# Chapter 16 – Gases

## *16.1 Pressure*

Gas pressure: force per unit area exerted by gas molecules colliding against the walls of the container.

P increases when

1) number of collisions increase (more hits on the container walls)

2) energy of collisions increase (harder hits on the container walls)

Vacuum: no gas molecules are present, so gas pressure equals zero

Atmospheric pressure: pressure exerted by air molecules colliding with surfaces in environment.

$\Rightarrow$ decreases as altitude increases because air becomes less dense (thinner)

Barometer: instrument invented by Torricelli to measure atmospheric pressure

$\Rightarrow$ Atmospheric pressure is 760 torr at sea level, lower at higher altitudes like Denver

Standard atmospheric pressure: a column of mercury measuring 760 mm Hg.

$$1 \text{ atm} \equiv 760 \text{ torr} \equiv 760 \text{ mm Hg} = 14.7 \text{ psi (approx.)}$$

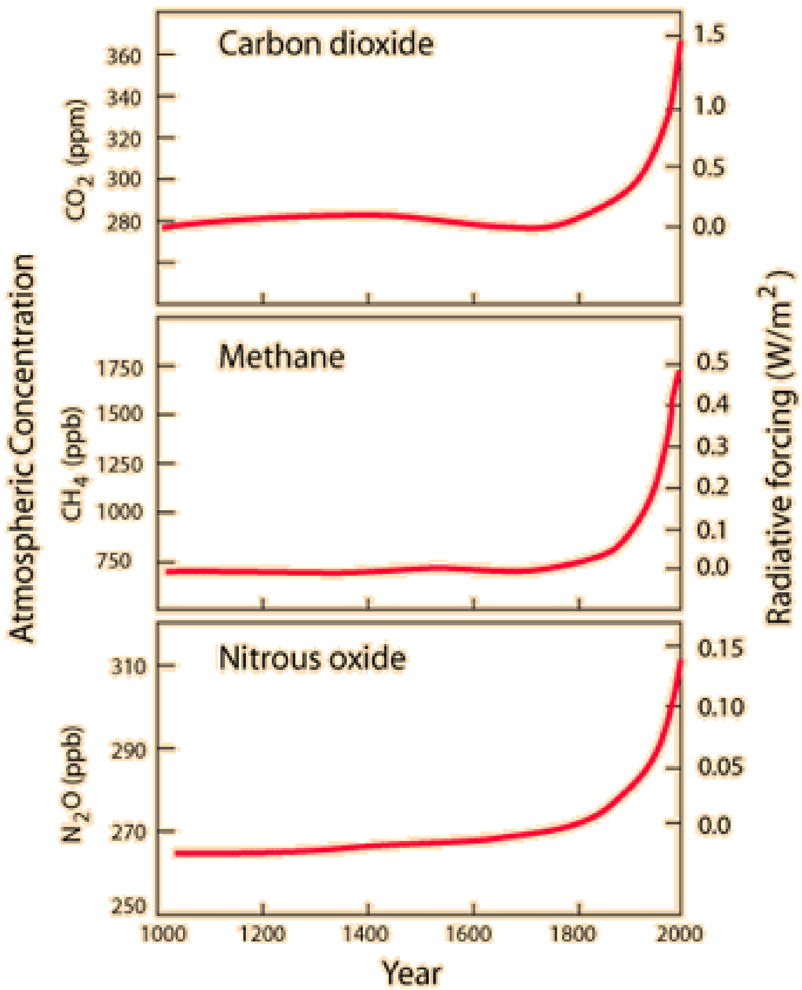
Know how to convert from one unit of pressure to the other units.

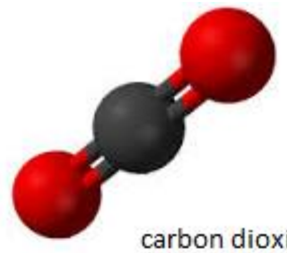
You should review properties of gases in chapter 1. You should also know standard temperature and pressure, STP = 1 atm and $0^oC$.

## *16.2 Greenhouse Gases*

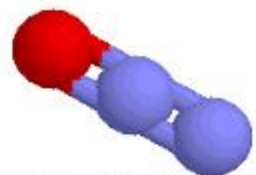
Greenhouse gases are in the news daily it seems because they are so important to our future environment here on Earth. Greenhouse gases (GHG) are gases in the atmosphere they act like a blanket keeping heat here around planet Earth. In fact we would not here without GHG, so a certain amount of them is necessary for life. But we have been increasing the balance of GHG over the past century to the point where we are keeping more heat in than desired which is giving rise to global climate change. The main GHG that we are concerned about are carbon dioxide, $CO_2$, methane, $CH_4$, and nitrous oxide, $N_2O$.

