

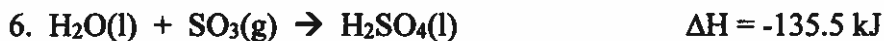
## Introduction to Thermochemistry

### Calculations

Converting J  $\leftrightarrow$  kJ

1. Convert -230,000J to kJ
  
2. Convert 214 kJ to cal
  
3. Convert 634,000 Cal to kJ
  
4. Convert 9,875 kJ to J
  
5. Compare exothermic and endothermic reactions.

Label the following reactions as exothermic or endothermic



10. When water begins to freeze, what happens to the water molecules? Is this process exothermic or endothermic? Why?

11. When ice is in water in a cup, and starts to melt, what is happening, thermodynamically speaking? Phrased another way, where is the flow of energy?

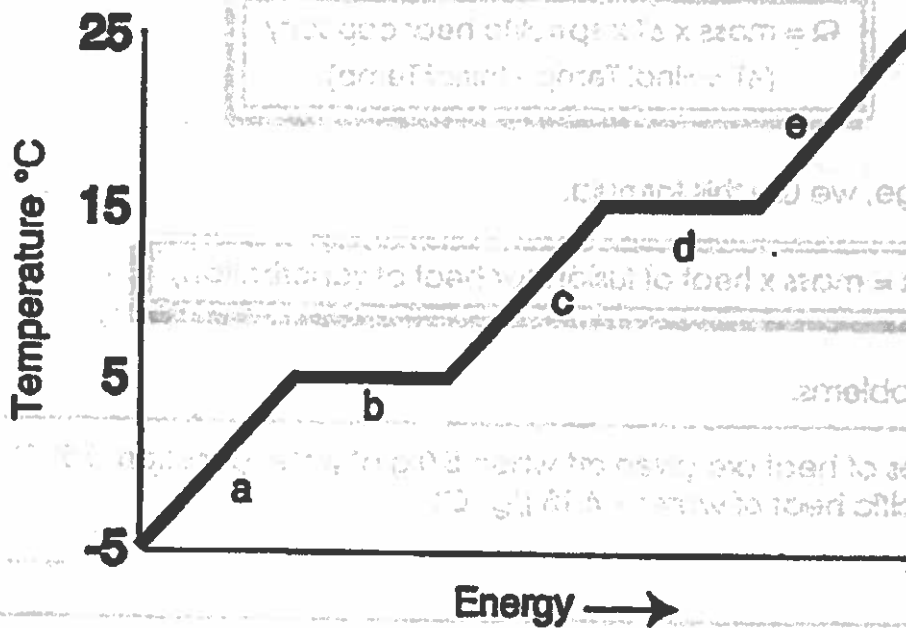
12. Does the water get colder or warmer? Why?

13. What happens to the overall volume of the ice and water after the ice melts? Why?

## Heat Calculations

1. How much energy is needed to change the temperature of 50.0 g of water 15.0°C?
2. How many grams of water can be heated from 20.0 °C to 75°C using 12500.0 Joules?
3. How many joules are required to melt 100 grams of water?
4. What is the final temperature after 840 Joules is absorbed by 10.0g of water at 25.0°C?
5. The heat capacity of aluminum is 0.900 J/g°C.
  - a. How much energy is needed to raise the temperature of a  $8.50 \times 10^2$ g block of aluminum from 22.8°C to 94.6°C?
  - b. What is the heat capacity of aluminum per mole?
6. How much heat is lost when 164 g of water condenses?

# POINT GRAPH



Answer the following questions using the chart above.

1. What is the freezing point of the substance? \_\_\_\_\_
2. What is the boiling point of the substance? \_\_\_\_\_
3. What is the melting point of the substance? \_\_\_\_\_
4. What letter represents the range where the solid is being warmed? \_\_\_\_\_
5. What letter represents the range where the liquid is being warmed? \_\_\_\_\_
6. What letter represents the range where the vapor is being warmed? \_\_\_\_\_
7. What letter represents the melting of the solid? \_\_\_\_\_
8. What letter represents the vaporization of the liquid? \_\_\_\_\_
9. What letter(s) shows a change in potential energy? \_\_\_\_\_
10. What letter(s) shows a change in kinetic energy? \_\_\_\_\_
11. What letter represents condensation? \_\_\_\_\_
12. What letter represents crystallization? \_\_\_\_\_
13. Calculate the total amount of energy absorbed as the temperature of water is increased from  $-5.0^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ . (10.0g of water are used)

### More Heat Calculations

1. A piece of metal weighing 59.047 g was heated to 100.0 °C and then put it into 100.0 mL of water (initially at 23.7 °C). The metal and water were allowed to come to an equilibrium temperature, determined to be 27.8 °C. Assuming no heat lost to the environment, calculate the specific heat of the metal.

