Biology 12 - Introduction to Biochemistry: Chapter Notes

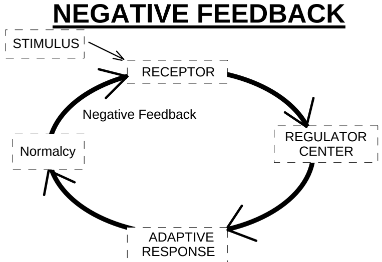
- *In this chapter, we'll start to look at "**Homeostasis**." We will learn about the molecules that make up living organisms. We will learn what these molecules are made of, how they are formed, and what their functions are in living systems.*
- **Biology is the <u>STUDY of LIFE</u>**. All living things:
  1. are made up of **<u>cells</u>**
  2. **<u>grow</u>** and **maintain** structure by taking in chemicals and energy from their environment
  3. **<u>respond</u>** to the external environment
  4. **<u>reproduce</u>** and pass on their organization (genetic information) to their offspring
  5. at the species level, **<u>evolve</u>/change**, and **<u>adapt</u>** to the environment
- Biologists use the **<u>SCIENTIFIC</u> <u>METHOD</u>**
- *we **ask questions**, **observe** the world, formulate **hypotheses**, test them in **controlled experiments**, **revise**, make **conclusions**.*
- ask **<u>causality</u>** questions (**How**...?), not **<u>teleological</u>** questions (Why...?). Not because we don't care about the "why" (like, for example, why we all must go through some suffering), but because these questions can't be answered in way that is testable.
- **Inductive reasoning**: the thinking that you do that produces a first explanation or suggests a general rule, reached after observing specific facts; this reasoning is used to create a **hypothesis**. (It's the sort of thinking that you just before you shout "Eureka, I've got it!"). e.g. Hmm... the sun rises in the east and sets in the west every day. The sun must be going around the Earth!"
- **Deductive reasoning**: This sort of thinking is more systematic and logical, and leads you to a statement that could be used to set up an experiment. It often takes the form of an **"if...then" statement**.
- used to decide the type of experiment needed to test hypotheses.
- *For example: "If green light is the best light for growing tomato plants, then tomatoes grown under green light will be heavier than tomatoes grown under red or blue light.*
- **<u>HYPOTHESIS</u> -** this is a tentative explanation of what you've observed (e.g. "AIDS is caused by a retrovirus"). *can be wrong!*
- **<u>THEORY</u>** - widely accepted, successful, tested hypothesis accepted around the world. By the time a hypotheses becomes a theory, scientists have the utmost confidence in it. (e.g. Theory of General Relativity).
- Experimental "**<u>CONTROL</u>**": a control is a sample that undergoes all the same steps in the experiment except the one being tested.
  - necessary in order to eliminate other effects that might influence the outcome of the experiment
  - necessary so that scientists may establish a ***<u>cause</u>*** <u>and</u> ***<u>effect</u>*** <u>relationship</u>. (want to eliminate, for example, the "placebo effect"). Important for testing new medicines, for example.

HOMEOSTASIS: Maintaining Living Systems

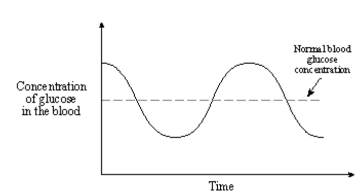
- **Homeostasis**: all the things living organisms do that cause it to **maintain a relatively constant, stable internal environment** regardless of the external environment. There are countless examples in the human body:
- *blood pH =7.4* *body temp. = 37°C*
- *blood pressure = 120/80* *blood [glucose] = 0.1%*
- **Homeostatic Mechanisms**: all the **<u>body</u> <u>systems</u>** that help to maintain homeostasis.
- e.g. **digestive system**: takes in food and turns it into a usable form for cells that are constantly using nutrients.
- **respiratory system**: adds O_2 to blood to replace O_2 used up metabollically, takes away CO_2 as it's produced.
- **liver** and **kidney's**: monitor and maintain constant blood chemistry

How is homeostasis controlled? It relies on **<u>POSITIVE</u>** and **<u>NEGATIVE</u> <u>FEEDBACK</u> <u>MECHANISMS</u>**.

