Chapter 13

GASES

Characteristics of Gases

- Where are they found?
  - Everywhere!
- Can we see them?
  - Most are invisible
- What gases are in the atmosphere?
  - 78% N_2
  - 21% O_2
  - 1% Ar
  - < 1% CO_2

EXPLANATION OF CHARACTERISTICS OF GASES

Characteristics of Gases

1) Have mass & occupy space.
2) Separated by relatively large distances.
3) Are in constant, rapid, random motion.
4) Exert pressure when collide with walls of container.
5) Easy to compress.
6) Gases with lightest mass travel fastest.

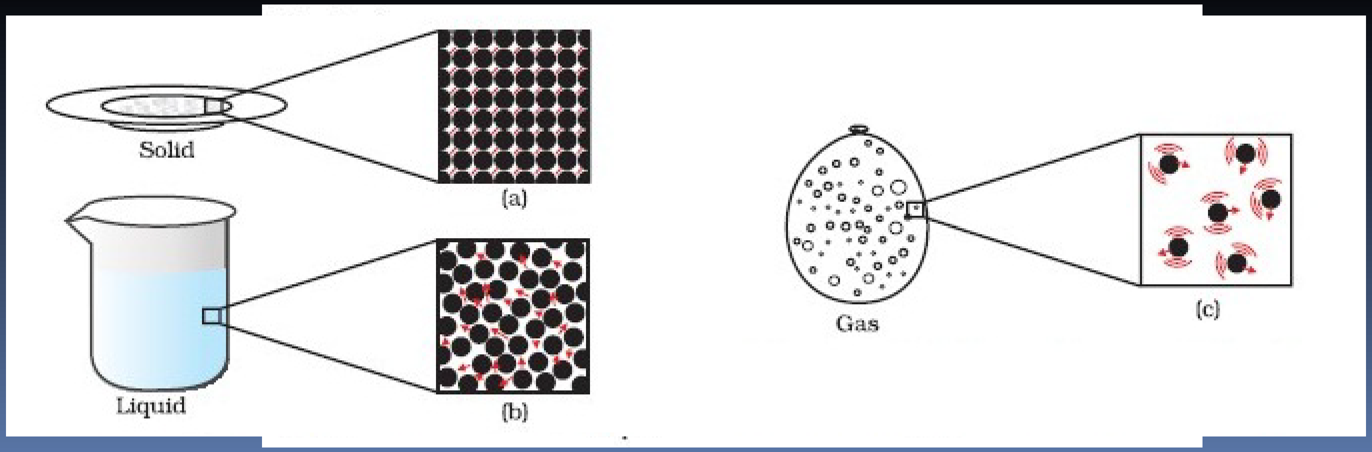
1) Have mass and occupy space

- Matter: "anything that has mass and takes up space"
  - Gases do both of these!
  - Ex) molar masses of gases on the periodic table
- Make a prediction:
  - The mass of a soccer ball <u>de</u>flated
  - The mass of a soccer ball <u>in</u>flated
  - The same, heavier, lighter??
    - Watch video:
    - http://www.youtube.com/watch?v=_p--sGYfGnU

2) Separated by relatively large distances

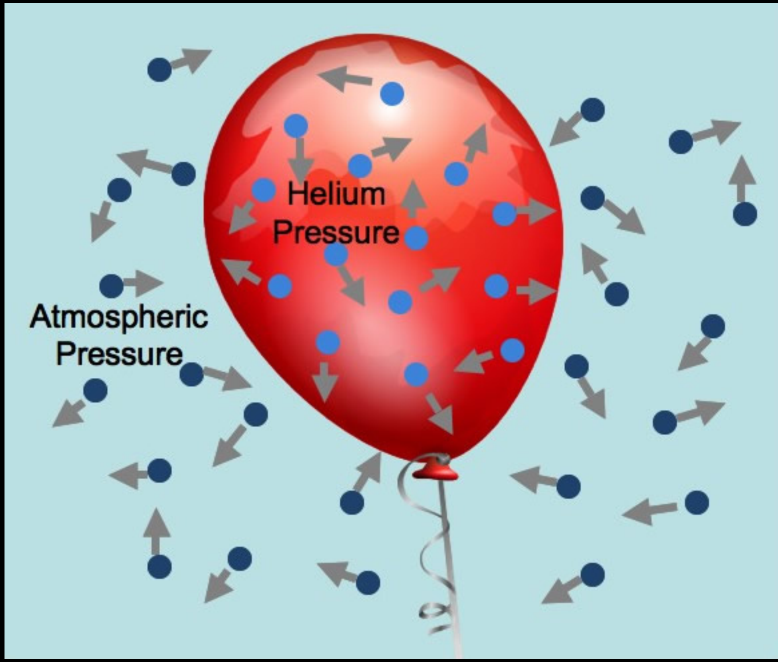
3) Constant, rapid, random motion

- *Review from Ch 12:*
- Gases molecules are spread further apart and move much faster than solids and liquids
- They never stop moving!



4) Exert pressure when collide with walls of container

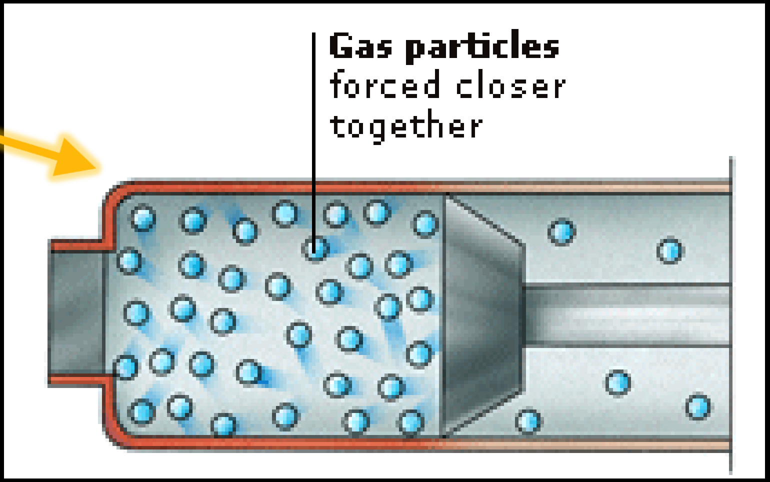
- Ex) a helium filled balloon
  - The helium on the inside of the balloon exerts pressure on the inside walls of the balloon
  - The gas molecules in the atmosphere collide with the outside walls of the balloon



- Ex) more particles = more pressure = balloon inflated more
  - http://mutuslab.cs.uwindsor.ca/schurko/animations/avogadro/avogadro.htm

5) Easy to compress

- Because there is so much space between gas molecules



- Demo: textbooks on cylinder
- Convenient for transporting commercial gases
  - Liquid propane, acetylene, oxygen
- Can be hazardous
  - MythBusters:

http://www.youtube.com/watch?v=ejEJGNLTo84

6) Gases with the lightest mass travel fastest

- Animation: http://mutuslab.cs.uwindsor.ca/schurko/animations/avogadro/avogadro.htm
  - The balloon at the left has hydrogen (H_2) and the balloon at the right has carbon dioxide (CO_2). Why are the H_2 molecules moving faster than the CO_2 molecules?

Factors that can affect gases

- Temperature
- Pressure
- Volume
- Number of particles

Units for these factors

- Temperature
  - must be in Kelvin (not in Celsius)
- Pressure
    - a variety of units used!
  - atmospheres (atm)
  - kilopascals (kPa)
    - named after scientist: Pascal
  - millimeters of mercury (mm Hg)
    - like a barometer (more info to come)
- Volume
  - 1000 mL = 1 L
  - 1 dm^3 = 1 L
  - 1 cm^3 = 1 mL
- Number of particles
  - use moles
    - If given grams, then you must convert to moles

Temperature Conversions Review

- Convert -14^{o}C to Kelvin
  - Answer: 258 K

- Convert 315 K to ^{o}C
  - Answer: 42^{o}C

Volume Conversions Review

- Convert 357 mL to Liters
  - Use dimensional analysis to get your units to cancel out
  - Answer: 0.357 L

- Convert 4.8 dm^3 to cm^3
  - Use your notes to see what these unfamiliar units are the same as
  - Answer: 4800 cm^3

Pressure Conversions

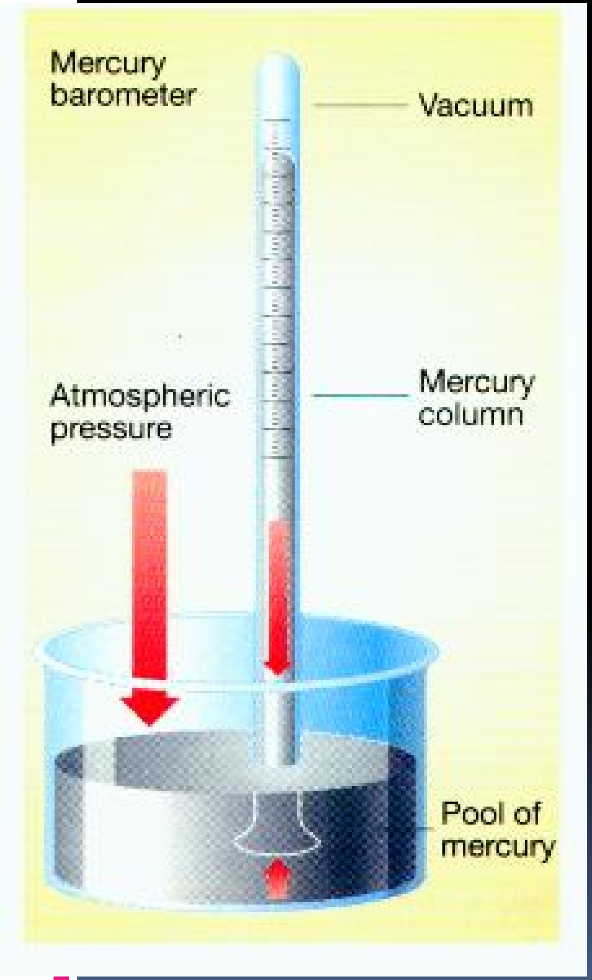
- There are MANY units for pressure. We are only going to be using 3.
- COPY IN YOUR NOTES: *(do not memorize)*
  - **1 atm = 101.3 kPa = 760 mmHg**
- Use dimensional analysis to get your units to cancel out!

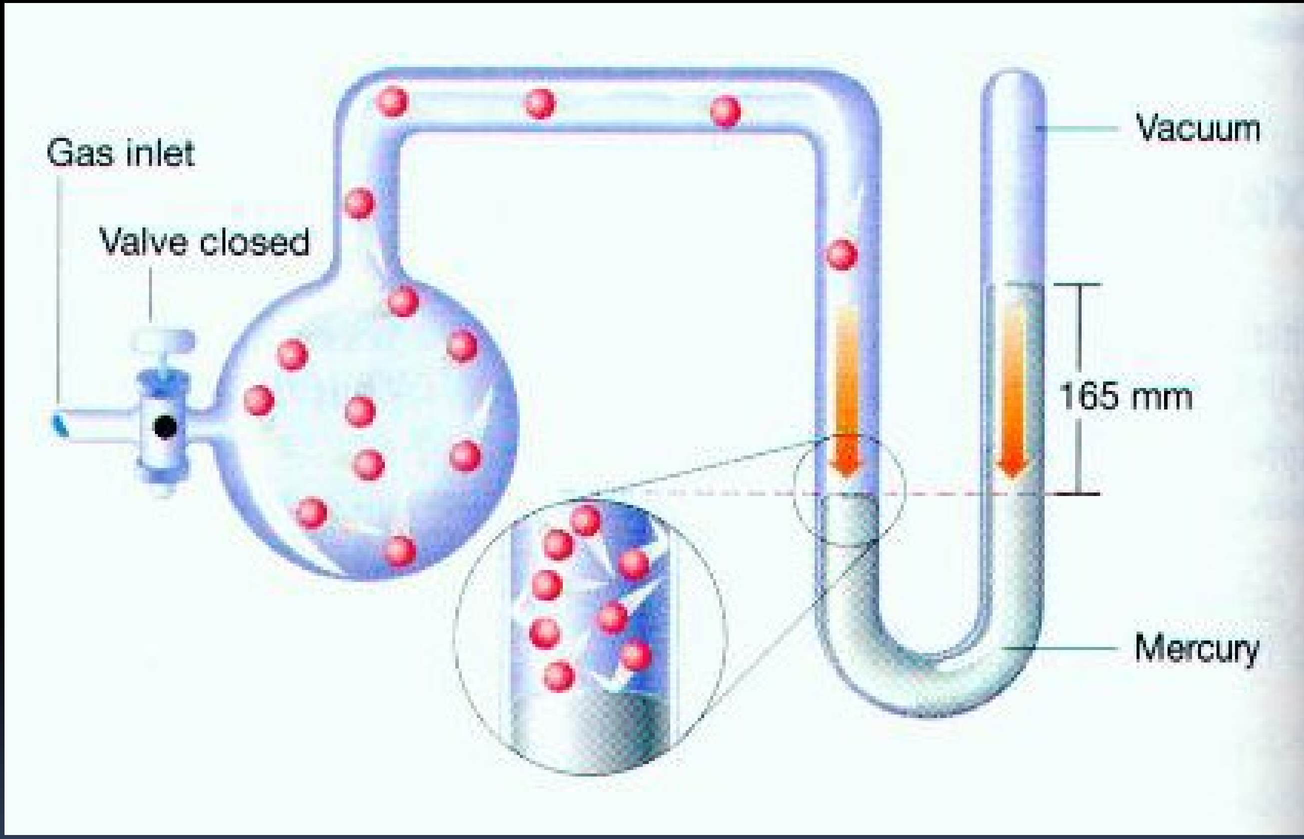
- Convert 283.6 kPa to atm
  - Answer: 2.8 atm

