3.2 STANDARD TEMPERATURE AND PRESSURE

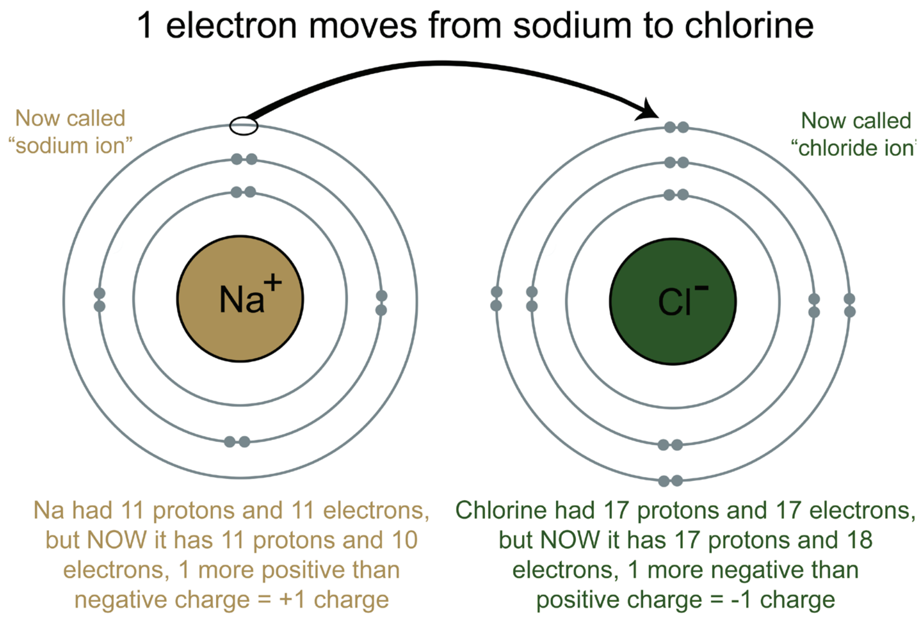
The physical properties of liquids and gases are more affected by pressure and temperature than solids. However, I don't want to give the impression that solids are not affected at all. They are, but much less than gases and liquids. One of the first things that we do when describing the physical properties of any matter is to state what phase of matter it is. But the critical part of stating what phase of matter something is centers upon under what temperature and pressure the matter is. For example, the "official" state of matter of water is a liquid. Ok, we all get that it's a liquid, but it is only a liquid provided certain conditions are met. If the temperature outside is -3 °C, then the water in your pond isn't going to be a liquid; it will be a solid because it's frozen. And, as we will see, not only does temperature affect the state of matter, but so does the atmospheric pressure around the matter.

That being said, then, the only reason that we can state that "water is a liquid," or "sodium chloride is a solid" or "chlorine is a gas" is if we all have the same frame of reference relative to the temperature and atmospheric pressure surrounding the matter when we say it is whatever state it is. That common frame of reference is something called "standard temperature and pressure." There are actually several "standard temperature and pressure" definitions used when describing states of matter, so right off the bat it's clear that there isn't any one "standard" that everyone agrees is "*the* standard." So, we need to choose one and the one we'll go with is defined by the National Institute of Standards and Technology (NIST). NIST refers to their standard conditions as "STP"—**standard temperature** and **pressure**. NIST **standard temperature** is 293.15 K (20 °C, or 68 °F) and **standard pressure** is 101.325 kPa of atmospheric pressure (we'll get to pressure in the next section, but 101.325 kPa is basically the atmospheric pressure present at sea level). So, when we say, "water is a liquid," we mean, "At STP—20 °C and 101.325 kPa—water is a liquid." When we say, "Carbon dioxide is a gas," we mean, "At STP—20 °C and 101.325 kPa—carbon dioxide is a gas." Whenever we describe the "usual" phase of a specific solid, liquid or gas, we mean when the matter is at STP (and, again, since "standard" conditions can vary, STP needs to be defined by whoever is using that term).

3.3 ATMOSPHERIC PRESSURE

For many of you, this next section may be a mind bomb, but stick with me through it and we'll be good! As we just defined, standard pressure is defined as 100 kilopascals, or kPa. What does that mean? Well, the first thing to realize is that pressure—how hard one thing presses against another—is measured in units of pascal (Pa). And, this is strange to think about, but there is a lot of air above us, a lot of molecules. When we are on land at sea level, there is about 10,000 km of atmospheric air above us. Remember, since the air is a gas, it is made of molecules, which is matter. Since it is matter, it has mass. Since it has mass, it has weight, and if it has weight, that means it will press down on anything underneath it. If you aren't sure about that, have your mom or dad, who have mass and therefore weight, start to step on your foot and you will quickly feel the pressure exerted on your foot as a result of their mass being placed on it. The gases of the atmosphere do the same thing, even if you can't see them.

