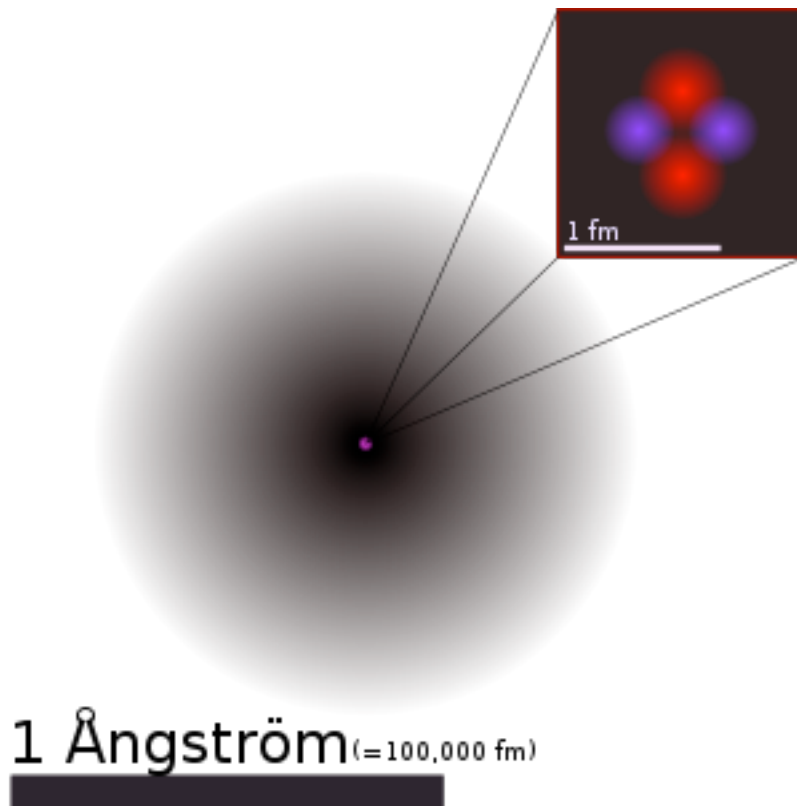


## Basic Chemistry of Life

Everything in the universe is composed of two things: matter and energy. We can never detect energy directly. We only study energy through its effects on matter.

Matter is composed of atoms. An **atom** is the smallest particles into which an element can be divided and still have the properties of that element. There are many different types of atoms called elements. According to this definition, an atom of gold is different from atoms of any other element. Elements can be combined into **molecules** that are made of two or more atoms. Molecules can be made of the same element or different elements. Oxygen ( $O_2$ ) in the air is made of two oxygen atoms chemically bonded together. If a molecule is made of atoms from two or more elements, it is called a **compound**. It follows from deductive reasoning that all compounds are molecules but all molecules are NOT compounds.

The helium atom is about 1 angstrom in diameter.



There are 88 naturally occurring elements. There are 22 more elements that are made in research laboratories. 99.9% by weight of almost any living thing is made of the six elements: **h**ydrogen, **c**arbon, **n**itrogen, **o**xxygen, **p**hosphorus, and **s**ulfur (backwards using just the letter abbreviations this spells SPONCH). Many other elements occur in small (e.g. iron, Fe) or trace (very small) amounts (e.g. copper, Cu).

Atoms are made of protons, neutrons, and electrons. If you have any hope of it stopping there, you will be disappointed. Nature is seldom simple. Protons and neutrons are each made of smaller particles, but that is for another discussion. Happily, electrons are an elementary particle. Elementary means (to a physicist) it is made of nothing else...it is what it is.

A **Proton** is a positively charged particle with a mass of a little more than one atomic mass unit.

A **Neutron** has no charge and a mass of a little more than one atomic mass unit (weighs almost the same as a proton).

An **electron** is a negatively charged particle with an atomic mass of about 1/1800th of a proton...they have such little mass that we usually ignore their masses.

Particles of the same charge will repel each other.  
Particles with opposite charges...protons and electrons, will attract each other.

Protons and the electrically neutral neutrons make up the center or **nucleus** of an atom and we call them nucleons because of where they often are located. The electrons occur in energy levels sometimes called shells moving around the nucleus; they are held there by the attraction of oppositely charged particles. Electrons are the creators of light. When they are excited to higher levels of energy, they will return to their "ground state" and in doing so give birth to a photon. Almost all the light we encounter is from this creation.

The **Atomic Number** of an element is the number of protons in the nucleus of an atom of a given element. Since hydrogen has only a single proton in its nucleus, its atomic number is 1. Helium is 2 and Lithium is 3. In a neutral atom, the number of protons is balanced by an identical number electrons; therefore "neutral" atoms have no net charge because the positive protons are balanced by the negative electrons.

The **mass number** (I do not like this term but I have to live with it) of an element is the sum of the protons and neutrons in a nucleus. The total number of nucleons of an atom is the mass number. IT IS NOT THE MASS OF AN ATOM.

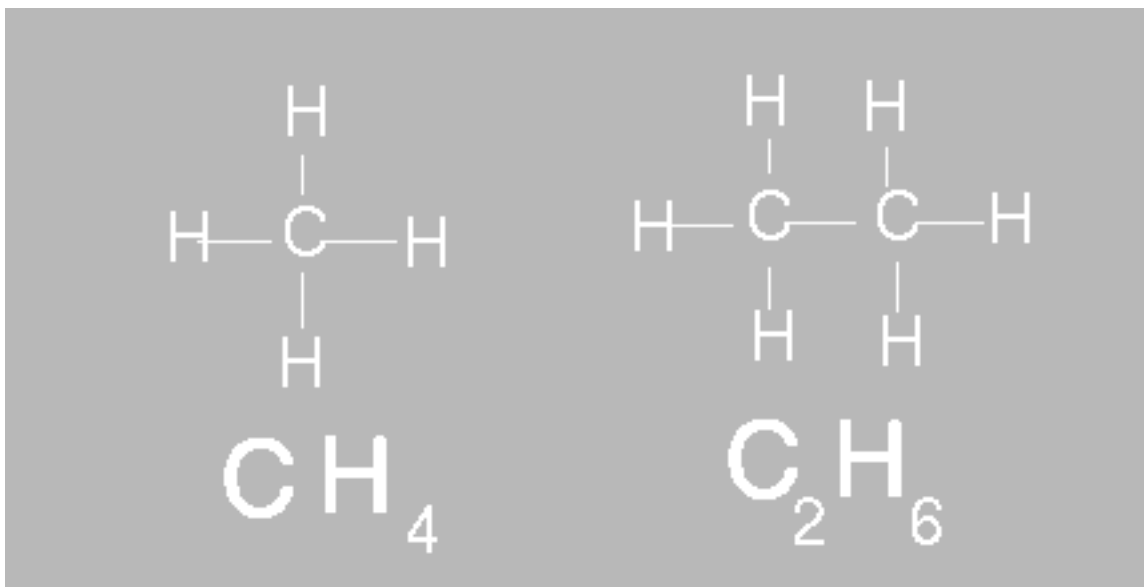
The **atomic mass unit**, abbreviated amu, is used for the mass of atoms since they have such small masses that most other units such as grams would be cumbersome. The amu is defined by assigning a mass of 12 to the carbon-12 atom.  $1 \text{ amu} = 1.66054 \times 10^{-24} \text{ grams}$  Chemistry. The amu has no units since it is based on  $1/12^{\text{th}}$  of a carbon-12 isotope.

**Isotopes** of an element differ in the number of neutrons in the nucleus. For example, Hydrogen has 3 naturally occurring isotopes. H-1, H-2 and H-3. H-1 has a mass number of 1 because it has 1 proton. H-2 has a mass number of 2 because it has 1 proton and 1 neutron and H-3 has 1 proton and 2 neutrons.

**Ions** are atoms that do not have a balance of charged particles...electrons and protons. For example, the calcium in our bodies is most often found as a divalent cation...very fancy name for an ion with 2 positive charges (written as  $\text{Ca}^{++}$  or  $\text{Ca}^{2+}$ ). Sodium is often found as a monovalent cation (written as  $\text{Na}^+$ ) ...1 positive charge. Chlorine exists often as a monovalent anion (written as  $\text{Cl}^-$ )

**ORGANIC MOLECULES**  
(organic molecules are the molecules of life)

**ALL BASED ON CARBON BECAUSE CARBON CAN MAKE 4  
BONDS**



The C in the figure above represents the atom carbon. A solid line represents a stable chemical bond called a covalent bond...but we will just call it a bond for now. The figures represent the same two chemicals in two different ways. The formula that shows the bonds as lines and what atom is connect to what are called "structural formulas because from the formula you can see how the atom's are attached to each other. The lower formulas are called condensed formulas and do NOT show how the atoms are arranged in a structure. Condensed formulas are easier to write but less informative. In some cases a single condensed formula can represent many different molecules...more on this later.

Some nomenclature first:

NOMENCLATURE is a fancy word for how things can be named.

Nomenclature in science is very exact to keep confusion to a minimum. You are familiar with nomenclature for living organisms. An animal is given a genus and species. This is a nomenclature for living things. Scientists have given a genus and species name to every living thing we have discovered. *Homo sapiens* is the genus and species nomenclature for humans. Can you guess what animal *Felis domestiucus* is?

Now to the nomenclature for carbon (organic) molecules.

The prefix of a carbon molecule depends on how many carbons are in the molecule.

Prefixes:

1 carbon...meth-  
2 carbon...eth-  
3 carbon...prop-  
4 carbon...but-  
5 carbon...pent-  
6 carbon...hex-  
7 carbon...hept-  
8 carbon...oct-

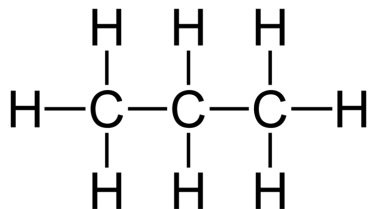
The suffix of a carbon molecule is based on whether the molecule has one or more double or triple bonds between carbon atoms.

Suffixes:

-ane...only single bonds  
-ene...contains a double bond  
-yne...contains a triple bond

Let's combine the prefix rule and suffix rule:

Propane...has three carbons and all single bonds among the carbon atoms.



