Advanced Biology: ***Biological Chemistry - Notes on Organic Compounds***
Chapter 4 (Sections 4.1 & 4.2, pages 58-63) and Chapter 5 (pages 68-87)

When studying the chemistry of living organisms, we focus on **organic compounds**, molecules made or obtained by living cells that **contain carbon atoms** bonded to hydrogen atoms. *Carbon's 4 valence electrons make carbon atoms capable of forming a diverse array of covalently bonded molecules* that are well suited to performing the many life-sustaining functions within cells. **(4.2, pp. 60 – 63)**

The organic compounds are divided into 4 categories: **carbohydrates, lipids, proteins, and nucleic acids**.

Carbohydrates (Section 5.2; pages 69-74)
Molecules that contain carbon, hydrogen, and oxygen in a ratio of 1:2:1 – $\mathbf{C_6H_{12}O_6}$ for example

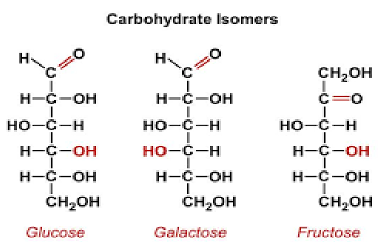
- Carbohydrates function as *energy storage molecules* as well as *structural molecules* within cells.

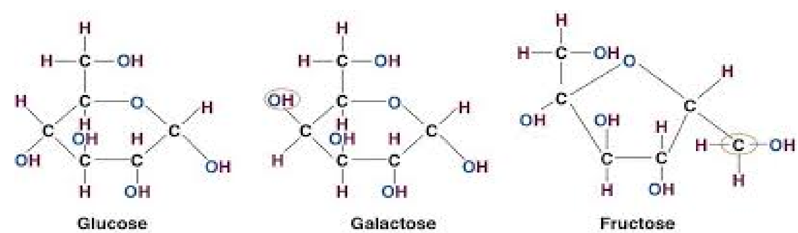
a) **Monosaccharides**: "simple sugars" consisting of 3 - (more commonly) 6 carbon atoms: $\mathbf{C_6H_{12}O_6}$

- ex: glucose, fructose, galactose

Monosaccharides serve as *immediate energy sources within cells*, and as building blocks for larger carbohydrate molecules.

Within cells, monosaccharides form ring structures, shown below:





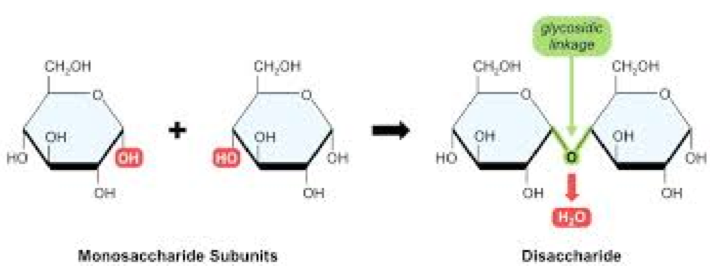
See **this short video,** *Hydrolysis & Dehydration Synthesis*

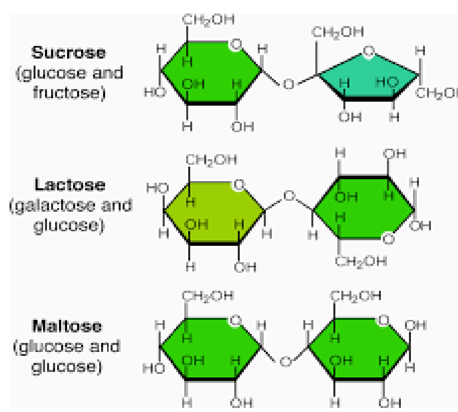
b) **Disaccharides**: pairs of monosaccharides bonded together (by "condensation" / "dehydration" reactions)

- ex: sucrose (table sugar), maltose, lactose

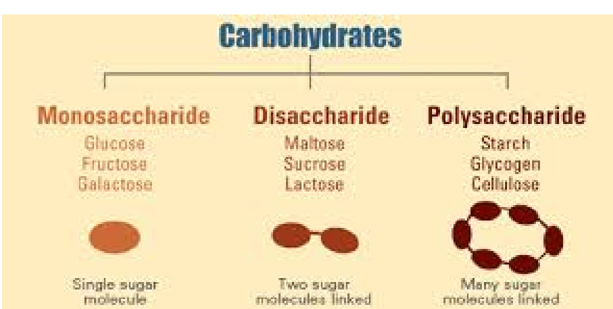
Disaccharides function to *transport carbohydrate energy around the bodies of plants and animals*.
At their cellular destinations, disaccharides can be "hydrolyzed" into their monosaccharide building blocks.

