# Section One: Chapter 2: The Chemistry of Physiology

In order to get a good understanding of the fundamentals of human physiology, we need to know enough about the chemistry of things to enable us to see the connection between the various levels of organization of the human body.

Working on the recurring premise of approaching the concepts of physiology from the smaller components to the larger components, we will first examine the aspects that are extremely small structures, like atoms and molecules. These are things we cannot see with the naked eye and have to trust that they exists in some form or another. We use the idea of these structures to then build up to the construction of the larger structures, like tissues, organs and systems that we can begin to see with our own eyes. Yay!

## Levels of Organization for the Human Body

The "Levels of Organization" is a way of describing how building blocks create the various levels of organization in living organisms. Here is an example below (**Fig. 2.1**) of the basics of what we need to know for about the levels of organization for human physiology.

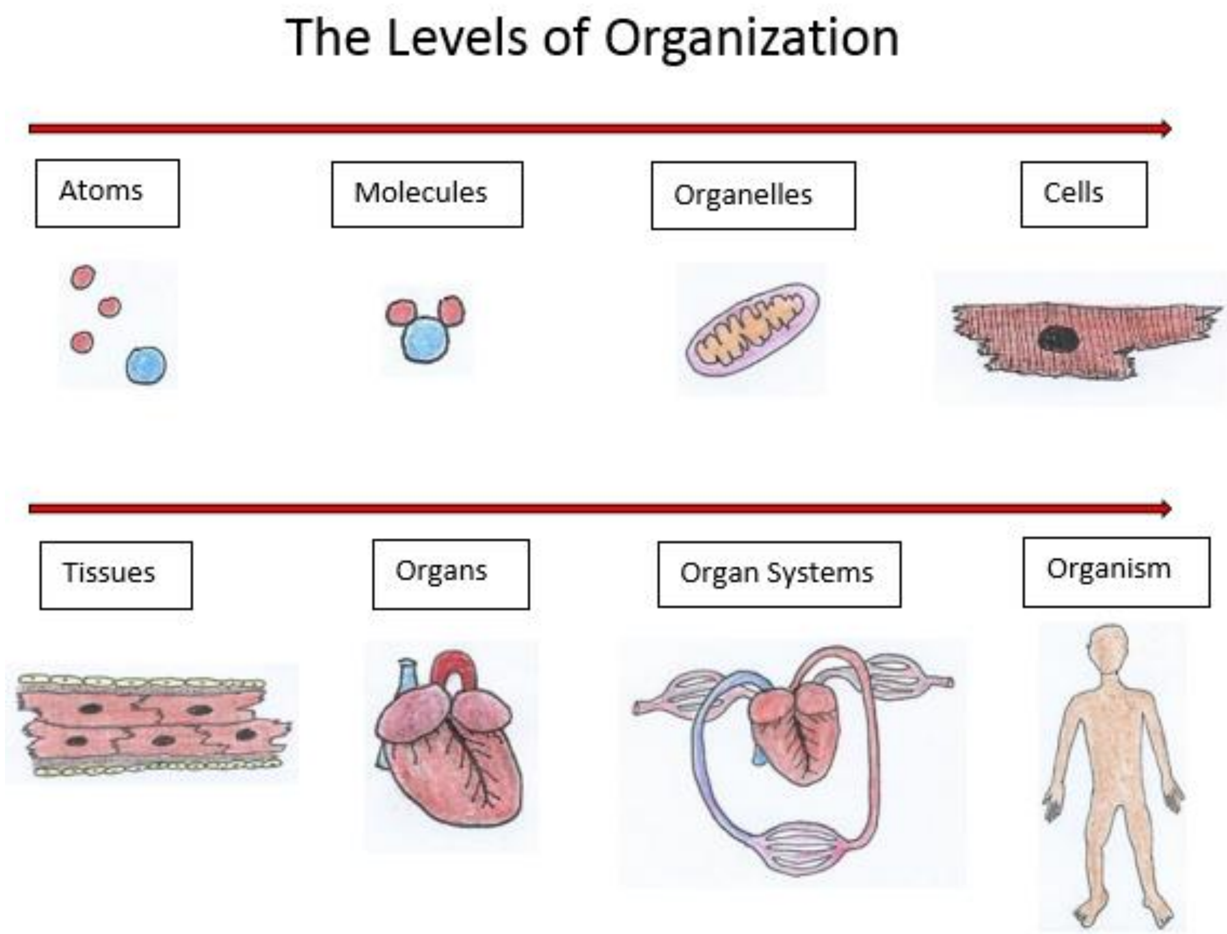



**Figure 2.1** The levels of organization in physiology start with atoms which combine through chemical bonds to form the next level, molecules. These then combine to form the next level, and so on, with each level being the building blocks for the next level, as we move from left to right and to the bottom in direction of red arrow. The levels become more complex as they contain all that came before them, until we get to the human organism.

For physiological systems, the succinct details and definitions of the **levels of organization** that are commonly used in our approach (shown above) are listed and succinctly defined below.

**Atoms** - these are the building blocks where we can begin our discussion, they are the smallest (neutral) particle of an ***element*** that can exist. As you may know, there are subatomic particles (protons, neutrons and electrons) and we will examine the basics of the how these are arranged in an atom in order to understand the nature of ions, chemical bonds and the formation of molecules.

**Molecules** - these consists atoms that are joined together by chemical bonds to make larger structures.

**Organelles** - are a specialized structure contained within a cell (e.g., mitochondria, ribosomes, or a nucleus) that have a specific function and are often compartmentalized from other organelles in the cell.

**Cells** - the smallest unit of life, it is self-contained and metabolically active. There are about 60 trillion cells in the human body! However, there are only about 200 different types of cells in the body.

**Tissues** - contain groups of similar cells and cell products working together to perform a specific function. There are four (4) primary tissues in the body: Epithelium, Connective, Muscular and Nervous.

**Organs** - are composed of two or more tissues working together to perform a higher-level function.

**Organ Systems** - consists of all of the organs involved in performing that fundamental vital function.

**Organisms** - this level includes every previous element and consists of the whole person.

Summary of the order of the Levels of Organization in the body:

**Atoms > Molecules > Organelles > Cells*** (unit of life) **> Tissues > Organs > Organ Systems > Organism**

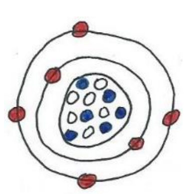
This is a basic approach most texts take when examining each section of the Human Body.

## Atoms, Ions and Chemical Bonds

**Atoms** (e.g., C, H, O) are neutral (not charged) and when they combine by forming chemical bonds they create **Molecules** (e.g., $H_2O$, $C_6H_{12}O_6$). Therefore, molecules are more complex than atoms, and as we proceed up the levels of organization, these levels get more complex but at the same time they are built by the simpler elements. It is important to note that cells are considered the 'unit of life', as single cell organisms, like an **amoeba**, can exist alone and sustain life. Humans are allegedly composed of about 60 trillion cells, many of which we have never seen unaided with microscopes or machinery.

