بسم الله الرحمن الرحيم

King Saud University

College of Science

Department of Biochemistry

Biochemical fundamentals of Life (BCH 103)

Chapter 3:

Functional Groups

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Functional Groups

- Functional groups are attached to carbon skeletons in organic molecules (including biological molecules) and give compounds their functionality.
- The basic backbone of organic molecules is the hydrocarbon chain , upon which functional groups are found. The functional groups, together with their hydrocarbon backbone, provide the physical characteristics, structure, and function of biological molecules.

Functional Groups

- Hydroxyl (OH). Hydroxyl groups are contained in polar compounds such as alcohols and carbohydrates. The hydroxyl group is polar, increases water solubility, and is involved in hydrogen bonds.
- Carbonyl (C=O). Carbonyl groups are polar groups with a double bond between C and O and are contained in aldehydes and ketones, including formaldehyde.

Functional Groups

- Carboxyl (COOH). Carboxyl groups are polar groups contained in carboxylic acids. They lose their H ions to form acids such as acetic acid (vinegar) and have a negative charge when they lose their proton.
- Fatty acids and amino acids have carboxyl groups.

Functional Groups

- Amino (NH). Amino groups are polar groups found in molecules such as methylamine and amino acids. Amines can be primary, secondary, or tertiary, depending on where they are found in the hydrocarbon backbone. Amines can act as bases, with primary amines becoming positively charged when protonated in molecules like amino acids.
- Sulfhydryl (SH). Sulfhydryl groups help stabilize proteins by reacting with each other to form cross bridges in the protein structure. They are contained in thiols, such as mercaptoethanol and the amino acid cysteine.

Functional Groups

- Phosphates (PO). Found in organic phosphates such as glycerol phosphate, these groups store energy that can be passed from one molecule to another by the transfer of a phosphate group. DNA and
- ATP are important biological molecules that contain phosphate.

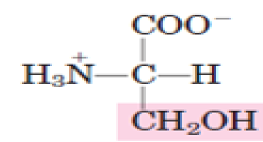
Functional Groups in Biochemistry

Examples from biochemistry

R-OH
Alcohol

—OH
Hydroxyl

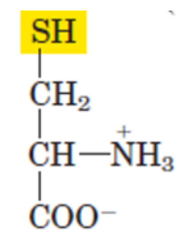
Example:
amino acid
(serine)



R-SH
Thiol

—SH
Sulfahydryl

Example:
amino acid
(cysteine)



O
||
R-C-OH
Carboxylic acid

O
||
—C—OH

O
||
R-C—O⁻

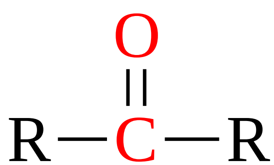
Carboxylate

Example:
fatty acid
(Palmitic acid)

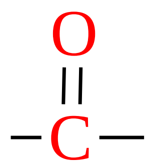
$CH_3(CH_2)_{16}COOH$

Functional Groups in Biochemistry (Cont.)

