# CHEM 116

## Chemical Principles II
## Intro to Behavior of Gases

Lecture 1
Prof. Sevian

## Birdseye view of Chemical Principles I and II

1. Matter is made of atoms, and atoms are conserved
2. Elements display periodicity
3. Chemical bonds form when electrons pair
4. The shapes and sizes of particles determine the properties of materials
5. The behavior of particles is explained by attractions and repulsions between unlike and like particles, respectively
6. Energy is conserved
7. Entropy tends to increase
8. There are barriers to reaction
9. There are only four types of reactions

See http://www.rsc.org/Education/EiC/issues/2005_jan/skeletal.asp

## Welcome to Chem 116

- Begin with Chapter 10: Gases
  - Describing and characterizing gases
  - Predicting the behavior of gases
  - Useful behaviors of gases
- Begin by comparing three phases of matter

  Phases of matter
  - Solid
  - Liquid
  - Gas

  Describe them.
  - How are they the same?
  - How are they different?
  - What makes them different?

## Characteristics of gases vs. other two phases

| Macroscopic observations | |
|---|---|
| **Gases** | **Liquids and/or solids** |
| • Very compressible<br>• Spread out to occupy all the space given in a container<br>• Low density | • Not (very) compressible<br>• Occupy specific volumes, regardless of the container<br>• High density |
| **Particle level explanation** | |
| • Particles are far apart<br>• Particles are in rapid motion (kinetic energy) | • Particles are much closer together<br>• Particles have less kinetic energy than in gases |

1. **Gases are compressible because the particles are widely separated.**
2. **Gases immediately fill all available space because the particles are in ceaseless chaotic and rapid motion.**

## Conceptualizing gases

We often play with gases in syringes. Syringe parts:

- barrel
- tip
- plunger

Imagine YOU are a gas particle. You are going to be placed in a syringe with about 100 billion trillion other gas particles. How can we describe your *behavior* as a gas particle?


Image from www.vetmed.wsu.edu/ ClientED/dog_fluids.asp

## How gas particles behave

How you will behave when you are impersonating a gas particle

- ***You are very small***
  - So small that the sum of the volumes of all of the individual gas particles (you and your friends all squished up into a corner together) is negligible compared to the volume that you and the other gas particles occupy.
  - The gas is mostly empty space.
- ***When you move, you fly in straight line paths.***
  - You only change direction if you collide with another particle or bounce off a wall.
  - When you collide with something, you bounce off it elastically.
  - During a collision with another particle, the law of conservation of energy always means that the total energy of you and the other particle before the collision is equal to the total energy of you and the other particle after the collision, though one of you may speed up afterward and the other may slow down.*
- ***Temperature is a measure of the average kinetic energy*** of the all of the gas particles (remember that kinetic energy is related to motion).
  - Some of you may move a little faster than the average and others may move a little slower.
  - The average of the distribution of speeds tells about the overall temperature of the gas.

* This assumption dictates that energy remains stuck in your walking speed - energy cannot be transferred into other places in you, such as making your arms start wiggling or making your hair stand on end or making you dance and do spins while you are walking along in straight lines.

## Conceptualizing gases:
## Some thought experiments assisted by animation

- Animation
  - http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm
- To do the thought experiments, we are going to need to define 4 things that can be measured for gases

| Variable | Meaning in the animation | Meaning in the gas law model |
|---|---|---|
| Number of particles (*N*) | | |
| Volume (*V*) | | |
| Temperature (*T*) | | |
| Pressure (*P*) | | |

## Conceptualizing gases:
## Some thought experiments assisted by animation

- Animation
  - http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm
- **Thought experiment #1**
  - Fix the temperature and volume
  - Add particles
  - What happens to pressure?
  - What would happen to the pressure if you took away particles instead?

*1)*

- **Thought experiment #2**
  - Fix the number of particles and the volume
  - Increase the temperature
  - What happens to pressure?
  - What would happen to pressure if you decreased the temperature instead?

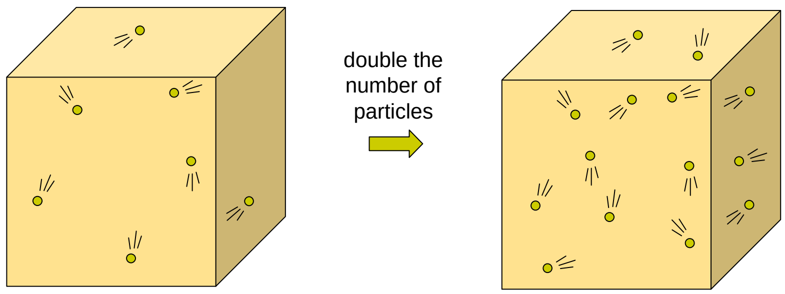
*2)*

- **Thought experiment #3**
  - Fix the temperature and number of particles
  - Decrease the volume
  - What happens to pressure?
  - What would happen to pressure if you increased the volume instead?