To understand atoms we need to know the basics about the subatomic particles, protons, neutrons and electrons.

**1. Proton** (positively charged). Location: Nucleus
**2. Neutrons** (neutral). Location: Nucleus
**3. Electrons** (negatively charged). Location: Orbitals

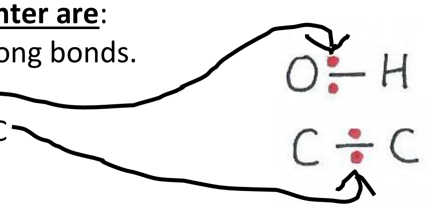


Representation of an atom with the protons (blue) and the neutrons (white) in the central nucleus, and the electrons (red) in orbitals going around the nucleus.

**Valence electrons** = outer shell electrons ($e^-$s). These are very important to know about because these electrons are the ones that are responsible for the chemical properties of the atom and therefore determine the types of chemical bonds the atom will participate in. In the drawing above of a Carbon atom, there are 6 protons, 6 neutrons (in the nucleus) and 6 electrons. Note, the carbon (C) atom has 4 *valence* electrons. This is a significant factor in its ability to bind with other atoms.

**In general, the three types of chemical bonds we will encounter are**:

1. **Covalent bonds** – a sharing electrons between atoms, strong bonds.
    a) Polar: *unequal* sharing of electrons. e.g., $H_2O$
    b) Non-Polar: *equal* sharing of electrons. e.g., C=C




Covalent bonds occur between atoms which have affinity for electrons (that is, they have similar electro-negativities), thus they do not particularly want to give their electrons away to anyone. There are differences in how strongly some atoms tug or pull at the shared set of electrons with other atoms, and this determines if the elections are shared unequally (polar) or equally between them (non-polar).

**Polar covalent bonds** result when electrons are unequally shared between atoms. As seen above, the oxygen atom (**O**) is more electronegative than the hydrogen atom (**H**). Therefore, the electrons (seen as the 2 red dots) are held closer to the **O**, and this creates a slight imbalance or 'polarity' in the charge distribution of the molecule. Water, $H_2O$, is a perfect example of a molecule with polar covalent bonds!

**Non-polar covalent bonds** result when electrons are more equally shared between atoms. Again as seen above in the way the two carbon atoms (**C**) share the electrons more in between them. This gives a more even or 'non polar' charge distribution of the molecule. Many long chain lipids are non-polar and the main reason why they are not soluble (wont mix) with water.

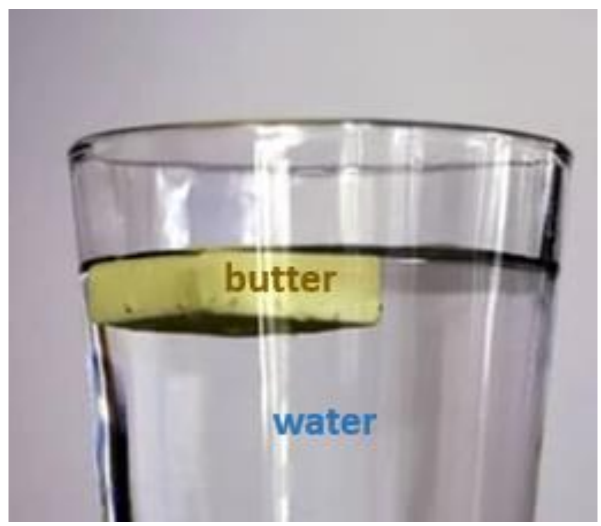



**Figure 2.2** As seen in the photo above, the water in the glass is a polar molecule, and the butter floating on top is a non-polar lipid molecule. Water is also more dense than lipids, hence the reason butter floats on top of the water. At normal body temperature, lipids are much more fluid and integrate very easily into body fluids. Importantly, the notion that lipids 'clog arteries' in the body is total nonsense and has never been shown to occur. As seen to the left, polar bears love water because water is polar!

This is a timely place to mention that understanding whether molecules in the body are **polar** or **non-polar** is of great importance. Maybe think of polar in relation to polar bears and how they love the water (see **Fig. 2.2** above). Water is a polar molecule and any molecules that dissolve in water (are soluble in water) are also polar, or **hydrophilic**, meaning 'water loving'.

2. **Ionic bonds** – complete transfer of electrons, relatively weak bonds that break in water (but strong in crystalline form). Ions are charged particles (atoms or molecules). They dissociated in water to form ***electrolytes*** in solution. Examples are $Na^+$, $K^+$, $Cl^-$, $Ca^{2+}$, $OH^-$, $Mg^{2+}$, $HCO_3^-$, and $H_2PO_3^-$.

The '**octet rule**' helps to explain the tendencies of ionic bonds. Having 8 outer shell (valence) electrons ($e^-$s) is a very stable configuration for an atom to have. Under certain circumstances, atoms give away $e^-$s or accept additional $e^-$s in order to achieve 8 outer shell e-s, hence the 'octet' (8) rule. Atoms that have between 1 to 3 valence $e^-$s tend to 'give them away' and therefore become positively charged ions (**cations**). While atoms with 5 to 7 valence e-s tend to 'take extra' electrons and therefore become negatively charged ions (**anions**). Sodium (Na) is an atom that has 1 valence $e^-$, while Chloride (Cl) is an atom that has 7 valence $e^-$s (see **Figures 2.3** and **2.4** below).

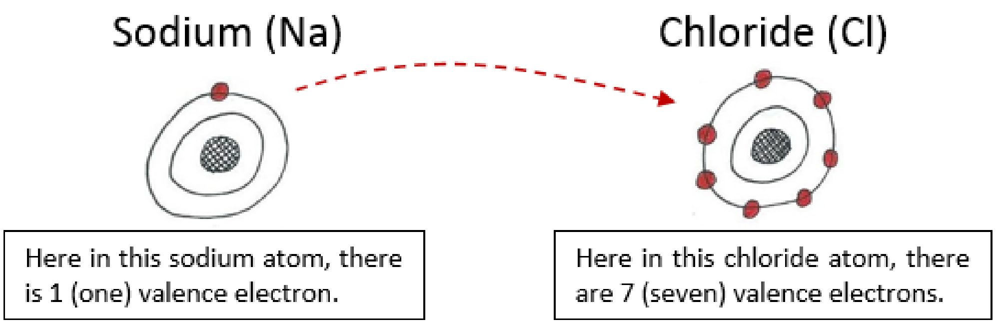



**Figure 2.3** Representations of two important atoms sodium, with the chemical symbol of Na, and chloride with the chemical symbol of Cl. The Na has only 1 valance electron (and will easily lose it), while the Cl has 7 valence electrons and will happily add another in order to get a stable number of 8 valance electrons.

