UNIT 6: THERMODYNAMICS--Guided Notes

TOPIC 6.1: ENDOTHERMIC & EXOTHERMIC PROCESSES

Learning Objective: Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation

I. Energy, Systems, and Surroundings

A. Energy is _________________________ to break bonds and attractive forces

1. Remember:

2. Energetically __________________________

B. Energy is ___________________________ when forming bonds and attractive forces

1. Remember:

2. Energetically ________________________________

3. Coulomb's Law Connection:

C. BARF:

D. Enthalpy:

E. System:

1. This is where:

2. Not always ________________________

3. Can exchange ____ with the surroundings

F. Surroundings:

1. Examples:

2. When we measure temperature changes, we are measuring the:

II. Energy & Work

A. _________________ or ___________________ are always transferred between system and surroundings

B. Formulas:

C. Heat:

1. Units:

2. Symbol:

3. Heat is negative when:

4. Heat is positive when:

D. Work:

1. Symbol:
2. Typical application in chemistry:

    a) Formula:

    b) How does this correspond to energy?

3. Work is negative when:

4. Work is positive when:

III. Exothermic

A. Exothermic reaction:

1. The temperature of the surroundings:

2. Surroundings feel:

3. Changes that involve:

4. Phase changes:

    a) Examples:

5. Describe the relationship between the energy to break and the energy to form bonds in an exothermic reaction:

6. Work is:

7. Sketch an exothermic reaction energy diagram:

    a) How does the energy of the reactants and products compare?

    b) Enthalpy (ΔH) is:

8. Sketch the heating curve for an exothermic reaction:

IV. Endothermic

A. The temperature of the <u>surroundings</u>:

B. Surroundings feel:

C. Changes that involve:

D. Phase changes:

E. Describe the relationship between the energy to break and the energy to form bonds in an exothermic reaction:

F. Work is:

G. Sketch an endothermic reaction energy diagram:

1. How does the energy of the reactants and products compare?

2. Enthalpy (ΔH) is:

H. Sketch the heating curve for an endothermic reaction:

V. Quick Check:

A. Is the vaporization of ethanol exothermic or endothermic? Explain.

B. Is the condensation of ethanol exothermic or endothermic? Explain.

VI. Solutions

A. When a solution forms, 3 processes take place:

B. How can you determine if the dissolution overall is endothermic or exothermic?

VII. Ambiguous System Change

A. Ambiguous change:

B. The dissolving of ionic compounds is an ambiguous change

Claim	Physical	Chemical
Evidence		
Reasoning		

VIII. Practice

A. I Do:

1. When urea, H_2NCONH_2, is dissolved in water a decrease in temperature is measured. A student makes the following conclusion. Do you agree or disagree? Explain your position.

   The decrease in temperature indicates that the system is losing heat, suggesting that the dissolving process is exothermic as heat is released when urea hydrogen bonds with water.

B. We Do:

SCAN ME

1. A solution of ammonium nitrate was created by dissolving 5.02 g of ammonium nitrate in 100.0 mL of water at 22.3℃. After forming the solution the temperature was 17.3℃.
   a) Did heat enter or leave the system?

   b) What is the sign for q?

   c) Was the dissolution process endothermic or exothermic?

C. You Do:

1. Classify the following processes as endothermic or exothermic:
    a) When whipped cream is forced out of the can, it is propelled by dinitrogen monoxide gas, N_2O. After expelling the whipped cream, the can feels cold. The can is the surroundings.

    b) When water is placed into a freezer, it forms ice cubes. The water is the system.

    c) Ice melt, calcium chloride, $CaCl_2$, is used in the winter to melt ice on sidewalks and driveways. The $CaCl_2$ is the system and the ice is the surroundings.

2. When an ionic compound is formed from its elements there are many steps involved, collectively they are referred to as the Born-Haber cycle, and added together they give the heat of formation. They are listed below. Classify each step as exothermic or endothermic.

$$M_{(s)} + \frac{1}{2} X_{2(g)} \rightarrow MX_{(s)}$$

	Process	Endothermic or Exothermic?
Enthalpy of sublimation	$M_{(s)} \rightarrow M_{(g)}$	
Ionization energy	$M_{(g)} \rightarrow M^{+}_{(g)} + e^{-}$	
Enthalpy of dissociation	$\frac{1}{2} X_{2(g)} \rightarrow X_{(g)}$	
Electron Affinity	$X_{(g)} + e^{-} \rightarrow X^{-}_{(g)}$	
Lattice energy	$M^{+}_{(g)} + X^{-}_{(g)} \rightarrow MX_{(s)}$	

3. For a demo, a chemistry teacher puts some samples of 2 different pure solid powders in a beaker. The teacher places the beaker on a small wooden board with a wet surface, then stirs the contents of the beaker. After a short time the students observe that the bottom of the beaker is frozen to the wood surface. The teacher asks the students to make a claim about the observation and to justify their claims. Which of the following is the best claim and justification based on the students' observations?
    a) An exothermic chemical change occurred because heat flowed from the contents of the beaker to the room
    b) An exothermic physical change occurred because heat flowed from the contents of the beaker and the water on the board to the room
    c) An endothermic physical change occurred because the freezing of water is an endothermic process
    d) An endothermic chemical change occurred because the temperature of the beaker and the water on the board decreased as heat was absorbed by the reaction

4. Which of the following phase changes involves the transfer of heat from the surroundings to the system?
    a) CH_4 (g) → CH_4 (l) because CH_4 molecules in the gas phase must absorb energy in order to move closer together, thereby increasing the intermolecular attractions in the solid state
    b) CO_2(g) → CO_2(s) because CO_2 molecules in the gas phase must absorb energy in order to move closer together, thereby increasing the intermolecular attractions in the liquid state
    c) H_2O(l) → H_2O(s) because H_2O molecules in the liquid phase must absorb energy in order to create a crystalline structure with strong intermolecular attractions in the solid state
    d) NH_3(l) → NH_3(g) because NH_3 molecules in the liquid phase must absorb energy in order to overcome their intermolecular attractions and become free gas molecules

5. Oranges are typically grown in warm climates because the trees can be damaged by freezing temperatures. If a farmer knows that the temperatures are going to drop below freezing they will spray orange trees with water. Which of the following explains why this protects the oranges and orange trees from freezing damage?
    a) The water protects orange trees by freezing before the oranges do; the process of freezing releases heat which is absorbed by the oranges so they don't freeze
    b) The water protects the orange trees by freezing before the oranges do; the process of freezing absorbs heat which is released by the oranges so they don't freeze

6. Which of the following explains why the solution feels warm when a small amount of water is added to solid anhydrous copper (II) sulfate?
    a) Hydrogen bonding occurs between the solute and the solvent, releasing energy
    b) Energy is released as the new water molecules bond to the ionic solid, forming a hydrated molecule
    c) Energy is released as the solute ions interact with the solvent
    d) Energy must be added to the system to make the ionic solid dissolve

7. The dissolution of the compound LiI is found to be an exothermic process. Which of the following statements must be true?
    a) The solute-solvent interactions have the same strength as the solute-solute and solvent-solvent interactions
    b) The solute-solvent interactions are weaker in strength than the solute-solute and solvent-solvent interactions combined
    c) The solute-solvent interactions are greater in strength than the solute-solute and solvent-solvent interactions combined
    d) The relative strength of solute-solvent, solute-solute, and solvent-solvent interactions before and after the dissolution process are not related to whether the process is endothermic or exothermic

8. A gas is heated at constant pressure. Which of the following is true concerning this system?
    a) $\Delta H = q + w$ where q represents the quantity of heat transferred and w is the work term
    b) Since the pressure is constant, no work is being done
    c) The surroundings do work on the system
    d) Because the process occurs at a constant pressure, the volume of the system must be increasing

TOPIC 6.2: ENERGY DIAGRAMS

Learning Objective: Represent a chemical or physical transformation with an energy diagram

I. Exothermic vs. Endothermic
   A. Exothermic reaction:

      1. Heat _______________ the system

      2. Work is __________________ the system

      3. The products are ________________________________ than the reactants

         a) Energy has been:

II. Energy Diagrams
   A. Also called:

   B. Draw the energy diagram labeling the following:
      1. X-axis
      2. Y-axis
      3. Reactants
      4. Products
      5. Energy curve
      6. Activation energy
      7. Activated complex
      8. Enthalpy

C. Activation energy
   1. Definition:

   2. Used to:

   3. E_A forward is the difference between:

   4. The lower the E_A :

D. Activated complex
   1. Description:

   2. It's equally like to form:

E. Enthalpy
   1. Also called:

   2. $\Delta H =$

III. Exothermic Energy Diagram
   A. Relationship between E_P and E_R:

B. Enthalpy:

C. Energy is ____________________ from the ___________________ to the

____

D. The __________________________ are more stable

E. This process is energetically:

IV. Endothermic Energy Diagram

A. Sketch an endothermic energy diagram below:

B. Relationship between E_P and E_R:

C. Enthalpy:

D. Energy is ____________________ from the ___________________ to the

____

E. The __________________________ are more stable

F. This process is energetically:

V. Energy Diagrams & Catalysts

A. Catalysts are added in order to:

B. Some work by:

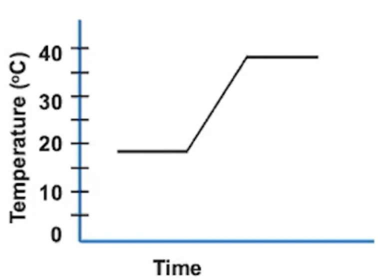
C. Enthalpy is _________ changed by a catalyst

D. Sketch an energy diagram with and without a catalyst:

VI. Practice

A. I Do:

1. An experiment was performed in an insulated container to determine the energy changes in a chemical reaction. A graph of temp. Vs. time is shown below. Is the reaction endothermic or exothermic? Justify your answer.