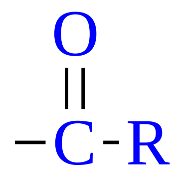
Examples from biochemistry



Ketone

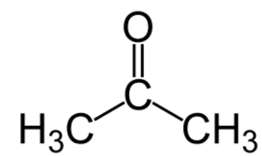


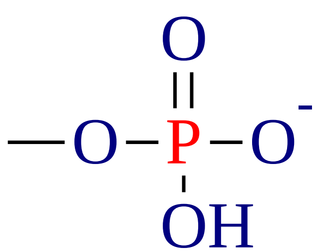
Carbonyl



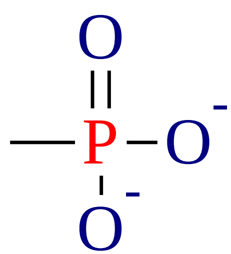
Acyl

Example:
acetone



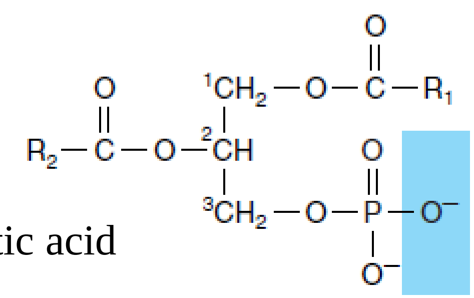


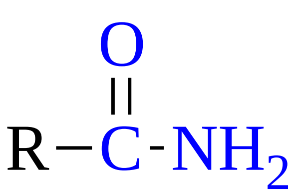
Phosphate



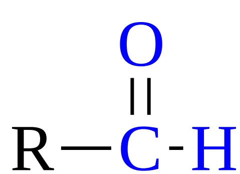
Phosphoryl

Example:
Phosphatetic acid



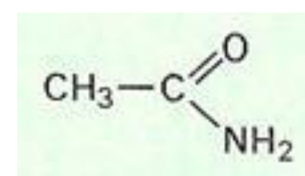


Amide



Aldehyde

Example:
acetamide



Functional Groups in Biochemistry (Cont.)

Examples from biochemistry

$R-NH_2$ Primary

$R-N(R_1)-H$ Secondary

$R-N(R_1)-R_2$ Tertiary

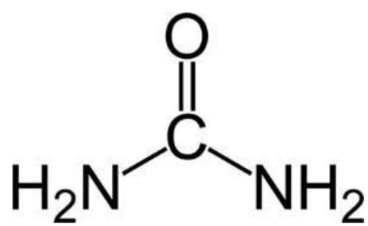
Amines

$-NH_3^+$

$-NH_2$

Amino

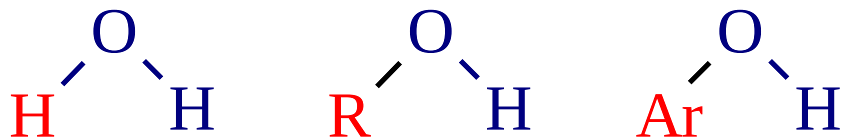
Example:
Urea



Alcohols & Phenols

- Alcohols:
  - Any molecule having –OH group (Hydroxyl) bound to an alkyl chain.
    - Primary, secondary, and tertiary alcohols based on what's bound to the C-OH group.
  - Important in many biological molecules
    - Some Amino acids, carbohydrates, and certain lipids
- Phenols
  - A hydroxyl group bound to an aryl or aromatic group (e.g., phenyl)

- **Both can be viewed as a substituted water.**



Properties of Alcohols

The -OH in alcohols has properties like H_2O

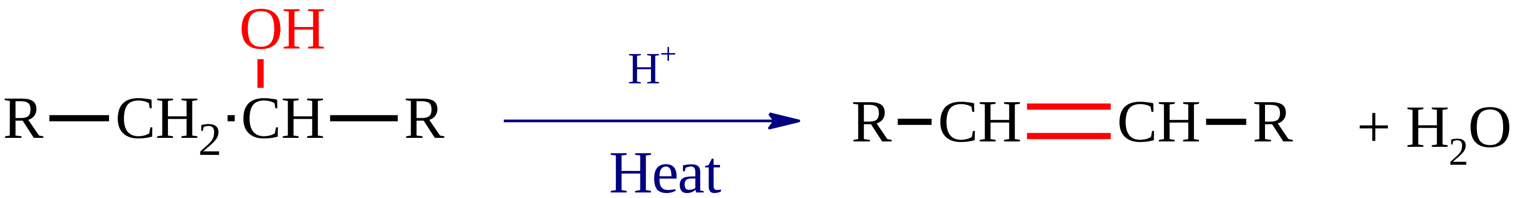
- Can participate in H-bonding (acceptor & donor)
- Polar group
- Water soluble
- but long carbon chain reduces solubility: R-OH
  - C_1 - C_5 Highly soluble
  - C_5 - C_7 Moderately soluble
  - C_8 and above Slightly soluble/insoluble