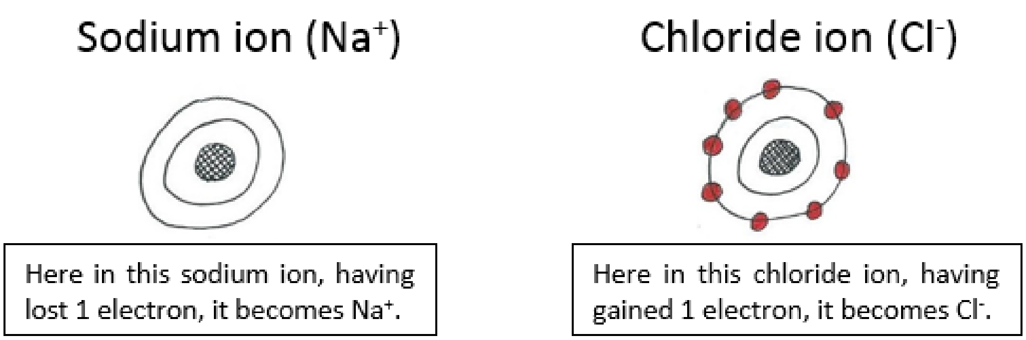
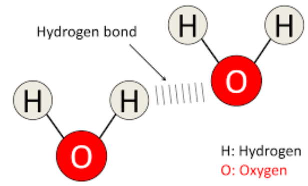



**Figure 2.4** In comparison to Figure 2.2 above, the 1 valence electron of the Na atom jumped over to the Cl atom, making the formerly neutral Na now a cation ($Na^+$) and the formerly neutral CL now an anion ($Cl^-$)

Na and Cl have an important relationship to each other and a significant role in human physiology, as they are important electrolytes that we will commonly encounter. They exemplify the octet rule perfectly as the crystal sodium chloride (table salt) is held together by ionic bonds, yet in water it ionizes such that the Na gives away its 1 valence electron and reverts to the 8 valence $e^-$s in its deeper shell, while the Cl takes that extra $e^-$ so it then has 8 in its outer shell. The Na becomes $Na^+$ and the Cl becomes $Cl^-$.

3. **Hydrogen bonds** – are attractive forces between H atoms and O or N atoms. This force is very weak but extremely important. The molecules that participate in hydrogen bonds are **polar**. As shown below, water molecules ($H_2O$) are the perfect example of how hydrogen bonds generate slight forces individually but cumulatively are extremely influential.




The hydrogen atoms (H) in the example above of water ($H_2O$) are slightly positively charged and thus become attracted to the slightly negatively charged part of other water molecules, the oxygen (O) in this case. This is because the oxygen is more electronegative than hydrogen and creates an uneven sharing of the elections within the bond between them – as already seen in **polar covalent bonds** above.

## Molecules can be Inorganic and Organic

**Molecules** are atoms or groups of atoms joined together by chemical bonds. Importantly in physiology, molecules are categorized as **Inorganic** (do not contain chains of carbon, e.g. $H_2O$, $NH_3$ or **Organic** (contain carbon chains), e.g. $CH_4$, $C_6H_{12}O_6$. These categories are created by the types of atoms that are making up the molecule and the types of chemical bonds that hold them together.

<ins>Inorganic molecules:</ins> Water is the most important inorganic molecule. The human body can be anywhere in between 60 to 80% water!

**Water** ($H_2O$) typically accounts for at least 70% of total body mass in humans. Heck, lung tissue is 90% water (see **Fig. 2.5**). Water is a molecule that exhibits many unique qualities stemming from the nature of its **polar** structure. In physiology, there are **4 Important Properties of Water** that we need to know about, and they are discussed below.

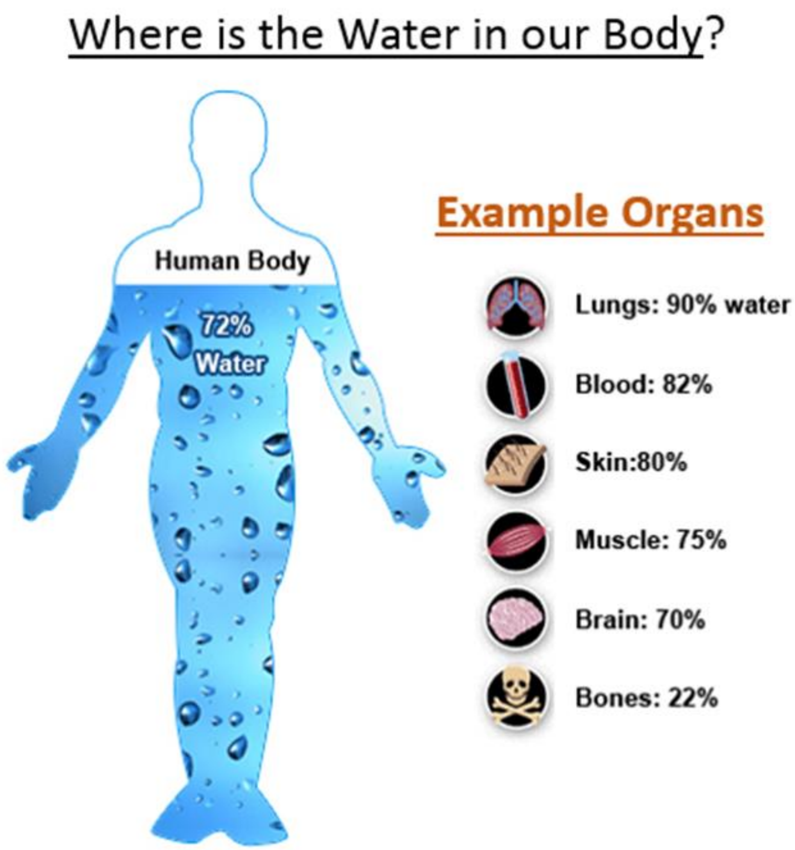
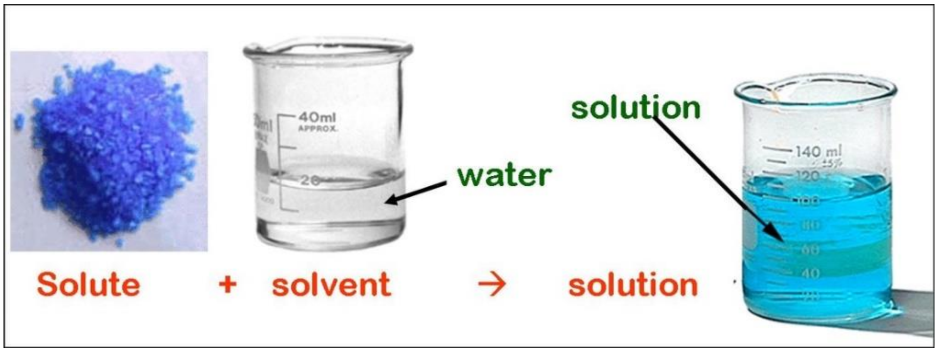



**Figure 2.5** The vast majority of the body is water, and each organ show remarkable variation in water content.

### The 4 Properties of Water

① **<ins>Solvency</ins>** - Water is able to dissolve a wide range of chemical substances, but particularly polar molecules. That is why water is often described as the **universal solvent**. Think of how many important things are dissolved in our bodies right now, all due to the solvency of water!

