Unit 2 Packet: Gas Laws
Introduction to Gas Laws Notes:

Key

Major Objectives: At the end of this unit, you should be able to:

1. Describe the Kinetic Theory particularly as it relates to gases.
2. Relate kinetic energy and temperature.
3. Convert ^{o}C to K.
4. Describe what is meant by pressure as it relates to gases.
5. Convert between the various pressure units; atm, KPa, mm Hg.
6. Describe what is meant by STP and be able to use this information to do calculations.
7. Distinguish between the various gas laws - Boyle's, Charles', Gay-Lussac's, Combined, and Dalton's.
8. Relate the information studied to laboratory exercises.

Abbreviations

atm - atmosphere
mm Hg - millimeters of mercury
torr - another name for mm Hg
Pa - Pascal (kPa = kilo Pascal)
K - Kelvin
°C - degrees Celsius

Items to KNOW

- **STP = Standard Temperature and Pressure (0.00 °C = 273 K and 1 atm)**
- **Standard Temperature = 0.00 °C = 273 K**
- **Standard Pressure = 1.00 atm = 101.3 kPa = 760 mmHg = 760 torr**
- **^{0}C + 273 = K**

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- In chemistry, the relationships between gas physical properties are described as gas laws. Some of these properties are pressure, volume, and temperature. These laws show how a change in one of these properties affects the others. The gas laws in chemistry are: Boyle's Law, Charles' Law, the Combined Gas Law, Avogadro's Law, and the Ideal Gas Law.

- **Gas Variables and Definitions:**
  - **Pressure (P)** – The force per unit area on a surface. Gas molecules exert force, and therefore pressure, on any surface, sides of container, with which they collide.
  - **Temperature (T)** – Temperature is measured in the Kelvin scale; it is an index of gas motion and not a measure of heat. Absolute zero, K = 0^o, all motion stops!
  - **Volume (V)** – Volume is the quantity of three-dimensional space occupied by a liquid, solid or gas. Common units used to express volume include liters and cubic meters.
  - **Moles (n)** – A mole is the amount of pure substance containing the same number of chemical units as there are atoms in exactly 12 grams of carbon-12 (i.e., 6.023×10^{23}).
- **Standard Temperature and Pressure (STP):** Standard temperature is defined as zero degrees Celsius ($0\ ^0C$), which translates to 32 degrees Fahrenheit ($32\ ^0F$) or 273.15 degrees Kelvin. Standard pressure is 101.325 kPa, 1 atmosphere (1 atm) or 760 millimeters in a mercurial barometer (760 mmHg) or 760 torrs.

Equations Representing Relationships:

$P_{total} = P_1 + P_2 + P_3 ...$	Dalton's Law of Partial Pressure
$P_1V_1 = P_2V_2$	Boyle's Law
$V_1 / T_1 = V_2 / T_2$	Charles' Law
$P_1 / T_1 = P_2 / T_2$	Gay-Lussac's Law
$P_1V_1 / T_1 = P_2V_2 / T_2$	Combined Gas Law

Pressure and Kinetic Molecular Theory Notes

What is pressure?

$$Pressure = \frac{Force}{Area}$$

What is force? You can think of it like weight or like a push. How much does your body push on the floor? How much do you have to push to move something across the floor?

Liquids and solids exert pressure.

Ex: Diving, your body is under more pressure when under water than when above it.

If you are trapped under a piece of furniture you feel the pressure of the furniture on you.

What does area have to do with it?

Could you sleep on a bed of nails? How about just one nail?

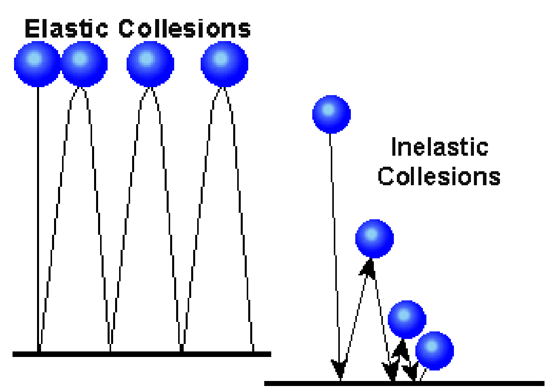
Carpenters…why are screws pointy at the end instead of flat?

The same force over a smaller area results in a higher pressure.

Gas pressure is similar but hard to visualize.

