7.7 - Liquids

Liquids

Although most substances we come in contact with on a daily basis are solids and gases, we often understand the properties of liquids most simply because in our lives, water is very prevalent. Therefore we understand that water flows when we pour it, vaporizes when it is absorbs enough energy, freezes when it releases enough energy, eventually evaporates, and some mix together as others do not.

Liquids fall between gases and solids in terms of their intermolecular forces of attractions. Gases have very weak intermolecular attractions whereas solids have very strong intermolecular attractions (covalent network, metallic, ionic, and molecular). So liquids must have some level of attractions that are strong enough to hold molecules somewhat closely together but not strong enough to lock them in place.

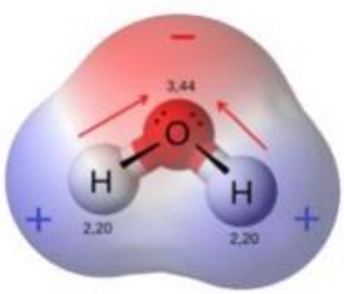
Intermolecular Forces of Attractions of Liquids

The level of attractions that a liquid has depends on a substance's polarity. **Polarity** is a difference in the electric charge giving a positive pole and a negative pole. Different atoms with different **electronegativities** (attraction for an electron in a bond) will result in a polarity or a dipole moment.

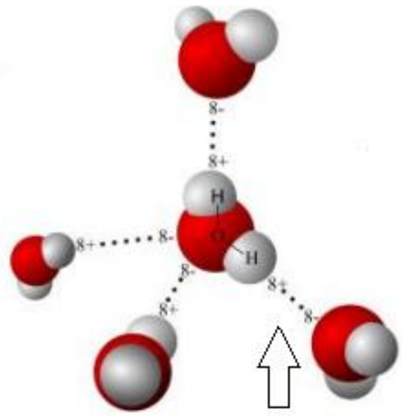
Example: In the molecule below, the yellow atom is more electronegative and so the molecule has a polarity or a dipole moment in which the yellow atom (red shading) is more negative (δ-) and the white atom (blue shading) is more positive (δ+).

Most liquids at room temperature and standard pressure have molecular or covalent intermolecular attractions. Those attractions are classified into three categories:

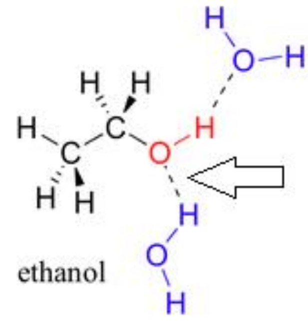
- **Hydrogen Bonding Attractions** - Hydrogen bonding interactions results from large electronegativity differences (hydrogen attracted to F, O, or N). Substances with hydrogen bonding will be readily soluble or able to be dissolved in water (has similar intermolecular attractions of hydrogen bonding as shown below with ethanol and water). Water (H_2O), ammonia (NH_3), hydrogen fluoride (HF), and ethanol (CH_3CH_3OH) all have hydrogen bonding attractions. Due to the high level of attractions, these substances will have the greatest boiling point of liquids.



Water is Polar

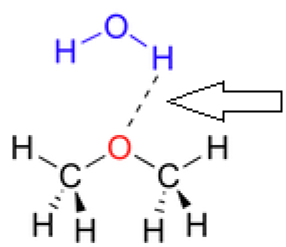


Hydrogen Bonding Attractions of Water



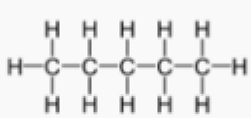
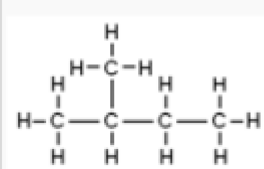
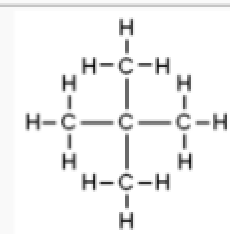
Hydrogen Bonding Attractions between ethanol and water

- **Dipole to Dipole Forces** - Dipole to dipole interactions occur when the positive and negative ends of the polar molecules have molecule to molecule attractions. Hydrogen bonding is simply a stronger level of attraction as compared to Dipole-to-Dipole. H_2S, PH_3, HCl, and CH_3OCH_3 all have dipole to dipole forces of attractions. Substances with just dipole-to-dipole will be moderately soluble in water (has similar intermolecular attractions of polarity as shown below with dimethyl ether and water)

