Chemistry Lecture #66: Kinetic Theory, Introduction to Boyle's & Charles's Law

A balloon is filled with gas. What are the properties of the gas that give the balloon its size and shape?

Kinetic theory makes the following assumptions about the gas inside the balloon:

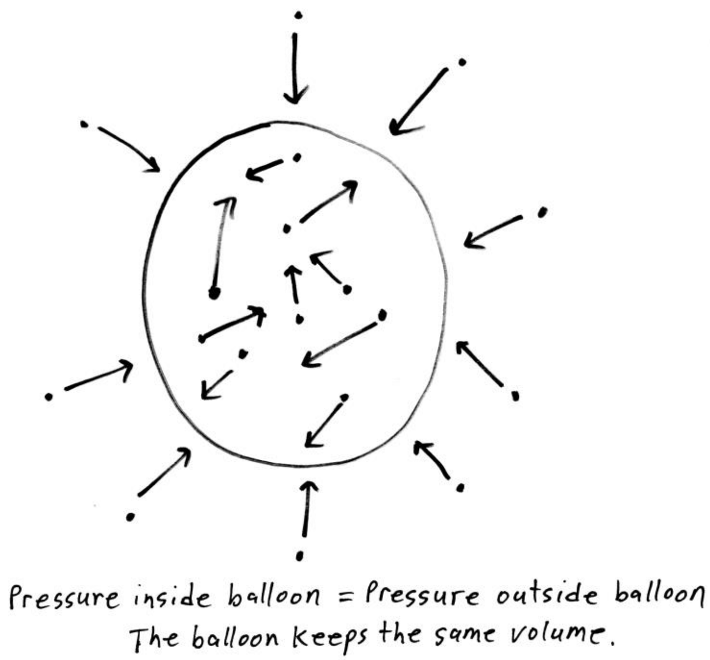
- The balloon is filled with tiny, indestructible particles (atoms and molecules).
- The particles that make up a gas have a very tiny volume. The volume is so tiny we assume the volume of a gas particle is zero.
- The particles do not attract or repel each other.
- Gas particles are in constant, random motion. The particles move in straight lines at very high speed. Particles change direction only when they collide with each other or with the walls of the container.
- No kinetic energy is lost when gas particles collide with each other or with the walls of their container. These types of collisions are called *elastic collisions*. If collisions were not elastic, energy would be lost to friction, and a balloon would get smaller and smaller as the particles moved slower and slower.

- All gases have the same average kinetic energy at a given temperature. Thus, a balloon filled with oxygen gas will have the same kinetic energy as a balloon filled with helium gas as long as both balloons are at the same temperature. If one balloon has a higher temperature, then it has a higher kinetic energy and its particles move faster.

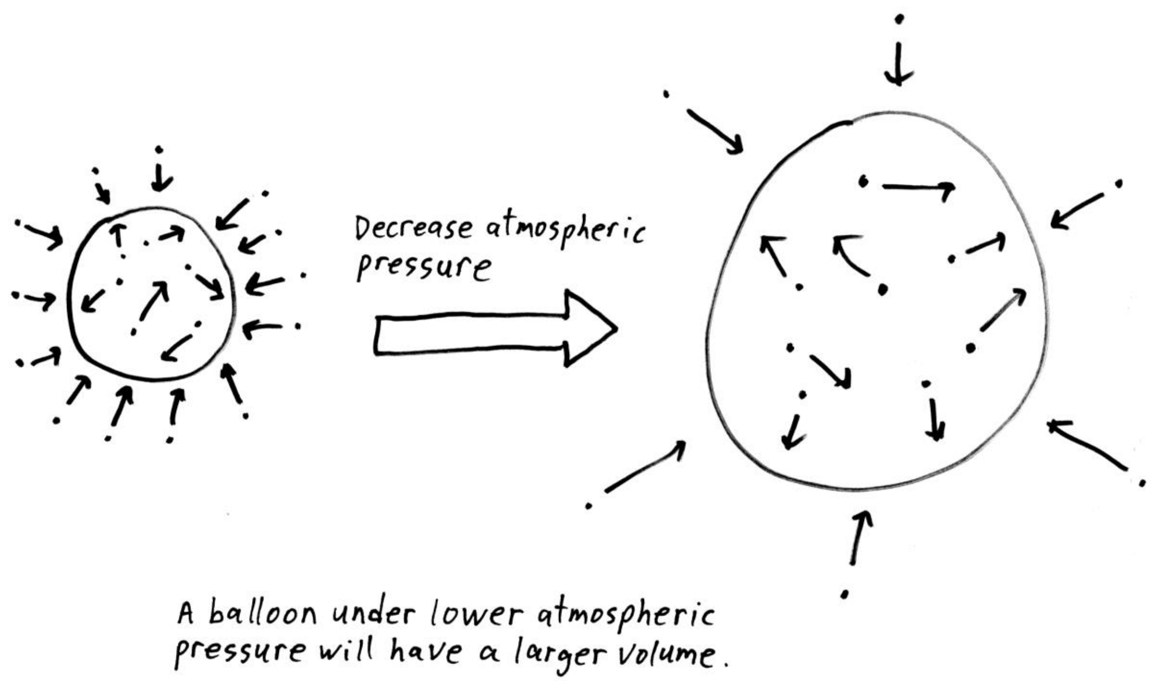
Kinetic theory explains how the size of a balloon can change as the surrounding air pressure changes. A balloon filled with gaseous atoms and molecules are in constant motion and collide with the inner wall of the balloon. This pressure inside the balloon pushes the walls outward.