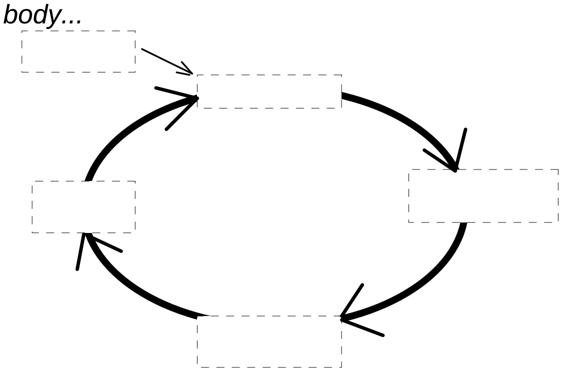
<u>NEGATIVE FEEDBACK</u>



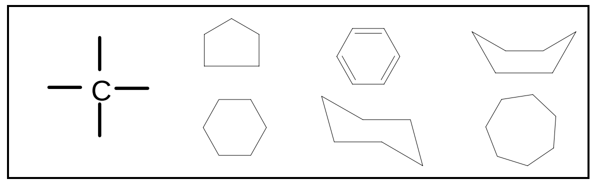
- Brain **<u>control</u> <u>centers</u>** (e.g. in the **hypothalamus**) monitor and control body conditions (e.g. pH, temperature, glucose levels)
- **<u>Sensors</u>** all over body **detect unacceptable** levels and signal the appropriate brain center (e.g. temperature sensors in skin stimulate brain if skin gets colder than 37°C).
- **control center directs body** to behave so that **normal state is regained** (e.g. shivering)
- Once normal state is regained, the **<u>sensor</u> <u>stops</u> <u>signaling</u> <u>the</u> <u>brain</u> <u>center</u>** (this the "*negative feedback part*"), so adaptive behaviour stops. This results in a **FLUCTUATION** between two levels.



Here is an example from your own body...



BIOCHEMISTRY & CELL COMPOUNDS



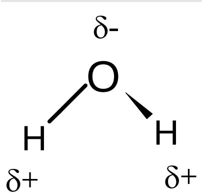
Life on Earth is "Carbon Based..."

- **Biochemistry**: the chemicals of life and their study
- **Organic Chemistry**: the study of carbon compounds

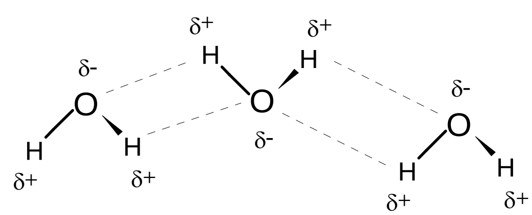
Why Carbon?

1. has four available covalent bonds -- allows for other atoms to bind.
2. capable of **forming strong bonds** with itself
   - therefore **can form long chains** -- can be straight or branched --> great **VARIETY** of possible combinations.
   - carbon atoms in chains can rotate, forming single, double, and multiple **ring structures** (e.g. glucose, nucleotides)

WATER - Structure, Properties and Importance



- water is **inorganic** (contains no carbon)
- water is **covalently bonded**), but is **POLAR** - the shared electrons spend more time circulating the larger oxygen than the smaller hydrogens. Thus, the **oxygen** has a *slight net **negative** charge,* while the **hydrogens** have a *small net **positive** charge*.
- **Hydrogen Bonds** occurs whenever a **partially positive H is attracted to a partially negative atom** (like oxygen and nitrogen. It is represented by a ***dotted line*** because it is **weak** and **fairly easily broken**. *Covalent* and io*nic bonds* are both much stronger. Hydrogen bonds, when numerous, can add up to have a large effect, and explain some of the unique properties of **water**.