B. We Do:

SCAN ME

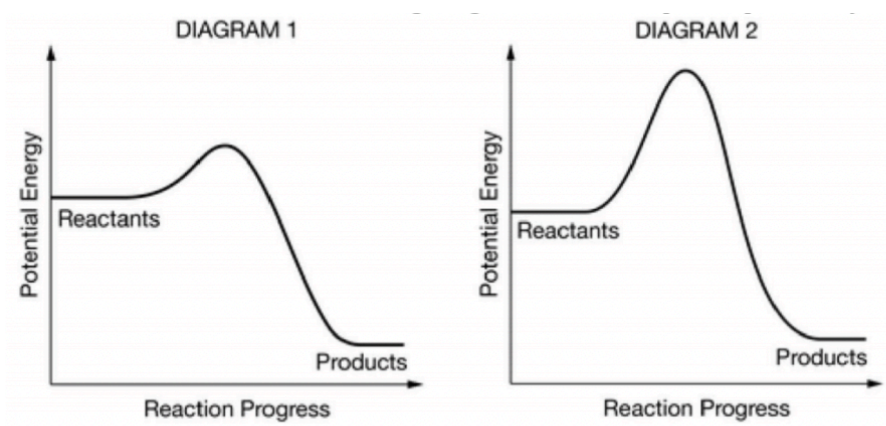
1. Draw a reaction pathway diagram on the graph using the following characteristics:
   a) The reactant's energy is 40 kJ/mol
   b) ΔH = -15 kJ/mol
   c) E_A= 50 kJ/mol
   d) The product's energy is:
   e) The E_A for the reverse reaction is:
   f) Using a dotted line, show the curve of the same reaction with a catalyst.

C. You Do:

1. Methane combusts according to the following equation:

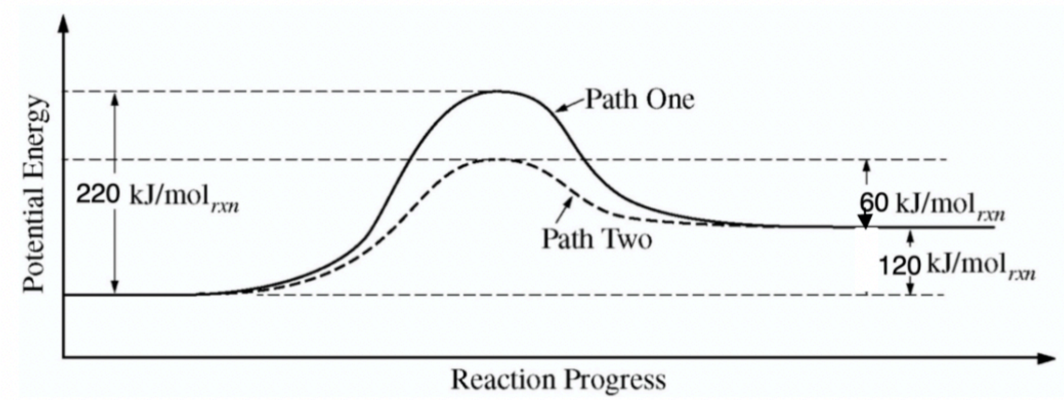
   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ ΔH= -890.7 kJ/mol

   At 25℃ very little CO_2 or H_2O is produced after a few hours when the reactants are mixed. Which of the following diagrams could help to explain why the reaction is not producing yield and why?



*AP Classroom diagrams

Base questions #2 & 3 on the information below
The decomposition of A_2B is shown by the equation: $A_2B \rightarrow 2A + B$. Two possible reaction pathways are shown below in the diagram:



2. Is this reaction endothermic or exothermic?
   a) Describe the direction of heat flow in terms of the system and surroundings

   b) What is the enthalpy of reaction for the decomposition of A_2B in kJ/mol?

3. Why would Path 2 require less energy than Path 1? Explain.
   a) What is the activation energy of the forward reaction?

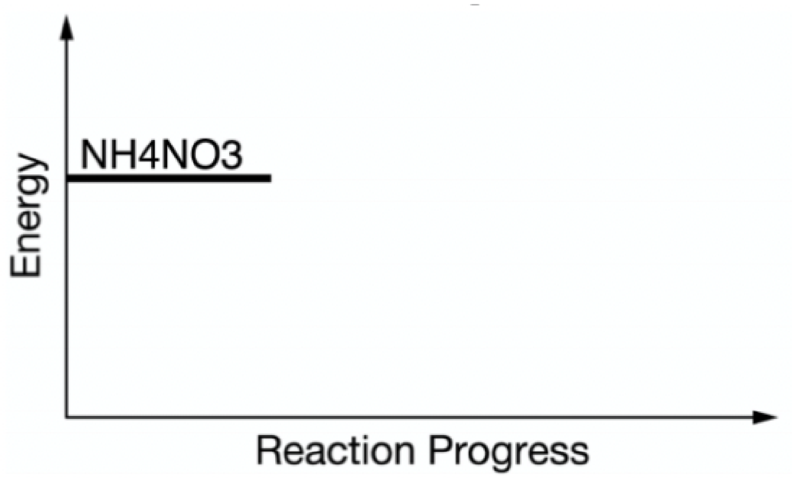
   b) What is the activation energy of the reverse reaction?

   c) What happens to ΔH when Path 2 is followed rather than Path 1?

4. The dissolution of ammonium nitrate, NH_4NO_3, is represented by the equation:

$$NH_4NO_3\ (s) \rightarrow NH_4^+\ (aq) + NO_3^-\ (aq)$$

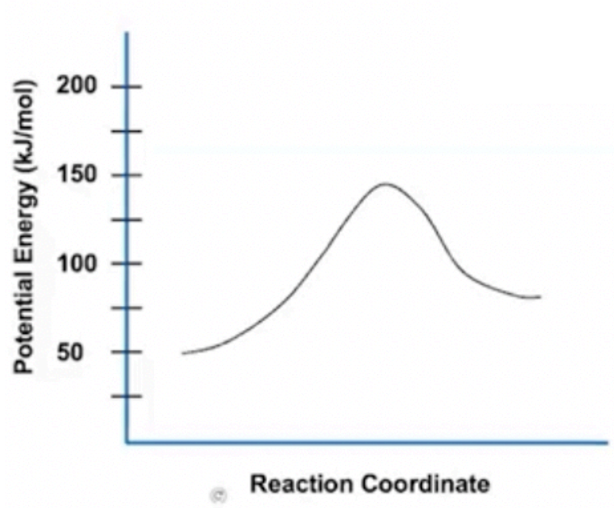
One common use of this process is in chemical "ice packs" for first aid for injuries. Water is mixed with solid ammonium nitrate, NH_4NO_3, when the inside pouch of the "ice pack" is broken. This results in the "ice pack" getting cold enough to cool injured muscles or joints. Using this information, complete the reaction pathway diagram shown below. Label the products and ΔH.



5. Draw a reaction pathway for the reaction below, labeling the products, reactants, and ΔH.

$$2ClF_3 + 2NH_3 \rightarrow N_2 + 6HF + Cl_2 \quad \Delta H= -1196\ kJ/mol_{rxn}$$

6. Which of the following best describes the changes occurring in the reaction represented by the energy profile shown below?



a) 25 kJ is transferred from the system and the products are more stable than the reactants
b) 25 kJ is transferred into the system and the products are more stable than the reactants
c) 25 kJ is transferred from the system and the products are less stable than the reactants
d) 25 kJ is transferred into the system and the products are less stable than the reactants

TOPIC 6.3: HEAT TRANSFER & THERMAL EQUILIBRIUM

Learning Objective: Explain the relationship between the transfer of thermal energy and molecular collisions

I. Temperature & Kinetic Energy
   A. Temperature:

   B. Formula for kinetic energy:

C. Sketch and label the Maxwell-Boltzmann Distribution Curve below:

D. Heat transfer/exchange:

E. What happens when particles with different energies collide? Describe in terms of energy, speed, and heat.

F. Thermal equilibrium:

II. Practice:

A. I Do:

1. 50.0 grams of Al (specific heat capacity = 0.900 J/g℃) at 85℃ was placed into 100.0 grams of water (specific heat capacity = 4.184 J/g℃) at 25℃. What happens to the temperature, average kinetic energy, and average speed of the aluminum?