Note the condensation / dehydration reaction below:





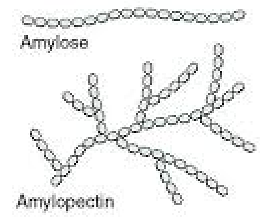
Above are examples of disaccharides.



c) **Polysaccharides**: many glucose monosaccharides bonded together for *long-term energy storage* or for *structural molecules* within or outside cells.

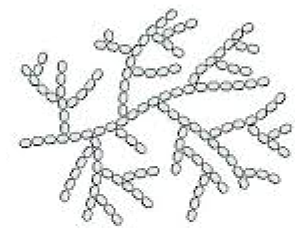
Polysaccharides are discussed in more detail below.

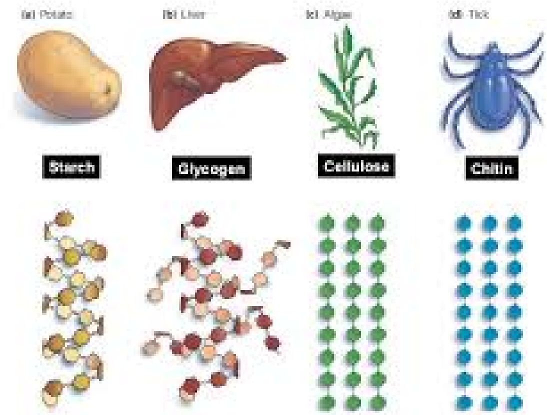
c) **Polysaccharides** (continued): In plants, polysaccharides are mostly linear molecules known as **starches**. Linear molecules are more easily metabolized by enzymes within cells, providing quick sources of energy.



Starch

In animal cells, polysaccharides are found in the more branched form of **glycogen molecules**. Branched molecules take longer to metabolize, thus allowing longer storage of energy for these heterotrophs, whose food supplies are less regular than those of autotrophs.


Glycogen



Additional polysaccharides also function as *structural molecules* in the cells of some organisms. These large molecules include **cellulose** - the most abundant organic compound on earth - in the cell walls of plant cells, as well as **chitin**, found in the exoskeleton of arthropods such as insects, arachnids, and crustaceans.

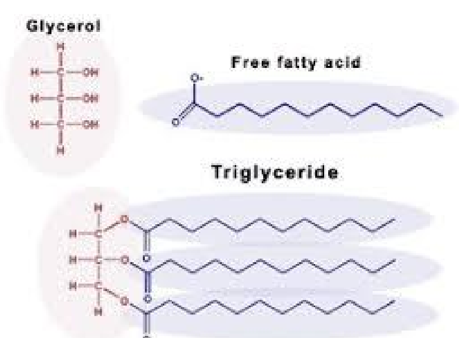
This carbohydrate video provides a helpful summary.

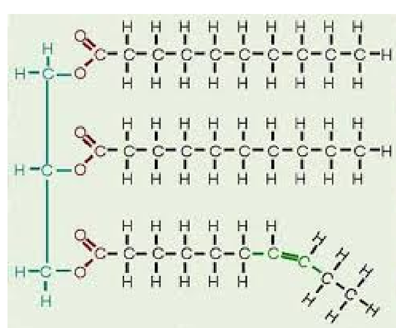
Lipids (Section 5.3; pages 74-77)

Lipids are defined as "hydrophobic" organic compounds that are *nonpolar*, and therefore dissolve poorly in water. See **this brief video: Oil & Water**

These **fats and oils** (among other molecules) serve two primary functions: *the long-term storage of energy* (even longer than more "hydrophilic" polysaccharides) *building the structural parts of cell membranes*.

