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?
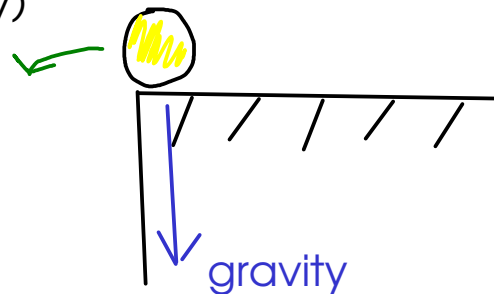
- energy is the ability to do "work"

↑
└— 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)

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)

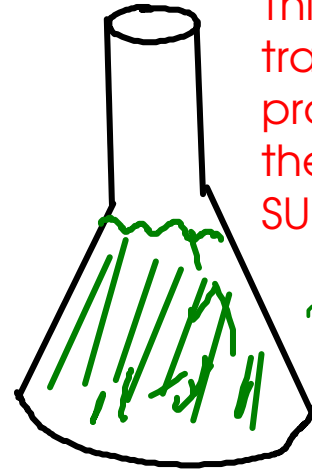Q : heat

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

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$
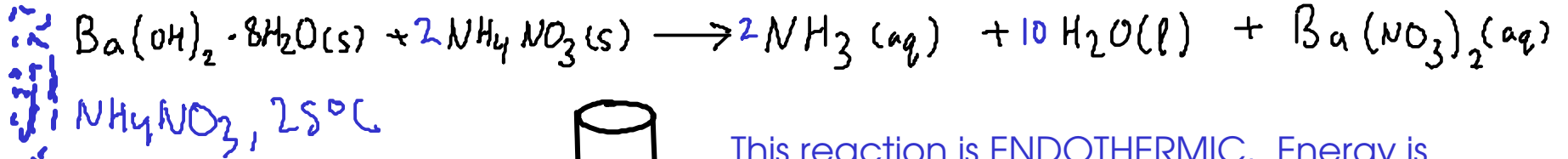
3M HCl, 25°C
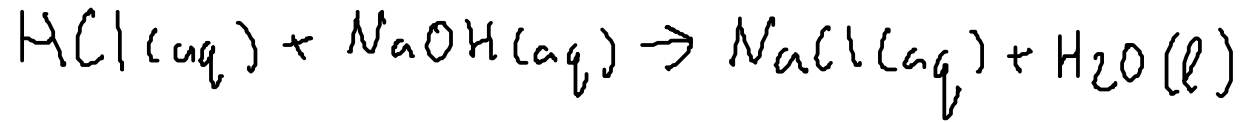
3 M NaOH, 25°C

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)
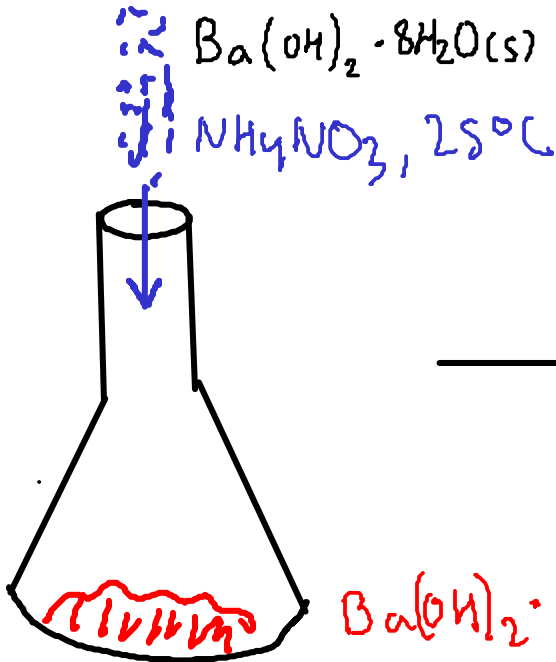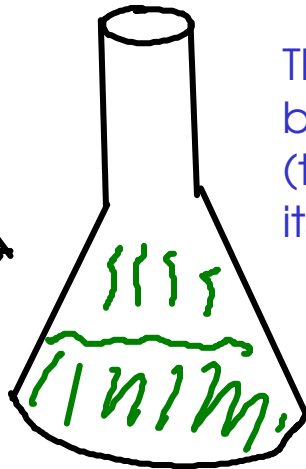
3 M NaCl + H₂O, ~40°C

$$Ba(OH)_2 \cdot 8H_2O_{(s)} + 2NH_4NO_{3\,(s)} \rightarrow 2NH_{3\,(aq)} + 10\,H_2O_{(l)} + Ba(NO_3)_{2\,(aq)}$$

NH₄NO₃, 25°C

This reaction is ENDOTHERMIC. Energy is being transferred from the room/flask/etc. (the SURROUNDINGS) to the reaction itself (the SYSTEM).
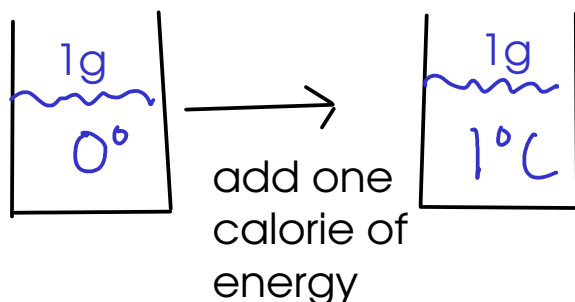
NH₃, H₂O,
Ba(NO₃)₂(aq), <0°C

Ba(OH)₂·8H₂O, 25°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 0° → add one calorie of energy 1g 1°C

$1g \hat{=} 1 mL$ 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.

