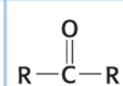
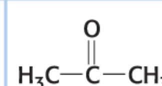


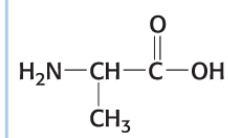
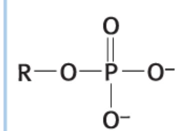
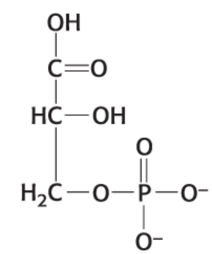
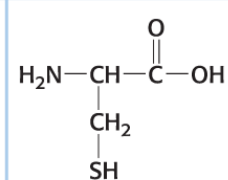
Figure 3-7
Molecular Cell Biology, Sixth Edition

- Four major classes of biomolecules
- Three types of reversible, noncovalent interactions + hydrophobic effect
- Key functional groups found in all biomolecules

Functional Groups Have Specific Chemical Properties

Functional group	Class of compounds	Structural formula	Example
Hydrophobic	Hydrocarbon chains (aliphatic)	$R{-}CH_3$	 **Alanine**
	Aromatic (hydrocarbons in a ring structure with multiple double bonds)		 **Phenylalanine**
Hydroxyl	Alcohol	$R{-}OH$	$H_3C{-}CH_2{-}OH$ **Ethanol**
Aldehyde	Aldehydes		 **Acetaldehyde**
Keto	Ketones		 **Acetone**

Functional Groups Have Specific Chemical Properties

Functional group	Class of compounds	Structural formula	Example
Amino	Amines	R—NH_2	 **Alanine**
Phosphate	Organic phosphates		 **3-Phosphoglyceric acid**
Sulfhydryl	Thiols	R—SH	 **Cysteine**

When environmental pH goes awry…

pH and Its Importance in Biological Systems

- pH is the measure of H^+ concentration of a solution.
- Controlling pH is a crucial function in biological systems.
- **Organic acids are prominent biomolecules.**

$$H_2O \rightleftharpoons H^+ + OH^-$$

The equilibrium constant K_{eq} for the dissociation of water is given by:

$$K_{eq} = [H^+][OH^-]/[H_2O]$$

K_w, the ion constant of water, is given by:

$$K_w = K_{eq} \times [H_2O]$$

This can be simplified to:

$$K_w = [H^+][OH^-]$$

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}\,M^2$$

$$pH = \log_{10}(1/[H^+]) = -\log_{10}[H^+]$$

Remember ionization of an acid:

$$HA \overset{K_a}{\rightleftharpoons} H^+ + A^-$$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

Acid ionization constant, the larger the value, the stronger the acid.

$$\frac{1}{[H^+]} = \frac{1}{K_a}\frac{[A^-]}{[HA]}$$

The Relationship Between pH and pK_a

- We can derive a relationship between pH and the ratio of acid to base by first manipulating the formula for the ionization of the acid.

$$\frac{1}{[H^+]} = \frac{1}{K_a}\frac{[A^-]}{[HA]}$$

- Taking the logarithm of both sides gives:

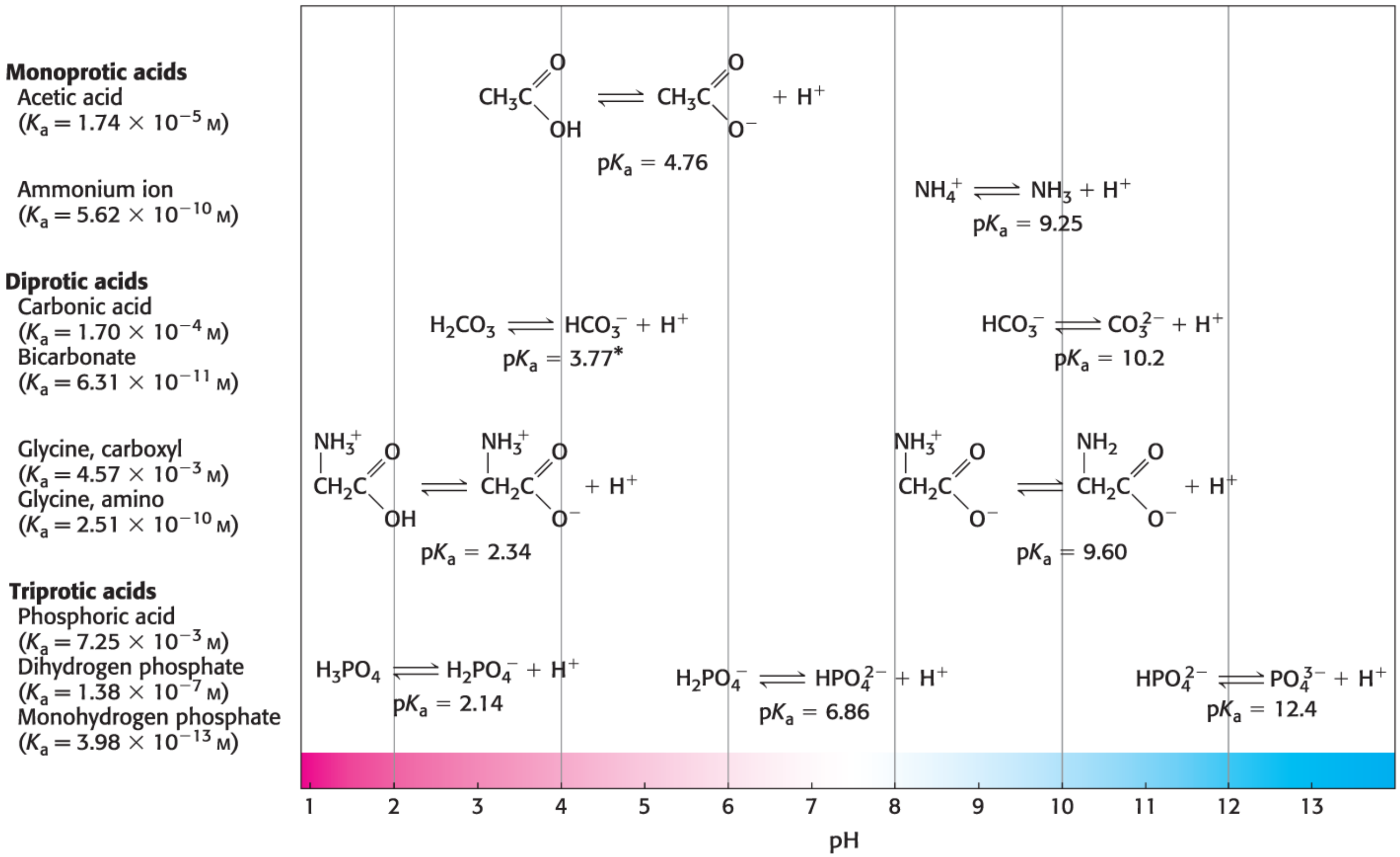
$$\log\left(\frac{1}{[H^+]}\right) = \log\left(\frac{1}{K_a}\right) + \log\left(\frac{[A^-]}{[HA]}\right)$$

- The log(1/K_a) is called the pK_a of the acid.
- Substituting pH for log(1/H^+) and pK_a for log of (1/K_a) yields the **Henderson-Hasselbalch equation:**

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[A^-]}{[HA]}$$

- When [A^-] = [HA], log ([A^-]/[HA]) equals 0, and pH =pK_a.
- For any acid, at pH > pK_a, A^- predominates.
- At pH < pK_a, HA predominates.

Conjugate Acid-Base Pairs in Biochemistry



$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

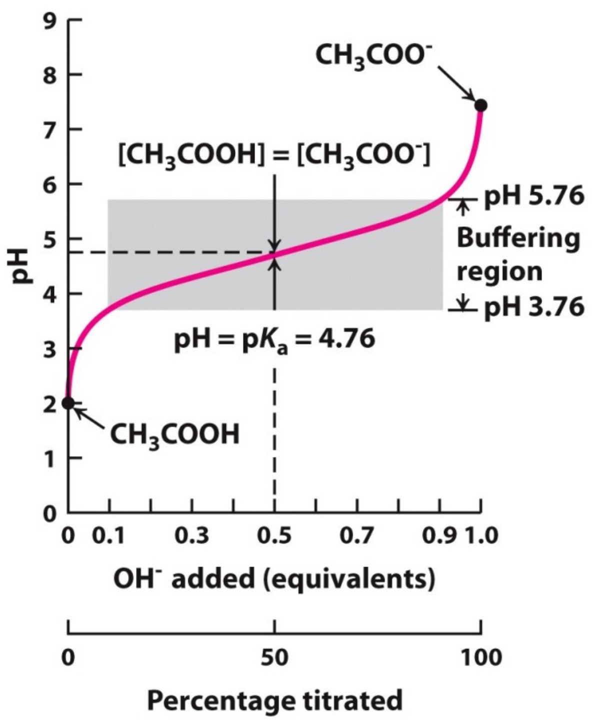
Tymoczko et al., *Biochemistry: A Short Course*, 4e, © 2019 W. H. Freeman and Company