One of the frustrating things about measuring atmospheric pressure is that there are several different units that can be used to report it. The most common unit is inches of Hg, or "inches of mercury." You will hear the weather lady say, "The barometric pressure today is 28.85," and even though she usually doesn't say them, the units are inches of Hg. However, the "official" unit of pressure is the pascal (Pa) or kilopascal (kPa).



So, having those ions in the water changes the conductivity of water; it is a better conductor of electricity with the Na+ and Cl- than it is without. Of course, dissolving NaCl in water to form Na+ ions and Cl- ions changes the chemical composition of the water, but that is the point of this discussion! The chemical composition of matter can have profound effects on the physical properties of matter. Water is transformed from a so-so electrical conductor to an excellent electrical conductor just by adding chloride and sodium ions.

Figure 3.4.2

Some Physical Properties of Liquids

These are just some of the physical properties of liquids. A note about boiling and melting points. Normally, in order to get matter to move from solid to liquid and liquid to gas, energy, in the form of heat, needs to be added to the matter. As energy in the form of heat is added to a solid, its molecules begin to absorb the energy, and that makes them start to vibrate a little faster. The more heat the molecules absorb, the faster they move. Eventually, the solid matter molecules absorb enough energy and are all vibrating fast enough that the bonds holding them together can't hold them anymore, which means the solid can no longer maintain its shape and turns into a liquid. Once in liquid form, the molecules are free to move around one another. As the liquid is heated further, its molecules vibrate faster and faster, eventually absorbing enough energy that the liquid turns into gas; it boils. So, when we describe the phase of matter, we do so at STP, which means that at 101.325 kPa and 20 °C, the matter is a solid, liquid or gas. Therefore, if at STP, the matter is a liquid, then clearly that means the melting point of matter that is a liquid at STP is lower than that of matter that's solid at STP.

Arrangement of atoms/molecules in the matter	Not packed as tightly as solids, but tighter than gases
Ability of atoms/molecules in the matter to move	Can move freely around other liquid molecules
Shape	Cannot maintain its own shape
Volume (the space matter takes up)	Has a finite volume
Malleability (Ductility)	None
Density (number of atoms per unit of space)	Generally similar to solids and higher than gases
Response to heating	Low expansion
Compressibility	Almost none
Rigidity	No rigidity and flow easily
Ability to be cut	None
Visibility and color	Visible and with color
Melting Point	Lower temperatures than solids but higher than gases
Boiling point	Lower temperatures than solids but higher than gases
Brittleness (the pressure under which a solid breaks)	None
Electrical conductivity (ability to conduct electricity)	Variable, some are very good, others not so much; better than gases

3.9 GAS MATTER—GENERAL

As was the case for solid and liquid matter, there are many physical properties of gas matter. However, it is interesting to note that, for purposes of physics, gases are treated as liquids because they follow the same rules as liquids. The main reason that gases follow a fluid model is that, like liquids, the particles of gases are free to move around each other. I have summarized the same physical properties for gases as we looked at for solids and liquids in **Figure 3.9.1**.

Figure 3.9.1

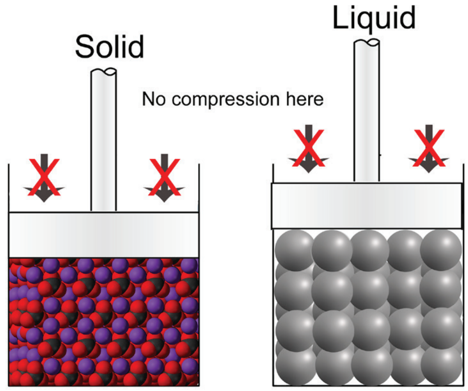
Some Physical Properties of Gases

These are just some of the physical properties of gases. Also, I 'd like to discuss the same issue of melting and boiling points briefly for gases as we did for liquids. Because of the chemical composition of gases, their molecules have enough energy that at STP, they are already gases. So, in order to find their "boiling" and "melting" points, what we really do is find their condensation and freezing points. Since matter that is a gas at STP is already a gas, we need to cool it to below 20 °C (293.15 K) to find the temperatures at which it condenses and then freezes. As you cool a gas below 20 °C, it gets closer and closer to its "boiling" point, which we learned above is referred to as the condensation point when the temperature is being lowered. Once the temperature around the gas falls below its condensation/boiling point, it becomes liquid matter. As you cool the liquid matter further, is gets closer and closer to its "melting" point, which we learned above is the freezing point when the temperature is being lowered. Once the temperature goes below the freezing/melting point, the matter turns to a solid. The bolded properties of the gases are ones that are significantly different than solids and liquids.