However, the atmosphere outside the balloon also exerts a pressure on the balloon. Gaseous atoms and molecules from the atmosphere collide with the outside surface of the balloon. Thus, the atmospheric pressure pushes the walls of the balloon inward.

If the size of the balloon remains constant, then the atmospheric pressure pushing inward is equal to the gas pressure inside the balloon that is pushing outward.



If the pressure outside the balloon is reduced, the pressure inside the balloon pushing out will be greater than the pressure outside the balloon pushing in. The balloon will begin to expand.



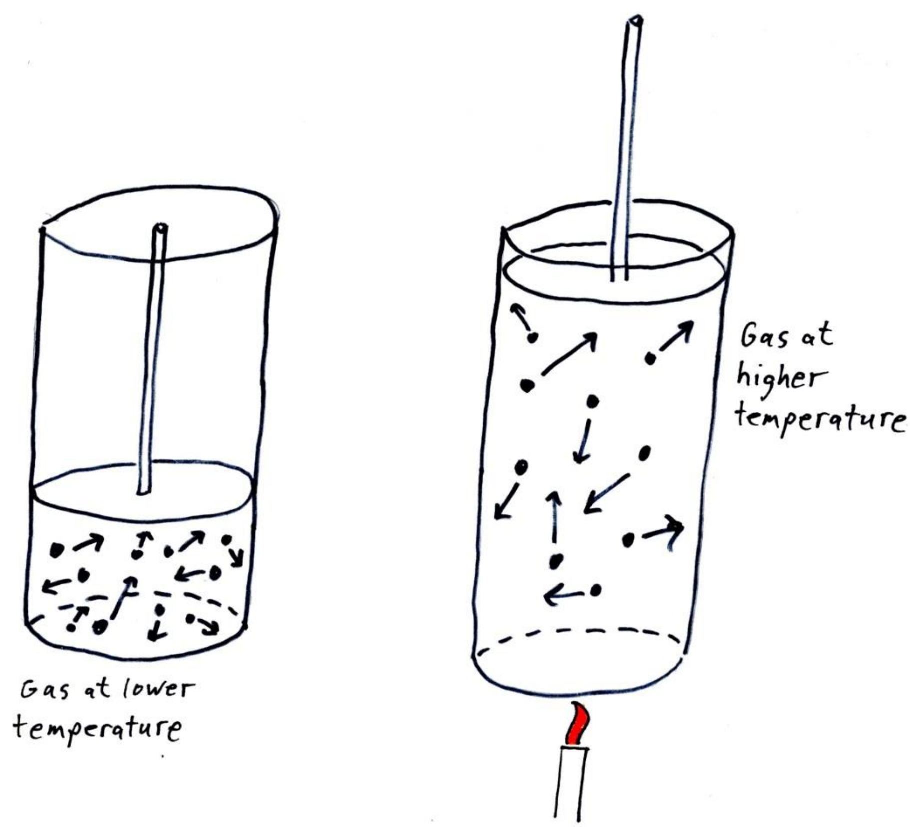
As the balloon expands, there will be more space inside the balloon. There will be fewer collisions between the gas particles and the inner wall. Internal gas pressure decreases as the volume of the balloon increases. Eventually, the internal pressure of the balloon will equal the outer atmospheric pressure, and the balloon will stop growing. The internal pressure of the gas is now smaller but its volume is larger.