- Convert 692 mmHg to kPa
  - Answer: 92.24 kPa

Barometer/ Manometer

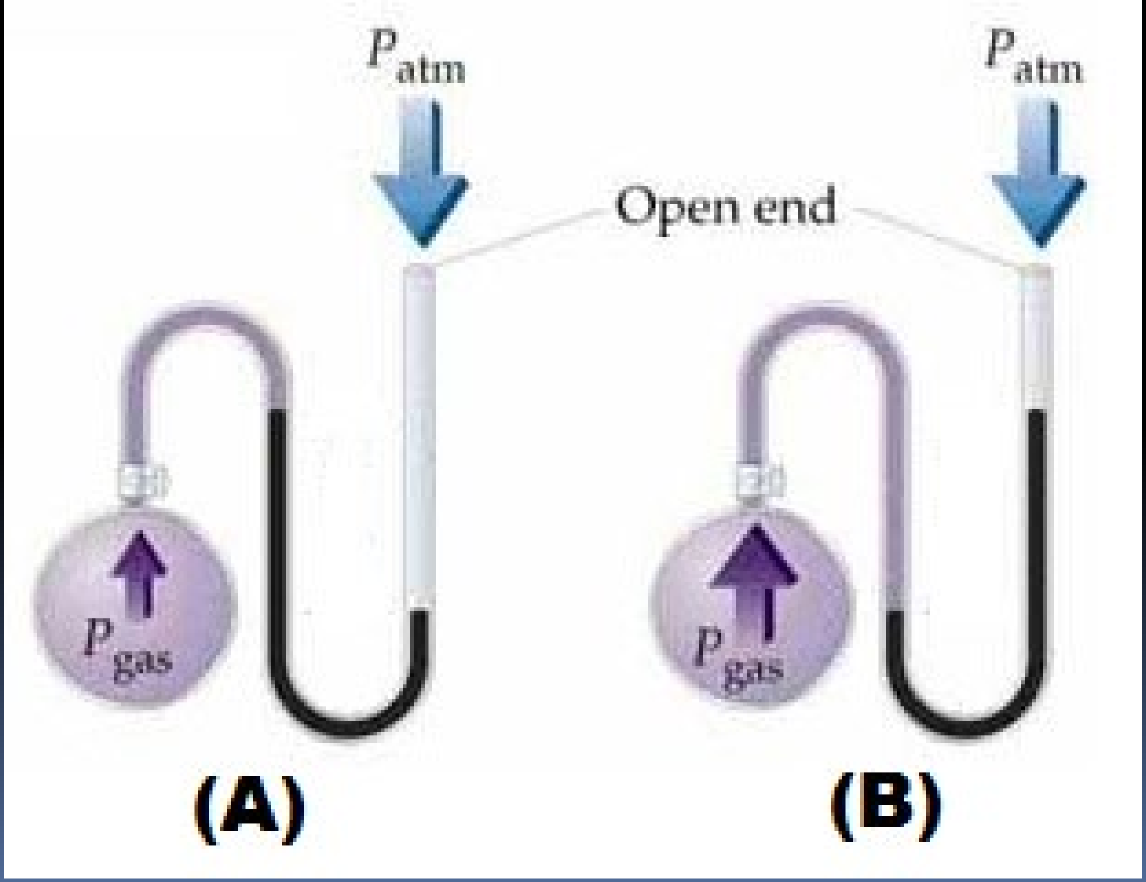
- Instruments to measure pressure





Manometer Example Problem:

- In which manometer is the pressure of the gas in the flask greater than atmospheric pressure?
- *Answer: B*
- *The pressure of the gas in B pushes the liquid further up the tube than in A*



A way to mathematically describe the factors impacting gases.

GAS LAWS

Boyle's Law

- Pressure and volume change
  - Temperature remains constant
    - not included in equation
- Inverse relationship
  - As pressure increases, volume decreases

$$P_1V_1 = P_2V_2$$

P = Pressure of the gas
V = Volume of the gas

Temperature must be constant

Boyle's Law: Demo

- Marshmallow in a cylinder

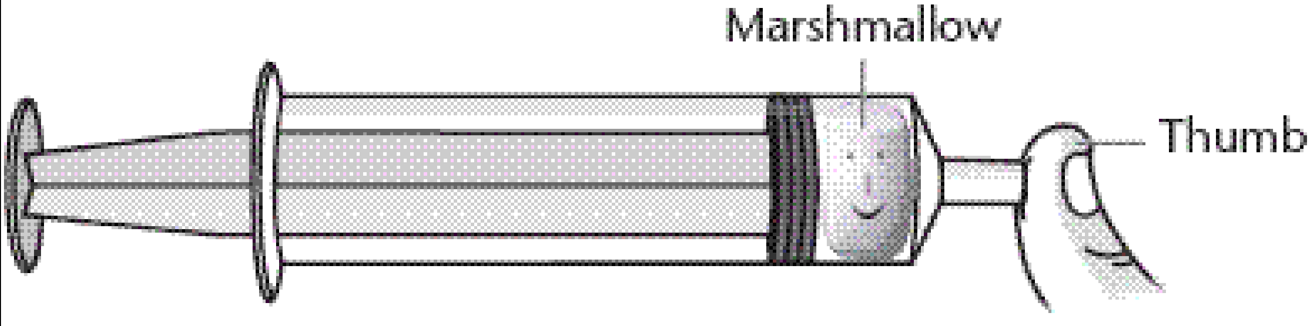


FIGURE 1.1. Boyle's Gas Law: Plunger In

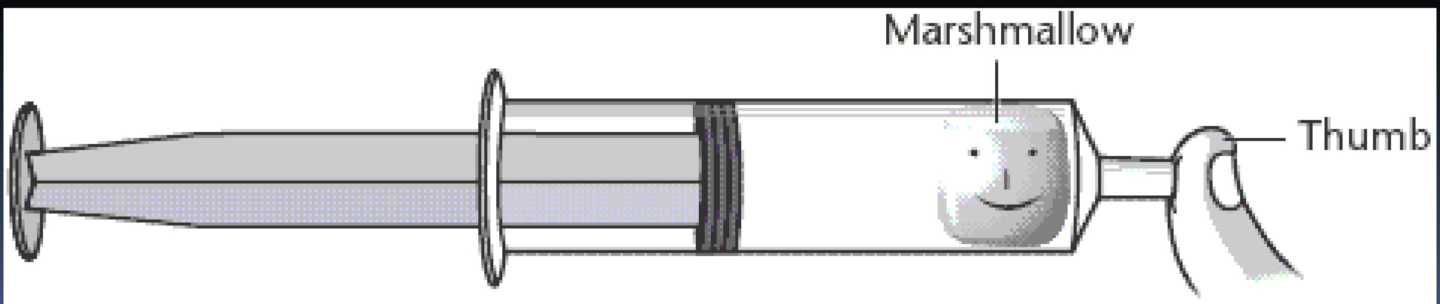


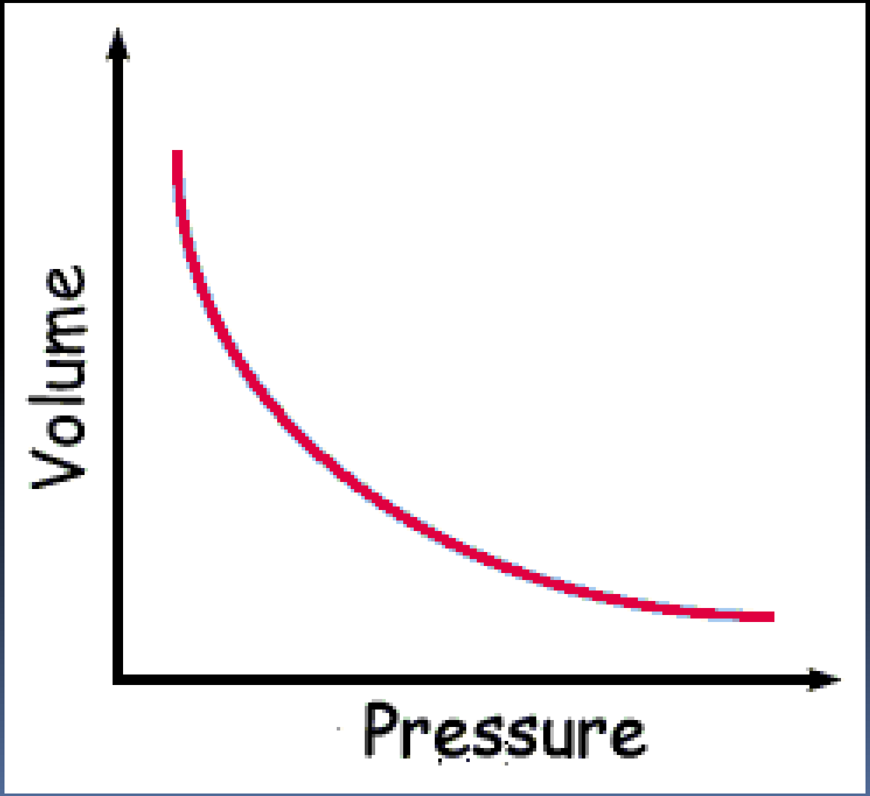
FIGURE 1.2. Boyle's Gas Law: Plunger Out

Boyle's Law: Animation

- http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law.swf
- What is the relationship between volume and pressure?

Boyle’s Law: Graphing

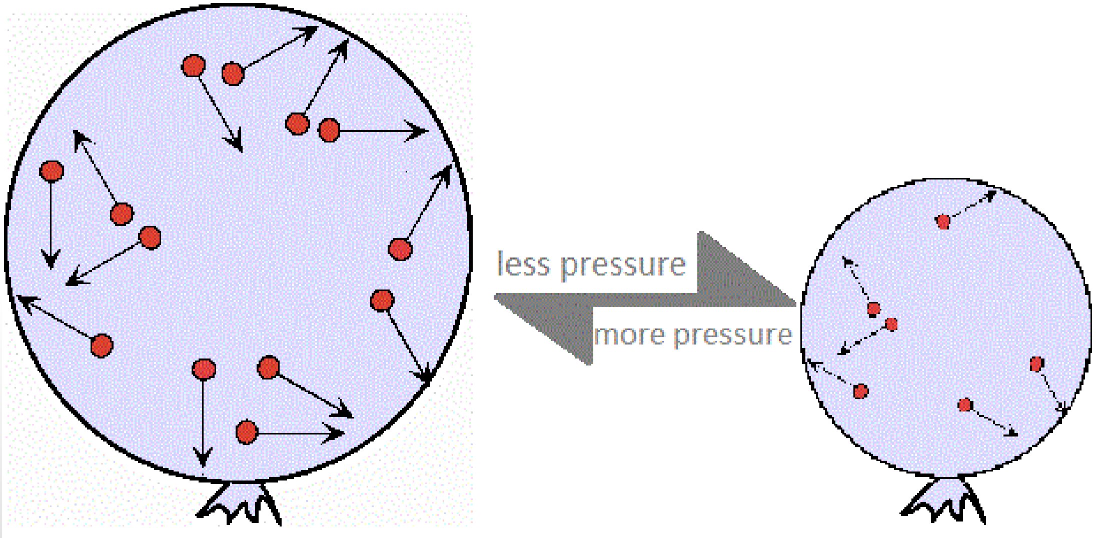
- As pressure increases, volume decreases.
  - Draw this graph in your notes (very important!)
- Inverse relationship



Boyle's Law Example:

- Example problem for PreIB and Gen Chem (not on a worksheet)

- A balloon begins at a pressure of 1.2 atm and a volume of 2.5 L. If the pressure increases to 3.7 atm, what is the volume of the balloon? (see graphic)
  - Answer: 0.81 L (the balloon got much smaller!)



Do Now: Quiz Review on Dry Erase Board

- A balloon begins at a pressure of 1.2 atm and a volume of 2.5 L. If the pressure increases to 3.7 atm, what is the volume of the balloon?

- On her way to being an awesome biscuit lady, Mrs. Cook has a 4.0 L birthday balloon in her car, which is at $42^{o}C$. She takes the balloon into McDonald's and stashes it in the $-30^{o}C$ freezer where her boss cannot find it. What is the volume of the balloon when she retrieves it at the end of the day?

