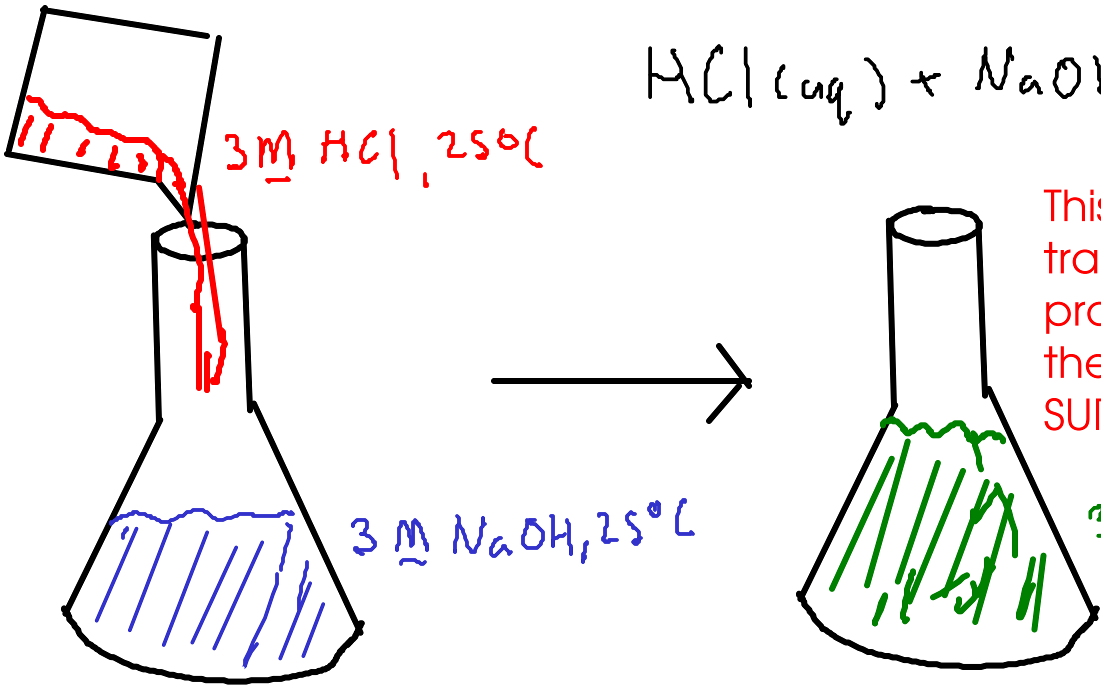
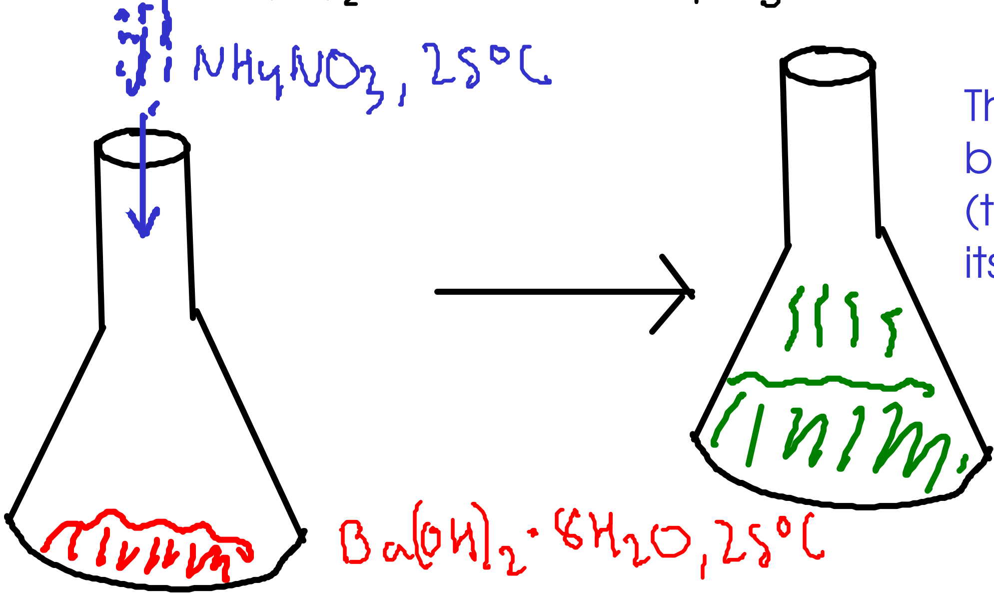
$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$$



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)

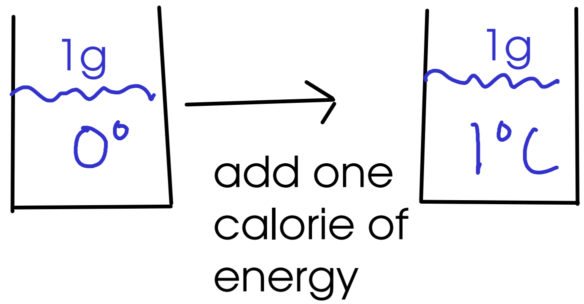
$$Ba(OH)_2 \cdot 8H_2O(s) + 2NH_4NO_3(s) \longrightarrow 2NH_3(aq) + 10H_2O(\ell) + Ba(NO_3)_2(aq)$$



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.