Thus, if atmospheric pressure is reduced, the volume of the balloon will increase. This is an example of Boyle's law. Boyle's law states that at constant temperature, the volume of a gas varies inversely with its pressure. A gas under lower pressure will have a larger volume. A gas under higher pressure will have a smaller volume.

The next time you drive over a mountain range bring a bag of potato chips with you. As you climb the mountain range, the bag will often begin to swell and get bigger. This occurs because there are fewer air molecules at the top of a mountain. There is less air pressure pushing against the bag, so the internal pressure in the bag has less resistance, allowing the bag to swell.

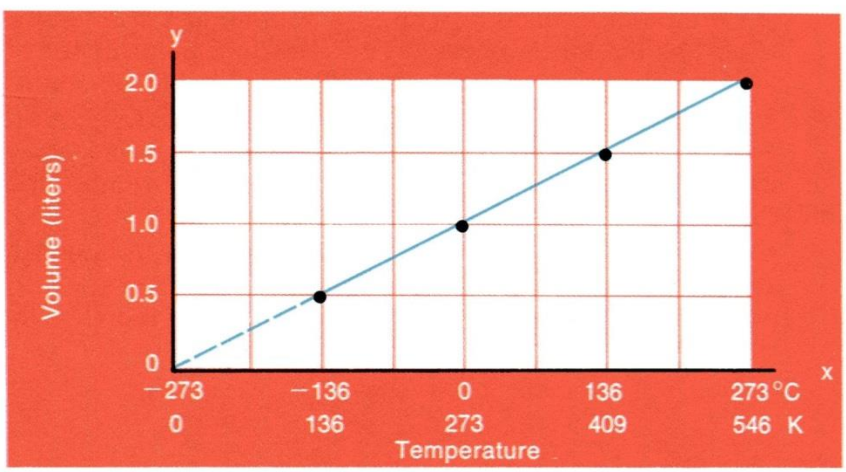
Kinetic theory also explains how the volume of a gas changes as temperature changes. If the temperature of the gas inside a cylinder that is covered with a piston increases, the atoms and molecules would move faster. This would cause more collisions against the inside wall of the cylinder, so there would be more pressure inside.

When the pressure inside the cylinder becomes greater than the atmospheric pressure outside the cylinder, the gas will expand and push the piston up. As the piston moves up, there is more space in the cylinder, resulting in fewer collisions of gas molecules against the inside wall. Eventually the pressure in the cylinder matches the pressure outside the cylinder, and the gas will stop expanding.



Thus, if the temperature of a gas inside a cylinder is increased, the volume of the gas will increase. This is an example of Charles's law. Charles's law states that at constant pressure, the volume of a gas is directly proportional to its temperature (in Kelvins). A gas at high temperature will have a larger volume than a gas at low temperature.

If you were to cool a gas, then plot its volume against temperature, you would get a straight line. In the graph below, the volume of a gas in liters is plotted against its temperature in both Celsius and Kelvin.



Notice that when the volume of the gas is zero, its temperature is -273 °C or zero Kelvin. Zero Kelvin is absolute zero - it is the complete absence of kinetic energy. You can't get any colder than absolute zero!

The Kelvin scale gives the true measurement of the kinetic energy of a gas. If the Kelvin temperature is doubled, the average kinetic energy is doubled, and the volume of the gas will be doubled. Notice that at 273 K the volume of the gas is 1.0 L, but at double the Kelvin temperature (546 K) the volume is 2.0 L.

This doesn't work if you use Celsius temperature. If the Celsius temperature increases from 50 °C to 100 °C, the kinetic energy has increased, but it has *not* doubled.

To convert Celsius temperature to Kelvins, use the formula

$$K = C + 273$$

where K = Kelvin temperature
C = Celsius temperature

50 °C is really 50+ 273 = 323 K, and 100 °C is really 100 + 273 = 373 K. A temperature increase from 323 K to 373 K is not a doubling of kinetic energy.