Gas Laws

For CHM1020

PROPERTIES OF GASES

1. **Variable shape and volume** (same shape and volume as container)
2. **Expand uniformly** (as container increases in volume, gas expands and distributes uniformly in container)
3. **Compress uniformly** (as container decreases in volume, gas compresses, molecules are closer together - if volume is reduced sufficiently a gas will liquefy)
4. **Low density** (density of air is 1 g/L, density of water is 1g/mL so water is 1000x more dense than air)
5. **Mix uniformly with other gases**

ATMOSPHERIC PRESSURE

Gas pressure is the result of constantly moving molecules striking the inside surface of their container.

1. If molecules collide more often, pressure ↑
2. If molecules collide with more energy, pressure ↑
3. If temp ↑, molecules move faster and collide more frequently with more energy, therefore pressure ↑

↑ temp = ↑ pressure
↓ temp = ↓ pressure

UNIT	Standard Pressure
atmosphere	1 atm (exactly)
inches of mercury	29.9 in Hg
centimeters of mercury	76 cm Hg (exactly)
millimeters of mercury	760 mmHg (exactly)
torr	760 torr (exactly)
pounds per square inch	14.7 psi
kilopascal	101 kPa

EXAMPLES *(gas pressure unit conversion)*

1. Given that air pressure inside an automobile tire is 34.0 psi, express pressure in each of the following units:
   a. atm
   $$34.0\ psi \times \frac{1\ atm}{14.7\ psi} = 2.31\ atm$$
   b. cm Hg
   $$34.0\ psi \times \frac{76\ cm\ Hg}{14.7\ psi} = 176\ cm\ Hg$$
   c. torr
   $$34.0\ psi \times \frac{760\ torr}{14.7\ psi} = 1758\ torr$$
   d. kPa
   $$34.0\ psi \times \frac{101\ kPa}{14.7\ psi} = 234\ kPa$$

2. Which of the following is the greatest gas pressure: 1 atm, 1 in Hg, 1 torr, 1 cm Hg, 1 mmHg, or 1 psi?
   The atm is the largest unit, so 1 atm is the greatest gas pressure from this list. You can check this my converting all units to atm, and see that all others are smaller than 1 atm.

GAS PRESSURE CHANGES

1. Pressure is inversely related to the volume

   ↑ volume = ↓ pressure

   ↓ volume = ↑ pressure

2. ↑ temp = ↑ pressure (faster movement)
   ↓ temp = ↓ pressure (slower movement)

   Can be explained by collision and movement

3. Pressure is directly related to the # of moles of gas or number of gas molecules
   # gas molecules ↑, then pressure ↑

EXAMPLES *(gas pressure changes)*

1. State whether pressure of a gas in a sealed container increases or decreases with each change:
   a. Volume – 250mL to 500mL *(decreases according to #1)*
   b. Temp – 20°C to ⁻ 80°C *(decreases according to #2)*
   c. Moles of gas change from 1 mol to 1.5 mol *(increases according to #3)*

2. Which of the following <u>decreases</u> gas pressure?
   a. increase volume *(yes, according to #1)*
   b. increase temp *(no, according to #2, gas pressure would increase)*
   c. increase molecules *(no, according to #3, gas pressure would increase)*

BOYLES LAW (Pressure-Volume Relationships)

Pressure ↑, Volume ↓

$P_1V_1 = K = P_2V_2$

EXAMPLES *(using Boyle's Law)*

1. 5.00 L of propane gas is compressed and pressure increases from 1.00 atm to 1.50 atm. What is the new volume?
   Step 1: Define your variables from the given information.
   P_1 = 1.00 atm, P_2 = 1.50 atm, V_1 = 5.00 L, V_2 = ?
   Step 2: Rearrange $P_1V_1=P_2V_2$ to solve for V_2.
   Divide both sides by P_2 to obtain: $V_2 = \frac{P_1V_1}{P_2}$
   Step 3: Substitute givens into the equation for the appropriate variables and solve.
   $$V_2 = \frac{1\ atm \times 5.0\ L}{1.5\ atm} = 3.33\ L$$

2. Ethane gas has a volume of 125mL at 20° C and 725 torr. What is the volume of gas when pressure decreases to 475 torr?
   Step 1: Define your variables from the given information.
   P_1 = 725 torr, P_2 = 475 torr, V_1 = 125 mL, V_2 = ?
   Step 2: Rearrange $P_1V_1=P_2V_2$ to solve for V_2.
   Divide both sides by P_2 to obtain: $V_2 = \frac{P_1V_1}{P_2}$
   Step 3: Substitute givens into the equation for the appropriate variables and solve.
   $$V_2 = \frac{725\ torr \times 125\ mL}{475\ torr} = 191\ mL$$

CHARLES'S LAW (Volume-Temperature Relationships)

Volume can be listed in any unit, temperature MUST be in Kelvin.

Volume of gas is directly proportional to the Kelvin temperature if pressure remains constant.