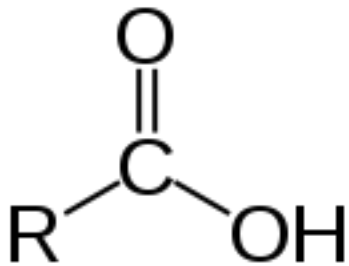
can you draw the condensed formula for propane?

Remember...Polar molecules have positive and negative charges and are therefore attracted to water molecules because water molecules are also polar. They are said to be **hydrophilic** because they interact with (dissolve in) water by forming hydrogen bonds.

Now we have a foundation to move to the four classes of biomolecules. These biomolecules behave in certain ways not only because of their carbon structure but also because of what are called functional groups.

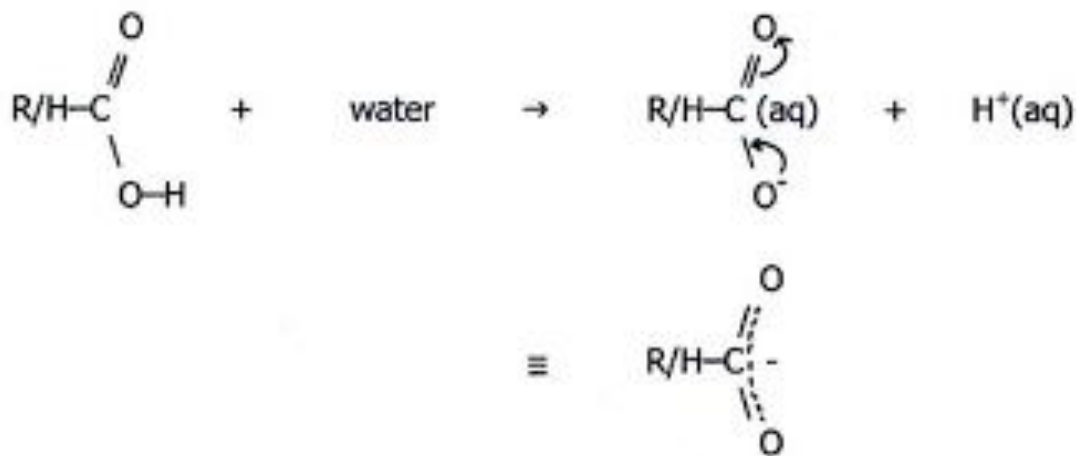
Functional; groups are groups of atoms that when found in molecules give those molecules a certain characteristic. For example, any molecule with an acid group will have the potential to act like...you guessed it...an acid. See how logical science is.

This is the functional group called an acid group. Since it is an acid group with carbon it is often called a carboxylic acid group. The capital letter R in the structural formula represents whatever the acid group is attached to.



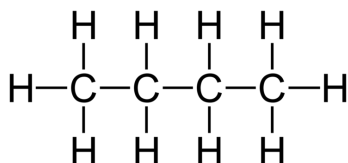
## IN WATER...THE REAL WORLD

Acid group will lose their hydrogen (proton) to the water. And the acid group is then charges and polar.

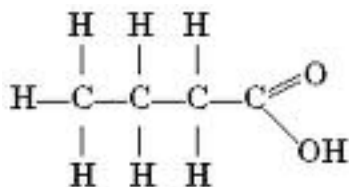


We can now see how an acid group will lend a certain characteristic to a molecule.

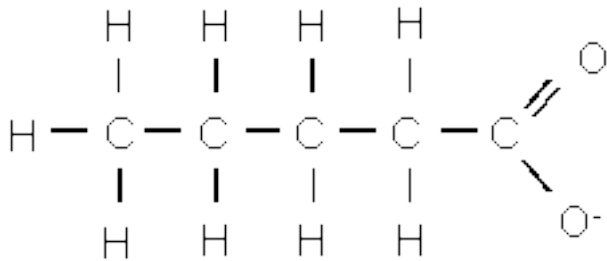
The molecule immediately below is a butane molecule.



Below, we have attached the acid group to a butane molecule.

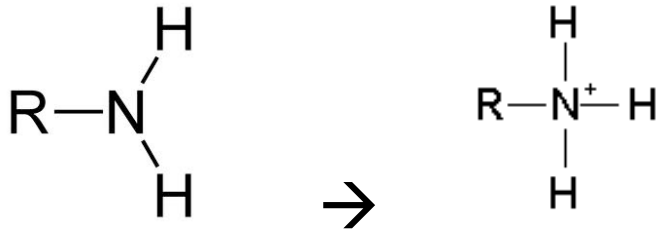


When we put it in water it becomes ionized by losing a proton (a hydrogen).  
IS THIS POLAR???????

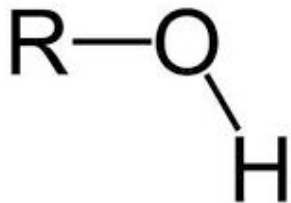


Here are some other important functional groups (remember what the R stands for?):

Amino group when placed in water becomes ionized by taking up a proton (hydrogen nucleus from the water)



Alcohol (or hydroxyl) functional group





# METABOLISM

## The buildup and breakdown of biological molecules (anabolism and catabolism)

Before we study the detail of metabolism, we must review the structure and functions of biomolecules...most importantly the first three of the following four:

### FOUR CLASSES OF BIOMOLECULES (ALL ORGANIC MOLECULES)

1) CARBOHYDRATES 2) LIPIDS 3) PROTEINS 4) NUCLEIC ACIDS

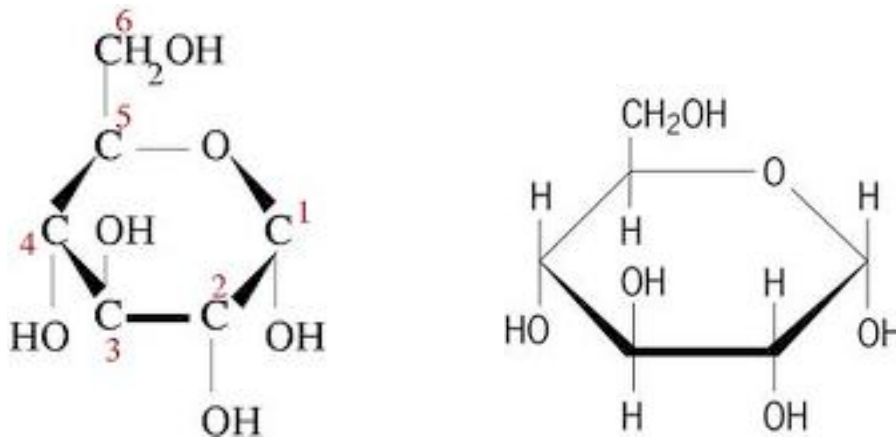
### 1) Carbohydrates

During photosynthesis, water ( $H_2O$ ) is combined with Carbon from the  $CO_2$  in the air to form CARBO, HYDRATES (when you drink water you get “hydrated”). Adding water to carbon hydrates the water.

1. **Carbohydrates** (carbon-water) are the most abundant organic compounds (things made of carbon and hydrogen and often some oxygen) on Earth.

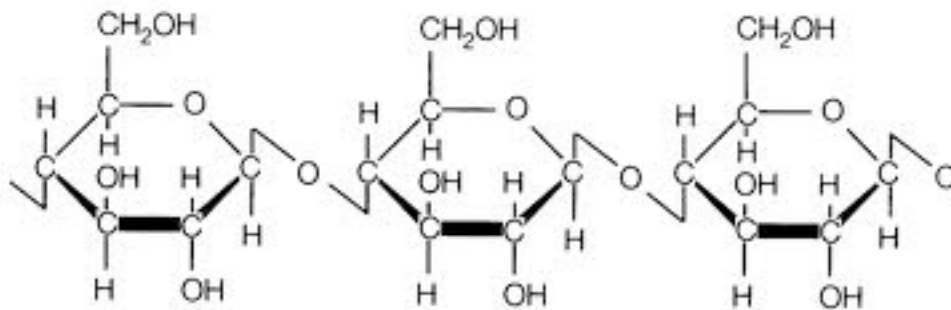
Carbohydrates have carbon and the two elements of water (H and O).

The simplest carbs are single sugar molecules called monosaccharaides. A common single sugar is glucose. Glucose is called a ring structure...guess why?

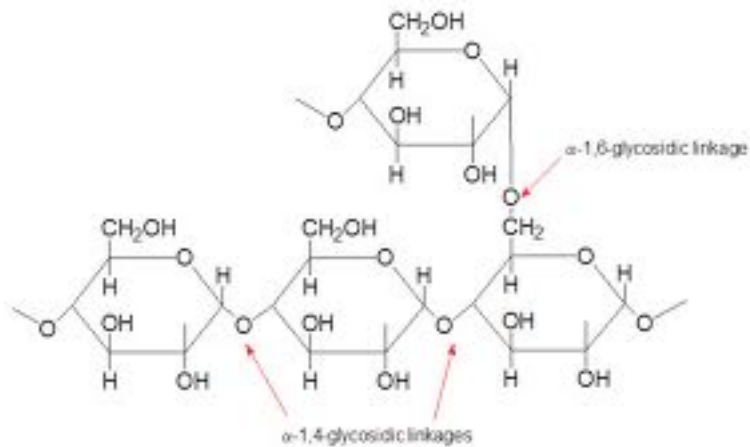


The left formula shows the carbons. The right formula represents most of the carbons as corners in the drawing. Note that the condensed formula for glucose is  $C_6H_{12}O_6$

When many sugars are bonded together they are called polysaccharides. Cellulose (plants are mostly cellulose) is the most common polysaccharide (a very big carbohydrate) by weight. Cellulose is a polymer of glucose monomers. Cellulose functions as a structural support molecule in plants but is a food source for many primary consumers and herbivores.



The most common carbohydrate or monosaccharide in mammals is glucose (from the Greek word glukus meaning sweet), which has the chemical formula  $C_6H_{12}O_6$ .



Fructose (also a  $C_6H_{12}O_6$ ) is a common monosaccharide in fruits (and does not promote tooth decay... so eat lots of fruits).