KINETIC MOLECULAR THEORY

1. Gases have a very small_attraction to each other__
2. Gases are constantly in _ motion _at high speeds in random but _ straight _line paths
3. Gases experience no _ real _ attractions between _ other gas molecules.
   a. All collisions between particles in a gas are perfectly elastic.
      i. No attractive or repulsive forces
      ii. No transfer of Kinetic Energy
      iii. The average Kinetic Energy is dependent only on _temperature_



4. The speed of a gas molecule is directly proportional to its mass and speed.
   a. As the temperature increases, the speed of the gas molecule increases.

KE=½ mV^2

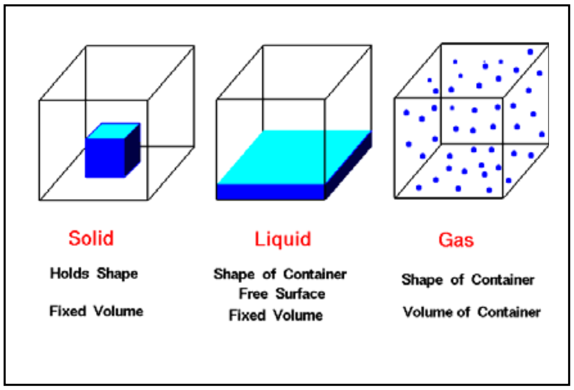
These assumptions are good for IDEAL gases and are used quite often with little error. However, when one needs to be exact that you must account for the fact that REAL gases

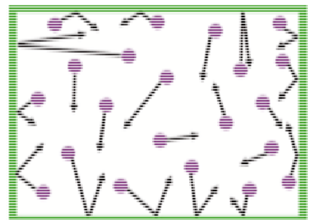
- Have volume
- Experience electrostatic attractions

For Introductory Chemistry, though, we will just deal with Ideal gases.

Pressure is the sum of all the forces of all the gas molecules colliding with a surface.

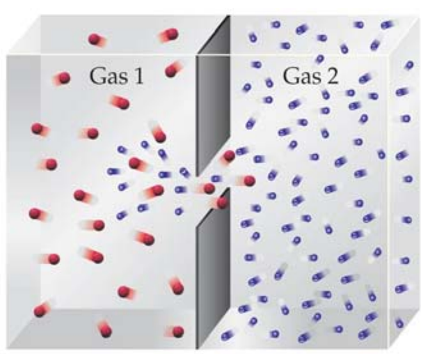
Gas particles are in **constant random motion** exerting pressure as they collide with the walls of the container. Therefore, the __ **more** _ collisions, the _**higher**__ the pressure.



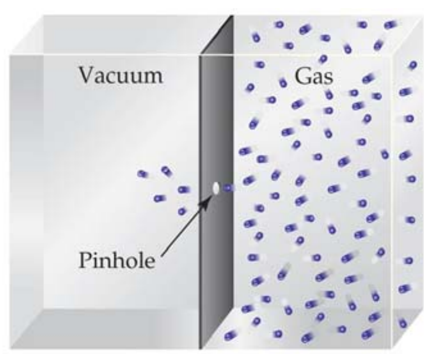


Gases have certain properties that can be explained by the KMT.

1. ***Low Density*** they _**have small volume**_ because the molecules are moving at a high rate of speed and are not held back by electrostatic attractions as well as being spread out, they have low density.
2. ***Compressibility***, they can be _**easy**__ to compress because the molecules have space between them, unlike liquids and solids where there is little space between the molecules
3. ***Expansion***, they will _**spread**__ given the opportunity because the molecules are moving at a high rate of speed.
4. ***Diffusion*** they will spread out, again because the molecules are moving at a high rate of speed,
    a. Example: perfume diffusing through air
    b. Example: Liquids also diffuse: food coloring in water



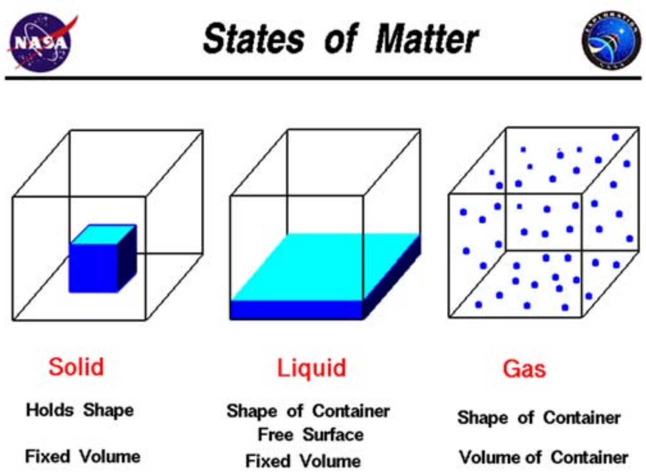
Diffusion is the mixing of gas molecules by random motion under conditions where molecular collisions occur.



