Name ANSWERS   **Chemistry**   ___/___/___

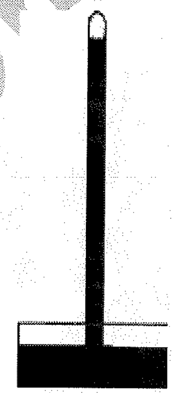
Gas Laws – Dalton, Boyle, Charles & Gay-Lussac

Today we will begin our investigation into the wonderful world of **gas laws**. Basically we will be looking at the different ways a gas reacts when temperature, pressure and volume are changed. The first thing you need to be aware of is that **when solving gas law problems temperature must always be in Kelvin (K).** To convert Celsius to Kelvin add 273 (K = °C + 273). **Standard temperature is 0 °C or 273 K.**

Volume should be in **liters(L), cubic decimeters (dm^3), milliliters(mL) or cubic centimeters(cm^3),** whichever is specified. Liters and cubic decimeters are the same and milliliters and cubic centimeters are the same. The most important thing is that both volume measurements use the same unit.

Pressure can be given in a number of different units. All of these values represent Standard pressure, the atmospheric pressure at sea level.

1atm = 760 torr = 760 mm Hg = 101.3 kPa = 101325 Pa = 14.7 psi



Atm is the abbreviation for atmospheres; torr is for Evangelista Torrecelli (1608 – 1647). Torrecelli's work with Galileo led him to create the first mercury barometer. When Torrecelli upended a glass tube full of mercury into a dish of mercury, the liquid level fell to about 760 mm. Torrecelli's observations of the daily changes in the level of mercury in the tube led to the concept of changing atmospheric pressure. Notice that both torr and mm Hg are equal, 760 torr = 760 mm Hg (the Hg is mercury). These values are always equal. The next unit is the SI (System International) for pressure. It is the kilopascal, kPa. The last is the unit with which you may be most familiar. It is pounds per square inch, or psi.

Dalton's Law of Partial Pressure

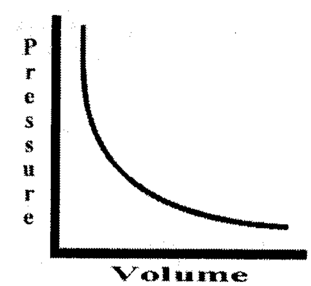
Dalton's Law *states that the total pressure of a gas is equal to the sum of its partial pressures.* Dry air at sea level is composed mostly of Nitrogen (78.1%), Oxygen (20.9%) and Argon (0.9%).
Dalton's Law of partial pressure uses the following formula: $\mathbf{P_{total} = P_1 + P_2 + P_3}$... In this equation, $\mathbf{P_{total}}$ represents the **total pressure**; $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$ and so on (when necessary) represent **the partial pressures of each of the different gases**. The important thing to remember when solving these problems is that all of your units are the same. Convert when necessary.

For example: If I have a balloon with the three gases at the following pressures: N: 79.11 kPa, O: 21.22 kPa, and Argon 0.95 kPa, what is the total pressure pushing out on the balloon?

$\mathbf{P_{total} = P_1 + P_2 + P_3}$
P_{total} = 79.11 kPa + 21.22 kPa + 0.95 kPa
$\mathbf{P_{total}}$ **= 101.28 kPa**

Boyle's Law for Pressure – Volume Changes

Boyle's Law is named for Anglo-Irish chemist Robert Boyle (1627 – 1691). **Boyle's Law** *states that for a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure.* The formula, ah yes, but before we get to that I want to talk about that I-word from above...inversely. The word **inversely** in this case means as one goes up, the other goes down. As the pressure increases, the volume will decrease and vice-versa. A graph showing an inverse relationship is shown on the right.



OK, now the formula: $\mathbf{P_1V_1 = P_2V_2}$
P_1: 1st pressure P_2: 2nd pressure
V_1: 1st volume V_2: 2nd volume

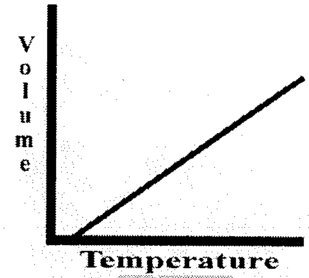
Let's try a problem. A balloon contains 30.0 L of helium gas at 100.0 kPa. What is the volume when the balloon rises to an altitude where the pressure is only 25.0 kPa?

