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.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \xrightarrow{P_1=P_2} \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$V_1 = 3.5L$

$T_1 = 27.0°C = 300.2K$

$V_2 = ?$

$T_2 = -5.0°C = 268.2K$

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

$V_2 = 3.1L$ in the freezer

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

$V_1 = 2.25L$

$T_1 = 25.0°C = 298.2K$

$P_2 = ?$

$V_2 = 1.00L$

$T_2 = 31.0°C = 304.2K$

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

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

$P_2 = 2.30$ atm

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) Find the moles of oxygen gas using the IDEAL GAS EQUATION, PV=nRT
2) Convert moles of gas to mass using the FORMULA WEIGHT.

① $PV = nRT$

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

$P = 1.18 \text{ atm}$

$V = 22650 \text{ L}$

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

$T = 25.0°C = 298.2 K$

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

② $$1092.222357 \text{ mol } O_2 \times \frac{32.00 \text{ g } O_2}{\text{mol } O_2} = 35\bar{0}00 \text{ g } O_2$$

= 35.0 kg
~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. Use CHEMICAL EQUATION
3) Convert moles carbon dioxide to volume. Use IDEAL GAS EQUATION.

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

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

(1) (2)

(3) $PV = nRT$

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

$n = 0.2975942481\ mol\ CO_2$ $T = 25.0°C = 298.2\ K$

$R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$ $P = 0.950\ atm$

$$V = \frac{(0.2975942481\ mol\ CO_2)(0.08206 \frac{L \cdot atm}{mol \cdot K})(298.2\ K)}{0.950\ atm} = 7.67\ L \text{ of } CO_2 \text{ at } 25.0°C,\ 0.950\ atm$$

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

STP: "Standard Temperature and Pressure" (0 C and 1 atm)

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$P_1 = 0.950$ atm
$V_1 = 7.67$ L
$T_1 = 298.2$ K

$P_2 = 1$ atm
$V_2 = ?$
$T_2 = 0°C = 273.2$ K

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

$V_2 =$ 6.67 L at STP

(Alternate solution: Plug the number of moles carbon dioxide into PV=nRT while using the pressure and temperature from STP...)

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?

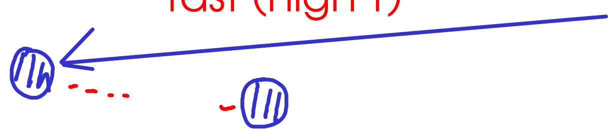
      - at high pressure, molecules would be much closer together!

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

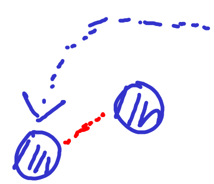
      - at high pressure, attractions and repulsions should be stronger!

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

fast (high T)



slow (low T)



-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

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$ van der Waals equation

nb: attempts to account for molecular size

$\frac{n^2 a}{V^2}$: attempts to account for attractive / repulsive forces

* "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 moleculres

CH_3CH_2OH: $a = 12.56$ $b = 0.08710$ larger, and strong attractions between molecules

$25\bar{0}0$ 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 of chlorine gas to moles. Use IDEAL GAS EQUATION, PV=nRT
2) Convert moles of chlorine gas to moles HCl. Use CHEMICAL EQUATION.
3) Convert moles HCl to mass. Use FORMULA WEIGHT.

---

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

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

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

---

(2) $\text{mol}\ Cl_2 = 2\ \text{mol}\ HCl$

(3) HCl — $H: 1 \times 1.008$
$Cl: 1 \times 35.45$
$36.458\ \text{g}\ HCl = \text{mol}\ HCl$

$$102.164983\ \text{mol}\ Cl_2 \times \underset{(2)}{\frac{2\ \text{mol}\ HCl}{\text{mol}\ Cl_2}} \times \underset{(3)}{\frac{36.458\ \text{g}\ HCl}{\text{mol}\ HCl}} = \boxed{7450\ \text{g}\ HCl}$$

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

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 HCl solution to moles. Use MOLARITY (0.250 M)
2) Convert moles HCl to moles carbon dioxide. Use CHEMICAL EQUATION.
3) Convert moles carbon dioxide to pressure. Use IDEAL GAS EQUATION.

---

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

$$48.90\,mL \times \frac{10^{-3}\,L}{mL} \times \underbrace{\frac{0.250\,mol\,HCl}{L}}_{(1)} \times \underbrace{\frac{mol\,CO_2}{2\,mol\,HCl}}_{(2)} = 0.0061125\,mol\,CO_2$$

---

(3) $PV = nRT$

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

$n = 0.0061125\,mol\,CO_2$

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

$T = 290.2\,K$

$V = 50.0\,mL$

$$50.0\,mL \times \frac{10^{-3}\,L}{mL} = 0.0500\,L$$

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

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

ENERGY

- thermodynamics: the study of energy transfer

Conservation of energy: Energy may change form, but the overall amount of energy remains constant. "first law of thermodynamics"

- ... but what IS energy?

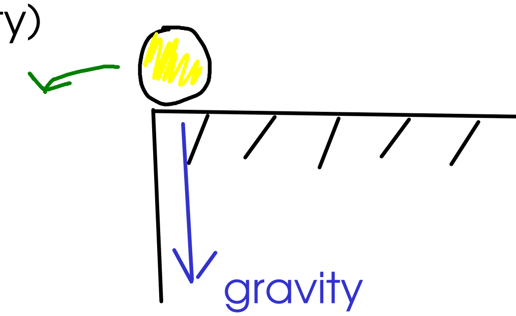
  - energy is the ability to do "work"

    ("work" ← motion of matter)

Kinds of energy?

- Kinetic energy: energy of matter in motion $E_K = \frac{1}{2} m v^2$ (m = mass, v = velocity)

- Potential energy: energy of matter that is being acted on by a field of force (like gravity)



When the ball falls, its potential energy is converted to kinetic!

- What sort of energy concerns chemists? Energy that is absorbed or released during chemical reactions.

- Energy can be stored in chemicals ... molecules and atoms.

INTERNAL ENERGY: "U"

↑ related to the kinetic and potential energy of atoms, molecules, and their component parts.

- We measure energy transfer ... which is called HEAT. (HEAT is the flow of energy from an area of higher temperature to an area of lower temperature)

Q: heat

SYSTEM: the object or material under study

SURROUNDINGS: everything else

Type of process	Energy is ...	Sign of Q	Temp of SURROUNDINGS ...
ENDOTHERMIC	transferred from SURROUNDINGS to SYSTEM	+	decreases
EXOTHERMIC	transferred from SYSTEM to SURROUNDINGS	—	increases