B. We Do:

SCAN ME

1. 50.0 grams of Al (specific heat capacity = 0.900 J/g℃) at 85℃ was placed into 100.0 grams of water (specific heat capacity = 4.184 J/g℃) at 25℃. The final temperature of the two substances was 30.8℃.
    a) What can be said of the temperature changes for each substance?

    b) What is true of the amount of thermal energy exchanged?

C. You Do:

1. 15.0 g of $CaCl_2$ is dissolved into 100.0 mL of water at 22.5℃, the final temperature of the solution was 32.2℃. After the dissolution took place, consider the water and what happened to:
    a) The temperature?

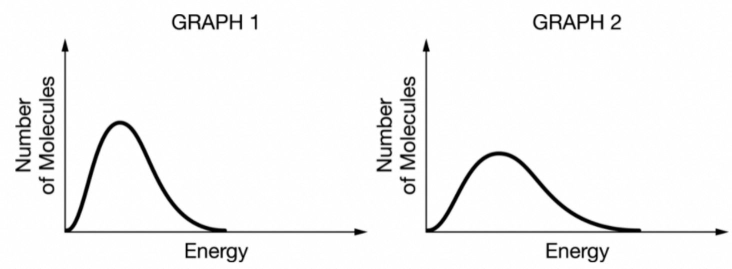
    b) The average kinetic energy?

    c) The average speed?

d) Was the dissolution reaction endothermic or exothermic?

2. A piece of Fe (s) at 25℃ is placed into H_2O (l) at 75℃ in an insulated container. A student predicts that when thermal equilibrium is reached, the Fe atoms, being more massive than the H_2O molecules, will have a higher average kinetic energy than the H_2O molecules. Which of the following best explains why the student's prediction is incorrect?
    a) At thermal equilibrium, the less massive H_2O molecules would have a higher average kinetic energy than the Fe atoms because they are more free to move than are the Fe atoms.
    b) At thermal equilibrium, the collisions between Fe atoms and the H_2O molecules would cease because the average kinetic energies of their particles would have become the same.
    c) At thermal equilibrium, the movement of both the Fe atoms and the H_2O molecules would cease; thus, the average kinetic energy of their particles would have to be the same
    d) At thermal equilibrium, the average kinetic energy of the Fe atoms cannot be greater than that of the H_2O molecules; the average kinetic energies must be the same according to the definition of thermal equilibrium

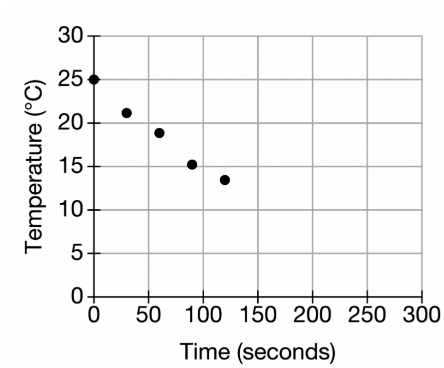
3. The graphs below show Maxwell-Boltzmann distributions for



one-mole samples of Ar (g). Graph 1 shows the distribution of particle energies at 300 K and graph 2 shows the distribution of particle energies at 600 K. A student predicts that if the samples are combined in an insulated container and thermal equilibrium is attained, then the most probable particle energy will be between the most probable energy shown in graph 1 and the most probable energy shown in graph 2. Which of the following is the best justification for the student's claim?

a) When the samples are combined, the gas particles will collide with one another, with the net effect being that the speed of the lowest energy particles decreases while the speed of the highest energy particles increases, leaving the average speed of the particles in the original samples unchanged
b) When the samples are combined, the gas particles from each sample will collide with the gas particles from the other sample until every particle in the mixture has the same speed, which is between the average speed of the particles in the hotter sample and the average speed of the particles in the cooler sample
c) When the samples are combined, the gas particles collide with one another until eerie particle in the mixture has the same kinetic energy, which is between the average kinetic energy of the particles in the hotter sample and the average kinetic energy of the particles in the cooler sample
d) When the samples are combined, the gas particles will collide with one another, with the net effect being that energy will be transferred from the more energetic particles to the less energetic particles until a new distribution of energies is achieved at a temperature between 300 K and 600 K.

4. A student adds 50.0 g of liquid water at 25℃ to an insulated container fitted with a temperature probe. The student then adds 10.0 g of ice at 0.0 ℃, closes the container, and measures the temperature at different intervals. Part of the data is shown in the graph below. The student predicts that the temperature will continue to decrease then level out to a constant temperature. Which of the following best explains why the student's prediction is correct?



a) The water molecules initially in the ice and the molecules initially in the liquid will have the same average kinetic energy
b) The transfer of energy between the water molecules in the ice and the liquid water stops once all the molecules are in the liquid phase
c) Once all of the water molecules are in the liquid phase, the individual molecular speeds either increase or decrease until all the particles have the same speed
d) Once all the water molecules are in the liquid phase, collisions between them virtually stop as they reach an equilibrium distance from their neighboring molecules

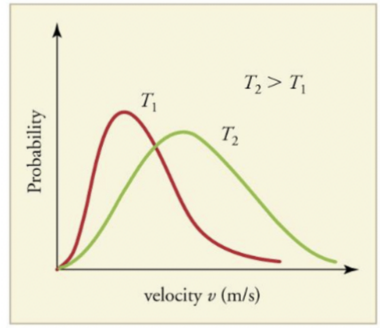
5. When 39.0 g of Cu (s) at 92.5 ℃ is dropped into 200 mL of water, at 25℃, the two substances reach thermal equilibrium. Which substance has:
   a) Greater kinetic energy?

   b) Particles with the greatest average speed?

   c) Highest temperature?

6. One mole of Ne gas at T_1 is added to one mole of Ne gas at T_2 as shown in the Maxwell-Boltzmann distribution below. Will the final temperature, T_f, of the gases be:
    a) $T_f < T_1, T_2$?
    b) $T_1 < T_f < T_2$?
    c) $T_1, T_2 < T_f$?

    Justify your answer.



TOPIC 6.4: HEAT CAPACITY & CALORIMETRY

Learning Objective: Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature

I. Heat
    A. Heat:

        1. Label:

        2. Units:

    B. Quantity of heat:

    C. Factors that contribute to the amount of heat transferred:

D. Useful heat conversions:

II. Heat Capacity

A. Heat capacity:

B. Specific heat capacity:

1. How does specific heat capacity relate to how quickly something heats up?

2. Label:

3. Units:

C. Molar heat capacity:

1. Label:

2. Units:

**AP EXAM TIP:

III. Heat Transfer Equations

A. When do you use $q = mc\Delta T$?

B. Identify each variable in $q = mc\Delta T$

1. q =
2. m =
3. c =
4. ΔT =

C. What is the formula for measuring heat transfer with a temperature change using moles?

D. Identify the the new variables for this equation:

1. n =
2. C =

E. Why do we measure the amount of heat transferred to/from the surroundings?

F. In heat transfer, heat lost ________ heat gained

G. Write the formula for heat transfer below:

1. What do you notice about the placement of the negative (-) sign?

2. What does the (-) sign NOT represent?

3. Explain, in your own words, what it DOES represent.

H. Heat lost + heat gained =

IV. Calorimetry

A. Calorimetry:

B. Calorimeters:

C. Sketch and label a calorimeter below:

D. Write the combined $q = mc\Delta T$ equations for each of the following examples. Pay close attention to the placement of the (-)

1. Example: a piece of hot metal is put into a calorimeter containing cold water.

2. Dissolving salts

3. Neutralization between acids and bases

E. What do all calorimeter calculations assume?

V. Practice:

A. I Do:

1. Almonds and cashews were burned in a bomb calorimeter containing water. The data table below was created.

	Almonds	Cashews
Mass of Calorimeter Water	2000. mL	1000. mL
Specific Heat of Water	4.18 J/g°C	4.18 J/g°C
Initial Temperature of Water	22.5 °C	22.5 °C
Final Temperature of water	40.5 °C	51.3 °C
Mass of Nut burned	6.00 grams	5.00 grams

a) Calculate the heat gained by the water for each nut

b) Calculate the energy for each nut, which provides more energy per gram?