Effusion is the escape of a gas through a pinhole into a vacuum without molecular collisions.

5. ***Effusion***, molecules moving at a high rate of speed will eventually "collide" with a hole and escape.
    a. Effusion is gas escaping through a hole,
    b. Example: air escaping through a hole in your tire

6. The word *kinetic* comes from a Greek word that means "to move." The **kinetic molecular theory** is based upon the assumption that particles of matter (atoms or molecules) are in constant ____**motion**____
7. Of the three states of matter, which one has the most kinetic energy? ____**gas**____
8. Which state of matter has particles that are separated by the largest distance? ____**gas**____



9. **A scientific theory is an explanation of some type of natural phenomena. Theories are normally developed from careful study of the way the world behaves. Let's look at how gases behave and see if the kinetic molecular theory makes sense.**
10. Compared to liquids and solids, gases tend to have____**lower**____densities. This can be explained because the particles of gas are __**far apart in constant motion**__.

Units of pressure

- **Kilopascals** = SI units of pressure, named after scientist Pascal
- **Torr** = named after scientist Torricelli
- **mmHg** = millimeters of mercury, comes from old way of measuring pressure by the height of a column of mercury open to atmosphere
- **atm** = atmosphere, unit most often used in chemistry. One atmosphere is what we feel experience every day. It is the standard pressure on earth.
- **psi** = pounds per square inch. Most often used in real life (tire pressure)

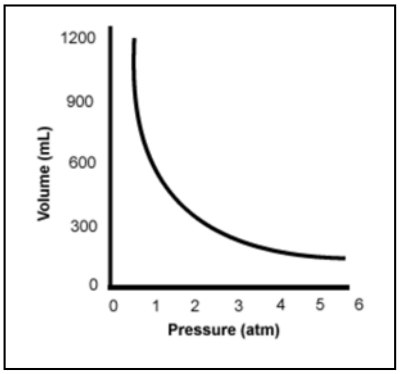
Gas Law Problems

Steps to Solve any Gas Law Problem:

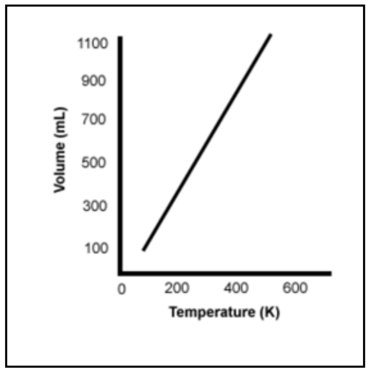
- Step 1: Write everything you are given in the problem.
- Step 2: Which law do you want to use? (What remains constant?)
- Step 3: Do your units match? If not, convert. **(Temperature must always be in Kelvin)**
- Step 4: Plug in your values and solve.

Proportional

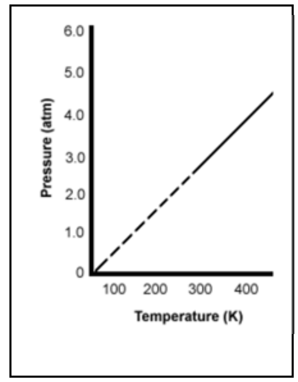
Indirectly	Directly	Directly



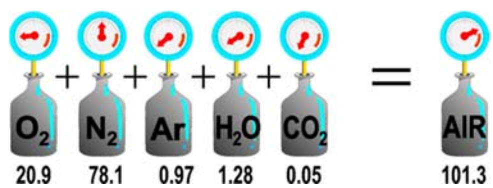
Boyle's Law



Charles Law



Gay-Lussac's Law



Dalton's Law of Partial Pressures

- **Boyle's Law**

$$P_1V_1 = P_2V_2$$

  - As the pressure decreases, the volume <u>increases.</u>
  - <u>Indirectly</u> proportional
  - <u>Temperature</u> remains constant

Example Problem: A balloon contains 30.0 L of helium gas at 1 atmosphere, and it rises to an altitude where the pressure is only 0.25 atm, assuming the temperature remains constant, what is the volume of the balloon at its new pressure?

