Thermochemistry, Reaction Rates, & Equillibrium

Reaction Rates

The rate at which chemical reactions occur

Reaction Rates

- **<u>RXN rate</u>** = rate at which reactants change into products over time.
  - This tells you how fast a reaction is going
- Some reactions are fast: TNT exploding

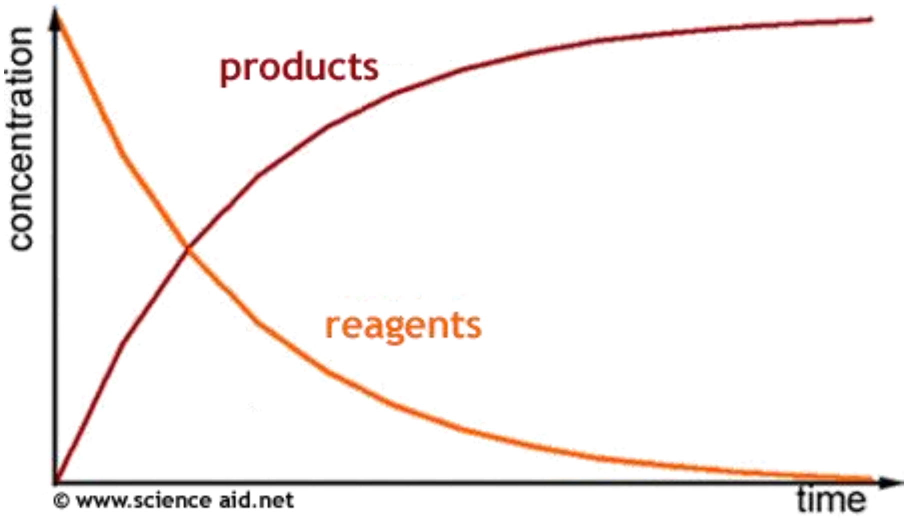
- Some are slow: nail rusting

Reaction Rate

ex: $CH_4 + O_2 \rightarrow CO_2 + H_2O$

- At the start there are 100 % reactants & 0% products.

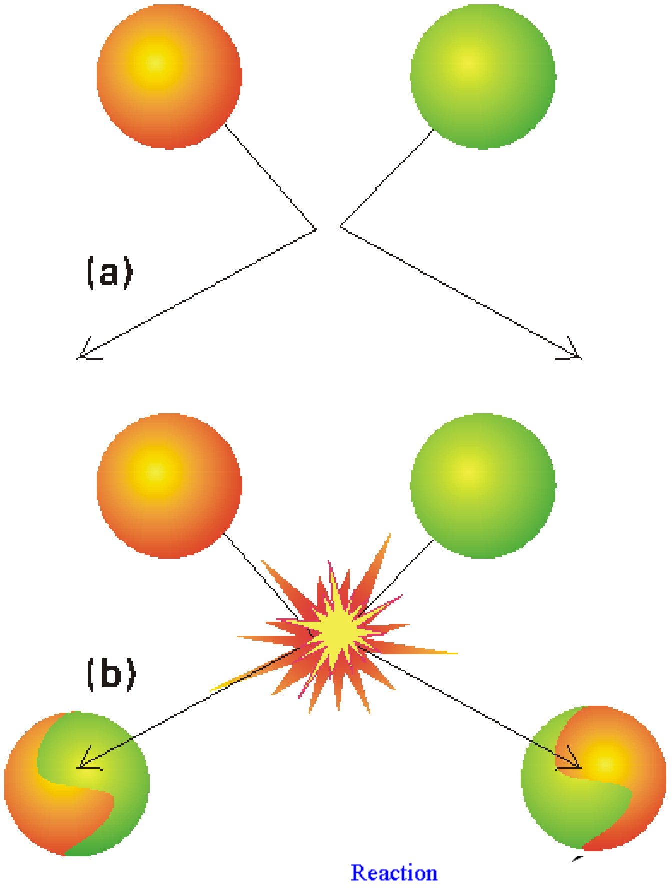
- As the reaction proceeds, amount of reactants ↓ & products ↑



Collision Theory

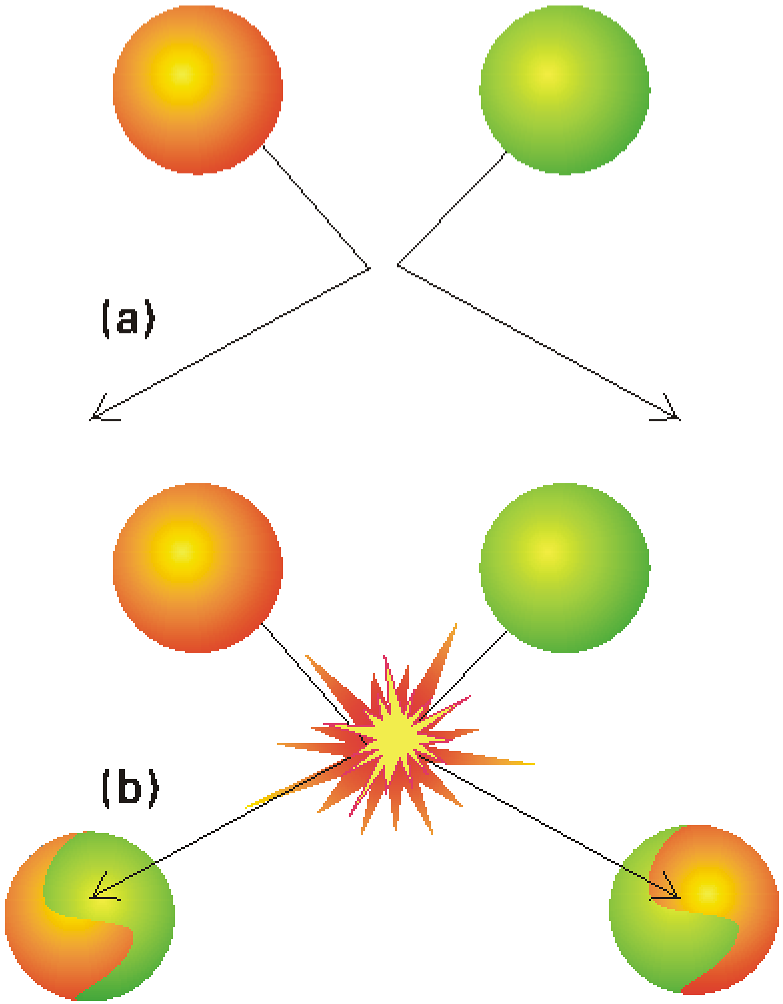
In order for a reaction to occur 3 things must happen:

1. reactants must collide
2. while favorably oriented/ positioned
3. must combine with enough energy to disrupt current bonds (**activation energy**)



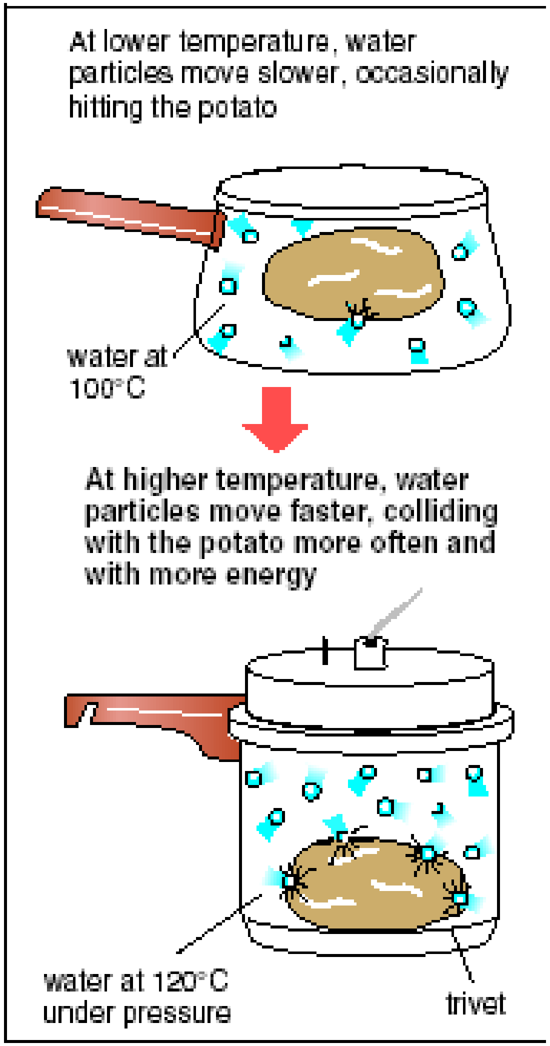
Reaction Rates are affected by:

1) Temperature
2) Surface Area
3) Concentration
4) Pressure (gases only)
5) Catalysts
6) Nature of reactants



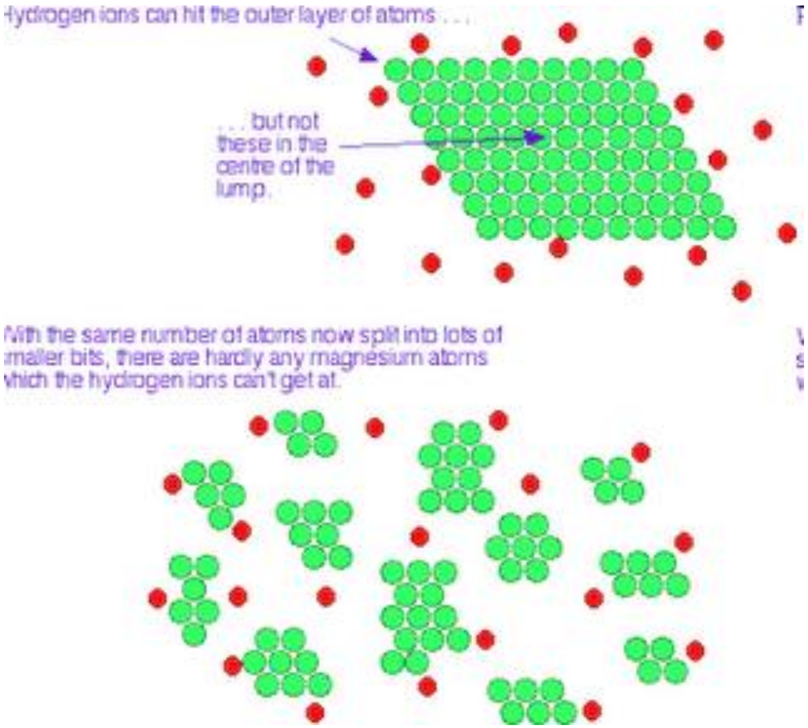
Temperature

- ↑ temperature = ↑ the rate of reaction
- ↑ temperature means particles move faster and are more likely to collide.
  - Ex: Egg cooks faster with higher heat
  - Ex: refrigerators slow down bacterial growth