B. We Do:

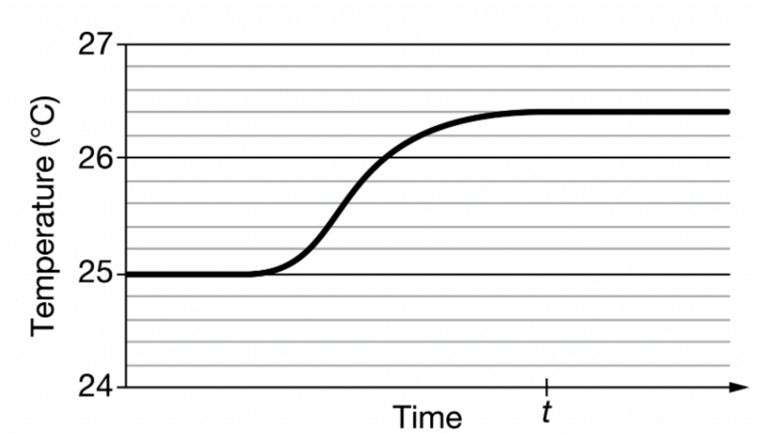
1. A coffee cup calorimeter contains 50.00 g of water at 20.73℃. When 2.13 g of NH_4NO_3 pellets are stirred into the water, the temperature falls to 17.41℃. Assume the heat capacity of the resulting solution is the same as that of water and that no energy is absorbed or released from or to the surroundings. Calculate the molar enthalpy of dissolution of ammonium nitrate, a chemical commonly used in the production of cold packs. [textbook p. 133, instructions on p. 132]

C. You Do:

1. A 25.0 g sample of water was cooled from 23.9℃ to 12.7℃, how much heat was released? (Assume the specific heat of water is 4.18 J/g℃)

2. 75.0 grams of an unknown metal was heated to 95.0℃, it was then placed into 150.0 g of water at 23.1℃, when the metal and water reached thermal equilibrium, the temperature was 27.8℃. Calculate the specific heat of the metal. (Specific heat of water = 4.18 J/g℃)

3. A student did an experiment to determine the specific heat capacity of a metal alloy. The student put a sample of the alloy in boiling water for several minutes, then quickly transferred the alloy into a calorimeter containing water originally at 25℃. The temperature of the water was monitored over time. The data are given in the graph below.



a) What is the value of ΔT that the student should use to calculate the value of q, the heat gained by the water?

b) In terms of what occurs at the particulate level, explain how the temperature of the water increases after the alloy sample is added.

c) The student claims that thermal equilibrium is reached at time *t*. Justify the student's claim. In your justification, include a description of what occurs at the particulate level when the alloy and the water have reached thermal equilibrium.

4. For an experiment, 50.0 g of H_2O was added to a coffee-cup calorimeter, as shown in the diagram below. The initial temperature of the water was 22.0℃, and it absorbed 300 J of heat from an object that was carefully placed inside the calorimeter. Assuming no heat is transferred to the surroundings, which of the following was the approximate temperature of the water after thermal equilibrium was reached? Assume the specific heat of water is 4.2 J/g℃.

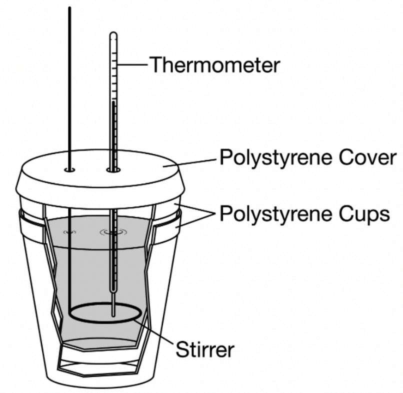


Diagram 1

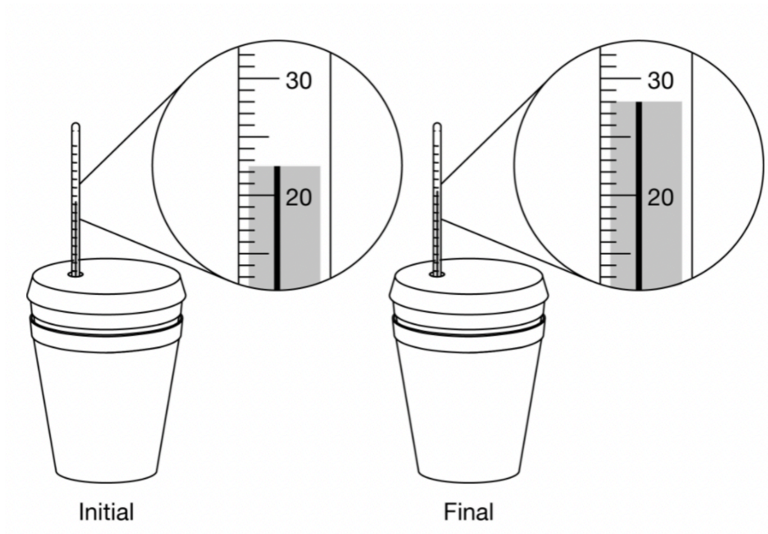
a) 21.3℃
b) 22.0℃
c) 22.7℃
d) 23.4℃

5. In an experiment to determine the specific heat of a metal, a student transferred a sample of the metal that was heated in boiling water into room-temperature water in an insulated cup. The student recorded the temperature of the water after thermal equilibrium was reached. The data are shown in the table below. Based on the data, what is the calculated heat q absorbed by the water reported with the appropriate number of significant figures?

Mass of water	50.003 g
Temperature of water	24.95°C
Specific heat capacity for water	$4.184 \text{ J/g}^\circ\text{C}$
Mass of metal	63.546 g
Temperature of metal	99.95°C
Specific heat capacity for metal	$?$
Final temperature	32.80°C

a) 1600 J
b) 1640 J
c) 1642 J
d) 1642.3 J

6. A student mixes 50 mL of 1.0 M HCl and 50 mL of 1.0 M NaOH in a coffee-cup calorimeter and observes the change in temperature until the mixture reaches thermal equilibrium. The initial and final temperatures (℃) of the mixture are shown in the diagram below of the laboratory setup. Based on these results, what is the change in temperature reported with the correct number of significant figures?



a) 5.5℃
b) 5.50℃
c) 5.800℃
d) 6℃

7. A student is asked to determine the molar enthalpy of a solution of ammonium nitrate, NH_4NO_3. She sets up a calorimeter, using two nested foam coffee cups. She places water in the calorimeter. She then adds solid NH_4NO_3 and observes the resulting temperature change. Her data table is below.

   Assume that the specific heat capacity of the resulting solution is 4.2 J/g°C and that the density of the solution is 1.00 g/mL. The molar mass of NH_4NO_3 is 80.0 g/mol. Which of the following is the correct value of $q_{solution}$ for NH_4NO_3 in units of J? [#2, exo or endo]

Data Entry	Measurement*
Mass of NH_4NO_3 used	4.0 g
Volume of Water in Calorimeter	46.0 mL
Initial Temperature in Calorimeter	$21.0°\text{C}$
Final Temperature in Calorimeter	$15.0°\text{C}$

   a) 1,260
   b) -1,260
   c) 2.5×10^4
   d) -2.5×10^4

8. The change in internal energy of a system is -5.155 kJ. The system absorbs 2500 J of heat. Which of the following BEST describes the work related to the system? [work & internal energy change]
    a) The system performs 7.655 kJ of work on the surroundings
    b) The system has 7.655 kJ of work done by the surroundings
    c) The system has 2.655 kJ of work done by the surroundings
    d) The system performs 2.655 kJ of work on the surroundings

9. A metal sample with a specific heat that is half the value of water is placed into a mass of water that is three times that of the metal sample. The initial temperature of the metal sample is four times cooler than the water's initial temperature. Which of the following would most closely approximate the final temperature of the system? [specific heat comparison]
    a) The final temperature would fall directly between the initial temperature of the metal and the water
    b) The final temperature would be closer to the initial temperature of the water
    c) The final temperature would be closer to the initial temperature of the metal sample
    d) A prediction of the final temperature of the system cannot be made based on the information provided

10. The equipment shown below is provided so that a student can determine the value of the molar heat of solution for $CaCl_2$. Knowing that the specific heat of the solution is 4.18 J/g°C, list the specific measurements that are required to be made during the experiment and what tool would be most appropriate.

11. Use the data in the table to answer the following questions:

Mass calorimeter (g)	**11.31**
Mass calorimeter and water (g)	**56.57**
Mass calorimeter, water, and salt (g)	**61.54**
Initial temperature (°C)	**20.0**
Final temperature (°C)	**36.5**

a) Is the dissolving process exothermic or endothermic? Justify using only the data.

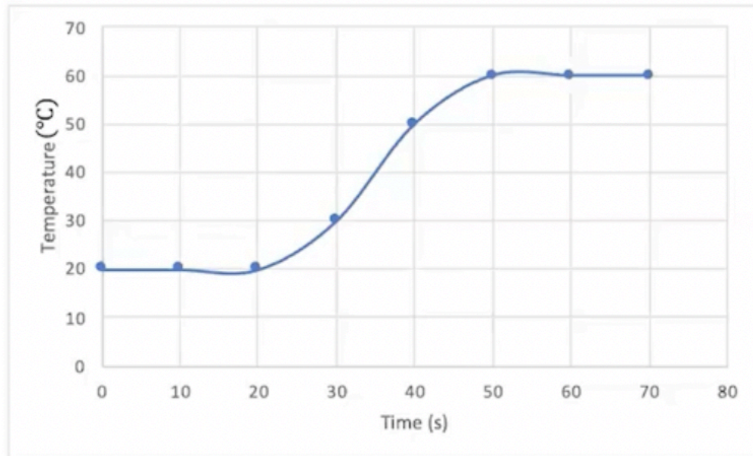
b) Calculate the mass of solution used.

c) Determine the change in temperature

d) Calculate the moles of $CaCl_2$ dissolved.

e) Calculate the molar heat of solution in J/mol.

12. A 27.00 g sample of an unknown metal was heated until 420 J of heat had been absorbed. The graph below shows the data collected during the experiment.



