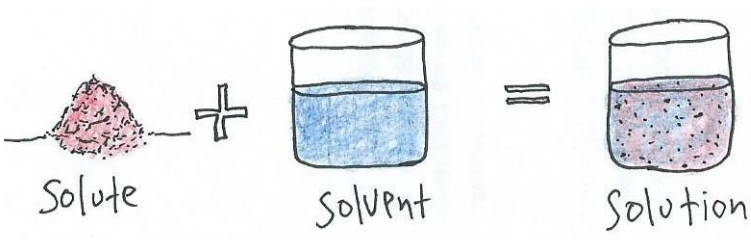
Section One: Chapter 6: Physiological Solutions

Introduction to Physiological Solutions

Solutions in the human body play an instrumental role in physiology. The composition of a solution in a particular region of the body will have an impact on everything around it. Therefore, we need to know what solutions are, how to measure them, and how exactly they impact the human body.

What is a solution?



A **solute** is added to a **solvent** to make a **solution**. Various molecules can be solutes (including liquids) and the solvent is distinguished by being present in greater abundance than the solute. In physiology, **the solvent is always water** (H_2O). In fact, at least **70%** of the body is water!

Concentrations of Solutions: As we study various solutions in human physiology we will examine the conventional methods of expressing concentrations of solutions and use this information to examine how the body responds to these solutions.

Electrolyte Solutions: All body fluids (e.g., blood, lymph, cerebrospinal, interstitial fluid, etc.) are **electrolyte solutions**, meaning they contain ions (charged particles) such as Na^+, K^+, and Cl^- that are dissolved in water. This is a very important concept in physiology, as electrolyte solutions are necessary to maintain water balance, stabilize pH of body fluids and they are used to conduct electrical current used in communication.

The 3 Tissue Compartment Volumes of the Body

Physiologists divide the solutions of the body into different 'compartments' of **intracellular fluid (ICF)** and **extracellular fluid (ECF)**. The **ICF** is the solution found inside cells and **ECF** is the solution in which cells are bathed in. The ECF can be further divided into **a) plasma**, which is the fluid component of blood and is contained within blood vessels; and **b) interstitial fluid**, which is the fluid found in the interstitial spaces of the body (see **Figure 6.1** below). All of these fluids function to provide the body's cells with the vital elements they need, to protect cells and to assist them in dealing with changes in their environment.

Body Fluid Compartments

It has been estimated that the human body is anywhere from **60** to **75% water**, thus the human body is ultimately a myriad of solutions. In a typical 150lb (75Kg) person, that can equate to about 42 liters or 10 gallons of water that is contained in one person.

As discussed above, the body's fluids are separated into two main compartments: Intracellular fluid (ICF) and extracellular fluid (ECF). Of the 42L (or about 10gal) of water found in the body, most of it, about 70%, is within the cells (intracellular fluid). So that water is the structured water that resides inside our cells. This is amazingly complex water that we are still learning more about all the time.

Water

As we have learned so far in this text, water is vital to life and it is also very versatile. Water is the great **Universal Solvent**. Water is an inorganic molecule which is transparent, tasteless, odorless, and almost colorless. Not only is it vital to the Earth's existence, but also vital for all forms of life! It is one of the six (6) categories of 'nutrients', along with carbohydrates, lipids, proteins, minerals and vitamins.

In all of the solutions that we encounter in physiology, **water** is the solvent which dissolves many solutes to yield various solutions.

Our initial focus in physiology is on the general body fluids that compose the three tissue compartment volumes of the body, those being: **1)** Plasma (sometimes referred to as *intravascular* fluid); **2)** Intracellular fluid (ICF); and **3)** Extracellular fluid (ECF). There are many other solutions at specific locations or within our bodies that are very useful to be familiar with. It is also valuable to know the basics about these body fluids as we will see them again in the various systems ahead of us in physiology. Described and listed alphabetically at the end of this chapter are examples of the common different specific body fluids in the body. OK, back to the 3 tissue fluid compartments!

The Three Tissue Fluid Compartments

Essentially all fluid in the body can be described as being in one of 3 different compartments (see **Fig. 6.1**):

1. Intracellular fluid (ICF): the fluid *inside* cells (within the plasma membrane).

2. Interstitial fluid: the fluid *in between* cells directly bathing them (tissue fluid).

3. Plasma: the fluid portion of blood, it can also be referred to as vascular volume.

} Extracellular Fluid (ECF)

Tissue Fluid Compartments

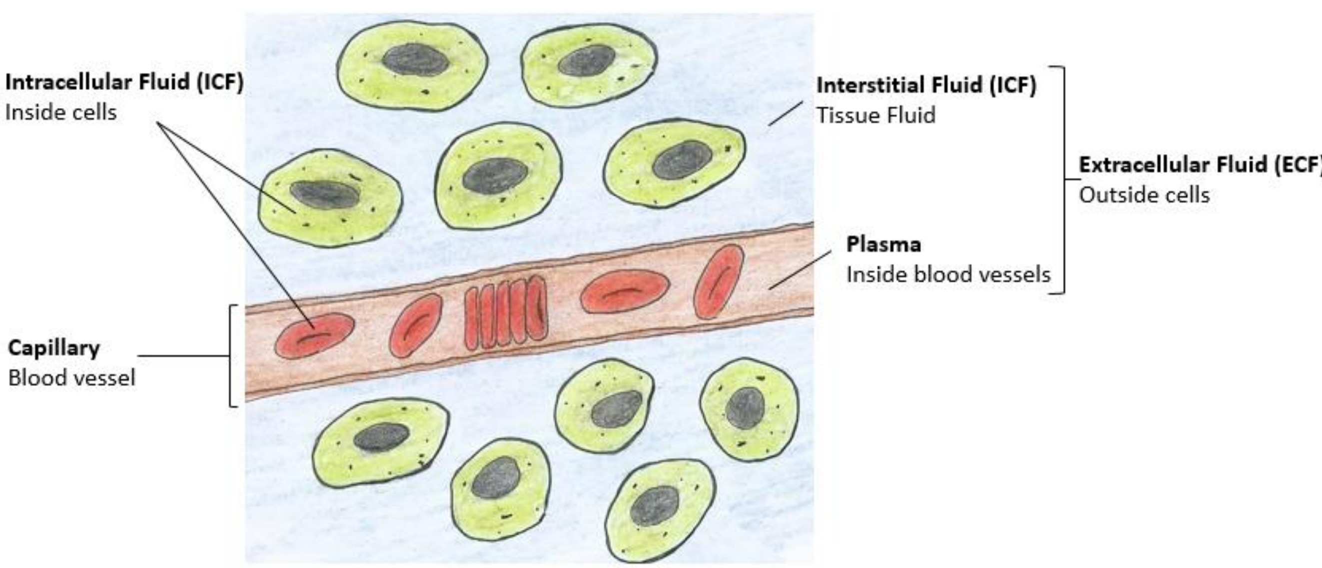


Figure 6.1 Shown in the diagram above are the three tissue compartment volumes of the body, **1)** Intracellular fluid (ICF) which is contained inside all cells, even those cells inside blood vessels; and **2)** Plasma, which is completely contained within the blood vessels; and **3)** Interstitial fluid, which is fluid in between the cells in the tissue. Both plasma and interstitial fluid are extracellular fluid (ECF), which just means that this fluid is outside the cells.