P_1 = 1 atm
V_1 = 30.0 L
P_2 = 0.25 atm
V_2 = x

$$P_1V_1 = P_2V_2$$

$$(1\ \text{atm})(30.0\ \text{L}) = (0.25\ \text{atm})x$$

$$\frac{(1\ \text{atm})(30.0\ \text{L})}{(0.25\ \text{atm})} = \frac{(0.25\ \text{atm})x}{(0.25\ \text{atm})}$$

X = 120 L

- **Charles' Law**

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

  - Lower temperature leads to a lower volume
  - Higher temperature leads to a higher volume
  - Directly proportional
  - Temperature must be converted to Kelvin
  - Pressure remains constant

Example Problem: A balloon inflated in a room at $24^{O}C$ has a volume of 4.00 L. The balloon is then heated to a temperature of $58^{O}C$ what is the new volume if the pressure remains constant?

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

$$\frac{4.00\ L}{297\ K} = \frac{x}{331\ K}$$

$$X = 4.46\ L$$

V_1=4.00 L

T_1=$24^{O}C$ + 273 = 297 K

V_2=x

T_2=$58^{O}C$+ 273 = 331 K

- **Gay-Lussac's Law**

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

  - Temperature always in Kelvin Scale
  - Volume remains constant

Example Problem: Aerosol cans carry labels warning not to store them above a certain temperature. The gas in a used aerosol can is at a pressure of 1atm at 25°C. If the can is thrown into a fire, what will the pressure be when the temperature reaches 1201°C?

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

$$\frac{1\ atm}{298K} = \frac{x}{1474\ K}$$

$$\frac{(1474\ K)(1\ atm)}{(298\ K)} = \frac{(298\ K)x}{(298\ K)}$$

$$4.95\ atm = x$$

P_1=1 atm

T_1=$25^{O}C$ + 273 = 298 K

P_2=x

T_2=$1201^{O}C$+ 273 =1474 K

- **The Combined Gas Law**

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

  - No variable remains constant
  - Temperature always in Kelvin Scale

Example Problem: The volume of a gas filled balloon is 30.0L at 313 K and has a pressure of 153 kPa. What would the volume be at standard temperature and pressure (STP)?

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

$$\frac{(153\ kPa)\ (30.0L)}{313\ K} = \frac{(101.325kPa)(x)}{273\ K}$$

39.5 L = x

P_1=153 kPa V_2=x

T_1=313 K T_2=273 K

V_1 =30.0 L

P_2= 101.325 kPa

- **Dalton's Law of Partial Pressures**

Dalton's Law of Partial Pressures In a ___**closed system**___ of gases, the ____**total**____ pressure exerted by the mixture of gases is equal to the ____**sum**______of the partial pressure of each gas.

Example – Air contains N_2, O_2, H_2O, Ar, CO_2, the sum of which makes up the air pressure around us at any time.

$$P_{Total} = P_{Gas\ 1} + P_{Gas\ 2} + P_{Gas3} \ldots$$

What is the air pressure at sea level if N_2, O_2, H_2O, Ar, CO_2, have the following pressures 78.1 kPa + 20.9kPa + 1.28kPa + 0.97kPa + 0.05kPa ?

$$N_2 + O_2 + H_2O + Ar + CO_2 = Air$$
$$78.1\ kPa + 20.9kPa + 1.28kPa + 0.97kPa + 0.05kPa = 101.3kPa$$

Gas Laws Practice:

1) A chemist collects 59.0 mL of sulfur dioxide gas on a day when the atmospheric pressure is 0.989 atm. On the next day, the pressure has changed to 0.967 atm. What will the volume of the SO_2 gas on the second day?

$$P_1V_1 = P_2V_2$$
$$(0.989\ atm)(0.0590\ L) = (0.967\ atm)\ x$$
$$0.0603422958\ L = x$$
$$0.0603\ L = x \text{ or } 60.3\ mL$$

2) A can contains a gas with a volume of 56 mL and 20.0 °C. What is the volume in the can if it is heated to 50.0 °C?