*3)*

# Thought Experiment #1 = Avogadro's law

- You have a container with some amount of gas in it.
- The volume (*V*) and the temperature (*T*) remain the same (constant).
- You double the number of particles (*N*) in the container.
- The variable that responds is ___________. What does it do? ________



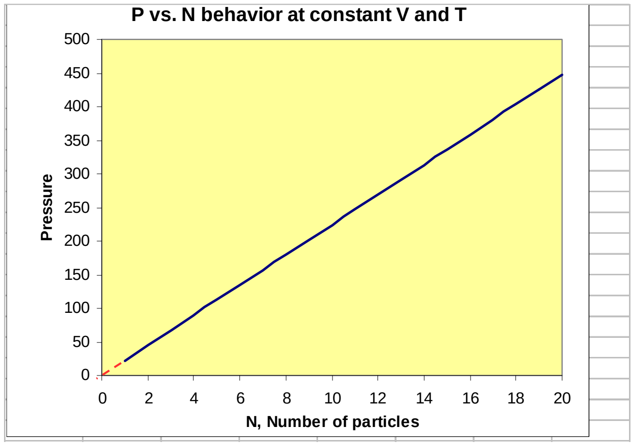

# Avogadro's law

- *When the volume and temperature of gas particles remain constant, the pressure is proportional to the number of particles.*

$$P \propto N$$

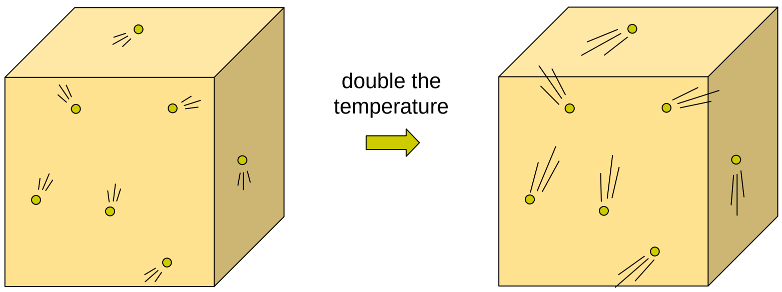
$$\frac{P}{N} = \text{constant}$$

$$\frac{P_1}{N_1} = \frac{P_2}{N_2}$$



## Thought Experiment #2 = Gay-Lussac's law

- You have a container with some amount of gas in it.
- The volume (*V*) and the number of particles (*N*) remain the same (constant).
- You double the temperature (*T*) in the container.
- The variable that responds is _______. What does it do? ________



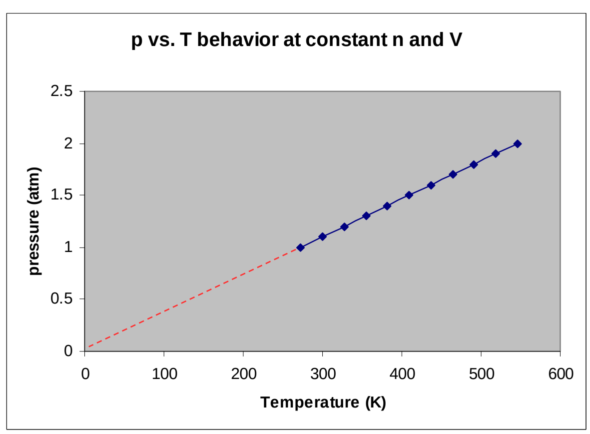

## Gay-Lussac's law

- *When the number of gas particles (N) and the volume remain constant, the pressure is proportional to the temperature.*