Surface Area

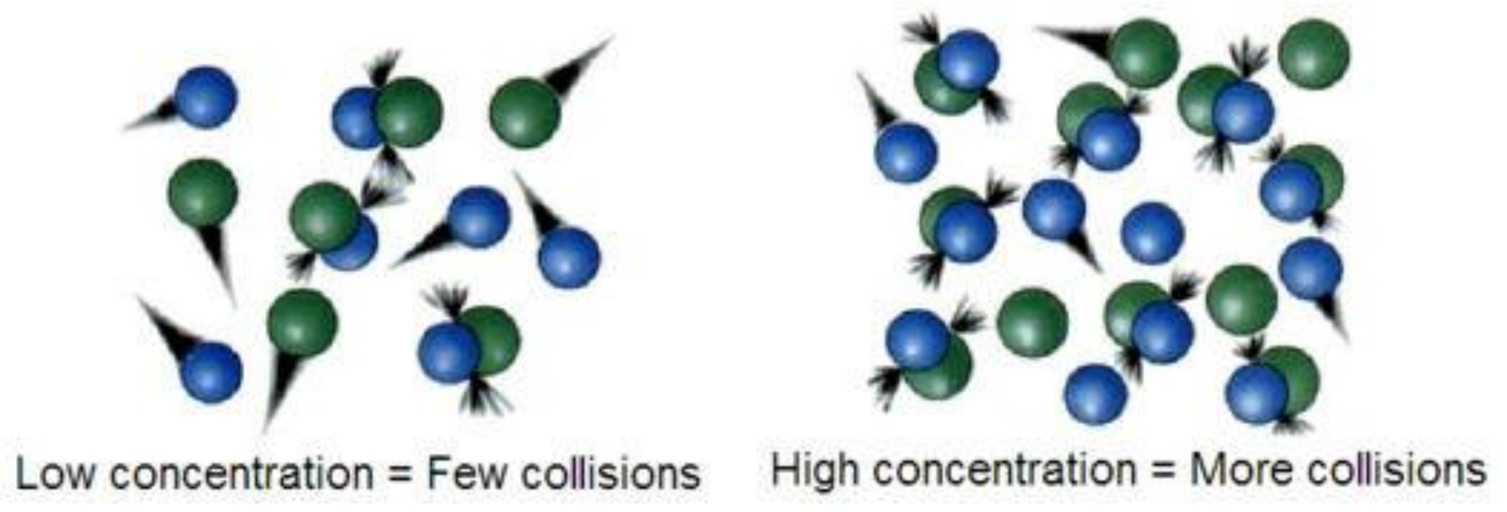
- ↑ the surface area = ↑ reaction rate.
- It ↑ the exposure of the reactants to each other = ↑ chance for collisions.



Demo: Coffee Creamer and Bunsen Burner

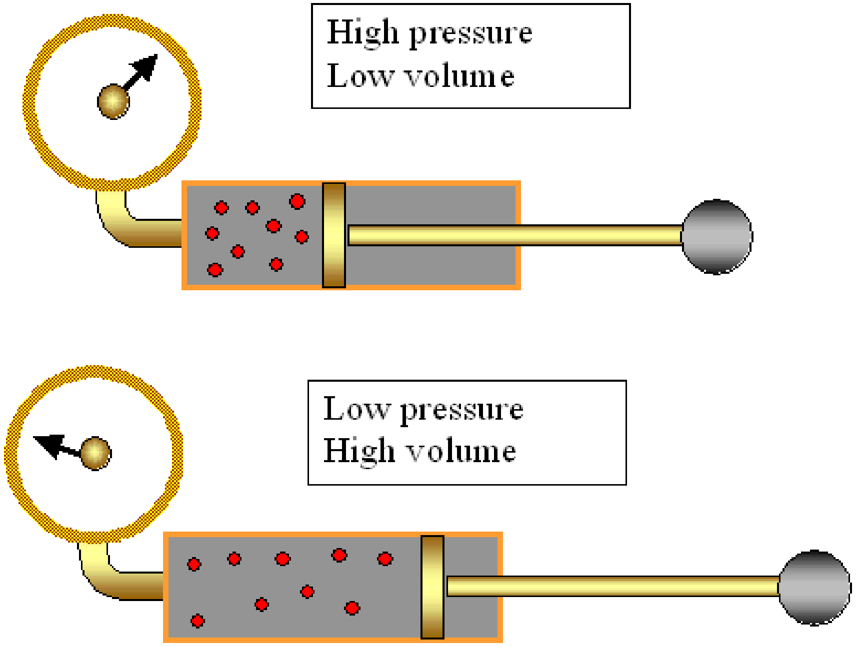
Concentration

- The more particles that are around in a given volume, the more likely they are to collide and react.



Pressure (on gases only)

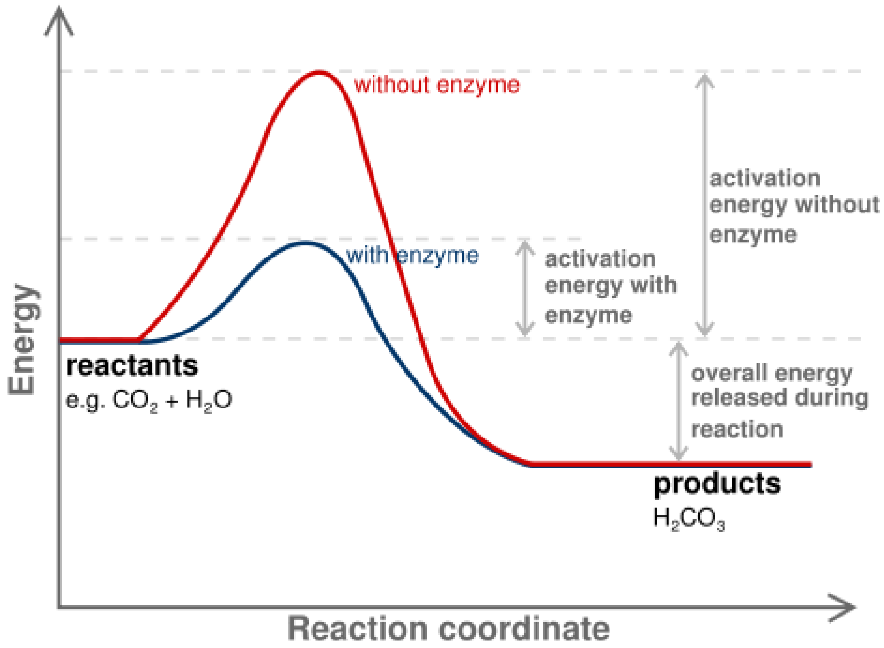
- molecules in a gas are very spread out.
- By ↑ the pressure, you squeeze the molecules together so you will ↑ the frequency of collisions between them.



<u>Catalysts</u>- speed up chemical reactions by lowering activation energy

How they are written: $CO_2 + H_2O \xrightarrow{TiO_2} H_2CO_3$

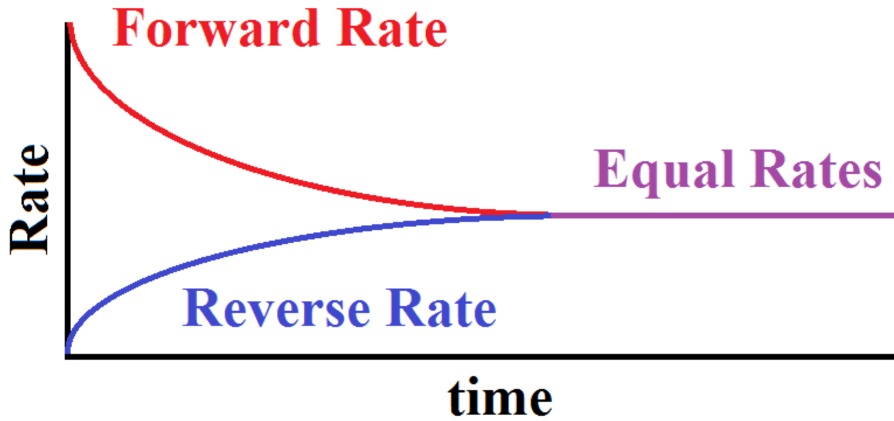
- They do not get used up in the reaction & can be used over and over.
- Ex: enzymes in your digestive track help break down food.



Chemical Equilibrium

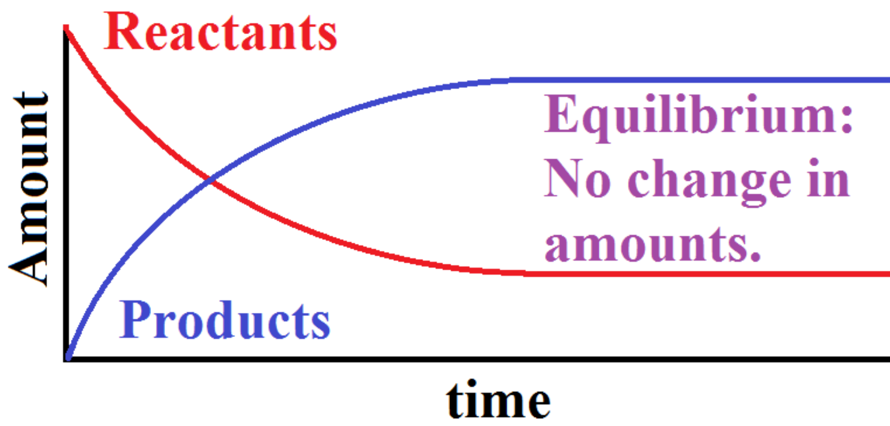
Chemical Equilibrium

Ex: $Cl_2(g) + H_2(g) \leftarrow \rightarrow 2\,HCl(g)$ + heat

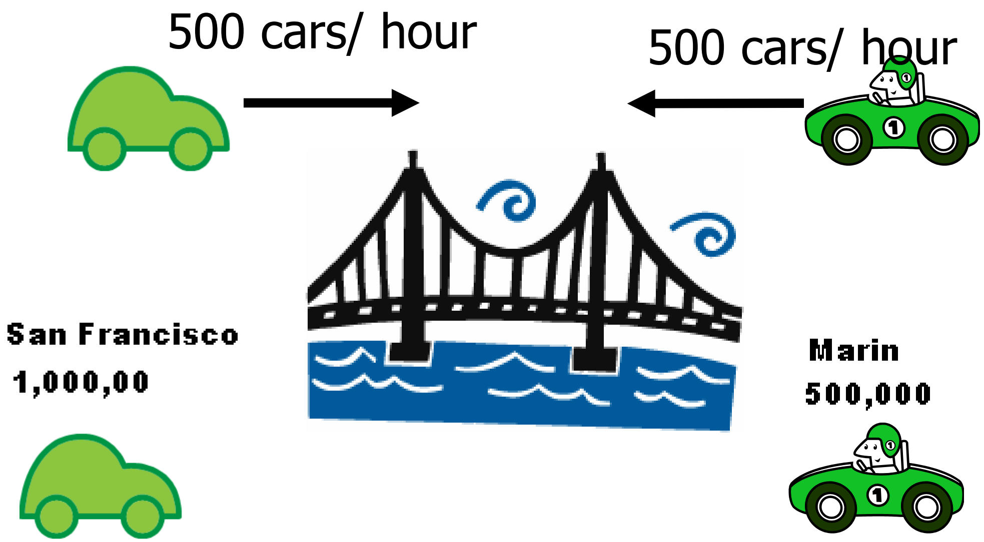


Chemical equilibrium - the rate of the forward reaction is equal to the rate of the reverse reaction.

- The concentration of reactants and products is constant.



Equilibrium Example



Equilibrium Ex:

-if 500 cars/hour cross the Golden Gate bridge in each direction then the rate of reaction is equal.

-The # of cars in each city remains constant, but isn't the same.