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

$$\frac{0.056\ L}{293\ K} = \frac{x}{323\ K}$$
$$0.0617337884\ L = x$$
$$0.062\ L = x \text{ or } 62\ mL$$

3) A gas with a volume of 4.0L at a pressure of 90.0 kPa is allowed to expand until the pressure drops to 20.0 kPa. What is the new volume?

$$P_1V_1 = P_2V_2$$

$$(90.0\ kPa)(4.0L) = (20.0\ kPa)x$$
$$18\ L= x$$

4) At a winter carnival, a balloon is filled with 5.00 L of helium at a temperature of 273 K. What will be the volume of the balloon when it is brought into a warm house at 295 K?

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

$$\frac{5.00\ L}{273\ K} = \frac{x}{295\ K}$$

$$5.40\ L = x$$

5) The initial temperature of a 1.00 liter sample of argon is 20.0° C. The pressure is decreased from 720 mm Hg to 360 mm Hg and the volume increases to 2.14 liters. What was the change in temperature of the argon?

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

$$\frac{(720\ mm\ Hg)(1.00\ L)}{293\ K} = \frac{(360\ mm\ Hg)(2.14\ L)}{x}$$

$$310\ K = x$$

6) 2.2 L of hydrogen at 6.5 atm pressure is used to fill a balloon at a final pressure of 1.15 atm. What is its final volume?

$$P_1V_1 = P_2V_2$$

$$(6.5\ atm)(2.2\ L) = (1.15\ atm)\ x$$

$$12\ L = x$$

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?

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

$$\frac{200.\ kPa}{298\ K} = \frac{223\ kPa}{x}$$

$$330\ K = x$$

8) A sample of argon has a volume of 5.00 L and the pressure is 0.920 atm. If the final temperature is 30.0° C, the final volume is 5.7 L, and the final pressure is 800. mm Hg, what was the initial temperature of the argon?

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

** must have the same units for pressure! Remember **1 atm = 760 mmHg**

so $\frac{800\ \text{mmHg}}{} \Big| \frac{1\ atm}{760\ \text{mmHg}} = 1.05\ atm$

$$\frac{(0.920\ atm)(5.00\ L)}{x} = \frac{(1.05\ atm)(5.7\ L)}{303\ K}$$

$$x = 230\ K$$

Gas Law Practice - Worksheet

1. Why does air come out of a bicycle tire when you open the valve, even if the valve is pointing up?

   Effusion occurs because the pressure inside the bicycle tire is greater than outside the tire.

2. Why do aerosol cans come with the warning, "Contents under pressure. Do not heat."?

   Because pressure is directly proportional to temperature and the can will rupture if heated.

Dalton's Law Worksheet

1) A metal tank contains three gases: oxygen, helium, and nitrogen. If the partial pressures of the three gases in the tank are 35 atm of O_2, 5 atm of N_2, and 25 atm of He, what is the total pressure inside of the tank?

35 atm + 5.0 atm+ 25 atm = 65 atm

2) Blast furnaces give off many unpleasant and unhealthy gases. If the total air pressure is 0.99 atm, the partial pressure of carbon dioxide is 0.05 atm, and the partial pressure of hydrogen sulfide is 0.02 atm, what is the partial pressure of the remaining air?

$$0.99 \text{ atm} = 0.05 \text{ atm} + 0.02 \text{ atm} + P_{remaining}$$
$$P_{remaining} = 0.92 \text{ atm}$$

Charles' Law Worksheet

1) The temperature inside my refrigerator is about 40 Celsius. If I place a balloon in my fridge that initially has a temperature of 220 C and a volume of 0.5 liters, what will be the volume of the balloon when it is fully cooled by my refrigerator?

T_1= 22+273 = 295K V$_1$=.5L T_2= 4+273=277K V_2 =X .

$\frac{5L}{295K} = \frac{X}{277K}$ cross multiply and divide

X = 0.47 L

2) A man heats a balloon in the oven. If the balloon initially has a volume of 0.4 liters and a temperature of 20.0C, what will the volume of the balloon be after he heats it to a temperature of 250.0C?

T_1 = 20+273 = 239K V_1 = 0.4 L T_2 = 250+273 = 523 K V_2 = x

$\frac{0.4\ L}{293\ K} = \frac{x}{523}$ cross multiply and divide

X = 0.71 L

Combined Gas Law Problems

1) If I initially have a gas at a pressure of 12 atm, a volume of 23 liters, and a temperature of 200 K, and then I raise the pressure to 14 atm and increase the temperature to 300 K, what is the new volume of the gas?