Boyle's Law Example:

- Example problem for Gen Chem: (#5 on worksheet)
- A balloon has a volume of 250 mL at a pressure of 202.6 kPa. What will be the new volume of the balloon in mL if the pressure is changed to 810.4 kPa?
  - Answer: 62.5 mL

Boyle's Law Example

- Problem for PreIB & Gen Chem (#7 on worksheet)
- A cylinder contains 12 L of a gas at a pressure of 834 mm Hg. What will be the new pressure in mmHg if the volume is decreased to 842 mL?
  - Answer: 11885.99 mm Hg

Charles's Law

- volume and Kelvin temperature change
  - Pressure remains constant
    - Not included in equation
- Direct relationship
  - As temperature increases, volume increases

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

T = Temperature of the gas
V = Volume of the gas

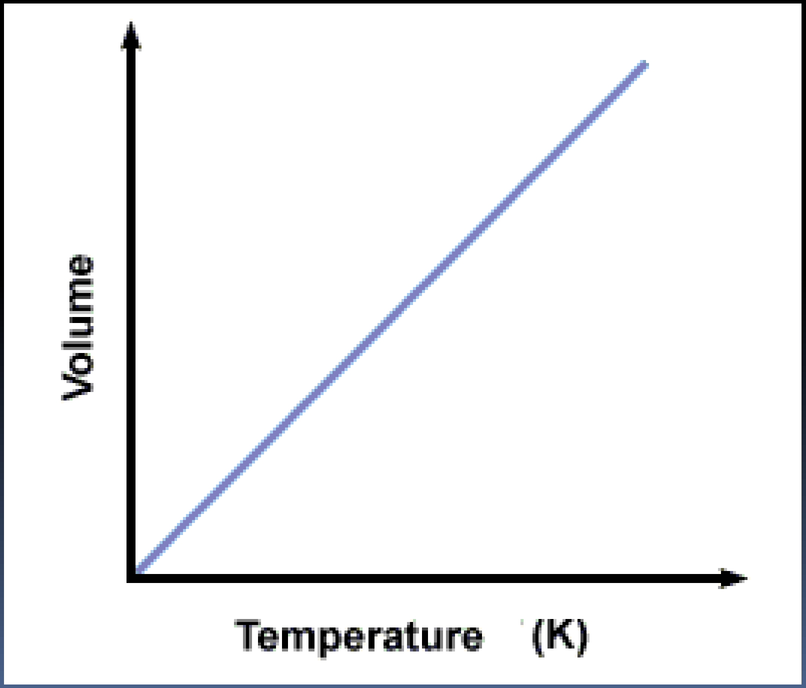
Pressure must be constant

Charles's Law: Animation

- http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/charles_law.html
- What is the relationship between temperature and volume?

Charles's Law: Graphing

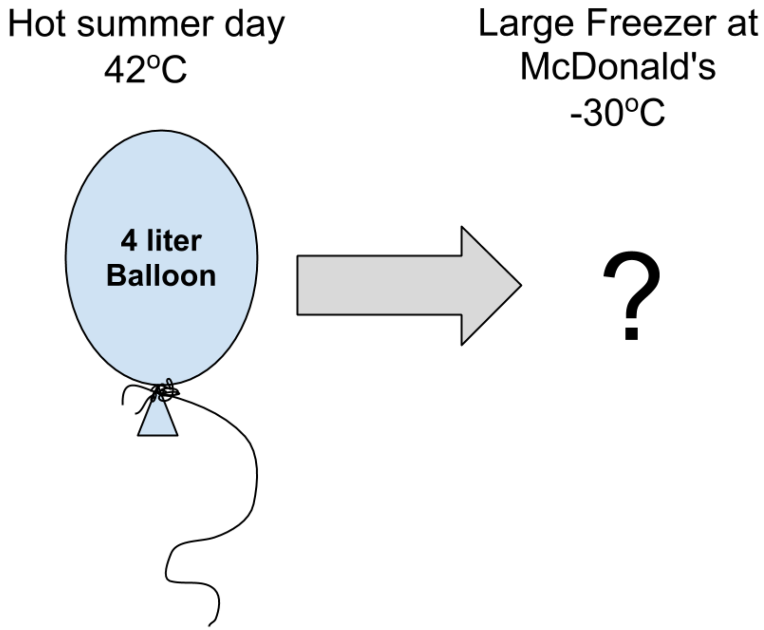
- As temperature increases, volume increases
  - Draw this graph in your notes (very important!)
- Direct relationship



Charles's Law Example

- Example problem for PreIB and Gen Chem (not on worksheet)

- On her way to being an awesome biscuit lady, Mrs. Cook has a 4.0 L birthday balloon in her car, which is at 42°C. She takes the balloon into McDonald's and stashes it in the -30°C freezer where her boss cannot find it. What is the volume of the balloon when she retrieves it at the end of the day?
  - Answer: 3.09 L



Charles's Law Example

- Example problem for Gen Chem (#9 on worksheet)
- A car tire has a volume of 15 L at a temperature of 22°C. What will be the new volume in liters if the temperature increases to 34°C? *(Hint: convert °C to Kelvin before calculating)*
  - Answer: 15.61 L

Charles's Law Example

- Example problem for PreIB and Gen Chem (#11 on worksheet)
- A balloon has a volume of 1.25 L at a temperature of 298 K, What will be the new volume in milliliters if the room is heated up to 35 ^{o}C?
  - Answer: 1290 mL

Combined Gas Law

- pressure, volume, & Kelvin temperature change

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

P = Pressure of the gas
T = Temperature of the gas
V = Volume of the gas

Combined Gas Law

- Where did it come from?
  - If Boyle's Law is: $P_1V_1 = P_2V_2$
  - If Charles's Law is: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
  - All three variables are combined!

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

Combined Gas Law Example

- Example for PreIB and Gen Chem:
  - #1 on Gen Chem worksheet
  - Not on PreIB worksheet
- A sample of chlorine gas occupies 9.2 L at 45^oC and 1.3 atm. What would be the pressure when the volume is reduced to 7.8 L at 38^oC?
  - Answer: 1.5 atm

Combined Gas Law Example

- Example for PreIB and Gen Chem:
  - #4 on Gen Chem worksheet
  - Not on PreIB worksheet
- A 5.00 L air sample has a pressure of 107 kPa at a temperature of -50^{o}C. If the temperature is raised to 102^{o}C and the volume expands to 7.00 L, what will the new pressure be?
  - Answer: 128.52 kPa

Combined Gas Law Example

- Example for PreIB and Gen Chem:
  - #1 on PreIB worksheet
- A gas at 110 kPa and 30.0^{o}C fills a flexible container with an initial volume of 2.00 dm^3. If the temperature is raised to 80.0^{o}C and the pressure increases to 440 kPa, what is the new volume in dm^3?
  - Answer: 0.58 dm^3

Do Now: Combined Gas Law

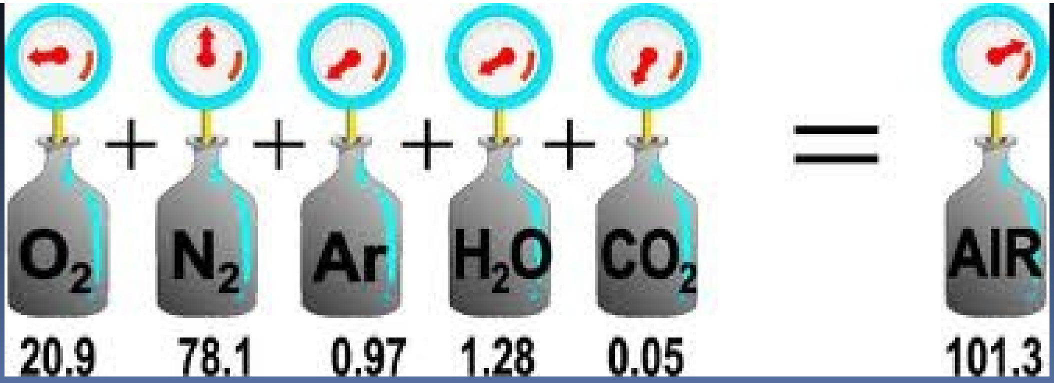
- A sample of nitrogen occupies 10.0 liters at 25^{o}C and 98.7 kPa. What would be the volume in liters at 20^{o}C and 102.7 kPa?

Dalton's Law of Partial Pressures

- <u>Long definition</u>: *(do not copy into notes)*
  - "the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of the individual gases"
- <u>Paraphrase</u>: "If I add up the pressure of individual gases, then I get the total pressure of them mixed together."
  - Copy the equation in your notes:

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

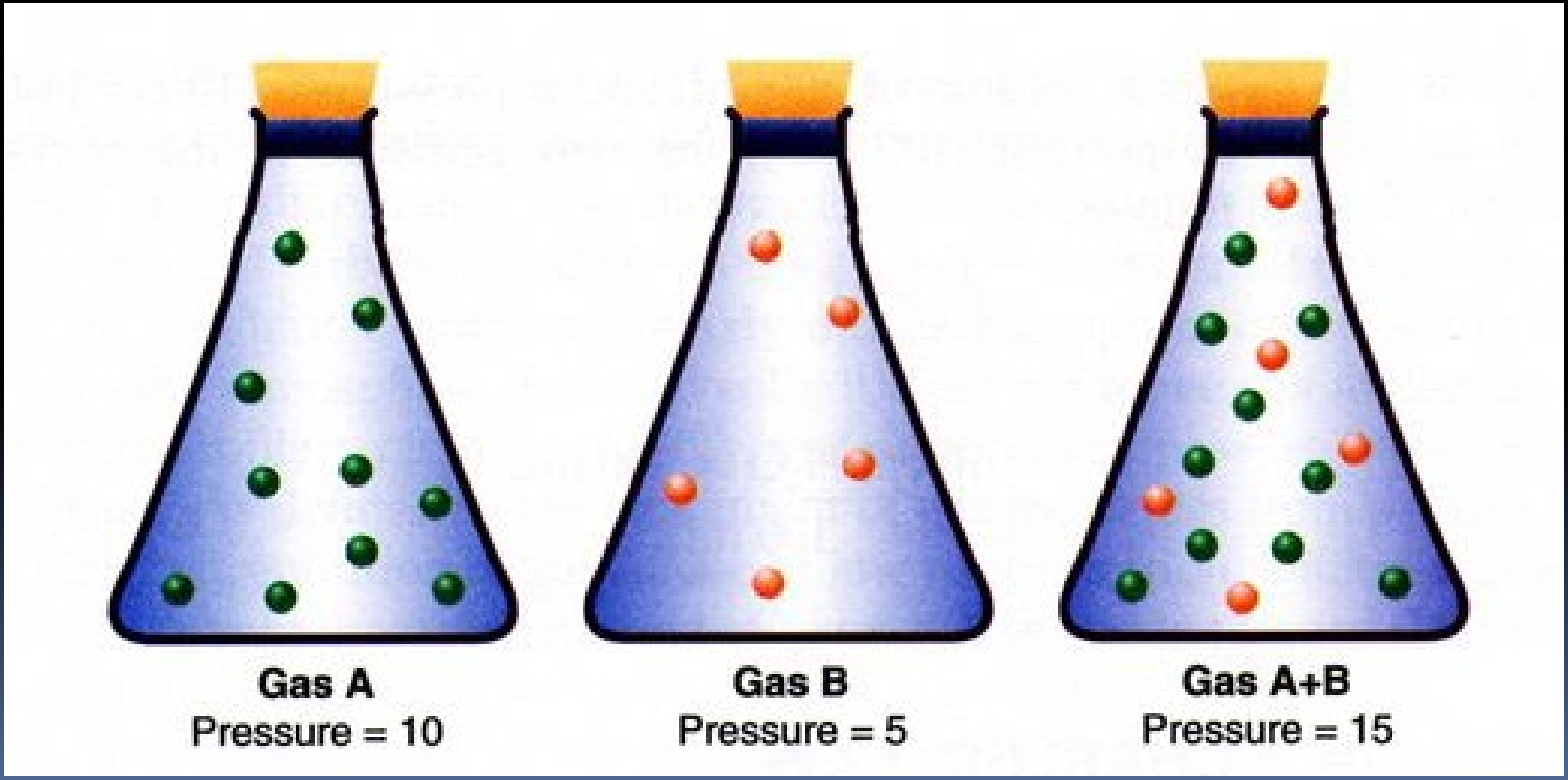
<u>Example</u>: the gases in air *(units are kPa)*