Le Chatelier's Principle

- if a stress is applied to a system at equilibrium, the reaction will shift one direction to relieve the stress.
- Stresses:
  - Change in <u>concentration</u>
  - Change in <u>temperature</u>
  - Change in <u>pressure</u>

Change in Concentration & Equilibrium

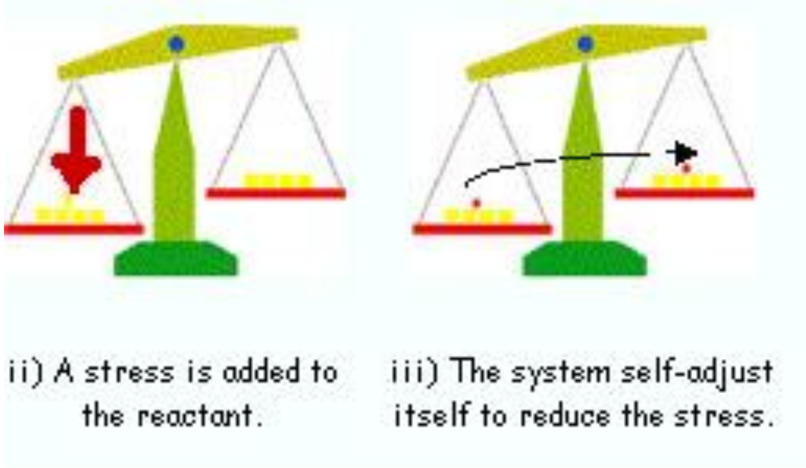
Ex: N_2 (g) + 3 H_2 (g) ← → 2 NH_3 + heat

<u>Stress</u> <u>Relief</u>

- increase N_2 Use excess N_2

<u>How</u>

- Reaction will shift →, (right)



Change in Temperature & Equilibrium

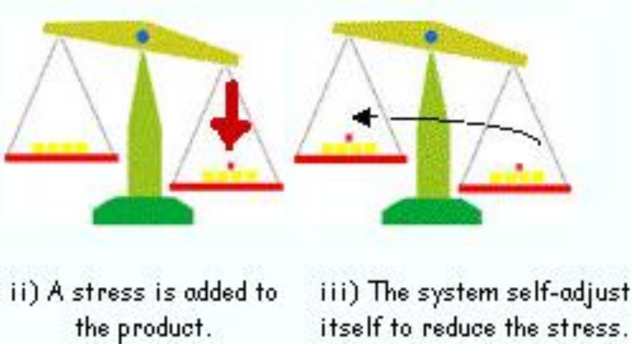
N_2 (g) + 3 H_2 (g) ← → 2 NH_3 + heat

Stress / Relief

- add heat — Use up excess heat

How

- Reaction will shift to the ← left
- because that direction is endothermic (heat absorbing). Going right would increase the heat.



Change in Pressure & Equilibrium (Gases only!)

- Increase of pressure causes shift in the direction that results in the **fewer number** of moles of a gas
- if pressure is relieved, the reaction will shift in the direction that produces more moles of a gas

$$N_2\,(g) + 3\,H_2\,(g) \leftarrow \rightarrow\ 2\,NH_3 + \text{heat}$$

(4 moles) (2 moles)

Stress	Relief
• add pressure	lower pressure

How

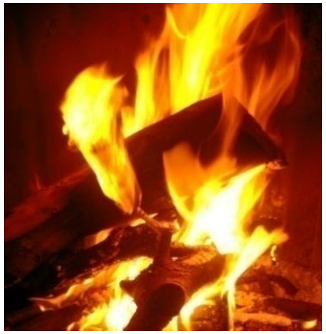
- – Reaction will shift to the →, (right), forward rxn to reduce the pressure (less moles of gas in products)

Thermochemistry

Study of energy transfers that occur during chemical & physical changes

Energy is absorbed or released in all chemical reactions & physical changes

- **Chemical reactions:**
  - Energy absorbed to break bonds
  - Energy given off when bonds form



- **Physical (aka phase) changes:** Energy absorbed or released
  - when molecules move faster/ slower
  - break/ form attractions between molecules

Endothermic & Exothermic

Endothermic & Exothermic- direction that heat flows

- Exothermic= process that releases energy to the environment.

  Ex: $2\ H_2 + O_2 \rightarrow 2\ H_2O + 483.6\ kJ\ (heat)$

- Endothermic= process where energy is absorbed from the environment.

  Ex: $2\ H_2O + 483.6\ kJ\ (heat) \rightarrow 2\ H_2 + O_2$

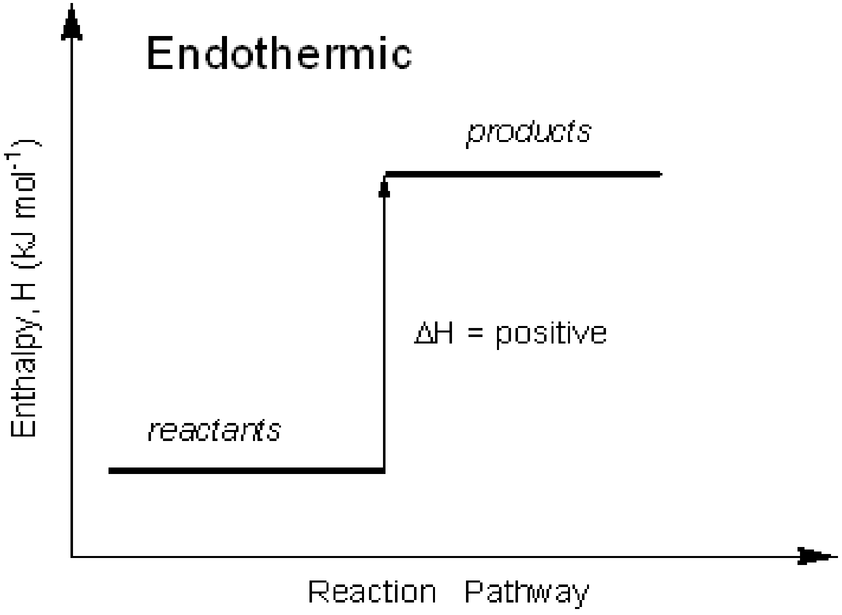
<u>Endothermic Processes-</u> heat is absorbed from environment

- In cold packs, ammonium nitrate, NH_4NO_3, is often used because it absorbs a lot of heat when it dissolves in water.

Heat is taken from the environment <u>into</u> the cold pack.

Heat is absorbed by the ice pack and reduces swelling

Endothermic Reaction
(a graph view)



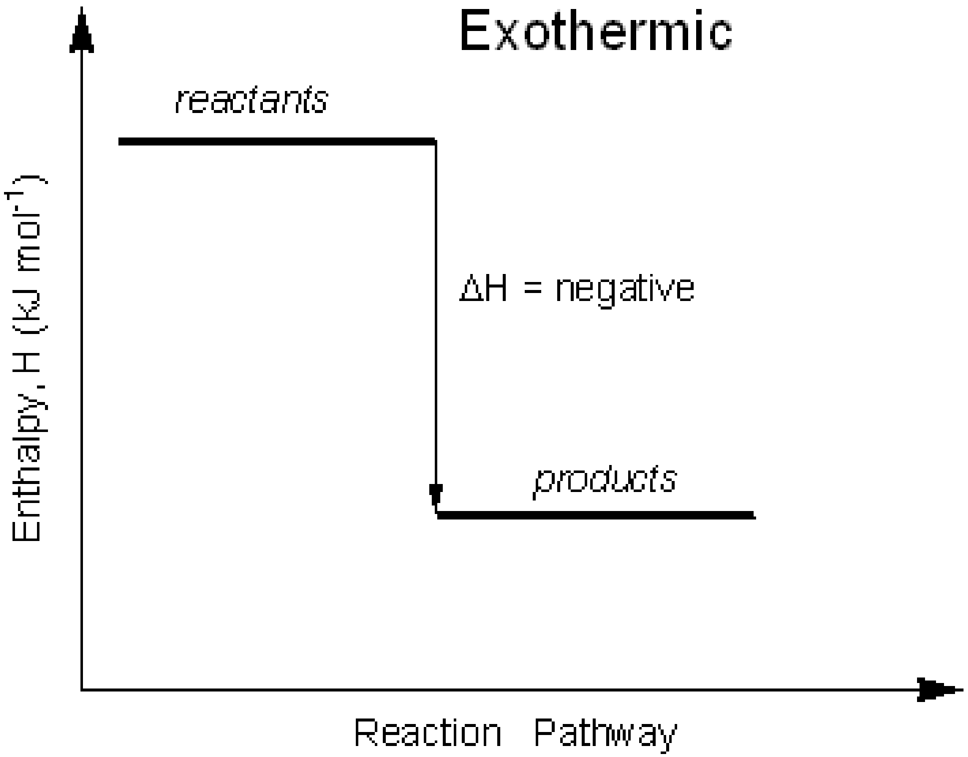
- **Endothermic:**
  Reaction gains heat from the environment
- **Products have more heat energy than the reactants**

Exothermic Processes- releases heat into the environment

- In hot packs, O_2 reacts with Fe inside the hot pack.
- This chemical reaction releases heat.

Heat is being released from the chemical reaction into the environment

Exothermic Reaction (graph view)

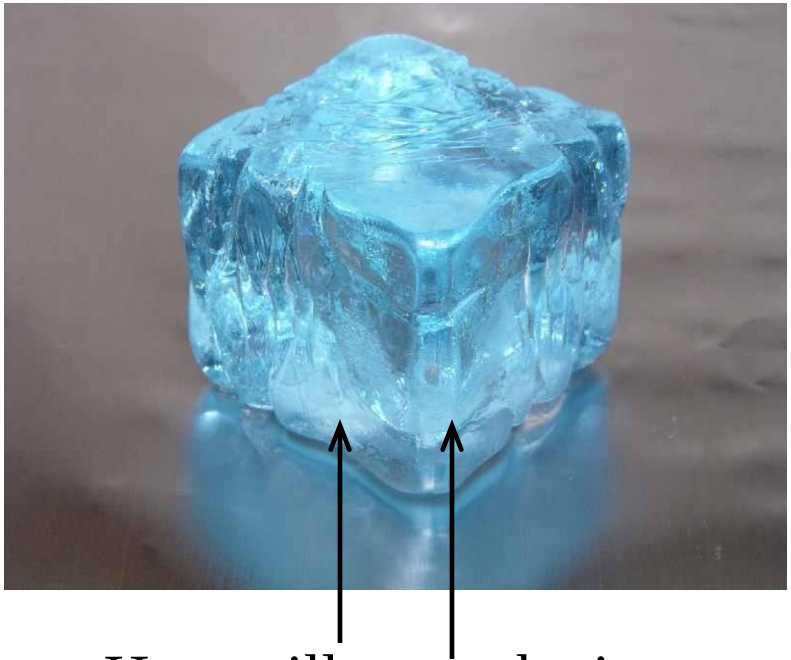


- **Exothermic:** **reaction loses heat to the environment**
- **Products have less heat energy than the reactants.**

Heat

Heat = energy that transfers from a higher temp. object to a lower temp. object

- Heat always moves from a hotter object → colder object
- Heat moves until thermal equilibrium is established and the temperatures are the same.
- Ex: getting used to the swimming pool



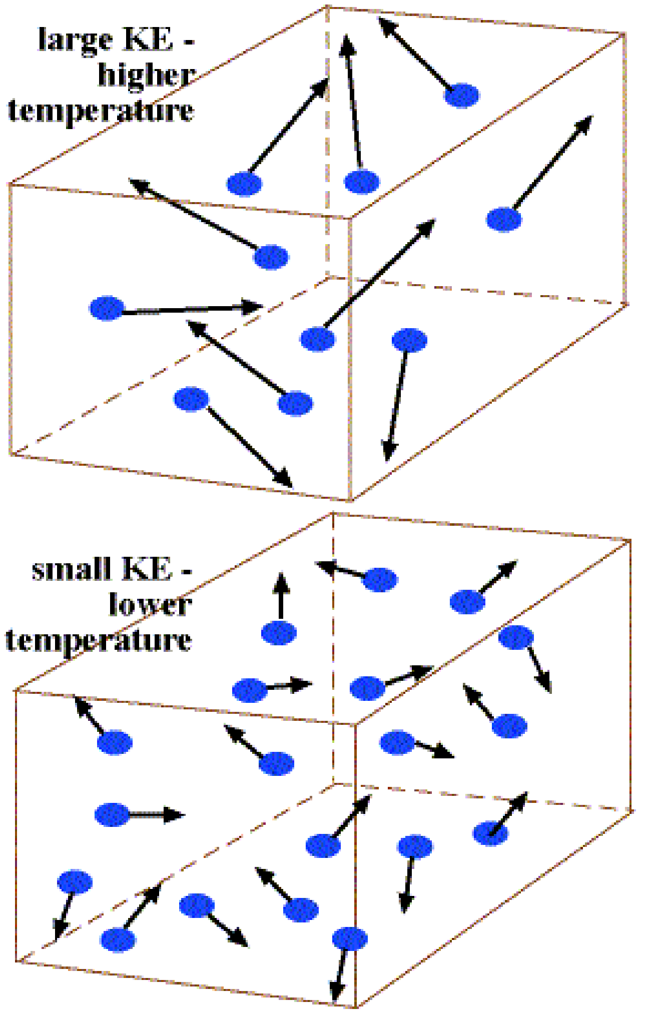
Heat will enter the ice cube from the environment and cause the ice cube to melt.