The pictures below illustrate that a solution has 2 components: The **solvent** (which is more abundant) and the **solute** (present in lesser amounts) that is mixed into the solvent. In human physiology, the solvent is always **Water**.




② **Cohesion** - $H_2O$ molecules have a high affinity for each other (due to their H-bonds) and cling together. $H_2O$ molecules on a surface tend to pull one another from below and inward - this creates the 'beading' appearance of water on surfaces, and creates a force called **surface tension** at the fluid to gas interface, giving the surface of water an elastic surface layer - enough tension for small insects to walk on (see **Figure 2.6** below). This is due to the very strong attraction that water molecules have for other water molecules! This property of water has very significant implications in human physiology.

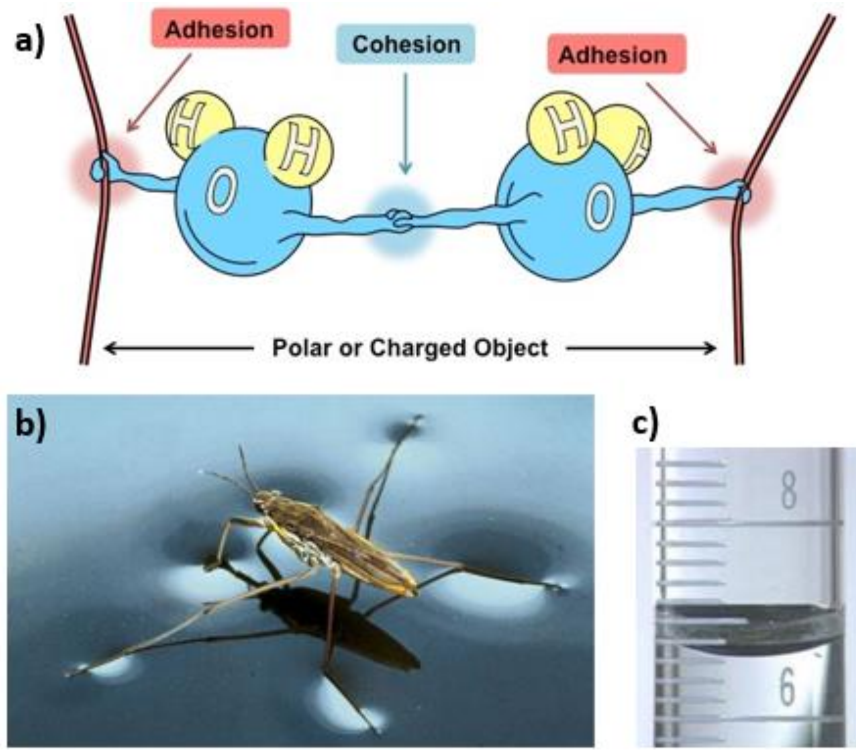
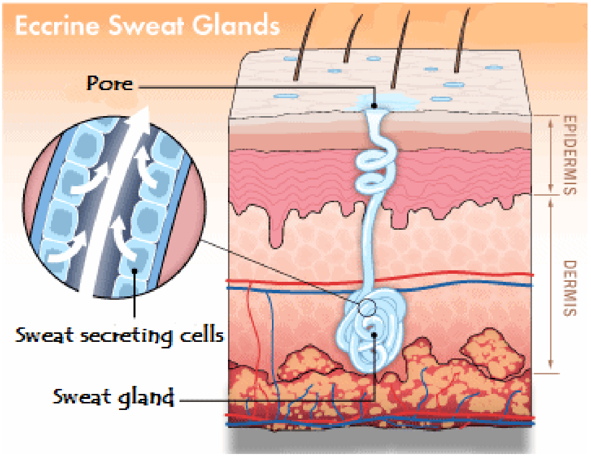



**Figure 2.6**. The forces of **a)** adhesion (sticking to things) and cohesion (sticking to each other) are shown. Surface tension is illustrated in **b)** with a cute bug who can stand on the water due to this force. Water loves to adhere to surfaces as seen in **c)** by the water adhering to the graduated cylinder and crawling up the sides of the surface, creating the lowest portion in the middle called a meniscus. What is the etymology of meniscus?

Water is also able to adhere to many other surfaces other than water, a term called **adhesion**. This is why water tends to 'crawl' up the sides of a test tube and the water level is measured at the meniscus ('moon') which is the lowest portion in the middle.

③ **Thermostability** - The temperature of water remains fairly stable despite changes in the surrounding temperature. This means that **water has a high heat capacity**. In other words, it takes a lot of heat energy




to change the temperature of water, such that heat capacity is *the ability to absorb heat energy with only moderate changes in temperature*. This special quality of water is used to measure energy in metabolic processes. A **calorie** is the amount of heat energy required to raise 1g of water 1° C (from 14°C to 15°C). Water also has a **high heat of vaporization**, in that it requires a large amount of energy to go from a liquid to a gaseous phase. This is the reason why when we sweat and it is blown off in vapor form, it is enormously effective in cooling us down, as so much heat energy leaves with it.

④ **Reactivity** - Water molecules not only dissolve substances but they also actively participates in chemical reactions with many different molecules. Some of the most fundamental reactions require water as a reactant or liberate water as a product. For example: **a) Dehydration Synthesis** involves removing water in order to synthesize are larger, more complex molecule. Whereas **b) Hydrolysis** involves breaking chemical bonds using water, yielding simpler molecules, see **Fig. 2.7** below. Note that dehydration synthesis reactions are **anabolic**, and that hydrolysis reactions are **catabolic**.

