$$2\,NH_4NO_3(s) \longrightarrow \underline{2}\,N_2(g) + O_2(g) + \underline{4}\,H_2O(g)$$

At 300°C, ammonium nitrate violently decomposes to produce nitrogen gas, oxygen gas, and water vapor. What is the total volume of gas that would be produced at 1.00 atm by the decomposition of 15.0 grams of ammonium nitrate?

To simplify this calculation, we'll calculate the TOTAL MOLES OF GAS instead of the individual moles of each gas!

F_W NH_4NO_3 = 80.052 g/mol

1 - Convert 15.0 grams ammonium nitrate to moles. Use FORMULA WEIGHT.
2 - Convert moles ammonium nitrate to TOTAL MOLES OF GAS. Use CHEMICAL EQUATION.
3 - Convert TOTAL MOLES OF GAS to volume. Use IDEAL GAS EQUATION.

① 80.052 g NH_4NO_3 = mol NH_4NO_3

② 2 mol NH_4NO_3 = 7 mol gas (2+1+4=7)

$$15.0\text{ g } NH_4NO_3 \times \underbrace{\frac{\text{mol } NH_4NO_3}{80.052\text{ g } NH_4NO_3}}_{①} \times \underbrace{\frac{7\text{ mol gas}}{2\text{ mol } NH_4NO_3}}_{②} = 0.6558237146\text{ mol gas}$$

③ $PV = nRT$

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

$n = 0.6558237146$ mol gas

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

$T = 300.°C = 573K$

$P = 1.00$ atm

$$V = \frac{(0.6558237146\text{ mol gas})\left(0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}\right)(573\text{K})}{1.00\text{ atm}} =$$

$$= \boxed{30.8\text{ L gas @ }300.°C,\ 1\text{ atm}}$$

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

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

van der Waals equation

attempts to account for molecular size

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 kilograms of hydrochloric acid could be produced if all the chlorine reacts?

$$H_2 + Cl_2 \rightarrow 2HCl$$

---

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

---

① $PV = nRT$

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

$P = 1.00\ atm$ $R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$

$V = 25\bar{0}0\ L$ $T = 25.0°C = 298.2\ K$

$$n_{Cl_2} = \frac{(1.00\ atm)(25\bar{0}0\ L)}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(298.2\ K)} = 102.1696983\ mol\ Cl_2$$

---

② mol Cl_2 = 2 mol HCl ③ HCl – H: 1x1.008

Cl: 1x35.45

36.458 g HCl = mol HCl

$$102.1696983\ mol\ Cl_2 \times \overset{②}{\frac{2\ mol\ HCl}{mol\ Cl_2}} \times \overset{③}{\frac{36.458\ g\ HCl}{mol\ HCl}} = 7450\ g\ HCl$$

Problem asks for kg, so convert units...

$kg = 10^3\ g$

$$7450\ g \times \frac{kg}{10^3\ g} = \boxed{7.45\ kg\ HCl}$$

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

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 to moles. Use MOLARITY.
2 - Convert moles HCl to moles carbon dioxide. Use CHEMICAL EQUATION.
3 - Convert moles carbon dioxide to pressure. Use IDEAL GAS EQUATION.

---

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

$$48.90\text{ mL} \times \frac{10^{-3}\,L}{mL} \times \frac{\overset{①}{0.250\text{ mol HCl}}}{L} \times \frac{\overset{②}{\text{mol } CO_2}}{2\text{ mol HCl}} = 0.0061125\text{ mol } CO_2$$

---

③ $PV = nRT$

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

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

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

$$P = \frac{(0.0061125\text{ mol } CO_2)\left(0.08206\frac{L\cdot atm}{mol\cdot K}\right)(290.2\,K)}{(0.0500\,L)} = \boxed{2.91\text{ atm}}$$

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"

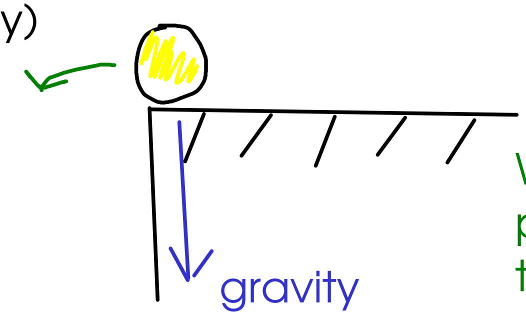
- ... but what IS energy?
  - energy is the ability to do "work"

motion of matter

Kinds of energy?