δ^- δ^+ δ^-

-O-H ········ A-

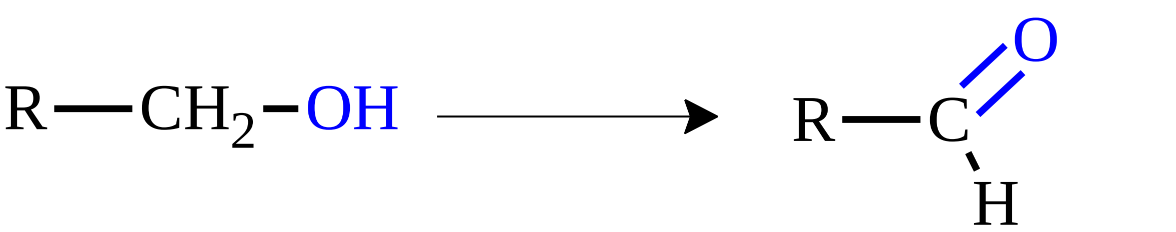
Reactions of alcohols

- Dehydration: removal of a water



- Oxidation: conversion of OH to =O.

Ketone

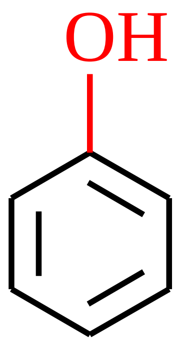


Aldehyde

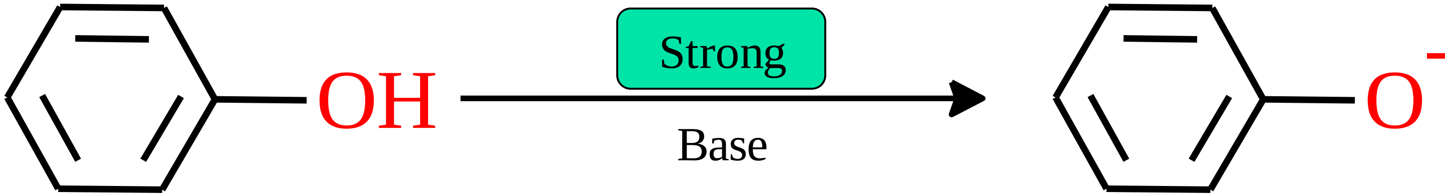
- Remember OIL RIG
  - Oxidation Is Loss of electron (before, the gain of oxygen)
  - Reduction Is Gain of electron (before, the loss of oxygen)

Phenols

- Compounds with hydroxyl group bound to a benzene ring



- They are weak acids
  - Can lose a proton to strong bases.
    - (Notice) Aliphatic alcohols do not act as acids.
      - The anion formed is not stable.



- The ring of phenol is easily oxidized.
  - *In vivo*, special enzymes can accomplish this.
    - *In vivo* means “in life” or “in a living cell”
    - *In vitro* means “in glass”

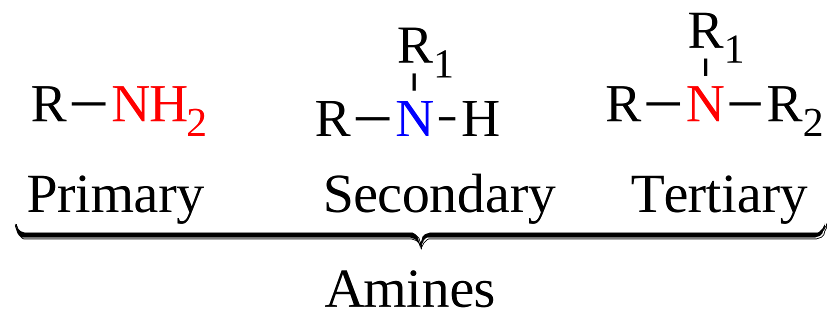
Thiols

- Similar to alcohols but contain S instead of O = R-S-H
  - The -SH can be called the thiol, mercaptan, or sulfhydryl group.
- S is less electronegative than O →
  - Less polar than alcohols
  - Weaker H-boding capability
  - Less water solubility