Temperature vs. Heat

- **<u>Temp</u>** (°C, K) = avg kinetic energy in molecules

(how fast they are moving)

- **<u>Heat</u>** (Joules/ kJ or Calories) = energy that can be transferred between objects
  - based on TOTAL amount of energy (kinetic & potential)



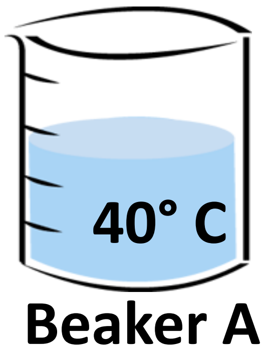
Ex: Heat Vs. Temperature

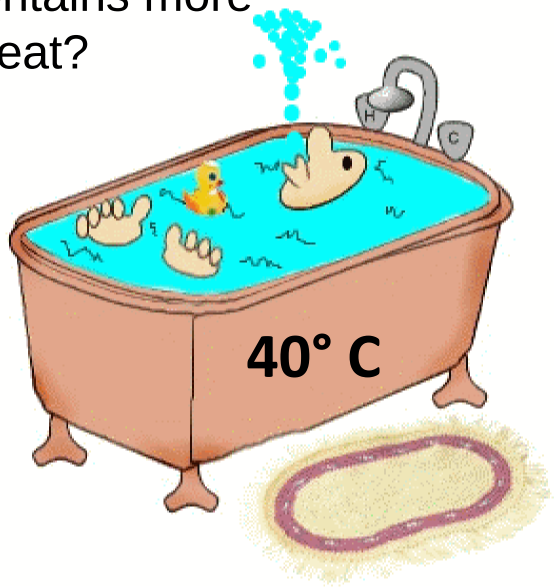
- Temps are same b/c both contain molecules moving at the same avg. speed

But…

- Bath contains more heat because it has more molecules that can transfer more heat

Which contains more heat?





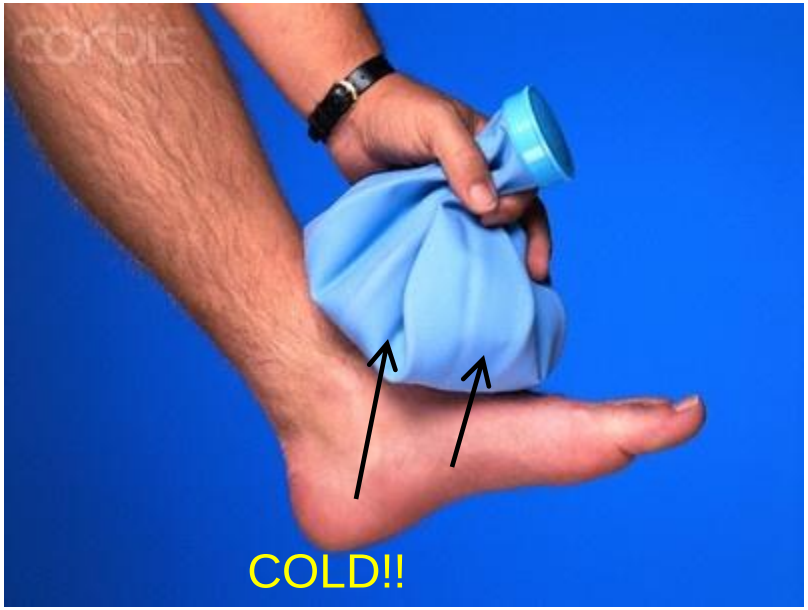
Example of heat vs. Temp.

Which contains more heat?

TEA!!!!

- Both contain molecules moving at the same avg. speed (temp.)
- Heat content is much more for the tea because it has more molecules that can transfer more heat

How your body senses hot/ cold:



- Thermoreceptors= special sensory cells that detect gain or loss of heat
- Heat is leaving your foot and going to the cold pack, thereby making your skin "feel cold"
- "Feel hot" when warm object transfers heat to your cells.

http://cloningmagazine.com/skin.html

Hot/ Cold Vs. Temperature

- Temperature= is absolute, measurement of average speed of molecules.
- Hot/ Cold= terms are relative and reflect heat loss or gain.
- Ex: same temperature, yet 1 person might say “hot” other might say “cold”

How Thermometers Work

- Does not measure temp. directly
- Measures the effect of temperature on physical property of material used in the thermometer.

Mercury expands when it absorbs heat, so it rises up.

Calculations involving Specific Heat

Units for Measuring Heat (q)

- **Joule = SI system unit for measuring heat:**

- **Calorie = heat required to raise the temperature of 1 gram of water by 1 Celsius degree**

$$1 calorie = 4.18 Joules$$

Calculation involving Heat

$$q = m \cdot c \cdot \Delta T$$

q = amount of energy lost or gained during a chemical reaction

Reported in Joules or calories

Mass (grams)

Specific Heat

Amount of heat it takes to raise the temperature of 1 gram of a substance by 1 C.

“delta” T is change in temperature

Final Temp – Initial Temp

Specific Heat

Which slide would you rather go down in summer?

- Is unique to every substance due to the way they absorb energy.
  - Energy can make molecules move faster (temp. increases)
  - Energy can break attraction between molecules (does not raise temperature)

•The plastic slide has a higher "specific heat" (aka heat tolerance) than the metal slide.

•It takes more heat to raise the temperature of 1 g of the plastic by 1 °C than it does the metal.

Specific Heat of some common subtances

Specific Heat (at 25° C)

SUBSTANCE	CAL / GRAM °C	JOULE / GRAM °C
Air	0.24	1.01
Aluminum	0.22	0.90
Ethyl alcohol	0.59	2.45
Gold	0.03	0.13
Granite	0.19	0.80
Iron	0.11	0.45
Olive oil	0.47	2.00
Silver	0.06	0.24
Stainless steel	0.12	0.51
Water (liquid)	1.00	4.18
Wood	0.42	1.76
Water (solid)		2.1
Water (gas)		1.9

Water has an extremely high specific heat

When you heat 1 gram of water it take 4.18 joules of energy to get the temperature to increase 1° C.

Pools cost a lot of money to heat because of this.

Sample Calculation

- Gold has a specific heat of 0.129 J/(g×°C). How many joules of heat energy are required to raise the temperature of 15 grams of gold from 22 °C to 85 °C?

Answer: $q = m \cdot c \cdot \Delta T$

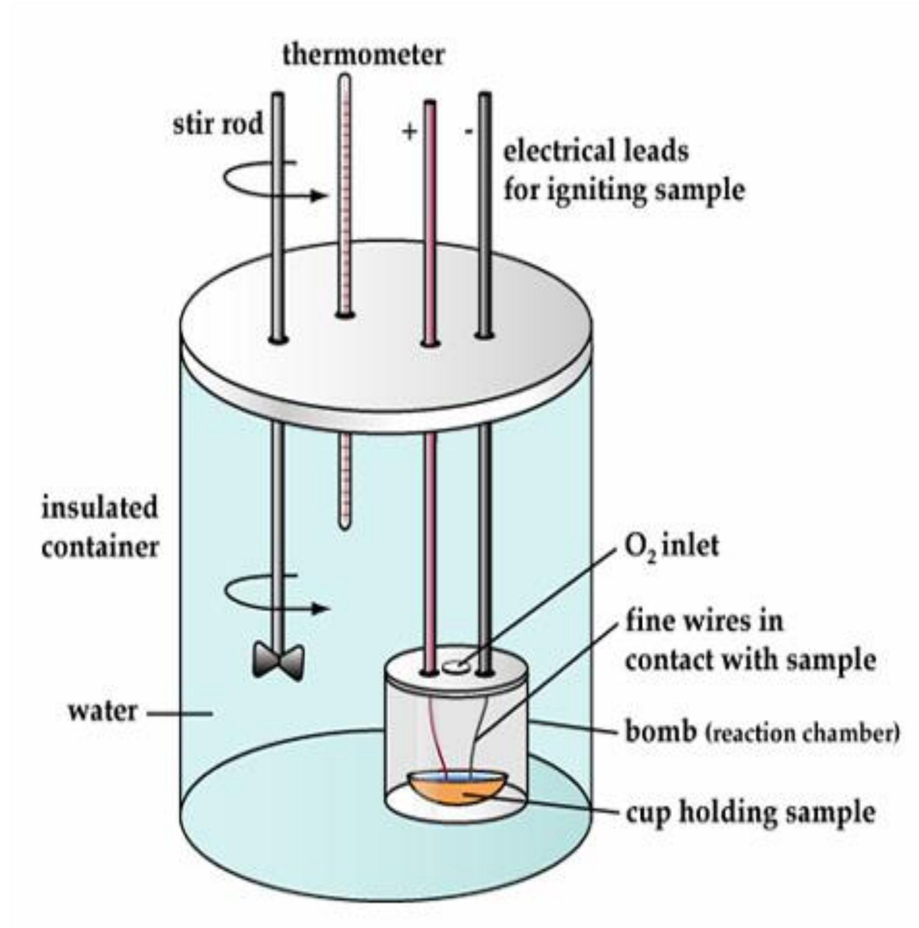
$q = (15\ g)\ 0.129\ J/(g\times°C)\ (85\ °C - 22\ °C)$