The term extracellular fluid (ECF) simply means the fluid outside of a cell. So you can see that both **plasma** and **interstitial fluid** are considered to be **ECF**. The term 'interstitial' is from the word *interstitium*, both are derived from Latin. Here is another example of how useful etymology is, and the origin of this word is in appendix A. Basically this word means 'in between', like the space in between other things. It is a great description of this fluid, it really is found in between the cells and other structures in the tissues.

In a healthy human body, all of these fluids must have an osmolarity within the range of **295 to 310 mOsM**. However, they differ dramatically in the relative concentrations of important ions and molecules. **Table 6.1** below shows an important comparison of the relative concentrations of the critical components K^+, Na^+, Cl^-, Ca^{2+} and proteins. In later sections the actual concentration (M) values will be discussed, however at this time the most important issue is the relative amounts in comparison to each other and what body fluid volume it is.

Table 6.1 A comparison of the relative concentrations of common ions and proteins found in the three tissue compartment volumes, the plasma, interstitial and intracellular fluid.

Ion or Molecule	Plasma	Interstitial Fluid	Intracellular Fluid
K^+	↓	↓	↑
Na^+	↑	↑	↓
Cl^-	↑	↑	↓
Ca^{2+}	↑	↑	↓*
Proteins	↑↑	↓↓	↑

*In muscle cells, calcium ions (Ca^{2+}) are stored intracellularly in the sarcoplasmic reticulum (SR).

Distribution of Water and Solutes in the Body

As we work our way to fully understanding how living cells function, we will see the importance of maintaining various differences across the plasma membrane.

At the end of this chapter we will pull together everything that has been presented relating to why cell membranes are set up the way they are. All living cells constantly use energy to maintain a state of **chemical** and **electrical** ***disequilibrium*** (un-evenness) across the cell membrane. That may seem surprising at first, but as we will see the different chemicals (concentration of substances) and different electrical charge (voltage) across a cell membrane give the cell **potential energy**. From the earlier information in chapter 2, this means stored energy by virtue of position. This creates an **electrochemical gradient** (a disequilibrium) across the cell membrane as a way of storing energy there for the potential to do **work**. Recall that work can be defined as **moving things**!

These differences created across cell membranes (including capillary endothelial cells that make the walls of blood vessels) are maintained by **active protein transporters** which move solutes *against* their concentration gradients constantly. This action leads to and maintains the chemical and electrical disequilibrium across the plasma membrane of cells. As things are constantly being moved up or against their gradients, this requires a constant input of energy in the form of **ATP** that must be generated in all living cells.

The Distribution Water in the Body

Water is everywhere in the body, and there can be considerable variation in the percentage (%) of water that any one individual has. This can vary with factors such as age, health, water intake, weight, and sex. As seen in **Figure 6.2** below, in terms of the three compartments, most of the water is inside cells or bathing cells. What is also displayed below, and is very interesting, is the variety of levels of water in the various organs. For example, the liver is extremely important in detoxifying our bodies, and it is about 85% water! Although bones contain only about 22%, water, in life bones are not dry and light, they are saturated with water and dense. It is seen repeatedly how vital water is to our existence.

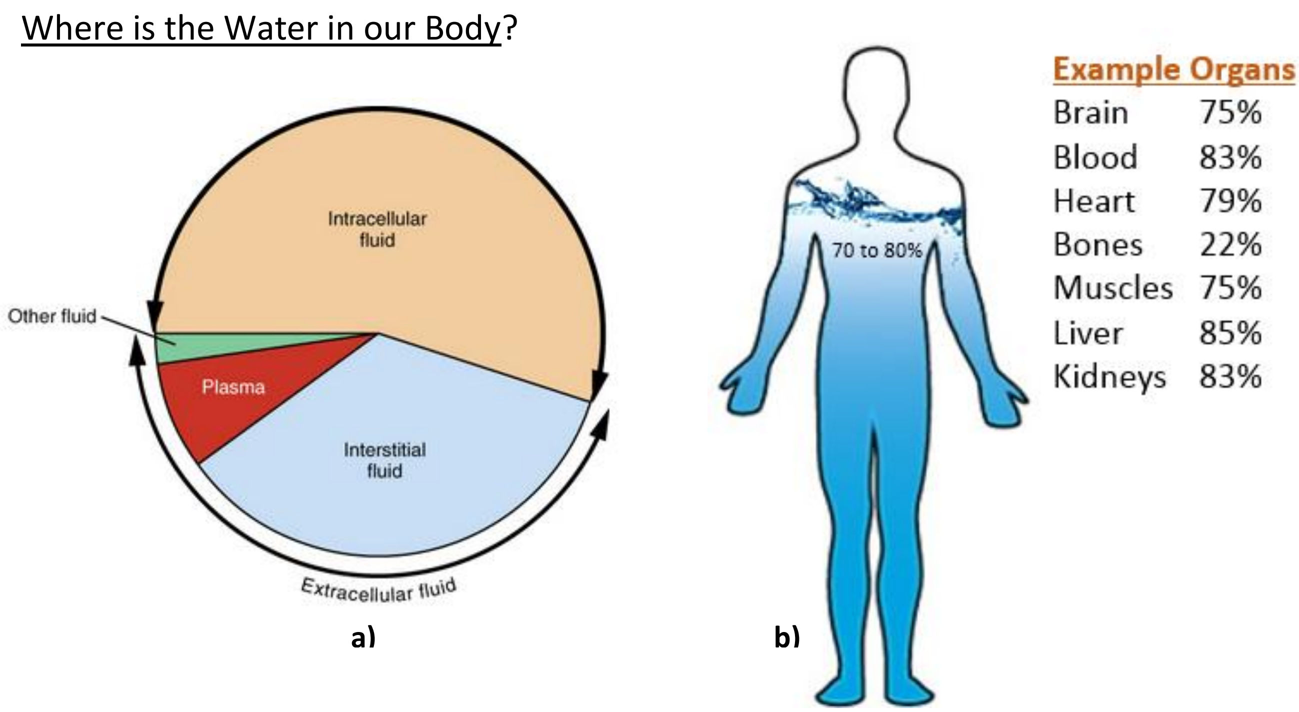


Figure 6.2 The proportions of water in the body in terms of **a)** the three tissue compartment volumes, and **b)** a few specific examples of key organs in the body. In the pie chart **a)** we can see that most of the water is located inside cells, or is intracellular fluid (ICF), this makes sense since we have trillions of cells. Also notice that plasma and interstitial fluid are extracellular fluid (ECF). Examples of 'other fluid' represent a small percentage but are very important. A list of other body fluids is included on page 110.

There are many studies with slightly varying results, but we can safely state that most adults are composed of at least about **70%** water. Again, this means that we are mostly water! Most of this water is in the cells. The total amount of water in the extracellular fluids in the body are split with the plasma being about **8%** of the ECF and the interstitial fluid is about **25%** of the total ECF.

Changes Water content over a Lifespan

Despite the observed changes in total body water, both animal and human studies indicate that there is little or no change in the relationship between total body water and fat-free mass with aging. At the same time, it is likely that infants and children require proportionally greater volumes of water than adults to ***maintain*** their fluid equilibrium and are more susceptible to volume depletion. This is also likely true regarding the elderly.

Physiological Solutions

Let's take a closer look at some fundamental **Physiological Solutions**.

Essentially we will be examining the concepts with the checkboxes ☐ below in order: First we will review the concept of osmosis, because the most important part of assessing solutions is to figure out where water will go. Then we will outline the definitions and categories of the solutions of molarity, osmolarity, tonicity, and percentage (%) solutions.