- Have some of the strongest & unpleasant odors

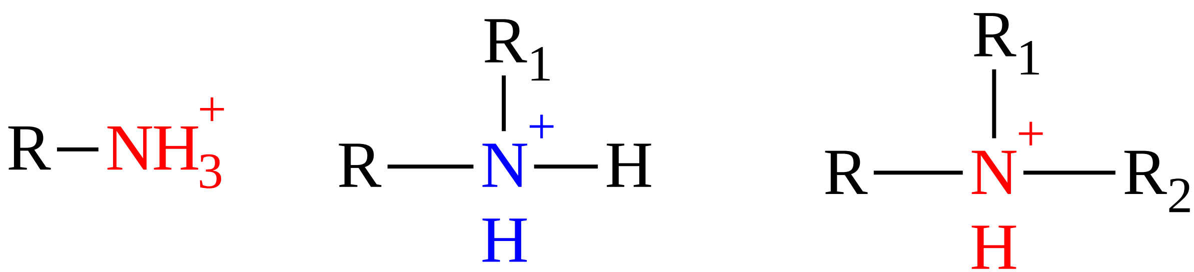
Amines

- Many biological molecules contain amino groups.
  - amino acids, DNA, RNA bases, alkaloids (e.g., caffeine, nicotine)
- General formula



  - R's are not necessarily identical.
  - Can be considered as substituted ammonia molecules.

- Amines are basic groups and can accept protons to become acidic.



Properties of Amines

- Nitrogen is very but not quite as electronegative as oxygen.
- Electronegativity is a chemical property that describes the tendency of an atom or a functional group to attract electrons towards itself
  - O > S > N

$$-\overset{\delta^-}{N}-\overset{\delta^+}{H}\cdots\cdots\overset{\delta^-}{A}-$$

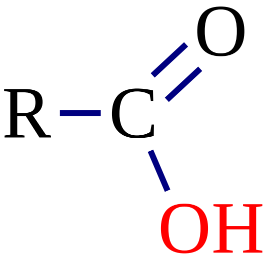
Thus:

- Amino group are polar groups
- Can participate in H-bonding (acceptor & donors)
  - Amines can also share H bonds with water, so they are more soluble in water than alkanes.
  - H bonds are not as strong as in alcohols
- Weak bases (similar to ammonia, a common weak inorganic base).

Carboxylic acids

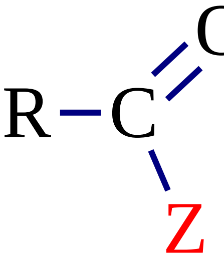
- Many biological molecules contain carboxylic group or one of its derivatives.
  - Proteins, amino acids; , lipids, fatty acids; carbohydrates, sugar, and many others.

General Formula: -COOH (carboxyl)



- Any R possible: H, alkyl or aromatic chain

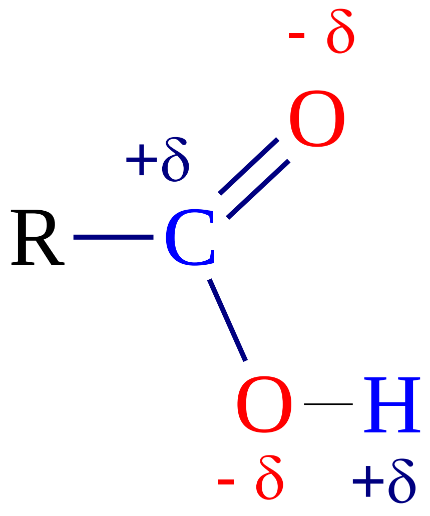
Derivatives Formula, where Z = could be:



- -Cl (Acid chloride)
- -OR, -OAr (Ester)
- $-NH_2$, -NHR (Amide)

Properties of Carboxylic Acids

- The carboxylic group is one of the most polar groups in biochemistry
- Both parts of the group are polar
  - -C=O
  - -O-H
    - –O-H is so polar, it is nearly ionic bond



- Presence of carboxylic group:
  - increases the solubility in water
    - Solubility decreases rapidly as MW increases.
  - Adds acidic character

Acidity of Carboxylic Acids

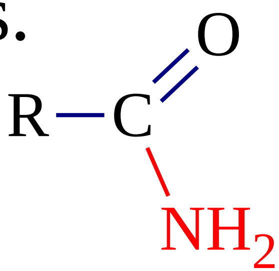
- All carboxylic acids are weak acids.