P_1: 100.0 kPa
V_1: 30.0 L
P_2: 25.0 kPa
V_2: X

$\mathbf{P_1V_1 = P_2V_2}$
(100.0)(30.0) = (25.0)(X)
3000.0 = 25.0X
120 L = X

Charles' Law for Temperature – Volume Changes

Charles's Law is named for the French physicist and balloonist Jacques Charles (1746 – 1823). **Charles' Law** *states that the volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant.* Note, in Charles' Law there is a direct relationship between volume and temperature. The graph of a direct relationship is shown on the right.



The formula is: $\mathbf{V_1/T_1 = V_2/T_2}$

Note that with Boyle's Law there was an inverse relationship and we multiplied our original values. With Charles Law there is a direct relationship, so we will divide our values. More appropriately, we will cross multiply.

V_1: 1st volume V_2: 2nd volume
T_1: 1st temperature T_2: 2nd temperature

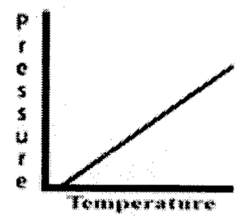
Let's practice one. A balloon, inflated in an air-conditioned room at 27 °C, has a volume of 4.0 L. The balloon is then heated to a temperature of 57 °C. What is the new volume of the balloon if the pressure remains constant?

V_1: 4.0 L
T_1: 27 °C + 273 = 300 K
V_2: X
T_2: 57 °C + 273 = 330 K

$$\mathbf{V_1 / T_1 = V_2/T_2}$$
$$\frac{4.0}{300} = \frac{X}{330}$$
$$(4.0)(330) = (300)(X)$$
$$1320 = 300\,X$$
$$\mathbf{4.4\ L = X}$$

Gay–Lussac's Law for Temperature – Pressure Changes

Gay-Lussac's Law is named for the French chemist Joseph L. Gay-Lussac (1778 – 1850). **Gay-Lussac's Law** *states that the pressure of a gas is directly proportional to the Kelvin temperature if the volume is kept constant.* This law also shows a direct relationship. Thus, as the pressure increases, the temperature will increase and vice versa; and as the pressure decreases, so will the temperature and vice versa.
The formula is: $\mathbf{P_1/T_1 = P_2/T_2}$



P_1: 1st pressure P_2: 2nd pressure
T_1: 1st temperature T_2: 2nd temperature

Practice problem: The gas left in an aerosol can is at a pressure of 100 kPa at 27 °C. If the can is thrown onto a fire, what will be the internal pressure of the gas when its temperature reaches 927 °C?

P_1: 100kPa
T_1: 27 °C + 273 = 300 K
P_2: X
T_2: 927 °C + 273 = 1193 K

$$\mathbf{P_1/T_1 = P_2/T_2}$$
$$\frac{100}{300} = \frac{X}{1193}$$
$$(100)(1193) = (300)(X)$$
$$119300 = 300\,X$$
$$\mathbf{397.7\ kPa = X}$$

Homework:

General Questions

1. What is standard temperature in Celsius? 0 °C In Kelvin? 273 K
2. In all gas law calculations, temperature must be measured in Kelvin.
3. What is standard pressure in: 1.0 atm 760 torr 14.7 psi 760 mmHg 101.3 kPa
4. What does psi stand for? pounds per square inch
5. What does atm stand for? atmospheres
6. What does kPa stand for? kilopascals

Dalton's Law of Partial Pressure:

1. What is Dalton's Law of Partial Pressure?

The total pressure of a gas is equal to the sum of its partial pressures.

2. List the three main gases found in the air we breathe and their percentage of the total.

$N_{2(g)} = 78.1\%$, $O_{2(g)} = 20.9\%$, $Ar_{(g)} = 0.9\%$

3. What formula for Dalton's Law of Partial Pressure?

$P_{total} = P_1 + P_2 + P_3 \ldots$

4. Air contains oxygen, nitrogen, carbon dioxide, and trace amounts of other gases. What is the partial pressure of oxygen if the total pressure = 101.30 kPa, the pressure of nitrogen = 79.10 kPa, the pressure of carbon dioxide = 0.040 kPa, and the pressure of the trace gases = 0.94 kPa?

$P_{tot} = P_{N_2} + P_{CO_2} + P_{O_2} + P_{trace}$ $\quad P_{O_2} = 101.3 - (79.1 + 0.040 + 0.94)$

$P_{O_2} = P_{tot} - (P_{N_2} + P_{CO_2} + P_{trace})$ $\quad = 21.22\ kPa$

5. A gas is collected over water at 25°C. If the vapor pressure of water is 3.2 kPa and the total pressure is 105.2 kPa, what is the partial pressure of the gas?