The main sources of GHG increasing in our atmosphere are coal power plants, gasoline powered vehicles, and the meat industry. Our reliance on fossil fuels is changing our environment by slowly heating up our world. Scientific measurements show that global average temperatures are increasing, mean sea level is increasing, Artic and Antarctic ice is melting, glaciers are melting, and GHG concentrations are increasing. Also predicted by climate change is an increase in severe weather events such as tornadoes, hurricanes, floods and drought.

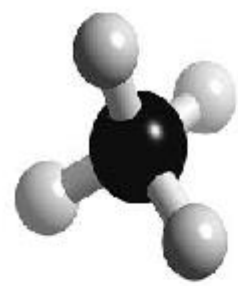


carbon dioxide



nitrous oxide



methane

## 16.3 Gas Laws

Several different scientists studied gases and how they depend on different variables such as volume, V, pressure, P, and temperature, T.  What happens to the pressure of a gas given the following changes?

a. If Volume ↑, pressure_____.                ↑        ↓        *stays same*

   Thus, pressure and volume are _____ related.        *not*        *directly*        *inversely*

b. If Temperature ↑ , pressure _____.                ↑        ↓        *stays same*

Thus, pressure and temperature are _____ related. *not* *directly* *inversely*

c. If # of gas molecules ↑, pressure _____. ↑ ↓ *stays same*

Thus, pressure and # of molecules are _____ related. *not* *directly* *inversely*

Boyle studied pressure volume relations and in 1662 determined that when T is held constant $P_1V_1 = P_2V_2$. Charles studied volume temperature relations and in the 1780's determined that when P is held constant $\frac{V_1}{T_1} = \frac{V_2}{T_2}$. And Gay Lussac studied pressure temperature relations and in 1808 determined that $\frac{P_1}{T_1} = \frac{P_2}{T_2}$.

## *16.4 Combined Gas Law*

Instead of memorizing three separate gas laws from above, we can combine them into one law: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$. But be careful, when using gas laws the temperature MUST be in Kelvin. Here are some guidelines for using the combined gas law:

1. List all of the measurements given, and label each as $P_1$, $V_1$, $T_1$, etc.
2. Convert all temperatures to Kelvin, convert all pressures to the same units, and convert all volumes to the same units.
3. Starting with the Combined Gas Law $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$, omit variables that remain constant. If a variable is not given, assume it remains constant so it cancels out.
4. Isolate the unknown variable. The unknown variable must be alone on one side of =.
5. Solve for the unknown, making sure your final answer has the correct units and the correct number of sig figs.
6. Check if your final answer makes sense.

**Example Combined Gas Law Problem**

A variable volume container holds 24.3 L of $N_2$ gas at 55 °C. What will the volume of the $N_2$ gas be if the temperature falls to 17 °C?

Change T to Kelvin: $T_1 = 55 + 273 = 328$ K $T_2 = 17 + 273 = 290$ K

$V_1 = 24.3$ L $V_2 = ?$

Omit P from combined gas law: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Solve for $V_2$: $V_2 = \dfrac{V_1 T_2}{T_1}$

$V_2 = \dfrac{(24.3L)(290K)}{(328K)} = 21.5$ L ✓ T↓ V↓ so makes sense ☺

## 16.5 Ideal Gas Law

The ideal gas law is an equation that is used to approximate the conditions of a gas. It was first published in 1834 by Emile Clapeyron. The equation is PV=nRT where n is number of moles of gas and R is the gas constant 0.08206 $\frac{L\ atm}{mol\ K}$. Note that to use this equation volume must be in liters, pressure in atmospheres, and temperature in Kelvin. This equation is used to find out the status of a gas whereas the combined gas law is used to determine variables of a changing gas.

**Example Ideal Gas Law Problem**:

What is the pressure of the GHG carbon dioxide if there is 55.3 grams at 42.7°C in a 12.4 L container?

First we need moles of gas n so 55.3 g $CO_2$ $\left(\frac{1\ mol}{44.01\ g}\right)$ = 1.2565 moles $CO_2$

Now check our units – we need Kelvin, so 42.7 + 273 = 315.7 K

Now solve the equation for pressure P = $\frac{nRT}{V}$

And plug into the equation P = $\dfrac{(1.2565\ mol)(0.08206\frac{L\ atm}{mol\ K}(315.7\ K)}{12.4\ L}$ = 2.63 atm

## Practice Problems

1. The tire pressure for tires used on most automobiles is about 32 psi. Express this pressure in atm, torr, and mm Hg.

2. A 250.0-mL sample of CO gas at 1.20 atm is compressed to 125.0 mL. Calculate the new pressure.

3. A sample of $CO_2$ gas at 2.50 atm is cooled from 75˚C to 25˚C. Calculate the new pressure.

4. The gas in a 0.717 L cylinder exerts a pressure of 744 torr at 27 °C. What volume will it occupy at 48.6 atm and 547 °C?

