Gases

Objective #1: Know the postulates of the Kinetic Molecular Theory (K.M.T.)
This theory describes how an "Ideal Gas" (hypothetical gas) behaves under a series of set conditions. According to the kinetic molecular theory, gases:

- contain particles that are in ______________________, ___________________ straight-line motion
- are separated by great __________________________ relative to their size
- are so small that compared to the volume of space they occupy, their volume is ______________________ (_____________).
- Do NOT have ________________________ ____________________ between the particles
- have collisions that may result in a ____________________ of energy between particles, but the total energy of the system remains ______________________.

While the ideas of the Kinetic Molecular Theory sound good, the problem with it is there is NO SUCH THING as an ideal gas!!!

Instead, "_______________ GASES" are what we have here on earth. This is due to the atmospheric pressure and conditions here on earth.

Real gases:

1) DO have ____________________ ____________________ between particles
2) DO have a _________________________ and take up space

- Of all the gases that do exist here on earth, the most like an ideal gas would be ______________ and ______________
  - they are the lightest and smallest gas particles that exist

- To make a REAL GAS *behave like* an IDEAL GAS, the particles of a gas need to spread out as much as possible in the given container. This can be done only under conditions of:
  - ____________ temperature of a gas
  - ____________ pressure on a gas

Kinetic Molecular Theory Questions

1. A sample of a gas is contained in a closed rigid cylinder. According to kinetic molecular theory, what occurs when the gas inside the cylinder is heated?
   A) The number of gas molecules increases.
   B) The number of collisions between gas molecules per unit time decreases.
   C) The average velocity of the gas molecules increases.
   D) The volume of the gas decreases.

2. Under which conditions of temperature and pressure would He behave most like an ideal gas?
   A) 50 K and 20 kPa
   B) 50 K and 600 kPa
   C) 750 K and 20 kPa
   D) 750 K and 600 kPa

3. The kinetic molecular theory assumes that the particles of an ideal gas
   A) are in random, constant, straight-line motion
   B) are arranged in a regular geometric pattern
   C) have strong attractive forces between them
   D) have collisions that result in the system losing energy

4. The concept of an ideal gas is used to explain
   A) the mass of a gas sample
   B) the behavior of a gas sample
   C) why some gases are diatomic
   D) why some gases are monatomic

5. Under which conditions does a real gas behave most like an ideal gas?
   A) at low temperatures and high pressures
   B) at high temperatures and high pressures
   C) at low temperatures and low pressures
   D) at high temperatures and low pressures

6. Two basic properties of the gas phase are
   A) a definite shape and a definite volume
   B) no definite shape but a definite volume
   C) a definite shape but no definite volume
   D) no definite shape and no definite volume

7. An assumption of the kinetic theory of gases is that the particles of a gas have
   A) little attraction for each other and a significant volume
   B) little attraction for each other and an insignificant volume
   C) strong attraction for each other and a significant volume
   D) strong attraction for each other and an insignificant volume

8. According to the kinetic theory of gases, which assumption is correct?
   A) Gas particles strongly attract each other.
   B) Gas particles travel in curved paths.
   C) The volume of gas particles prevents random motion.
   D) Energy may be transferred between colliding particles.

9. A real gas behaves more like an ideal gas when the gas molecules are
   A) close and have strong attractive forces between them
   B) close and have weak attractive forces between them
   C) far apart and have strong attractive forces between them
   D) far apart and have weak attractive forces between them

10. A real gas differs from an ideal gas because the molecules of real gas have
   A) some volume and no attraction for each other
   B) some volume and some attraction for each other
   C) no volume and no attraction for each other
   D) no volume and some attraction for each other

Objective #2: Know the Gas Variables

A) Standard Temperature and Pressure (STP)

- These numerical values are often the starting or ending points for atmospheric conditions during an experiment with gases, and can be used when converting between gas units
- These measurements are found on Reference Table __________
  - Standard Pressure Values:
    - _________________, __________________, ________________
  - Standard Temperature Values:
    - _________________, __________________

B) Measuring a given gas sample

There are four main variables used to describe gases. Depending on what you are looking or solving for, these variables describe a gas under a set of given conditions.