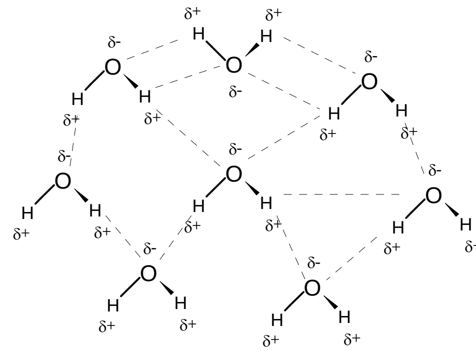
Water is Essential to All Life

- **Life began** in water, and all living organisms are “water-based.”
- All living organisms have **adaptations for maintaining water levels** (e.g. human skin, plant stomata, bacterial cysts)
- Humans life requires water:
  - i. we are approximately **70% water**.
  - ii. only **substances dissolved in water** can enter cell membrane of our cells (e.g. glucose, amino acids).
  - iii. water **carries away dissolved wastes** from our cells, and wastes excreted in liquid (**sweat**, **urine**)
  - iv. **ions** necessary for many body processes (e.g. Ca^{++} for movement, Na^{+}, K^{+} for generation of nerve impulses)
  - v. **joints** are **lubricated** by a watery fluid
  - vi. our **brains** partially protected against shock by a watery layer
  - vii. **sense organs** require water: **eyes** filled with thick fluid; **hearing** depends upon fluid-filled structure (called the Cochlea) that transmits vibrations.

WATER HAS SEVERAL UNIQUE CHARACTERISTICS

- **abundant** throughout biosphere. Life started in the water.

- **H-bonding** makes it have a **low freezing point** and a **high boiling point,** so that it is **liquid** at body temperature.
- water **absorbs much heat before it warms up** or boils, and **gives off much heat before it freezes** (this is why oceans maintain a basically constant temperature, and accounts for cooling effect of sweating). This is also due to H-bonding.
- has high **COHESIVENESS** -- makes it **good for transporting materials** through tubes. Water molecules tend to cling together and draw dissolved substances along with it.
- ***liquid water is more dense than ice*** because of H-bonding (so ice will form on top). Ice layers helps protect organisms below.
- **dissolves** other **polar molecules** -- is **one of the best solvents known** (--> promotes chem. reactions). Called the "**UNIVERSAL SOLVENT**."



ACIDS, BASES, & BUFFERS

- **ACIDS** are compounds that **dissociate in water** and **release H^+ ions.** e.g. HCl, H_2CO_3, H_2O, CH_3COOH
- **BASES** are compounds that dissociate in water and **release OH^- ions**. e.g. NaOH, KOH, H_2O
- **pH** is a measure of the **concentration of hydrogen ions** (how much acid is in a solution) and ranges from 0 to14. The **lower the number**, the more **acidic** the solution. A pH less than 7.0 is **acidic**.
- The **higher** the number, the more **basic** (or "alkaline") the solution. A pH more than 7.0 is a **basic** solution.
- A pH of 7 is said to be **neutral**. **Pure water** has a pH of 7.0
- pH can be calculated using the following formula:

$$\mathbf{pH = -log[H^+]}$$

for example, if pH = 3, $[H^+] = 10^{-3}$

- The numbers in the pH scale can seem misleading, because the pH scale is a **logarithmic scale**. That means each number on the pH scale represents a difference in magnitude of **10**. For example, a pH of 2 is ten times more acidic than a pH of 3. A pH of 2 is 100 times more acidic than a pH of 4. A pH of 13 is 1000 times more basic than a pH of 10, and so on.
- An easy way to figure out these sorts of calculations is to do the following:

1. Take the two pH's and **subtract** them. e.g. pH 10 and pH 4

10 - 4 = 6

2. Take that number and put that many **zeros** in front of the number one.

1	0	0	0	0	0	0

This means that a pH of 10 is **1,000,000 times** more **basic** than a pH of 4. (you could also say it the other way -- a pH of 4 is 1,000,000 times more **acidic** than a pH of 10)

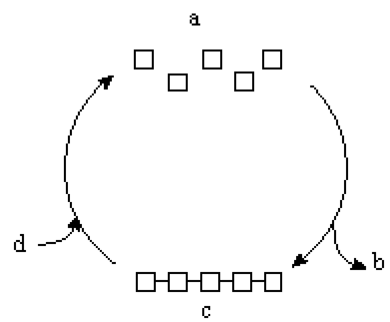
- Here's how the scale works:

0	1	2		3	4	5	6		7		8	9	10	11	12	13	14
<---ACIDIC--->									NEUTRAL		<---BASIC--->						
PURE HCl	BATTERY ACID	GASTRIC JUICE	LEMONS	SOFT DRINKS WINE BEER	TOMATOES	BLACK COFFEE	RAIN WATER	SALIVA	PURE WATER	BLOOD	SEA WATER	TUMS BAKING SODA	MILK OF MAGNESIA	HOUSEHOLD AMMONIA	BLEACH	OVEN CLEANER	PURE NaOH

- ***Why is pH important?*** All **living things need to maintain a constant pH** (e.g. human blood pH = 7.4). If pH changes, it can cause enzymes to denature (more on this later!). To keep the pH from changing, livings cells contain buffers to keep the pH constant.

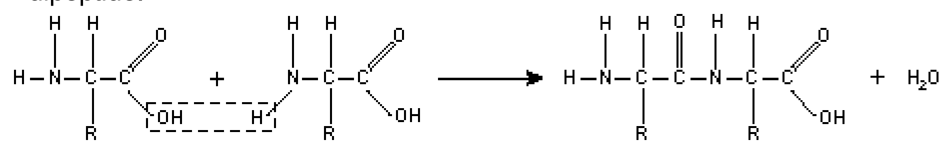
- **BUFFER**: a chemical or combination of chemicals that can take up excess hydrogen ions ***or*** excess hydroxide ions. Buffers ***resist*** changes in pH when acid or base is added. However, buffers can be overwhelmed if acid or base continues to be added.
- **SALT**: formed in a *neutralization reaction* between an acid and a base. e.g. HCl + NaOH $\Rightarrow$ H_2O + NaCl (table salt)

POLYMER FORMATION:*Making Big Molecules from Small Molecules!*



- a **POLYMER** is a large molecule formed from **repeating subunits** of smaller molecules (e.g. **proteins**, **starch**, **DNA** are all polymers).

- **DEHYDRATION SYNTHESIS**: **forms large molecules** (**polymers**) **from small molecules**. (Dehydration = to remove water) In the process ***water is produced***. Here is how two amino acids (small molecules) form a dipeptide.



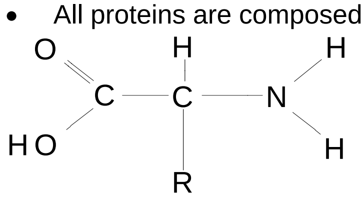
- In synthesis, one molecule **loses an H+**, one molecule **loses an OH-**. In the above example, amino acids can continue to be added to either end of the dipeptide to form polypeptides. Large polypetides are called **proteins**.
- **HYDROLYSIS** (***hydro*** = water, ***lysis*** = to split): is the **opposite reaction.** Water **breaks up another molecule**. The addition of water leads to the disruption of the bonds linking the unit molecules together. **One molecule takes on H+** and the **other takes an OH-**. This also requires the action of helping molecules called **enzymes**. Enzymes that do this are called **hydrolytic enzymes**.

The FOUR MAIN CLASSES of Biologically Significant Molecules: Proteins, Carbohydrates, Lipids, Nucleic Acids

I. PROTEINS

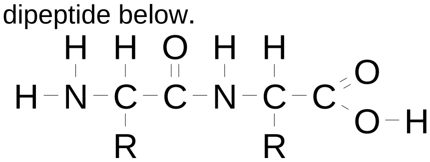
- large, complex organic macromolecules that have three main functions
  1) provide **STRUCTURAL SUPPORT** (e.g. **elastin**, **collagen** in cartilage and bone, muscle cells)
  2) **MOVEMENT** (actin and myosin etc. in muscle cells)
  3) **METABOLIC FUNCTIONS**:
     - **ENZYMES** (biochemical catalysts that speed up biochemical reactions). Crucial to life.
     - **ANTIBODIES**: proteins of your immune system that fight disease.
     - **Transport**: **HEMOGLOBIN** is a protein that transports oxygen in your blood. **Proteins in cell membranes** act as **channels** for molecules entering or leaving the cell.
     - **Hormones**: many hormones, like ***insulin***, are proteins. Hormones control many aspects of homeostasis.