$$P \propto T$$

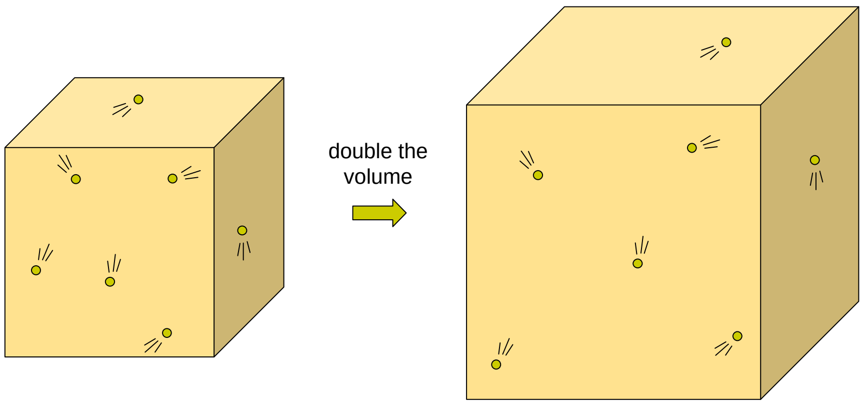
$$\frac{p}{T} = \text{constant}$$

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



## Thought Experiment #3 = Boyle's law

- You have a container with some amount of gas in it.
- The temperature (*T*) and the number of particles (*N*) remain the same (constant).
- You double the size of the container (*V*).
- The variable that responds is __________. What does it do? _______



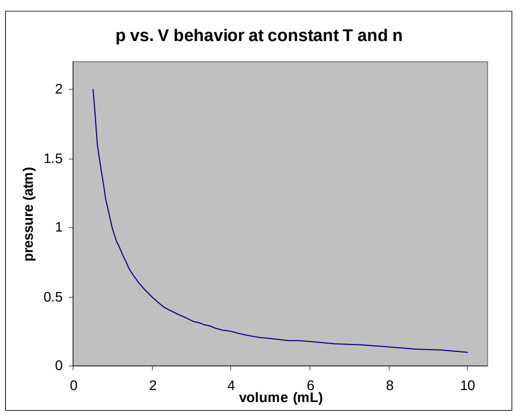

## Boyle's law

- At constant temperature (*T*) and number of particles (*N* or *n*), the volume (*V*) and pressure (*P*) of a gas are inversely related.

$$P \propto \frac{1}{V} \quad \textbf{and} \quad V \propto \frac{1}{P}$$

$$PV = \text{constant}$$

$$P_1V_1 = P_2V_2$$



## Putting them together

*1) P* goes up as *N* goes up
*P* is proportional to *N*
$P \propto N$

*2) P* goes up as *T* goes up
*P* is proportional to *T*
$P \propto T$

*3) P* goes up as *V* goes down
*P* is inversely proportional to *V*
$P \propto 1/V$

$$P \propto \overset{\#1}{(N)}\overset{\#2}{(T)}\overset{\#3}{(1/V)}$$

$$P \propto \frac{NT}{V}$$

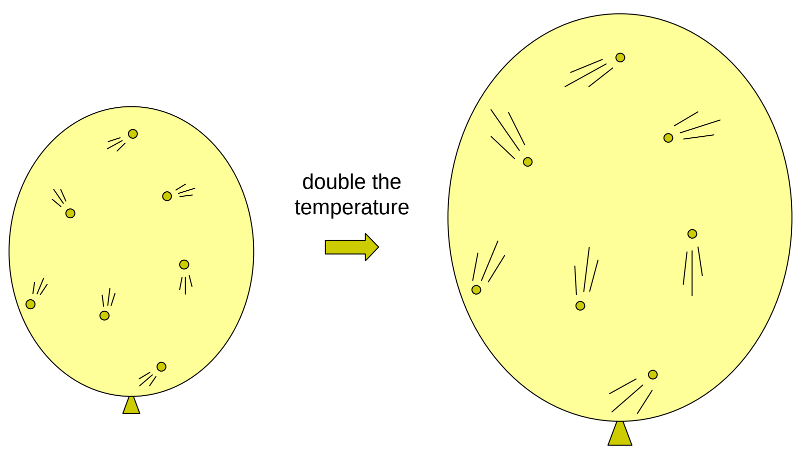
$$P = (constant)\frac{NT}{V} = (k_B)\frac{NT}{V} = \frac{Nk_BT}{V}$$

$$= \frac{\left(\frac{N}{N_A}\right)(k_BN_A)T}{V} = \frac{nRT}{V}$$

$$P = \frac{nRT}{V} \Longrightarrow \boxed{PV = nRT}$$

## One other "law" you should know: Charles' law

- What if you had a balloon (closed system, so *N* is constant) in a room (*P* is constant), and suddenly you doubled the temperature (*T*)?
- The variable that responds is _________. What does it do? _________