1) Temperature (T)
   - Temperature is a measurement of the __________________ _________________ __________________ of gas particles
   - The temperature of a gas MUST BE used in __________________ units
     - If measured in °C, convert to K with equation: _________________________
2) Volume (V)
   - volume of a gas is the volume of the ________________________ it is in
   - volume of a gas is measured in ____________, ____________ or ____________
3) Quantity
   - amount of a gas is often measured and recorded in _________________
     - if necessary, convert to moles using _______________ of a gas
4) Pressure (P)
   - Pressure of a gas results from _______________________ between gas particles
   - A barometer is most commonly used to measure gas pressure
   - There are several units of pressure
     - Atmospheres (atm), kilopascals (kPa), mmHg, torr, psi… It all depends on the situation that is being described

When doing pressure conversions, use the values of standard pressure from Reference Table A

Ex) 140.4 kPa = ? atm

Ex) 550. mmHg = ? kPa

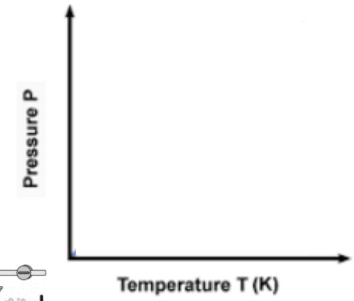
Objective #3: Relationships between Pressure, Volume and Temperature

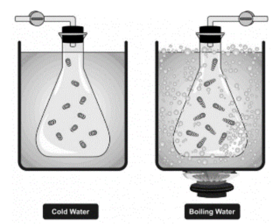
There are three main relationships when it comes to gas behavior. These three relationships between pressure, volume and temperature are described below:

A) Temperature vs. Pressure (Guy Lussac's Law)

As the temperature of a gas ______________________, there are _______________ collisions between gas particles and the walls of the containers.

- The increase in the number of collisions then causes an ____________________ in gas pressure

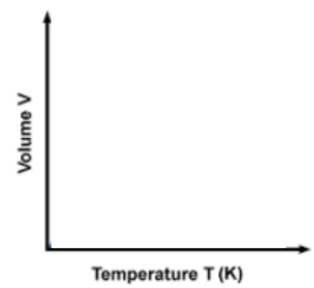


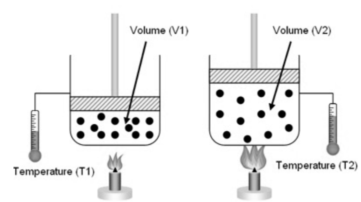


B) Temperature vs. Volume (Charles' Law)

As the temperature of a gas ______________________, there are _______________ collisions between gas particles and the walls of the containers

- The increase in the number of collisions causes gas particles to spread out more, therefore ______________________ the volume of a gas

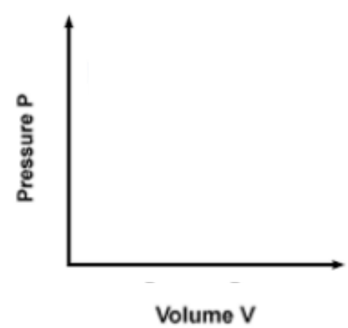


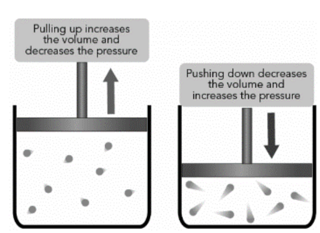


C) Volume vs. Pressure (Boyle's Law)

As the volume of a gas ______________________ (gas is compressed), there are ________________ collisions between gas particles and the walls of the containers

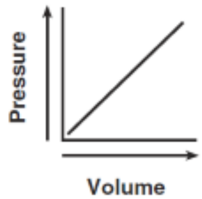
- This increase in the number of collisions causes the pressure to ____________________

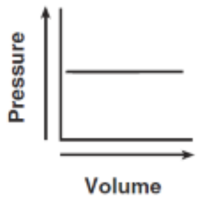


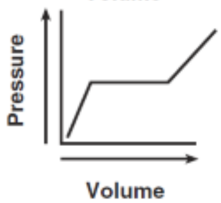


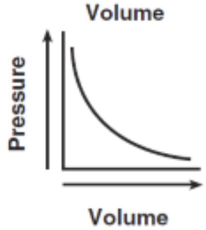
Gas Relationship Questions

____ 1) Which graph represents the relationship between pressure and volume for a sample of an ideal gas at constant temperature?