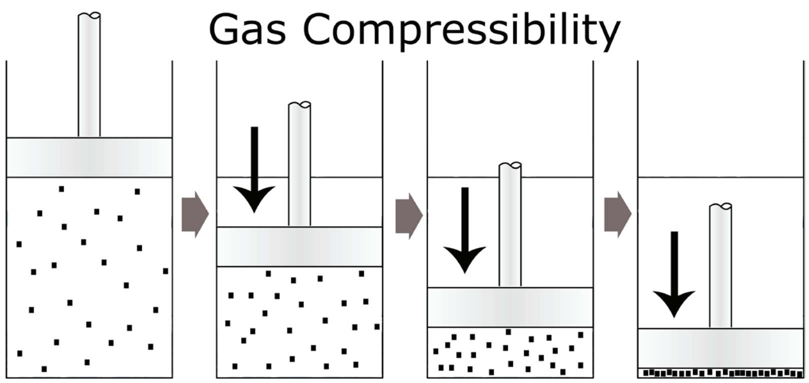
Arrangement of atoms/molecules in the matter	Not packed tightly all
Ability of atoms/molecules in the matter to move	Can move freely around other gas particles
Shape	Cannot maintain its own shape
Volume (the space matter takes up)	**Has infinite volume**
Malleability (Ductility)	None
Density (number of atoms per unit of space)	Lower than solids and liquids
Response to heating	**Expands significantly**
Compressibility	**High**
Rigidity	No rigidity and flows easily
Ability to be cut	None
Visibility and color	Variable, but often colorless
Melting Point (when a solid becomes a liquid)	Lower than solids and liquids
Boiling point (when a liquid becomes a gas)	Lower than solids and liquids
Brittleness (the pressure under which a solid breaks)	None
Electrical conductivity (ability to conduct electricity)	Poor

Even though gases and liquids are both included in hydraulics and liquid mechanics, there is one major difference between the two, related to their volumes, that I'd like to explore a bit more—liquids have a finite volume, but gases have infinite volume. Whoa, what do I mean by that? Let's find out.

As we know, the particles of liquids and gases are free to move around one another, but the way that this property is manifested is very different between the two types of matter. On the next page, liquid matter is in a beaker on the left and gas matter in a beaker on the right. Note that the beakers have an open top, which does not limit the volume that either the liquid or the gas can occupy, and this is where we see the fundamental difference in the property of volume. Even though its container has an open top, the liquid matter doesn't go out of its container. The liquid is poured into its container, and there it sits. As a liquid, it will sit in that beaker and occupy the same space regardless of how long it sits because, even though the particles of the liquid matter are free to move around one another, and they do, they are incapable of leaving the confines of their container. Liquids are finite.



But gases are far less dense. Gases have way fewer molecules per unit of volume, which makes them highly compressible:



Gases are so compressible, in fact, that another effect of pressure becomes apparent—the condensation point can be changed. The more you compress a gas, the closer you bring it to its condensation point at room temperature. Eventually, if a gas is compressed under enough pressure, it will turn into a liquid at room temperature (see **Figure 3.10.1**).

Figure 3.10.1

Compressed Gas
If you look for them you can see these tanks all over the place, but a lot of folks don't realize what's in there (or how much). This is an oxygen cylinder to provide portable oxygen gas for people with lung diseases. If I were to pour water into this tank, it would hold about 6,000 cm^3 (a little over a gallon-and-a-half). But when it is filled with compressed oxygen gas, it holds the equivalent of more than 688,000 cm^3 (about 182 gallons)! The oxygen is under high compression—13,000 kPa, which is 130 times the regular atmospheric pressure. At standard pressure, 101.325 kPa, the boiling point of oxygen is -182.96 °C, but when it is under 13,000 kPA, its boiling point is raised high enough that oxygen is a liquid at room temperature. The tank is filled partially with liquid oxygen and partially with gas oxygen, and when the tank is turned on, it lets oxygen gas out to the patient, the pressure in the tank lowers a little bit, some of the liquid oxygen inside of the tank "boils" into gas matter and goes out the tank to the patient. As gas inside the tank continues to run out of the tank, the pressure inside the tank decreases, which continues to lower the boiling point of the liquid oxygen. Since the boiling point of the liquid oxygen decreases, it continues to turn from a liquid into a gas to replace the gas that just left the tank. This is how it is possible for the tank to dispense 688,000 cm^3 of oxygen even though the real capacity of the tank is 100 times less. Liquids are so much denser than gases that a very small volume of liquid oxygen holds more than 100 times the volume of oxygen molecules in gas form.