Dalton's Law of Partial Pressures

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

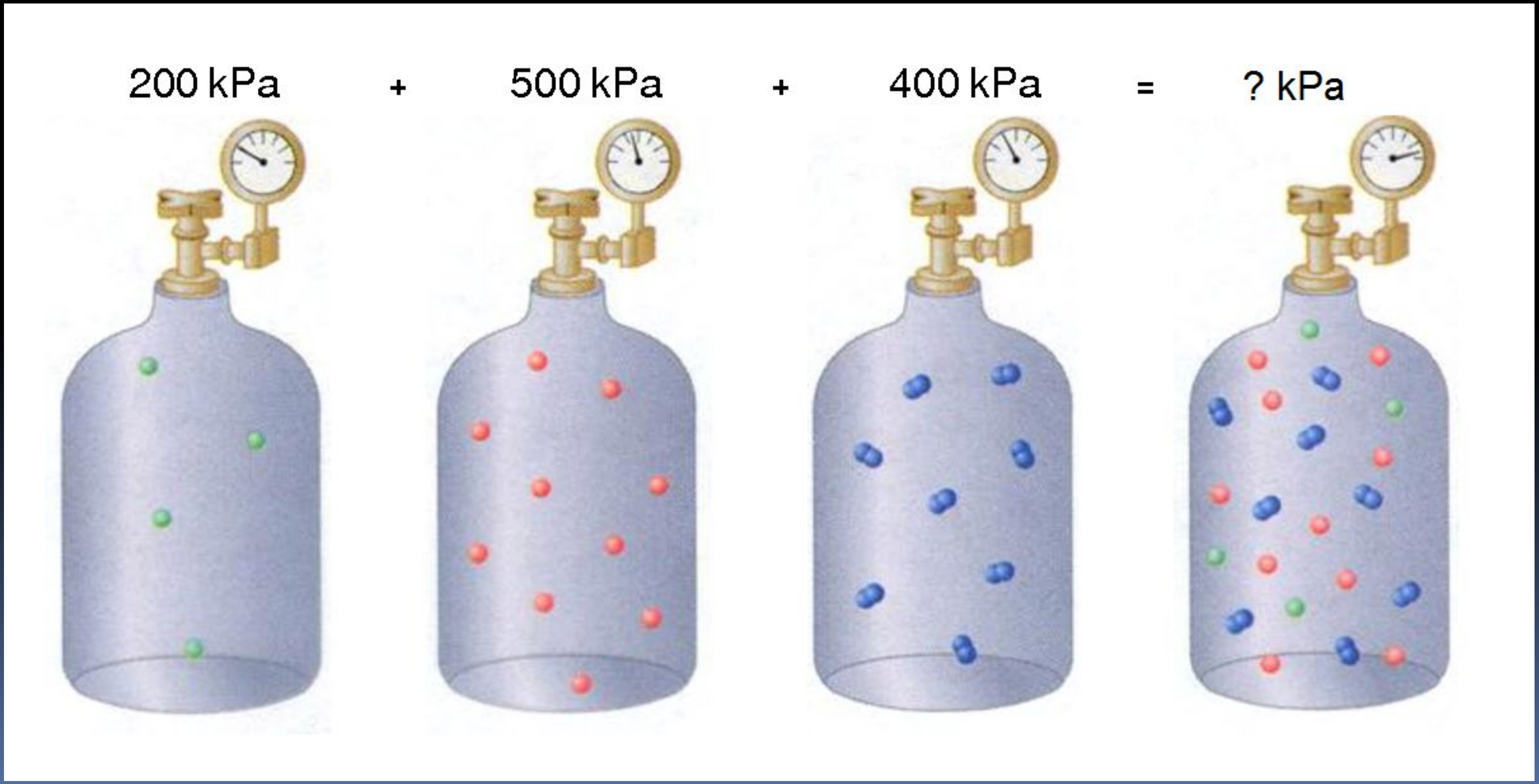
- Example:



Dalton's Law of Partial Pressures

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

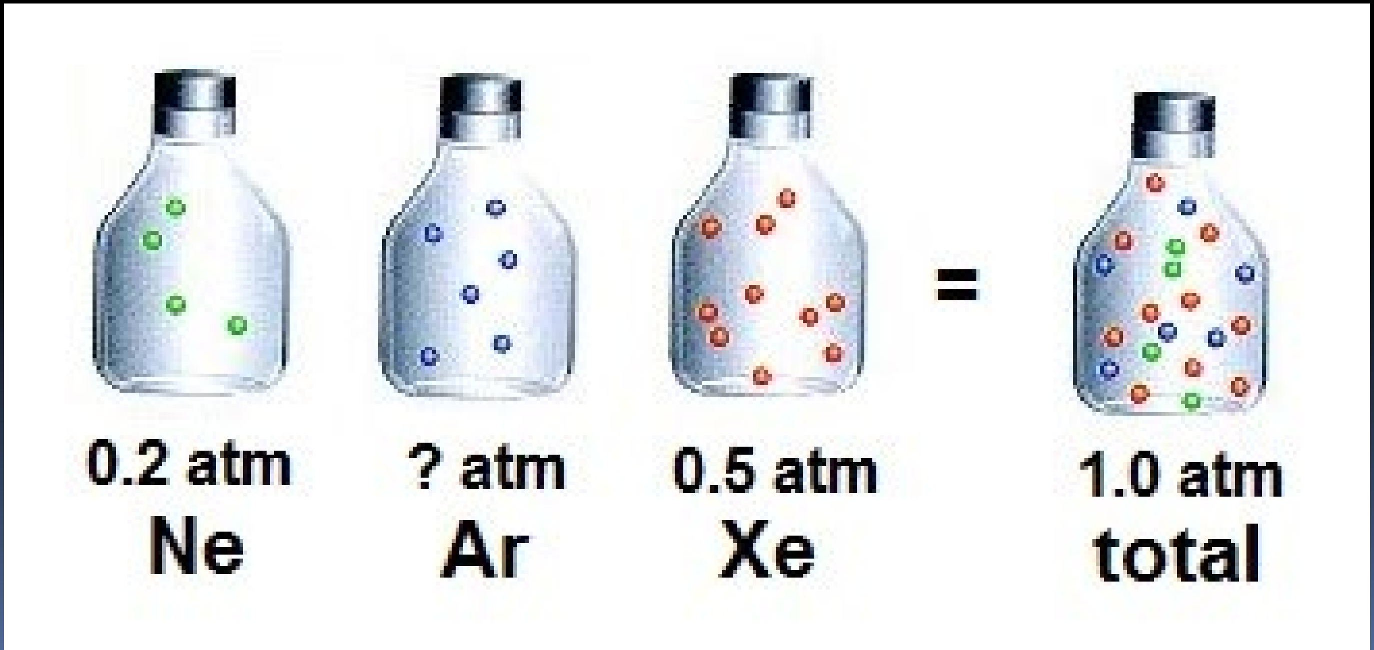
- Determine the total pressure of the mixture of gases.
- answer: 1100 kPa



Dalton's Law of Partial Pressures

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

- Samples of neon, argon, and xenon are combined together. Using the information below, determine the partial pressure of argon.
- answer = 0.3 atm



Dalton's Law of Partial Pressures Example

- **Two main types of Partial Pressures problems:**
  - Type A) Individual Gas Pressures are given
  - Type B) Percentages of Gases are given

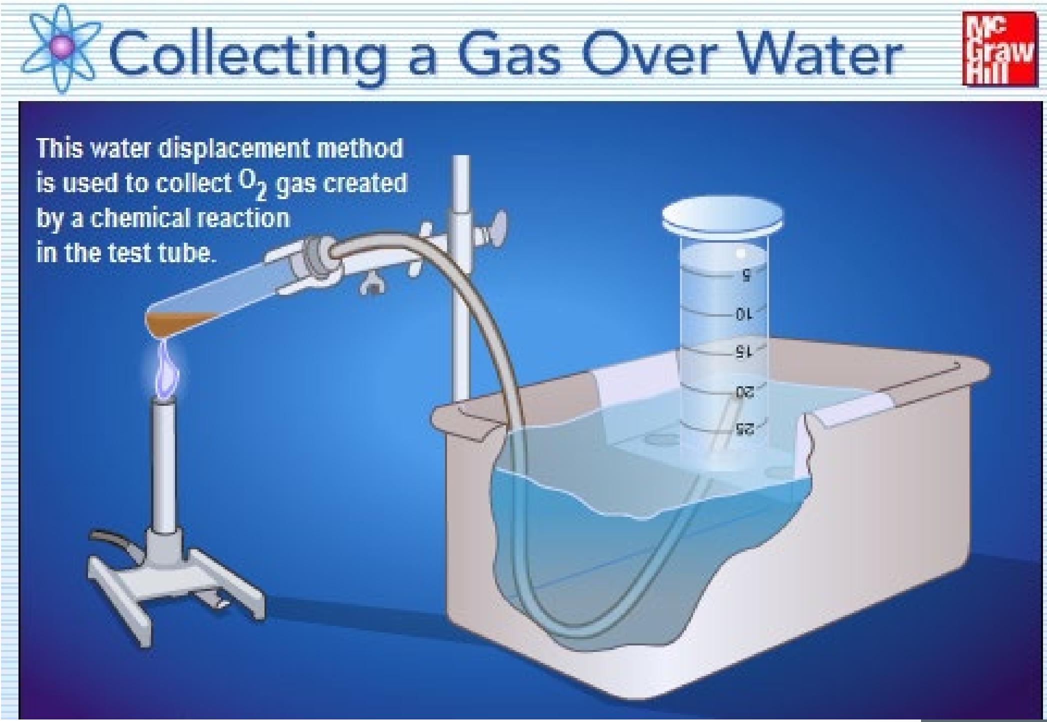
- **Example of Type A: Individual Gas Pressures given**
    - Problem #3 on PreIB worksheet
- A tank contains N_2 at 1.4 atm and O_2 at 2.2 atm. Helium is added to this tank until the total pressure is 5.9 atm. What is the partial pressure of the helium?
  - Answer: 2.3 atm

Dalton's Law of Partial Pressures Example

- **Two main types of Partial Pressures problems:**
  - Type A) Individual Gas Pressures are given
  - Type B) Percentages of Gases are given

- **Example of Type A: Individual Gas Pressures given**
    - Problem #8 on Gen Chem worksheet
- A mixture of neon and argon gases exerts a total pressure of 189 kPa. The partial pressure of the neon alone is 82 kPa, what is the partial pressure of the argon?
  - Answer: 107 kPa

Dalton's Law of Partial Pressures Example



- PreIB only; #7 on worksheet

- **<u>Type A:</u>**
- **<u>Individual Gas Pressures given</u>**
  - Very awkward wording!
  - Water displacement is used as an experimental technique to collect gases generated in a chemical reaction (see picture & video)
    - scroll to video called "Collecting a Gas Over Water" http://www.kentchemistry.com/links/GasLaws/dalton.htm
- A sample of oxygen gas is collected over water at 22 °C and a total pressure of 85.41 kPa. If the partial pressure of the water is 5.64 kPa, what is the partial pressure of the oxygen?
  - Answer: 79.76 kPa (ignore temperature in partial pressure problems= extra info!)

Dalton's Law of Partial Pressures Example

- **Two main types of Partial Pressures problems:**
  - Type A) Individual Gas Pressures are given
  - Type B) Percentages of Gases are given

- **Example of Type B: Percentage of Gases given**
  - #10 on PreIB worksheet
  - #11 on Gen Chem worksheet
- A mixture of gases with a pressure of 753.0 mmHg contains 70% nitrogen and 30% oxygen by volume. What is the partial pressure of oxygen in this mixture?
  - Answer: 225.9 mmHg

- Notice the "extra information" given; we are not asked to solve for nitrogen, but they give us the % anyhow. Ignore it! Only focus on the gas they ask you to solve for.