The exercises provided in this chapter will interconnect all of these solutions so that by the time we arrive at the calculations for % solutions, it should make perfect sense why knowing this information is useful.

- ☐ **Osmosis – Where will water go?**
- ☐ **Molar Solutions and Molarity**
- ☐ **What is Osmolarity? How do we calculate it?**
- ☐ **Assessing Tonicity of Solutions**
- ☐ **Converting Molarity to Osmolarity from % Solutions**

Osmosis

Osmosis is <u>the net movement of water across a semipermeable membrane from a higher water concentration to a lower water concentration</u>. Simply put, osmosis is a special case of **diffusion** for water. Essentially water can pass through any cell membrane in the body, there are very rare exceptions in the body (which will be covered in the renal section), thus we can assume that water is freely permeable. So where will water go? It will always go to where it is less. Also, if allowed, water will move freely to where it is less until **osmotic equilibrium** is reached, that is, until there is no longer any water gradient.

When we know the concertation gradients for various substances on either side of a membrane, we can predict where water will move and this is a powerful tool.

Molarity

Molarity is an important way to measure the concentration of solutions. It is defined as **the number of moles** in 1.0 liter of solution, expressed in units of moles per liter, Molar (M) or mM solutions. More on this below.

Osmolarity

Osmolarity describes the **number of particles** per 1.0 liter of a solution in units of Osmoles per liter, or Osmol/L or OsM or milliosmoles (mOsM). Osmolarity takes into account the dissociation of molecules in solution and converts molarity to osmolarity. Osmolarity (osmol/L) = molarity x (the number of particles in solution). Osmolarity depends solely on the number of particles per liter of solution.

Tonicity

The tonicity of a solution is a measure of its **strength**, the word comes from how the strength of a muscle can be referred to as its 'tone' or tension. A solution is made up of two components; the **solvent** (water in physiology); and the **solute** (whatever is dissolved in the water). By definition, the solvent is more abundant than the solute and the relative concentration of the solute will determine the tonicity (or strength) of a solution. Importantly, the tonicity of a fluid determines how the volume of a cell will change if placed in that solution. Tonicity has no units, it is always comparative. This means that the terms **isotonic** (same), **hypertonic** (too high) and **hypotonic** (too low) are used in physiology.

A. What is a Mole?

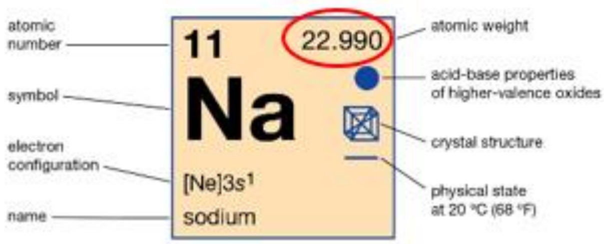
A mole of any substance = 6.02 x 10^{23} particles of that substance, e.g., 1 mole of sodium (Na) atoms = 6.02 x 10^{23} Na atoms. To which one might say, "Whatever". The reason we need to understand the basic chemistry is so we can apply it to solving problems related to **physiological solutions**.

B. What is Mole Weight or Molecular Weight (MW)?

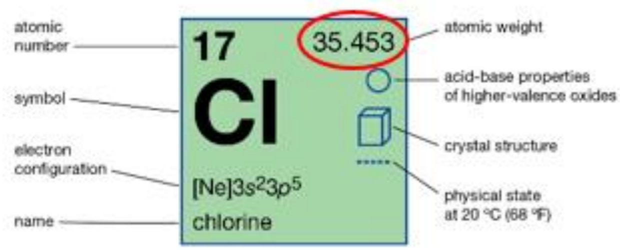
By agreement, the ***mass of 1 mole of atoms or ions*** *or* ***a molecule or an ionic compound*** *is numerically equal to the* ***atomic mass of that atom in grams****.*

To find these values, we consult a **periodic table of the elements**, found in the back of most physiology textbooks or online. There we will see that Na has an atomic mass of 23.0. Therefore 1 mole of Na = 23.0g.

Sodium



Chlorine



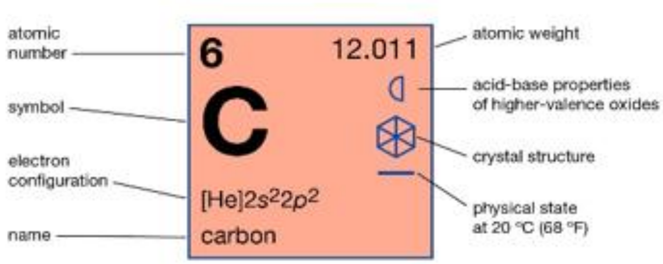
To get the hang of how this works, find the following:

1) Cl has a molecular weight of __________, therefore 1 mole of Cl = _______________.

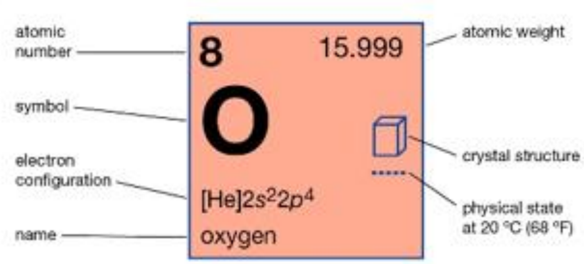
2) NaCl has a molecular weight of __________, therefore 1 mole of NaCl = _____________.

Here is the periodic table information for Carbon and Oxygen. Hydrogen has a MW of 1.0.

Carbon



Oxygen



<u>Now find the following</u>:

3) Water (H_2O) has a molecular weight of ________, therefore 1 mole of H_2O = ___________.

4) Glucose ($C_6H_{12}O_6$) has a molecular weight of ______, thus 1 mole of $C_6H_{12}O_6$ = __________.

C. What is Molarity (M)?

Molarity is the concentration of a substance in a solution. It is the ratio of the number of moles in a liter of solution: **e.g.**, a 1.0 M NaCl solution means 1 mole of NaCl for every 1 liter of solution. In science and medicine, concentrations of solution are often defined in terms of molarity (M) moles/liter; or **mM** = millimoles/liter.

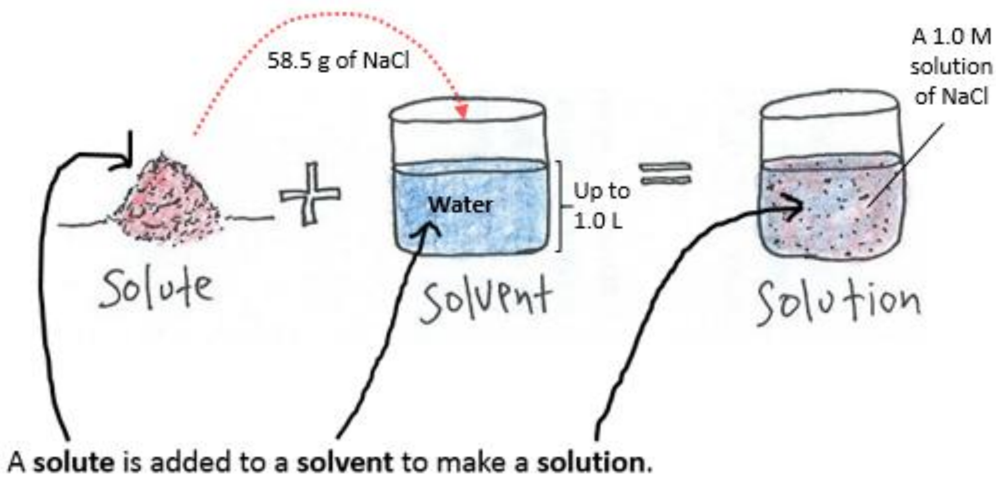


Figure 6.3 If you had to make a 1M solution of NaCl, you don't need to measure out 6.02×10^{23} molecules of NaCl, all you need to do is find out how much one mole of NaCl weighs in g. Looking at the previous page the MW of NaCl it is 58.5g. Then dissolve 58.5 g of sodium chloride in enough water to equal 1.0 liter of total solution (note: not *in* 1 liter of water!). The result is not a 1.0 M solution of NaCl.