$$R-COOH \rightleftharpoons R-COO^{-} + H^{+}$$

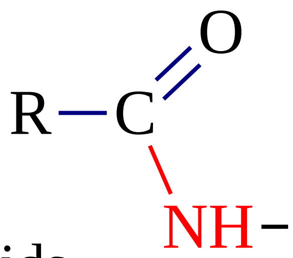
  - They can ionize into H^+ and an anion.
    - Addition of strong acids drive the reaction to the right
  - Carboxylic acids occur largely as their anions in living cells and body fluids.
  - The carboxylates are salts, example, sodium acetate .

Amides

- One of the important bonds in Biochemistry
  - Amides are derivatives of carboxylic acids.



- General formula:
  - Can be prepared from acids
    - + ammonia → simple amides
    - + amine → Substituted amides
      - Peptide bond is an amide bond between amino acids



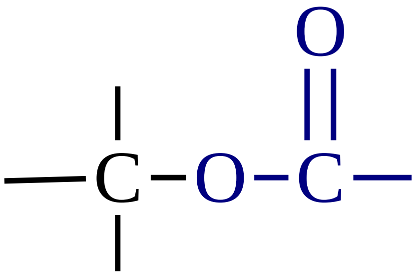
- The C-N bond is the amide bond.
  - One of the strongest bonds in biochemistry .
  - It can be broken but require strong acid or base + high temperatures.

Amide Properties

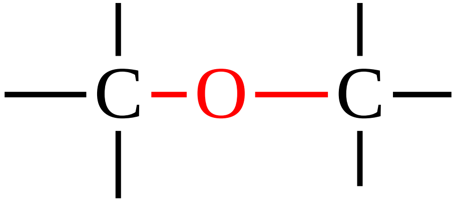
- Amide molecules are polar.
  - They can participate in H-bonding as donor or acceptor
  - The forces among simple amides are so great that all except are solids at room temperature, except methanamide (formamide).
- Amides are NOT basic molecules.
  - The amine group of amide can not accept protons or get ionized
  - They are neutral in an acid-base sense.