- All proteins are composed of **AMINO ACIDS** (like a train is made up of individual railway cars)



- Note the "**amino**" group on right (ammonia = NH_3), "**acid**" group on the left (COOH = organic acid) of the central carbon. All amino acids have this formula.
- Difference is in "**R**" (= **Remainder**) group -- different for each amino acid.
- There are **20 different amino acids in living things**. Our bodies can make 12 of these. The other 8, which we must get from food, are called "**Essential Amino Acids.**"

i. Amino acids join together through dehydration synthesis. The bonds formed are called **PEPTIDE BONDS**. ***Circle the peptide bond*** on the dipeptide below.



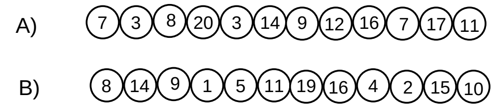
- Peptide bonds are **polar bonds** (this leads to H-Bonding, as we will see).

ii. **Dipeptide**: two amino acids joined together

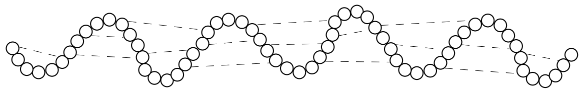
iii. **Polypeptide** (abreviation = ppt): >2 a.a.'s joined together. Usually short: less than 20 amino acids or so.
iv. **Protein**: a polypeptide chain is called a protein when it gets large (usually ~75 or more amino acids in length)

Proteins have 4 levels of organization:

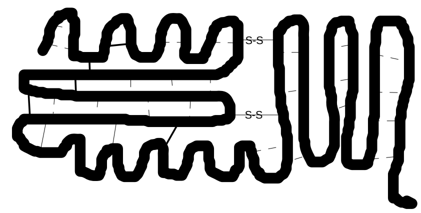
i. **PRIMARY STRUCTURE**: the sequence of a.a.'s joined together in a line. Here are two polypeptide chains that are 12 amino acids long. Note however, that they have different primary structures (different sequences of the 20 amino acids).



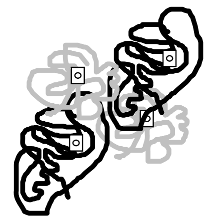
ii. **SECONDARY STRUCTURE**: since peptide bonds are polar, H-Bonding routinely occurs between amino acids in the primary line. Often, this will cause the chain coil up into a shape called an **alpha helix**. Layers called β-pleated sheets can also form.



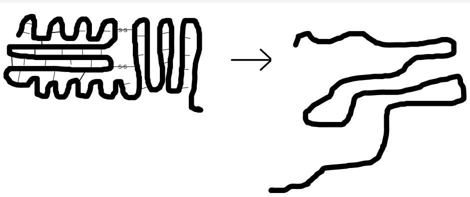
iii. **TERTIARY STRUCTURE**: different types of bonding (covalent, ionic, hydrogen) between -R groups makes the alpha helix bend and turn, forming "globs" of protein of all shapes. This three-dimensional arrangement of the amino acid chain is called the "**tertiary structure**." Although it may look randomly formed, the final 3-D shape is very exact and precise. The shape is due to the **original sequence of amino acids** (the ***primary structure***), as this is what will determine which amino acids in the chain will bind with each other, and in what way.



iv. **QUARTERNARY STRUCTURE**: for proteins with more than one polypeptide chain, the quarternary structure is the **specific arrangement of polypeptide chains** in that protein. (e.g. **hemoglobin**: this is the O_2 carrying protein in blood -- made of four polypeptide chains interlocked in a specific way).