5. A gas occupies 2.33 L at STP. What pressure (atm) will this gas exert if it is expanded to 6.19 L and warmed to 17 °C?

   At STP, the temperature = __________ and the pressure = __________.

6. What is the volume of 87.24 grams of nitrogen gas if the temperature is 25.5$^{o}$C and the pressure is 0.893 atm?

**7.** What is the temperature of 2.45 grams of hydrogen gas if the volume is 17.35 liters and the pressure is 782 torr?

| Answers |
|---|

**1.** $32 \text{ psi} \left(\frac{1 \text{ atm}}{14.7 \text{ psi}}\right) = \mathbf{2.2 \text{ atm}}$

$32 \text{ psi} \left(\frac{760 \text{ torr}}{14.7 \text{ psi}}\right) = \mathbf{1.7x10^3 \text{ torr}} = \mathbf{1.7x10^3 \text{ mm Hg}}$

**2.** $\mathbf{V_1 = 250.0 \text{ mL}}$ $\mathbf{P_1 = 1.20 \text{ atm}}$

$\mathbf{V_2 = 125.0 \text{ mL}}$ $\mathbf{P_2 = ?}$

**Omit T from combined law:** $P_1V_1 = P_2V_2$

**Solve for $P_2$:** $\mathbf{P_2} = \frac{P_1 x V_1}{V_2}$

$\mathbf{P_2} = \frac{(1.20 \text{ atm}) x (250.0 \text{ mL})}{(125.0 \text{ mL})} = 2.40 \text{ atm}$ ✓**V**↓ **P**↑

**3.** $P_1 = 2.50 \text{ atm}$ $\mathbf{T_1 = 75 + 273 = 348 \text{ K}}$

$P_2 = ?$ $\mathbf{T_2 = 25 + 273 = 298 \text{ K}}$

**Omit V from the combined gas law:** $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

**Solve for** $P_2$: $P_2 = \frac{P_1 \times T_2}{T_1}$

$P_2 = \frac{(2.50 \text{ atm}) \times (298 \text{ K})}{(348 \text{ K})} = 2.14 \text{ atm}$ ✓**T**↓ **P**↓

4. $\mathbf{V_1 = 0.717\ L}$ $\mathbf{T_1 = 27 + 273 = 300\ K}$ $\mathbf{P_1 = 744\ torr}$

$\mathbf{V_2 = ?}$ $\mathbf{T_2 = 547 + 273 = 820\ K}$ $\mathbf{P_2 = 48.6\ atm}$

Convert $P_1$ to atm: $P_1 = 744\text{ torr}\left(\frac{1\text{ atm}}{760\text{ torr}}\right) =$ 0.979 atm

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Solve for $V_2$: $V_2 = \frac{P_1V_1}{T_1} \times \frac{T_2}{P_2}$

$$V_2 = \frac{(0.979\text{ atm})(0.717\text{ L})}{(300\text{ K})} \times \frac{(820\text{ K})}{(48.6\text{ atm})} = 0.0395\text{ L}$$

V $\downarrow$ **since P $\uparrow$ a lot**

**5. At STP, the temperature =** 273 K **and the pressure =** 1 atm.

$V_1 = 2.33$ L STP: $T_1 = 273$ K $P_1 = 1$ atm

$V_2 = 6.19$ L $T_2 = 17 + 273 = 290$ K $P_2 = ?$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Solve for $P_2$: $P_2 = \frac{P_1V_1}{T_1} \times \frac{T_2}{V_2}$

$$P_2 = \frac{(1\text{ atm})(2.33\text{ L})}{(273\text{ K})} \times \frac{(290\text{ K})}{(6.19\text{ L})} = 0.400\text{ atm}$$

P $\downarrow$ **since V $\uparrow$**

6. 87.24g $N_2$ $\left(\frac{1\ mol}{28.02\ g}\right)$ = 3.1135 mol $N_2$ gas 25.5°C + 273 = 298.5 Kelvin

P = 0.893 atm so we are NOT changing so use ideal gas law PV = nRT

Solve for $V = \frac{nRT}{P} = \frac{(3.1135\ mol)(\ 0.08206\frac{L\ atm}{mol\ K})(298.5\ K)}{0.893\ atm} =$ 85.4 L

7. 2.45 g $H_2$ $\left(\frac{1\ mol}{2.02\ g}\right)$ = 1.21287 mol $H_2$ gas 782 torr $\left(\frac{1\ atm}{760\ torr}\right)$ = 1.02895 atm

Solve for T in ideal gas law PV = nRT, $T = \frac{PV}{nR} = \frac{(1.02895\ atm)(17.35\ L)}{(0.08206\frac{L\ atm}{mol\ K})(1.21287\ mol)}$ = 179 K