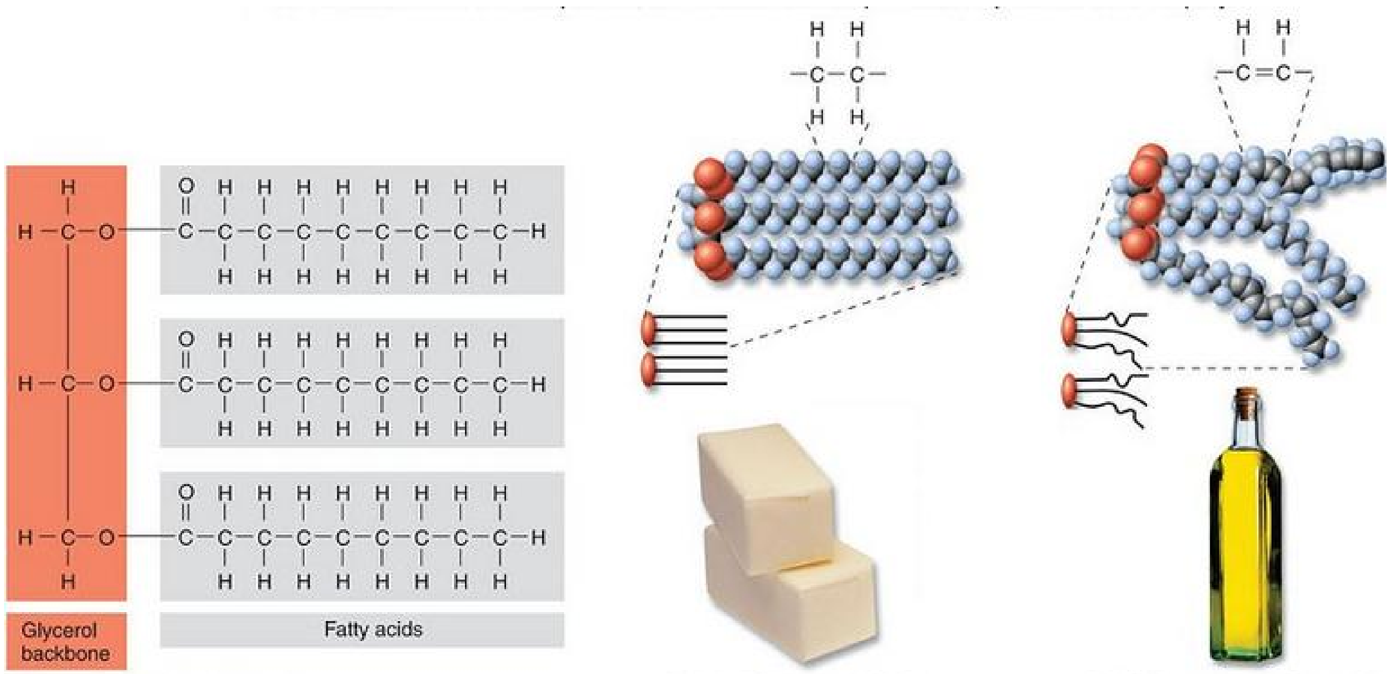
a) **Triglycerides**: these fats (lipids that are solid at room temperature) and oils (lipids that are liquid at room temperature) serve to store the energy of many C-H bonds. These large molecules are composed of 3 "fatty acid" chains, which are long hydrocarbon molecules, bonded to a 3 carbon glycerol backbone. The name **triglyceride** describes the *3 (tri-) fatty acids* bonded to the alcohol *glycerol (-glyceride)*.





Note how the top 2 fatty acids are linear, whereas the bottom fatty acid is bent. This bending is due to the presence of a double bond between carbon atoms.
Absent hydrogen atoms cause this double bond to form. This kinked fatty acid is described as ***unsaturated***.

Saturated lipids form fats, whereas unsaturated lipids form oils!
Unsaturated oils metabolize more efficiently within cells, compared to fats.
(See the additional illustration below.)