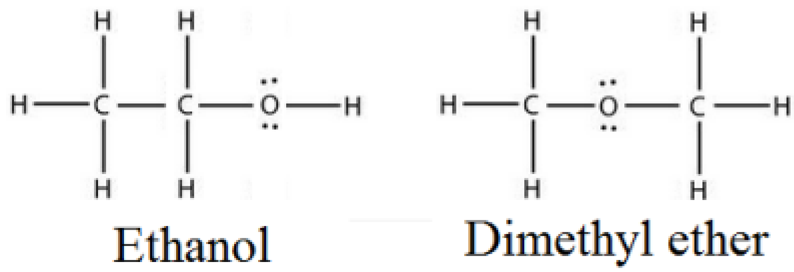


Dipole to Dipole Forces of Attraction

- **London Dispersion Forces** - London Dispersion Forces arise in all nonpolar substances because of temporary, instantaneous dipoles created by electrons in a substance. Every substance has London Dispersion Forces present since all substances have some amount of electrons. Substances with just carbons and hydrogens will have only London Dispersion Forces such as the substances shown below such as C_6H_6 (benzene) and Br_2 (bromine). Due to only instantaneous attractions, these substances will have a very low boiling point.

IUPAC name	pentane	2-methylbutane	2,2-dimethylpropane
Molecular diagram			
Boiling Point (°C)[2]	36.0	27.7	9.5

Example: Structures of the ethanol molecule and the dimethyl ether molecule are shown below. Which substance has the highest boiling point and which will be most readily able to dissolve in water.



Answer: The intermolecular forces of attraction among molecules of ethanol consist primarily of hydrogen bonding between the H of one ethanol molecule and the O of an adjacent ethanol molecule. The molecules of dimethyl ether only consist primarily of dipole-to-dipole interactions. The hydrogen bonding present in ethanol is particularly strong intermolecular forces, therefore they require more energy to overcome this intermolecular attraction during the boiling process. As a result, a higher temperature is needed to boil ethanol than is needed to boil dimethyl ether. Also, since ethanol has hydrogen bonding it will be readily soluble in water whereas dimethyl ether (only dipole to dipole) will be moderately soluble in water.

Liquid Pressure

Since a liquid has a density (density = mass / Volume), the liquid molecules are affected by the force of gravity. And since liquid molecules provide a force over an area of space, a liquid exerts a pressure.

Pressure is defined as the product of the density of a liquid, gravity, and the depth.

$$Pressure = density \ x \ gravity \ x \ height$$

$$P = \rho g h$$

The S.I. Units of pressure is Pascals. Pressure can also be measured in mmHg (millimeters of mercury), atm (atmospheres), torr, bar, kPa (kiloPascals).

Example: If you are fully submerged at a depth of 2 m in a freshwater lake ((ρ = 1000 kg/m^3), what pressure do you experience? (gravity = 10 m/s^2)

Answer:

$$P = \rho g h = (1000) \ x \ (10) \ x \ (2) = 20000 \ Pa$$

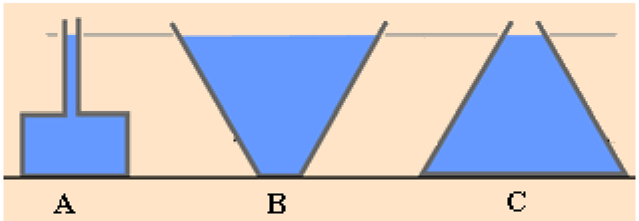
Example: The gauge pressure of an object in saltwater ((ρ = 1025 kg/m3) is 153750 Pa. How deep is the object underneath the surface?

Answer:

$$P = 153750 = (1025) \ x \ (10) \ x \ h$$

$$h = 15 \ m$$

Example: Below are three containers all with liquid water. Rank the containers from the greatest to least pressure that the bottom of the container experiences.



Answer: All three containers have the same pressure at the bottom since all three are liquid water (same density) and have the same depth (same height).

Buoyancy

An ancient Greek scientist named Archimedes discovered that the when a solid object is submerged in a liquid, the volume of the liquid raises equal to the volume of the object. This gave rise to Archimedes Principle which helps to explain the buoyancy or the upward force that an object experiences in a fluid.