Remember; Amines are basic groups. But Amides aren't

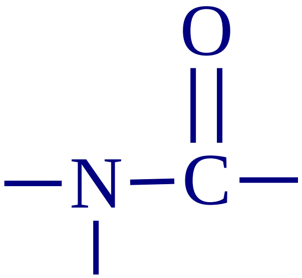
Common Linkages in biochemistry



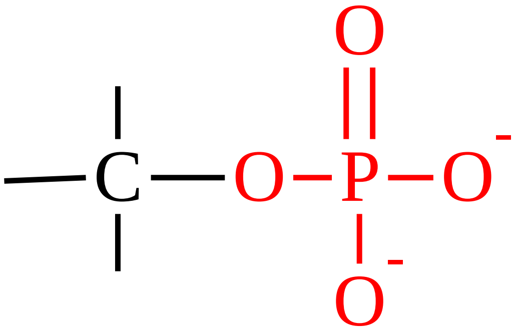
Ester



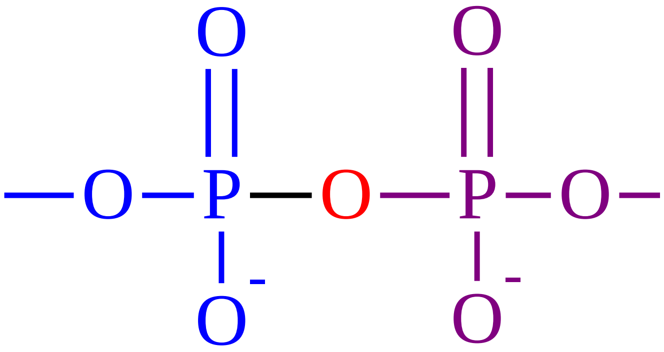
Ether



Amide

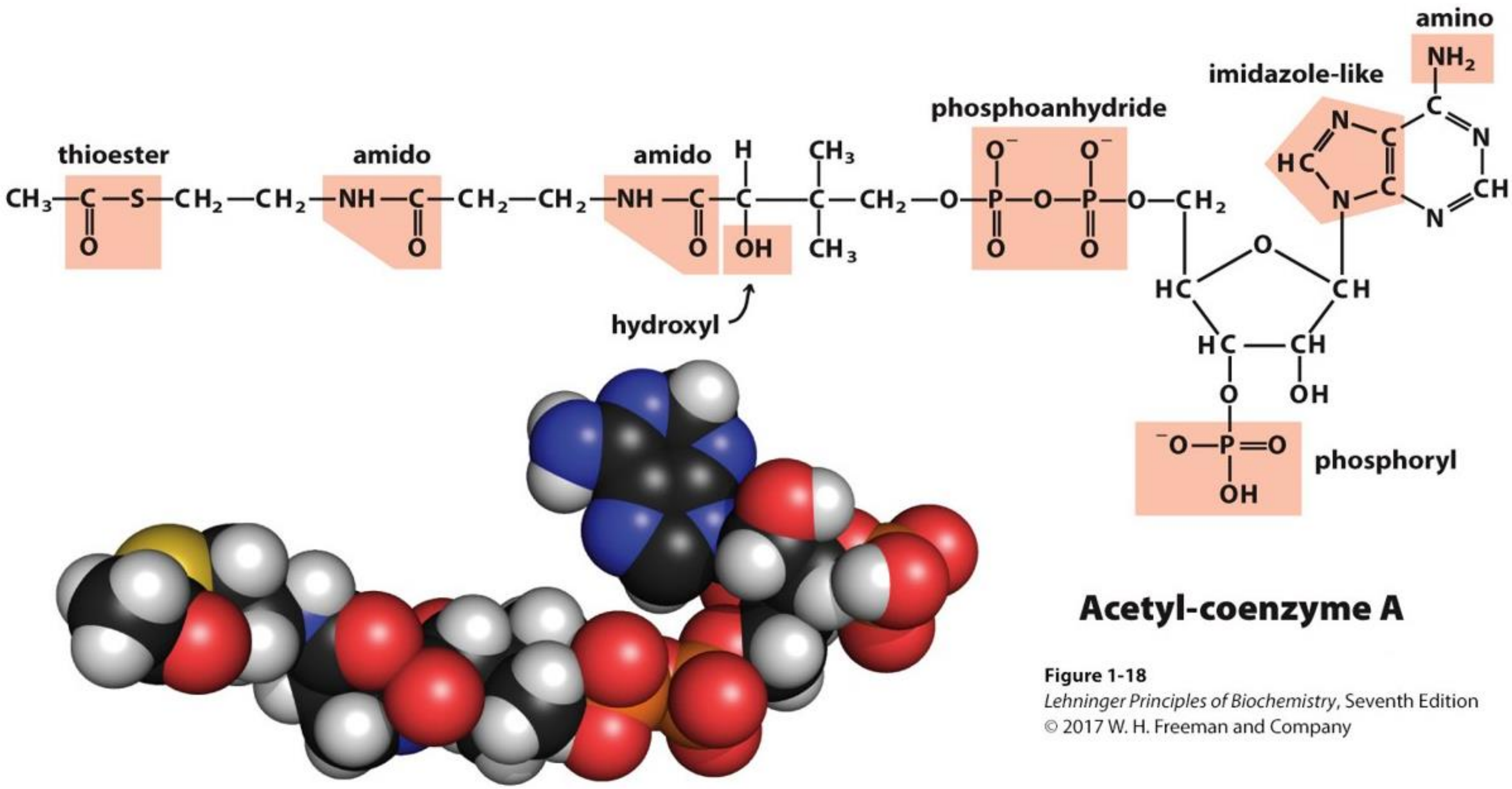


Phosphate Ester



Phosphodiaester
(phosphoanhydride)

Biological Molecules Typically Have Several Functional Groups



Acetyl-coenzyme A

Figure 1-18
Lehninger Principles of Biochemistry, Seventh Edition

Several common functional groups in a single biomolecule. Acetyl-coenzyme A (often abbreviated as acetyl-CoA) is a carrier of acetyl groups in some enzymatic reactions. The functional groups are screened in the structural formula. As we will see in Chapter 2, several of these functional groups can exist in protonated or unprotonated forms, depending on the pH. In the space-filling model, N is blue, C is black, P is orange, O is red, and H is white. The yellow atom at the left is the sulfur of the critical thioester bond between the acetyl moiety and coenzyme A.