D. What is Osmolarity?

If Molarity is the # moles of a substance in 1 liter of solution, then **Osmolarity** is the **total # of particles** in solution. Since NaCl in water breaks up to Na^+ and Cl^- in solution, there are actually twice as many dissolved particles in that solution compared to a molecule that does not dissociate (ionize) in solution.

Osmolarity is very important in the body. The normal osmolarity of the various fluids in the body should exist in between the range **295 to 310 mOsM.** Solutions of the body in this range are considered "isotonic". We will expand on the importance of this range shortly.

Exercise: Predict the *Osmolarity* for each of the following solutions. **(No Calculations Necessary!)*

a) 1.0 Molar Glucose ($C_6H_{12}O_6$) solution:

b) 1.0 Molar Saline (NaCl) solution:

Ans: **a)** = 1.0 OsM Glucose; **b)** = 2.0 OsM NaCl

Succinctly, what is the key element for converting the ***Molarity*** of a solution into ***Osmolarity***?

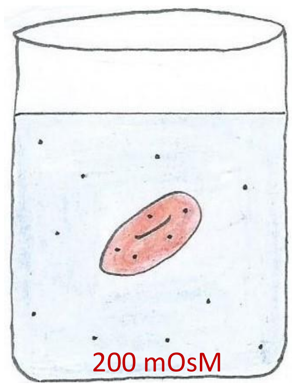
E. What is Tonicity?

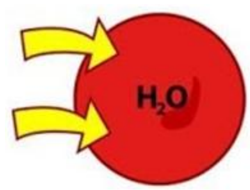
In general, tonicity means the "**strength**" of a solution. Remember, in physiology, water is the *solvent* and *solutes* are dissolved in it. Therefore, the more solutes dissolved in water, the 'stronger' the solution is. Conversely, the fewer solutes dissolved in water, the 'weaker' the solution is.

Tonicity is matched with osmolarity in such a way that the optimal value range for human cells, which is 295 to 310 mOsM, is termed **isotonic**. This is the tonicity range that must be maintained for health. The tonicity of physiological solutions is very important because it can impact the direction of water movement.

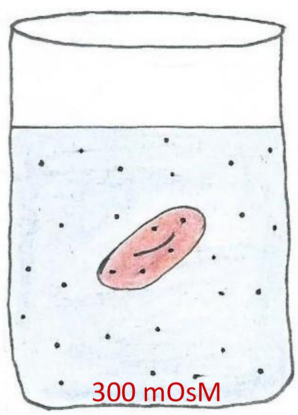
For the solutions in following beakers, let's explore the effect of them on a normal red blood cell (RBC).

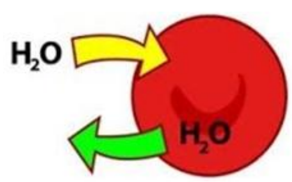
The RBC



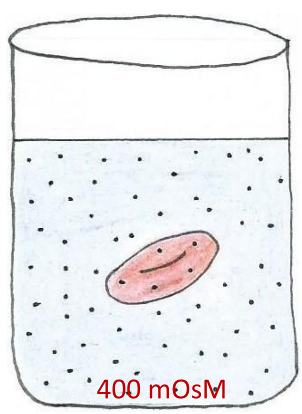


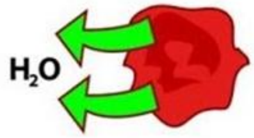
Hypotonic solution: This solution is too weak (hypo = below), having fewer solutes in the surrounding beaker solution than the intracellular fluid of the cell. Water is in higher concentration in the beaker and water will move down its concentration gradient (via osmosis) into the cell, where water is less. The cell's volume increases and may even burst (cell **lysis**). When cells expand, they lose function, which is not good for the body.





Isotonic solution: This is when the cell's intracellular fluid has the same osmolarity as the fluid surrounding it in the beaker, so there is no net movement of H_2O into or out of the cell and its volume doesn't change. It will not lyse and not swell. This is the environment cells like and how they function best.





Hypertonic solution: This solution is too strong (hyper = above), having more solutes in the surrounding beaker solution than the intracellular fluid of the cell. Water is in higher concentration inside the cell and water will move down its concentration gradient (via osmosis) into the beaker, where water is less. The cell's volume decreases or shrinks as a result, this is called crenation. When cells **crenate**, they lose function, which is not good for the body.

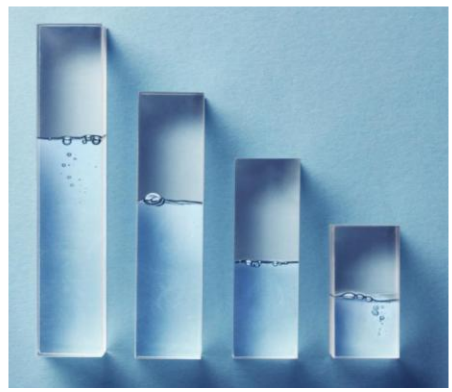
In summary, after accounting for all permeabilities, the simplest definition for tonicities are as follows:

- In an **isotonic** solution, the extracellular fluid has the same osmolarity as the cell. There will be no net movement of water into or out of the cell. (iso = same, tonic = strength)
- In a **hypotonic** solution, the extracellular fluid has lower osmolarity than the fluid inside the cell. The net flow of water will be into the cell. (hypo = lower, tonic = strength)
- In a **hypertonic** solution, the extracellular fluid has a higher osmolarity than the cell's cytoplasm. The net flow of water will move out of the cell. (hyper = higher, tonic = strength)

In the human body, homeostatic regulation of tonicity of body fluids is critical. The tonicity of body fluids will normally fall within the range of **295 to 310 mOsM,** thus this range is "isotonic". The body is in constant flux but typically maintains this range in order to protect all tissues.

Dehydration: Three Main Types

Dehydration is the harmful reduction in the amount of water in the body. We are primarily water, and when we do not have enough water structures and functions of cells and tissues in the body begin to be impaired.



Let's examine how changes in body fluid tonicity might arise in the three (3) major Types of Dehydration show in **Table 6.2** below, outlining what the impact on body fluids and plasma osmolarity are, listing some of the main causes and finally suggesting what the simple remedy usually is.

Table 6.2 Comparison of the three major types of dehydration, their causes and remedies.