P_1 = 12 atm T_1 = 200 K V_1 = 23 L

P_2 = 14 atm T_2 = 300 K V_2 = x

$\frac{12\ atm \times 23\ L}{200\ K} = \frac{14\ atm\ x}{300\ K}$ cross multiply and divide

V_2 = 27.6 L V_2 = 28 L

2) A gas takes up a volume of 17 liters, has a pressure of 2.3 atm, and a temperature of 299 K. If I raise the temperature to 350 K and lower the pressure to 1.5 atm, what is the new volume of the gas?

P_1 = 2.3 atm T_1 = 299 K V_1 = 17 L

P_2 = 1.5 atm T_2 = 350 K V_2 = x

$\frac{2.3\ atm \times 17\ L}{299\ K} = \frac{1.5\ atm\ x}{350\ K}$ cross multiply and divide

V_2 = 32.512 L V_2 = 33 L

Boyle's Law

1. A gas occupies 12.3 liters at a pressure of 40.0 mm Hg. What is the volume when the pressure is increased to 60.0 mm Hg?

(40.0 mmHg) (12.3 liters) = (60.0 mmHg) (x)
x = 8.20 L, note three significant figures

2. If a gas at 25.0 °C occupies 3.60 liters at a pressure of 1.00 atm, what will be its volume at a pressure of 2.50 atm?

(1.00 atm) (3.60 liters) = (2.50 atm) (x)
x = 1.44 L

3. A gas occupies 1.56 L at 1.00 atm. What will be the volume of this gas if the pressure becomes 3.00 atm?

(1.56 L) (1.00 atm) = (3.00 atm) (x)
X = 0.520 L

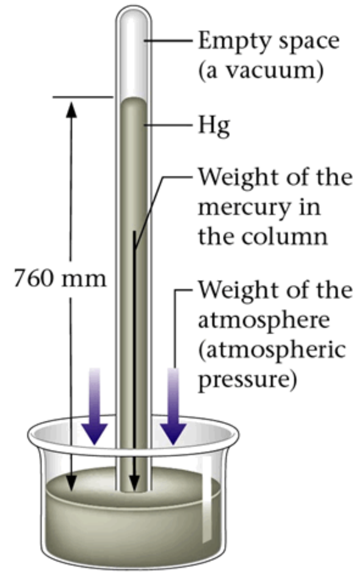
4. A gas occupies 11.2 liters at 0.860 atm. What is the pressure if the volume becomes 15.0 L?

(11.2 liters) (0.860 atm) = (x) (15.0 L)
x = 0.642 atm

- Atmospheric pressure is measure using a **Barometer**

- The pressure of a gas is measured using a **Manometer**

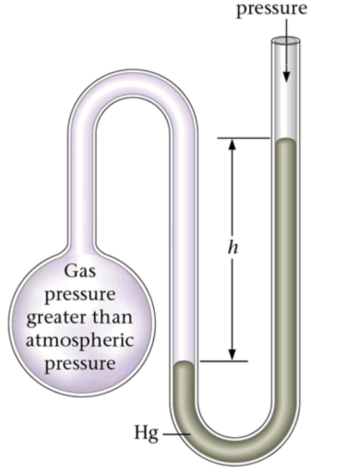
- As you increase in elevation the atmospheric pressure **decreases (Olympic Training in Denver).**



  - A *Manometer* is a device to measure the pressure of an enclosed gas sample. A common simple manometer consists of a *U* shaped tube of glass filled with some liquid. Typically the liquid is mercury because of its high density.
  - The height difference determines the pressure.

Gas pressure = atmospheric pressure + h.