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

$$E_K = \frac{1}{2} m v^2$$

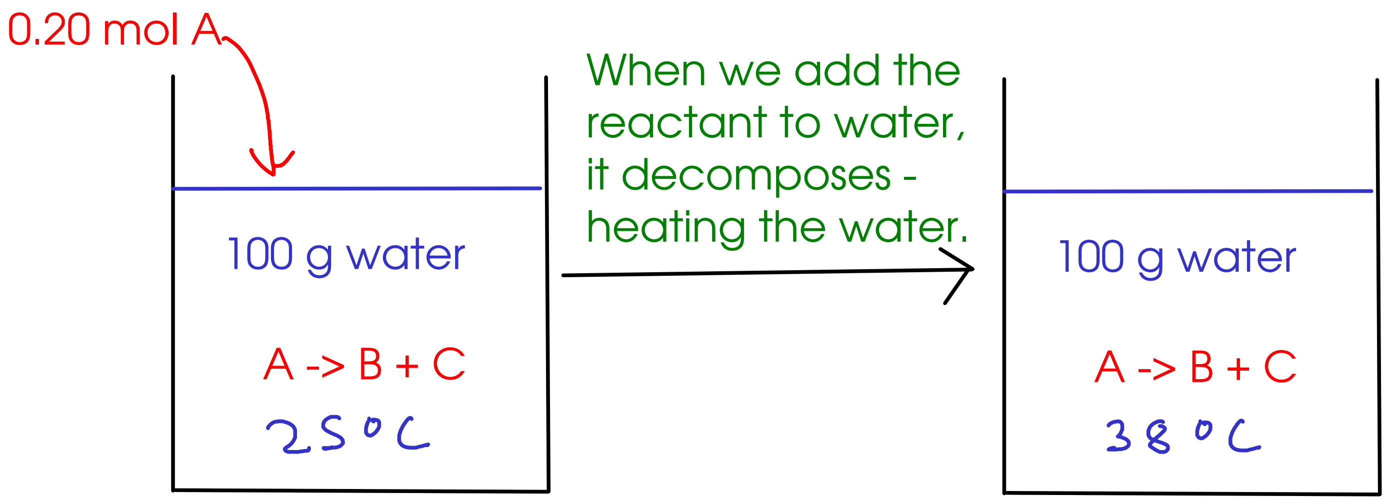
E_K: kinetic energy; m: mass; v: velocity

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?



... what is Q for this reaction?

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

$$Q_r + Q_w = 0$$

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

Q_r: reaction

Q_w: water

... 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,

$$4.184 \frac{J}{g\,^{\circ}C} \quad \text{or} \quad 1.000 \frac{cal}{g\,^{\circ}C}$$

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

m = mass
s = specific heat
ΔT = Tfinal - Tinitial

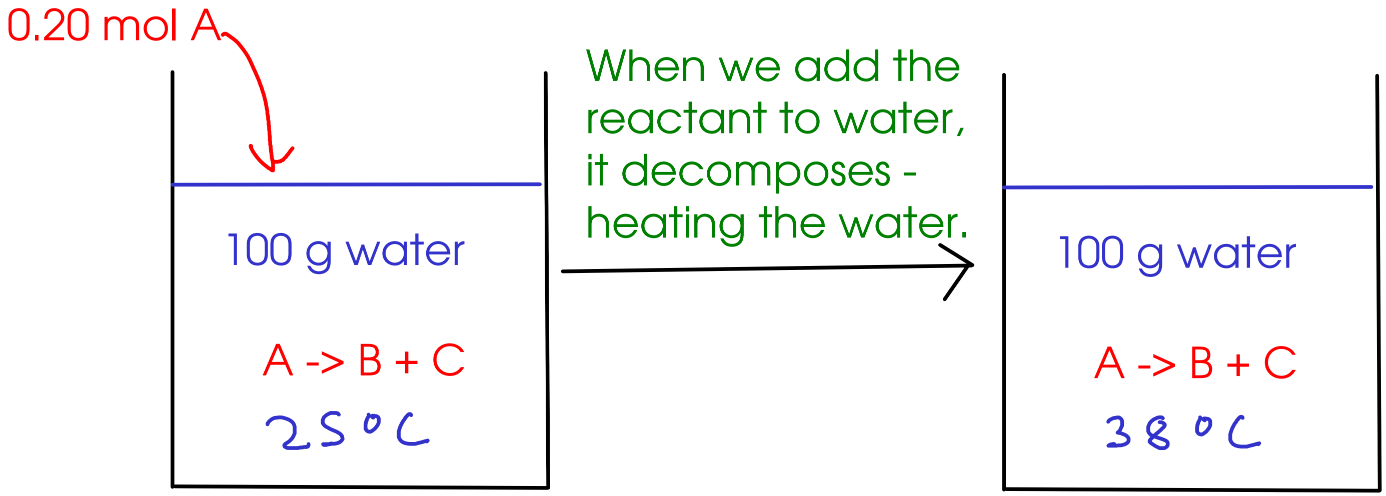
This is ALWAYS final temp minus initial temp!