Celsius to Kelvin Conversion:
__° C + 273

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

EXAMPLE *(using Charles's Law)*

A krypton balloon has a volume of 555mL at 21°C. If the balloon is cooled and the volume decreases to 475mL, what is the final temperature? (Pressure remains constant).

Step 1: Define your variables using the given information.

$V_1 = 555\ mL,\ T_1 = 21°C,\ V_2 = 475\ mL,\ T_2 = ?$

Step 2: Change temperature units to Kelvin.

$T_1 = 21°C + 273 = 294\ K$

Step 3: Rearrange $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ to solve for T_2.

Crossmultiply to get: $V_1 T_2 = V_2 T_1$

Divide both sides by V_1: $T_2 = \frac{V_2 T_1}{V_1}$

Step 4: Substitute givens into the equation for the appropriate variables and solve.

$$T_2 = \frac{475mL \times 294\ K}{555\ mL} = 252\ K$$

Step 5: Convert back to original temperature units (°C).

$T_2 = 252\ K - 273 = -21°C$

Kelvin to Celcius Conversion:
__K - 273

GAY- LUSSAC'S LAW (Pressure-Temperature Relationships)

Volume constant, ↑ pressure ↑ temperature

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

*Temperature must be in Kelvin

EXAMPLE *(using Guy-Lussac's Law)*

A copper container has a volume of 555mL and is filled with air at 25°C. The container is then immersed in dry ice and the pressure drops from 761 torr to 495 torr. What is the final temp of the air in the copper container?

Step 1: Define your variables using the given information.

P_1 = 761 torr, T_1 = 25°C, P_2 = 495 torr, T_2 = ?

Step 2: Change temperature units to Kelvin.

T_1 = 25°C + 273 = 298 K

Step 3: Rearrange $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ to solve for T_2.

Crossmultiply to get: $P_1T_2 = P_2T_1$

Divide both sides by P_1: $T_2 = \frac{P_2T_1}{P_1}$

Step 4: Substitute givens into the equation for the appropriate variables and solve.

$$T_2 = \frac{495\ torr \times 298\ K}{761\ torr} = 194\ K$$

Step 5: Convert back to original temperature units (°C).

T_2 = 194 K - 273 = -79°C

COMBINED GAS LAW

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

STP = 273 K/0°C, 1 atm/760mm Hg/760 torr/76cm Hg

*Temperature must be in Kelvin

EXAMPLE *(using Combined Gas Law)*

An oxygen gas sample occupies 50 mL at 27°C and 765 mm Hg. What is the final temperature if the gas is cooled to a volume of 35.5 mL and a pressure of 455 mm Hg?

Step 1: Fill in the table to help solve.

	Pressure	**Volume**	**Temperature**
Initial	*765 mm Hg*	*50 mL*	*27°C = 300 K*
Final	*455 mm Hg*	*35.5 mL*	*?*

Step 2: Rearrange the equation to solve for T2.

$$T_2 = \frac{T_1P_2V_2}{P_1V_1}$$

Step 3: Substitute the values from the table into the rearranged equation.

$$T_2 = \frac{300\ K\ \times 455\ mm\ Hg\ \times 35.5\ mL}{765\ mm\ Hg\ \times 50\ mL} = 127\ K = -146°\text{C}$$

DALTON'S LAW OF PARTIAL PRESSURES

Total pressure of gas mixture = sum of the individual pressures of each gas

Pressure of each gas in a mixture is partial pressure

Sum of individual partial pressures = Total atmospheric pressure

EXAMPLE *(using Dalton's Law of Partial Pressures)*

An atmospheric sample contains nitrogen, oxygen, argon, and trace gases. If the partial pressure of nitrogen is 592 mm Hg, oxygen is 160 mm Hg, argon is 7 mm Hg and trace gas is 1 mm Hg, what is the atmospheric pressure?

$P_{total} = P_{nitrogen} + P_{oxygen} + P_{argon} + P_{trace} = 592 + 160 + 7 + 1 = 760$ *mm Hg*

IDEAL GAS LAW

PV = nRT

Pressure (atm)

Volume (L)

Moles of gas

Ideal gas constant, 0.0821 L*atm/mol K

Temperature (Kelvin)

Summarizes the behavior of gases

EXAMPLE *(using Ideal Gas Law)*

What is the temperature of 0.250 mol of chlorine gas at 655 torr if the volume is equal to 3.5 L?

Step 1: Identify givens.

P = 655 torr (need in atm to use formula), $655\ torr\ \times \frac{1\ atm}{760\ torr} = .862\ atm$

V = 3.5 L

n = 0.250 mol

*R = 0.0821 L*atm/mol K*

T = ?

Step 2: Rewrite formula to solve for unknown.

$$T = \frac{PV}{nR}$$

Step 3: Plug in givens to rewritten formula and solve.

$$T = \frac{.862\ atm\ \times 3.5\ L}{0.250\ mol\ \times 0.0821\ \frac{L\ atm}{mol\ K}} = 147\ K$$