- Kinetic energy: energy of matter in motion $E_K = \frac{1}{2} \overset{\text{mass}}{m} \underset{\text{velocity}}{v}^2$

- 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)

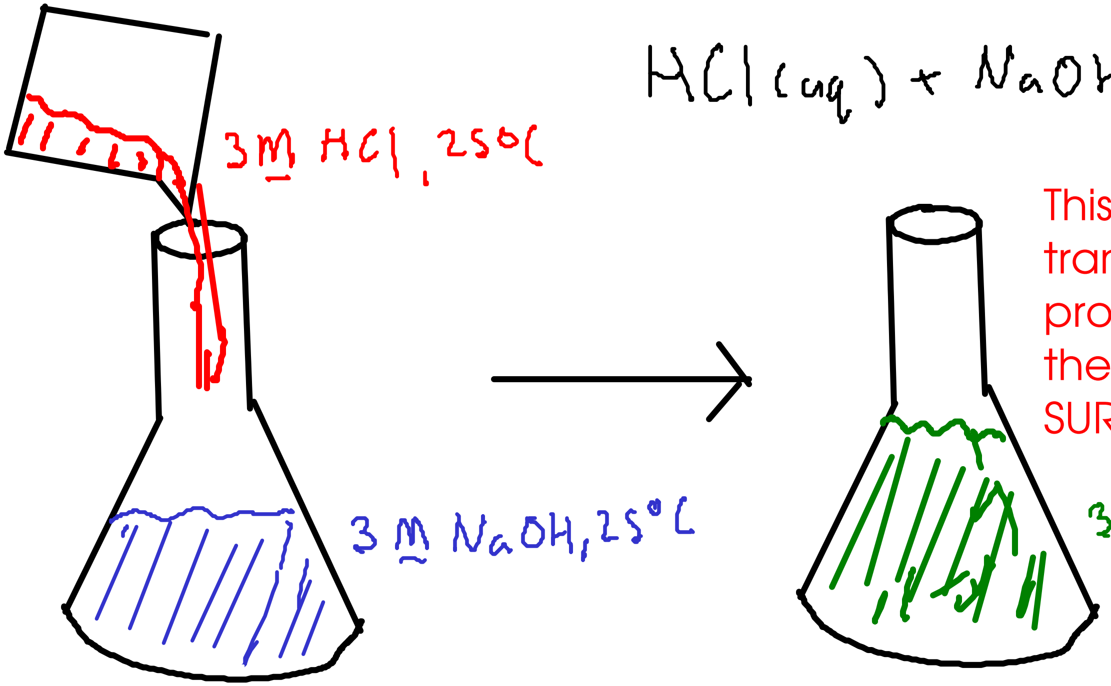
Q : heat

SYSTEM: the object or material under study

SURROUNDINGS: everything else

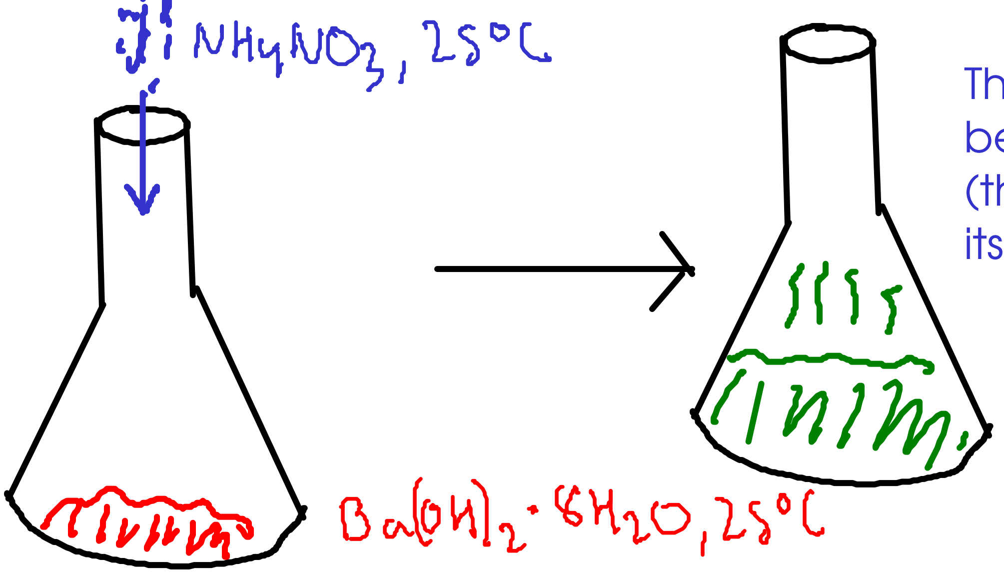
Type of process	Energy is ...	Sign of Q	Temp of SURROUNDINGS ...
ENDOTHERMIC	transferred from SURROUNDINGS to SYSTEM	+	decreases
EXOTHERMIC	transferred from SYSTEM to SURROUNDINGS	—	increases

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$



This reaction is EXOTHERMIC. Energy is transferred from the reactants and products (the SYSTEM) to the water in the flask, the flask, etc. (the SURROUNDINGS)

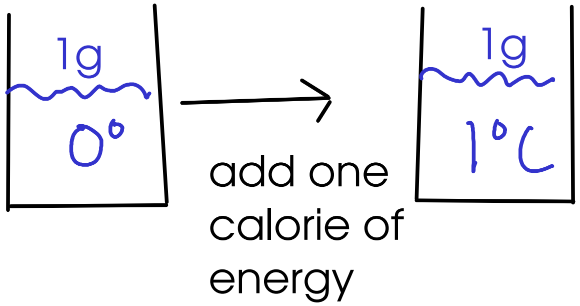
$$Ba(OH)_2 \cdot 8H_2O(s) + 2NH_4NO_3(s) \rightarrow 2NH_3(aq) + 10H_2O(l) + Ba(NO_3)_2(aq)$$



This reaction is ENDOTHERMIC. Energy is being transferred from the room/flask/etc. (the SURROUNDINGS) to the reaction itself (the SYSTEM).