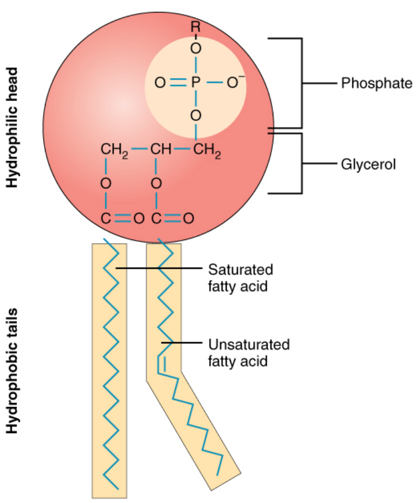
(a) Fat molecule (triacylglycerol)

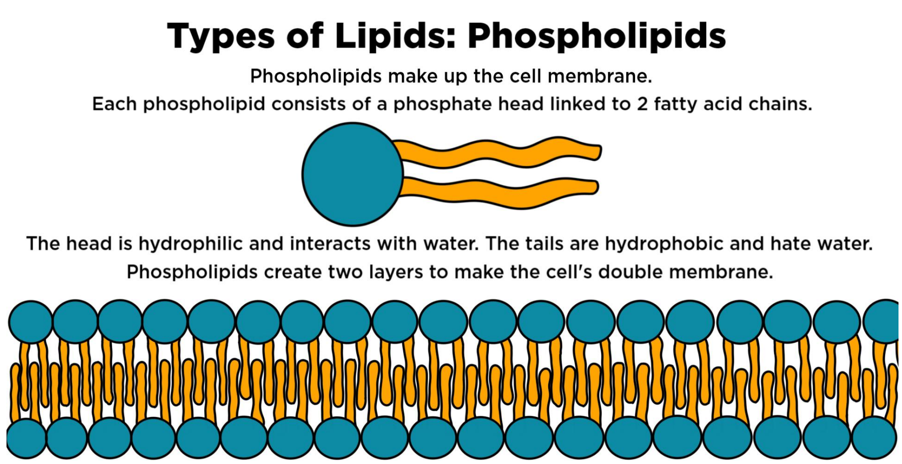
(b) Hard fat (saturated): Fatty acids with single bonds between all carbon pairs

(c) Oil (unsaturated): Fatty acids that contain double bonds between one or more pairs of carbon atoms

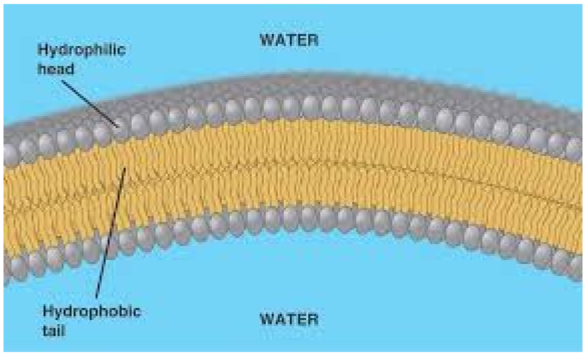
b) **Phospholipids**: these structural components of all cell membranes ensure that the membranes are not dissolved by the watery cytoplasm they contain nor by the watery environment the cell is surrounded by.

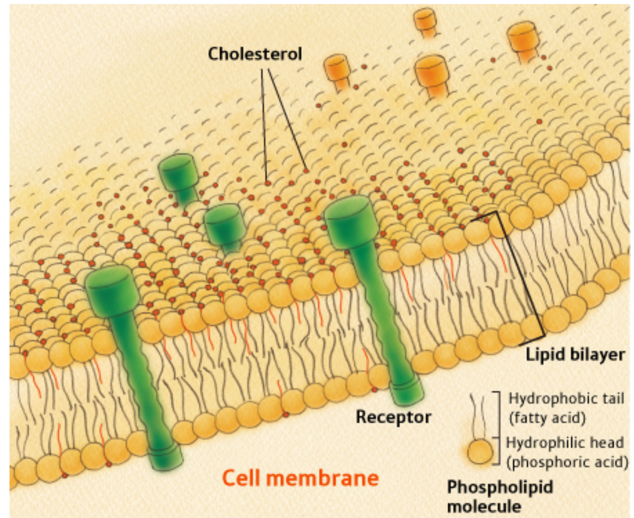
Structurally, phospholipids are similar to triglycerides, with **one of the fatty acid chains being replaced by a phosphate group (PO_4^-)**. See http://www.johnkyrk.com/cellmembrane.html for some informative imagery.