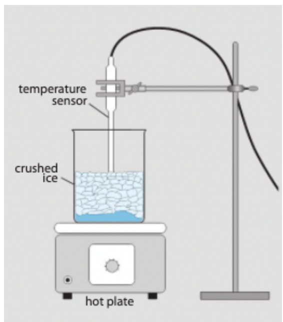
a) Determine the temperature change of the metal

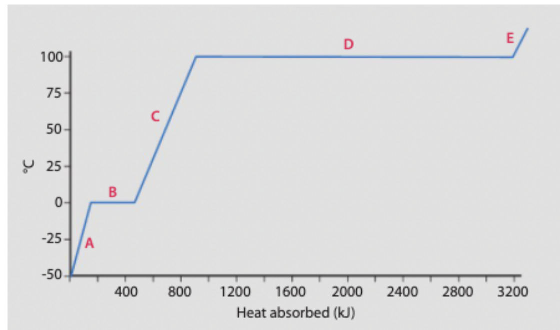
b) Determine the specific heat of the metal. Include units in your answer.

TOPIC 6.5: ENERGY OF PHASE CHANGES

Learning Objective: Explain changes in the heat q absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition

Do Now: The apparatus shown below is used to collect data that produces the graph below. Compare regions B & D. What might cause those lines to be different lengths?





I. Heat & Phase Change

A. Solid → liquid → gas ______________________ energy

B. Gas → liquid → solid ______________________ energy

C. Explain why this is on a molecular level:

D. Define each of the following:

1. Melting:
2. Vaporization:
3. Condensation:
4. Solidification:
5. Sublimation:
6. Deposition:

E. Copy the diagram on Slide #9 below:

F. Sketch and label the graph from Slide #10 below:

G. Why doesn't the temperature change during a phase change?

H. Latent heat:

I. Why can't $q=mc\Delta T$ be used to calculate the energy lost/gained during a phase change?

J. Heat of fusion:

K. Heat of vaporization:

L. Heat of condensation:

M. Heat of solidification:

N. What is the relationship between the heat absorbed and the heat released during a phase change?

    1. Describe this symbolically:

O. Write the 4 equations for calculating changes in heat during a phase change below;

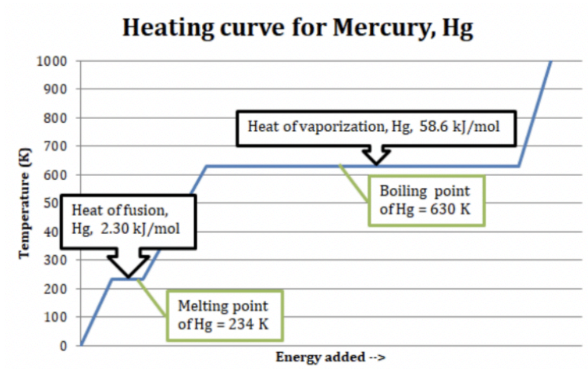
P. Sketch and label an ENDOTHERMIC graph below:

Q. Sketch and label an EXOTHERMIC graph below:

II. Practice:

A. I Do:

1. Given the heating curve for mercury, calculate the heat released to freeze 100.0 g of Hg at its melting point.



B. We Do:

SCAN ME

1. Calculate the heat required to change a 55.00 g ice cube at -15.0℃ into steam at 125.0℃. The ΔH_{fus}water = 334 J/g and the ΔH_{vap}water = 2250 J/g. (p.129 in your textbook)

2. AP Classroom Video We Do, 6.5 Video #2:
   a) Answer the following questions about gallium, a metal often used to make computer chips.

Molar heat capacity of solid	$25.86\ J\ mol^{-1}K^{-1}$
Heat of fusion	$5.59\ kJ\ mol^{-1}$
Heat of vaporization	$256\ kJ\ mol^{-1}$
Melting point	$303\ K$

(1) Gallium can be purified by melting. How much energy in kJ is required to melt 2 moles of gallium originally at 239 K?

(2) Use principles of bonding to explain why the heat of vaporization is much greater than the heat of fusion.

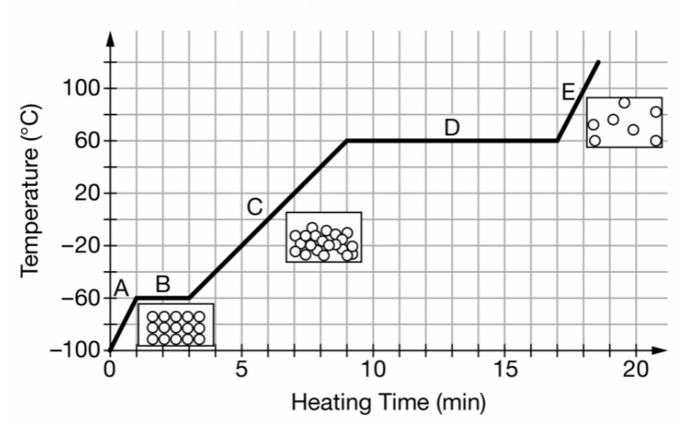
b) Answer the following questions about polyethylene terephthalate (PET), the plastic typically used in water bottles.

(1) One step in the production of PET involved the crystallization of melted PET. While the plastic is solidifying, is the net flow of thermal energy from the plastic to the surroundings or from the surroundings to the plastic? Justify your answer.

(2) Determine the amount of heat, in kJ, involved when solidifying 12.0 moles of PET at its melting point. ΔH_{fus} = 26.0 kJ/mol. Include the correct sign in your answer.

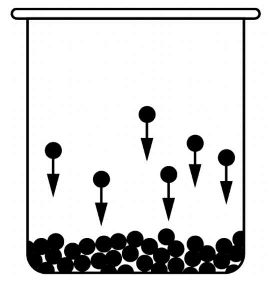
C. You Do:

1. A sample of $CHCl_3$ (s) was exposed to a constant source of heat for a period of time. The graph below shows the change in the temperature of the sample as heat is added. Which of the following best describes what occurs at the particle level that makes segment D longer than segment B?



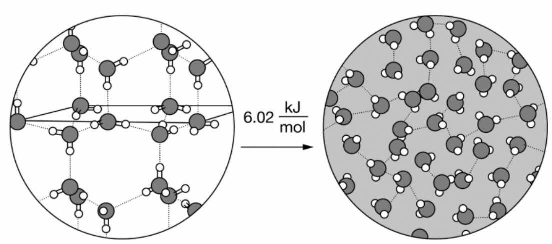
a) The specific heat capacity of the liquid is significantly higher than that of the solid, because the particles in the liquid state need to absorb more thermal energy to increase their average speed
b) The specific heat capacity of the solid is significantly higher than that of the gas, because the particles in the solid state need to absorb more thermal energy to increase their average speed
c) The enthalpy of fusion is greater than the enthalpy of vaporization because separating molecules from their bound crystalline state requires more energy than separating molecules completely in the liquid state
d) The enthalpy of vaporization is greater than the enthalpy of fusion because separating molecules completely from the liquid to for form a gas requires more energy than separating molecules from their bound crystalline state to a liquid state

2. A 2.00 mol sample of C_2H_5OH undergoes the phase transition illustrated in the diagram below. The molar enthalpy of vaporization, ΔH_{vap}, of C_2H_5OH is +38.6 kJ/mol. Which of the following best identifies the change in enthalpy in the phase transition shown in the diagram?



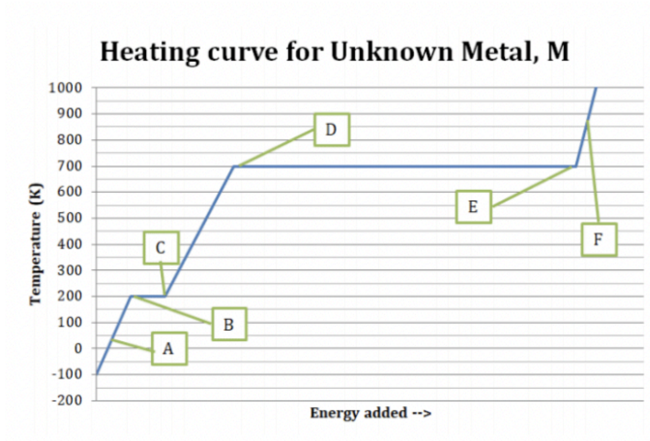
   a) +19.3 kJ
   b) +77.2 kJ
   c) -19.3 kJ
   d) -77.2 kJ

3. The diagram below represents the melting of $H_2O(s)$. A 2.00 mole sample of $H_2O(s)$ at 0℃ melted, producing H_2O (l) at 0℃. Based on the diagram, which of the following best describes the amount of heat required for this process and the changes that took place at the molecular level?



   a) 3.01 kJ of heat was absorbed to decrease the average speed of the water molecules in the liquid, which decreases the distance between molecules
   b) 6.02 kJ of heat was absorbed to increase the number of hydrogen bonds between water molecules in the liquid compared to the solid
   c) 12.0 kJ of heat was absorbed to decrease the polarity of the water molecules, which increases the density of the liquid compared to the solid
   d) 12.0 kJ of heat was absorbed to overcome some of the hydrogen bonding forces holding water molecules in fixed positions in the crystalline structure

4. An unknown metal, M, was heated and the following heating curve was created. Answer the following with the letter, letter range (ex. A→B) or a temperature.



a) Point(s) where only a gas is present

b) Temperature at which vaporization occurs

c) Point(s) where a mixture of a solid and a liquid are present

d) Point(s) where a gas turns into a liquid

e) Temperature at which the substance starts to freeze

f) Range where there is only liquid

5. Calculate the amount of energy needed to boil 91.2 g of CCl_4 at its boiling point, 350.0 K. ΔH_{fus} = 2.67 kJ/mol ΔH_{vap} = 30.0 kJ/mol

    a) Draw a particulate level diagram to show this phase change. Make a key for your CCl_4 molecule.

