A balloon is taken from a room where the temperature is 27.0 C to a freezer where the temperature is -5.0 C. If the balloon has a volume of 3.5 L in the 27.0 C room, what is the volume of the balloon in the freezer. Assume pressure is constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

($P$ constant)

$V_1 = 3.5\,L$

$T_1 = 27.0°C = 300.2\,K$

$V_2 = ?$

$T_2 = -5.0°C = 268.2\,K$

$$\frac{3.5\,L}{300.2\,K} = \frac{V_2}{268.2\,K}$$

$$\boxed{3.1\,L} = V_2$$

2.25 L of nitrogen gas is trapped in a piston at 25.0 C and 1.00 atm pressure. If the piston is pushed in so that the gas's volume is 1.00 L while the temperature increases to 31.0 C, what is the pressure of the gas in the piston?

$P_1 = 1.00\,atm$ $\quad P_2 = ?$

$V_1 = 2.25\,L$ $\quad V_2 = 1.00\,L$

$T_1 = 25.0°C = 298.2\,K$ $\quad T_2 = 31.0°C = 304.2\,K$

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

$$\frac{(1.00\,atm)(2.25\,L)}{298.2\,K} = \frac{P_2(1.00\,L)}{304.2\,K}$$

$$\boxed{2.30\,atm} = P_2$$

Calculate the mass of 22650* L of oxygen gas at 25.0 C and 1.18 atm pressure.

$O_2$

*Volume of a 10'x10'x8' room

$O_2$: 32.00 g $O_2$ = mol $O_2$

1 - Calculate the moles of oxygen gas using the ideal gas equation, PV=nRT
2 - Convert the moles of oxygen gas to mass using FORMULA WEIGHT.

① $PV = nRT$

$n = \frac{PV}{RT}$

$P = 1.18$ atm

$V = 22650$ L

$R = 0.08206 \frac{L\text{-}atm}{mol \cdot K}$

$T = 25.0°C = 298.2$ K

$$n_{O_2} = \frac{(1.18 \text{ atm})(22650 \text{ L})}{(0.08206 \frac{L\text{-}atm}{mol\text{-}K})(298.2 \text{ K})} = 1092.222357 \text{ mol } O_2$$

② 32.00 g $O_2$ = mol $O_2$

$$1092.222357 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{\text{mol } O_2} = \boxed{35000 \text{ g } O_2} = 35.0 \text{ kg } O_2$$

~77 lb

# CHEMICAL CALCULATIONS WITH THE GAS LAWS

$FW_{NaHCO_3} = 84.007\ g/mol$

$$H_2SO_4(aq) + 2NaHCO_3(s) \rightarrow 2H_2O(l) + 2CO_2(g) + Na_2SO_4(aq)$$

Given 25.0 g of sodium bicarbonate and sufficient sulfuric acid, what volume of carbon dioxide gas would be produced at 25.0 C and 0.950 atm pressure?

1 - Convert 25.0 grams sodium bicarbonate to moles. Use FORMULA WEIGHT.
2 - Convert moles sodium bicarbonate to moles carbon dioxide gas. Use CHEMICAL EQUATION
3 - Convert moles carbon dioxide gas to volume. Use IDEAL GAS EQUATION.

① $84.007\ g\ NaHCO_3 = mol\ NaHCO_3$ ② $2\ mol\ NaHCO_3 = 2\ mol\ CO_2$

$$25.0\ g\ NaHCO_3 \times \underbrace{\frac{mol\ NaHCO_3}{84.007\ g\ NaHCO_3}}_{①} \times \underbrace{\frac{2\ mol\ CO_2}{2\ mol\ NaHCO_3}}_{②} = 0.2975942481\ mol\ CO_2$$

③ $PV = nRT$

$V = \dfrac{nRT}{P}$

$n = 0.2975942481\ mol\ CO_2$ $P = 0.950\ atm$

$R = 0.08206\ \dfrac{L\text{-}atm}{mol\text{-}K}$

$T = 25.0°C = 298.2\ K$

$$V = \frac{(0.2975942481\ mol\ CO_2)\left(0.08206\frac{L\text{-}atm}{mol\text{-}K}\right)(298.2\ K)}{0.950\ atm} =$$

$= \boxed{7.67\ L}$ of $CO_2$ at $25.0°C$, $0.950\ atm$

What volume would the gas in the last example problem have at STP?

(0°C, 1 atm)

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

$P_1 = 0.950$ atm

$V_1 = 7.67$ L

$T_1 = 298.2$ K

$P_2 = 1$ atm

$V_2 = ?$

$T_2 = 0°C = 273.2$ K

$$\frac{(0.950 \text{ atm})(7.67 \text{ L})}{298.2 \text{ K}} = \frac{(1 \text{ atm})V_2}{273.2 \text{ K}}$$

$\boxed{6.67 \text{ L at STP}} = V_2$

# REAL GASES

- The empirical gas laws (including the ideal gas equation) do not always apply.

  - The gas laws don't apply in situations where the assumptions made by kinetic theory are not valid.