q= 120 Joules of heat is absorbed by gold

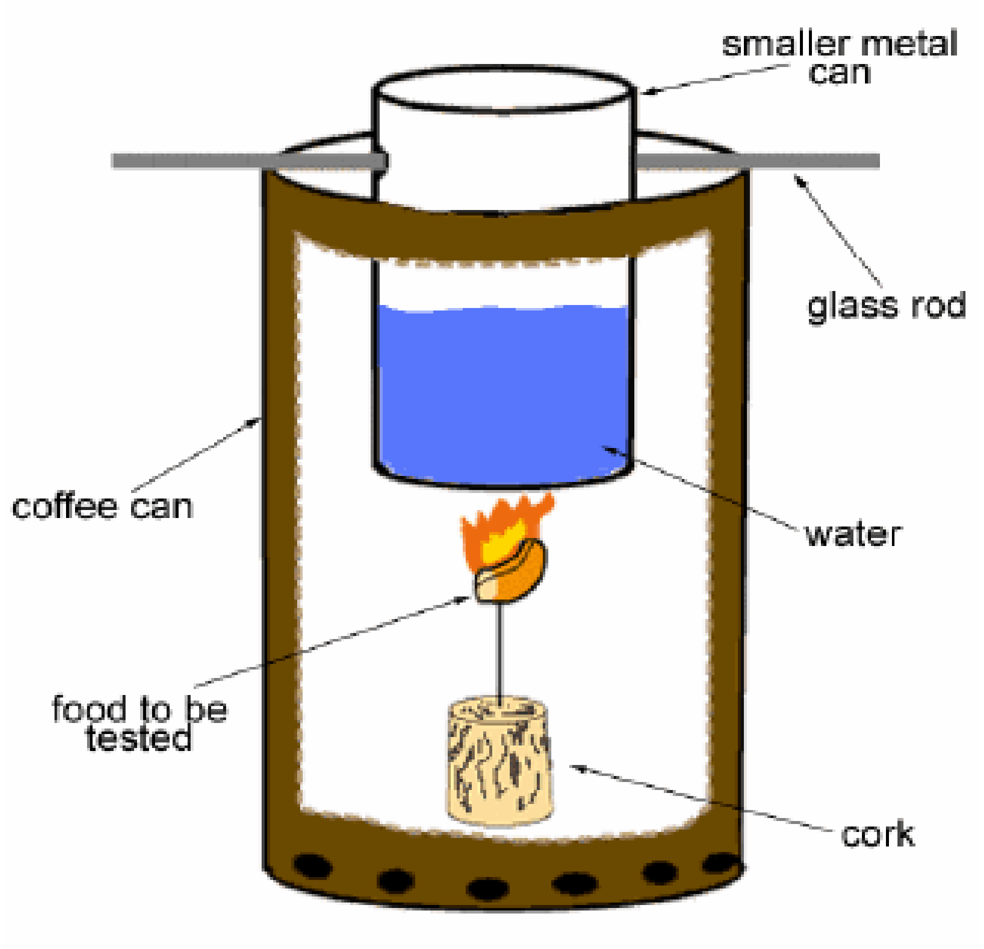
This is an endothermic reaction because energy is entering from outside the system.

Bomb Calorimeter

- Measures the heat absorbed or released in a physical or chemical change
- Amount of heat lost/gained is calculated using the specific heat of water (4.18 J/g ºC)



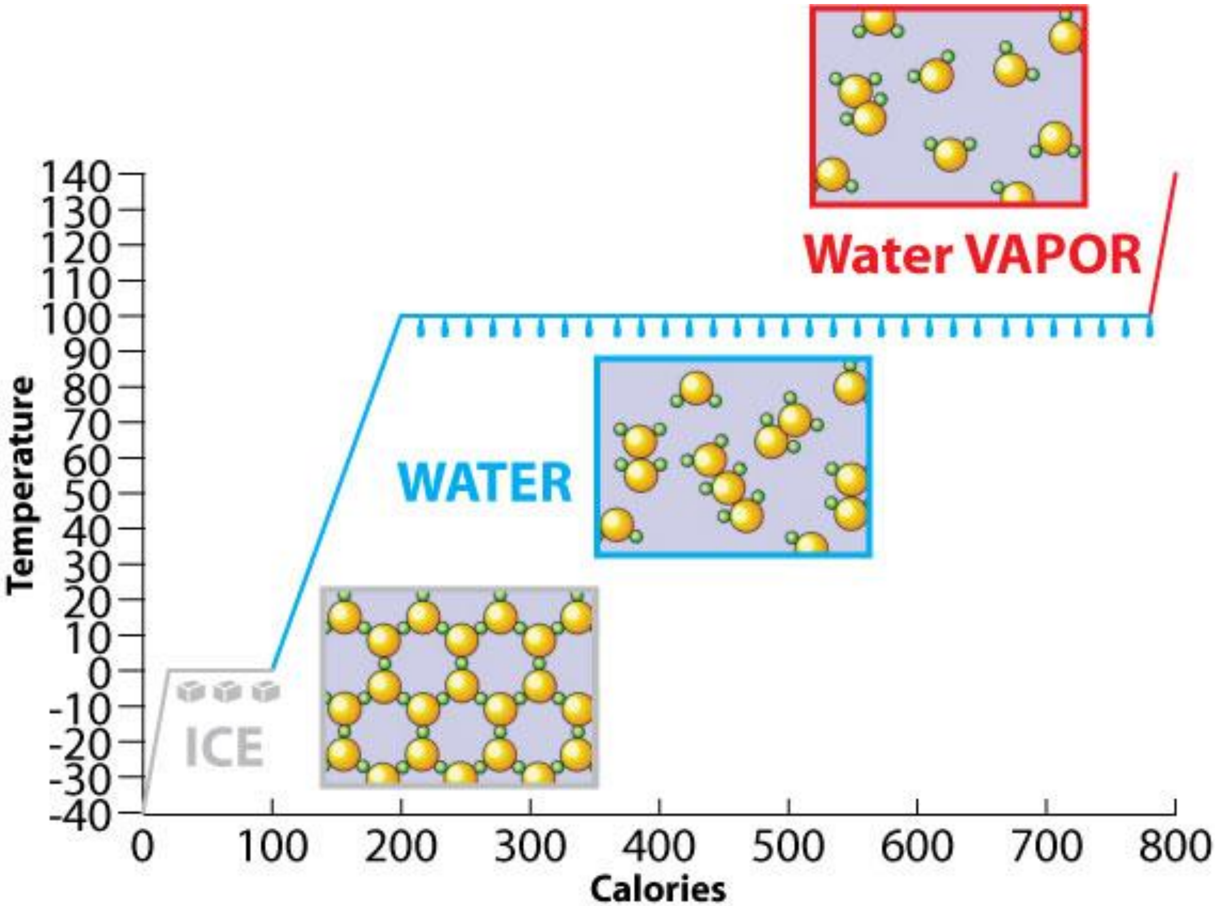
Homemade calorimeter



- Determines how many joules of heat are released by a burning peanut (or any food item).
- The heat from the peanut is transferred to water and that amount of heat is calculated for the water using $q = m \cdot c \cdot \Delta T$