DENATURING PROTEIN



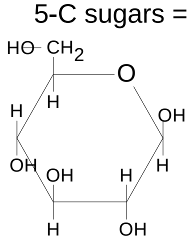
- protein shape is ***critical*** to its function
- changes in **temperature** or **pH** can **disrupt the bonds** that hold a protein together in its particular shape.
- If a protein is **DENATURED**, it has lost normal structure/shape because **normal bonding between -R groups has been disturbed**.
  - e.g. **heating an egg white**, **adding vinegar to milk**. Heavy metals such as **lead** and **mercury** also denature proteins.

II. CARBOHYDRATES

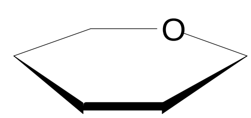
- Carbohydrates are molecules made of Carbon, Hydrogen, and Oxygen
- all carbohydrates have the general formula: $\mathbf{C_n(H_2O)_n}$ ⇒ hence the name *"Hydrated Carbon"* or *"Carbo - Hydrate"*
- Carbohydrates are very important in living systems for the following functions:
  1. **Short-term energy supply** (e.g. glucose)
  2. **Energy storage** (e.g. glycogen, starch)
  3. As **cell membrane markers** (receptors & "identification tags")
  4. As **structural material** (e.g. plant cell walls, chitin in insect exoskeletons)
- different forms used for **ENERGY**, **FOOD STORAGE**, & **STRUCTURAL SUPPORT** in plants and animals

i. **MONOSACCHARIDES** (e.g. **Glucose**, **ribose**, galactose, fructose)

- simple sugars with only **one unit molecule**
- groups of monsaccharides may be designated by the number of carbons they contain (i.e. "hexose" = 6-C sugar, 5-C sugars = "pentose" sugars). *Note the "..ose"*

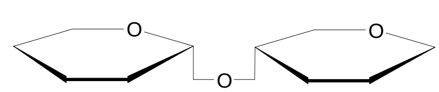


Here is the structure of **Glucose**: on the left is the actual molecule. It is more usually drawn like the picture on the right, to save time.



ii. **DISACCHARIDES** (e.g. maltose, sucrose). At right is maltose.

- are formed from dehydration synthesis reaction between two monosaccharides.



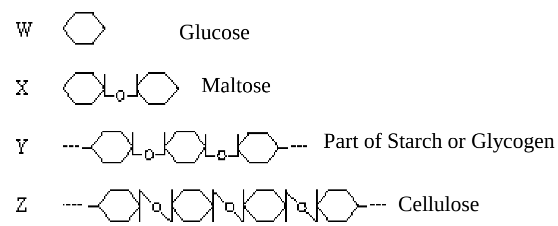
- maltose = 2 glucose. Table sugar (sucrose) = 1 glucose + 1 fructose)

- Monosaccharides and disaccharides are all water soluble.

iii. **<u>POLYSACCHARIDES</u>**
- a carbohydrate that contains a **large number of monosaccharide molecules**
- Three main important types in living systems. **All** are made of **<u>repeating</u> <u>glucose</u>** <u>subunits</u>:
  1. **<u>STARCH</u>** - the **storage form of glucose in <u>plants</u>**. Made of **<u>fairly</u> <u>straight</u> <u>chains</u>** of glucose, with few side branches off the main chain.

synthesis
***n* glucose<=======> starch + (*n* - 1)H_2O**
hydolysis

  2. **<u>GLYCOGEN</u>** - the storage form of glucose in **<u>animals</u>**. **<u>Many</u> <u>side</u> <u>chains</u> of glucose**. In animals, the **<u>liver</u> <u>converts</u> <u>glucose</u> <u>to</u> <u>glycogen</u> <u>for</u> <u>storage</u>**. In between meals, liver releases glucose into blood so blood [glucose] remains at 0.1%.
  3. **<u>CELLULOSE</u>** - primary **structural component of plant cell walls**. Linkage of glucose subunits different than in starch or glycogen.



- Human digestive system ***can't digest cellulose***, so it passes through the intestines undigested. Other names for the cellulose in plant foods are "**<u>fiber</u>**" or "roughage."
- dietary fiber is important to health and for the prevention of such things as **colon cancer**.