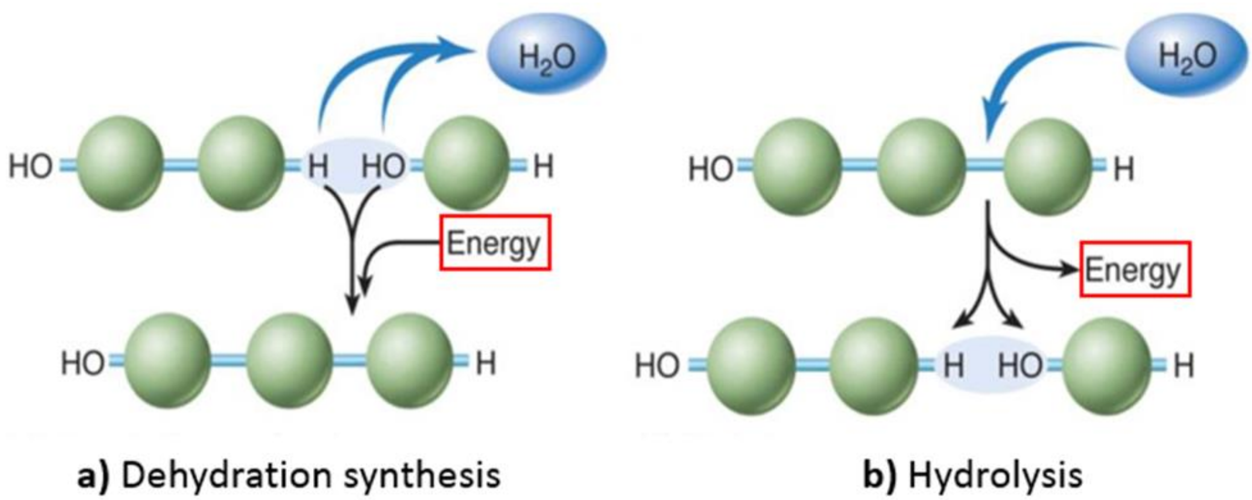



**Figure 2.7** The reactions above illustrate the two (2) basic categories of chemical reactions that water participates in. For **a)** the dehydration synthesis reactions remove water ($H_2O$), invest energy and create larger, more complex molecules. These are anabolic reactions. For **b)** hydrolysis reactions, water ($H_2O$) is added, energy is released and as a consequence this creates smaller, simpler molecules. These are catabolic reactions.

## Structured Water

Interestingly, it is likely that water is more dynamic than we have realized. Many investigators have begun to distinguish a distinct type of water called **structured water**, as separate from what most of us know as water (like the water in a glass), which is often referred to as **bulk water**. Structured water can also be called **coherent water**, **exclusion zone** (EZ) water, **magnetized** water, **crystalline** water, **hexagonal** water, etc. To read more about this water, see the special topic "Structured Water" on the faculty website.

## The Phases of Water

Within the typical range of environmental temperatures and pressures, water is conventionally found in three physical states or phases. We are likely to be very familiar with these phases of water (see below). To briefly put structured water into perspective, it has different qualities to the other states or phases of water we are more familiar with.

**1) Solid** (ice)

**2) Liquid** (fluid)

**3) Gaseous** (vapor)


Several scientists are presenting a **fourth phase of water**. This phase is a plasma-like liquid crystalline gel state, this is the water called **structured**, **coherent**, **crystalline**, **hexagonal**, or **biological** water.

**4) Structured Water** (hexagonal). This is the phase of water in our body tissues and various cells and is not like water in a glass - which is more like bulk water. Rather, structured cellular water is **ordered** and **energetically** enhanced, very much like a crystal, but it's in a fluid state.

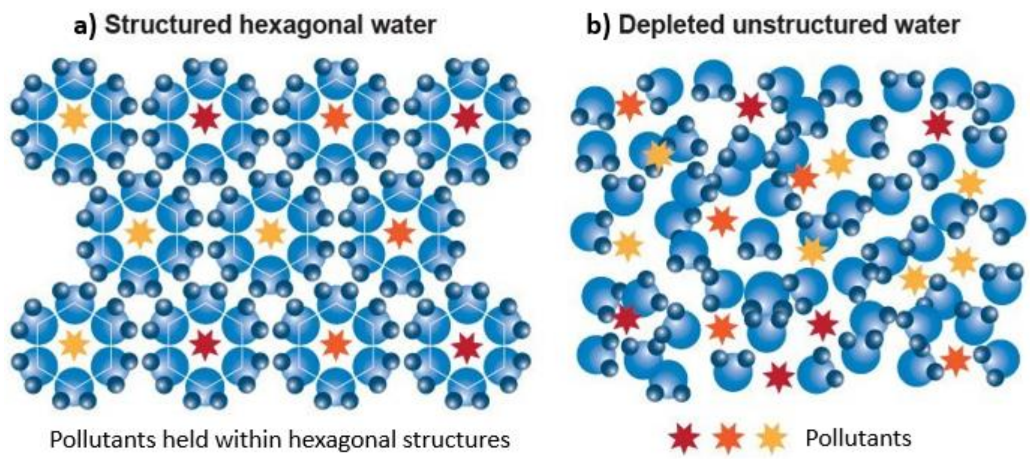



**Figure 2.8** Shows a diagrammatic comparison of **a)** structured hexagonal water, which displays a significant hexagonal order when compared to **b)** depleted and unstructured water. Note the repeating hexagonal pattern in the organized structured water. An element of the potential benefits of structured water is the protective mechanism of how the water molecules interact with each other and with the other elements in its environment.

A working theory is that this water is not in a 'free state' like the water in a glass, but that it is structured in a **hexagonal lattice** (see **Fig. 2.8** above) with the surrounding water. Individual water molecules (**$H_2O$**) form loose ionic bonds creating an **$H_3O_2$** lattice. This imparts more viscosity and it is postulated that it is the basis for creating cellular life. It is a topic of interest, just when we thought we knew everything!

## Minerals

Minerals are inorganic elements from soil, plants and animals that account for about 4% of body mass. More than 75% of this 4% in the body is accounted for by calcium (Ca) and phosphorus (P). Minerals are very important in human physiology in maintaining a healthy body. Sodium (Na) is not bad and should not be avoided – it is absolutely vital for good health. It must be in balance with many other minerals. Potassium (K), Chloride (Cl), Magnesium (Mg), Selenium (Se), Phosphorus (P), etc., all are necessary, but so too are the ***trace minerals***. Trace minerals are needed in very small amounts but needed none the less!

Shown below in **Table 2.1** are the essential minerals and the types of good food you can eat to get them.