Type of Dehydration	Body Fluids	Plasma Osmolarity	Major Causes	Remedy
Isotonic	Both solutes and water lost at same rate.	***No Change***	Decreased fluid intake; Hemorrhage; Excessive urine loss; Excessive vomiting*; Diarrhea*; Burns; Ascites.	Ingestion or I.V. of an **Isotonic** solution.
Hypertonic	More fluid is lost than solutes.	***Increases***	Pure water loss with high fevers; Watery Diarrhea; Diabetes Insipidus; Inadequate water intake; Tachypnea.	Ingestion or I.V. of a **hypotonic** solution.
Hypotonic	More solute is lost than water.	***Decreases***	Heat Stroke or Heat Exhaustion; Extreme physical exertion; Renal failure; Adrenocortical deficiency; Vomiting* and Diarrhea*; Hyperglycemia.	Ingestion or I.V. of a **hypertonic** solution.

*Remedy dependent on the amount of electrolytes lost.

What are the significant signs of dehydration?

They include the following symptoms:

- Feeling thirsty. Noticing thirst is a strong sign of dehydration. Pay attention to the type of thirst.
- Dark and strong-smelling urine. Always check the color of your urine to assess hydration.
- A dry mouth, lips and eyes.
- Feeling dizzy or lightheaded.
- Feeling tired, low energy.
- Urinating small volumes and infrequently.
- Dry, cool skin, often that doesn't bounce back when pinched.
- Headache, confusion, dizziness or lightheadedness. All can be disorientating.
- Rapid heartbeat and breathing when at rest.
- Muscle cramps.

Treatment of Dehydration - What is the best solution to drink in order to restore body hydration?

As shown in **Table 6.2** above, the treatment for any dehydration will depend on the type of dehydration experienced, since they are not all the same. Recall that tonicities have no units, the terms hypo-, iso-, or hypertonic are relative to what is determined to be 'normal and healthy'. As indicated in the table above, the remedy will be to deliver a solution to the body that will take the body back to the normal isotonic range that is between 295 and 310 mOsM. Replacement of fluids or solutes must be done without damaging the tissues or red blood cells. Nice 'n easy.

Here are some suggestions of what to ingest to keep well-hydrated:

- **Isotonic** - Coconut water. Milk. Fruit-infused water.
- **Hypertonic** – Water, dilute tea, dilute fruit juice.
- **Hypotonic** – Watermelon, electrolyte drinks, fruit or full fruit juice.

Introduction to Intravenous Solutions

There are a number of reasons someone might receive an *intravenous (I.V.) solution*. For example we have just covered the ways that people can become dehydrated, and ways that various solutions can be used to relieve dehydration from both water and electrolyte loss. An I.V. solution may also be used to relieve shock, or replace fluids lost after suffering burns, or to administer vitamins, pain relievers, antibiotics and other medications.

The I.V. solution, as its name implies, is going to be delivered into a systemic vein in the body. The blood pressure is very low in veins and they are also very easy to access because they are superficial and have thinner walls compared to arteries. The solution in the I.V. is going to mix with the blood (recall that plasma is the fluid component of blood), thus it will affect the composition of the plasma (an extracellular fluid) surrounding all the blood cells in the blood, and will also impact interstitial and intracellular fluid. Shown in **Figure 6.4** below are various I.V. solutions and a discussion of how to remedy the solution conditions to prevent cell swelling or shrinking (crenation).

If the wrong solution is used, it could cause the red blood cells to either shrivel up (crenate) or to swell up and burst (lyse) due to ***osmosis***. Thus, we must understand what all the conditions are, then determine the best course of action on a case by case approach.

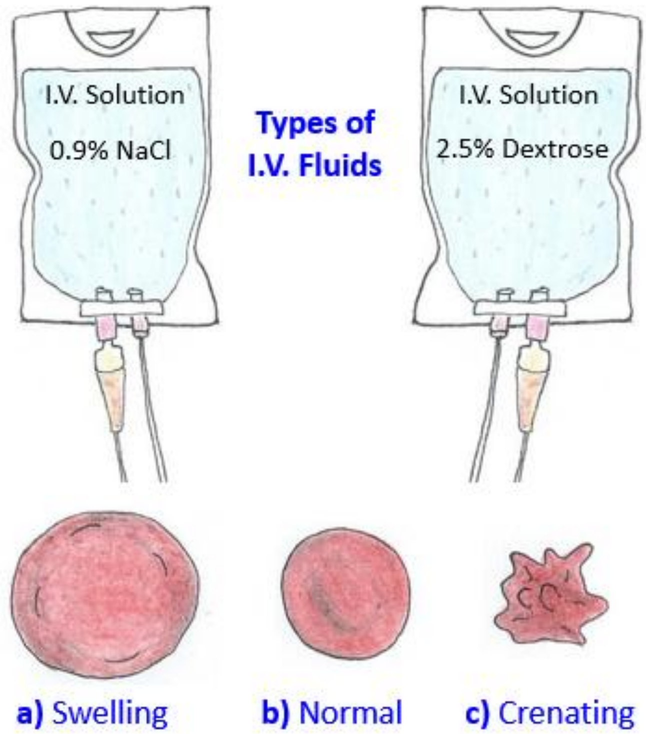


Figure 6.4 During periods of dehydration, or with any condition that alters the normal tonicity of body fluids, it may be necessary to rehydrate and restore normal osmolarity of body fluids by using an intravenous (I.V.) solution. The specific composition of the I.V. solution will depend on the nature of the condition of the body. The three red blood cells shown above will have been in surrounding fluid that caused **a)** swelling appearance of cells, **b)** normal looking cells, and **c)** crenation or shrinking cells.

Physiological Saline

In the next two pages that follow, there are detailed examinations and exercises on how to calculate the molarity of a solution based on information regarding % concentration of the solution, which when known, will then yield the osmolarity of the solution. Recall that in simple terms, the osmolarity of a solution means the number of particles in a solution, and this information will tell us where water will go.

An intravenous solution of 0.9% NaCl is called "Physiological Saline", and is often given to re-hydrate a person and to deliver other substances and maintain stable body fluid osmolarity. This is because when we convert a 0.9% NaCl solution into Molarity, then convert it into Osmolarity, it turns out to be approximately **308 mOsM**. The strength or tonicity of this solution is within the **isotonic** range of 295 to 310 mOsM. After engaging in calculation various % solutions to osmolarity (below), it will make sense that the osmolarity of a physiological saline solution is readily accepted by the body.

This is a good segue into discussing the relationship between the various ways we can measure a "concentration" of a solutions. There is molarity and osmolarity, and another common way to describe the concentration of a solution is as a percentage (the % of solute in the solution), and we will now integrate all of these so we can always be aware of how the concentration of a solution will impact the environment of the cells and tissues.

Calculating Osmolarity from % Solutions

A percentage (%) solution is defined as an amount or volume of a chemical or compound per 100 ml of a solution. Percentage means 'per 100', and the 100 in this instance is the 100 ml of volume that the substances is dissolved in.

Example: **1% Glucose solution (w/v) =** $\frac{\textbf{1g of glucose}}{\textbf{100 ml of solution}}$ **(100 ml = deciliter, or dl)*

It is often easier to describe solutions that are made with large solutes (e.g., proteins or starch), in terms of percentages because their molecular weights are very large and awkward to calculate.

Remember that when given the **% solution**, you are being told how many grams of a solute there are in a 100 ml volume of given solution.

If the percentage solution is "a 0.45% NaCl Solution"

Think of it this way: a 0.45% NaCl Solution (saline solution) = $\frac{\text{0.45 g NaCl}}{\text{100 ml of Solution}}$

Calculating Osmolarity from % Solutions

Here is an example of converting a % Solution to Molarity and finally to Osmolarity.