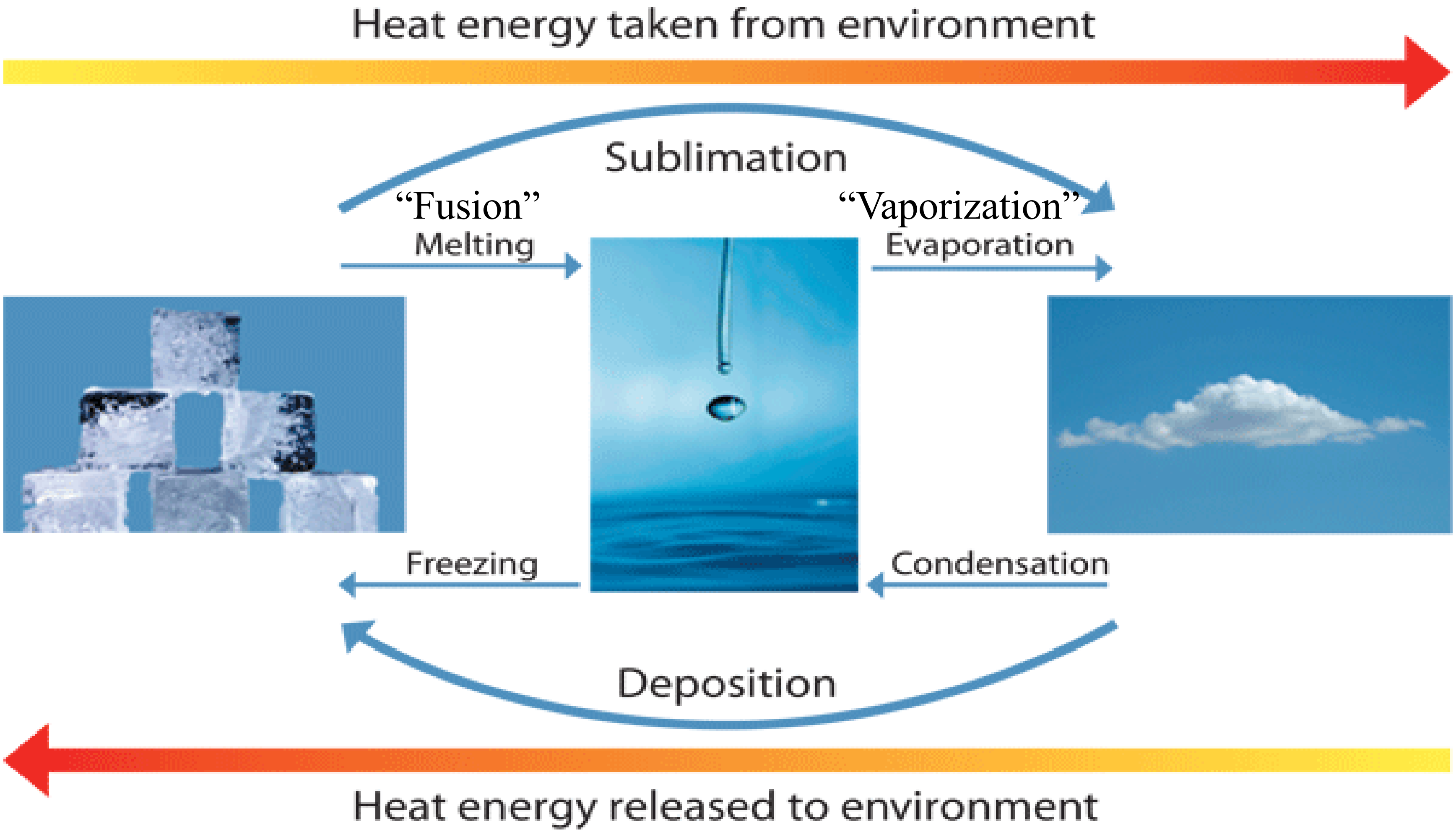
Phase Changes

Phase changes in water

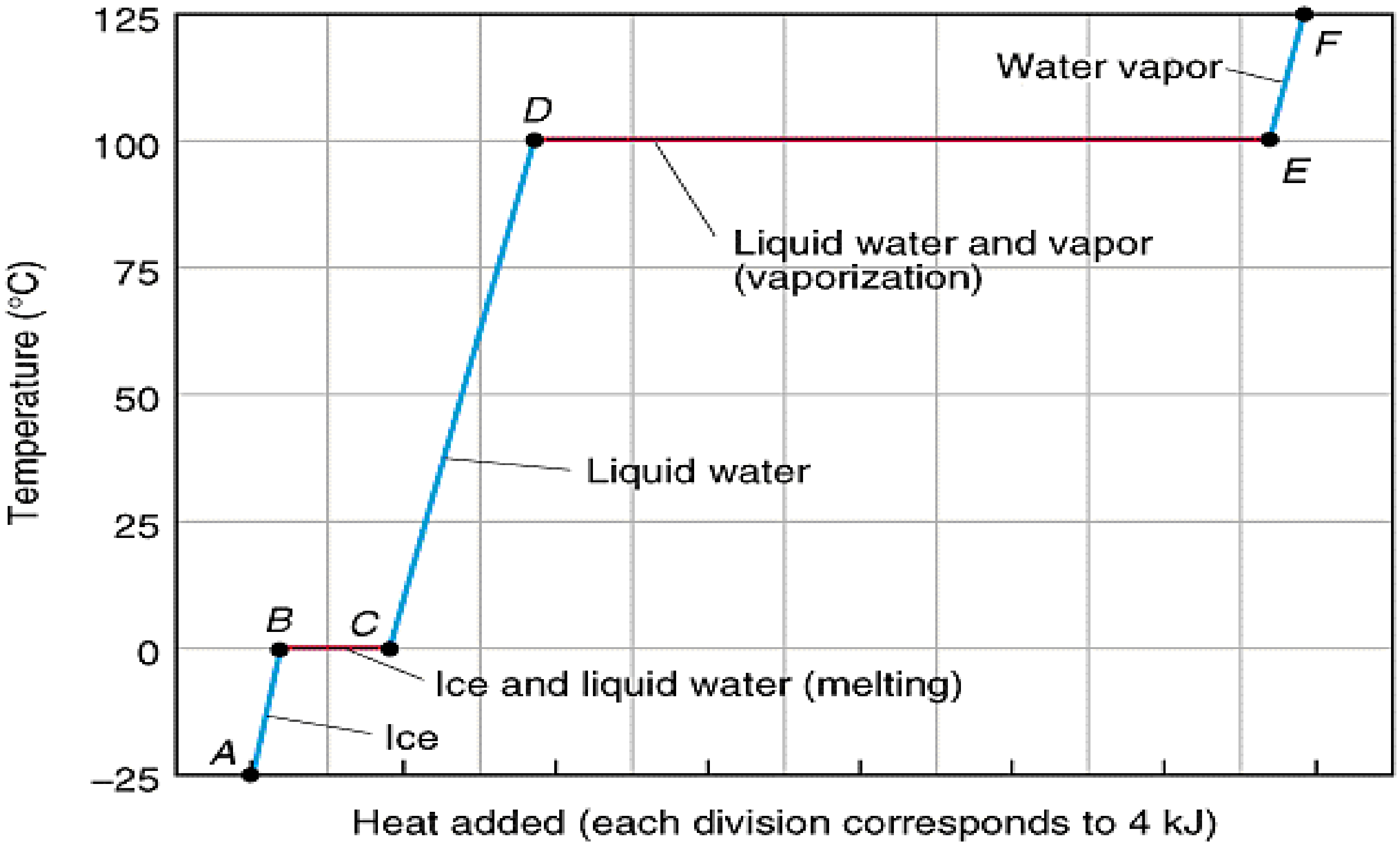


Phase Change Names

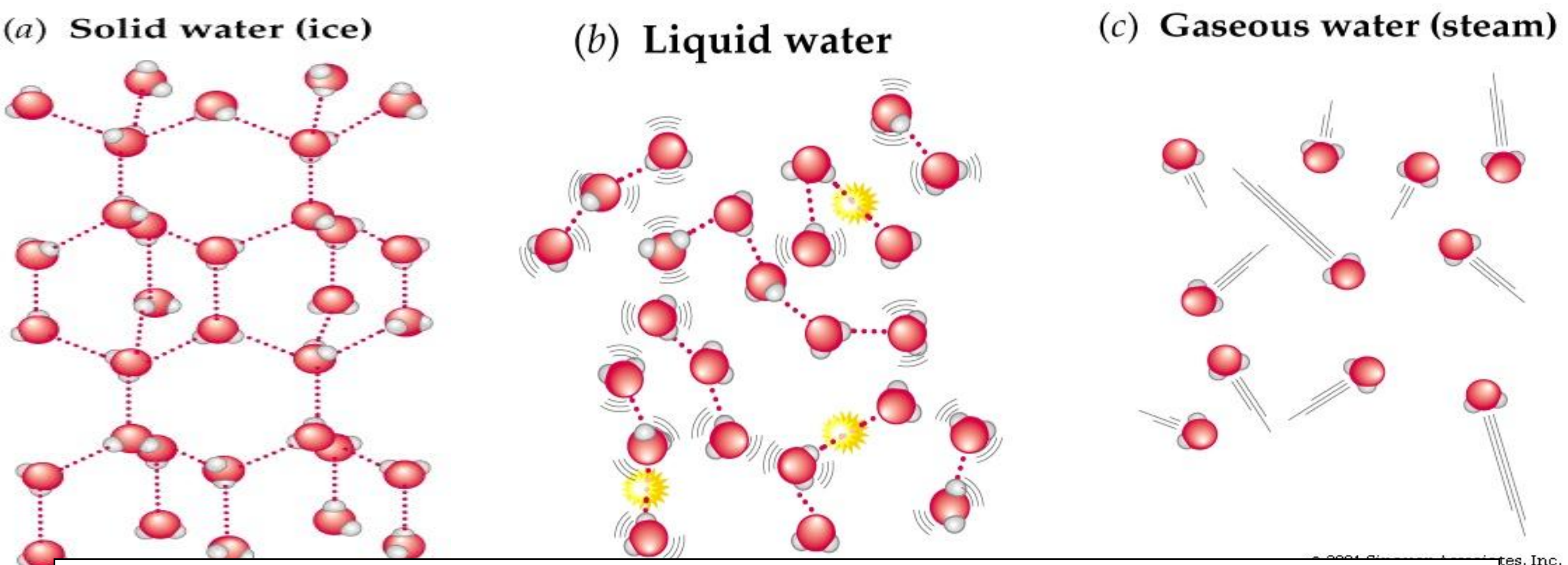
Figure 7



Phase Diagram (water)



Why phase changes require heat energy



Heat breaks/ weakens the intermolecular attraction between molecules.

Calculations involving Phase changes

Calculations with heat & phase changes

2 things can happen when you heat a substance:

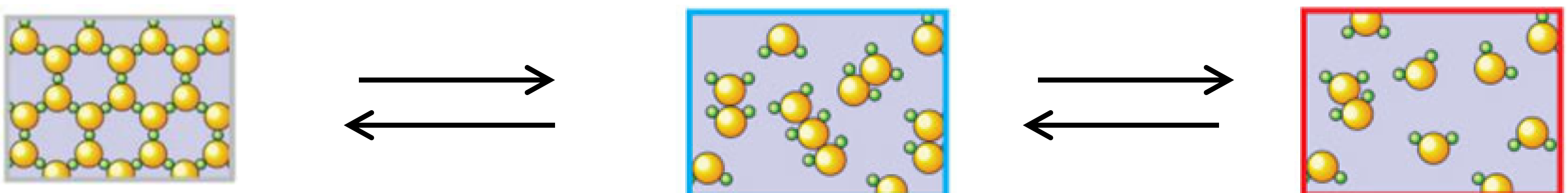
1) heat can be used to speed up the molecules of the substance (**temp. change**) $q = m \cdot c \cdot \Delta T$

2) energy is used to break the H- bonding between the molecules (**substance can change phase**).

$q = m \cdot \Delta H_{Fus}$ (constant) or $q = m \cdot \Delta H_{vap}$ (constant)

ΔH fus H_2O = + 334 Joules/ g

$\Delta H_{vap\ water}$ = + 2260 Joules/ g



ΔH fus H_2O = - 334 Joules/ g

$\Delta H_{vap\ water}$ = - 2260 Joules/ g

See notes from class… I did #9 on heating curve Wksht.

Sample problem

How much heat is required to melt 2 grams of ice at O C?

- This is a phase change (no temp. change)
- Use formula: $q = m \cdot \Delta H_{Fus}$

$$q = (2\ g)\ (334\ J/\ g)$$

q= 668 Joules to melt ice

Heat energy being used to disrupt hydrogen bonds between water molecules.

Sample problem

How much heat is required to vaporize 2 grams of water at 10O C?

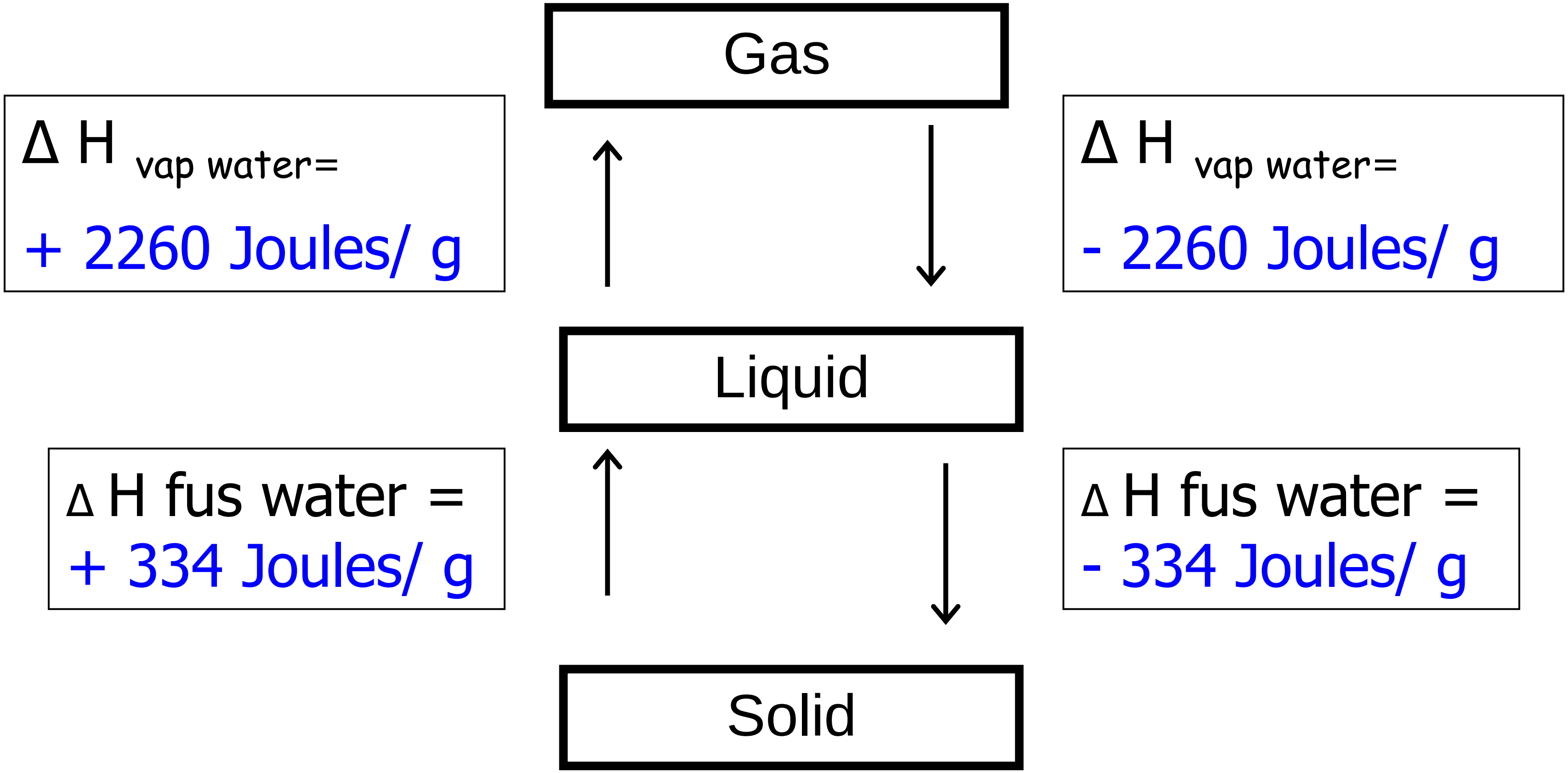
- This is a phase change (no temp. change)
- Use formula: $q = m \cdot \Delta H_{vap}$

$q = (2\ g)\ (2260\ J/g)$

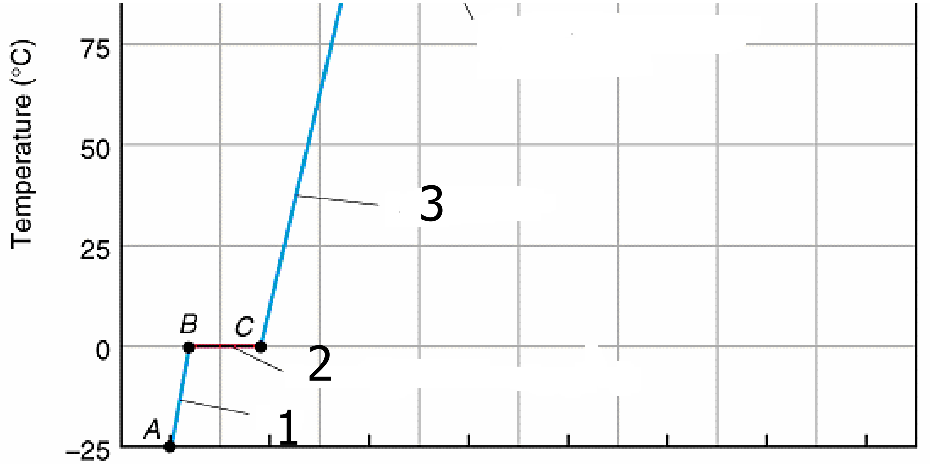
$q = 4520$ Joules to vaporize

Heat energy being used to disrupt hydrogen bonds between water molecules…all have to be broken to turn into gas

Summary:
Fusion and Vaporization for Water



Sample Problem: How much heat in KJ is required to change 50 grams of ice at -10 ° C to a liquid at 40 ° C?