1) 

2) 

3) 

4) 

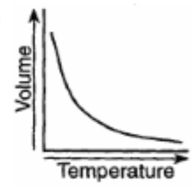
____ 2) A sample of gas is held at constant pressure. Increasing the kelvin temperature of this gas sample causes the average kinetic energy of its molecules to

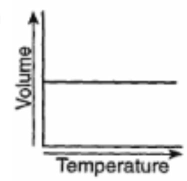
1) decrease and the volume of the gas sample to decrease
2) decrease and the volume of the gas sample to increase
3) increase and the volume of the gas sample to decrease
4) increase and the volume of the gas sample to increase

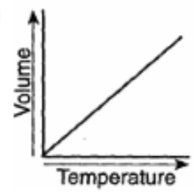
____ 3) As the temperature of a given sample of a gas decreases at constant pressure, the volume of the gas

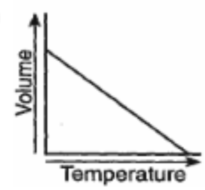
1) decreases
2) increases
3) remains the same

____ 4) Which graph represents the relationship between volume and Kelvin temperature for an ideal gas at constant pressure?

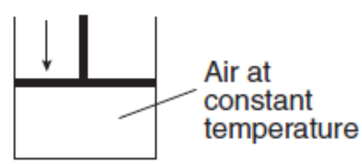
1) 

2) 

3) 

4) 

____ 5) A cylinder with a tightly fitted piston is shown in the diagram below.



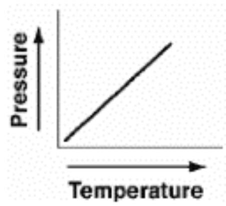
As the piston moves downward, the number of molecules of air in the cylinder

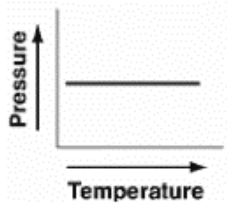
1) decreases
2) increases
3) remains the same

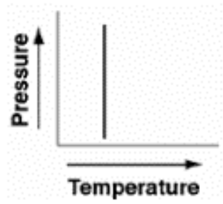
____ 6) As the volume of a fixed mass of a gas increases at constant temperature, the pressure of the gas

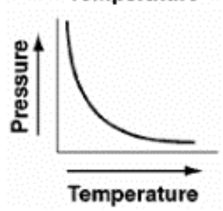
1) decreases
2) increases
3) remains the same

____ 7) Which graph shows the pressure-temperature relationship expected for an ideal gas?

1) 

2) 

3) 

4) 

____ 8) As the temperature of a gas increases with the volume remaining constant, the pressure of the gas

1) decreases
2) increases
3) remains the same

____ 9) The volume of a 1.00-mole sample of an ideal gas will decrease when the

1) pressure decreases and the temperature decreases
2) pressure decreases and the temperature increases
3) pressure increases and the temperature decreases
4) pressure increases and the temperature increases

____ 10) As the pressure of a gas at 150 kPA is changed to 100 kPa at constant temperature, the volume of the gas

1) decreases
2) increases
3) remains the same

____ 11) Under which conditions will the volume of a given sample of a gas increase?

1) decreased pressure and decreased temperature
2) decreased pressure and increased temperature
3) increased pressure and decreased temperature
4) increased pressure and increased temperature

____ 12) A sample of a gas is at STP. As the pressure decreases and the temperature increases, the volume of the gas

1) decreases
2) increases
3) remains the same

____ 13) As the volume of a 1-mole sample of gas increases, with temperature remaining constant, the pressure exerted by the gas