**Table 2.1** The important vital minerals needed for good health and some of the foods they are found in.

| Minerals | Dietary Sources |
|---|---|
| **Calcium** | Milk, cheese, dairy, green leafy vegetables, broccoli, cabbage and okra, nuts, bony fish (sardines and pilchards). |
| **Iodine** | Seaweed, sea fish and shellfish, whole grains. |
| **Iron** | Liver, meat, beans, nuts, dried fruit (apricots), whole grains, brown rice, dark-green leafy vegetables. |
| **Boron** | Green vegetables, fruit, nuts. |
| **Chromium** | Meat, whole grains, and whole oats, lentils, spices. |
| **Cobalt** | Fish, nuts, green leafy vegetables, such as broccoli and spinach, such as oats. |
| **Copper** | Nuts, shellfish, offal. |
| **Magnesium** | Nuts, spinach, whole grain bread, fish, meat, dairy foods. |
| **Manganese** | Tea, nuts, green vegetables such as peas and runner beans. |
| **Phosphorus** | Red meat, dairy foods, fish, poultry, whole grain bread, rice, oats. |
| **Potassium** | Fruit such as bananas, vegetables, pulses, nuts and seeds, milk, fish, shellfish, beef, chicken, turkey. |
| **Selenium** | Brazil nuts, whole grain bread, fish, meat, eggs. |
| **Sodium** | Meat products, such as bacon, dairy products (cheese), vegetables, fruits, seaweed. |
| **Zinc** | Meat, shellfish, dairy, wheat germ, seeds (pumpkin, sunflower, poppy), nuts (cashew, pecan, macadamia). |

**Acid-Base** Balance: Water is used to reduce or increase pH levels in body fluids because it can yield an acid $\mathbf{H^+}$ or a base $\mathbf{OH^-}$.

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

An **Acid is a Proton Donor**, which can be a hydrogen ion ($H^+$) and a **Base is a Proton Acceptor**, which can be a hydroxide ion ($OH^-$). The pH of a solution is described as the negative log of the [$H^+$].

### The pH Scale

The pH scale ranges from 0 (strongly acidic) to 14 (strongly basic or alkaline), and the pH right in the middle of this scale of 7.0 is **neutral**. Anything below 7.0 is **acidic** and anything above 7.0 is **basic**. Since the pH scale is **logarithmic**, an increase or decrease of one integer value, say from 6 to 5, changes the concentration by a magnitude of 10! Going from 6 to 4 changes the concentration by a magnitude of 100! Similarly a pH of 11 is ten times more basic than a pH of 10.

Basic ← pH Scale → Acidic

1 2 3 4 5 6 7 8 9 10 11 12 13 14

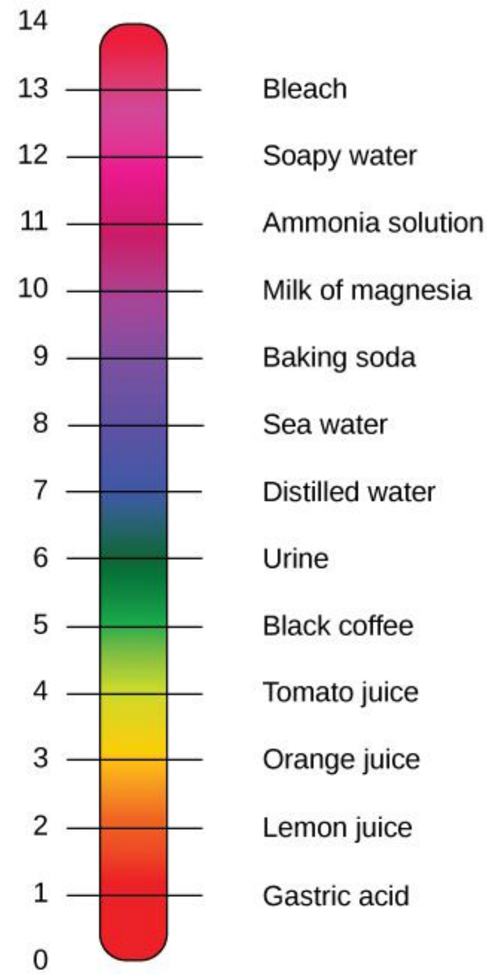
### The pH of Blood

Blood is a very important body fluid and <u>normally blood has a pH in a range between **7.35** to **7.45**</u>. Sometimes people describe blood as neutral. <u>**No**</u>, be very precise here. The pH of blood is over 7.0, and therefore blood is not neutral but normally **slightly basic**. It is very important the blood always remain alkaline (basic) because all of the critical elements, enzymes, receptors, chemical massagers, etc., are designed to work optimally in these alkaline conditions. In fact, if the pH of blood should drop below this range to 7.3, even though it is still an alkaline solution, the term used to describe this condition is

**metabolic acidosis**. Accordingly, although a pH of 7.3 is a basic solution, it is below the normal homeostatic range of 7.35 to 7.45 and therefore considered acidic in reference to **normal physiology**.

**The pH of Other Fluids**

We have introduced that the pH of blood is between 7.35 and 7.45, and other body fluids (such as lymph, cerebrospinal fluid and tissue fluid) also maintain this pH range. However, different regions of the body may have very different pH levels. For instance, during the digestion of proteins in the **stomach, the pH of chyme there is about 2**, this is **highly acidic**, and again since the pH scale is logarithmic, this is a million times more acidic than a neutral solution with a pH of 7.




From the chart to the right, we can see that orange juice has a pH of 3 and lemon juice has a pH of 2. This means that lemon juice is 10 times more acidic that orange juice! If you have been in the kitchen with oranges and lemons, you may be able to testify to their substantial difference in acidity from experience.

Other areas of the body, such as the small intestine, are more basic. For instance, after the gallbladder releases **bile, the small intestine has pH of about 8.** As we will see in the next section, the pH of the body’s surroundings have an enormous impact on the activity of enzymes and other structures.

**You need to be Alkaline – Not Acidic!**

As an important health note, the condition of **metabolic acidosis** is literally a gateway to **disease states**. If people wish to avoid an array of disease conditions, it is imperative that people not become acidic, and this includes our thoughts and emotions! For optimal physiological functions, we need to remain alkaline. Get rid of toxic acidity in your life! Be more Basic.

**Do not inhibit your Own Breathing – it creates metabolic acidosis and is Very Bad for your Health**

There are important things you can do to remain basic and healthy. One example is not to cover your face unnecessarily with restrictive masks that compels the wearer to re-breathe their own $CO_2$. This is not a healthy thing to do in normal natural circumstances.

If you are spray painting or there are other definable concrete aerosolized toxins in your environment, by all means, protect yourself from inhaling them. However, in the normal state of existence the body was not designed with a mask over the mouth and nose for a reason – you do not need the additional barrier, and it causes great harm to do so for any extended length of time. Re-breathing $CO_2$ that was intended to be exhaled will create **hypercapnia**, which causes a decrease in your body’s pH. Almost every disease state you can think of begins with having chronically depressed pH of body fluids.

**Consume More Alkaline Food**

Here are the top **10 alkaline foods** you can eat to keep you from being acidic: Swiss chard, Dandelion greens, Spinach, Kale, Almonds, Avocado, Cucumber, Beets, Figs and Apricots (see **Figure 2.9** below). Who could say no to avocados? Foods that make the body more acidic: Refined sugar, processed foods and grains, alcohol, bad coffee, sodas, breads and too many bad tomatoes.


**Figure 2.9** Shown above are the 10 most important alkaline natural whole foods that can be consumed to prevent human body fluids from being too acidic.