6. The heat of fusion for water is 6.01 kJ/mol and the heat of vaporization for water is 40.7 kJ/mol. How much energy is needed to melt 22.5 grams of ice?

7. Naphthalene is a primary component of mothballs; they readily sublime at room temperature. The heat of sublimation for naphthalene, $C_{10}H_8$, is 72.9 kJ/mol. How much energy is needed to sublime 15.0 g of naphthalene?

TOPIC 6.6: INTRODUCTION TO ENTHALPY OF REACTION

Learning Objective: Calculate the heat, q, absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction

I. Enthalpy Change of a Reaction
   A. Definition:

   B. Symbol:

   C. Represents:

   D. Units:

   E. What does the magnitude of ΔH_{rxn} reflect?

   F. Example:
   $N_2(g) + O_2(g) \rightarrow 2NO(g) \quad \Delta H_{rxn} = 180\ kJ/mol_{rxn}$
      1. How much heat is required to react 2.4 moles of $N_w(g)$ with excess $O_2(g)$ to form NO(g)?

2. If 25 kJ of heat was absorbed in the reaction, how many moles of NO were produced?

G. Note: At constant pressure:

II. Practice

A. I Do:

1. If you were to react 7.25 moles of H_2S with 9.34 moles of O_2, how much heat would be released?

$2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g) \quad \Delta H = -1120\ kJ/mol_{rx}$

B. We Do:

1. If you performed the reaction below and produced 92.1 kJ of energy, how many moles of water are also produced?

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g) \quad \Delta H = -481.6\ kJ/mol_{rxn}$

SCAN ME

2. AP Classroom Video We Do, 6.6 Video #1:
   a) Consider the combustion of methane (CH_4). Suppose 39.8 g of CH_4 combust according to the following equation. How much heat would be absorbed or produced?

      $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\ (l)$ $\Delta H = -890.1\ kJ/mol_{rxn}$

   b) Consider the combustion of methane (CH_4). Suppose that 1,789 kJ of heat are produced. What mass of O_2 was consumed?

      $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O\ (l)$ $\Delta H = -890.1\ kJ/mol_{rxn}$

c) If 29.98 g of Al and 320 g of Fe_2O react as completely as possible, how much heat would be released?

$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(s)$ $\Delta H = -850.2\ kJ/mol_{rxn}$

C. You Do:

1. Hydrazine, N_2H_4, is formed through the reaction below. Calculate the standard enthalpy change when 0.452 moles of N_2H_4 is formed at 1 atm and 298 K.
   $2H_2(g) + N_2(g) \rightarrow N_2H_4\ (l)$ $\Delta H = +50.63\ kJ/mol_{rxn}$

2. Given the reaction below, how many moles of EF would also be produced if the reaction gave off 750 J?
   $AB(g) + 2CD(g) \rightarrow 3EF(g)$ $\Delta H = -9.52$ kJ

3. A student mixes 0.100 L of 1.00 M HA with 0.200 L of 1.00 M MOH according to the reaction below:
   $HA(aq) + MOH(aq) \rightarrow H_2O(l) + MA(aq)$
   a) If the temperature of the solutions changed from 22.3℃ to 29.1℃, calculate the heat evolved in this reaction. (Assume that the specific heat of the solution is 4.184 J/g℃ and the density of the solution is 1.00 g/mL)

   b) Calculate the enthalpy per mole of HA

c) If 0.491 moles of HA is reacted with excess MOH, how much heat would be evolved?

4. The formation of magnesium oxide, MgO, is shown below:
   $Mg(s) + \frac{1}{2} O_2(g) \rightarrow MgO(s) + 601.7\ kJ$
   a) Is this an endothermic or exothermic reaction?

   b) If 0.321 moles of O_2 reacted, how much heat would be absorbed/released?

5. 2.00 grams of NaOH is added to 100.0 mL of water at 22.0℃. After dissolving, the temperature of the solution is found to be 27.3℃. (Assume that the specific heat of the solution is 4.184 J/g℃ and the density of the solution is 1.00 g/mL)
    a) Find the experimental value for the molar enthalpy of dissolution for NaOH

    b) Write the equation for the dissolution of NaOH, including the value for ΔH

6. When solid phosphorous, P, reacts with gaseous chlorine, Cl_2, it forms liquid phosphorous trichloride, PCl_3. When 4.62 g of phosphorous reacts with excess chlorine at a constant pressure 47.8 kJ of heat is released to the surroundings. Write the thermochemical equation for this reaction, including the correct value for ΔH for the reaction as you have written it.

TOPIC 6.7: BOND ENTHALPIES

Learning Objective: Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction

I. Bond Energy
    A. Why do atoms form bonds?
    B. Bond energy:
        1. Also called:
        2. Definition:
    C. Importance of bond energy:
        1. Helps describe:
        2. How does it relate to Lewis Dot structures?
        3. We can estimate:
    D. Trends in bond energy:
        1. More energy required =
        2. The higher the bond order =
        3. The smaller the atomic size =

E. How can you determine bond energy?

F. Steps for estimating the potential energy change for a reaction:

G. Endothermic vs. bond energy:

H. Exothermic vs. bond energy:

I. Write the equation(s) for calculating the ΔH_{rxn} using bond energies below:

J. What is the mnemonic device for remembering these equations?

II. Practice:

A. I Do:

1. How much heat is released through the complete combustion of propane, C_3H_8?

   $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

B. We Do:

SCAN ME

1. Is the reaction between $CH_2Cl_2(g) + Br_2(g) \rightarrow CH_2Br_2(g) + Cl_2(g)$ endothermic or exothermic? Calculate the energy involved in this reaction.

2. AP Classroom Video We Do, 6.7 Video #2:
    a) What is the enthalpy of the combustion of methane?

b) The decomposition of $H_2O_2(aq)$ is represented by the equation below. Assume that the bond enthalpies of the oxygen bonds in H_2O are not significantly different from those in H_2O_2. Based on the value of the ΔH° of the reaction, which of the following could be the bond enthalpies (in kJ/mol) for the bonds broken and formed in the reaction? Try this with no calculator!

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g) \qquad \Delta H° = -196\ kJ/mol_{rxn}$$

A)

O—O In H_2O_2	O=O In O_2	O—H
300	500	500

B)

O—O In H_2O_2	O=O In O_2	O—H
150	500	500

C)

O—O In H_2O_2	O=O In O_2	O—H
500	300	150

D)

O—O In H_2O_2	O=O In O_2	O—H
250	300	150

C. You Do:

1. The oxidation of carbon monoxide can be represented by the chemical equation $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$. The table above provides the average bond enthalpies for different bond types. Based on the information in the table, which of the following mathematical expressions is correct for the estimated enthalpy change for the reaction?

Bond Type	Average Bond Enthalpy $\left(\frac{\mathrm{kJ}}{\mathrm{mol}}\right)$
$\mathrm{C}-\mathrm{C}$	360
$\mathrm{C}=\mathrm{O}$	799
$\mathrm{C}\equiv\mathrm{O}$	1072
$\mathrm{O}-\mathrm{O}$	142
$\mathrm{O}=\mathrm{O}$	498

a) $$\Delta H_{rxn} = [2(1072\,\frac{\mathrm{kJ}}{\mathrm{mol}}) + (498\,\frac{\mathrm{kJ}}{\mathrm{mol}})] - 2(799\,\frac{\mathrm{kJ}}{\mathrm{mol}})$$

b) $$\Delta H_{rxn} = [2(1072\,\frac{\mathrm{kJ}}{\mathrm{mol}}) + (498\,\frac{\mathrm{kJ}}{\mathrm{mol}})] - 4(799\,\frac{\mathrm{kJ}}{\mathrm{mol}}).$$

c) $$\Delta H_{rxn} = [2(799\,\frac{\mathrm{kJ}}{\mathrm{mol}}) + (142\,\frac{\mathrm{kJ}}{\mathrm{mol}})] - 4(360\,\frac{\mathrm{kJ}}{\mathrm{mol}})$$

d) $$\Delta H_{rxn} = [2(799\,\frac{\mathrm{kJ}}{\mathrm{mol}}) + (142\,\frac{\mathrm{kJ}}{\mathrm{mol}})] - 2(360\,\frac{\mathrm{kJ}}{\mathrm{mol}})$$

2. Shown below are the equation representing the decomposition of H_2O_2 (l) and a table of bond enthalpies. On the basis of the information, which of the following is the enthalpy of decomposition of 2 mol of H_2O_2 (l)?