$P_{tot} = P_{gas} + P_{H_2O}$ $\quad P_{gas} = 105.2\ kPa - 3.2\ kPa$

$P_{gas} = P_{tot} - P_{H_2O}$ $\quad = 102\ kPa$

6. A balloon contains mostly helium and a little methane. The partial pressure of helium is 101.2 kPa. If the pressure inside the balloon is 101.30 kPa, what is the partial pressure of methane?

$P_{tot} = P_{He} + P_{CH_4}$ $\quad P_{CH_4} = 101.3 - 101.2\ kPa$

$\quad = 0.10\ kPa$

$P_{CH_4} = P_{tot} - P_{He}$

Boyle's Law

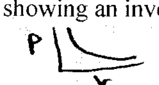
1. What is Boyle's Law?

At constant temp, the volume of a gas varies inversely with pressure

2. What is meant by vary inversely?

As pressure goes up volume goes down & vice-versa

3. Draw a graph showing an inverse relationship.



4. What formula is used for Boyle's Law?

$P_1V_1 = P_2V_2$

5. A sample of oxygen gas occupies 250 mL at 740 torr pressure. What volume will it occupy at 800 torr pressure?

$V_2 = \frac{P_1V_1}{P_2}$ $\quad V_2 = \frac{(740)(250)}{(800)}$ $\quad V_2 = 231.25\ ml$

6. A sample of carbon dioxide occupies a volume of 3.50 liters at 125 kPa pressure. What pressure would the gas exert if the volume were decreased to 2.0 liters?

$P_2 = \frac{P_1V_1}{V_2}$ $\quad P_2 = \frac{(125)(3.5)}{(2.0)}$ $\quad P_2 = 218.75\ kPa$

7. A 2.0 liter container of nitrogen had a pressure of 3.2 atm. What volume would be necessary to decrease the pressure to 1.0 atm?

$V_2 = \frac{P_1V_1}{P_2}$ $\quad V_2 = \frac{(3.2)(2.0)}{(1.0)}$ $\quad V_2 = 6.4\ L$

8. Ammonia gas occupies a volume of 450 mL at a pressure of 720 mm Hg. What volume would it occupy at standard pressure?

$V_2 = \frac{P_1V_1}{P_2}$ $\quad V_2 = \frac{(720)(450)}{(760)}$ $\quad V_2 \doteq 426.3\ ml$

9. A 175 mL sample of neon had its pressure changed from 75 kPa to 150 kPa. What is the new volume?

$V_2 = \frac{P_1V_1}{P_2}$ $\quad V_2 = \frac{(75)(175)}{(150)}$ $\quad V_2 = 87.5\ ml$

10. A sample of hydrogen at 1.5 atm had its pressure decreased to 0.5 atm producing a new volume of 750 mL. What was its original volume?

$V_1 = \frac{P_2V_2}{P_1}$ $\quad V_1 = \frac{(0.5)(750)}{(1.5)}$ $\quad V_1 = 250\ ml$

11. Chlorine gas occupies a volume of 1.2 liters at 720 torr pressure. What volume will it occupy at 1 atm pressure?

$P_1 = 720\ torr \times \frac{1\ atm}{760\ torr}$ $\quad V_2 = \frac{P_1V_1}{P_2}$ $\quad V_2 \doteq 1.14\ L$

$P_1 \doteq 0.947\ atm$

$= \frac{(0.947)(1.2)}{(1)}$

Charles' Law

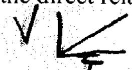
1. What is Charles' Law?

   At constant pressure, the volume of gas is directly proportional to its Kelvin temperature.

2. What is meant by directly proportional?

   As pressure goes up, temperature goes up & vice-versa

3. Draw a graph that shows the direct relationship between volume and temperature.

4. What formula is used for Charles' Law?

   $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

5. A sample of nitrogen occupies a volume of 250 mL at 25 °C. What volume will it occupy at 95 °C?

   $T_1 = 25°C + 273 = 298\,K$ $\quad V_2 = \frac{V_1 T_2}{T_1}$ $\quad V_2 = \frac{(250)(368)}{(298)}$ $\quad V_2 = 308.7\,ml$
   $T_2 = 95°C + 273 = 368\,K$

6. Oxygen gas is at a temperature of 40 °C when it occupies a volume of 2.3 liters. To what temperature should it be raised to occupy a volume of 6.5 liters?