The ABCs of Life

The organic compounds from which most cellular materials are constructed: the ABCs of biochemistry. Shown here are (a) six of the 20 amino acids from which all proteins are built (the side chains are shaded pink); (b) the five nitrogenous bases, two five-carbon sugars, and phosphate ion from which all nucleic acids are built; (c) five components of membrane lipids; and (d) D-glucose, the simple sugar from which most carbohydrates are derived.

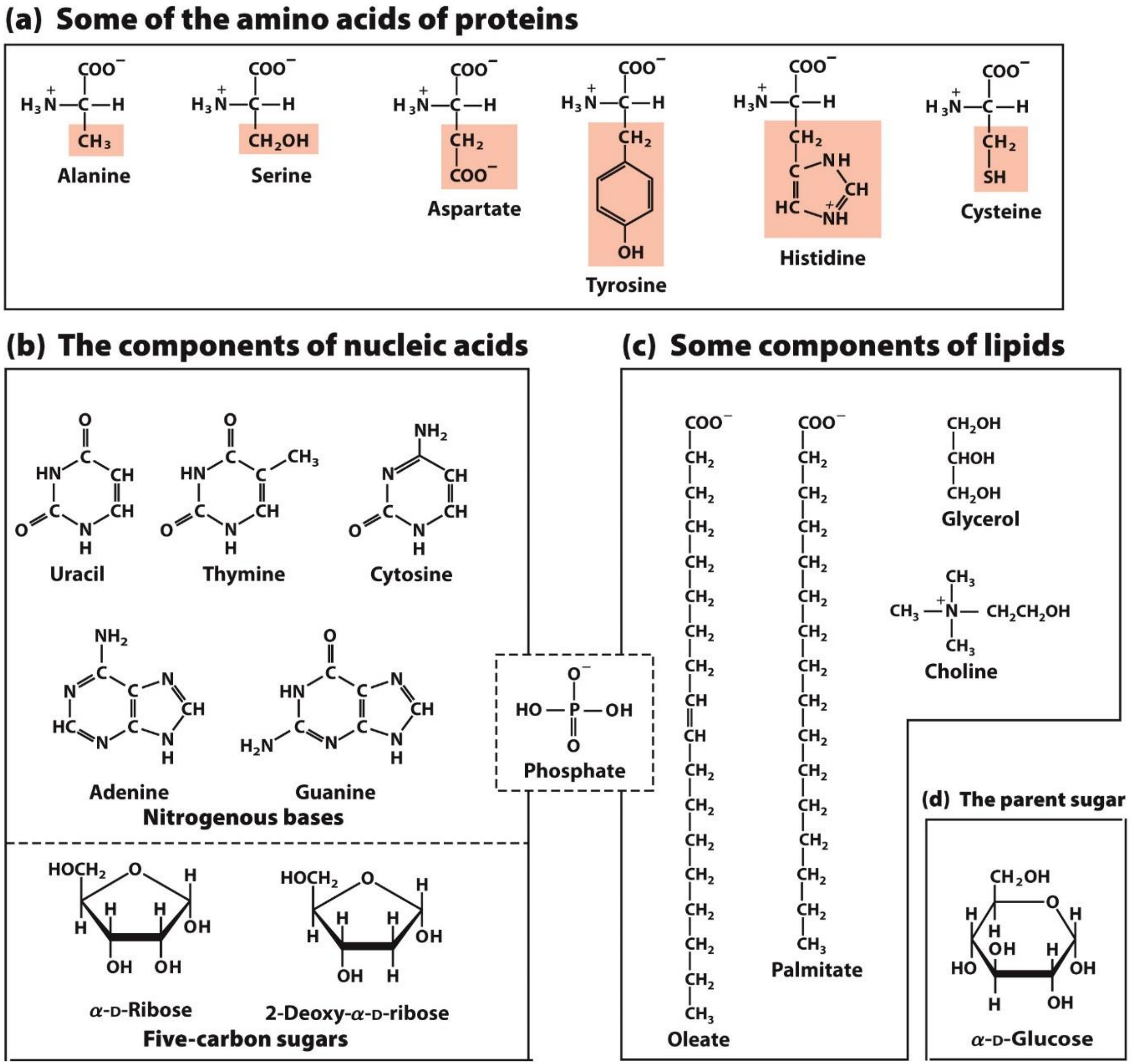


Figure 1-11
Lehninger Principles of Biochemistry, Seventh Edition

Organisms Perform Energy Transductions to Accomplish Work to Stay Alive

Some energy transformations in living organims. As metabolic energy is spent to do cellular work, the randomness of the system plus surroundings (expressed quantitatively as entropy) increases as the potential energy of complex nutrient molecules decreases.

(a) Living organisms extract energy from their surroundings;

(b) convert some of it into useful forms of energy to produce work;

(c) return some energy to the surroundings as heat; and