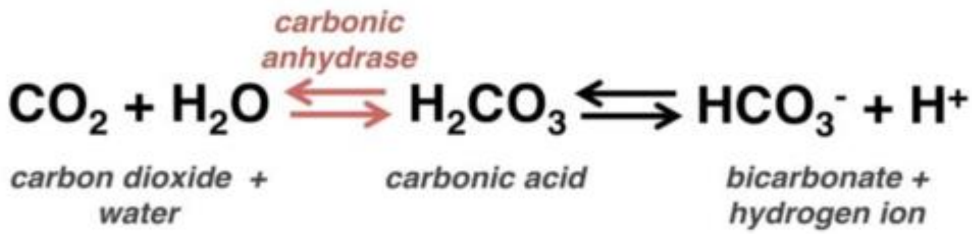
For good measure, below in **Fig. 2.10** are some of the 'foods' you'd want to avoid or significantly reduce if you want to remain basic, or keep your body in a healthy alkaline state.


**Figure 2.10** It may not be a surprise to most that the categories of food shown above create highly acidic conditions in the body. Chronic consumption of these products can lead to metabolic acidosis. If they cannot be avoided entirely, try to reduce them, as the acidic promotion may be the least of their harmful actions.

### The Importance of Buffers in Physiology

A buffer is a solution that resists changes in pH. The actions of buffers in physiologically systems are very important, since the efficiency of many enzymes and metabolic reactions are sensitive to changes in pH. A physiological buffer system usually consists of a weak acid and its conjugate base.

An example of a buffer system commonly used in the body is the **bicarbonate buffer system** (shown below). This is an acid-base equation involving the balance of carbonic acid ($H_2CO_3$), bicarbonate ion ($HCO_3^-$), and carbon dioxide ($CO_2$) in order to maintain the pH of the blood and other tissues.




### Reversible Reactions, Reaction Rate, and the Law of Mass Action

Reversible reactions proceed to a state of equilibrium, where the forward reaction rate = the reverse reaction rate. For example, adding more substrate increases the forward reaction rate and more product forms in order to establish equilibrium.

### The Law of Mass Action

The **Law of Mass Action** is part of **Le Chatelier's principle**, which states that if a system at equilibrium is disturbed by a change in concentration of one of the components or in temperature or pressure, the system will shift until a new equilibrium is reached. It represents a method of self-balancing.

Law of Mass Action can also be described this way:
*The direction of a reversible equation (forward or reverse) will be driven by the amount of reactant (substrates) or products present; the direction of the reaction will be to decrease whatever is in abundance, until equilibrium is reached. At reaction equilibrium, the ratio of substrates to products is always equivalent; the system adjusts the ratio until equilibrium is restored.*

## Organic Molecules

The organic molecules we will be looking at can be categorized into three main groups based on their molecular components and our dietary intake. They are **1) Carbohydrates**, **2) Lipids**, and **3) Proteins**. There is also another very important organic category called **Nucleic Acids** (DNA, RNA, ATP, GDP, etc.), although we will not be covering these until later sections.

From basic chemistry, we know that the **Carbon** atom has 6 protons, 6 electrons and most commonly 6 neutrons (Hmmm!). In terms of its orbital or electron shell configuration, carbon has 4 outer shell, or valence electrons. Thus, it can make 4 covalent bonds, giving it versatile qualities.

If we recall the *octet rule*, many atoms are more stable when they can achieve having 8 outer shell elections. As it turns out, because the Carbon atom has 4 valence electrons, it is most stable when it makes covalent bonds (sharing of electors) with other atoms in order to create 8 (4 shared pairs) of electrons. This is worth mentioning because this is what is responsible for the tremendous versatility of chains of carbon molecules, allowing the categories to be very different yet also share common features.

**Carbohydrates** = C + $H_2O$. The name comes from the notion that the carbons are hydrated.
A primary function of carbohydrates is as an energy (E) source, but they also function as energy storage. Carbohydrates supply the C for cell components and structural elements of some cells.

**Monosaccharides** – simple sugars (monomers). Here are three common examples:
1. Glucose – the most commonly used molecule as a source of E in the human body.
2. Fructose – a simple sugar found in fruits (fruit sugar).
3. Galactose – a component of milk sugar.

**Disaccharides** – 2 monosaccharides joined together by a glycosidic bond. Important examples:
1. Sucrose (table sugar) = glucose + fructose
2. Lactose (milk sugar) = glucose + galactose
3. Maltose (grain sugar) = glucose + glucose

**Polysaccharides** – common examples of complex carbohydrates – all are polymers of glucose.
**1. Glycogen** – the storage molecule for glucose in animal cells. Found in the **liver**, **skeletal muscle** and the **uterus**.

**2. Starch** - the storage molecule for glucose in plant cells. Think of potatoes and rice, this is a way for plants to store energy.

**3. Cellulose** – this is a structural component in plants for their cell walls. Cellulose is a type of 'fiber' in our diets and because humans lack the enzyme to catabolize it, we cannot utilize this molecule for energy, but the good microbes in our gut love it!

**Lipids** = C, H and O but not a 2:1 (H:O) ratio as in carbohydrates, much less O. Non-polar molecules.

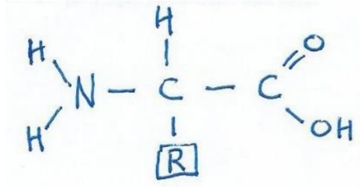
**Examine the 4 primary types of lipids**
**1)** Fatty Acids – 4 to 24 C's long with carboxylic acid and methyl group at either end. Rich source of Energy. Compare Saturated and Unsaturated (mono and poly) fatty acids.

**2)** Triglycerides – Made from 1 glycerol and 3 Fatty Acids. A *storage* molecule. Most abundant lipid in body and diet. Rich source of Energy, has at least 2 x the energy as carbohydrates.
Draw a Generalized Triglyceride:

**3)** Phospholipids – Similar to triglycerides: 1 glycerol + 2 F.A.'s + Phosphate group (+ N compounds)
An Amphiphilic molecule, has a *polar* head and *non-polar* tail region. Most abundant and important lipid molecule in the plasma membrane of cells. Draw a Generalized Phospholipid:

**4)** Steroids – A lipid with 17 of its C atoms arranged in 4 rings (3 x 6-C and 1 x 5-C rings). Most abundant steroid in human body is Cholesterol – important structural component of plasma membrane and precursor to many other important steroid lipids. Examples of other steroids are: progesterone, estrogen, testosterone (sex hormones), cortisol, Vitamin D.

**Proteins** = C, H, O, N, S. Most versatile and complex of the organic molecules. Largest range of functions.
Amino Acids (AA's) are the building blocks of proteins.
Draw a Generalized Amino Acid like the one shown:




**Levels of Structures of Proteins:**
**Primary** (1°) - linear sequence of amino acids joined together by covalent 'peptide' bonds.
**Secondary** (2°) - the formation of alpha (?) helix or beta (?) pleated sheet due to hydrogen bonds.
Tertiary (3°) - the three dimensional folding of protein, due to interactions of functional groups.
Quaternary (4°) - interactions of several polypeptides chains with each other (not all proteins).