Preparation for Ch 13 Quiz #1

- How can I tell which equation to use when they are all mixed together?
- Recognize the info given:
  - *(see next slide for your class)*

Gen Chem: {Prepare for Quiz #1}

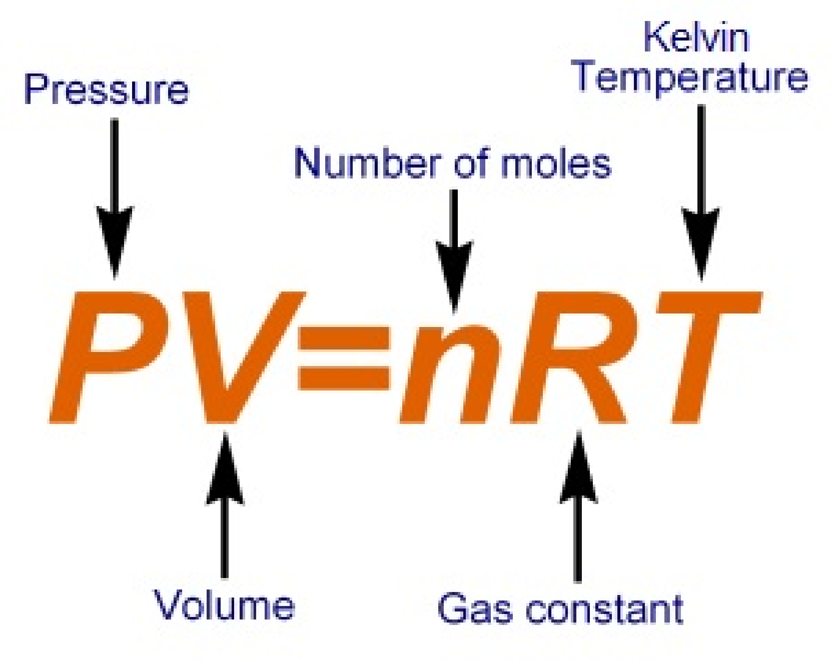
Equation	**Information Given**
Boyle's Law	P, V
Charles's Law	V, T
Combined Gas Law	P, V, T
Dalton's Law of Partial Pressures	P (the words "partial pressure" are used)

PreIB: {Prepare for Quiz #1}

Equation	Information Given	Info NOT provided, or held constant
Boyle's Law	P, V	T, n
Charles's Law	V, T	P, n
Combined Gas Law	P, V, T	n
Dalton's Law of Partial Pressures	P (the words "partial pressure" are used)	T, V

Ideal Gas Law

- Use to explain the behavior of a gas sample.
- Relationship between pressure, volume, temperature, and the amount of the gas (as measured by moles)
- Must use an "Ideal Gas Law Constant"



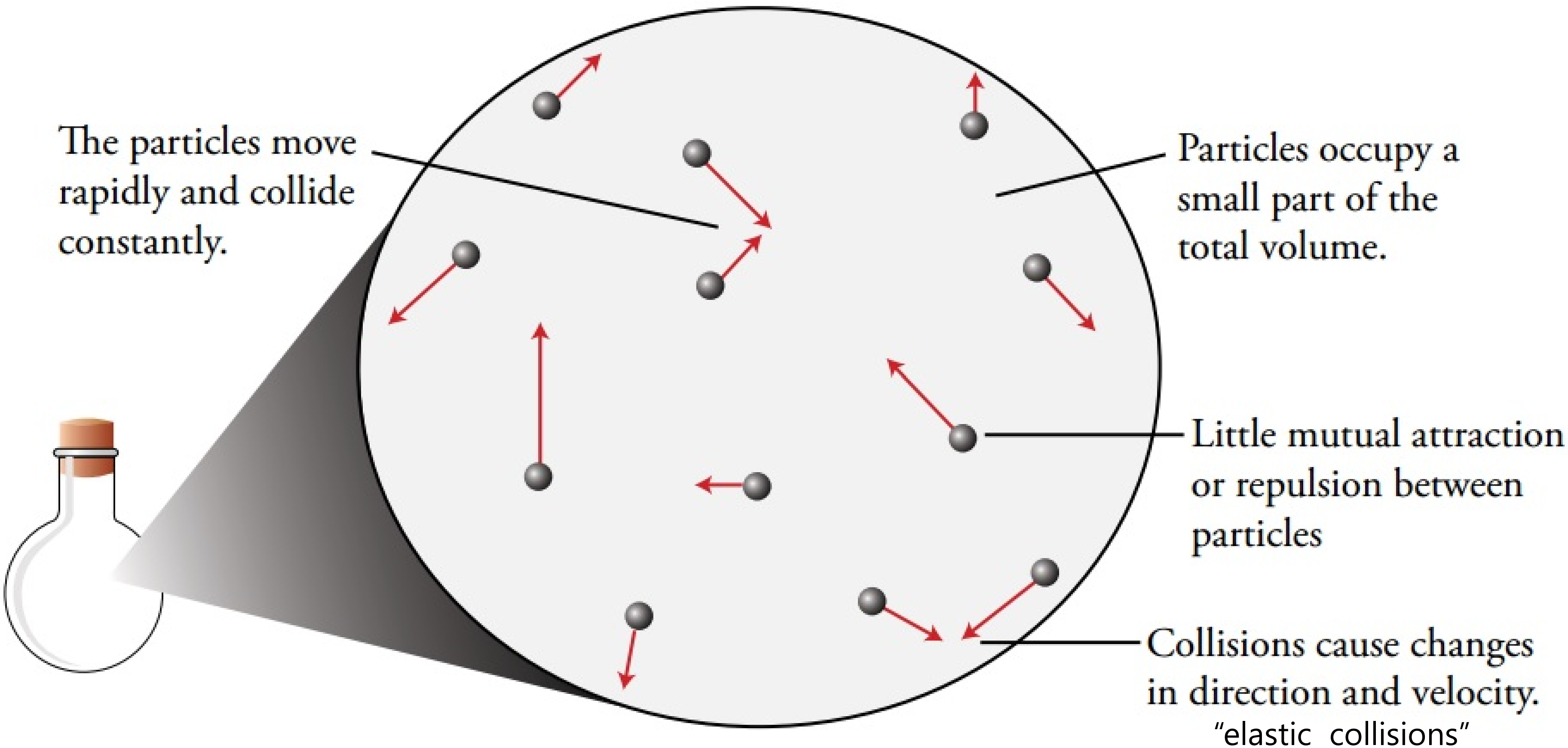
Ideal Gas Law Constant "R"	
Value of R	**Units of R**
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

Ideal Gases vs. Real Gases

<u>Assumptions of an Ideal Gas:</u>

- Gas particles have random, constant motion & travel in straight lines (not curved)
- Gas particles have negligible volume and are separated by large distances.
- There are no attractions between gas particles.
- Energy is transferred between colliding gas particles (an elastic collision)
- A "real gas" behaves most like an "ideal gas" at <u>high</u> temperatures and <u>low</u> pressures.

Ideal Gases vs. Real Gases



Standard Temperature & Pressure (STP)

- 1 atm pressure
- 273 K or 0°C

- *PreIB: you must know this for memory!*

Ideal Gas Law: Animation

- http://www2.biglobe.ne.jp/~norimari/science/JavaApp/Mole/e-gas.html

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- Gen Chem: guided practice- #2 on worksheet
- What pressure in atm is exerted by 0.625 mol of a gas in a 45.4 L container at -24°C?
  - Answer: 0.28 atm

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- Gen Chem: guided practice- #7 on worksheet

- A sample of 124.6 g of Br_2 gas is loaded into a cylinder at 0°C and 1 atm (STP). What is the volume of the cylinder in mL?
  - Answer: 17480 mL

Do Now: Dry Erase board

- Write the equations we have learned so far:
- Boyle's
- Charles'
- Combined
- Dalton

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- Gen Chem: independent practice- #5 on worksheet
- A welder uses a tank of acetylene with a volume of 7500 mL. It is stored at a temperature of 23.2^{o}C and pressure of 7667 kPa. How many moles of acetylene are in the tank?
  - Answer: 23.65 mol

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- PreIB: guided practice- #2 on worksheet
- In a closed system, 56g of fluorine (F_2) at a temperature of 35°C has a pressure of 207.5 kPa. What is the volume of this system in cm^3?
  - Answer: 18140 cm^3

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- PreIB: guided practice- #6 on worksheet
- How many grams of argon would it take to fill a light bulb with a volume of 475 mL at **STP**?
  - *(Hint: look in your notes for the P and T of STP)*
  - *Answer: 0.847 g*

Ideal Gas Law Example

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- PreIB: independent practice- #5 on worksheet
- A 9430 cm^3 car tire is filled with 45 g of O_2. What is the temperature of the tire in ^oC if the pressure becomes 428 kPa?
  - Answer: 71.29^oC

Ideal Gas Law: Do Now

Value of R	Units of R
8.314	$\frac{dm^3 \cdot kPa}{mol \cdot K}$
0.0821	$\frac{dm^3 \cdot atm}{mol \cdot K}$

- A 9430 cm^3 car tire is filled with 45 g of O_2. What is the temperature of the tire in ^oC if the pressure becomes 428 kPa?
  - Answer: 71.29^oC

(see suggestions in summary table for your class)

BE ABLE TO RECOGNIZE ALL 5 GAS LAWS

Gen Chem: {Summary Table}

Equation	Information Given
Boyle's Law	P, V
Charles's Law	V, T
Combined Gas Law	P, V, T
Dalton's Law of Partial Pressures	P (the words "partial pressure" are used)
Ideal Gas Law	P, V, T, **n** (one variable missing) ***if moles/grams is given or asked for, then it is an Ideal Gas Law problem***

PreIB: {Summary Table}

Equation	Information Given	Info NOT provided, or held constant
Boyle's Law	P, V	T, n
Charles's Law	V, T	P, n
Combined Gas Law	P, V, T	n
Dalton's Law of Partial Pressures	P (the words "partial pressure" are used)	T, V
Ideal Gas Law	P, V, T, **n** (one variable missing)	***if moles/grams is given or asked for, then it is an Ideal Gas Law problem***

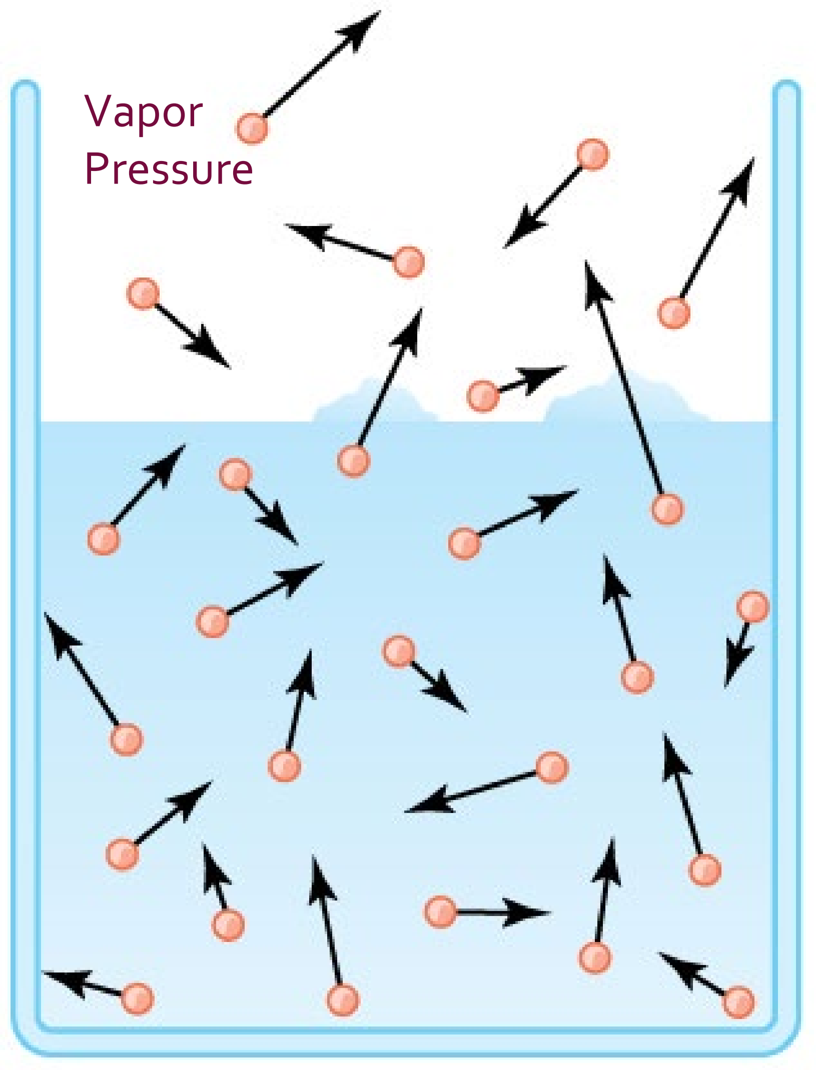
An important part of understanding boiling and solutions (Chapter 15)