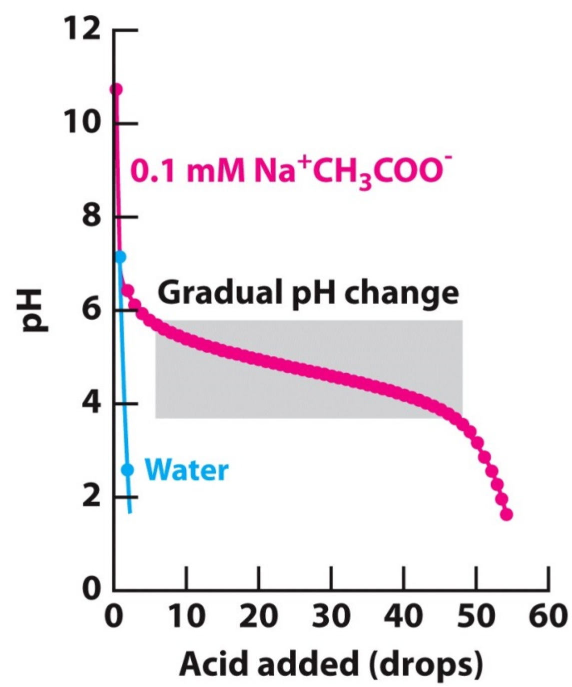
Buffers Resist Changes in pH

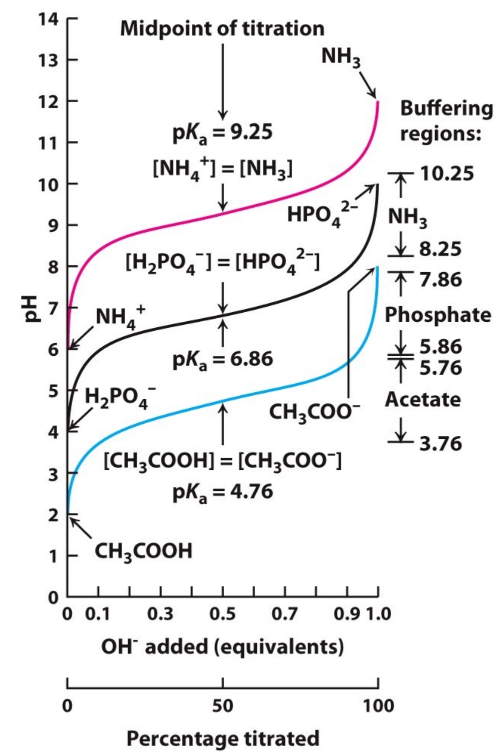
- An acid-base conjugate pair resists changes in the pH of a solution. In other words, it acts as a buffer. A buffer is most effective at a pH near its pKa.

$HA + OH^- \rightleftharpoons A^- + H_2O$

$A^- + H_3O^+ \rightleftharpoons HA + H_2O$







Importance of Buffers in Biological Systems

• Buffers maintain stable pH, crucial for enzyme function and metabolic processes.

$CO_2 + H_2O \rightleftharpoons H_2CO_3$
$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (buffer)

➢ Bicarbonate Buffer System

- $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
- maintains blood pH (~7.4), neutralizing acids like CO_2 and lactic acid

➢ Phosphate Buffer System:**

- $H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$
- Regulates intracellular pH and kidney function.

• Buffers protect cells from harmful pH changes caused by metabolic or environmental factors.

Making Buffers in the Lab

Supposed you are working in a clinical biochemistry lab and discussion with colleagues prompted you to try a new experiment that requires you to prepare an acetate buffer (1 L, 0.3 M) with a pH of 4.46. You have at your disposal stock solutions of 2 M acetic acid (pKa = 4.76) and 2.5 M KOH.

Quick Quiz 6

Solution X is at a pH of 3; solution Y is at a pH of 8. Which of the following is true?

A. Solution X contains more protons than solution Y.

B. Solution X contains fewer protons than solution Y.

C. Solution X is more basic than solution Y.

D. A & C

E. B & C

Assigned Problems

Chapter	Tymochko, Berg, Stryer, Biochemistry, 2nd Edition,	**Chapter**	Tymochko, Berg, Stryer, Biochemistry, 2nd Edition,
1	2, 3, 5, 7, 9, 12	2	4, 5, 6, 10, 11, 12, 13, 14, 16, 17
Chapter	Tymochko, Berg, Stryer, Biochemistry, 3rd and 4th Edition,	**Chapter**	Tymochko, Berg, Stryer, Biochemistry, 3rd and 4th Edition,
1	2, 3, 5, 7, 9, 12	2	4, 5, 6, 10, 11, 12, 13, 16, 18, 19