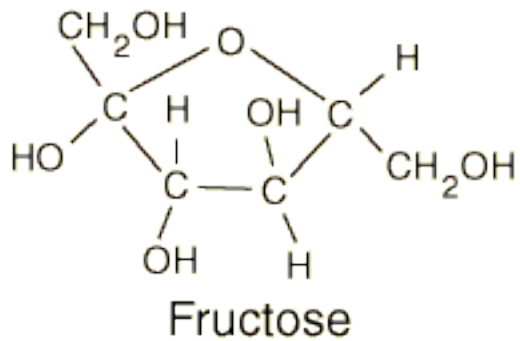
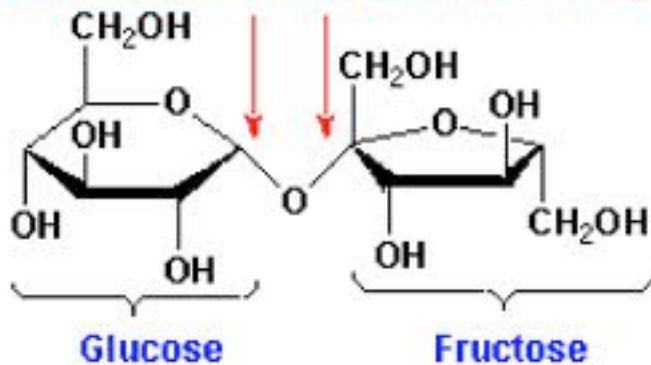


Table sugar or sucrose is a **disaccharide** made of two simple sugars (glucose and fructose bonded together).

## Sucrose

**$\alpha$ -Glucosidbinding  $\beta$ -Fructosidbinding**

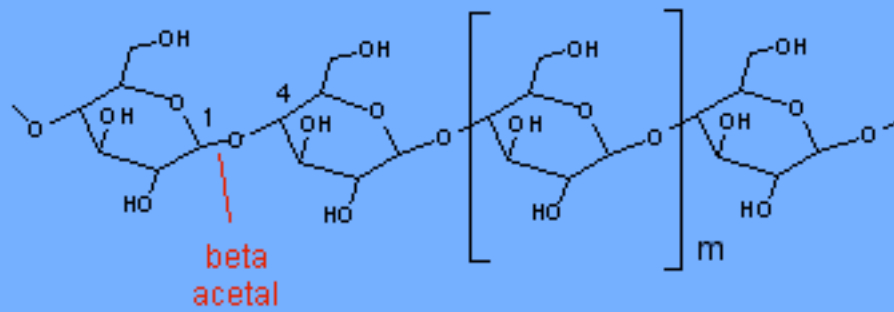


MTJ 5/10,00

Polysaccharides are carbohydrates made of up to thousands of individual sugar molecules (monomers) bonded together in one massive molecule. Starch, glycogen and cellulose are all polysaccharides made of monomers of glucose linked together in slightly different ways.

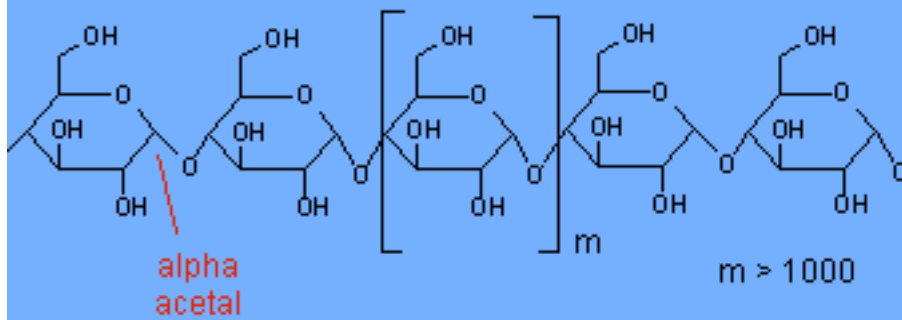
The figure below shows chemical models of the cellulose and starch molecules. Each hexagonal section represents a glucose monomer. The brackets with the subscript indicate that there are commonly between up to 26,000 glucose monomers in the cellulose molecule and often more than 1,000 glucose monomers in the starch molecule. NOTE that the molecules differ in the different manner in which the glucose molecules are joined.

## Cellulose



$m = 2000 - 26,000$

## Starch



$m > 1000$

C. Ophardt, c. 2003

## 2. LIPIDS (FATS AND OILS)

- include fats, oils, waxes, steroids, and phospholipids (lipids with a phosphate  $\text{PO}_4$  at one end). They function as energy storage, as waterproof coatings, and as chemical messengers. Although the term “fat” is commonly used for lipids, scientists do not use this term so loosely. Fats are solids at room temperature and oils are not...they are liquids.

There are many kinds of lipid molecules

BUT ALL LIPIDS:

-DO NOT dissolve well in water but DO dissolve in oil

-They are mostly non-polar or uncharged molecules

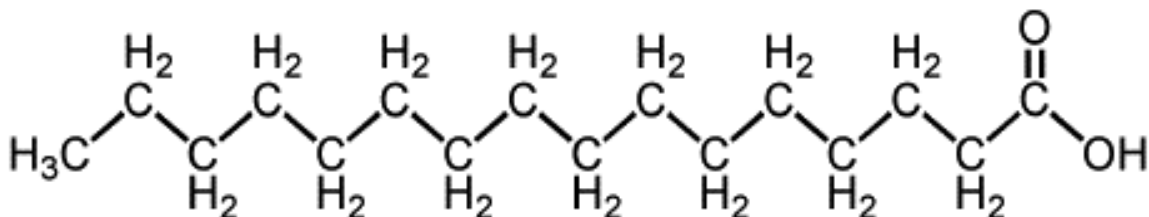
(LIKE DISSOLVES LIKE !!! Birds of a feather flock together)

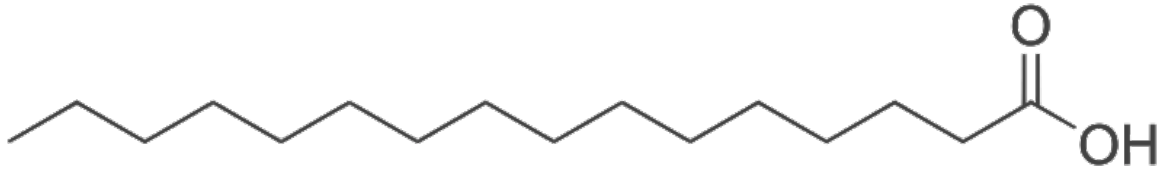
- are made of carbon atoms strung together often in long chains with an acid at the end so these very common lipids are called fatty acids. Palmitic acid is the most common fatty acid.

There are two general types of fatty acids: Saturated and unsaturated

- a) **Saturated fatty acid** (SFA or saturated fat) are those in which all the carbon atoms of the fatty acids are bonded to at least two hydrogen atoms. They form straight chain polymers in which the fatty acids are packed very closely; these include fats such as bacon fat and lard. Palmitic acid is a common SFA

PALMITIC ACID  $\text{C}_{16}\text{H}_{32}\text{O}_2$

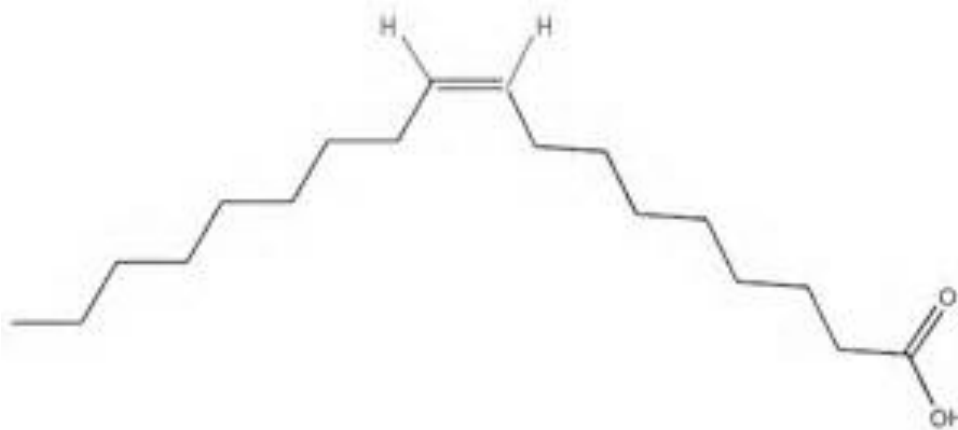
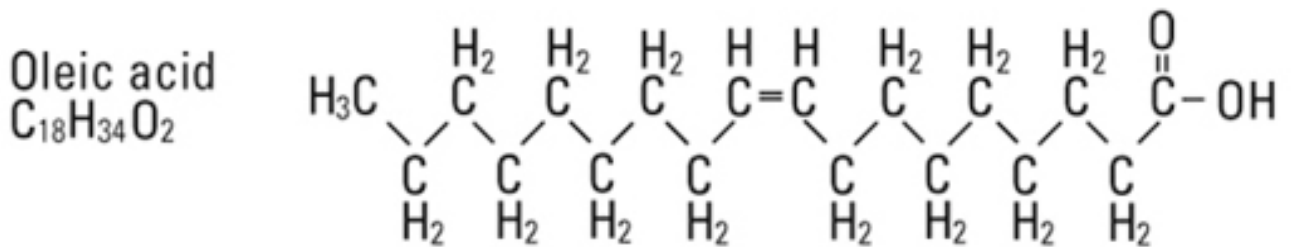




hydrocarbon tail HATES WATER  
non-polar, hydrophobic, lipophilic

acid part LIKES WATER  
polar and hydrophilic

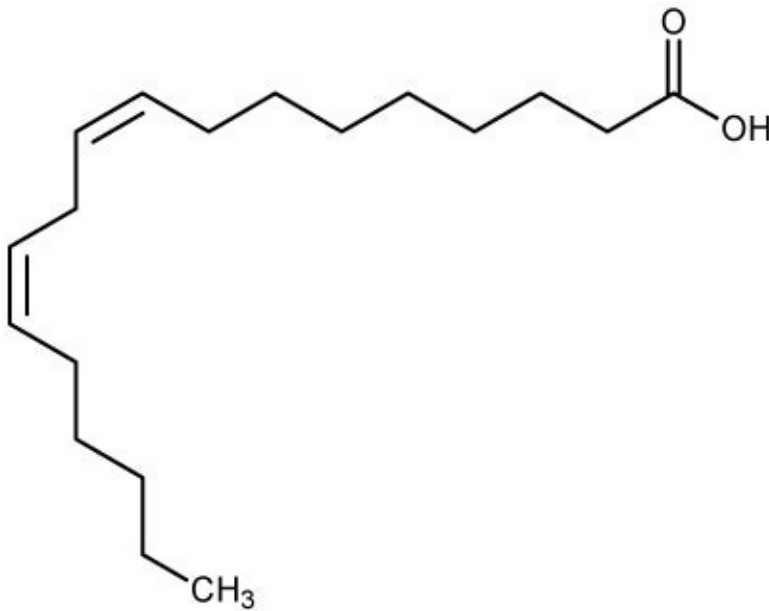
- b) **Unsaturated fats** (UFA's) are those two adjacent carbon atoms on the fatty acids that share a double bond and therefore have fewer hydrogens. They cannot pack as tightly as saturated fats. At normal temperatures they are liquids (These are the oils). Polyunsaturated fats (PUFA's) have even more of these double bonds.