Example: Please convert a **0.45% NaCl** solution to **Osmolarity** and comment on its **Tonicity**. This can be calculated using a number of different approaches, and please use whatever method works best for you. It can be achieved in three easy steps as outlined below.

Step 1: ***Convert the % Solution to Molarity***

Take whatever that number is in front of the % sign, in this case it is 0.45, and make it grams, 0.45g. Then use two 'conversion factors' to 1) get liters (L) on the bottom and moles on the top. This is because Molarity is defined as moles/liter, which is a Molar (M) solution.

$$\frac{\textbf{0.45 g}\text{ NaCl}}{\text{100 ml sol}^{n}} \times \frac{\text{1000ml}}{\text{1 liter}} \times \frac{\text{1 mole NaCl}}{\text{58.5 g NaCl}} = \frac{\text{0.077 moles NaCl}}{\text{1 L sol}^{n}} = \text{0.077M NaCl}$$

Step 2: ***Calculate Osmolarity***

All we need to ask ourselves is: Does this substance ionize (break apart) in solution? If no, then Molarity = Osmolarity. If yes, then times the Molarity by the number of particles it ionizes into.

NaCl will break up into Na^+ and Cl^- in water, that is, 2 particles.
Thus, the osmolarity will be 2 x 0.077 = 0.154 Osmoles (OsM)
Finally, convert OsM to mOsM by x the OsM by 1,000 = mOsM

0.077 Osmoles of Na^+
+ 0.077 Osmoles of Cl^-
0.154 Osmoles of Na^+ and Cl^-

0.154 OsM x 1,000 = **154 mOsM NaCl**.

Step 3: **Tonicity**: The final value is = **154 mOsM**. Does that fall within, above or below the range? It falls below 295 to 310 mOsM, therefore this solution is **hypotonic** and water would move out of the cell. This could cause the cell to swell and lyse (burst).

Determining Tonicity. What makes a good I.V. solution?

Normal Serum Osmolarity is approximately 0.295 OsM or 295 mOsM: In human physiology, the range of **295 to 310 mOsM** is used as a standard of comparison. Once you have calculated the osmolarity of an I.V. solution, you'll have a good idea of whether or not it would make an appropriate intravenous drip solution.

Here is one more example of converting using the 3 step method. It is a **7% Dextrose** solution. Note: Has the same MW as glucose = 180g; glucose molecule does not break up (ionize) in water.

Step 1: ***Convert the % Solution to Molarity***

Take whatever that number is in front of the % sign, in this case it is 7, and make it grams, 7g.
Then use two 'conversion factors' to 1) get liters (L) on the bottom and moles on the top. This is because Molarity is defined as moles/liter, which is a Molar (M) solution.

$$\frac{7\text{ g Glucose}}{100\text{ ml sol}^n} \times \frac{1000\text{ml}}{1\text{ liter}} \times \frac{1\text{ mole Glu}}{180\text{ g Glu}} = \frac{0.389\text{ moles Glu}}{1\text{ L sol}^n} = 0.389\text{ M Glu}$$

Step 2: ***Calculate Osmolarity***

All we need to ask ourselves is: Does this substance ionize (break apart) in solution? If no, then Molarity = Osmolarity. If yes, then times the Molarity by the number of particles it ionizes into.

Glucose will not break up in water.
Thus, the Osmolarity = Molarity (OsM), = 0.389 OsM Glucose
Finally, convert OsM to mOsM by x the OsM by 1,000 = mOsM

0.139 OsM x 1,000 = **389 mOsM Glucose**

Step 3: The final value is = **389 mOsM**. Does that fall within, above or below the range?
It falls above 295 to 310 mOsM, therefore this solution is **hypertonic**, and water would move out of the cell. This could cause the cell to shrivel (crenate).

More Solution Calculations – Examples of questions for quizzes and exams

In the space below, convert the following % solutions to molarity and then calculate the osmolarity of the solution. Determine if the solution is an isotonic, a hypertonic, or a hypotonic solution compared to extracellular fluid (ECF) and discuss the possible effects on a cell in these solutions.

<u>For the solutions below, make the same calculations (converting to molarity and osmolarity) for the following:</u>

1) D5W Solution (5% Dextrose, dextrose = glucose).

2) Saline Solution (1.3% NaCl).

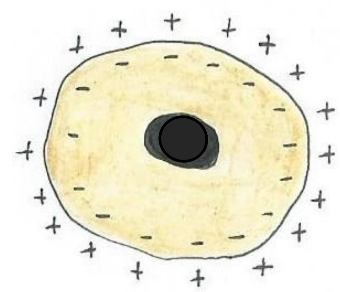
3) Normal Saline (NS) Solution (0.9% NaCl).

The answers are provided in Appendix B.

The Importance of Solutions

The Body's cells are in a State of Electrical and Chemical Disequilibrium

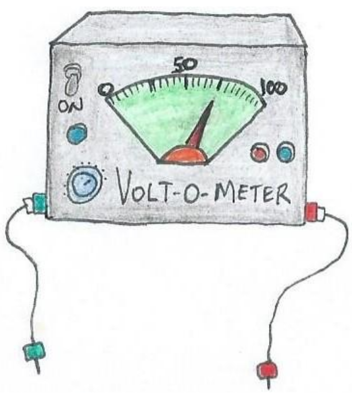
There is not only a chemical difference across the cell membrane, there is also an electrical difference across the two sides of the plasma membrane, which means there is charge or **voltage** across the cell. All living cells must maintain an electrical charge difference in order to do work and stay functional!



In living cells, this voltage is slightly negative inside the cell and slightly positive on the outside, as shown in the drawing to the right. This is termed the **electrical disequilibrium**, since they are not at equilibrium. The major intracellular ions are K^+, phosphate (PO_4^{3-}) and to some degree proteins, and the major extracellular ions are Na^+, Cl^- and Ca^{2+}. Thus, there is a difference in the concentrations of chemical between the two sides of the plasma membrane. This is termed the **chemical disequilibrium**. Together, this is referred to as the **Electrochemical Disequilibrium** and this creates the Resting Membrane Potential (RMP) of all living cells.

Electricity and Electrical Signals

Atoms are electrically neutral. Ions are created as electrons are added or removed from an atom, and for each cation (+) in the body, there is a matching anion (-) somewhere. There are important principles to remember for electricity in physiological systems. The Law of Conservation of Electric Charges means that the net amount of electric charge produced in any process is zero. Opposite charges attract, like charges repel and energy is required to separate opposite charges or bring together like charges. Conductors of electrical charge allow free movement of positive and negative charges, whereas insulators (like lipids) prevent movement of charged particles, and as it turns out, cell membranes are excellent insulators. As we will see in the following section, the voltage across the membrane can be measured, using equipment not unlike the handy 'Volt-O-Meter' we see to the left. When one probe is on the inside of the cell, and the other is on the outside of the cell, it can measure the electrical voltage that is across the cell membrane,



The Plasma Membrane is an Insulator but allows Work to occur across it

It is important to understand that the plasma membrane is set up to have electrical and chemical gradients across it. The separation of electrical charges and chemical concentrations across the lipid bilayer creates gradients and this is a very powerful arrangement. This electrochemical disequilibrium is also referred to as the **Electrochemical Gradient** and allows for work (moving things) to occur across the plasm membrane. This electrochemical gradient is created and maintained by active transport mechanisms and selective membrane permeability to certain ions.