VAPOR PRESSURE

Vapor Pressure

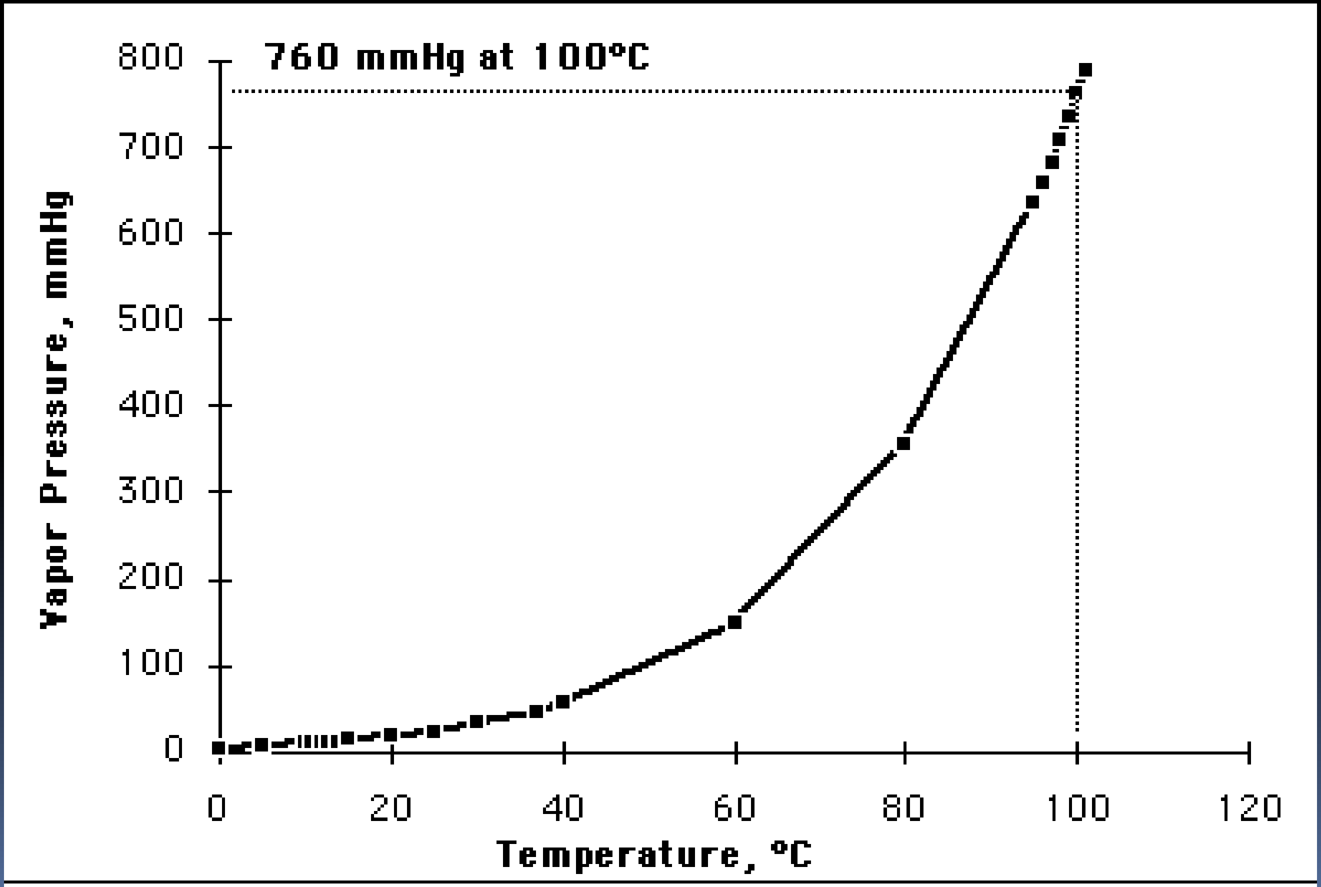
- The pressure exerted by a vapor over a liquid

- A substance boils when its vapor pressure equals atmospheric pressure



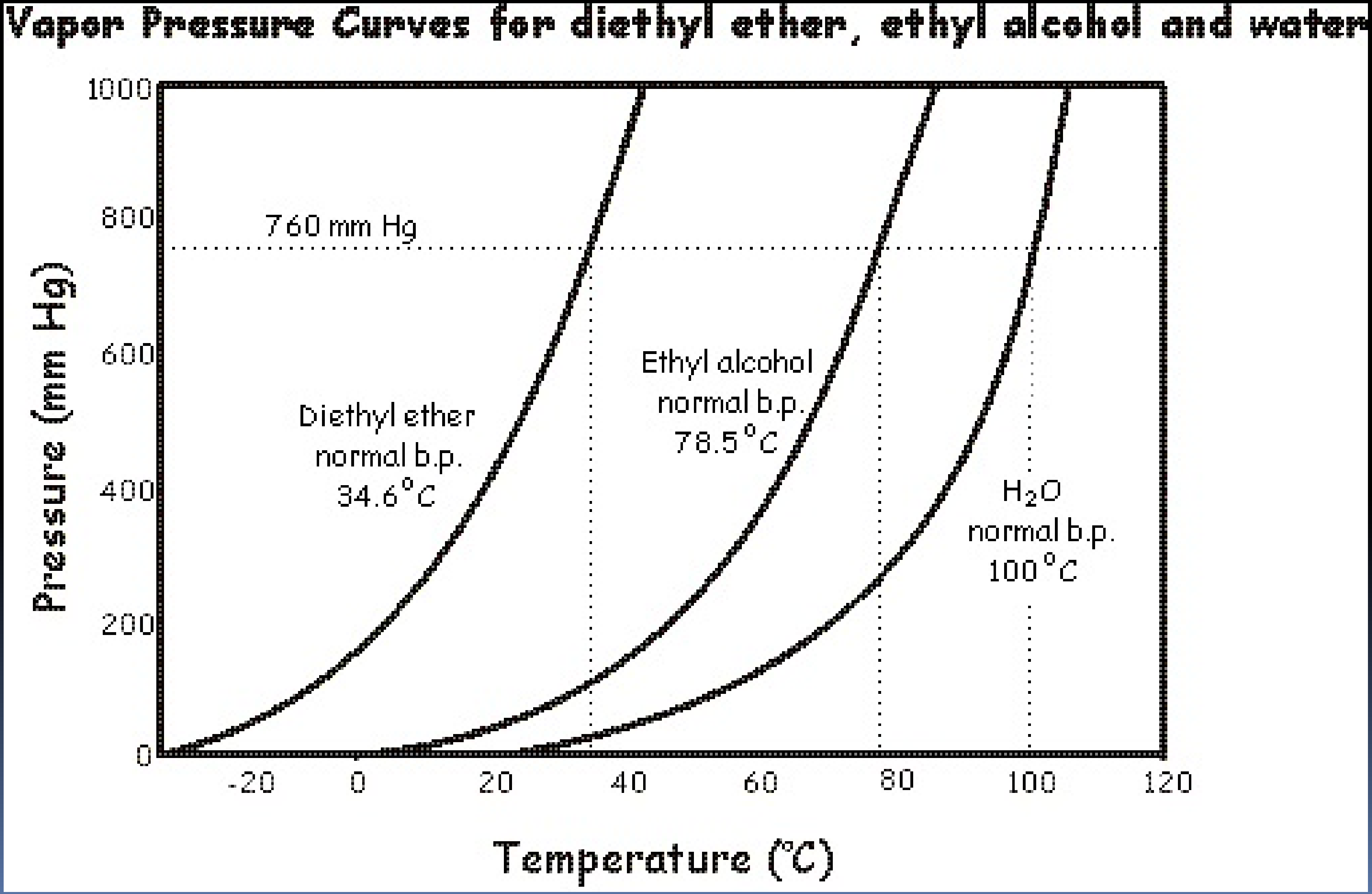
Vapor Pressure of Water

- When the vapor pressure of water reaches atmospheric pressure (760 mmHg at sea level), water boils. The temperature this occurs at is **100°C**.



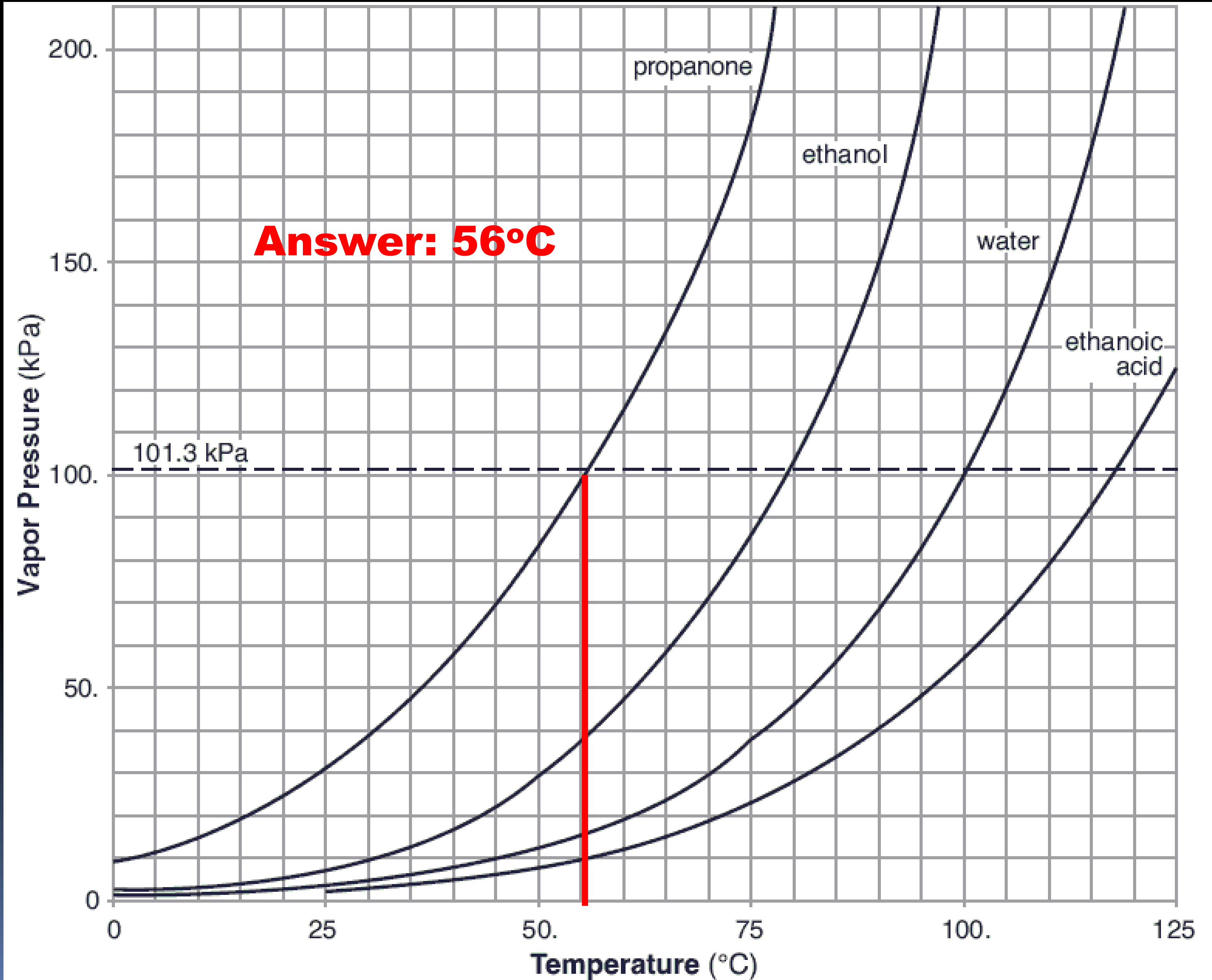
Determine Boiling Point of other liquids

- Look to see at what temperature their vapor pressures are equal to atmospheric pressure.



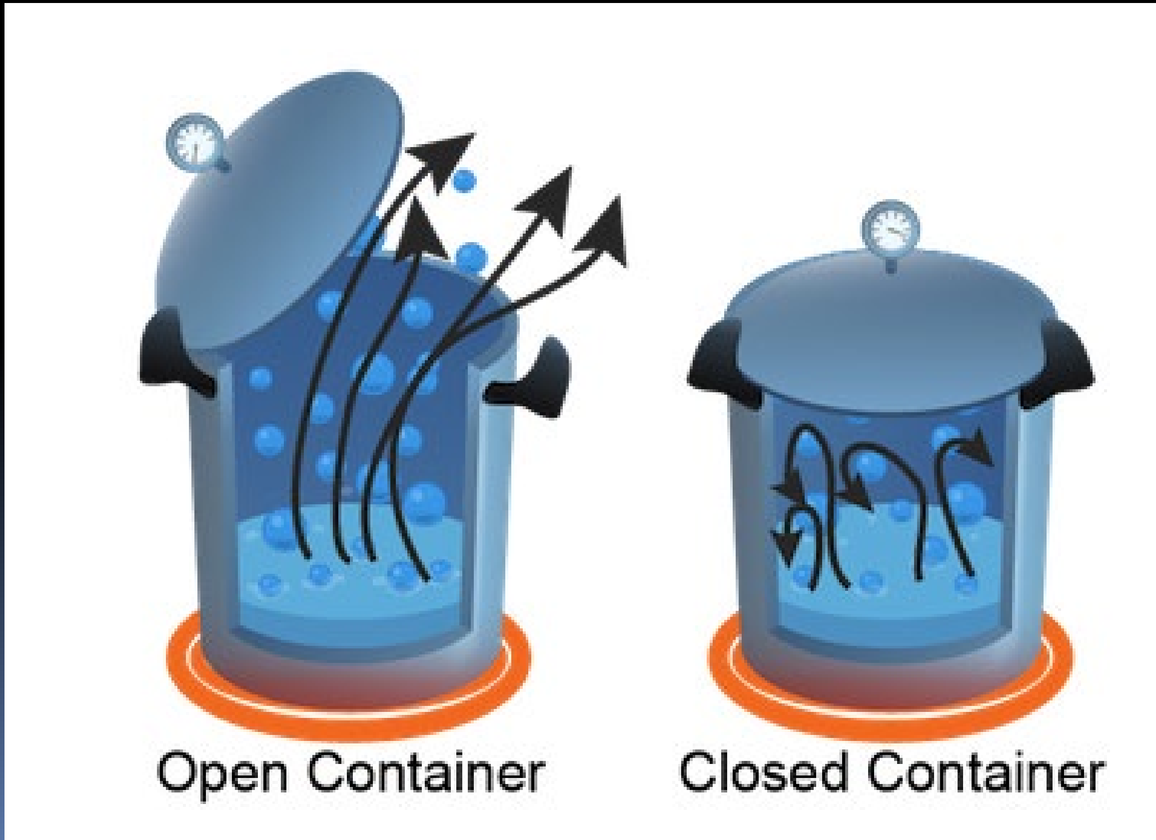
Vapor Pressure Practice

- What is the boiling point of propanone?
  - Atmospheric pressure at sea level is 101.3 kPa