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

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

kinetic energy   mass   velocity

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,

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

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

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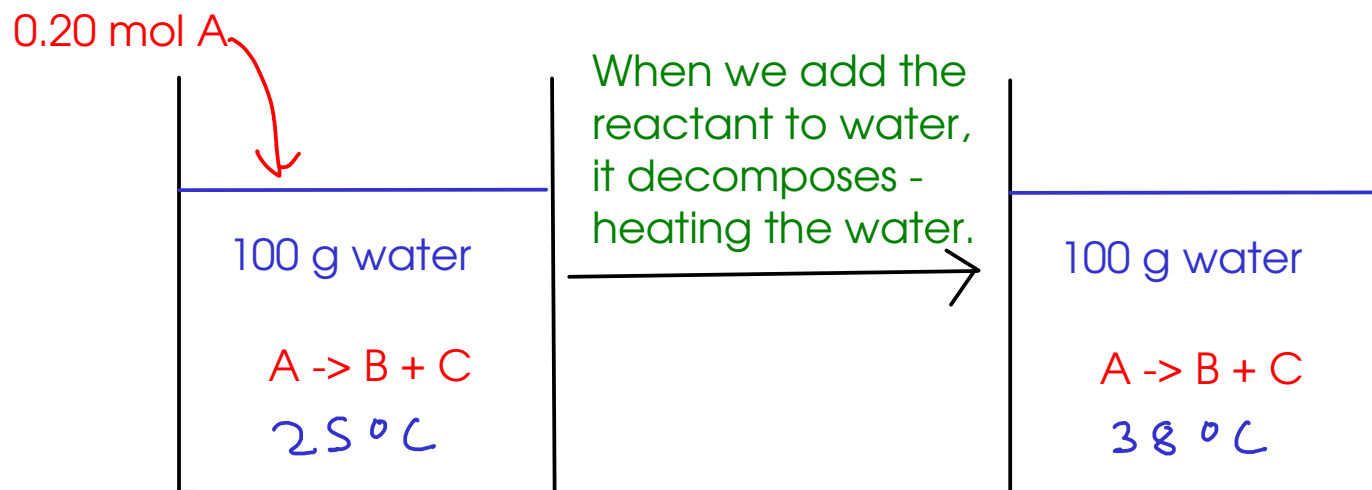
Units: $J/{}^\circ C$ or $cal/{}^\circ C$

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

c = heat capacity

CALORIMETRY

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

0.20 mol A

100 g water

A -> B + C

25 °C

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

100 g water

A -> B + C

38 °C

... 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.

0.20 mol A

100 g water

A -> B + C

$25\,°C$

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

100 g water

A -> B + C

$38\,°C$

Specific heat of water:
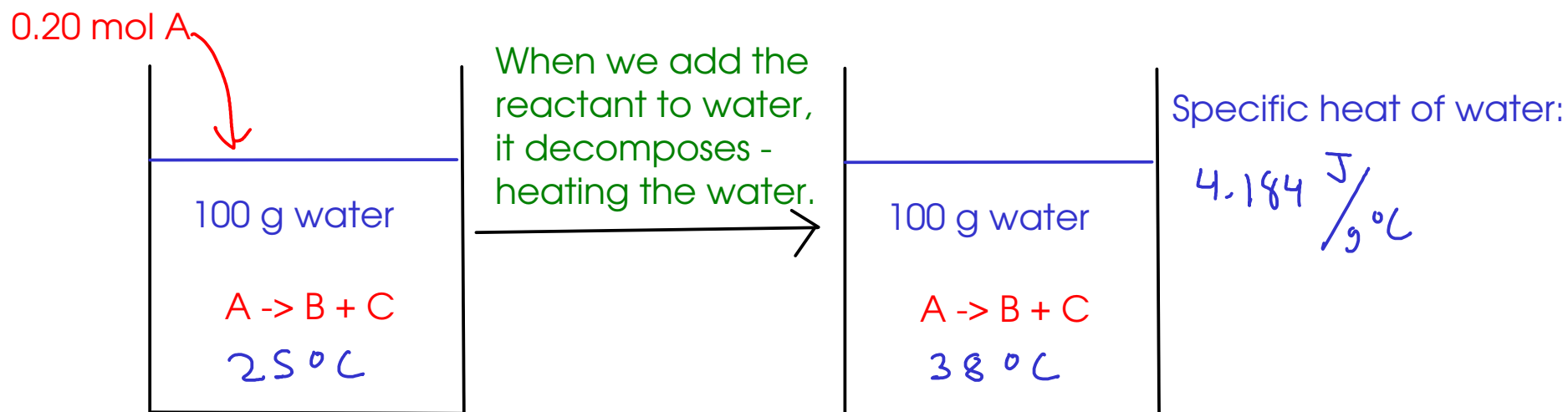
$4.184 \dfrac{J}{g\,°C}$

$Q_r + Q_w = 0$

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

$= 5439.2\,J$

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

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

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

This kind of number is called a "HEAT OF REACTION", and is usually expressed on a per-mole basis!

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)

Jeep Cherokee vs 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.