1) decreases
2) increases
3) remains the same

____ 14) When a sample of gas is cooled in a sealed, rigid container, the pressure the gas exerts on the walls of the container will decrease because the gas particles hit the walls of the container

1) less often and with less force
2) less often and with more force
3) more often and with less force
4) more often and with more force

Objective #4: Using the Combined Gas Law Formula (from Reference Table T)

Combined Gas Law	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	P = pressure V = volume T = temperature

- When using this formula, temperature MUST BE IN ______________________.
  - Pressure and volume can be any of the units as long as both values are converted to the same unit.
- If a gas is "at STP", use the variables found on Ref Table A
- If a variable is "held constant", ignore it in the formula (leave it out).
  - For example: if temperature is held constant during a problem, the formula changes to $P_1V_1 = P_2V_2$

Examples:

1) A 2.00 L sample of gas at 1.00 atmospheres and 300. K is heated to 500.K and compressed to a volume of 1.00 L. What is the new pressure of the gas?

2) A 3.50 L sample of gas at STP is heated to 500. K and compressed to 200. kPa. What is the new volume of the gas?

3) A 2.50 L sample of gas at 300. K and a pressure of 80.0 kPa is placed into a 1.50 L container. If the temperature remains constant, what is the new pressure of the gas?

Combined Gas Law	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	P = pressure V = volume T = temperature

4) A 2.5 L sample of gas is at STP. When the temperature is raised to 373°C and the pressure remains constant what will the new volume of the gas be?

5) A gas is in a 300. mL compressed can at 21°C with a pressure of 172 kPa. If the container is heated to a temperature of 550°C, what will be the new pressure?

Combined Gas Law Practice

___ 1) A sample of gas occupies a volume of 50.0 milliliters in a cylinder with a movable piston. The pressure of the sample is 0.90 atmosphere and the temperature is 298 K. What is the volume of the sample at STP?

1) 41 mL 3) 51 mL
2) 49 mL 4) 55 mL

___ 2) A sample of helium gas has a volume of 900. milliliters and a pressure of 2.50 atm at 298 K. What is the new pressure when the temperature is changed to 336 K and the volume is decreased to 450. milliliters?

1) 0.177 atm 3) 5.64 atm
2) 4.43 atm 4) 14.1 atm

___ 3) The volume of a sample of a gas at 273°C is 200. liters. If the volume is decreased to 100. liters at constant pressure, what will be the new temperature of the gas?

1) 0 K 3) 273 K
2) 100. K 4) 546 K

___ 4) A gas sample has a volume of 25.0 milliliters at a pressure of 1.00 atmosphere. If the volume increases to 50.0 milliliters and the temperature remains constant, the new pressure will be

1) 1.00 atm 3) 0.250 atm
2) 2.00 atm 4) 0.500 atm

Objective #5: Using the Ideal Gas Law Formula

The ideal gas law describes how the number of moles in a sample of gas is related to its pressure, volume and temperature at ONE given set of conditions.

*** this formula must have the following units**

P (pressure) = atm | n = moles of gas | R (Ideal Gas Constant) = $0.0821 \frac{L \cdot atm}{mol \cdot K}$

V (volume) = Liters | T = (temperature) = Kelvin

1) A 50.0 L container is designed to withstand a maximum pressure of 22.5 atm. If the container is holding 11.2 moles of N_2 gas, what is the maximum temperature the container can reach before bursting?

2) How many moles of helium gas will occupy a volume of 52.0 L at STP?

3) What pressure will 100. grams of oxygen gas exert in a 22.0 L container at 27.0°C?