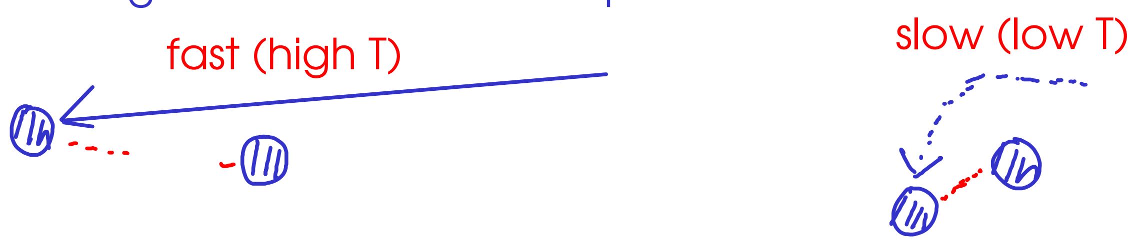
    - When would it be FALSE that the space between gas molecules is much larger than the molecules themselves?

      - at high pressure, molecules would be much closer together!

    - When would it be FALSE that attractive and repulsive forces would be negligible?

      - at high pressure, attractions and repulsions should be stronger!

      - at low temperature, attractions and repulsions have a more significant affect on the paths of molecules




-The gas laws are highly inaccurate near the point where a gas changes to liquid!

- In general, the lower the pressure and the higher the temperature, the more IDEAL a gas behaves.

## van der Waals equation

- an attempt to modify PV = nRT to account for several facts.
  - gas molecules actually have SIZE (they take up space)
  - attractive and repulsive forces

$$PV = nRT$$ Ideal gas equation

$$\left(P + \underbrace{\frac{n^2a}{V^2}}_{\text{attempts to account for attractive / repulsive forces}}\right)\left(V - \underbrace{nb}_{\text{attempts to account for molecular size}}\right) = nRT$$ van der Waals equation

* "a" and "b" are experimentally determined parameters that are different for each gas. p 208

He: $a = 0{,}0346$, $b = 0{,}0238$ tiny, no special attractive forces

$H_2O$: $a = 5.537$, $b = 0.03049$ small, but strong attractions between molecules

$CH_3CH_2OH$: $a = 12.56$ $b = 0{,}08710$ larger, and strong attractions between molecules

$2\bar{5}00$ L of chlorine gas at 25.0 C and 1.00 atm are used to make hydrochloric acid. How many grams of hydrochloric acid could be produced if all the chlorine reacts?

$$H_2 + Cl_2 \rightarrow 2\,HCl$$

1 - Convert 2500 L chlorine gas to moles. Use IDEAL GAS LAW, PV=nRT
2 - Convert moles chlorine gas to moles HCl. Use CHEMICAL EQUATION
3 - Convert moles HCl to mass HCl. Use FORMULA WEIGHT.

1 $PV = nRT$ | $P = 1.00$ atm   $R = 0.08206 \frac{L\cdot atm}{mol\cdot K}$

$n = \frac{PV}{RT}$ | $V = 25\bar{0}0\ L$   $T = 25.0°C = 298.2\ K$

$$n_{Cl_2} = \frac{(1.00\ atm)(25\bar{0}0\ L)}{\left(0.08206\frac{L\cdot atm}{mol\cdot K}\right)(298.2\ K)} = 102.164983\ mol\ Cl_2$$

2 $mol\ Cl_2 = 2\ mol\ HCl$

3 HCl - H: 1 x 1.008
Cl: 1 x 35.45
36.458 g HCl = mol HCl

$$102.164983\ mol\ Cl_2 \times \frac{2\ mol\ HCl}{mol\ Cl_2} \times \frac{36.458\ g\ HCl}{mol\ HCl} = \boxed{7450\ g\ HCl}$$

$$2\,HCl + Na_2CO_3 \rightarrow CO_2 + H_2O + 2\,NaCl$$

If 48.90 mL of 0.250 M HCl solution reacts with sodium carbonate to produce 50.0 mL of carbon dioxide gas at 290.2 K, what is the pressure of the carbon dioxide gas?

1 - Convert 48.90 mL of 0.250 M HCl to moles. Use MOLARITY.
2 - Convert moles HCl to moles carbon dioxide gas. Use CHEMICAL EQUATION.
3 - Convert moles carbon dioxide gas to pressure. Use IDEAL GAS LAW

(1) $0.250\ mol\ HCl = L$ $\quad mL = 10^{-3}\,L$ $\quad$ (2) $2\ mol\ HCl = mol\ CO_2$

$$48.90\ mL \times \frac{10^{-3}\,L}{mL} \times \frac{0.250\ mol\ HCl}{L} \times \frac{mol\ CO_2}{2\ mol\ HCl} = 0.0061125\ mol\ CO_2$$

(1) (2)

(3) $PV = nRT$

$$P = \frac{nRT}{V}$$

$n = 0.0061125\ mol\ CO_2$ $\quad T = 290.2\,K$

$R = 0.08206\ \frac{L\cdot atm}{mol\cdot K}$ $\quad V = 50.0\ mL = 0.0500\ L$

$$P = \frac{(0.0061125\ mol\ CO_2)\left(0.08206\ \frac{L\cdot atm}{mol\cdot K}\right)(290.2\ K)}{0.0500\ L}$$

$$= \boxed{2.91\ atm}$$