**Functions of Proteins:** Proteins can be either Globular or Fibrous (based on form or shape)
Some functions are: Structural, Catalytic, Transport, Contractile, Regulatory, and Immunological.

## Energy and Thermodynamics

What is Energy? The capacity to do work.
What is Work? Moving things.

**1)** Chemical Work - making and breaking chemical bonds (investing and releasing Energy).
**2)** Transport Work - movement of substances across a concentration gradient (plasma membrane).
**3)** Mechanical Work - movement of a 'whole'; organelles, flagella, muscle fibers inside cell.

| Two forms of Energy → | **Kinetic Energy (KE)** | and | **Potential Energy (PE)** |
|---|---|---|---|
| | Energy of motion (chemical, transport, mechanical) | | Energy that is stored (concentration gradient, chemical bond) |

KE and PE can be converted from one form to the other but it is never a 100% efficient conversion.
Work (chemical, transport, mechanical) involves the conversion of the 2 forms of energy.

## Thermodynamics - How Energy is converted to Work.

1st Law of Thermodynamics
Energy can be converted from one form to another but cannot be created or destroyed. Energy in the universe is constant.

2nd Law of Thermodynamics
**1)** In every Energy transfer, some Energy becomes heat and can no longer do useful work.

**2)** Natural spontaneous processes move from a state of order (non-randomness) to a state of disorder (randomness) known as Entropy (S, the degree of randomness).

## Example of Conversion of Energy into Work

**The Automobile:**

Fuel (PE) in a car used to move car (KE).

If $100 of fuel is used, $87 is lost as heat and exhaust and only $17 is used for the movement of the car. This means that the machinery is only 17% efficient in converting the fuel (PE) into movement (KE). Only 17% of original investment can be deemed useful work according the 2nd Law of Thermodynamics.

**The Human Body:**

Fuel (PE) in a person used to move and operate body (KE).

If 100 Kcal of fuel in the form of food is consumed, about 60 Kcal are lost as heat and about 40 Kcal are used for movement (chemical, transport and mechanical) of the body. This means that our machinery is only 40% efficient in converting the fuel (PE) into movement (KE).

Efficiency of the human body can change depending on the activity of the body. When exercising, for example, at least 70% is lost as heat energy and only 30% used for muscle contraction.

## <u>Chemical Reaction in the Body</u> – used to *Store*, *Release*, or *Transfer* Energy.

Metabolism - Sum total of all chemical reactions in body. **Metabolism** = **Anabolism** + **Catabolism**

### 1) Endergonic Reactions – Require Energy input

e.g. A + B + *E* → C

A specific example:

The formation of a dipeptide from 2 amino acids.

The removal of water ($H_2O$) to create a larger molecule is called a <u>Dehydration Synthesis</u> reaction.

Overall, these can be referred to as Anabolic Reactions – they are synthesizing something, building a more complex, larger molecule from simpler, smaller molecules and they require input of E.

<u>Other examples</u>
* making a di- or polysaccharide from monosaccharides
* making a mono-, di- or triglyceride from glycerol and 1 to 3 fatty acids.
* What plants do: **$CO_2$ + $H_2O$ + E → Glucose!**

### 2) Exergonic Reactions – Release Energy

e.g. A + B → C + D + *E* (or C → A + B + *E* )

A specific example:

The breakdown of a dipeptide into 2 amino acids.

Often in biological systems water ($H_2O$) is used to break chemical bonds, this is called <u>Hydrolysis</u>.

Overall, these can be referred to as Catabolic Reactions – they are breaking down chemical bonds. Large molecules are broken down to produce smaller molecules and they release E that can be used for physiological work.

<u>Other examples</u>
* creating 2 monosaccharides from a disaccharide.
* creating 2 fatty acids and 1 glycerol from a diglyceride.
* What we humans do: **Glucose → $CO_2$ + $H_2O$ + E!**

## Review Questions for Chapter 2: Chemistry of Physiology

**1.** Organs are made from combining:
- **a)** atoms
- **b)** organelles
- **c)** cells
- **d)** molecules
- **e)** tissues

**2.** The structural polysaccharide in plants is _____: In humans, the storage molecule for glucose ______.
**1.** glucose **2.** triglycerides **3.** cellulose **4.** lipids **5.** glycogen **6.** starch
- **a)** 1 and 6
- **b)** 3 and 1
- **c)** 6 and 2
- **d)** 3 and 5
- **e)** 2 and 5

**3.** If an atom or molecule becomes *positively* charged, it is referred to as
- **a)** an electron
- **b)** a cation
- **c)** an anion
- **d)** a proton
- **e)** an ion

**4.** If a glycerol and three fatty acids combined, this would yield:
- **a)** free fatty acids and glycerol
- **b)** glucose
- **c)** diglyceride
- **d)** monoglyceride
- **e)** triglyceride

**5.** If solution A has a pH of 6, and solution B has a pH of 5, then which statement is **true**?
- **a)** Solution B is less acidic than solution A.
- **b)** Solution A is 10 times more acidic than solution B.
- **c)** Solution B is 10 times more acidic than solution A.
- **d)** Solution A is twice as acidic as solution B

**6.** If a complex molecule is broken down to simpler molecules, what specific type of reaction is it?
**1.** anabolic **2.** catabolic **3.** exergonic **4.** endergonic **5.** dehydration synthesis
- **a)** 2 and 3
- **b)** 5 and 3
- **c)** 1 and 4
- **d)** 1 and 5
- **e)** 3, 2 and 5

**7.** Molecules which readily **dissolve in water** are called

- **a)** non-polar
- **b)** hydrophilic
- **c)** lipophilic
- **d)** hydrophobic
- **e)** hydroponic

**8.** Which of the following is **<u>not</u>** a carbohydrate?

- **a)** glycogen
- **b)** glucose
- **c)** phospholipid
- **d)** starch
- **e)** cellulose

**9.** All of the following describe the properties of water <u>except</u>

- **a)** it absorbs heat very quickly
- **b)** many things are solvent (dissolve) in it
- **c)** it is very cohesive
- **d)** it can participate in chemical reactions
- **e)** it is very adhesive

**10.** Which of the following describes **non-polar covalent bonds**?

- **a)** Weak attractive force between a H in one molecule and an O or a N atom in another molecule.
- **b)** Sharing of outer shell electrons by two or more atoms unequally.
- **c)** Complete transfer of outer shell electrons from one atom to another atom.
- **d)** Sharing of outer shell electrons among two or more atoms equally.

*Answers in Appendix B*