Ideal Gas Law Practice

1. What is the volume of 82.0 grams of NH_3 gas at STP?
   a) 0.215 L b) 17.0 g c) 62.2 L d) 108 L

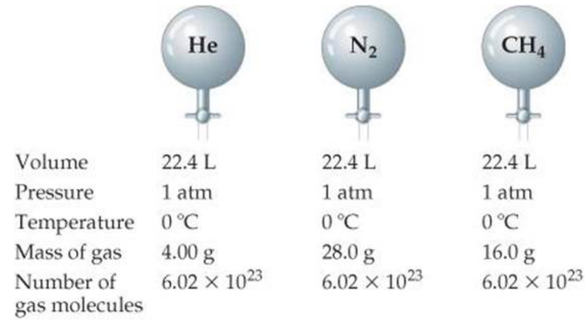
2. What mass of krypton gas has a volume of 2.33 L at 53°C and 3.07 atm?
   a) 22.4 g b) 44.8 g c) 342 g d) 2,080 g

3. A 17.0 gram sample of Cl_2 has a volume of 9.22 L at 17°C. What is its pressure?
   a) 0.618 atm b) 1.24 atm c) 43.8 atm d) 62.6 atm

Objective #6: Avogadro's Hypothesis

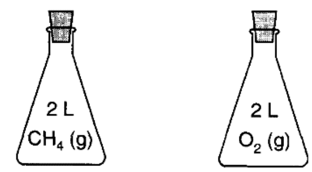
Avogadro's Hypothesis

→ ___________________ volumes of two or more samples of gas contain an ___________________ number of atoms (or molecules) under the _________ conditions of temperature and pressure



Avogadro's Hypothesis Questions

1. Each stoppered flask to the right contains 2 liters of a gas at STP. Each gas sample has the same
   A) density
   B) mass
   C) number of molecules
   D) number of atoms



2. A sample of oxygen gas is sealed in container X. A sample of hydrogen gas is sealed in container Z. Both samples have the same volume, temperature, and pressure. Which statement is true?
   A) Container X contains more gas molecules than container Z.
   B) Container X contains fewer gas molecules than container Z.
   C) Containers X and Z both contain the same number of gas molecules.
   D) Containers X and Z both contain the same mass of gas.

3. At the same temperature and pressure, 1.0 liter of CO(g) and 1.0 liter of CO_2(g) have
   A) equal masses and the same number of molecules
   B) different masses and a different number of molecules
   C) equal volumes and the same number of molecules
   D) different volumes and a different number of molecules

4. A sample of H_2(g) and a sample of N_2(g) at STP contain the same number of molecules. Each sample must have
   A) the same volume, but a different mass
   B) the same mass, but a different volume
   C) both the same volume and the same mass
   D) neither the same volume nor the same mass

5. The table to the right shows temperature and pressure data for four samples of substances at 298 K and 1 atm. Which two samples could consist of the same substance?
   A) *A* and *B*
   B) *B* and *C*
   C) *A* and *C*
   D) *C* and *D*

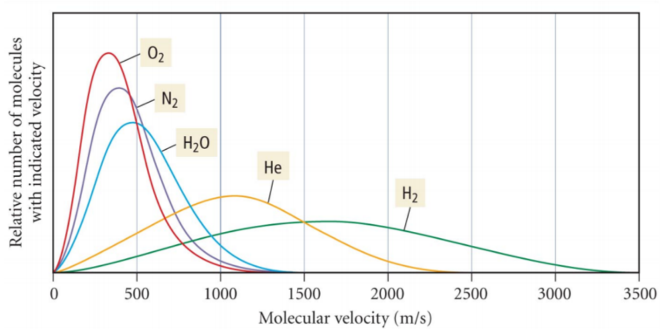
Masses and Volumes of Four Samples

Sample	Mass (g)	Volume (mL)
A	30.	60.
B	40.	50.
C	45	90.
D	90.	120.

Objective #7: Graham's Law of Diffusion

Diffusion is the movement of particles from an area of ___________________ concentration to an area of ___________________ concentration.

- If two gases are at the same temperature, they have the same average kinetic energy



However…

- If two gases have a different mass, their diffusion rate differs

Thomas Graham discovered that the average speed of gas particles is related to the molar mass (GFM) of the gas.

- The ___________________ the molar mass of a gas, the ___________________ its particles move
- The ___________________ the molar mass of a gas, the ___________________ its particles move

So, for two gases at the same temperature, the heavier gas will move a smaller distance than a lighter gas over a given amount of time.