Open Manometer

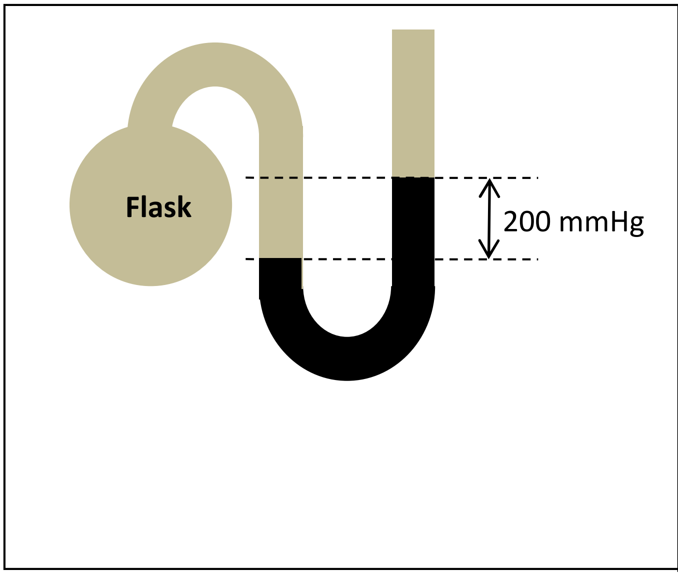


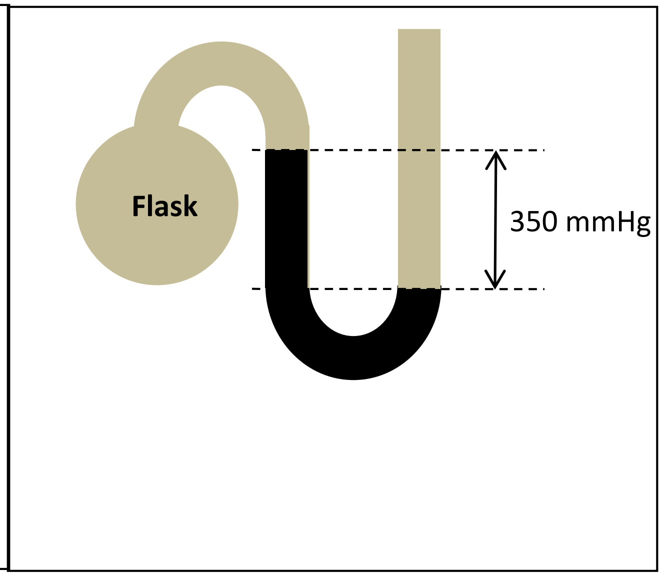
(b)

Avogadro's Law: under the same condition of **Temperature** and **Pressure,** equal **volumes** of all **gases** contain the same number of **particles**.

Calculate the pressure inside each flask, given an atmospheric pressure of

760 mmHg.





The gas in the flask has a *higher* pressure than 760 mmHg. The pressure is

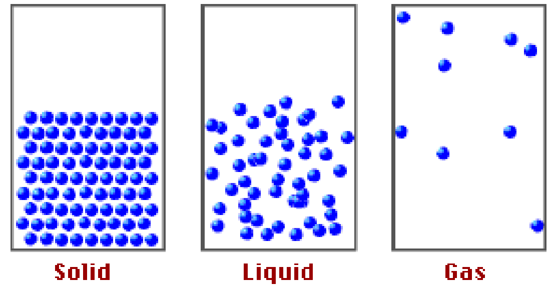
760 mmHg + 200 mmHg = 960 mmHg.

The gas in the flask has a *lower* pressure than 760 mmHg. The pressure is

760 mmHg − 350 mmHg = 410 mmHg.

Kinetic Molecular Theory Worksheet

1. The word *kinetic* comes from a Greek word that means "to move." The **kinetic molecular theory** is based upon the assumption that particles of matter (atoms or molecules) are in constant **random motion.**



2. Of the three states of matter, which one has the most kinetic energy? **Gas**
3. Which state of matter has particles that are separated by the largest distance? **Gas**
4. **A scientific theory is an explanation of some type of natural phenomena. Theories are normally developed from careful study of the way the world behaves. Let's look at how gases behave and see if the kinetic molecular theory makes sense.**
5. Compared to liquids and solids, gases tend to have **lower** densities. This can be explained because the particles of gas are **in constant motion**.
6. If you apply pressure to a sample of gas, it is fairly easy to **compress** its volume (think about what would happen to a balloon if you squeeze it gently). This can be explained because there is a lot of **empty space** between gas particles.
7. If someone sprays perfume in one corner of the room, eventually a person on the other side of the room can smell it. This can be explained because gas particles move **quick** and **random**. In general, we would expect lighter gas particles to travel **faster** than heavier gas particles.
8. When two gases mix together or move through each other, this process is known as **diffusion.** When gas particles escape out of a tiny hole in a container, this process is known as **effusion.** You should know the difference between these two words so you can avoid any confusion!
9. Kinetic molecular theory can be summarized as follows:

    a. Gas particles are in constant **motion**.
    b. Gas particles are separated by relatively **large** distances.
    c. When gas particles collide, they **do not transfer** kinetic energy.
    d. Gas particles have **no** attractive or repulsive forces between them.
    e. The kinetic energy of a gas is dependent on the **temperature** of the gas.

Unit 2 Review: Gas Laws

See Separate Key