Force of Buoyancy is defined as the product of the density of the fluid, the volume of the object, and gravity.

$$Force\ of\ Buoyancy\ =\ density\ of\ the\ fluid\ x\ Volume\ of\ the\ object\ x\ gravity$$

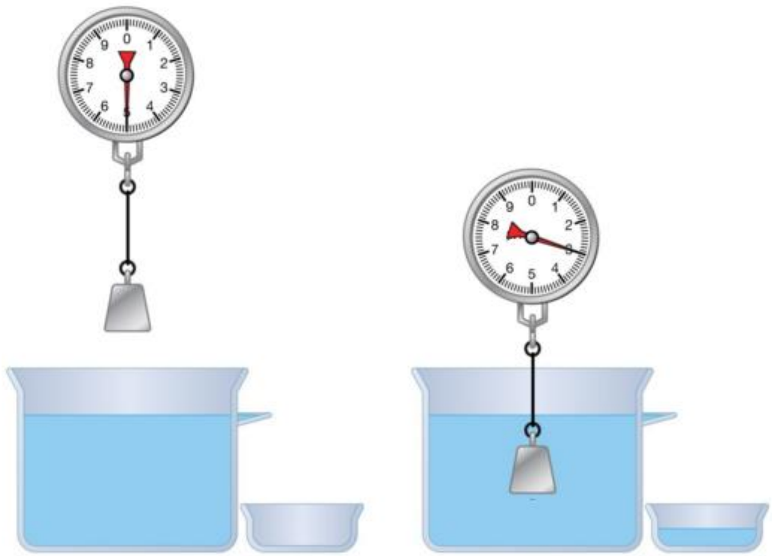
$$F_B = \rho V g$$

Example: What is the buoyant force on a 0.5 m^3 lead cube that is fully submerged in freshwater (ρ = 1000 kg/m^3)?

Answer:

$$F_B = \rho V g\ =\ (1000)\ x\ (0.5)\ x\ (10)\ =\ 5000\ N$$

Example: A solid object was hung from a spring scale and measured to weigh 5 N when outside of the water. When the object is completely submerged in the water (shown below), the object only weighs 3 N and water pours out of the side into a separate container. Find the force of buoyancy and then calculate the volume of the object given that water has a density of 1000 kg/m^3.



Answer: Since the object weighed 5 N outside of the water and inside the water only weighed 3 N, then the force of buoyancy provided a 2 N upward force.

$$F_B = 2 = (1000)\,V\,(10)$$

$$V = 0.0002\,m^3$$

Water on Earth

Our planet Earth is often called "the blue planet" because it is predominately water. In fact, about 71% of the surface of the earth is covered with water in the form of oceans, lakes, ponds, rivers, creeks, and streams. And that does not include the water underground, clouds, icebergs, and glaciers, all of which are mostly made up of water.

Collectively, all the water sources are called the **hydrosphere**.

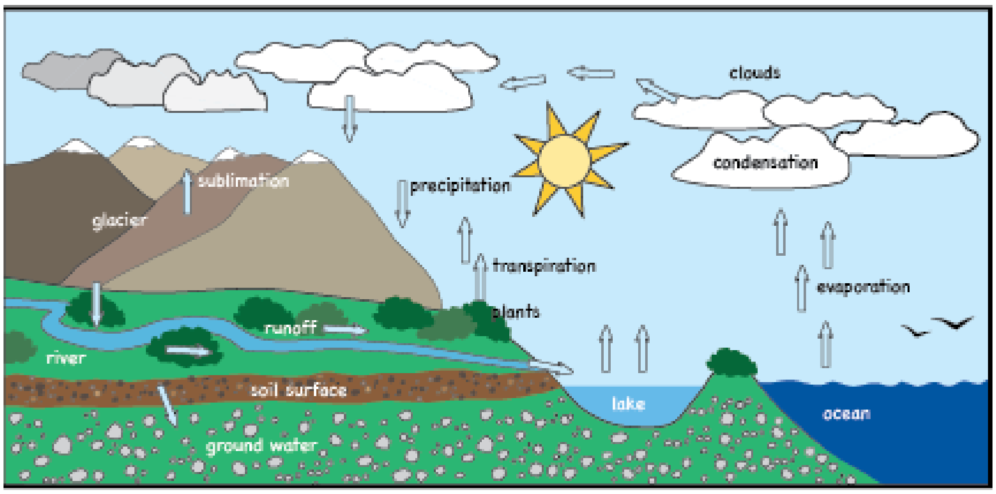
And liquid water, a necessity for life, can only be found in abundance on one planet, our Earth. This is because water is only found as a liquid within a certain temperature range (0ºC to 100ºC) and the vast majority of Earth is in that temperature ranges due to the distance from the sun and the atmosphere. As we will learn next unit, if the Earth's unique atmosphere were to change just slightly, then water may not exist on Earth as a liquid. Also, if the Earth were only a few percent closer or further from the sun, the water on Earth would not be a liquid. Therefore, without these specific properties of Earth and the properties of water's hydrogen bonding attractions, life on Earth would not be to exist.