As you can see from the structural formulas of palmitic and oleic acids, the oleic has a kink in it formed by the double...unsaturated bond. This results in the molecules of oleic acid to pack less densely and be more fluid (an oil) ...less solid than the palmitic which is less fluid and more solid (fat) at room temp.

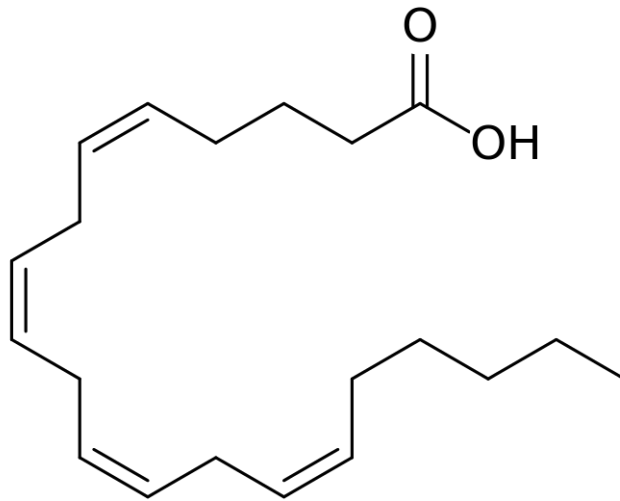
### SOME COMMON FATTY ACIDS

- Palmitic  $C_{16}H_{32}O_2$  (very common in both animals and plants and is the most common lipid in milk)
- Oleic  $C_{18}H_{34}O_2$  (common in both animals and plants) (*oleum* – Latin for ???)
- Linoleic  $C_{18}H_{32}O_2$  (a fatty acid essential in the diet of humans for good health)



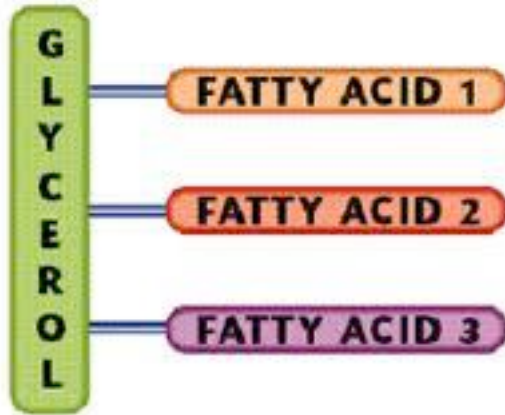


- Arachidonic  $C_{20}H_{32}O_2$  ... Arachidonic acid is a polyunsaturated fatty acid present in modified form in membranes of the body's cells, and is abundant in the brain, muscles, and liver.



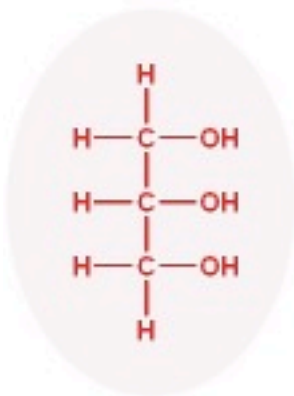
**Triglycerides**

**Organisms can take three fatty acids and join them in one molecule. Three fatty acids are joined to a single glycerol molecule.**



*Tri* means three, triglycerides have three fatty acids attached to a 3 carbon molecule called glycerol.

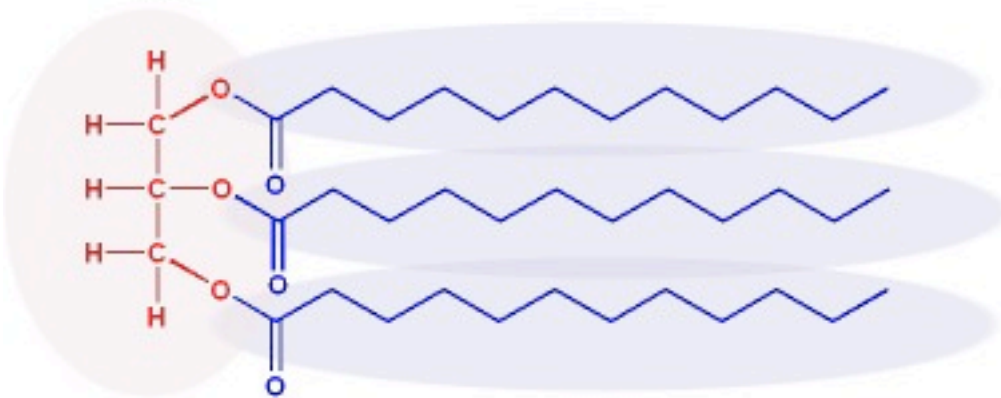
*Glycerol*



*A "free" Fatty Acid*

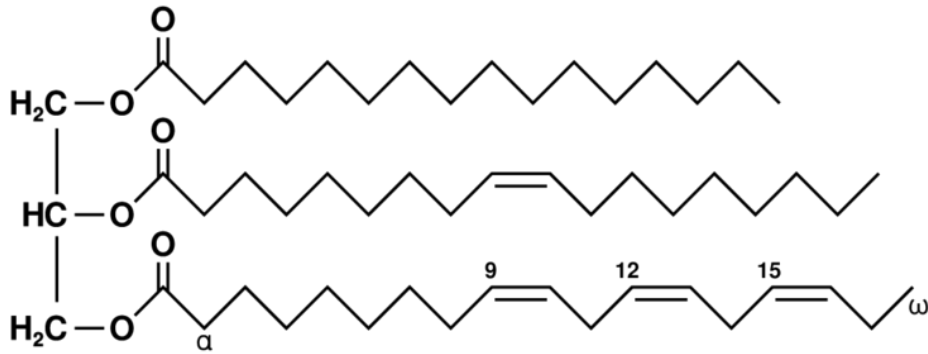


*Triglyceride*



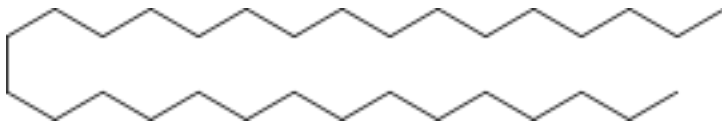
Below is an example a triglyceride. Left part in bold: glycerol

Right part from top to bottom are three fatty acids: palmitic acid, oleic acid, alpha-linolenic acid. Chemical formula:



Triglycerides are the main constituents of vegetable oil (typically more unsaturated) and animal fats (typically more saturated). Triglycerides are a major component of human skin oils. They contain more than twice as much energy as carbohydrates per gram.

**B. Waxes** – long chained hydro-carbon molecules that are insoluble in water, useful as waterproof coatings for organisms, and as a structural component of cell walls.



The hydrocarbon  $C_{31}H_{64}$  is a typical component of paraffin wax.

### 3. **Proteins** (polypeptides)

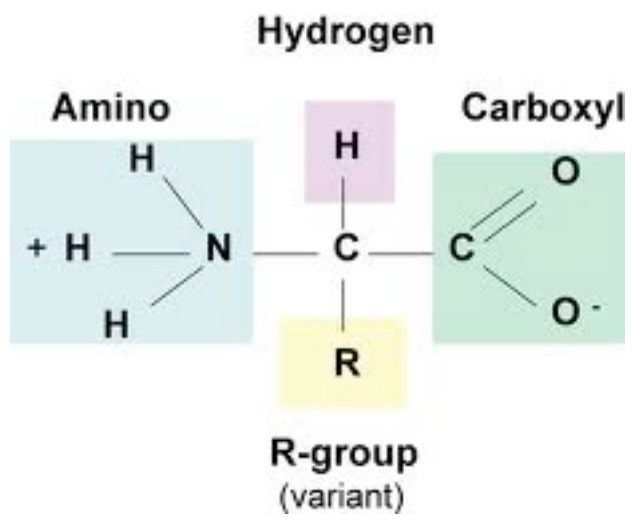
The specialized shapes and functions of different cell types (something we will explore later in the course) depend upon the bewildering variety of proteins. Proteins have many roles in cells (and between cells). They include, but are not limited to:

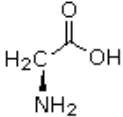
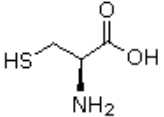
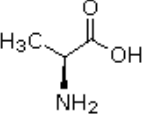
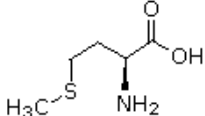
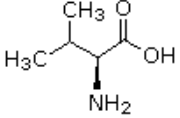
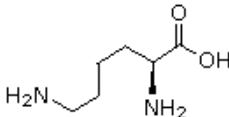
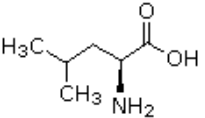
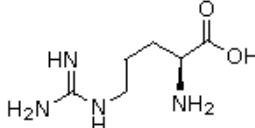
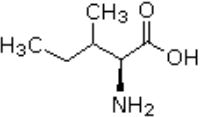
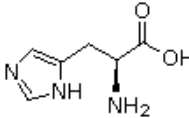
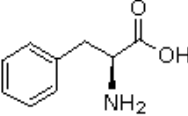
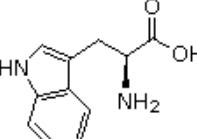
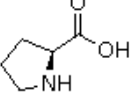
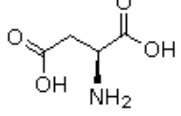
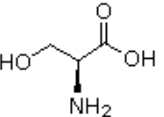
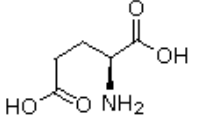
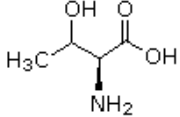
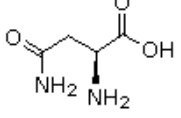
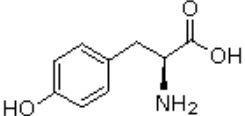
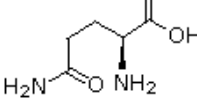
1. Structural proteins - form cell parts
2. Regulatory proteins - control cell processes
3. Enzymes - facilitate (help) many chemical reactions; they do this by lowering the amount of energy needed to start the reaction; the enzyme is not permanently altered in the process
4. Hormones - chemical messengers
5. Transport proteins - carry other substances around cells or from cell to cell.