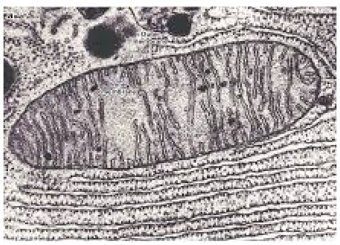


Note that the hydrophilic (water loving) heads are in close contact with water, while the hydrophobic fatty acid tails are in contact with each other, thus avoiding contact with water - and forming a cell barrier.



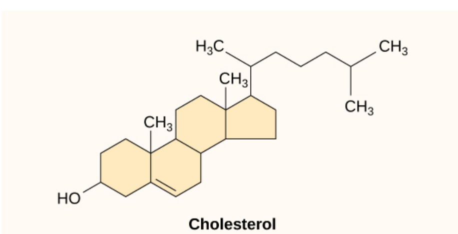


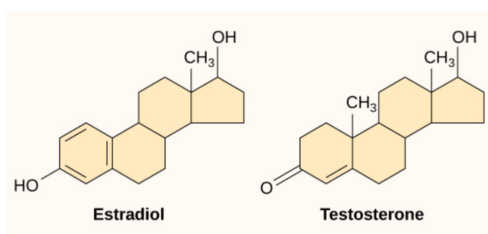
http://people.csail.mit.edu/seneff/statins_muscle_damage_heart_failure.html

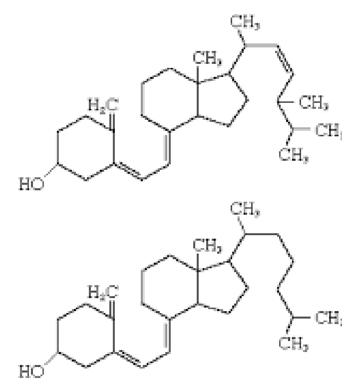


The self-assembling structure of this “lipid bilayer” makes an insoluble barrier around both the cytoplasm of the cell, as well as around the fluid within eukaryotic cell **organelles**.
Pictured to the left are a **mitochondrion** and **rough endoplasmic reticulum**.

Other lipids in cells and membranes include **steroids**. Steroid molecules are classified as lipids because these organic molecules are hydrophobic. All steroids share a common carbon skeleton consisting of 4 “rings.” The functional groups attached to these rings determine the role of each particular steroid.







(Top) Vitamin D_2; (bottom) Vitamin D_3

The most common example of a steroid is **cholesterol**.
Not only is cholesterol an important part of cell membranes in animal cells, this steroid is used to synthesize other steroids, such as the sex hormones estrogen, progesterone, and testosterone, as well as Vitamin D and other important metabolic molecules.

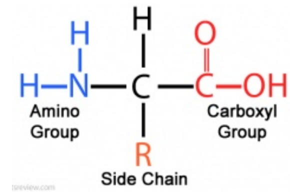
Because **waxes** are also organic, hydrophobic molecules, **waxes are also classified as lipids**.

Proteins (Section 5.4; pages 77-86)

a) Structure: ***proteins are chains (polymers) of amino acid monomers.***

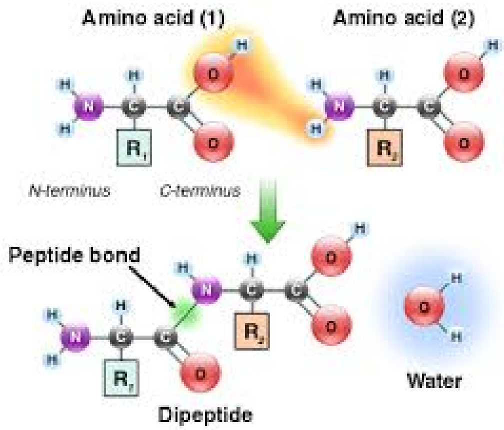
- Proteins are chains (polymers) of amino acid monomers.

All amino acids share an amino group, a central carbon atom, an acid group, and one of 20 side chains known as "R" groups.



(Acid Group)

(20 unique "R" groups account for 20 amino acids.)



Proteins are also formed by dehydration reactions, in which water is released as amino acids are linked. The bond linking amino acids is known as a **peptide bond**. Peptide bonds form between the acid group's carbon of one amino acid and the amino group's nitrogen of the next amino acid.

Since 20 unique amino acids exist within cells, and our genetics can encode any sequence of these amino acids to be assembled to any length, **proteins are by far the most diverse organic family**, both structurally and therefore functionally.

