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

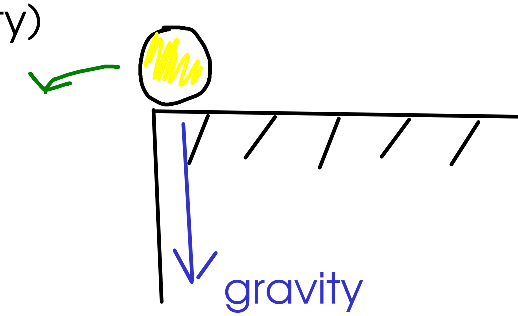
Kinds of energy?

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

  mass

  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)

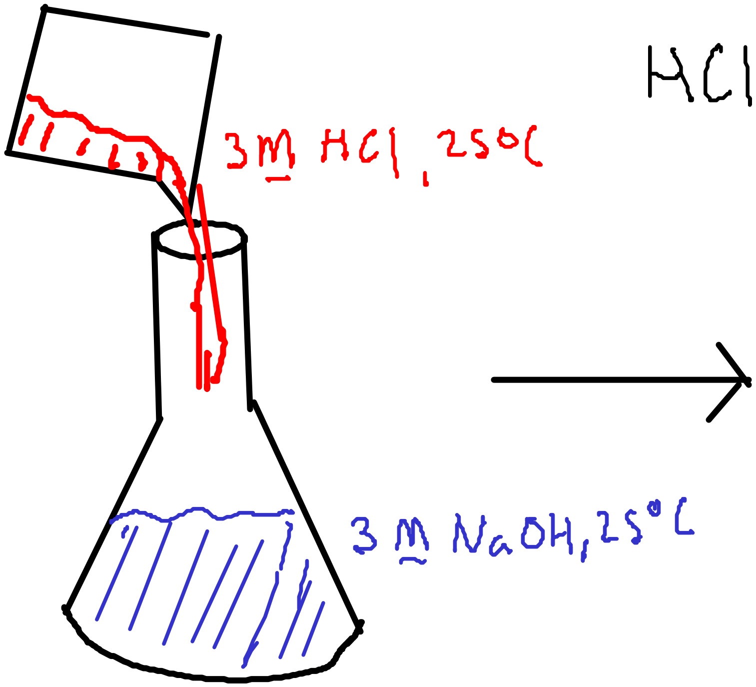
Q : heat

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

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



3 M HCl, 25°C

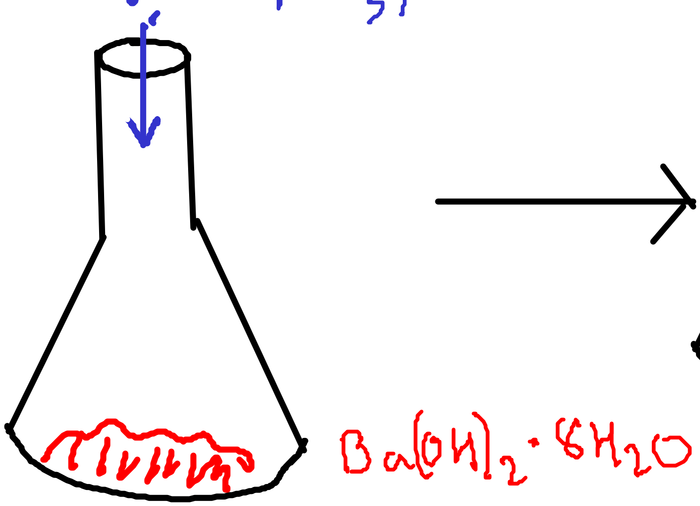
3 M NaOH, 25°C

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)

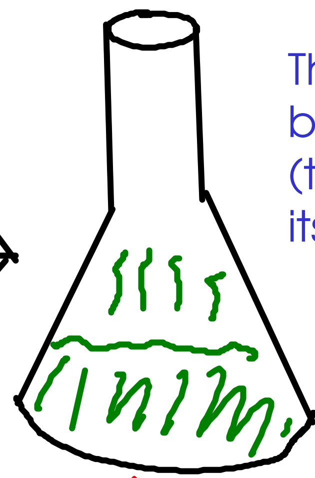
3 M NaCl + H_2O, ~40°C

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

NH_4NO_3, 25°C



$Ba(OH)_2 \cdot 8H_2O$, 25°C



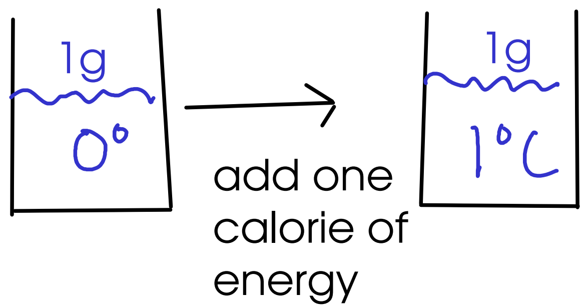
This reaction is ENDOTHERMIC. Energy is being transferred from the room/flask/etc. (the SURROUNDINGS) to the reaction itself (the SYSTEM).

NH_3, H_2O, $Ba(NO_3)_2(aq)$, <0°C

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.

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

$$\underbrace{E_K}_{\text{kinetic energy}} = \frac{1}{2}\,\underbrace{m}_{\text{mass}}\,\underbrace{v}_{\text{velocity}}{}^2$$

4.184 J = 1 cal

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

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)

$$H = U + PV$$

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

... 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.

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

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

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

$$\boxed{\begin{aligned} 1 \text{ mol } CH_3COCH_3 &= -1800 \text{ kJ} \\ 4 \text{ mol } O_2 &= -1800 \text{ kJ} \\ 3 \text{ mol } CO_2 &= -1800 \text{ kJ} \\ 3 \text{ mol } H_2O &= -1800 \text{ kJ} \end{aligned}}$$

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

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

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

1 - Convert 25 grams water to moles. Use FORMULA WEIGHT.
2 - Convert moles water to enthalpy. 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

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

A few notes:
1) This is an EXOTHERMIC process. Energy is released from the system to the surroundings.
2) The calculated enthalpy change also equals the measured heat (Q), as long as pressure is constant.

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!

Example problem:

$$\overset{2.016}{2H_2(g)} + \overset{32.00}{O_2(g)} \longrightarrow \overset{18.02}{2H_2O(g)}\ ;\ \Delta H = -484\ kJ$$

Calculate the enthalpy change for the combustion of 1.00 kg of hydrogen gas.

---

1 - Convert 1 kg hydrogen gas to moles. Use FORMULA WEIGHT.
2 - Convert moles hydrogen gas to enthalpy using THERMOCHEMICAL EQUATION.

1 $2.016\ g\ H_2 = mol\ H_2$ 2 $2\ mol\ H_2 = -484\ kJ$

$$1\bar{0}00\ g\ H_2 \times \frac{mol\ H_2}{2.016\ g\ H_2} \times \frac{-484\ kJ}{2\ mol\ H_2} = \boxed{-12\bar{0}000\ kJ/kg\ H_2}$$