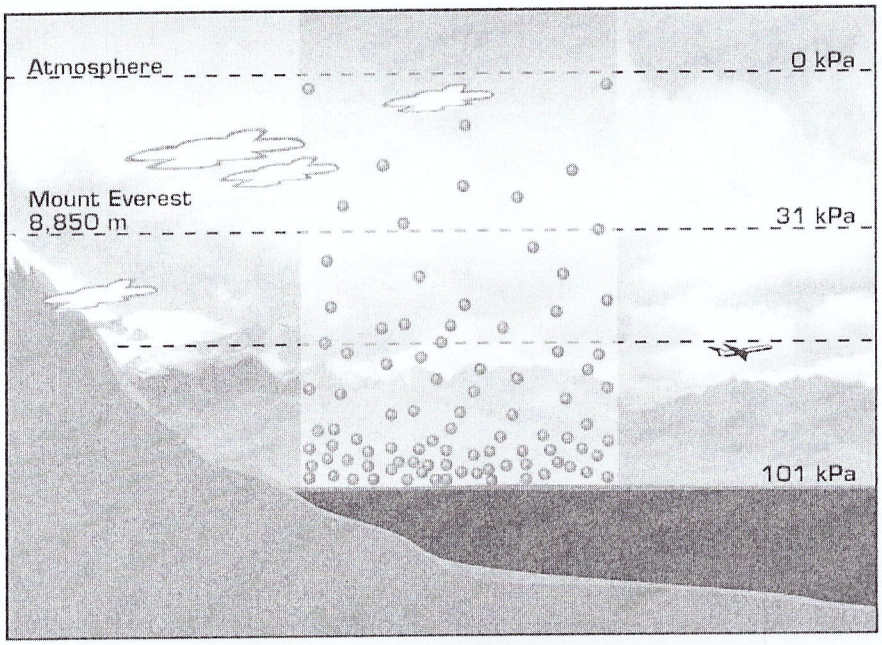
# Boyle's Law

- Recall the kinetic molecular theory explains that all gas molecules are in constant random motion
  - When the gas molecules collide with the walls of their container, the gas molecules will exert a force on container walls

linked ✳

- Therefore, **pressure** is defined as force per unit area and is exerted in all directions to the same extend
- **Atmospheric pressure** can be described as the force that a column of air exerts on a particular area of the Earth's surface
  - Air is less compressed as altitude increase because there is less weight from the atmosphere above. Therefore, there is less pressure at higher altitudes.

high altitude




less pressure → particles are more spread out ∴ less collisions

low altitude

more pressure → particles closer together ∴ more collisions

- There are several different units used to measure pressure
  - millimeters of mercury (mmHg)
  - Pascal (Pa) or kilopascal (kPa)
  - atmosphere (atm)
  - bar (bar)
- In order to complete gas calculations, pressure units may need to be converted from one form to another
  - The unit conversions are as follows:

**760mmHg = 1 atm = 101.325 kPa**

↑ in data booklet

EXAMPLES: Convert the following units.

1. 650.0 mmHg to kPa

$650.0\ \text{mmHg} \times \left(\frac{101.325\ \text{kPa}}{760\ \text{mmHg}}\right)$

$= 86.6595\ldots\ \text{kPa}$

$\boxed{86.7\ \text{kPa}}$

2. 0.25 atm to kPa

$0.25\ \text{atm} \times \left(\frac{101.325\ \text{kPa}}{1\ \text{atm}}\right)$

$= 25.33125\ \text{kPa}$

$\boxed{25\ \text{kPa}}$

3. 1.3 atm to mmHg

$1.3\ \text{atm} \times \left(\frac{760\ \text{mmHg}}{1\ \text{atm}}\right)$

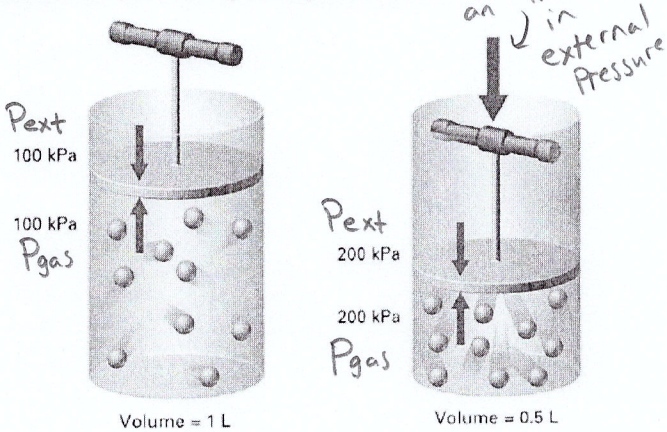
$= 988\ \text{mmHg}$

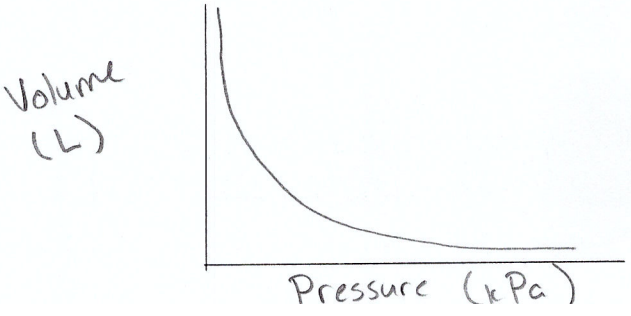
$\boxed{9.9 \times 10^2\ \text{mmHg}}$

*****Now try Practice Problems #1*****

- Scientist Robert Boyle studied the relationship between pressure and volume of gases at *constant temperatures*
- As the volume of a contained gas is reduced, there is less room for the gas particles to move around which means they will collide more frequently with the container walls
  - more collisions = higher pressure because there is more force per unit area on the container walls
  - Therefore, as the volume of a container is reduced, the gas pressure must increase
  - Boyle kept the temperature constant to ensure the average kinetic energy/speed of the particles remained constant

force needed to create an increase in external Pressure



* • Boyle's Law states that the volume of a gas is *inversely related* to the pressure of the gas at constant temperature and mass
    - **Inversely related** means that as one variable increases, the other variable must decrease and vice versa