Proteins consist of long chains of **amino acids**, the building blocks of proteins. Proteins are made of one or more polypeptides. There are usually 100 to 10,000 amino acids in a typical protein molecule. Many millions of combinations of amino acids are possible.

The image below is the basic structure of all amino acids. The R will vary among amino acids

# Amino Acid Structure



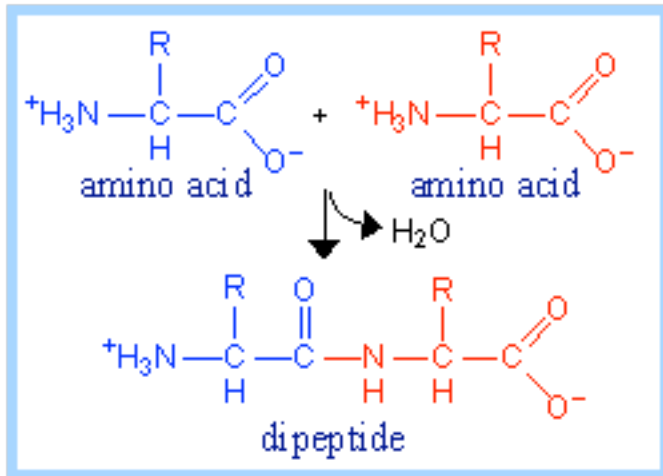
Name	Formula	Abbreviations	Name	Formula	Abbreviations
Glycine		Gly G	Cysteine		Cys C
Alanine		Ala A	Methionine		Met M
Valine		Val V	Lysine		Lys K
Leucine		Leu L	Arginine		Arg R
Isoleucine		Ile I	Histidine		His H
Phenylalanine		Phe F	Tryptophan		Trp W
Proline		Pro P	Aspartic Acid		Asp D
Serine		Ser S	Glutamic Acid		Glu E
Threonine		Thr T	Asparagine		Asn N
Tyrosine		Tyr Y	Glutamine		Gln Q

**Protein Structure** - proteins have four levels of organization (see Figures in

Text below)

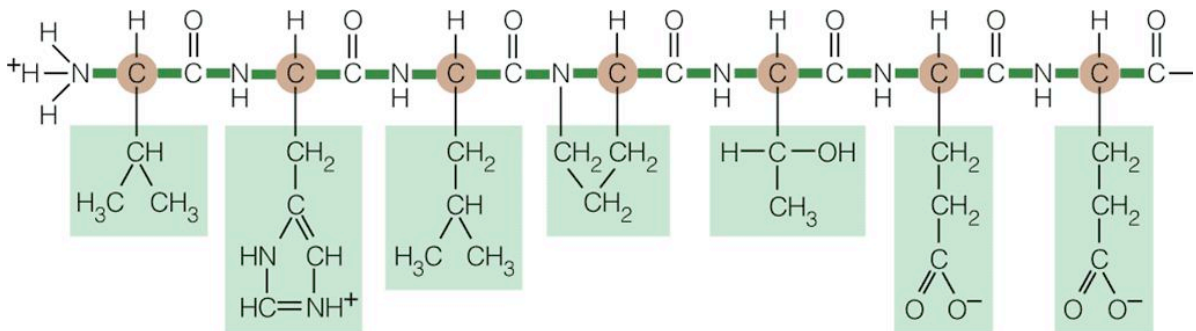
1. **Primary structure** - simply the order of amino acids in a polypeptide strand.

amino acids are joined by a peptide bond...a type of covalent bond.



Many amino acids joined are called a polypeptide or protein.

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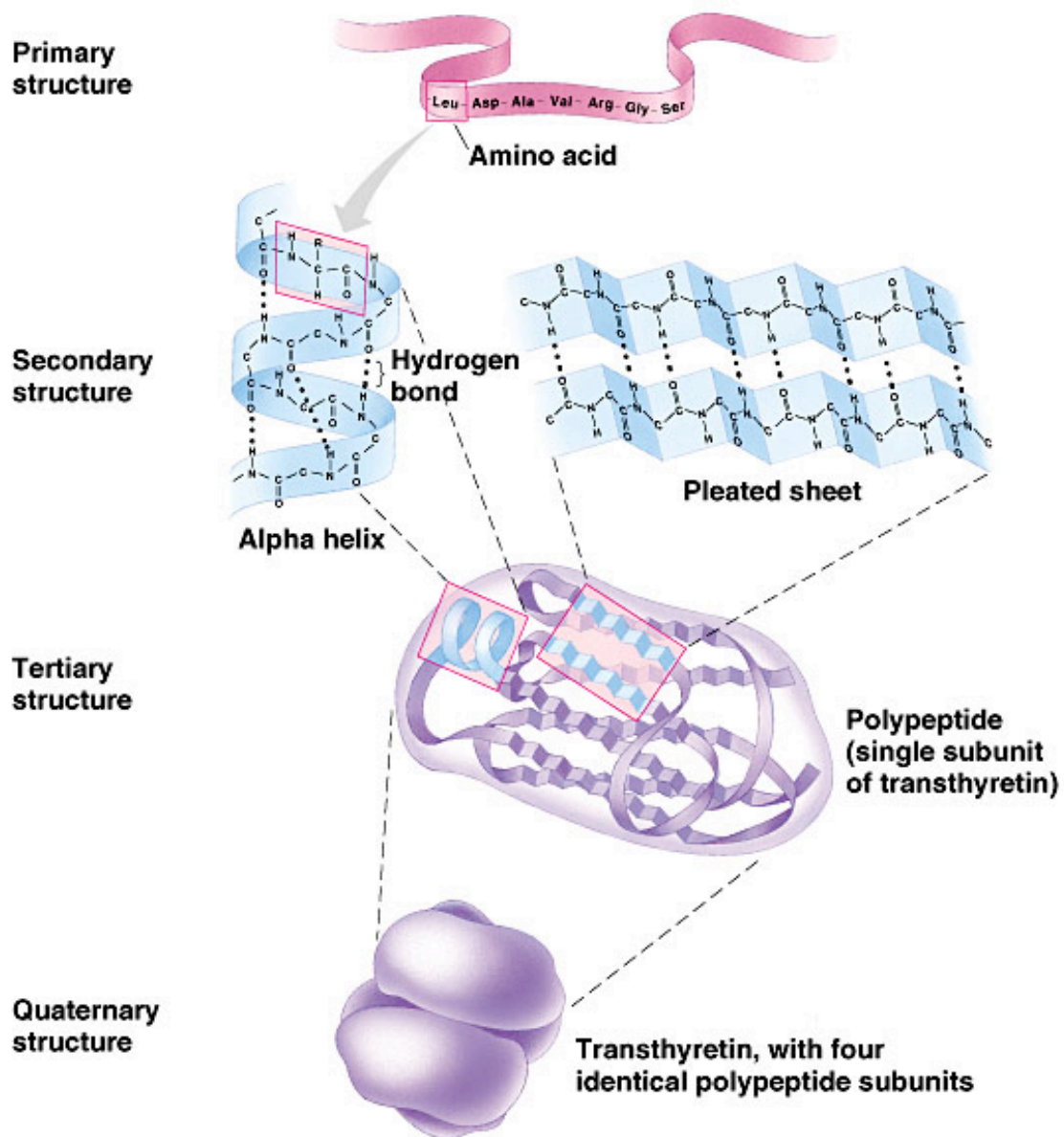


2. **Secondary structure** - regions of localized bending resulting in a) an alpha helix and/or b) pleating (like an accordion) called beta sheets give proteins their secondary structure. Weak hydrogen bonds cause this structure.

3. **Tertiary structure** - the three-dimensional folding of the entire polypeptide chain.

4. **Quaternary structure** - the fitting together of two or more polypeptide chains, thus forming a functional protein.





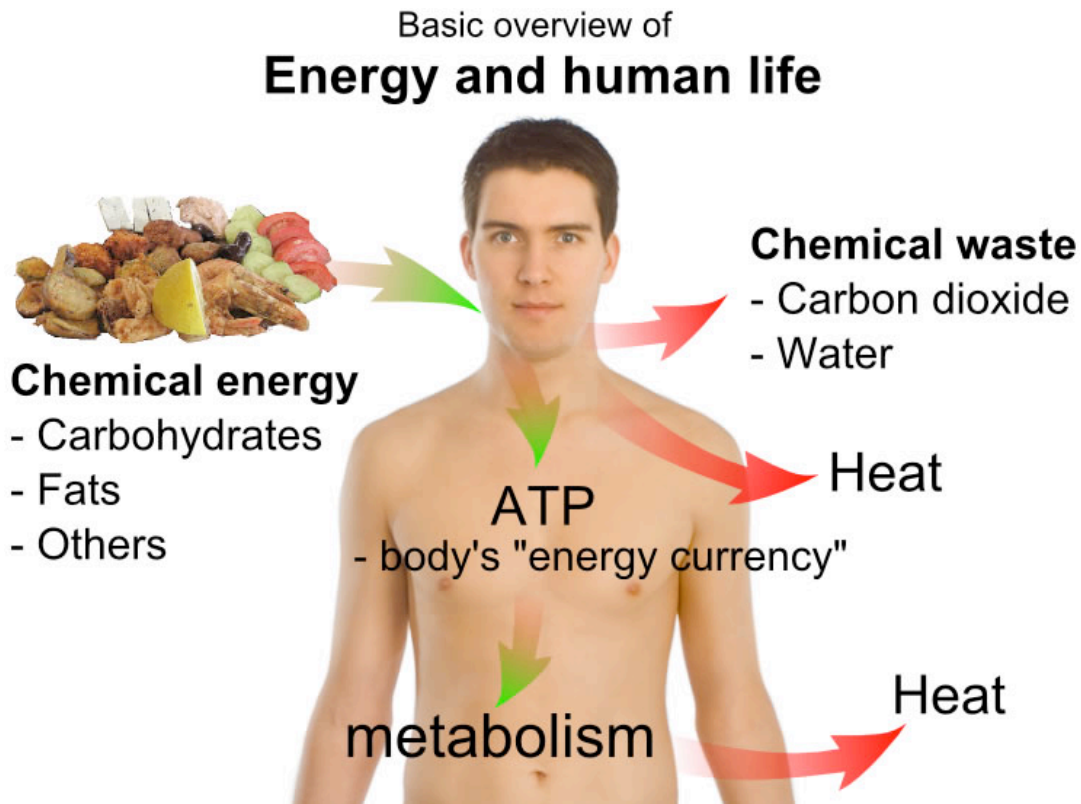
Now that we have an idea of the basic biomolecules we need to sustain life we will study how these molecules are anabolized and catabolized.