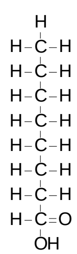
III. LIPIDS
- Lipids are a wide variety of compounds, more frequently known by their **common names**, including ***<u>fats</u>, <u>oils</u>, <u>waxes</u>.***
- are all **insoluble** in water.
- Functions of Lipids include the following:

1. **Padding** of vital organs
2. **Insulation** ("blubber")
3. Long-Term **<u>Energy</u> <u>storage</u>** (fat is excellent for storing energy in the least amount of space, and packs 9.1 calories of energy per gram, versus 4.4 for carbohydrates and proteins).
4. **Structural** (e.g. **cell membranes**, white matter of brain etc.)

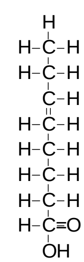
- **chemical messengers** (e.g. steroid hormones, prostaglandins).

There are four main types:

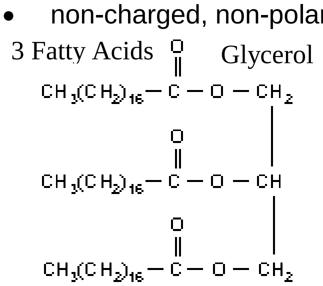
i. **<u>FATTY</u> <u>ACIDS</u>**: a long chain of carbons with hydrogens attached, ending in an acid group (-COOH). There are two main types:



- **<u>saturated</u> <u>fatty</u> <u>acids</u> - no double bonds** between carbons. All carbons are "saturated" with hydrogens. **<u>Solid</u>** at room temp. These are the "bad" dietary fats (e.g. butter, lard, meat fat), which are known to contribute to heart disease and strokes.
- **<u>unsaturated</u> <u>fatty</u> <u>acids</u>** - have one (monounsaturated) or more (polyunsaturated) **double bonds** between carbons in chain. **<u>Liquid</u>** at room temperature. e.g. vegetable oils, Omega-3 unsaturated fatty acids. Are thought to be better for your heart than saturated fats.



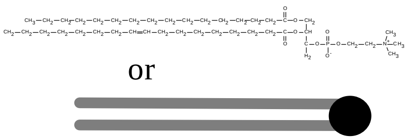
ii. **<u>NEUTRAL</u> <u>FATS</u>**: (also called **<u>Triglycerides</u>**)
- formed by dehydration synthesis rx. between **<u>glycerol</u>** (a molecule of 3 hydrated carbons and **3 fatty acids**.
- non-charged, non-polar molecules. Do not mix with water unless a soap is added.

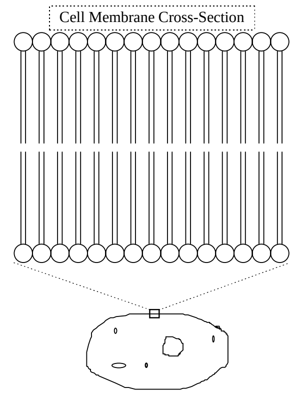


Neutral fats are sometimes drawn like this:

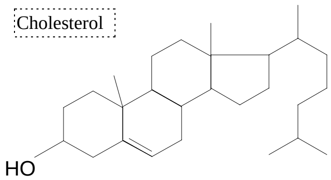
- **Soap** is made by combining a **base** and a **fatty acid**.
- soaps are **polar**, will mix with water. Soap molecules surround oil droplets to their polar ends project outwards, causing the oil to **disperse** in water (this process called **EMULSIFICATION**).

iii. **<u>PHOSPHOLIPIDS</u>**: important components of **cell membranes**





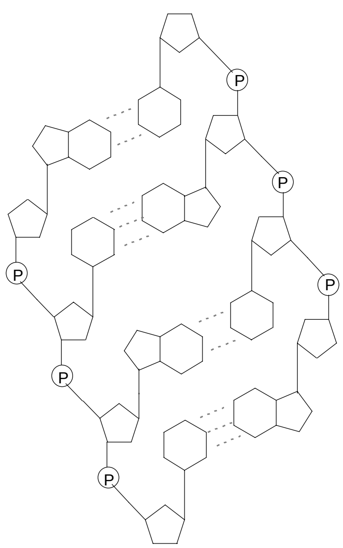
- same basic structure as neutral fats **except** that 1 fatty acid is replaced by a phosphate group with a charged nitrogen attached.
- phospholipids have a Phosphate-containing "**head**" and two long fatty acid **tails**. Head is **hydrophilic** ("water-loving"), tail is **hydrophobic** ("water-fearing")