Proteins are referred to as **polypeptides**, since proteins are chains of amino acids with many peptide bonds.

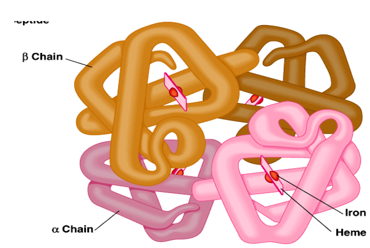
Biologists attempt to understand the structure of proteins by examining **4 levels of protein structure**.
Examine **Fig. 5.20 on pages 82 & 83** as well as at http://lectures.molgen.mpg.de/ProteinStructure/Levels/index.html and our text's online activity devoted to this important concept.
See also What is a Protein? Learn about the 3D shape and function of macromolecules

To summarize, **primary (1°) structure** refers to *the amino acid sequence of a protein*, discussed above.

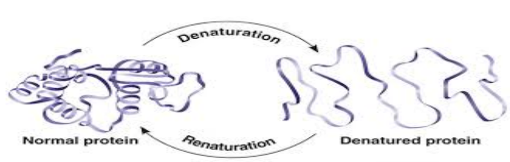
Secondary (2°) structure describes *the shapes of sections of a protein*. These are the folds and twists within regions of the overall structure of the protein. Hydrogen bonds maintain secondary structure within a protein.

Tertiary (3°) structure describes *the overall shape of the protein*. This tertiary structure is controlled by the different interactions between the R groups within the protein. See Video - The Levels of Protein Structure and Video: Visual Representation of Levels of Protein Structure for an appreciation of protein structure within cells.
All proteins possess these first 3 levels of protein structure.

Finally, **Quaternary (4°) structure** describes *the shape of a protein that is made of more than one polypeptide chain*. Only proteins that contain more than a single amino acid chain have this **4° structure**!
Hemoglobin, the oxygen carrying protein found in red blood cells, is an example of a protein with 4° structure, since it is made of four polypeptides.



A denatured protein loses its biological activity



A renatured protein regains its biological activity

b) Function: the function of each protein is determined by its folded shape ("conformation"). This shape is controlled by the sequence of amino acids making up each protein.
See **Simulating How Proteins Fold** .

A protein's functional shape can be altered if homeostatic conditions are not maintained, such as temperature, pH, & [salt].

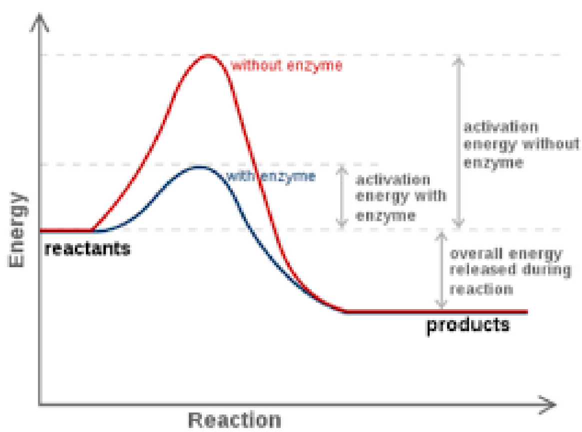
Enzymes and Chemical Reactions (Section 8.4; pages 152-157)

Of all the diverse functions of proteins, *the enzymes that accelerate the rates of the countless biochemical reactions in cells perform the most important functions of all!*

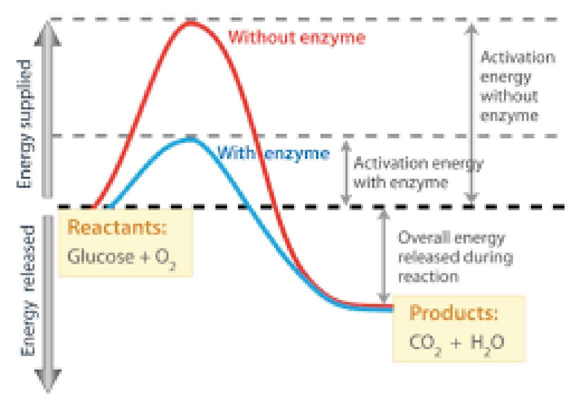
Biochemical reactions possess an “energy barrier” that must be overcome in order for these important reactions to proceed. Without the help of enzymes, the time required to overcome this barrier would be too long. Enzymes lower this barrier, known as “**activation energy**,” thereby allowing reactions to proceed swiftly and efficiently.