3.13 KEY CHAPTER POINTS

- Standard temperature and pressure—STP—is 20 °C (293.15 K) and 101.325 kPa, respectively.
- Defining STP is necessary so that we all have a common frame of reference when describing phases of matter.
- Atmospheric pressure, also called barometric pressure, can be measured with a barometer and is generated by the 10,000 km of atmospheric gas matter, which creates a downward pressure.
- Hydraulics is the branch of physics that studies liquid matter.
- Physical properties of matter are determined by the chemical composition of the matter.
- Many types of liquid matter have densities similar to many solids.
- Buoyancy is an upward force exerted by liquids on an object immersed or submerged in the liquid. The strength of the liquid's buoyant force becomes stronger the denser the fluid is.
- Archimedes' principle states that the strength of the buoyant force on an object is equal to the weight of the water displaced by the object.
- An object dropped into a buoyancy column will fall through the liquid layers until getting to the first layer that is denser than itself (or it hits the bottom).
- Pressure has great effect on gas matter, less effect on liquid matter, and very little effect on solid matter.
- The main physical property that differentiates gases from liquids and solids is that gases have infinite volumes.
- Gases are the only phase of matter that can be appreciably compressed.
- The Bernoulli principle and Newton's 3rd law of motion are both involved in generating the force of lift.

3.14 DEFINITIONS

Air pressure
See atmospheric pressure.

Aneroid barometer
A barometer that uses coiled metals that are sensitive to changes in the atmospheric pressure as the means for measurement.

Archimedes' principle
The buoyant force water exerts on an object is the same as the weight of the water displaced by the object.

Atmospheric pressure
The pressure exerted by the gas matter of the atmosphere.

Barometer
A device that measures the atmospheric pressure.

Barometric pressure
See atmospheric pressure.

Bernoulli's principle
The faster a liquid moves, the lower the pressure is immediately around the liquid.

Buoyancy
An upward force that liquids exert on matter immersed or submerged in the liquid.

Compress
To squeeze or press; to place under pressure.

Condensation point
The temperature at which a gas turns into a liquid.

Condense
When a gas turns into a liquid.

Freeze
When a liquid turns into a solid.

Freezing point
The temperature at which a liquid turns into a solid.

Hydraulics
The study of the physical properties of water.

Immerse
To be in, but only partially covered by, a liquid.

Lift
An upward force exerted by a liquid on another object.

Liquid mechanics
The physical properties of water.

Mercury barometer
A barometer that uses the amount of displacement of mercury in a glass tube to measure the atmospheric pressure.

Standard pressure
An atmospheric pressure of 101.325 kPa.

Standard temperature
20 °C or 293.15 K.

Submerse
To be in and completely covered by a liquid.

Water vapor
Water in gas form.

STUDY QUESTIONS

1. Which is the correct standard temperature and pressure that we use for this course?
   a. 0 °C and 293.15 kPa
   b. 293.15 °C and 1 kPa
   c. 0 °C and 10 kPa
   d. 20 °C and 101.325 kPa
   e. 293.15 °C and 10 kPa

2. What phase is water at STP?

3. True or False: right now, as you sit and read this sentence, 1,000 kg of matter is pressing down on you.

4. If you are standing at sea level, about how much atmosphere is there above your head (in kilometers)?

5. True or False: barometric pressure and atmospheric pressure are not the same measurement.

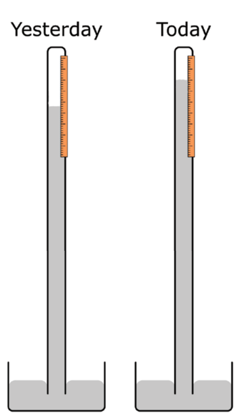
6. What is the "official" SI unit of pressure measurement?

7. True or False: for most areas on earth, the atmospheric pressure is between 32.77 kPa and 101.325 kPa.

8. What is this device called?

9. You have a mercury barometer, calibrated to read in kPa. Yesterday was a very nice day, with relatively high pressure of 103.2 kPa. Overnight, a strong storm system pushed in and it is still raining. You know that strong systems are associated with low barometric pressure, so when you look at your mercury barometer today, which choice below correctly shows what you would expect the barometer looked like yesterday and what it will look like today?

a.



b.