78.114 g|mol   123.111 g|mol <- Formula weights

22.4 g   31.6 g ACTUAL

$$C_6H_6 + HNO_3 \longrightarrow C_6H_5NO_2 + H_2O$$

benzene   nitric acid   nitrobenzene

22.4 grams of benzene are reacted with excess nitric acid. If 31.6 grams of nitrobenzene are collected from the reaction, what is the percent yield?

To solve this problem, we first need to calculate the THEORETICAL YIELD of nitrobenzene based on the starting material used (22.4 grams of benzene).

① $78.114\,g\ C_6H_6 = mol\ C_6H_6$ ② $mol\ C_6H_6 = mol\ C_6H_5NO_2$

③ $123.111\,g\ C_6H_5NO_2 = mol\ C_6H_5NO_2$

$$22.4\,g\ C_6H_6 \times \frac{mol\ C_6H_6}{78.114\,g\ C_6H_6} \times \frac{mol\ C_6H_5NO_2}{mol\ C_6H_6} \times \frac{123.111\,g\ C_6H_5NO_2}{mol\ C_6H_5NO_2} = 35.3\,g\ C_6H_5NO_2$$

① ② ③

(theoretical yield)

$$\%\,yield = \frac{actual}{theor.} \times 100 = \frac{31.6\,g}{35.3\,g} \times 100 = \boxed{89.5\%}$$

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?

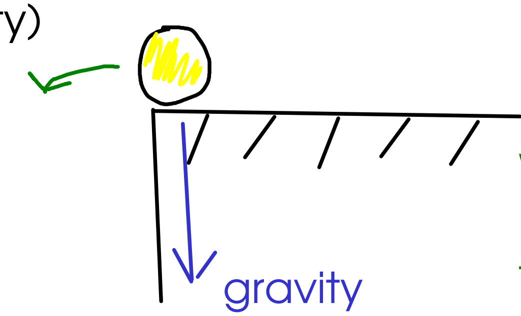
    - energy is the ability to do "work"

        ↑ motion of matter

Kinds of energy?