See the figures below to view the energetics of an enzyme-catalyzed reaction:

Below is a generic enzymatic reaction:



Below shows the enzymatic reactions of cell respiration:



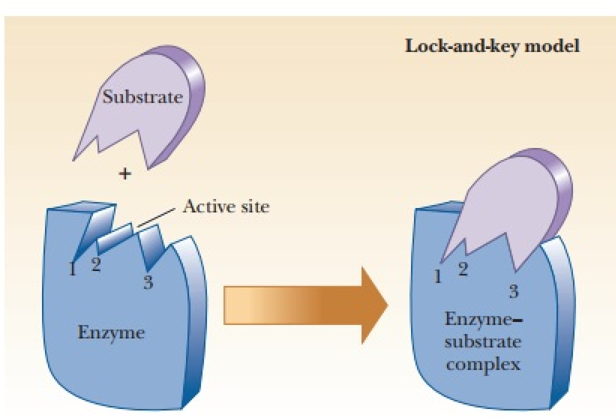
+ ATP

Note in both examples how enzyme-catalyzed reactions lower the activation energy needed for the reactions to take place! See Enzymes and Chemical Reactions

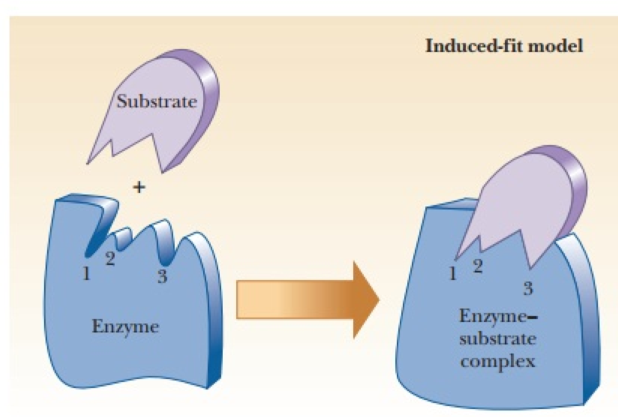
A summary of the properties of enzymes:

- ***Each enzyme is specific to the reaction it accelerates.***
- ***Enzymes speed up chemical reactions by lowering the activation energy required for the reaction to proceed.***
- ***Each enzyme emerges unchanged from the reaction it accelerates.***

Two models are used to explain how each enzyme interacts with its substrate to lower the activation energy.



A In the lock-and-key model, the shape of the substrate and the confirmation of the active site are complementary to one another.