Graham's Law of Diffusion Questions

1. At STP, which gas diffuses at the faster rate?
   A) H_2 B) N_2 C) CO_2 D) NH_3

2. Which gas diffuses most rapidly at STP?
   A) Ne B) Ar C) Cl_2 D) F_2

3. Under the same conditions of temperature and pressure, which gas will diffuse at the *slowest* rate?
   A) He B) Ne C) Ar D) Rn

4. Which of the following gases would have the *slowest* rate of diffusion when all of the gases are held at the same temperature and pressure?
   A) N_2 B) NO C) O_2 D) CO_2

6. Which gas would diffuse most rapidly under the same conditions of temperature and pressure?
   A) gas *A*, molecular mass = 4
   C) gas *B*, molecular mass = 16
   B) gas *C*, molecular mass = 36
   D) gas *D*, molecular mass = 49

7. Which gas is faster at the same temperature: PCl_3 or N_2? Provide evidence for your answer.

Objective #8: Dalton's Law of Partial Pressure

Each of the gases in a mixture of a gases contributes to the total pressure.

- The pressure EACH GAS contributes is its partial pressure.
- If the partial pressures of the gases in a mixture are added, the sum is the total pressure of the mixture.

Dalton's 1st Law of partial pressure:

Where P_A, P_B, P_C etc are partial pressure of gas A, B, C, etc.

* All pressures must be in the same unit to add together to get the total pressure
* this law assumes EQUAL molar quantities

Examples:

1) What is the total pressure of a mixture of three gases that have a partial pressure of 20.2 kPa, 37.7 kPa and 82.0 kPa?

2) The total pressure of a mixture of three gases is 4.65 atm. If the first gas has a partial pressure of 2.34 atm and the third gas has a partial pressure of 1.79 atm, what is the partial pressure of the second gas?

3) What is the total pressure in atmospheres (atm) of a mixture of three gases that have a partial pressure of 20.2 kPa, 1.7 atm and 660. mmHg?

1. What is the total pressure of a mixture of CO_2, SO_2, and H_2O gases, if each gas has a partial pressure of 25 kPa?
   A) 25 kPa B) 50 kPa C) 75 kPa D) 101 kPa

2. A flask contains a mixture of N_2(g) and O_2 (g) at STP. If the partial pressure exerted by the N_2 (g) is 40.0 kPa, the partial pressure of the O_2 (g) is
   A) 21.3 kPa B) 37.3 kPa C) 61.3 kPa D) 720 kPa

3. A mixture of oxygen, nitrogen, and hydrogen gases exerts a total pressure of 74 kPa at 0ºC. The partial pressure of the oxygen is 20 kPa and the partial pressure of the nitrogen is 40 kPa. What is the partial pressure of the hydrogen gas in this mixture?
   A) 14 kPa B) 20 kPa C) 40 kPa D) 74 kPa

If you know the total pressure a mixture of gases has, and want to find an individual partial pressure of ONE gas, where the molar quantities are NOT EQUAL, the following formula is used:

Dalton's 2nd Law of partial pressure:

where P_p is partial pressure,
X_A is mole ratio, and
P_T is total pressure of mixture

Example: What is the partial pressure of Gas C if a gas mixture has 1.0 mole of Gas A, 3.5 moles of gas B and 2.5 moles of gas C and its total pressure is 2.35 atm?

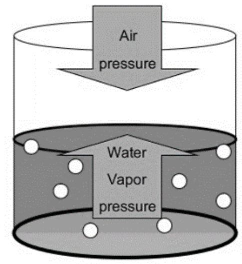
Example: A container is filled with 2.0 moles of Ne and 4.0 moles of Xe. The total pressure inside the container is 506.5 kPa. What is the partial pressure of just the Ne?