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

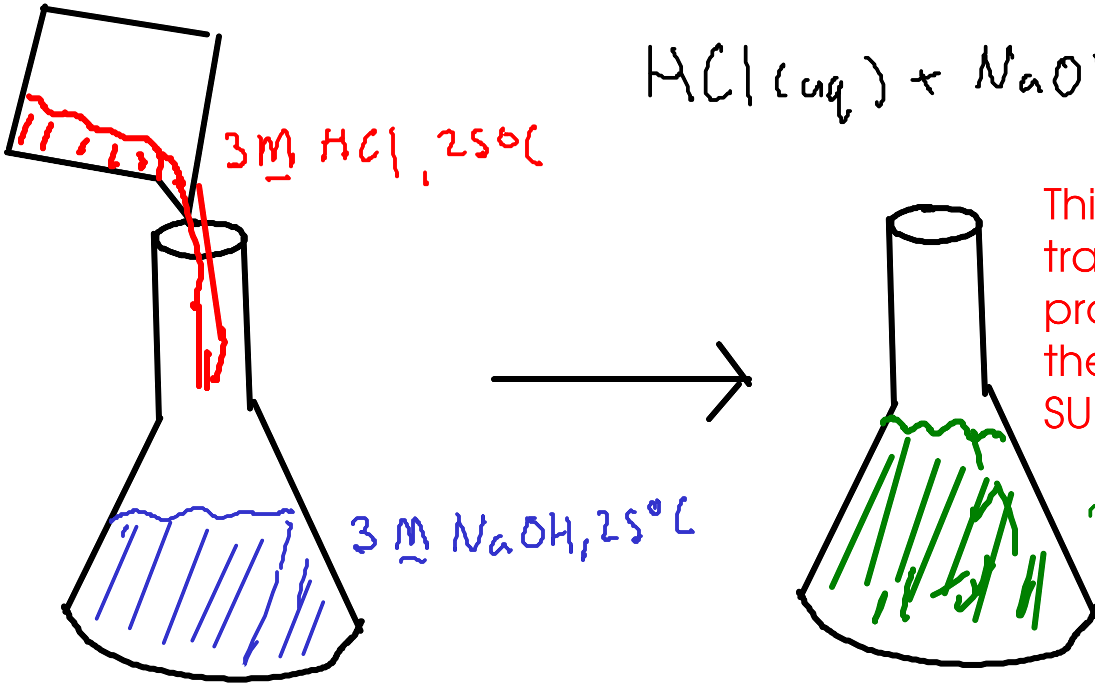
Q : heat

SYSTEM: the object or material under study

SURROUNDINGS: everything else

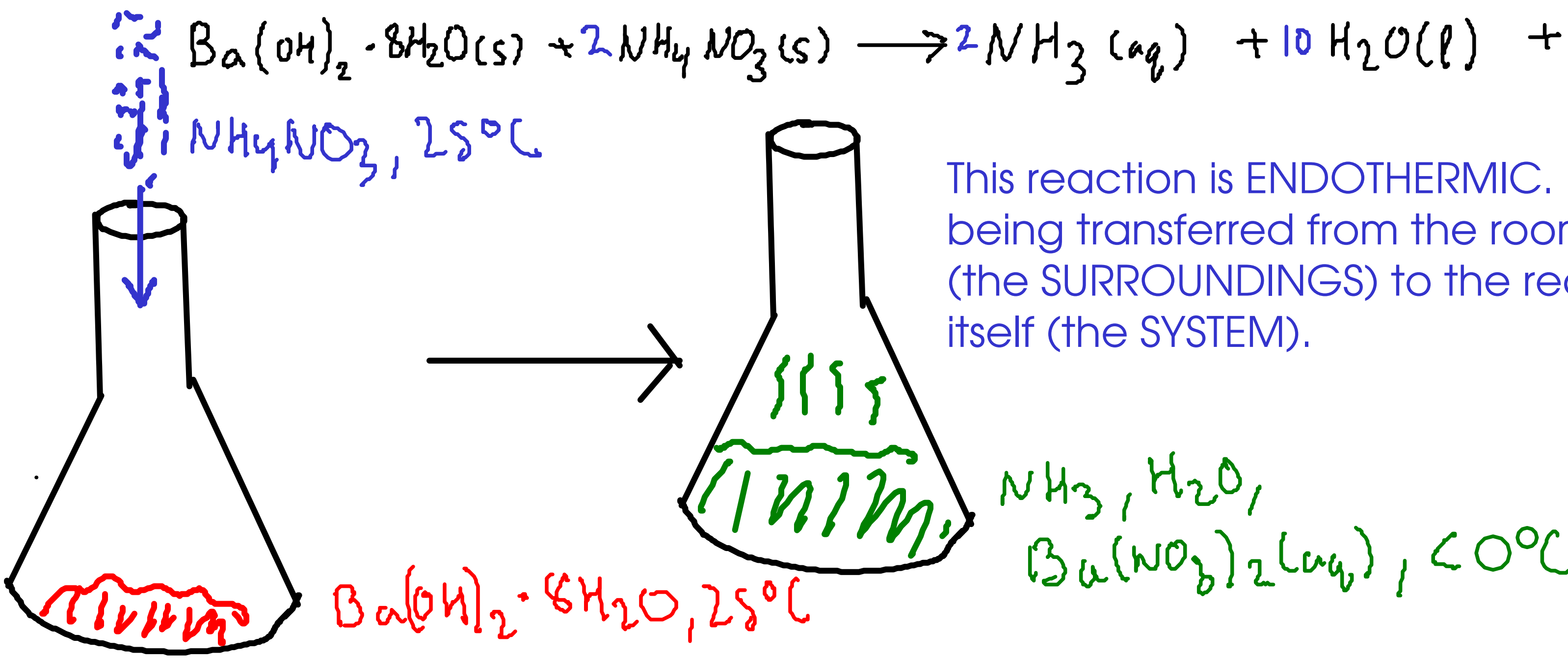
Type of process	Energy is ...	Sign of Q	Temp of SURROUNDINGS ...
ENDOTHERMIC	transferred from SURROUNDINGS to SYSTEM	+	decreases
EXOTHERMIC	transferred from SYSTEM to SURROUNDINGS	−	increases

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



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)

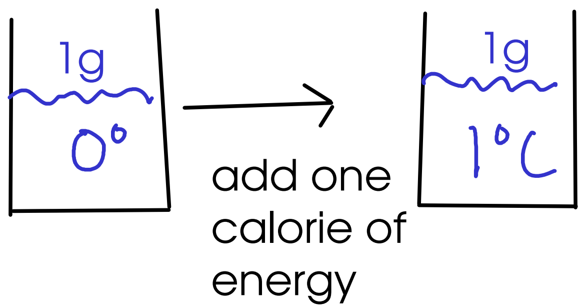
$$Ba(OH)_2 \cdot 8H_2O(s) + 2NH_4NO_3(s) \rightarrow 2NH_3(aq) + 10H_2O(l) + Ba(NO_3)_2(aq)$$



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.