Water Source	Type of Water	Percent of Hydrosphere
Oceans	Saltwater	97.250%
Glaciers and Icebergs	Freshwater	2.050%
Groundwater	Freshwater	0.685%
Surface Water (not oceans)	Mostly Freshwater	0.009%
Soil Moisture	Freshwater	0.005%
Atmospheric Moisture	Freshwater	0.001%

7.7 - Liquids

The vast majority of the earth's water supply is contained in the oceans as saltwater. The vast majority of the earth's freshwater supply is stored in icebergs and glaciers. And the largest source of liquid freshwater is groundwater. Lakes, ponds, rivers, streams, and creeks are all surface freshwater and only make up less than 0.01% of the earth's water.

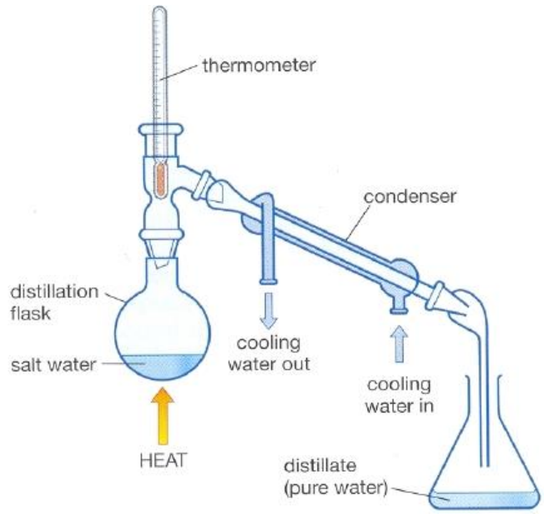
The **hydrologic cycle** is the process by which water is continuously exchanged between earth's various water sources.



Water gets into the atmosphere predominately by **evaporation** and **transpiration**. Evaporation is the vaporizing of the top layer of liquid molecules of a liquid surface such as the ocean or lake. Transpiration is evaporation of water from plants. Therefore the soil moisture is depleted by transpiration as well as water soaking down into lakes, rivers, and streams by a process called **groundwater flow**.

When evaporation or transpiration takes place, the water vapor goes into the atmosphere and forms clouds by **condensation**, when the water releases heat and changes from a gaseous form into a liquid form. Eventually, the oceans, lakes, rivers, streams, and soil moisture all get replenished when the water in the clouds perform **precipitation** in the form of rain, snow, sleet, or hail. The water can then replenish the soil moisture or perform **surface runoff** into an ocean, lake, river, or stream.

The hydrologic cycle performs a common laboratory technique in chemistry called **distillation** where chemists use the vaporization and condensation to separate ionic substances that were dissolved in water. In the Bible, the hydrologic cycle is described in Job 36:27, 28 when it says "For He draws up the drops of water, they distill rain from the mist, which the clouds pour down, they drip upon man abundantly." A picture of a laboratory distillation process is shown below.



Ocean Waters

The ocean, which makes up an overwhelming percentage of the earth's water, is mostly made up of ionic compounds called salts and water. About 96.5% of the ocean is water, with 2.7% sodium chloride (NaCl), and 0.8% of other ionic salts. The **salinity** of the ocean is the concentration of salt or the measurement of the mass of dissolved salt in a given mass of water. The salinity of ocean water is an average of about 35 grams of salt per 1 kg of water.

The reason the oceans have ionic salts is because during surface runoff, river flow, and groundwater flow, the water dissolves the ionic salts contained in the rocks and soils. Therefore, ionic salts are constantly being added to the ocean. Some of these ionic ions such as calcium get used by organisms in the ocean so they all do not build up in the ocean.

There are some dissolved ionic substances in lakes, rivers, and streams but the concentration is so low, it is not very noticeable. The primary reason why the oceans have such high concentration while other freshwater sources are so low is due to the hydrologic cycle. Since oceans principle method of water change in the hydrologic cycle is evaporation, the salt continues being left behind and adding to the salinity of the water. The salt in lakes, streams, and rivers tend to leave to other sources and therefore never build up in concentration.

Our oceans continue to get "saltier" or more concentrated each year.