4. A cylinder is filled with 2.00 moles of nitrogen, 3.00 moles of argon and 5.00 moles of helium. If the gas mixture is at STP, what is the partial pressure of just argon?
   A) 20.3 kPa B) 30.4 kPa C) 50.7 kPa D) 101 kPa

5. A mixture of gases has a total pressure of 1.97 atm. The mixture contains 8.0 moles of nitrogen gas and 2.0 moles of oxygen gas. What is the pressure exerted by oxygen only?
   A) 0.197 atm B) 0.394 atm C) 0 .494 atm D) 1.58 atm

Objective #9: Understanding Vapor Pressure

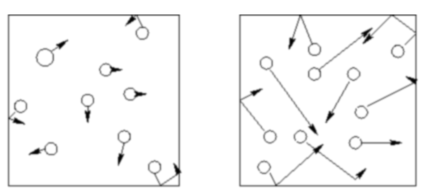
There is air all around us, pushing downwards and contributing to the given overall atmospheric pressure (standard atmospheric pressure = 1.0 atm or 101.3 kPa). When a substance changes from a liquid to a gas (evaporation), it exerts an upwards pressure against the atmospheric pressure. The upwards pressure during process of evaporation is known as vapor pressure.



- In order for a liquid to turn into a gas, the particles must ________________________ the space between them
    - o In order to increase the space between particles, the particles in the liquid must have enough force to "resist" upwards against the air pressure
- Once the liquid molecules have enough upwards force that is ___________________ ________ or ____________________ than the downwards atmospheric pressure, the molecules will be able to spread out and the gas phase will form

A) Vapor pressure is directly related to temperature.

- As the temperature of a liquid substance increases, its kinetic energy of the particles _____________________
    - o An increase in KE of the particles causes an _______________________ in collisions between particles
        - ▪ More collisions cause an increase in pressure

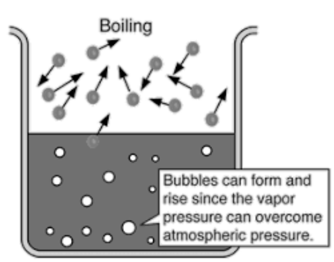


Cool gas, fewer and less energetic collisions

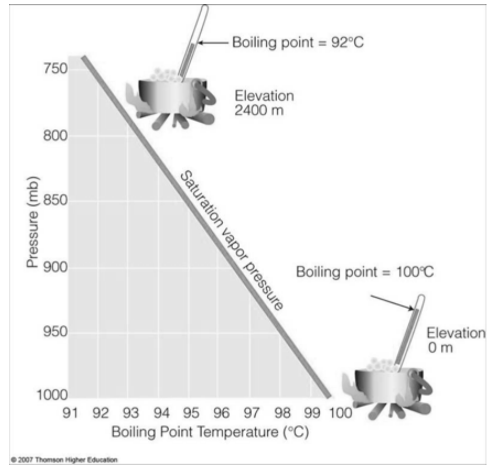
Hot gas, more and more energetic collision

- At a temperature where the vapor pressure ____________________ the atmospheric pressure, the liquid has enough energy to resist against the atmosphere and can begin to boil.

The boiling point of a liquid is the temperature at which its vapor pressure is equal to or greater than the atmospheric pressure.



How does the elevation change contribute to the change in the boiling point of water (<, > or = to)?

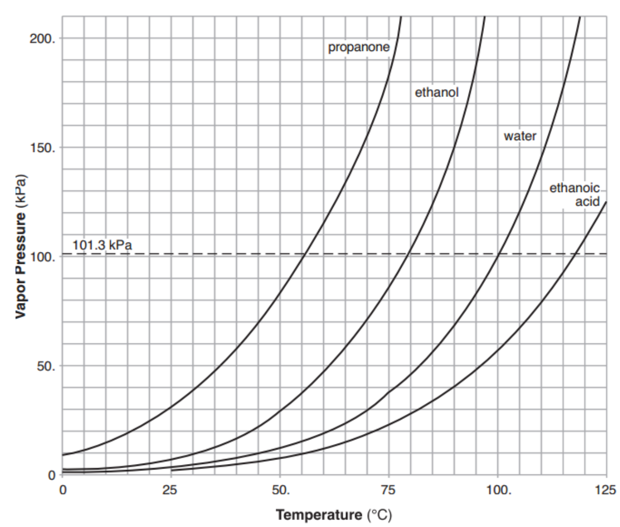


B) Vapor pressure is <u>indirectly</u> related to the strength of the intermolecular forces (IMF's).