iv. **STEROIDS**: a different type of lipid

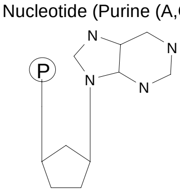
- They are multi-ringed structures, all derived from **CHOLESTEROL**
- You've heard many bad things about cholesterol, but it is actually an **essential molecule** found in every cell in your body (it forms parts of cell membranes, for example).
- The problem is that **dietary cholesterol** helps to form **arterial plaques**, which lead to **strokes** and **heart attacks**. Dietary cholesterol only found in **animal products** (meat, fish, poultry, dairy products). There is **no cholesterol in plant foods**. Your blood cholesterol should be no more than 150 mg/dl
- Steroids can function as **chemical messengers**, and form many important **HORMONES** (e.g. **testosterone**, **estrogen**, **aldosterone**, **cortisol**) that have a wide variety of affects on cells, tissues, and organs (especially sex characteristics, ion balance, and gluconeogenesis).

IV. NUCLEIC ACIDS: DNA & RNA

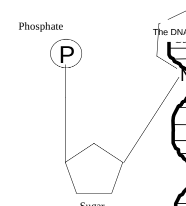


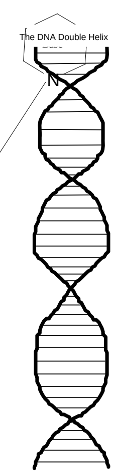
- huge, macromolecular compounds that are polymers of **nucleotides**. Two types:
  1. **DNA**: **DEOXYRIBONUCLEIC ACID** - makes up **chromosomes** and **genes**. **Controls all cell activities**, cell division, protein synthesis. Undergoes mutations which are important to the process of **evolution**.
  2. **RNA**: **RIBONUCLEIC ACID** - works with DNA to direct protein synthesis.
- Nucleotides consist of a **five-carbon sugar** (ribose or deoxyribose), a **phosphate**, and a **nitrogen-containing base** (which may have one or two **rings**). There are 4 different nucleotides in DNA. The sequence of these nucleotides is the "Genetic Alphabet" or "Genetic Code."

Nucleotide (Purine (A,G))



Nucleotide (Pyrimidine (T,C))





- **DNA** and **RNA** are **polymers** that form from the **dehydration synthesis** between **nucleotides**.
- DNA consists of **two antiparallel strands of nucleic acids**. Each strand has a **backbone of the sugars and phosphates of joined nucleotides**. The bases stick out the side and **hydrogen-bond** with the **complementary bases** of the other strand. The two strands wind around each other to form a **double helix**.
- Sections of DNA form functional units called **GENES**. A gene is one instruction for making one polypeptide, and is about 1000 nucleotides long, on average.
- DNA is packaged into **chromosomes**, and is located in the **nucleus**. You have about **4 billion nucleotide pairs** in each of your cells. Each of your **46 chromosomes** contains one very long **polymer of DNA** around **85,000,000 nucleotides long**!
- **RNA** is a **single strand** of nucleic acid, which is **formed off a DNA template** in the nucleus. It migrates to the cytoplasm during **protein synthesis**.

V. ATP - Adenosine Triphosphate - the Molecule of ENERGY

- ATP is a type of **nucleotide** that is used as the **primary CARRIER OF ENERGY** in cells
- consists of the sugar **Ribose**, the **base Adenine**, and **3 phosphate groups** attached to the ribose.
- the bond between the **outer two phosphates** is **very high in energy**: when it is broken, *much energy is released*, which can be used by the cell (for example, for muscle contraction).

- the bond between the first and second phosphate is also high in energy, but not as high as between the two end phosphates
- ATP is produced mostly produced inside **mitochondria** during the process of **cellular** **respiration**.