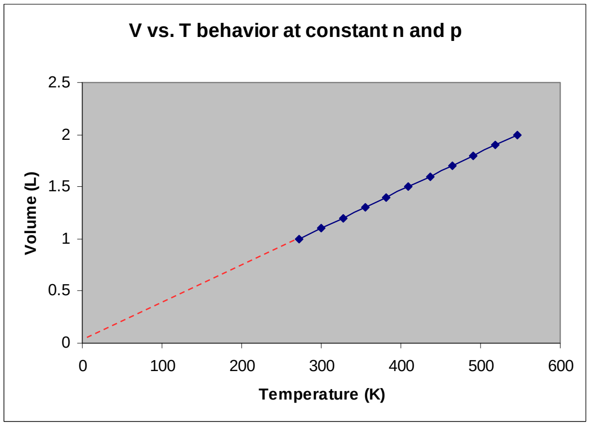
## Charles' law

- *When the number of gas particles and the pressure remain constant, the volume is proportional to the temperature.*

$$V \propto T$$

$$\frac{V}{T} = \text{constant}$$

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




## Variables that describe a gas

- Number of particles
  - Quantity: ***n*** (moles)
  - Can be converted from/to mass (grams)
- Volume (space) that the gas occupies
  - Three dimensional space: ***V*** (liters)
  - Could be given in other units: mL, $m^3$, $cm^3$
- Temperature
  - A measure of the motion of particles: ***T*** (degrees Kelvin)
  - Could be given in other units: ºC
- Pressure
  - Force per unit area: ***P*** (atm)
  - Also used in other units: kPa, Pa, mmHg, torr

## Summary of the gas laws

| Name | What's held constant | What is varied | What changes as a result | Equation |
|---|---|---|---|---|
| Avogadro | *V, T* | *n* | *P* | $\frac{P}{n} = \text{constant}$ |
| Boyle | *n, T* | *V* | *P* | $PV = \text{constant}$ |
| Charles | *n, P* | *T* | *V* | $\frac{V}{T} = \text{constant}$ |
| Gay-Lussac | *n, V* | *T* | *P* | $\frac{P}{T} = \text{constant}$ |

## Where does this lead?
## Combined gas law

$$\left.\begin{array}{l} \frac{n}{V} = \text{constant} \\ pV = \text{constant} \\ \frac{V}{T} = \text{constant} \\ \frac{p}{T} = \text{constant} \end{array}\right\} \quad \frac{pV}{nT} = \text{constant} = R$$

## Gas constant

$$R = \begin{cases} 8.206\times10^{-2}\,\dfrac{L\bullet atm}{mol\bullet K} \\[2ex] 8.314\,\dfrac{L\bullet kPa}{mol\bullet K} \\[2ex] 8.314\,\dfrac{J}{mol\bullet K} \\[2ex] 62.364\,\dfrac{L\bullet torr}{mol\bullet K} \end{cases}$$

## Ideal gas law

- There is no such thing as an ideal gas
- An ideal gas is a pretend gas

$$pV = nRT$$

# Balloons filled with different gases

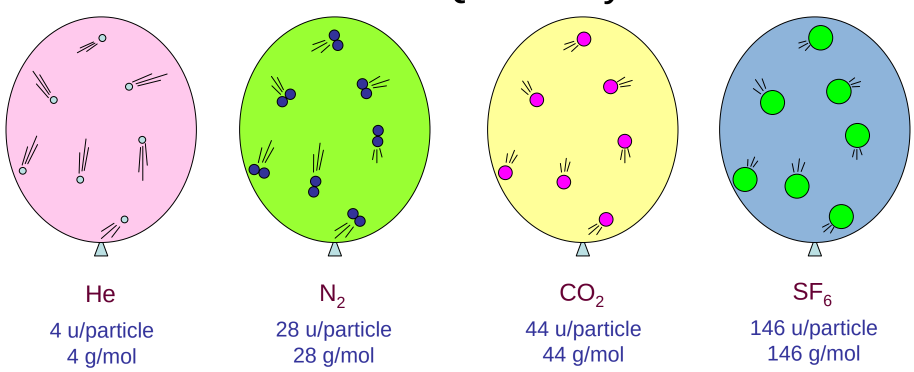
All four balloons have equal volume and are in the same room, so they have the same temperature and pressure.

- He = 4 g/mol
- $CO_2$ = 44 g/mol
- $SF_6$ = 136 g/mol
- $N_2$ = 28 g/mol

Describe them.

- How are they the same?
- How are they different?
- What makes them different?

## Balloon Quandary




- All four balloons have the same volume and temperature, and are under the same conditions of pressure.
- Assume the temperature is $T$ = 298 K, the volume is $V$ = 2.00 L, and the pressure is $p$ = 1.00 atm. The value of $R$ to use is 0.08206 L·atm/mol·K.
  - How many moles ($n$) of He are in the He balloon?
  - How many moles ($n$) of $N_2$ are in the $N_2$ balloon?
  - How many moles ($n$) of $CO_2$ are in the $CO_2$ balloon?
  - How many moles ($n$) of $SF_6$ are in the $SF_6$ balloon?