   $T_1 = 40°C + 273 = 313\,K$ $\quad T_2 = \frac{V_2 T_1}{V_1}$ $\quad T_2 = \frac{(6.5)(313)}{(2.3)}$ $\quad T_2 \doteq 884.6\,K$ $\quad T_2 = 611.6\,°C$

7. Hydrogen gas was cooled from 150 °C to 50 °C. Its new volume is 75 mL. What was the original volume?

   $T_1 = 150°C + 273 = 423\,K$ $\quad V_1 = \frac{V_2 T_1}{T_2}$ $\quad V_1 = \frac{(75)(423)}{(323)}$ $\quad V_1 \doteq 98.2\,ml$
   $T_2 = 50°C + 273 = 323\,K$

8. Chlorine gas occupies a volume of 25 mL at 300 K. What volume will it occupy at 600 K?

   $V_2 = \frac{V_1 T_2}{T_1}$ $\quad V_2 = \frac{(25)(600)}{(300)}$ $\quad V_2 = 50\,ml$

9. A sample of neon gas at 50 °C and a volume of 2.5 liters is cooled to 25 °C. What is the new volume?

   $T_1 = 50 + 273 = 323\,K$ $\quad V_2 = \frac{V_1 T_2}{T_1}$ $\quad V_2 = \frac{(2.5)(298)}{(323)}$ $\quad V_2 = 2.31\,L$
   $T_2 = 25 + 273 = 298\,K$

10. Helium occupies a volume of 3.8 liters at –45 °C. What volume will it occupy at 45 °C?

    $T_1 = -45 + 273 = 228\,K$ $\quad V_2 = \frac{V_1 T_2}{T_1}$ $\quad V_2 = \frac{(3.8)(318)}{(228)}$ $\quad V_2 = 5.3\,L$
    $T_2 = 45 + 273 = 318\,K$

Gay-Lussac's Law

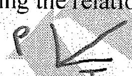
1. What is Gay-Lussac's Law?

   At constant volume, the pressure of a gas varies directly proportional to its Kelvin temperature.

2. What is the relationship between pressure and temperature?

   $P \propto T$

3. Draw a graph showing the relationship between pressure and temperature.

4. What is the formula for Gay-Lussac's Law?

   $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

5. A gas has a pressure of 6.58 kPa at 540 K. What will the pressure be at 210 K if the volume does not change?

   $P_2 = \frac{P_1 T_2}{T_1}$ $\quad P_2 = \frac{(6.58)(210)}{(540)}$ $\quad P_2 = 2.56\,kPa$

6. The gas in a container has a pressure of 300 kPa at 27 °C. What is the pressure if the temperature is lowered to –173 °C?

   $T_1 = 27 + 273 = 300\,K$ $\quad P_2 = \frac{P_1 T_2}{T_1}$ $\quad P_2 = \frac{(300)(100)}{(300)}$ $\quad P_2 = 100\,kPa$
   $T_2 = -173 + 273 = 100\,K$

7. The pressure in an automobile tire is 200 kPa at a temperature of 25 °C. At the end of a journey on a hot sunny day the pressure has risen to 223 kPa. What is the temperature of the air in the tire?

   $T_1 = 25 + 273 = 298\,K$ $\quad T_2 = \frac{P_2 T_1}{P_1}$ $\quad T_2 = \frac{(223)(298)}{(200)}$ $\quad T_2 = 332.3\,K = 59.3\,°C$

8. The gas in a balloon has a pressure of 250 kPa at 18 °C. What will the temperature be if the pressure rises to 294 kPa?

   $T_1 = 18 + 273 = 291\,K$ $\quad T_2 = \frac{P_2 T_1}{P_1}$ $\quad T_2 = \frac{(294)(291)}{(250)}$ $\quad T_2 = 342.2\,K = 69.2\,°C$

9. A gas confined in a rigid container exerts a pressure of 35.5 kPa at a temperature of 19 °C. What will the pressure of the gas be if it is cooled to a temperature of -28 °C?

   $T_1 = 19 + 273 = 292\,K$ $\quad P_2 = \frac{P_1 T_2}{T_1}$ $\quad P_2 = \frac{(35.5)(245)}{(292)}$ $\quad P_2 \doteq 29.8\,kPa$
   $T_2 = -28 + 273 = 245\,K$