- The ________________________ the intermolecular forces, the ________________________ the vapor pressure.
- If particles have weak IMF's (London Dispersion) and are weakly held together, they
  a) are more likely to evaporate, and
  b) will evaporate more quickly than a liquid with stronger IMF's

The reference table below shows the vapor pressure of four liquids. Their normal boiling points are found at standard pressure, which is 101.3 kPa on this graph.

Table H
Vapor Pressure of Four Liquids



Vapor Pressure (Table H) Practice Questions

a) What is the pressure if water boils at 20°C? _______________

b) What is the normal boiling point of water? _______________ ethanoic acid? _____________

c) Which liquid has the highest boiling point at 50kPa? _________________________________

d) Which liquid has the weakest intermolecular forces? _________________________________

e) What is the boiling point of propanone at 85 kPa? ________________

f) At what pressure will ethanoic acid boil at 110°C? ________________

g) What temperature will water boil at if the pressure is 85 kPa? ________________

h) What must the pressure be for ethanol to boil at 85°C? ________________

Vapor Pressure practice

____ 1) When the vapor pressure of a liquid is equal to the atmospheric pressure, the liquid will

A) freeze B) boil
C) melt D) condense

____ 2) Solid substances are most likely to sublime if they have

A) high vapor pressures and strong intermolecular attractions
B) high vapor pressures and weak intermolecular attractions
C) low vapor pressures and strong intermolecular attractions
D) low vapor pressures and weak intermolecular attractions

____ 3) At which temperature is the vapor pressure of ethanol equal to the vapor pressure of propanone at 35°C?

A) 35°C B) 60.°C
C) 82°C D) 95°C

____ 4) Which liquid has the lowest vapor pressure at 65° C?

A) ethanoic acid B) ethanol
C) propanone D) water

____ 5) Based on intermolecular forces, which of these substances would have the highest boiling point?

A) He B) O_2 C) CH_4 D) NH_3

____ 6) Using your knowledge of chemistry and the information in Reference Table *H*, which statement concerning propanone and water at 50° C is true?

A) Propanone has a higher vapor pressure and stronger intermolecular forces than water.
B) Propanone has a higher vapor pressure and weaker intermolecular forces than water.
C) Propanone has a lower vapor pressure and stronger intermolecular forces than water.
D) Propanone has a lower vapor pressure and weaker intermolecular forces than water.

____ 7) According to Reference Table *H*, what is the vapor pressure of propanone at 45°C?

A) 22 kPa B) 33 kPa
C) 70 kPa D) 98 kPa

____ 8) As the temperature of a liquid increases, its vapor pressure

A) decreases B) increases
C) remains the same

____ 9) Based on Reference Table *H*, which sample has the highest vapor pressure?

A) water at 20°C B) water at 80°C
C) ethanol at 50°C D) ethanol at 65°C

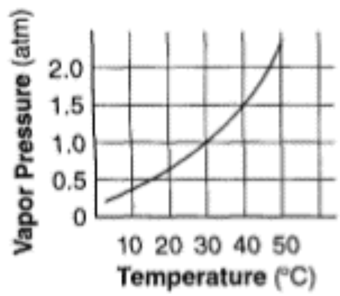
____ 10) Which sample of water has the *lowest* vapor pressure?

A) 100 mL at 50°C B) 200 mL at 30°C
C) 300 mL at 40°C D) 400 mL at 20°C

____ 11) Based on Reference Table *H*, which substance has the weakest intermolecular forces?

A) ethanoic acid B) ethanol
C) propanone D) water

____ 12) The graph below shows the relationship between vapor pressure and temperature for substance *X*.



What is the normal boiling point for substance *X*?

A) 50°C B) 20°C C) 30°C D) 40°C

____ 13) When the vapor pressure of water is 30 kPa, the temperature of the water is

A) 20°C B) 40°C
C) 70°C D) 100°C