- Boyle's law helps explain how our lungs function. As we inhale, we increase the volume of our chest cavity which decreases the air pressure inside our lungs. This decrease in air pressure inside of our lungs allows air to flow in from outside our bodies because atmospheric pressure is now at a higher our lung pressure.
- Boyle's Law can also be described by the following formula

$$P_1V_1 = P_2V_2$$

* memorize equations

where $P_1$ and $P_2$ are pressures

$V_1$ and $V_2$ are volumes

Any units are acceptable as long as they are consistent!

units are the same!

EXAMPLES:

1. A 2.5L cylinder of anesthetic gas is at 100kPa. The cylinder has an adjustable piston to vary the volume of the tank. If the cylinder is expanded to 6.25L, what will be the pressure of gas inside the cylinder if the temperature remains constant?

$V_1 = 2.5\ L$

$P_1 = 100_K Pa$

$V_2 = 6.25\ L$

$P_2 = ?$

$$P_1V_1 = P_2V_2$$

$$\frac{P_1V_1}{V_2} = P_2 = \frac{(100_K Pa)(2.5\ L)}{6.25\ L} = 40\ L$$

$$\boxed{P_2 = 40_K Pa}$$

2. A balloon is filled with 30.0L of helium gas at 750mmHg. What is the volume of the balloon when the balloon rises to an altitude where the pressure is only 25.0kPa? Assume a constant temperature.

$V_1 = 30.0\,L$

$P_1 = 750\,mmHg$

$V_2 = ?$

$P_2 = 25.0\,\cancel{kPa} \times \left(\frac{760\,mmHg}{101.325\,\cancel{kPa}}\right)$

$P_2 = 187.515\,42...\,mmHg$

$P_1V_1 = P_2V_2$

$V_2 = \frac{P_1V_1}{P_2}$

$V_2 = \frac{(750\,mmHg)(30.0\,L)}{187.515\,42...\,mmHg}$

$V_2 = 119.990...\,L$

$\boxed{V_2 = 120\,L}$

3. A flexible container has a volume of 10.0L. If the pressure is tripled, what will the new volume be?

$V_1 = 10.0\,L$

$P_1$

$P_2 = P_1(3)$

$V_2 = ?$

$P_1V_1 = P_2V_2$

$\frac{P_1V_1}{P_2} = V_2$

$\frac{\cancel{P_1}(10.0\,L)}{\cancel{P_1}(3)} = V_2$

$3.\overline{3}\,L = V_2$

$\boxed{3.33\,L = V_2}$

***Now try Practice Problems #2-8***

## Practice Problems

1. Convert the following pressures. Round to correct significant digits.

   a. 4.0 atm to kPa

   b. 855 mmHg to kPa

   c. 0.625 atm to kPa

   d. 150.0 mmHg to atm

   e. 0.78 atm to mmHg

   f. $2.7 \times 10^2$ kPa to atm

   g. 364 kPa to mmHg

2. When using a medicine dropper or a meat baster, you squeeze the rubber bulb and insert the end of the tube into a liquid. Why does the liquid rise inside the dropper or baster when you release the bulb?

3. A small oxygen canister contains 110mL of oxygen gas at a pressure of 3.0atm. All of the oxygen is released into a balloon with a final pressure of 2.0atm.

    a. Predict whether the final volume will be smaller, greater or the same. Explain.

    b. What is the final volume of the balloon?

4. A diving bell contains 32kL of air at a pressure of 98kPa at the surface. About 5m below the surface, the volume of the air trapped inside the bell is 21kL. What is the pressure of the air in the bell 5m below the surface, if you assume that the temperature remains constant?

5. A weather balloon containing 35.0L of helium at 98.0kPa is released and is allowed to rise. Assuming that the temperature remains constant, find the volume of the balloon when the atmospheric pressure is 0.247atm at a height of about 25km.

6. A flexible container holds 4.0L of air at 22°C. If the temperature remains constant, what is the pressure inside the container if the volume is doubled?

7. The volume of gas in a syringe is 2.50mL. If the pressure on the syringe is halved, what will the final volume of the gas be?

8. A sample of neon gas at room temperature is collected in a 2.50L balloon at standard atmospheric pressure (101.325kPa). The balloon is then submerged into a tub of water, also at the same temperature, so that the external pressure is increased to 843mmHg.

**Answers:**

1.
   a. $4.1 \times 10^2$ kPa
   b. 114 kPa
   c. 63.3 kPa
   d. 0.1974 atm
   e. $5.9 \times 10^2$ mmHg
   f. 2.7 atm
   g. $2.73 \times 10^3$ mmH

2. As you release the bulb, the volume of the bulb increases. According to Boyle's Law, an increase in volume will decrease the pressure. The reduced pressure on the inside of the bulb allows the liquid to flow up and fill the bulb because the pressure outside the bulb is greater and pushes the liquid up.

3.
   a. The volume the balloon will increase because the pressure decreased (according to Boyle's Law, pressure and volume are inversely related).
   b. $1.7 \times 10^2$ mL

4. $1.5 \times 10^2$ kPa

5. 137 L

6. 2.0 L

7. 5.00 mL

8. 2.25 L