- 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: $J/^{\circ}C$ or $cal/^{\circ}C$

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

c = heat capacity



Specific heat of water:

$4.184\ J/g\,°C$

$$Q_r + Q_w = 0$$

$$Q_w = m_w \times S_w \times \Delta T_w$$
$$= (100g)(4.184\ J/g\,°C)(38°C - 25°C)$$
$$= 5439.2\ J$$

$$Q_r + Q_w = 0;\quad Q_r + 5439.2\ J = 0;\quad Q_r = -5439.2\ J$$

To report the energy change in this reaction to others, we should express it in terms of heat transfer per mole of something. A different amount of reactant would have a different Q

$$Q_{rxn} = \frac{Q_r}{\text{moles } A} = \frac{-5439.2\ J}{0.20\ mol\ A} = -27000\ J/mol\,A = \boxed{-27\ \frac{kJ}{mol\ A}}$$

Numbers like these are usually called "HEATS OF REACTION"

One problem ...

PATH. The amount of energy required for a process depends on how the process is carried out.

Example: Driving from Florence to Columbia. How much energy is required? (gas)

2000 Jeep Cherokee vs 2008 Toyota Prius. The Jeep will use much more fuel than the Prius even though they start and end from exactly the same place. So the fuel usage is what we call a PATH FUNCTION, while the location is a STATE FUNCTION.

- so the heat of reaction depends on how the reaction is done.

  - we need (for reporting) some kind of standard condition. At constant pressure, we can define a state function called ENTHALPY (H)

$$H = U + PV$$

$$\Delta H = Q_{constant\ pressure}$$

... we record the "enthalpy change of reaction" in our data books.

$$\Delta H_r$$

SINCE the enthalpy change does NOT depend on path, this means that we can use standard values for enthalpy to predict the heat change in reactions that we have not tested in a calorimeter.

THERMOCHEMICAL EQUATIONS

- is like a regular chemical equation, except that phase labels are REQUIRED and the enthalpy for the reaction is given along with the equation.

$$CH_3COCH_3(l) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(l)\ ;\ \Delta H = -1800\ kJ$$

- Why are phase labels required? Because phase changes either absorb or release energy.

$\Delta H = -1800\ kJ$ ... what does this mean?

1 mol CH_3COCH_3 = $-1800\ kJ$
4 mol O_2 = $-1800\ kJ$
3 mol CO_2 = $-1800\ kJ$
3 mol H_2O = $-1800\ kJ$

We treat the enthalpy change as if it's another product of the reaction!

$CH_3COCH_3(l) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(l)\ ;\ \Delta H = -1800\ kJ$

What would be the enthapy change when 25 g of water are produced by the reaction?

1 - Convert 25 g water to moles. Use FORMULA WEIGHT.
2 - Convert moles water to enthalpy change. Use THERMOCHEMICAL EQUATION.

(1) H_2O - H: 2 x 1.008
O: 1 x 16.00
18.016 g H_2O = mol H_2O

(2) 3 mol H_2O = -1800 kJ

$$25\,g\,H_2O \times \frac{mol\,H_2O}{18.016\,g\,H_2O} \times \frac{-1800\,kJ}{3\,mol\,H_2O} = \boxed{-830\,kJ}$$

This is an EXOTHERMIC process. (Like most combustion reactions!)

If this reaction were done at constant pressure, then Q would also equal -830 kJ ...

A few more terms related to enthalpy:

- Enthalpy of vaporization / heat of vaporization: The enthalpy change on vaporizing one mole of a substance. (from liquid to vapor)

- Enthalpy of fusion / heat of fusion: The enthalpy change when a mole of liquid changes to the solid state.

Phase changes require energy, too!