Step 1: Find heat it takes to raise ice from -10 ° C to 0 ° C ($q = m \cdot c \cdot \Delta T$)

q= (50g) (2.1 J/g ° C) (10 ° C) = **1050 J**

Step 2: Find heat to do a phase change from solid- liquid ($q = m \Delta H_{Fus}$)

q = (50 g) (334 J/ g) = **16700 J**

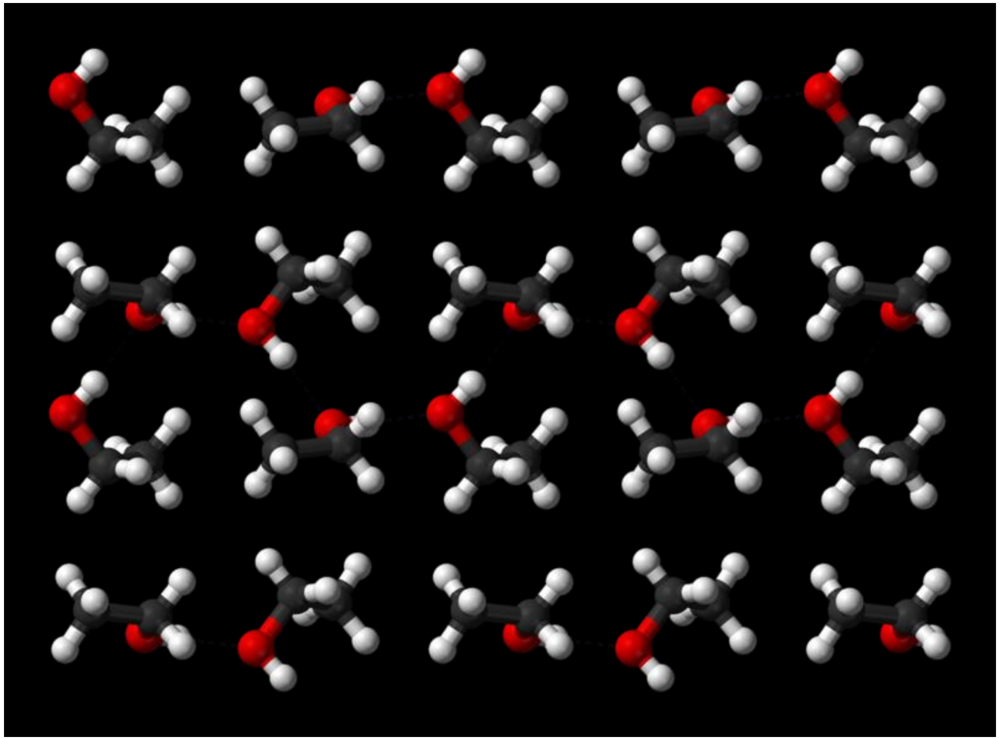
Step 3: Find heat it takes to raise temp from 0 ° C to 40° C ($q = m \cdot c \cdot \Delta T$)

q= (50 g) (4.18 J/g ° C) (40 ° C)= 8360 J

Total (add steps 1+2+ 3)= 27150 J or 27.150 KJ

Hydrogen bonding in Ethanol (alcohol) @ -186° C

- Notice how there is less hydrogen bonding than water.
- Melting point= -114 ° C
- Boiling Point = 78.4 ° C



Applications

Purpose of Sweat

When sweat evaporates from your skin, it removes excess heat and cools you

1 gram sweat uses 2260 Joules of body heat to evaporate

HeatGear- pulls perspiration away from the skin and push it through the clothing's surface, where it evaporates

Polar Phase Change Cooling Garments

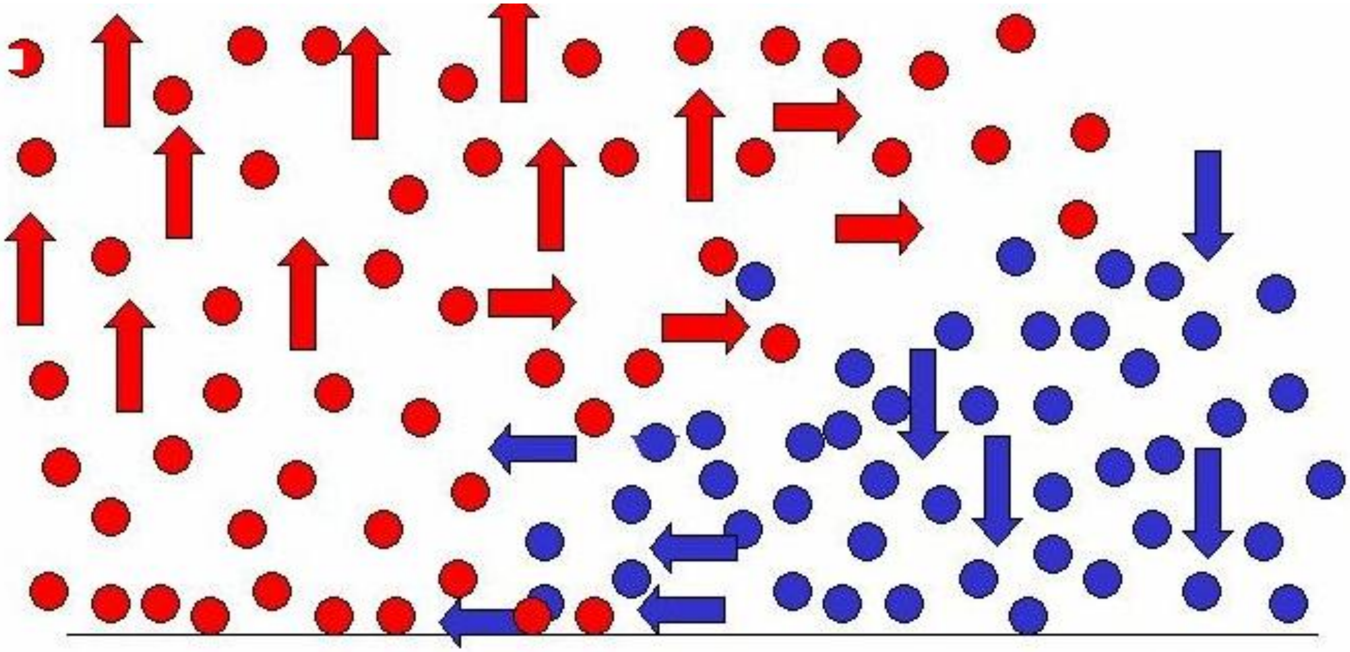
- "Passive Cooling Garments that release long lasting, 58 °F temperature specific, cooling energy."

How misters work

-Cools patios by up to 35 ° F

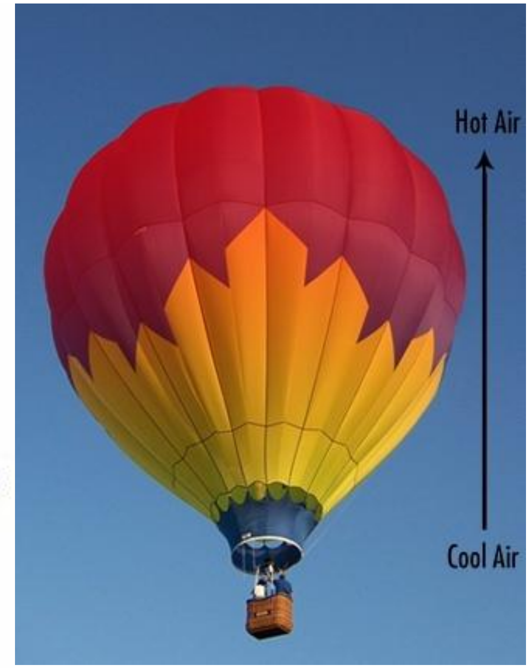
-Evaporation uses heat from the air, thus dropping the temperature.

Why does warm air rise?



Hot or sunny ground heats up the air above it.
The molecules move faster and spread out.

Cool water or shady ground chills the air above it.
The molecules move slower and are dense. The hotter air starts floating above.



This creates our wind/ weather patterns

Extras

Bond Energies

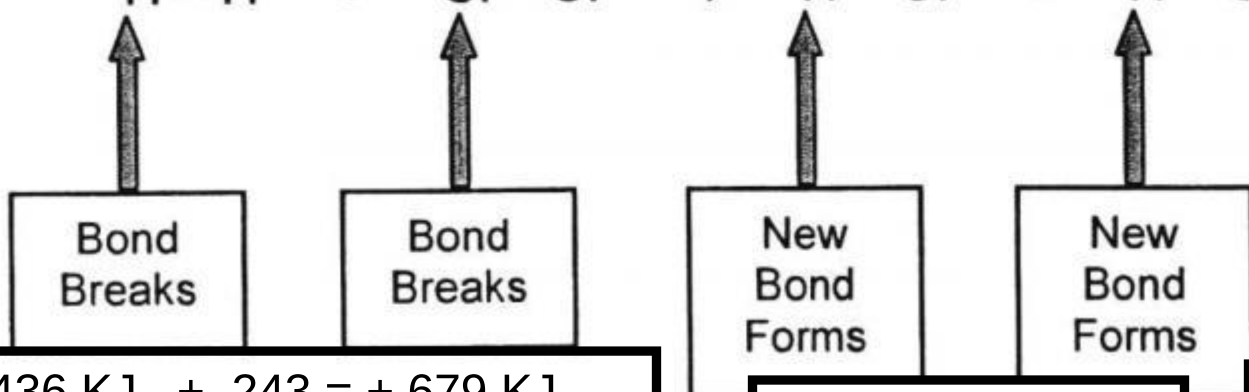
Energy is used to break bonds & is released when new bonds form.