The next chapter of this physiology text touches on the two control systems of the body, the nervous and endocrine systems, and then focuses intensely on neurophysiology.

Various Common Fluids (Solutions) in the Human Body

It has been estimated that the human body is anywhere from 60 to **75% water**, thus the human body is a myriad of solutions. As we have learned so for in this course, **water** is vital to life and very versatile. Water is the great **Universal Solvent**. Therefore, in all of the solutions that we encounter in physiology, water is the **solvent** which dissolves many **solutes** to yield various **solutions**.

Although our initial focus in physiology is on the general body fluids that compose the three **tissue compartment volumes** of the body, those being: **1) Plasma**; **2) Intracellular fluid** (ICF); and **3) extracellular fluid** (ECF). There are many other solutions at specific locations or within systems that are very useful to be familiar with. It is valuable to know the basics about these body fluids now as we will see them again in the various systems ahead in physiology.

Described and listed below alphabetically are common examples of specific body fluids in the body.

Amniotic fluid - The protective fluid surrounding the developing fetus within the amniotic sac of a pregnant female. It cushions the baby from injury and plays an important role in fetal development. The volume of amniotic fluid increases as the fetus develops and grows, going from 25ml at week 10 of gestational age, to 400ml at week 20, and plateaus at 800ml by week 28. There is about 1,000mL (1L) of amniotic fluid at birth.

Aqueous humor – The term 'humor' refers to a fluid (or semifluid) substance in the body. The aqueous humor is the fluid normally present in the front and rear chambers of the eye, that is, the space in the front of the eyeball between the lens and the cornea. It is a clear, watery fluid that flows between and nourishes the lens and the cornea; it is secreted by the ciliary body.

Bile - A greenish-yellow fluid secreted by hepatocytes of the liver and stored in the gallbladder. It is released into the duodenum where it aids in the digestion of fats. Bile is 97% water, with bile salts, bilirubin, other bile pigments, cholesterol, and inorganic salts. Bile salts are alkaline, with a pH of about 8 and are released in response to eating fats, aiding in the emulsification of fats, which is making larger lipid droplets smaller, this assists the enzymes ability to act more efficiently to digest lipids. Adults produce about 400 to 800 ml of bile per day.

Breast milk – This nutrient rich solution is made by mammary glands of the breast. It is primarily composed of water, lipids, proteins, carbohydrates (lactose) and variable minerals and vitamins. Each of these nutrients plays a vital role in the healthy growth and development of an infant. Breast milk has about 6.2% **lauric acid** (the primary lipid in coconut oil), shown to stimulate **neural** and **immunological** development. Breastmilk nutrients are better absorbed and utilized by babies. Studies of breastfed babies found they do better on intelligence tests when they grow older. They have better functioning eyes, fewer infections, far fewer digestive, lung, and ear infections. A lower risk for **SIDS** (sudden infant death syndrome) and a lower risk of getting asthma and skin problems related to allergies. A lower risk of developing leukemia. Fewer long-term health problems such as diabetes and obesity. Women who breastfeed also get many health benefits. They are more likely to lose weight gained during pregnancy and also less likely to get breast and ovarian cancer and diabetes later in life.

Cerebrospinal fluid - A clear, colorless body fluid that fills the ventricles of the brain and the central canal of the spinal cord. It has **no cells** in it. It's made in the **choroid plexuses** of the brain by a type of glial cell called **ependymal cells**. The total circulating volume is form 125-150 mL and must be made at a rate of about 25 mL per hour. The cerebrospinal (CSF) fluid is composed mostly of water (99%), and also has small amounts of glucose, small proteins and electrolytes. The CSF acts as an insulative cushion, protecting the brain from physical injuries. It also provides buoyancy for the relatively heavy brain, and it removes metabolic waste products from the brain as it returns to the vascular system. A lumbar puncture is when a sample of CSF is collected from the lower back for analysis.

Cerumen – Commonly called **ear wax**, there are two types: **1)** wet, which is honey colored and moist (most common); and **2)** dry, which is gray and flakey. The usual type is a thick, lipid rich viscous substance made by sebaceous glands and modified apocrine sweat glands on the tympanic membrane, moving outward down the canal at a rate similar to fingernail growth. It prevents desiccation of the skin in this area and has some bactericidal effects. The lipids include cholesterol and squalene, which provide lubrication and provide for pliability of the ear drum.

Chyle - A milky-white fluid that formed from in the lymphatics of the small intestine during digestion of fatty foods. It consists of lymph and emulsified fats carried through the lymphatic system back to the cardiovascular systemic via the thoracic duct.

Chyme - A smooth semifluid material of partly digested food produced by action of the gastric juice on ingested food in the stomach and discharged through the pylorus into the first part of the small intestine, the duodenum. It continues on and is transformed in the digestive tract.

Exudate - A fluid of solutes, proteins, cells, or cellular debris that oozes out or is discharged from the tissues during inflammation or injury. Fluid exudes out via pores or a wound, and may be cloudy or pus-like. It contains exudate cells (e.g., white blood cells), serum, and fibrin.

Gastric juice – This is an acidic digestive fluid secreted by various glands lining into the lumen in the stomach. For digestion of food as well as eradicating many pathogenic microbes that may enter the alimentary canal. It contains hydrochloric acid (HCl), salts, digestive enzymes, intrinsic factor, gastrin, mucus, and bicarbonates (to neutralize the acidic conditions). The pH is about 2, which activate digestive enzymes that destroy pathogens. The mucus produced during gastric secretions serves as a barrier to prevent the gastric acid from damaging the stomach.

Lymph – Usually a slightly opaque, mildly alkaline fluid found in the lymphatic vessels that drain the tissue fluids that filter out across the blood vessel walls from blood and bathes the tissues. It helps to form **chyle**, formed in digestion of fats, and transports the lipids from the digestive system into the body. Apart from fat transport, it returns excess interstitial fluid to the bloodstream. It also brings microbes to the lymph nodes for destruction.

Mucus - A viscous, slippery secretion of a gland that protects and lubricates surfaces. Mucus refers to the viscous, slippery substance that is secreted by the glands. It is the free slime of the mucous membranes. It consists of the secretion of the glands, along with various inorganic salts, desquamated cells and leucocytes. The main function of mucus is to protect and lubricate surfaces.

Pericardial fluid – Around the heart, the serous fluid secreted by the serous layer of the pericardium into the pericardial cavity. The pericardium consists of two layers, an outer fibrous layer and the inner serous layer. The pericardial sac normally contains up to 50ml of fluid but can hold 80 to 200ml of fluid acutely.

Peritoneal fluid - Around the internal viscera, the serous fluid that acts as a lubricant for all of the internal organs in the abdominal cavity. There are small amounts, normally 5 to 20ml, contained within the layers of the peritoneum that line the abdominal wall.

Pleural fluid - Around the lungs, the serous fluid located in the pleura cavity. The pleura is a two-layer membrane that covers the lungs and lines the chest cavity. Pleural fluid keeps the pleura moist and reduces friction between the membranes when breathing. In a healthy people, the pleural space or cavity contains about 10 to 20ml of fluid, with low protein concentrations.

Pus - A viscous exudate formed and discharged from inflamed tissue as an end-result of suppuration, which is the process of forming pus. One can use the noun ‘suppuration’ when as a nice clean medical term for the formation of pus. Its color can vary from yellowish, greenish, or brownish hue, which may depend on the causative agent of the infection. It also consists of leukocytes, dead pyogenic (pus making) bacteria, and necrotic cellular debris or tissue elements.