There are two main objectives in metabolism:

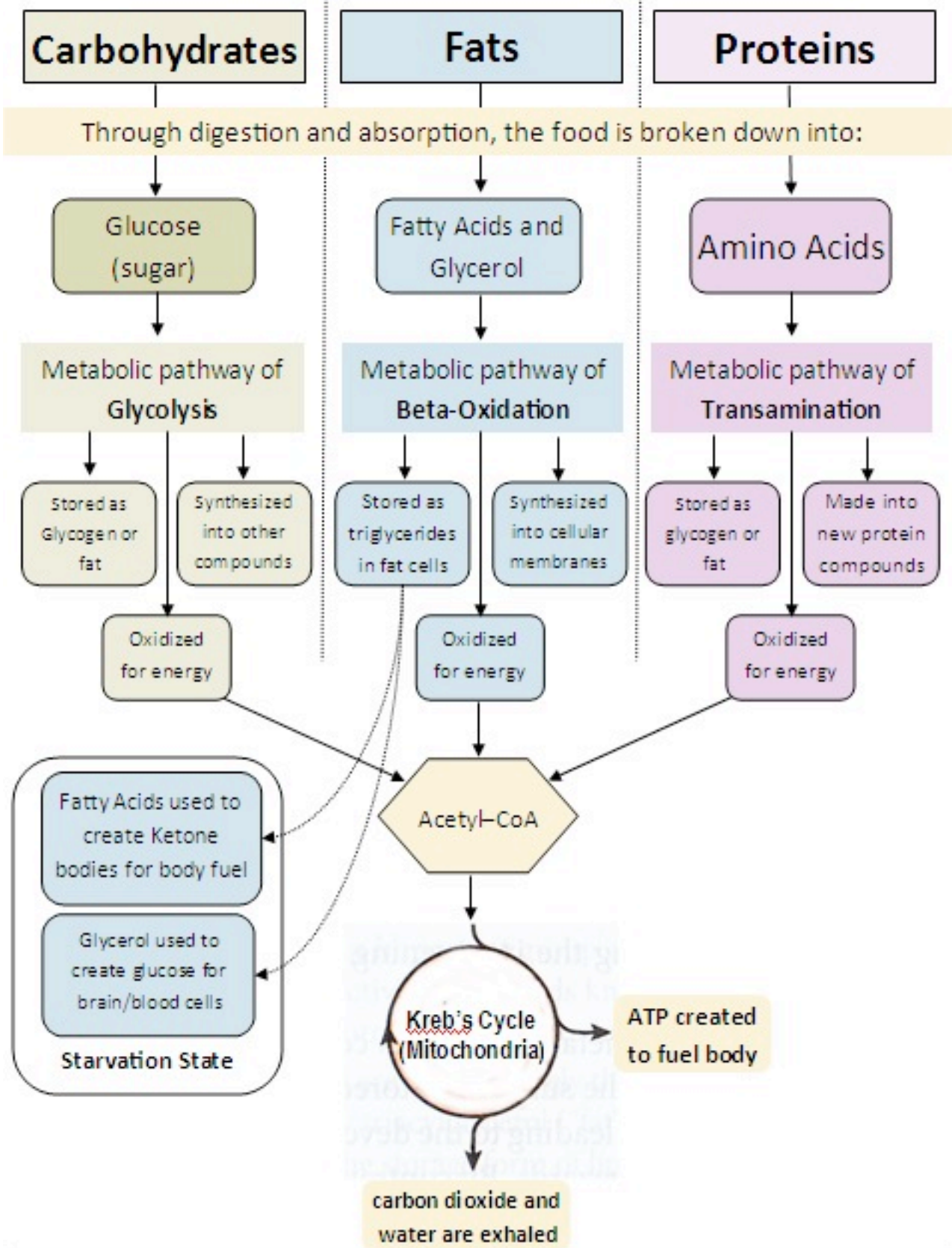
- Making Energy
- Metabolizing biomolecules (anabolism and catabolism)

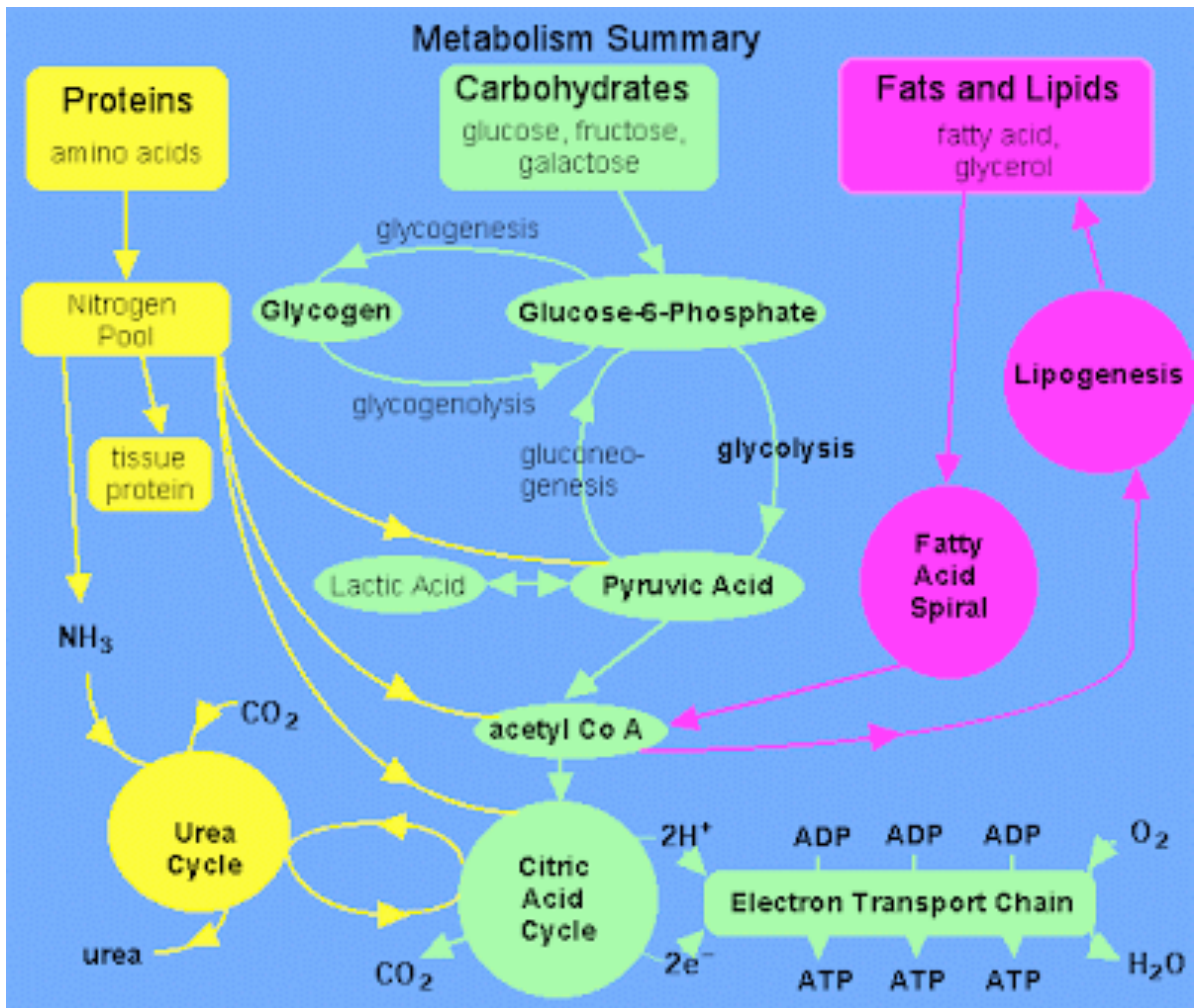
let us look first at making energy:

Organisms have evolved to use a special short-term energy molecule ATP that drives most of the organisms needs for energy...such as muscle contraction, thinking, and most cellular mechanisms such as making DNA.