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$$

Bond	Average Bond Enthalpy $(\mathrm{kJ/mol})$
$\mathrm{O-H}$	463
$\mathrm{O-O}$	146
$\mathrm{O{=}O}$	495

a) -349 kJ
b) -203 kJ
c) 203 kJ
d) 349 kJ

3. An equation representing the dissociation of O_2(g) and a table of bond enthalpies are shown below. Based on the information, which of the following is the enthalpy of dissociation for O_2(g)?

$O_2(g) \rightarrow 2O\ (g)$

Bond	Average Bond Enthalpy $(\mathrm{kJ/mol})$
$\mathrm{O{=}O}$	495
$\mathrm{O-O}$	146

a) -641 kJ/mol
b) -495 kJ/mol
c) 495 kJ/mol
d) 641 kJ/mol

4. Calculate the energy released in the reaction between hydrogen and oxygen forming water as shown below:

$H_2(g) + O_2(g) \rightarrow H_2O(g)$

5. Ammonia is an important precursor to fertilizer and explosives. It can be synthesized from hydrogen and nitrogen through the Haber-Bosch Process as shown:

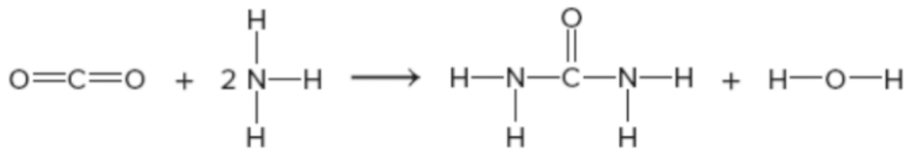
$$H_2(g) + N_2(g) \rightarrow NH_3\ (g)$$

a) Is the reaction endothermic or exothermic and how much energy is involved in the reaction?

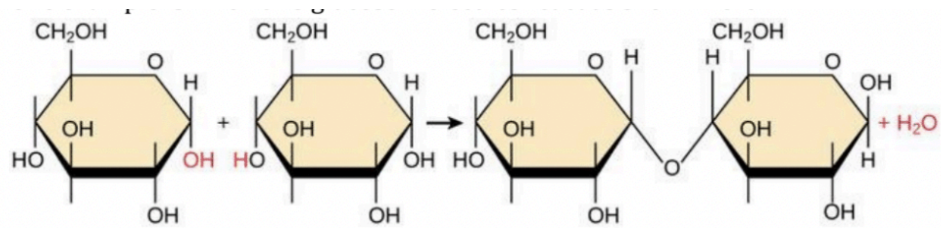
b) If 15g of NH_3 is synthesized, how much energy is involved in the reaction?

6. Calculate the energy involved in the reaction below:

$$CO_2 + 2\ NH_3 \rightarrow CO(NH_2)_2 + H_2O$$



7. A reaction that involves the formation of and removal of a water molecule is called dehydration synthesis. One example is when two glucose molecules react as shown below. Identify the bonds broken and the bonds that are formed and calculate the energy involved in this reaction and indicate if the reaction is endothermic or exothermic.



8. The enthalpy for the reaction below is -25 kJ:

   2A-A + B=B → 2A-B-A

   a) Given the following bond energies, find the missing value.

Bond	Bond Energy (kJ/mol)
A-A	??
B=B	32.
A-B	46.

   b) Sketch a potential energy diagram for this reaction.

TOPIC 6.8: ENTHALPY OF FORMATION

Learning Objective: Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation

I. Enthalpy of Formation
   A. Standard enthalpy of formation:
      1. Symbol: (include what each symbol represents)

B. Enthalpy of reaction:

C. The enthalpy of a reaction is equal to:

D. Formula:

1. Be sure to account for:

2. When is the enthalpy of formation = 0?

E. Note: See Slide #5 for resource links to enthalpy tables and bond energy tables

II. Practice:

A. I Do:

1. Is the combustion of propane endothermic or exothermic? How much energy is absorbed or released? Assume standard conditions.

B. We Do:

1. What is the reaction enthalpy for the decomposition of baking soda?

   $2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

   a) How much heat is involved when 7.0 g of baking soda is used for your favorite cookie recipe?

2. AP Classroom Video We Do, 6.8 Video #2:
   a) Using the table of standard enthalpies of formation below, determine the standard enthalpy change of the reaction when 2.00 moles of propene combust. The balanced equation for the combustion of 2.00 moles of propene is $2C_3H_6(g) + 9O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)$

Substance	$C_3H_6(g)$	$CO_2(g)$	$O_2(g)$	$H_2O(g)$
Standard Enthalpy of Formation (kJ/mol)	21	-394	0	-242

   b) What is the standard enthalpy change $\Delta H°$ for the reaction represented below? $\Delta H°_f$ of $C_2H_2(g)$ is 230 kJ/mol; $\Delta H°_f$ of C_6H_6 (g) is 83 kJ/mol.

$$3C_2H_{2x}(g) \rightarrow C_6H_6(g)$$

c) The standard molar heats of formation of ammonia, $NH_3(g)$, and gaseous water, $H_2O(g)$, are -46 kJ/mol and -242 kJ/mol, respectively. What is the value of ΔH°_{298} for the reaction represented below?

$$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g)$$

C. You Do:

1. Based on the information in the table below, which of the following expressions gives the approximate ΔH° for the reaction represented by the following balanced chemical equation?

$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$

Substance	ΔH_f° (kJ/mol)
$Fe_2O_3(s)$	-826
$CO(g)$	-111
$Fe(s)$	0
$CO_2(g)$	-394

a) $\Delta H^\circ_{rxn} = [(0\ \mathrm{kJ/mol}) + (-394\ \mathrm{kJ/mol})] - [(-826\ \mathrm{kJ/mol}) + (-111\ \mathrm{kJ/mol})]$

b) $\Delta H^\circ_{rxn} = [2(0\ \mathrm{kJ/mol}) + 3(-394\ \mathrm{kJ/mol})] - [(-826\ \mathrm{kJ/mol}) + 3(-111\ \mathrm{kJ/mol})]$

c) $\Delta H^\circ_{rxn} = [(-826\ \mathrm{kJ/mol}) + 3(-111\ \mathrm{kJ/mol})] - [2(0\ \mathrm{kJ/mol}) + 3(-394\ \mathrm{kJ/mol})]$

d) $\Delta H^\circ_{rxn} = [(-826\ \mathrm{kJ/mol}) + (-111\ \mathrm{kJ/mol})] - [(0\ \mathrm{kJ/mol}) + (-394\ \mathrm{kJ/mol})]$

2. The enthalpy change for the reaction below is -860 kJ/mol. Based on the standard enthalpies of formation ΔH°_f for $Fe_2O_3(s)$?

$2Al(s) + Fe_2O_3(s) \rightarrow 2Fe(s) + Al_{2,}O_3(s)$

Substance	ΔH_f° (kJ/mol)
$Al(s)$	0
$Al_2O_3(s)$	-1680
$Fe(s)$	0
$Fe_2O_3(s)$	?

a) 2540 kJ/mol
b) -2540 kJ/mol
c) 820 kJ/mol
d) -820 kJ/mol

3. The reaction between C(s) and H_2O(g) is represented by the balanced equation below. Based on the enthalpy change of the reaction (ΔH°) and the standard heats of formation ($\Delta H°_f$) given in the table below, what is the approximate $\Delta H°_f$ for CO(g)?

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g) \qquad \Delta H° = 131 \text{ kJ/mol}_{rxn}$$

Substance	ΔH_f° **(kJ/mol)**
$C\ (s)$	0
$H_2O(g)$	-242
$CO\ (g)$	?
$H_2(g)$	0

a) -373 kJ/mol
b) -111 kJ/mol
c) 111 kJ/mol
d) 373 kJ/mol

4. Is the formation of dinitrogen tetroxide from nitrogen dioxide endothermic or exothermic? How much energy is absorbed or released? Assume standard conditions.

5. Spacecraft often use hydrazine, N_2H_4, as a fuel. How much heat is released during this process for one mole of hydrazine?

$$N_2H_4(l) + N_2O_4(g) \rightarrow 2N_2O(g) + 2H_2O(g)$$

6. Solid calcium carbonate is the primary compound in limestone. When it decomposes it forms solid calcium oxide and gaseous carbon dioxide. How much heat is absorbed or released during the decomposition of 1.00 mole of calcium carbonate? Assume standard conditions.