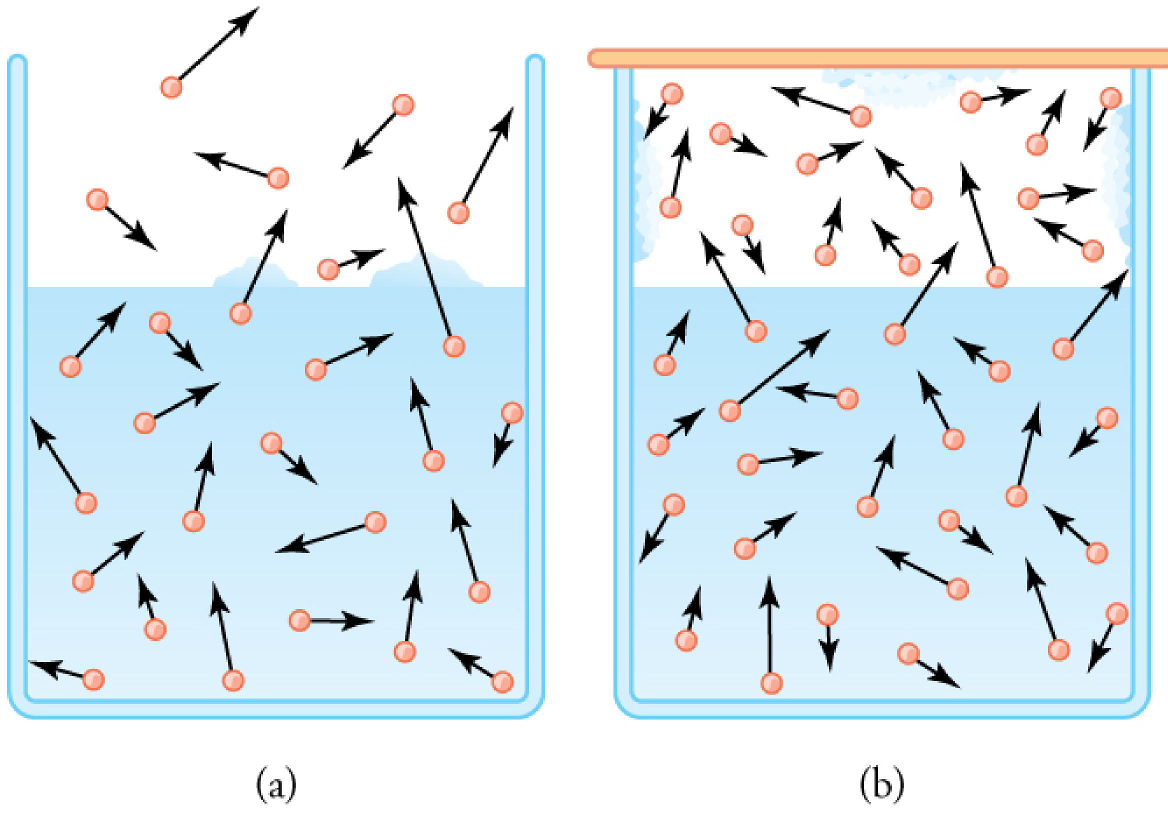
Why does a pot of water boil quicker on the stove when you put a lid on the pot?

Hypothesize: Use your knowledge of vapor pressure & boiling point to make a prediction.



Why does a pot of water boil quicker on the stove when you put a lid on the pot?

- The vapor pressure builds up quickly with the lid on. It can reach atmospheric pressure fast!
  - see beaker B
- Without a lid, it takes longer for the vapor pressure to get large enough to boil.
  - see beaker A



Why do different liquids have different vapor pressures?
…and as a result different boiling points?

INTERMOLECULAR FORCES
(PRE-IB ONLY)

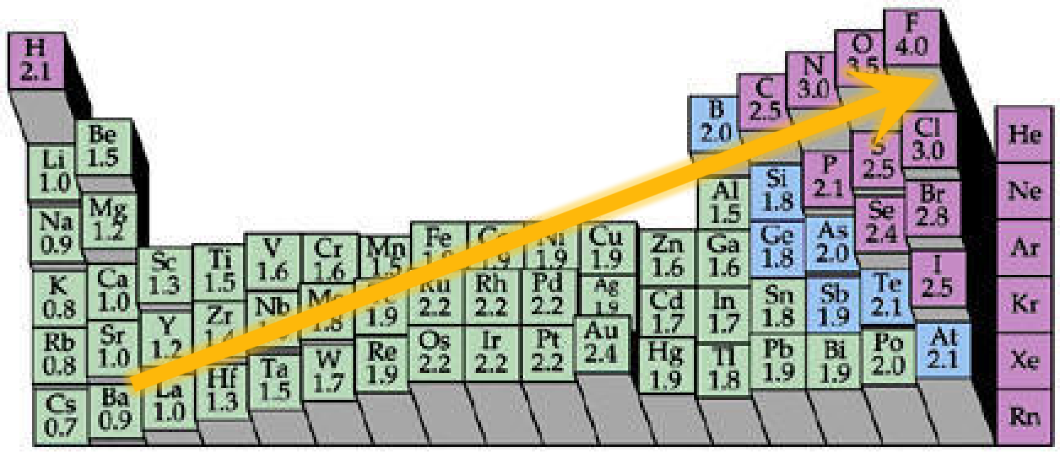
Intermolecular Forces

- Attractions between neighboring molecules
- 3 types:
  1) dipole-dipole
  2) hydrogen bonding
  3) London dispersion forces

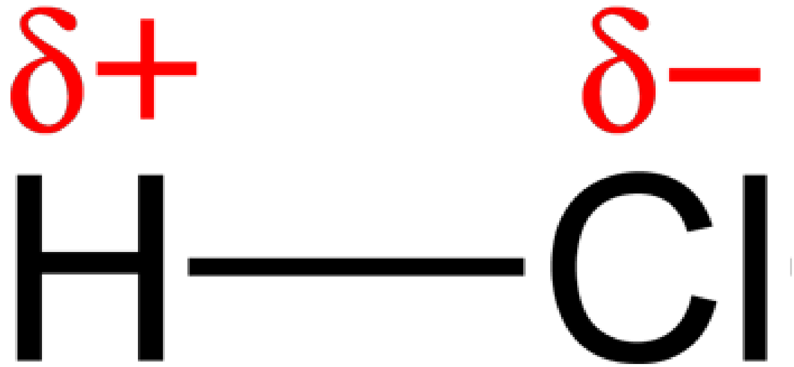
     (AKA: van der Waals forces)

(1) Dipole-dipole attraction

- **Attraction between two *polar* molecules**
- *Review from Chapter 8:*
- Why are molecules polar?
  - We learned rules to determine if a molecule was polar or nonpolar (ex: lone pairs on central atom)
- Because not all atoms share electrons equally in a bond
  - "Electronegativity"

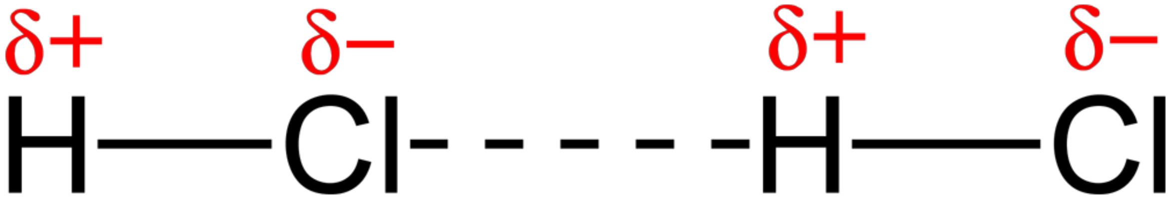


Dipole - Dipole



Explanation: Chlorine is more electronegative than hydrogen. The electrons in the bond are pulled towards chlorine, giving it a partially negative charge. Hydrogen has fewer electrons (because chlorine is pulling them away from hydrogen), giving hydrogen a partially positive charge.

Dipole - Dipole



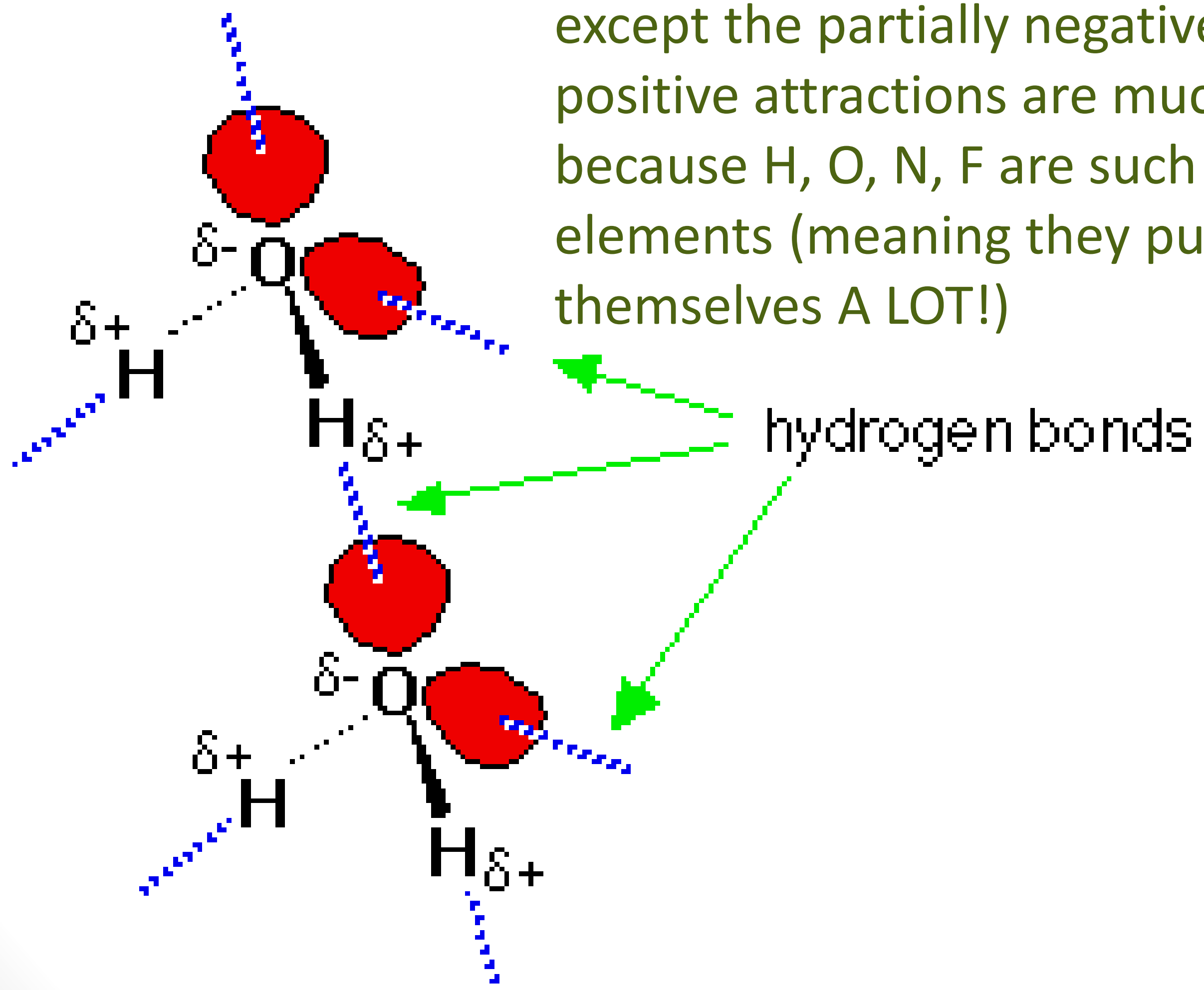
Explanation: The partially negative chlorine is attracted to a partially positive hydrogen in a nearby molecule.

(2) Hydrogen Bonding

- Strongest attraction
- **Between hydrogen and O, N, F**
- It is NOT a real bond
  - It is a magnetic attraction
- ex) surface tension

Hydrogen Bonding

Explanation: Very similar to dipole-dipole, except the partially negative and partially positive attractions are much stronger because H, O, N, F are such electronegative elements (meaning they pull electrons to themselves A LOT!)