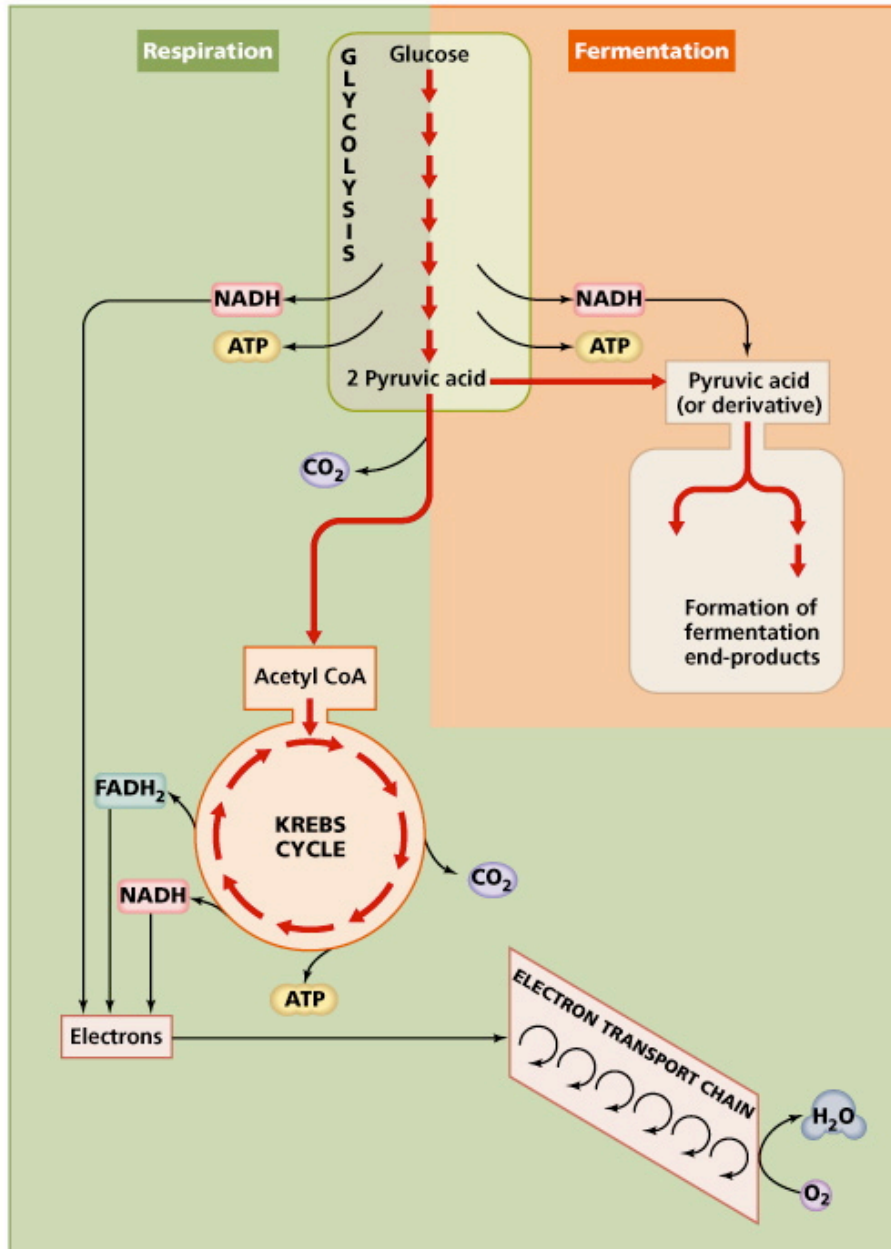


In the **fed** state, nutrients are stored; In the **fasting** state, they are oxidized for energy production





This chart emphasizes the generation of energy from the three types of biomolecules: proteins, carbs, and lipids...note that the title Fats and Lipids in magenta is from the “Department of Redundancy Department”...All fats are lipids...go figure (-:

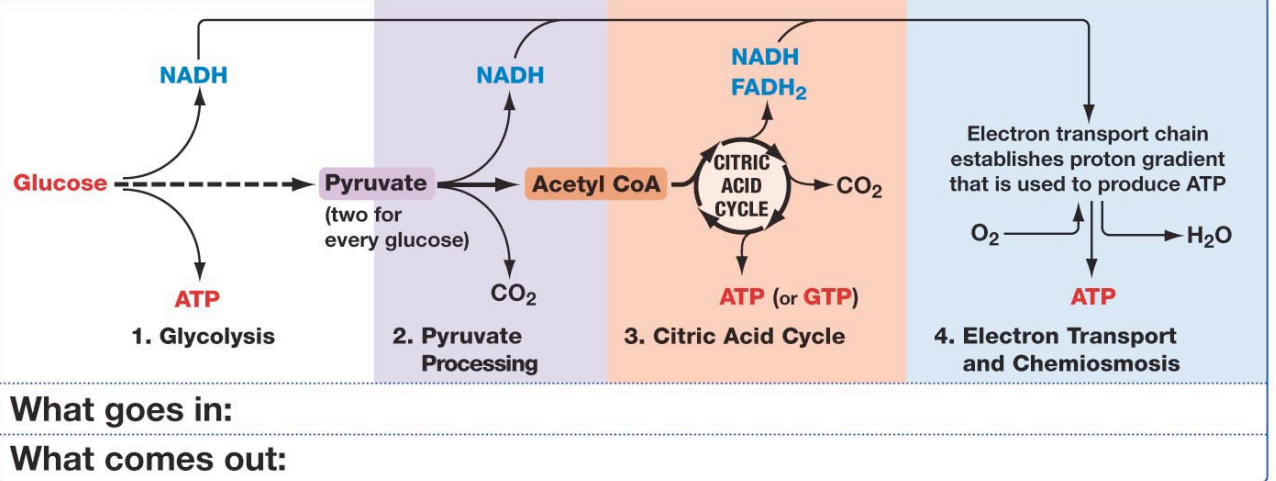


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A chart showing the energy metabolism of just glucose...

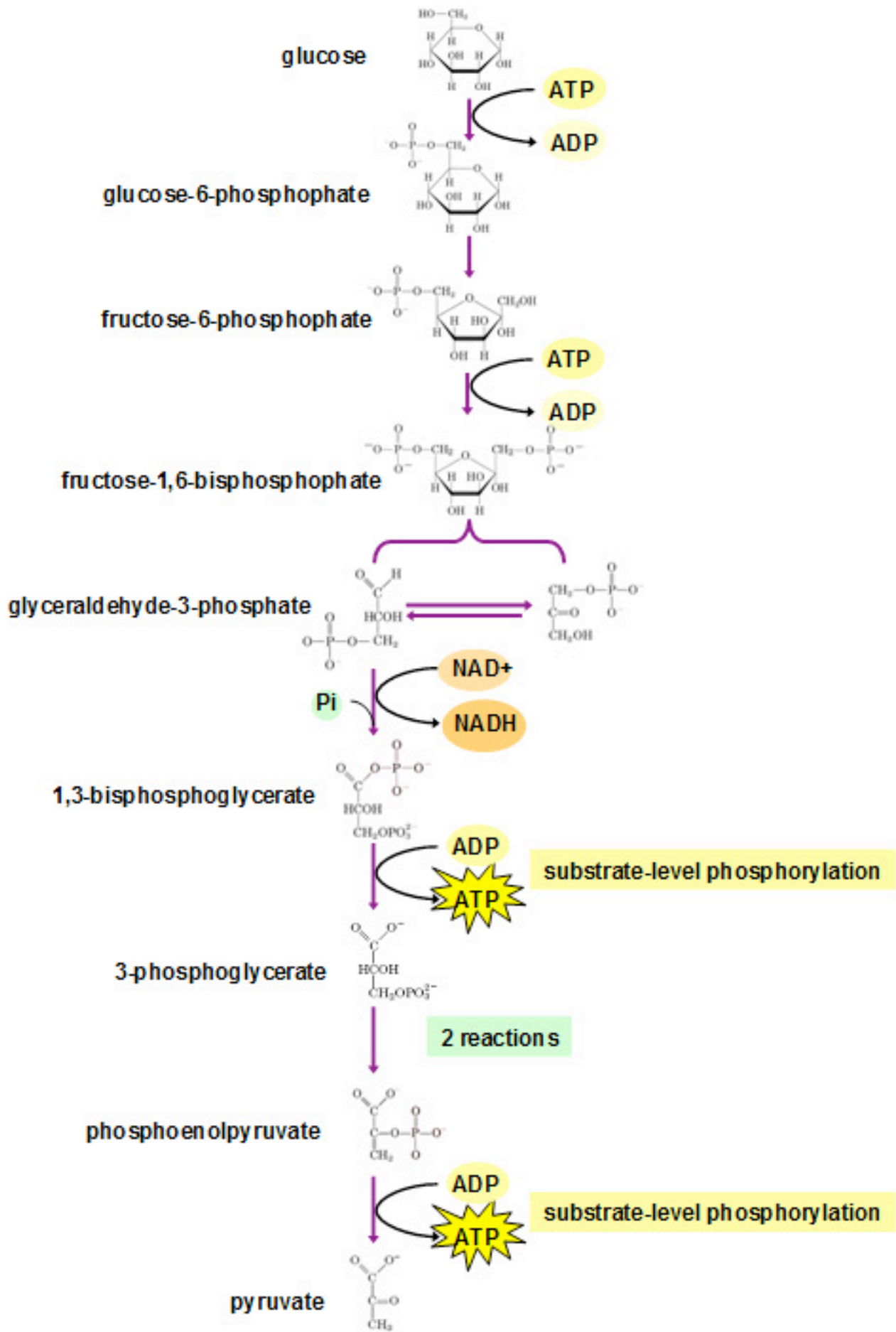
There are three main phases: Glycolysis (happens in the cell's cytoplasm) Krebs or Citric Acid Cycle, and ETS or Electron Transport System both occurring in the mitochondrion....NAD is made from the vitamin niacin. FAD is riboflavin or Vitamin B2...

## PROCESS: OVERVIEW OF CELLULAR RESPIRATION



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A chart showing the energy metabolism of just glucose... once again the three main phases of the breakdown of glucose are shown: Glycolysis (happens in the cell's cytoplasm) Krebs or Citric Acid Cycle, and ETS or Electron Transport System both occurring in the mitochondrion. I am not sure why they found it necessary to make pyruvate processing a stage...I would ignore it.