Bond	Bond Energy	Bond	Bond Energy
C–C	347 kJ/mol	H–Cl	432 kJ/mol
C–O	358 kJ/mol	H–O	464 kJ/mol
C–H	413 kJ/mol	H–N	391 kJ/mol
C–N	286 kJ/mol	H–H	436 kJ/mol
C–Cl	346 kJ/mol	O=O	498 kJ/mol
Cl–Cl	243 kJ/mol	N≡N	945 kJ/mol

hydrogen + chlorine → hydrogen chloride

$H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)}$ + 185 KJ

H – H + Cl – Cl → H – Cl + H – Cl

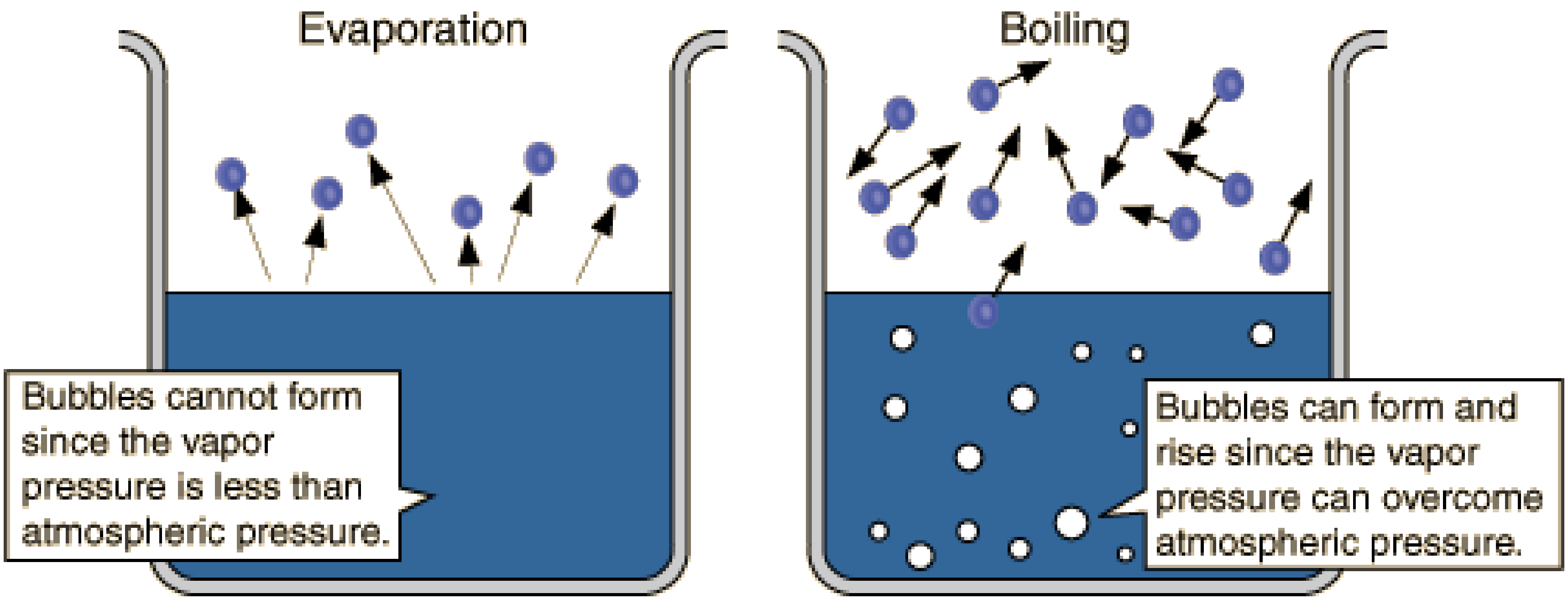


436 KJ + 243 = + 679 KJ (absorbed)

2 (432)= -864 KJ (released)

= -185 KJ lost

FYI: 2 ways Vaporization can occur: Evaporation Vs. Boiling



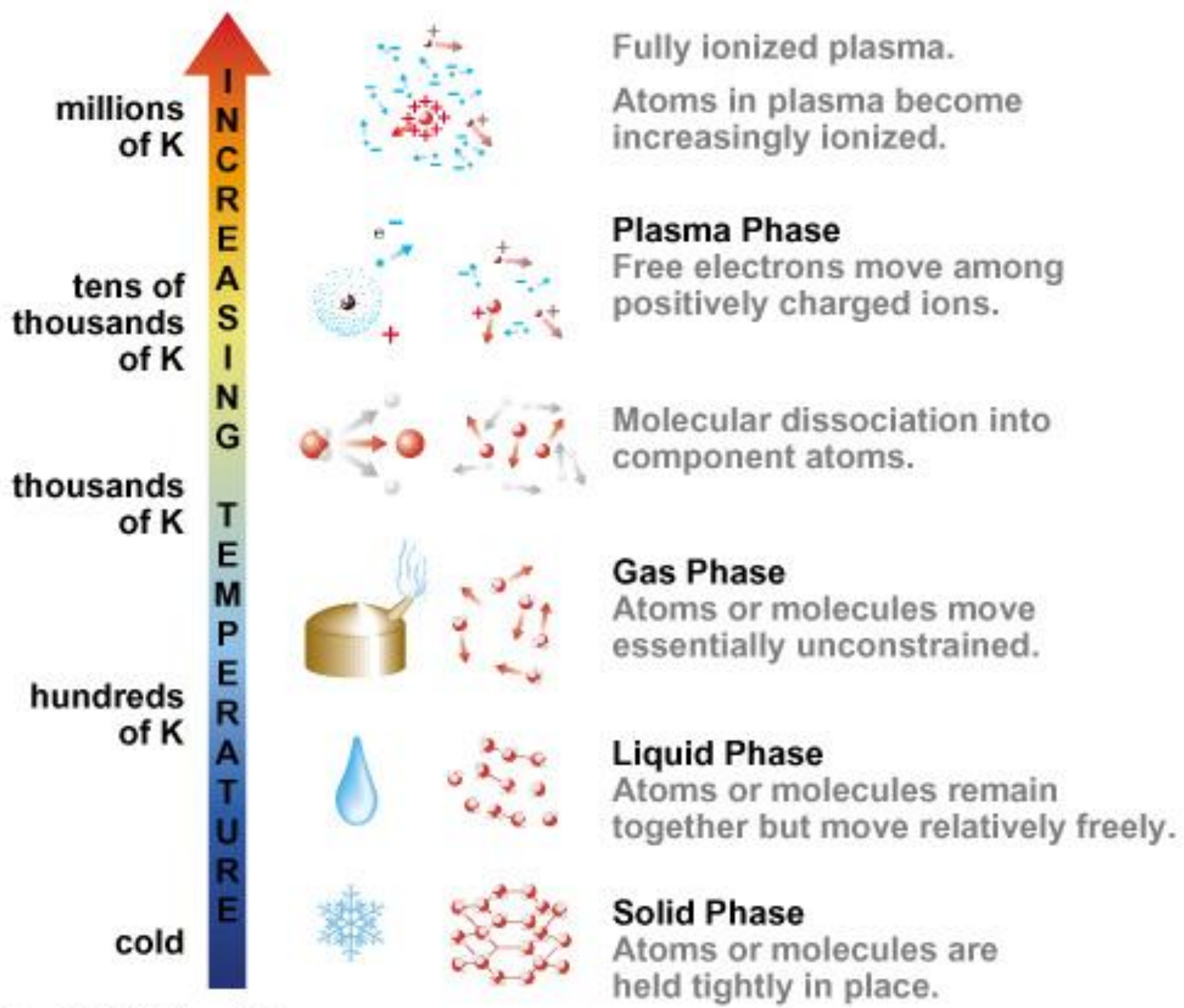
-Occurs at temperatures less than boiling (100° C)

-occurs on surface of the liquid

-Occurs at 100° C, but never goes above.

-Can heat up faster or slower, but same temp.

Phases of Matter



Phases of Matter (review)

Solid	**Liquid**	**Gas**
•Motion of particles is restricted (only vibrational) •Particles are more closely packed •Lowest kinetic energy •Strong intermolecular forces	•Have definite volume •Particles are in constant motion •Lower kinetic energy than gas particles •Attractive forces between particles effect their behavior •Particles are not fixed, but are closer together than in a gas	•Particles are in constant, rapid motion •Highest kinetic energy state of matter •Attractive forces do not effect their behavior •Particles are far apart

Salt in Boiling water

- The answer to the question why do bubbles form when water is boiled? explains how, as the temperature of water rises, its molecules move around faster, collide more often and release more water vapor gas molecules. When the temperature reaches boiling point - about 100°C (212°F) - the pressure from the release of these molecules (the vapor pressure) becomes greater than atmospheric pressure and water vapor starts to escape as bubbles.

  In salty water, Na+ and Cl- ions occupy some of the space between the water molecules. As temperature increases, although the water molecules are moving faster, there are less of them, so there are fewer collisions, less release of water vapor molecules and lower vapor pressure compared to pure water at the same temperature. It takes more energy (temperature) for the vapor pressure of salt water to reach and exceed atmospheric pressure and start to boil.

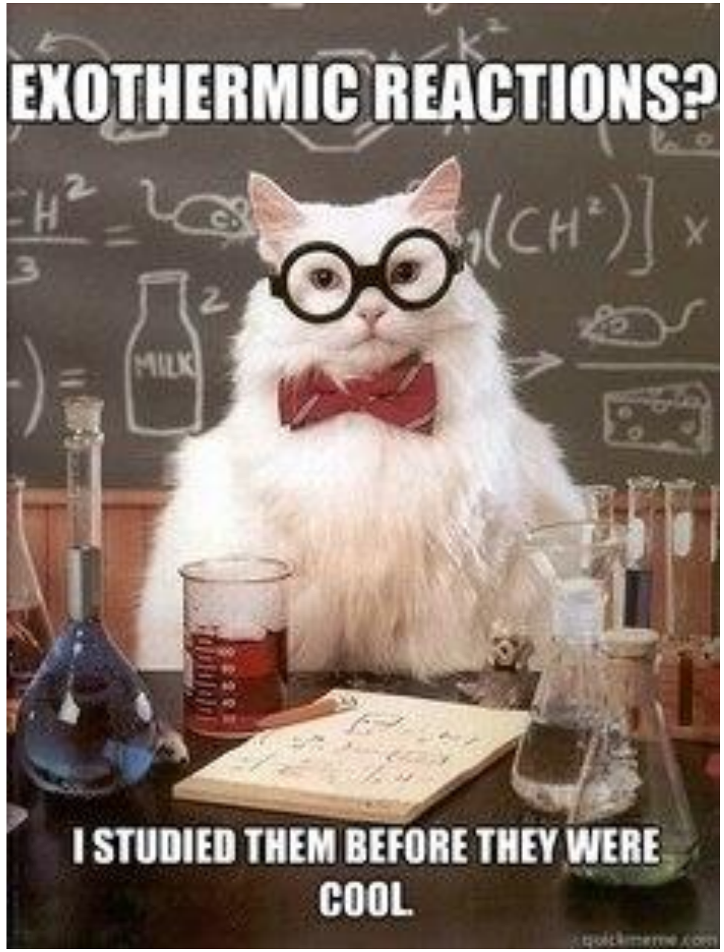
  To raise the boiling point of one liter (34 ounces) of water by 1°C (1.8°F) requires about 58 grams (2 ounces) of salt. This is much more that the amount of salt typically added to boiling vegetables, which is done primarily for taste.

If you ever watch salt melting ice, you can see the dissolving process happen -- the ice immediately around the grain of salt melts, and the melting spreads out from that point. If the temperature of the roadway is lower than 15 F or so, then the salt really won't have any effect -- the solid salt cannot get into the structure of the solid water to start the dissolving process. In that case, spreading sand over the top of the ice to provide traction is a better option.

- Put another way, if a solute is dissolved in a solvent, then the number of solvent molecules at the surface of the solution is less than for pure solvent. The surface molecules can thus be considered “diluted” by the less volatile particles of solute. The rate of exchange between solvent in the solution and in the air above the solution is lower (vapour pressure of the solvent is reduced). A lower vapour pressure means that a higher temperature is necessary to boil the water in the solution, hence boiling-point elevation.

Joke

- Two scientists walk into a bar
- The first one says “I’ll have some H2O.” The second one says, “I’ll have some H2O too.” Then he dies


EXOTHERMIC REACTIONS?
I STUDIED THEM BEFORE THEY WERE COOL.