ENERGY UNITS

- calorie (cal): the amount of energy required to change the temperature of one gram of water by one degree Celsius (or Kelvin)



1g ≈ 1mL for water

- Calories in food? The "Calorie" that is given on American food labels is actually the kilocalorie (kcal)

- Joule (J): SI unit for energy. It's defined based on the equation for kinetic energy.

$$1\ J = 1\ \frac{kg\ m^2}{s^2}, \text{ from}$$

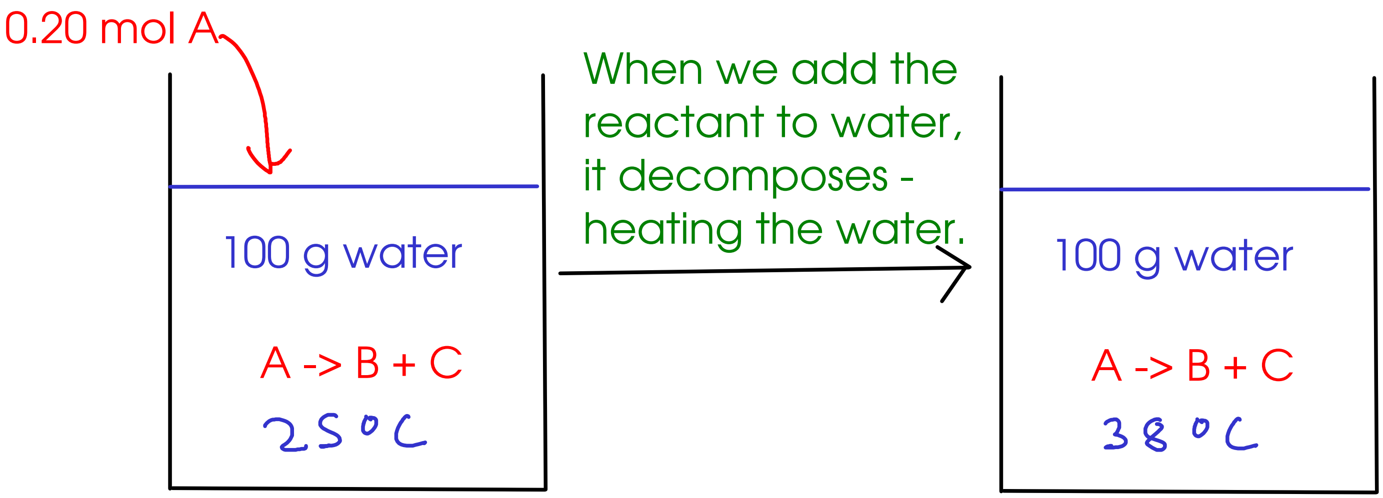
$$\underset{\text{kinetic energy}}{E_K} = \frac{1}{2}\underset{\underset{\text{mass}}{\uparrow}}{m}\,\underset{\underset{\text{velocity}}{\nwarrow}}{v}^2$$

$$\boxed{4.184\ J = 1\ cal}$$

- the Joule is a small unit. For most reactions at lab scale, we'll use kilojoules (kJ).

CALORIMETRY

- the measurement of heat. But how do we measure heat?



When we add the reactant to water, it decomposes - heating the water.

... what is Q for this reaction?

Assuming that no heat is lost from the water to the surrounding air,

$$\underbrace{Q_r}_{\text{reaction}} + \underbrace{Q_w}_{\text{water}} = 0$$

Conservation of energy. The terms add to zero because they have opposite signs.

... if we knew something about the WATER, we could use that to find the heat of the REACTION!

SPECIFIC HEAT

- a measured quantity. The amount of energy required to change the temperature of one gram of a particular substance by one degree Celsius.

- Specific heat information for common substances is readily available. For water,

$$4.184 \frac{J}{g\,°C} \text{ or } = 1.000 \frac{cal}{g\,°C}$$

$$Q = m \times S \times \Delta T$$

m = mass
s = specific heat
Δ T = Tfinal - Tinitial

This is ALWAYS final temp minus initial temp!

- For objects, like reaction vessels, you might know the HEAT CAPACITY, which is the amount of energy required to change the temperature of an object by one degree Celsius

Units: $J/°C$ or $cal/°C$

$$Q = C \times \Delta T$$

c = heat capacity