(d) release end-product molecules that are less well organized than the starting fuel, increasing the entropy of the universe. One effect of all these transformations is

(e) increased order (decreased randomness) in the system in the form of complex macromolecules.

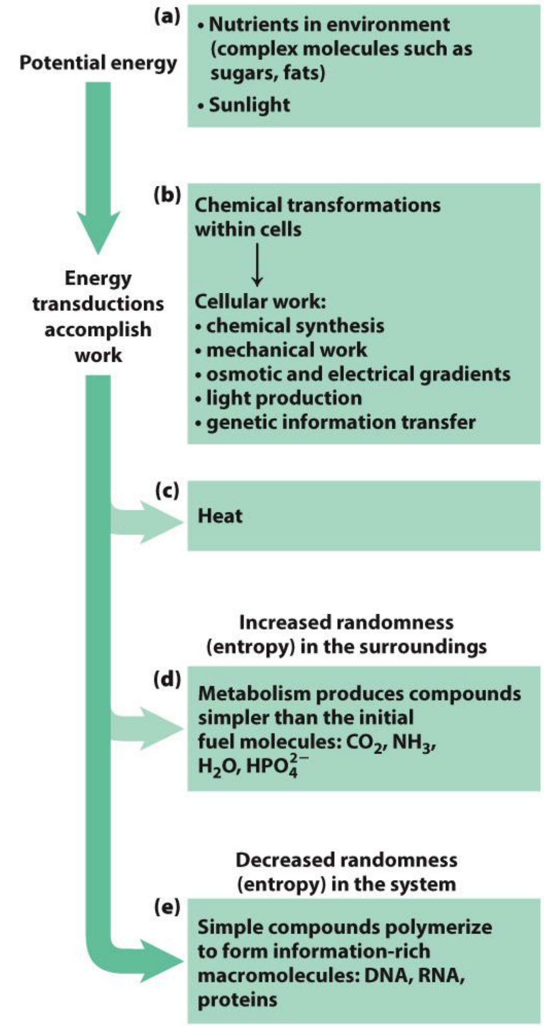


Figure 1-26
Lehninger Principles of Biochemistry, Seventh Edition

How to Speed Reactions Up

Higher temperatures

– stability of macromolecules is limiting

Higher concentration of reactants

– costly, as more valuable starting material is needed

Changing the reaction by coupling to a fast one

– universally used by living organisms

Lower activation barrier by catalysis

– universally used by living organisms

Quiz

Answer by marking true (T) or False (F)

1.H_2O can function as an acid or a base .... ( )

2.The structure of H_2O is a linear molecule .... ( )

3.Phenols act as a weak acid as it gives protons to a strong base .... ( )

4.Sulpher is less electronegative than Oxygen .... ( )

5.An acid is a substance that can accept a proton .... ( )