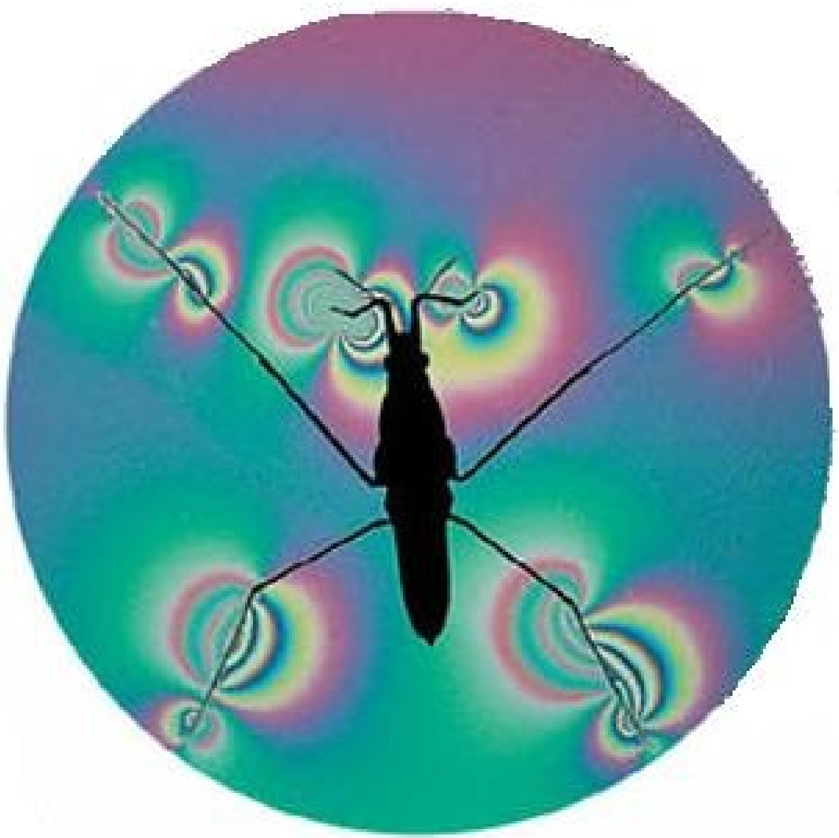


Hydrogen Bonding in H_2O

Explanation: In a glass of water, there is an entire network of hydrogen bonding that occurs between neighboring molecules. This contributes to many of water's unique properties.

Surface Tension

ex) bug walking on water

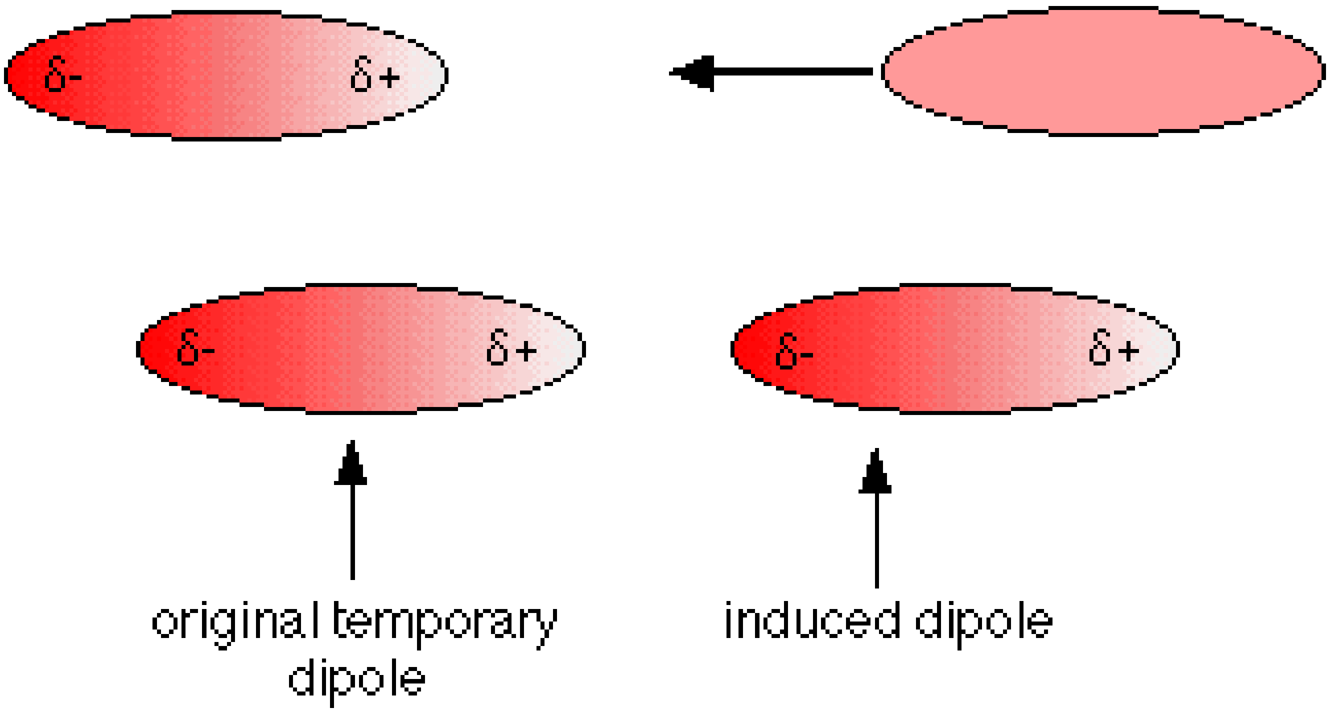


(3) London Dispersion Forces

AKA: "van der Waals Forces"

- A *temporary* dipole
- Weakest attractive force
- **Present in *nonpolar* molecules**

van der Waals Forces
AKA London Dispersion Forces



Explanation: In nonpolar molecules, electrons are unevenly distributed for a split second and a temporary partial charge is created. When a neighboring nonpolar molecule comes closer, the original partial charge "induces" or causes another temporary partial charge for a split second in the neighboring molecule.

Comparing Dipole-Dipole and London Dispersion

- http://chemsite.lsrhs.net/FlashMedia/html/dipoleVsLondon.html
- Explanation of picture on website:
- Notice the temporary nature of London Dispersion
  - It happens for an instants thousands of times
- Dipole-dipole is a permanent attraction between neighboring molecules
  - Not temporary

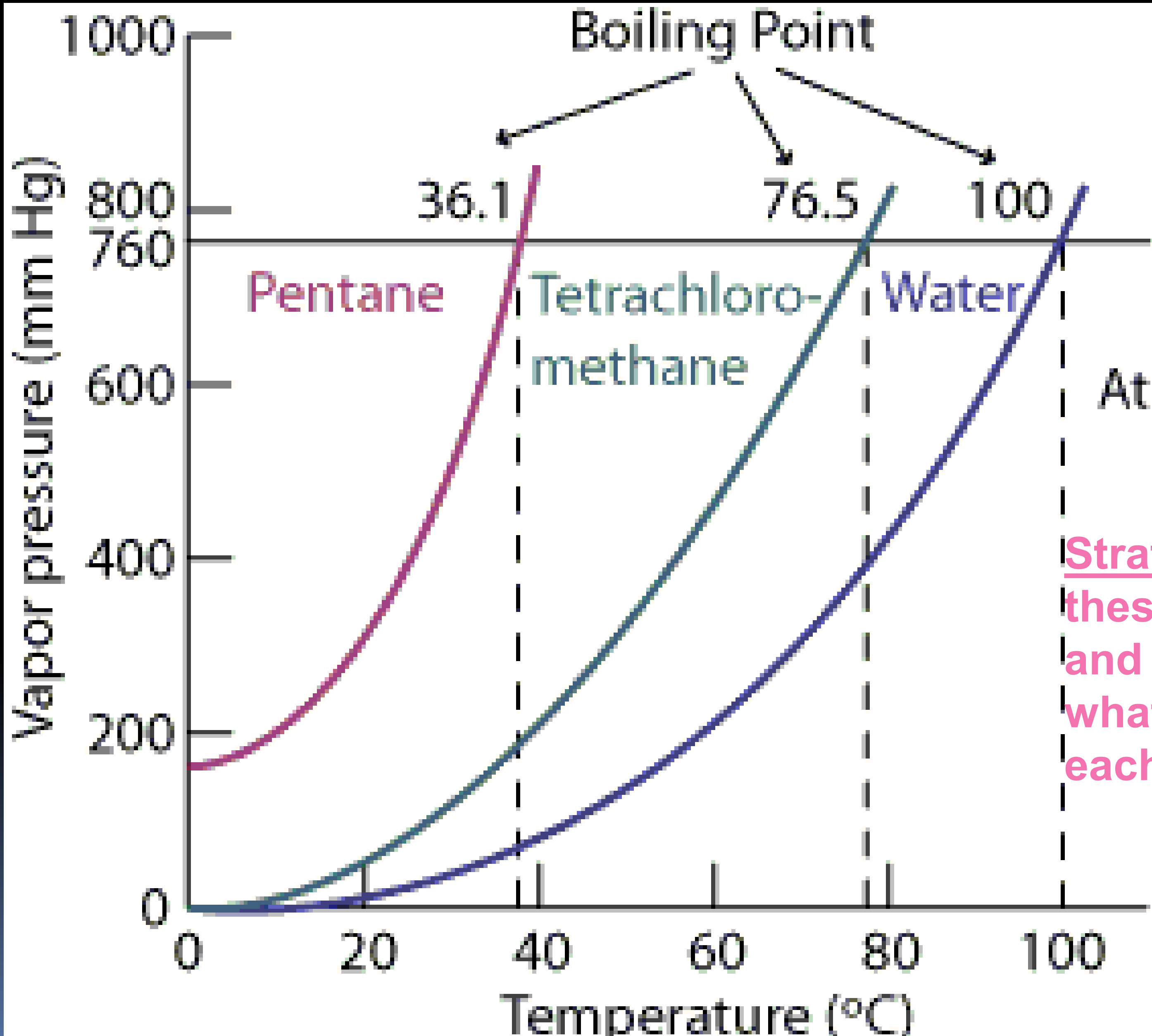
Summary: (copy in your notes!)

weakest attraction ⟶ strongest attraction

Type of Molecule	<u>London dispersion</u>	<u>Dipole-dipole</u>	<u>Hydrogen bond</u>
nonpolar	X		
polar	X	X	
polar with a bond of H to O, N, or F	X	X	X

RELATING INTERMOLECULAR FORCES TO VAPOR PRESSURE

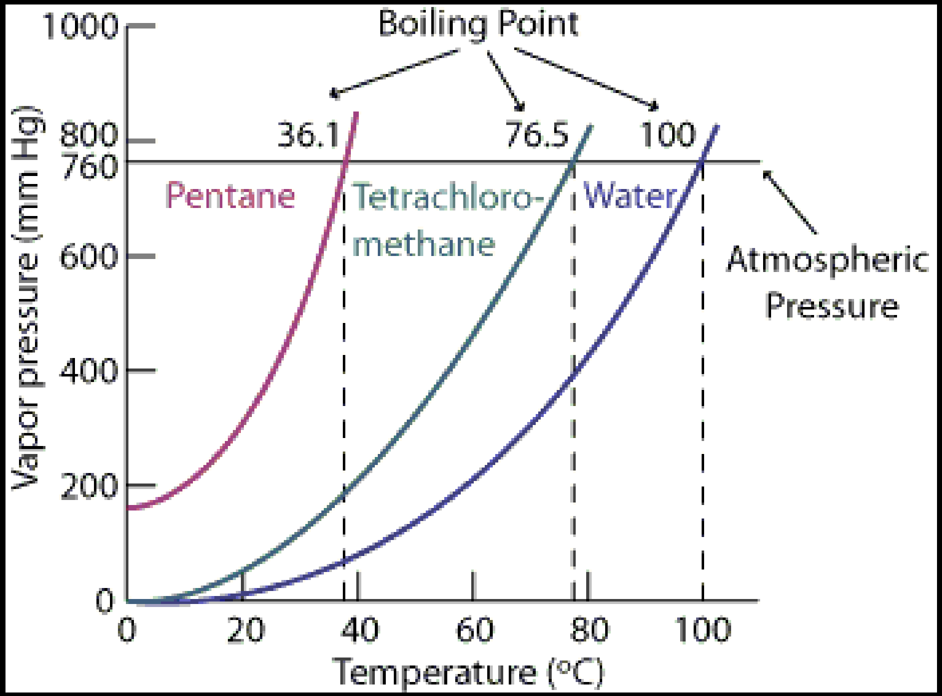
Which liquid has the strongest IMF?



Strategy: Draw these molecules and determine what type of IMF each has.

Which liquid has the strongest IMF?

- Water has the highest boiling point. The water molecules require more energy to “jump” into the gas phase because water has strong hydrogen bonds.



- Tetrachloromethane has only dipole-dipole IMF. It is a little easier for its molecules to transition into the gas phase, and therefore less energy for vapor pressure to equal atmospheric pressure.
- Pentane is nonpolar and only has London dispersion. It requires very little energy for its molecules to “jump” into the gas phase.

Encouragement ☺

- Intermolecular forces is a very difficult concept. Do not be overwhelmed! You will learn much more in IB Chemistry!
- You have done well young padawan. You are on your way to being a Jedi Chemist.