Saliva - The secretion from the salivary glands. Both viscous and watery fluids that are secreted predominantly from three pairs of intrinsic salivary glands, the parotid, submaxillary, and sublingual, each type generating their own special characteristic saliva. The saliva is a more or less turbid and slightly viscous fluid, generally slightly alkaline reaction. It is 99.5% water, with electrolytes (Na, K, Ca, Mg, Cl, HCO_3, PO_4^{3-}, I, etc.), mucus, urea, enzymes, secretory immunoglobulin A, lysozyme, white blood cells, and epithelial cells. The saliva moistens the mouth and food, aids in swallowing, and starts the digestion of starches. It is a thick transparent liquid rich in digestive enzymes like ptyalin (lingual lipase) and kallikrein (digests peptides) used to start the break down foodstuff. Note: Sputum is not the same as saliva.

Sebum - An oily substance produced and secreted by sebaceous glands in the skin and associated with hair follicles. Sebum is composed primarily of triglycerides, wax esters, squalene and fatty acids, thus it lubricates and protects the skin and hair against water loss; and also keeps skin and hair pliable and protects skin from infection. The highest density of sebaceous glands are on the face and scalp, whereas they are completely lacking on the palms of the hands and soles of the feet. Sebum pre-putial is a type of sebum that is secreted and collected under the prepuce of the foreskin of the penis or of the clitoris.

Serous fluid – A clear to yellowish watery fluid that fills and lines closed internal body cavities. There are three serous fluids inside of body cavities, they are: 1) pericardial; 2) peritoneal, and: 3) pleural.

Semen - The slippery opaque to whitish fluid is comprised of secretions from the male sexual glands and sperm cells that are released at orgasm through the male reproductive organ. It is also called ejaculate. Semen contains various enzymes and fructose, to promote the survival of the sperm cells as well as to provide medium for them to travel in. Typical components of semen are: **a)** spermatozoa (2-5%); **b)** seminal vesicle secretions (65-75%) being amino acids, citrate, flavins, fructose, and certain enzymes; **c)** prostate secretions (25-30%) being acid phosphatase, citric acid, fibrinolysin, proteolytic enzymes, and zinc; and **d)** bulbourethral gland secretions (<1%) being galactose and mucus).

Sputum – Also known as **phlegm**, it is a thick type of mucus from the lungs, occasionally with some saliva mixed in. It can be a result of infection or other disease affecting the lungs or airways and can make sputum be cough up. Sputum is not the same as spit or saliva.

Synovial fluid - Found in movable synovial joints, this clear viscous fluid is secreted by the membrane that lines the joints. It protects, nourishes, removes waste from and lubricates these joints. The fluid contains hyaluronic (a glycosaminoglycan) acid, lubricin (released by articular chondrocytes from the cartilage), and phagocytic cells (to remove cellular debris and microbes).

Sweat - A fluid or moisture secreted from the sweat (sudoriferous) glands located in the dermis onto the outer exposed surface of the skin (via pores) during perspiration. Sweat is composed primarily of water, with small amounts, about 0.2 to 1% of solutes, mostly NaCl and urea. Chiefly sweat is to regulate body temperature when it gets too hot. When the water in sweat is evaporated from the skin, it takes with it a lot of heat energy, allowing the person to cool down. The release of sweat can be triggered by external cues such as humidity and ambient temperature and body activity, physical or emotional stress.

Tears - The serous (watery) saline secretion of the lacrimal glands in the orbital of the eyes. They serve to lubricate and moisten the outermost covering of the eyeball, called conjunctiva. Tears are slightly alkaline and secreted by lacrimal glands sitting laterally over the eye and collected by the medial lacrimal sac. The tears drain through lacrimal ducts into the space between the eyeball and lids. Excess tears drain into the nasolacrimal duct and into the nasal cavity. This is why the nose gets runny when crying. If overflow occurs, then tears drop right out of you eye lids. There are different types of tears.

> **1)** The basal tears contain water, mucin, **lysozyme** (digests bacterial cell walls), lactoferrin, lipids, lacritin, lipocalin, immunoglobulins, and electrolytes.
>
> **2)** The reflex tears are tears resulting from eye irritations, and associated with coughing, yawning, and vomiting. **3)** The psychic tears are associated with strong emotions (grief, sorrow, pleasure, anger, etc.), and also associated with physical pain. Tears from emotions contain more hormones such as prolactin, adrenocorticotrophic hormone, and leu-enkephalin than the other two types of tears.

Urine – This acidic amber fluid is a liquid by-product of metabolism, a waste product produced by the kidneys from the continuous filtration of the blood to remove metabolic waste and toxins. It is composed mostly water (about 95%) and also contains inorganic salts, urea, uric acid, creatinine, hormones, and other metabolites and their byproducts. Normally urine has a pH range from **5** to **6**. It is typically slightly transparent and the intensity of the color can indicates levels of hydration of the body.

Review Questions for Chapter 6: Physiological Solutions

1. With regard to a **solution**, the difference between the **solvent** and the **solute** is:
- **a)** A mixture of solvents makes a solution
- **b)** The solute is always in abundance
- **c)** The solvent is always in abundance
- **d)** All solutions have a variety of solutes dissolved in the solvent
- **e)** Either the solvent or the solute can be in abundance

2. Approximately what percentage (%) of the human body is water?
- **a)** 70%
- **b)** 50%
- **c)** 66.6%
- **d)** 80%
- **e)** 45%

3. How many grams of glucose of glucose will be in 1.0 L of a 1.0 M solution of glucose? ________.

4. If more fluid is lost than solutes, what kind of **dehydration** would that be?
- **a)** An internal dehydration
- **b)** Hypotonic
- **c)** Isotonic
- **d)** Hypertonic

5. Outside of a cell (interstitium), the concentration of K^+ is ____ and the concentration of Na^+ is ____.
- **a)** high; high
- **b)** low; low
- **c)** low; high
- **d)** high; low

6. According to the information provided in this section, the liver is what % water? ________.

7. Compare these solutions: **1.0 M NaCl** and **1.0 M Glucose**. Which of the following statements are **true**?
1. their molarity is the same **2.** the NaCl solution has twice the osmotic pressure as the glucose solution
3. their osmolarity is the same **4.** NaCl gives four particles **5.** glucose can give 6 carbons in solution
- **a)** 1, 3 and 4
- **b)** 1 and 5
- **c)** 4, 3, 1 and 5
- **d)** 1 and 2
- **e)** 1 only

8. Which tissue compartment of the body would have a low concentration of both K^+ ions and proteins?
- **a)** intracellular fluid
- **b)** interstitial fluid
- **c)** plasma
- **d)** extracellular fluid
- **e)** none of these

9. If a solution is 4% glucose, what is the **osmolarity** and **tonicity** of that solution?

- **a)** 444 mOsM, hypertonic
- **b)** 40 mOsM, hypotonic
- **c)** 180 mOsM, hypotonic
- **d)** 222 mOsM, hypertonic
- **e)** 222 mOsM, hypotonic

10. Which of these statements about other body fluids is **true**?

- **a)** Sputum is the same as saliva.
- **b)** Basal tears are 100% saline and nothing else.
- **c)** Gastric juices usually have a pH of about 4.
- **d)** Cerebrospinal fluid (CSF) normally has white blood cells.
- **e)** Breast milk contains lauric acid which stimulates immune development.

Answers in Appendix B