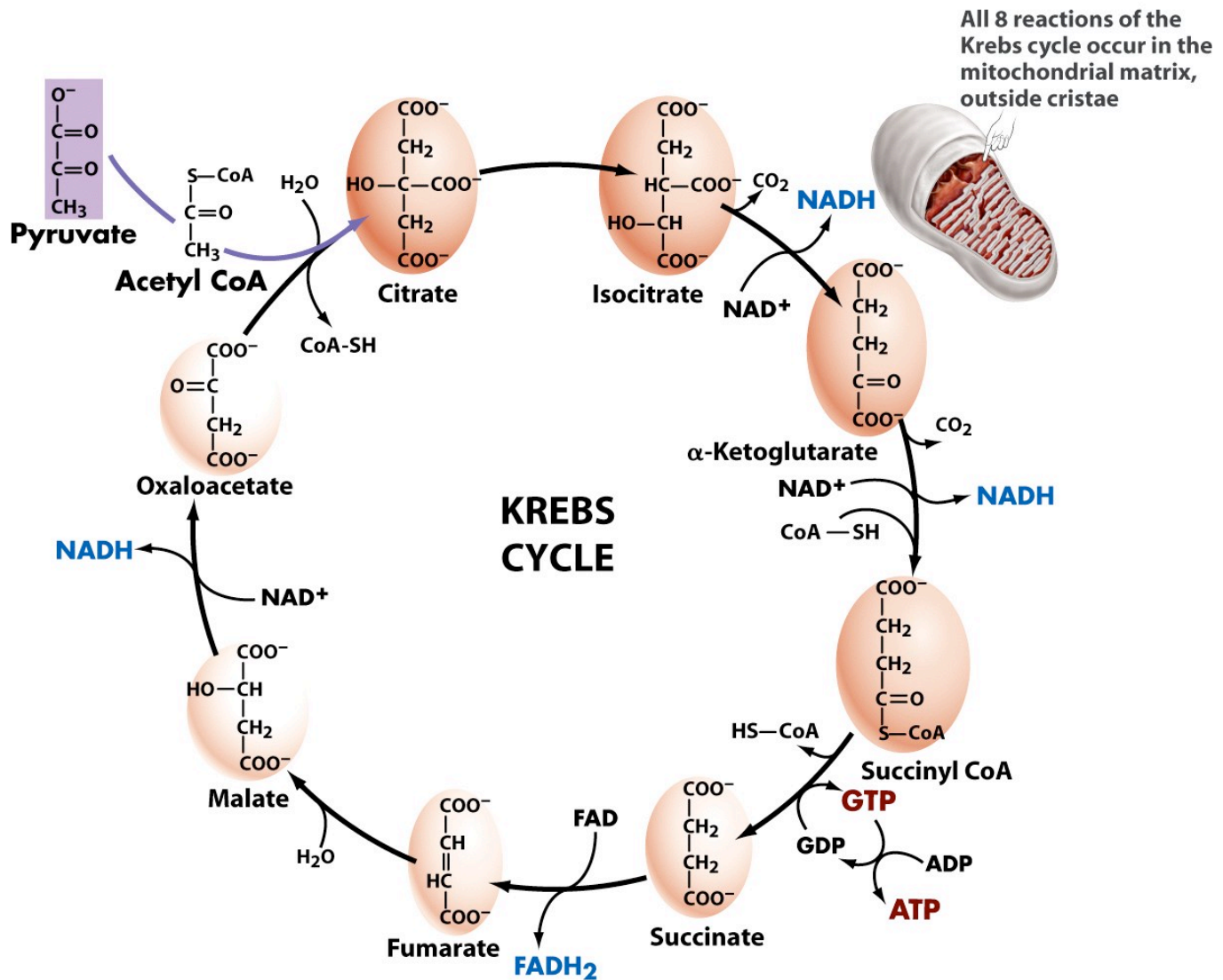
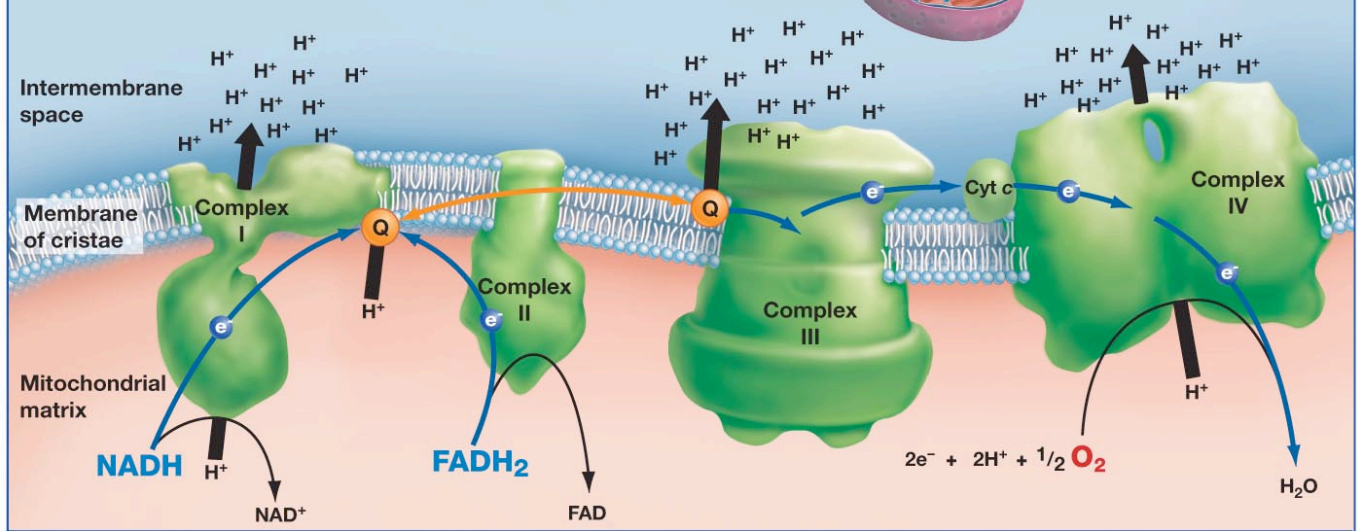


Figure 9-14 Biological Science, 2/e



The electron transport chain occurs in the inner membrane of the mitochondrion (membranes of cristae)

**PROCESS: ELECTRON TRANSPORT CHAIN**



**Complex I**

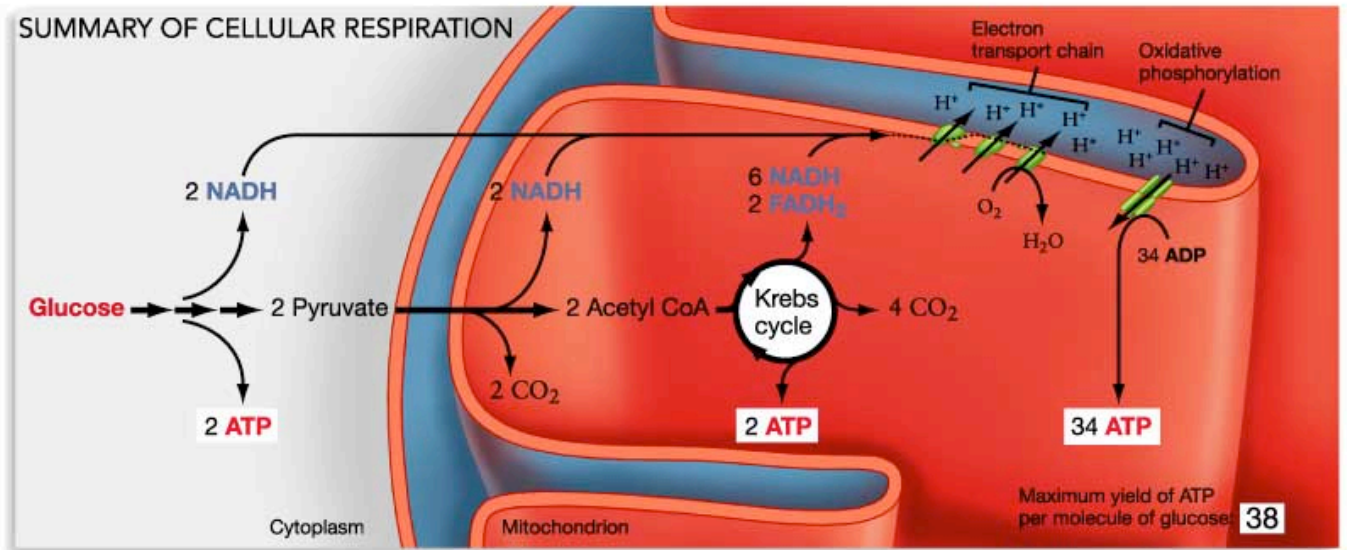
**Complex II**

**Complex III**

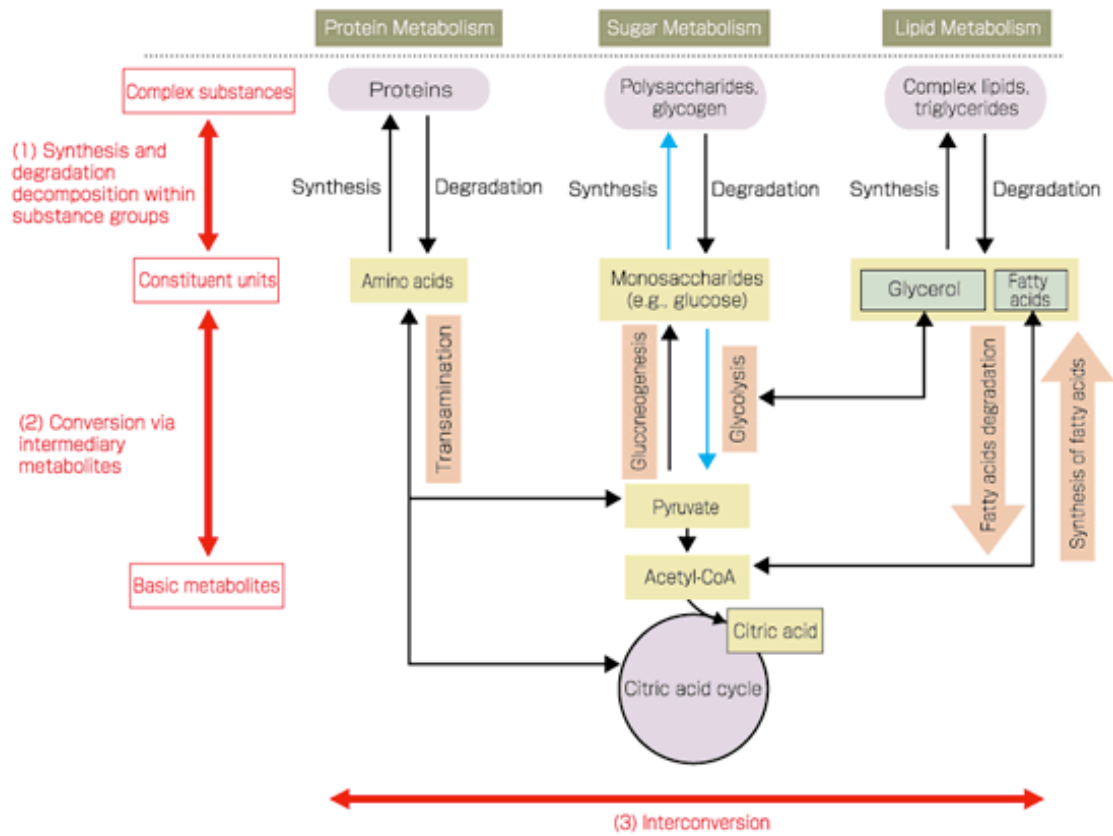
**Complex IV**

What goes in:

What comes out:



For every single glucose molecule about 34 total ATP molecules are produced.



+ ZOOM

This chart emphasizes the anabolic and catabolic pathways of proteins, carbs, and lipids