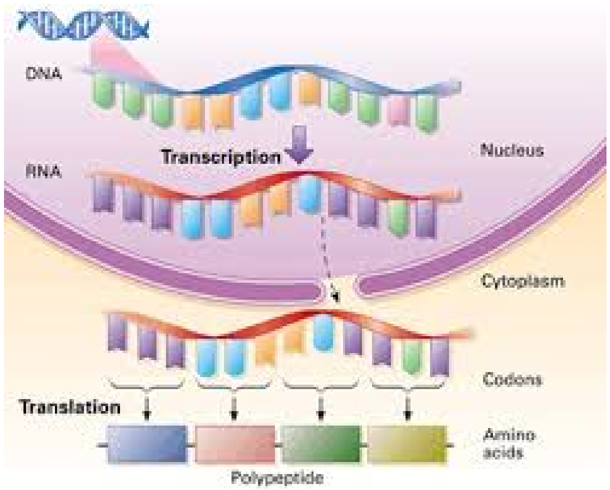


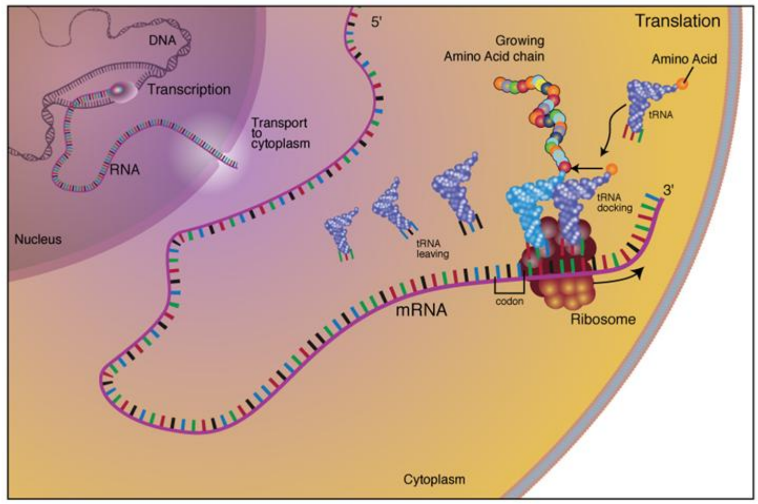
B In the induced-fit model, the enzyme undergoes a conformational change upon binding to substrate. The shape of the active site becomes complementary to the shape of the substrate only after the substrate binds to the enzyme.

[Nucleic acids](#): (Section 5.5; pages 86-88 through *"Nucleotide Polymers"*)
In our cells, nucleic acids exist as molecules of DNA and RNA.

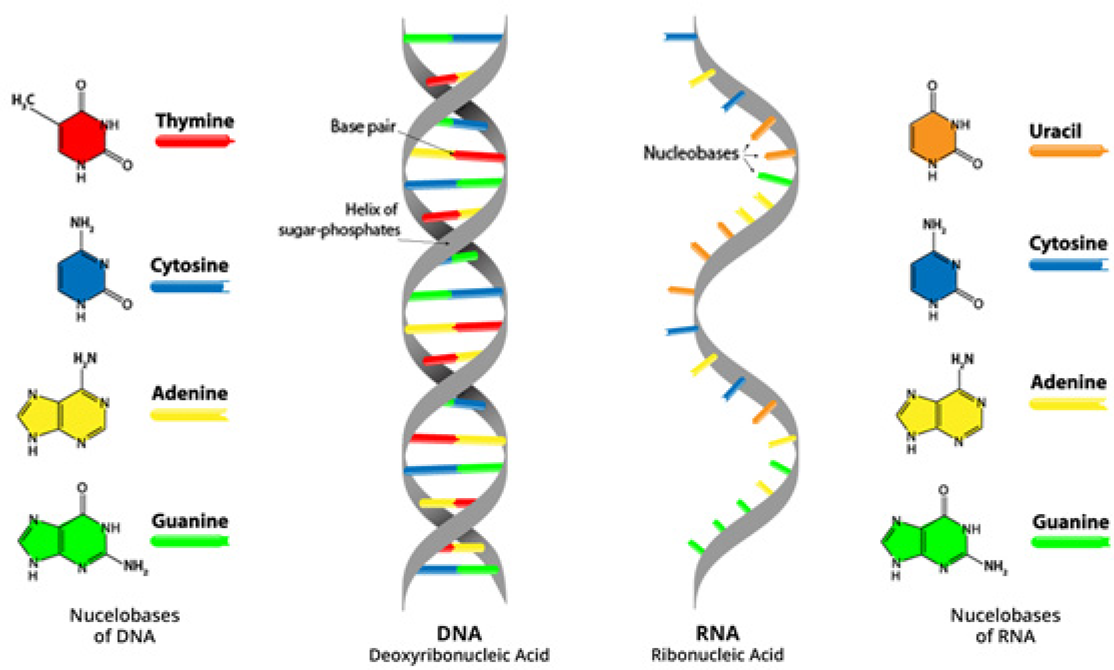
In eukaryotic cells, molecules of DNA join with proteins to form **chromatin (chromosomes)**.
Nucleic acids are the genetic material which control the sequence of amino acids that form proteins.

The diagrams below show how genetic information is coded in the nucleus as DNA, then moves into the cytoplasm as molecules of RNA, which direct the assembly of proteins by linking amino acids at ribosomes.





Structure of DNA molecules and RNA molecules:
"Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are responsible for the storage and reading of genetic information that underpins all life. They are both linear polymers, consisting of sugars, phosphates and nitrogen-containing bases, but there are some key differences which separate the two nucleic acids. These distinctions enable the two molecules to work together and fulfil their essential roles.



See [this link](#) to examine key differences between the structure and function of these two nucleic acids.
We will examine the family of nucleic acids in more detail when we study genetics later in the year.