TOPIC 6.9: HESS'S LAW

Learning Objective: Represent a chemical or physical process as a sequence of steps

I. Hess's Law
   A. Discovered by:
      1. In:
   B. Definition:
   C. Keys to Hess's Law:
   D. Tips:

II. Practice:

A. I Do:

1. Given the following reactions:

$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta H = -116$ kJ

$2N_2(g) + 5O_2(g) + 2H_2O(l) \rightarrow 4HNO_3(aq)$ $\Delta H = -256$ kJ

$N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H = 183$ kJ

Calculate the enthalpy change for the reaction below:

$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$

B. We Do:

1. Calculate the the enthalpy for the reaction:

$$A + 2B \rightarrow C + 2D$$

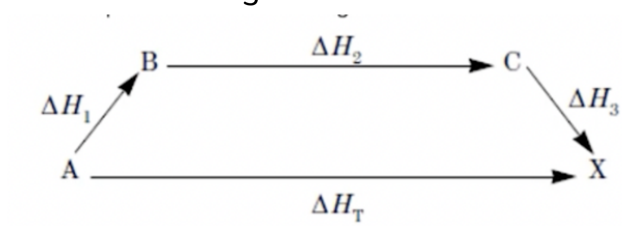
If:

$4B + 3E \rightarrow 2C$ $\Delta H = 124$ kJ

$2D + 3/2E \rightarrow A$ $\Delta H = -15$ kJ

SCAN ME

2. AP Classroom Video We Do, 6.9 Video #2:
   a) The enthalpy change for the reaction $A \rightarrow X$ is ΔH_T. This reaction can be broken down into a series of steps as shown in the diagram:



A relationship that must exist among the various enthalpy changes is:

A $\Delta H_T - \Delta H_1 - \Delta H_2 - \Delta H_3 = 0$

B $\Delta H_T + \Delta H_1 + \Delta H_2 + \Delta H_3 = 0$

C $\Delta H_3 - (\Delta H_1 + \Delta H_2) = \Delta H_T$

D $\Delta H_2 - (\Delta H_3 + \Delta H_1) = \Delta H_T$

E $\Delta H_T + \Delta H_2 = \Delta H_1 + \Delta H_3$

b) Based on the information below, what is the enthalpy change for the sublimation of iodine, represented below?

$$I_2(s) \rightarrow I_2(g)$$

Reaction 1: $\frac{1}{2} H_2(g) + \frac{1}{2} I_2(s) \rightarrow HI(g)$ $\Delta H = 26$ kJ/mol_{rxn}
Reaction 2: $\frac{1}{2} H_2(g) + \frac{1}{2} I_2(g) \rightarrow HI(g)$ $\Delta H = -5.0$ kJ/mol_{rxn}

(1) 15 kJ/mol_{rxn}
(2) 21 kJ/mol_{rxn}
(3) 31 kJ/mol_{rxn}
(4) 42 kJ/mol_{rxn}
(5) 62 kJ/mol_{rxn}

c) The elements K and Cl react directly to form the compound KCl according to the equation above. Refer to the information above and the table below to answer the questions that follow.

$$K(s) + \tfrac{1}{2} Cl_2(g) \rightarrow KCl(s) \quad \Delta H^\circ_f = -437 \text{ kJ/mol}$$

	Process	ΔH° (kJ/mol$_{rxn}$)
1)	$K(s) \rightarrow K(g)$	v
2)	$K(g) \rightarrow K^+(g) + e^-$	w
3)	$Cl_2(g) \rightarrow 2Cl(g)$	x
4)	$Cl(g) + e^- \rightarrow Cl^-(g)$	y
5)	$K^+(g) + Cl^-(g) \rightarrow KCl(s)$	z

(1) Which of the reactions on the table can be manipulated or combined to form the reaction given above?

(2) Write an algebraic expression equivalent to ΔH° using the variables on the table.

C. You Do:

1. Given the following information, how would the reaction between sulfur dioxide and oxygen to produce sulfur trioxide be best described? [net energy charge]

   $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$ $\Delta H = -790$ kJ
   $S(s) + O_2(g) \rightarrow SO_2(g)$ $\Delta H = -297$ kJ

   a) Exothermic with a net energy of 196 kJ
   b) Endothermic with a net energy of 196 kJ
   c) Exothermic with a net energy of 1384 kJ
   d) Endothermic with a net energy of 1087 kJ

2. The equation for the formation of magnesium oxide, MgO, from the elements is shown below. Which of the following **correctly** describes the heat transfer involved when 5.60 L of $O_2(g)$ is formed by decomposition of MgO? Assume STP. [Rxn enthalpy]

   $Mg(s) + \frac{1}{2} O_2(g) \rightarrow MgO(s)$ $\Delta H^\circ_{formation} = -602$ kJ/mol MgO

   a) 301 kJ is released
   b) 151 kJ is released
   c) 151 kJ is absorbed
   d) 301 kJ is absorbed

3. Based on the information for the two different reactions given below, which of the following gives the quantities needed to calculate the enthalpy change for the reaction represented by the overall equation?

Reaction 1: $N_2O_4(g) \rightarrow 2NO_2(g)$ $\Delta H_1 = 57.9$ kJ
Reaction 2: $2NO(g) + O_2(g) \rightarrow 2NO_2\ (g)$ $\Delta H_2 = -113.1$ kJ

Overall: $2NO(g) + O_2(g) \rightarrow N_2O_4(g)$

a) $\Delta H_1 + \Delta H_2$
b) $\Delta H_1 + (-\Delta H_2)$
c) $(-\Delta H_1) + \Delta H_2$
d) $\Delta H_1 + (2 \times \Delta H_2)$

4. Based on the chemical equations and their associated enthalpy changes shown below, which of the following identifies the quantities needed to calculate $\Delta H°_f$ the standard enthalpy of formation of $H_2O(l)$ in kJ/mol?

(1) $2H(g) \rightarrow H_2(g)$ $\Delta H°_1 = -436$ kJ
(2) $2O(g) \rightarrow O_2(g)$ $\Delta H°_2 = -249$ kJ
(3) $2H(g) + O(g) \rightarrow H_2O(g)$ $\Delta H°_3 = -803$ kJ
(4) $H_2O(g) \rightarrow H_2O(l)$ $\Delta H°_4 = -44$ kJ
(5) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H°_f = ?$

a) $2(-\Delta H°_1) + (-\Delta H°_2) + 2(\Delta H°_3) + 2(\Delta H°_4)$

b) $(-\Delta H°_1) + \frac{1}{2}(-\Delta H°_2) + (\Delta H°_3) + (\Delta H°_4)$

c) $(-\Delta H°_1) + \frac{1}{2}(\Delta H°_2) + (\Delta H°_3)$

d) $(\Delta H°_1) + \frac{1}{2}(\Delta H°_2) + (\Delta H°_3) + (\Delta H°_4)$

5. Which of the following combinations represents the individual reactions and the quantities needed to determine ΔH° for the overall reaction represented by the chemical equation below?

$$CS_2(l) + 2H_2O(l) \rightarrow CO_2(g) + 2H_2S(g) \qquad \Delta H^\circ_{rxn} = ?$$

a)	$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$ $2\ H_2O(l) + 2\ SO_2(g) \rightarrow 2\ H_2S(g) + 3\ O_2(g)$	$\Delta H^\circ = -1075$ kJ $\Delta H^\circ = +1136$ kJ
b)	$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$ $H_2O(l) + SO_2(g) \rightarrow H_2S(g) + \frac{3}{2}\ O_2(g)$	$\Delta H^\circ = -1075$ kJ $\Delta H^\circ = +568$ kJ
c)	$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$ $H_2S(g) + \frac{3}{2}\ O_2(g) \rightarrow H_2O(l) + SO_2(g)$	$\Delta H^\circ = -1075$ kJ $\Delta H^\circ = -568$ kJ
d)	$CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$ $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(l) + 2\ SO_2(g)$	$\Delta H^\circ = -1075$ kJ $\Delta H^\circ = -1136$ kJ

6. Nitrogen dioxide, NO_2, can be formed from nitrogen and oxygen according to the reaction below:

$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$ $\Delta H = ?$

Use Hess's Law to calculate the enthalpy for the formation of NO_2 using the following 2 equations:

$N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H = 180\ kJ$
$2NO_2(g) \rightarrow 2NOg + O_2(g)$ $\Delta H = 112\ kJ$

7. Calculate the enthalpy for the reaction: $PCl_3\ (g) + Cl_2(g) \rightarrow PCl_5\ (g)$
Given the reactions:

$P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(g)$ $\Delta H = -2439\ kJ$
$4PCl_5(g) \rightarrow P_4(s) + 10Cl_2$ $\Delta H = 3438\ kJ$

8. Acetylene is a fuel used in welding torches. Calculate the heat released in the reaction for the combustion of acetylene:

$$2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g)$$

$C_2H_2(g) + 2H_2(g) \rightarrow C_2H_6(g)$	$\Delta H = -94.5$ kJ
$2H_2O(g) \rightarrow 2H_2(g) + O_2(g)$	$\Delta H= 142.4$ kJ
$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$	$\Delta H = -566$ kJ

9. Find the enthalpy for the reaction between hydrochloric acid, HCl, and the sodium nitrite, $NaNO_2$

$$HCl(g) + NaNO_2(s) \rightarrow HNO_2(l) + NaCl(s)$$

$NO(g) + NO_2(g) + Na_2O(s) \rightarrow 2NaNO_2(s)$	$\Delta H = -427$ kJ
$NO(g) + NO_2(g) \rightarrow N_2O(g) + O_2(g)$	$\Delta H = -43$ kJ
$2HNO_2(l) \rightarrow N_2O(g) + O_2(g) + H_2O(l)$	$\Delta H = 34$ kJ
$2NaCl(s) + H_2O(l) \rightarrow 2HCl(g) + Na_2O(s)$	$\Delta H = 507$ kJ