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

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

kinetic energy (E_K), mass (m), velocity (v)

4.184 J = 1 cal

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

SPECIFIC HEAT AND HEAT CAPACITY

- 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,

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

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

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

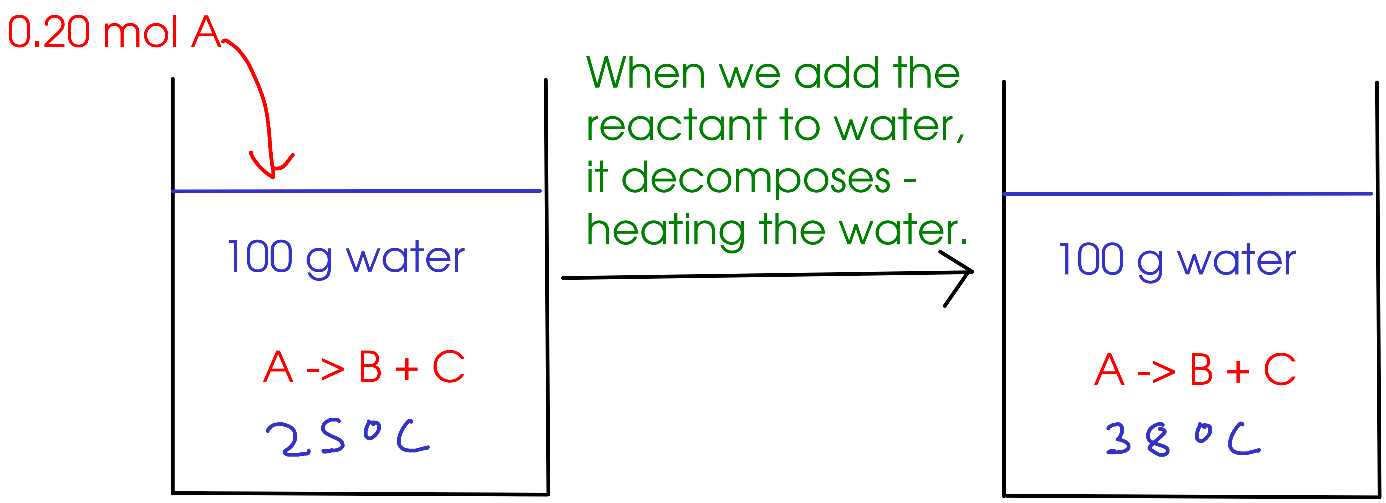
Units: $J/^{\circ}C$ or $cal/^{\circ}C$

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

c = heat capacity

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,

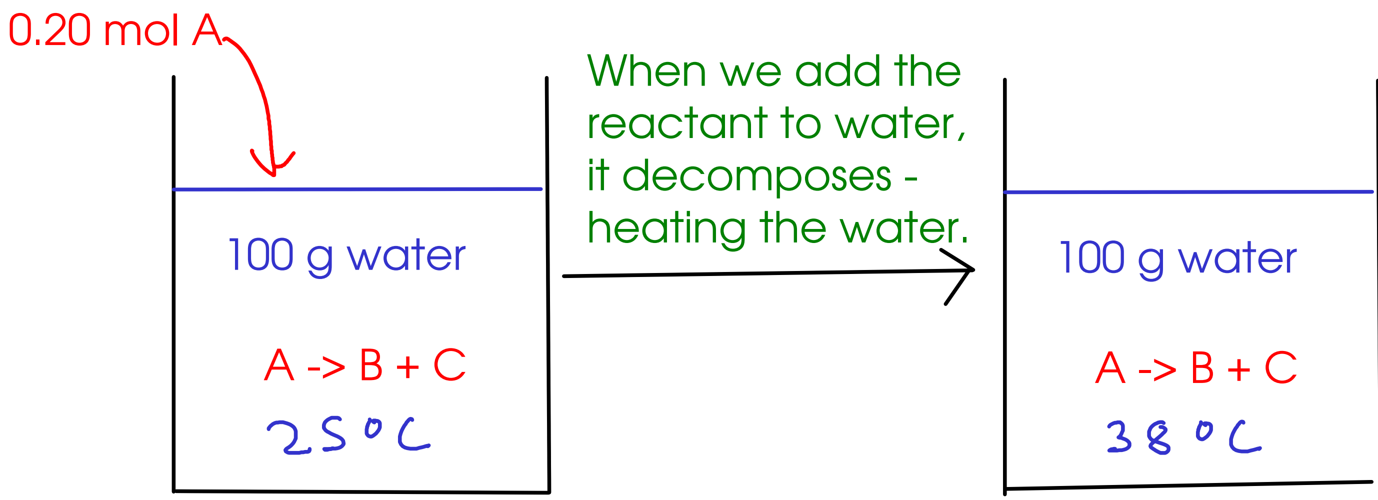
$$Q_r + Q_w = 0$$

reaction — water

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!

We can look up the water's SPECIFIC HEAT and use it to relate the temperature change of the water to Q.



Specific heat of water:

$4.184 \ J/g\,°C$

$$Q_r + Q_w = 0$$

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

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

Usually, reaction heats are reported on a per mole basis:

$$Q = \frac{Q_r}{mol\ A} = \frac{-5439.2\ J}{0.20\ mol\ A} = -27000\ J/mol\ A = \boxed{-27\ \frac{kJ}{mol\ A}}$$

This kind of number is often called a "heat of reaction"