2. In a coffee-cup calorimeter, 100.0 mL of 1.0 M NaOH and 100.0 mL of 1.0 M HCl are mixed. Both solutions were originally at 24.6 °C. After the reaction, the temperature is 31.3 °C. What is the enthalpy change for the neutralization of HCl by NaOH?

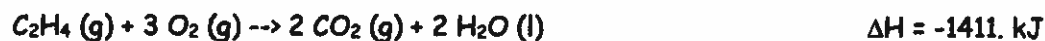
3. How many joules are required to heat 216.5 grams of water from 25°C to 125°C?

4. How many joules are given off when 120 grams of water are cooled from 25°C to -25°C?

5. How many joules are required to heat 75 grams of water from -85°C to 185°C?

## Hess's Law Worksheet

1. Calculate  $\Delta H$  for the reaction:  $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ , from the following Data.



2. Calculate  $\Delta H$  for the reaction  $4 NH_3(g) + 5 O_2(g) \rightarrow 4 NO(g) + 6 H_2O(g)$ , from the following Data.



3. Find

$\Delta H^\circ$  for the reaction  $2H_2(g) + 2C(s) + O_2(g) \rightarrow C_2H_5OH(l)$ , using the following thermochemical data.

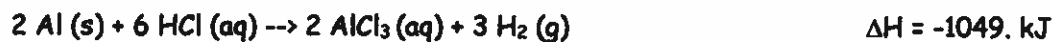


4. Calculate

$\Delta H$  for the reaction  $CH_4(g) + NH_3(g) \rightarrow HCN(g) + 3 H_2(g)$ , given:



5. Calculate  $\Delta H$  for the reaction  $2 Al(s) + 3 Cl_2(g) \rightarrow 2 AlCl_3(s)$  from the Data.



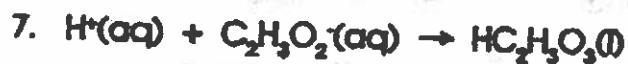
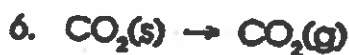
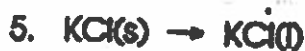
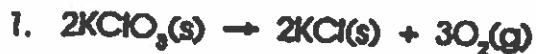
# ENTROPY

Name \_\_\_\_\_

Entropy is the degree of randomness in a substance. The symbol for change in entropy is  $\Delta S$ .

Solids are very ordered and have low entropy. Liquids and aqueous ions have more entropy because they move about more freely, and gases have an even larger amount of entropy. According to the Second Law of Thermodynamics, nature is always proceeding to a state of higher entropy.

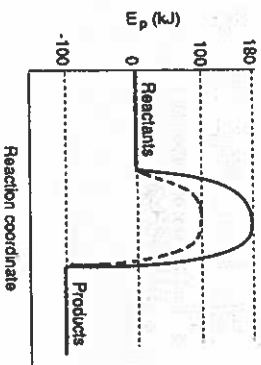
Determine whether the following reactions show an increase or decrease in entropy.



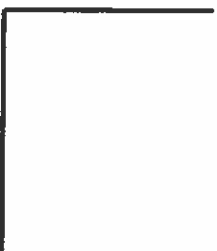
Potential Energy Diagrams Worksheet

1) Use the diagram to answer the following questions:

- a) Is this an endothermic or exothermic reaction?
- b) What do you think the solid line and the dotted line represent?
- c) What is the value of the activation energy for the uncatalyzed reaction?
- d) What is the value of  $\Delta H$ ?
- e) What is the value of the activation energy for the catalyzed reaction?
- f) Has the value of  $\Delta H$  changed?



2) Draw a potential energy diagram for a reaction in which  $\Delta H$  is  $-60\text{kJ}$  and  $E_a$  is  $28\text{kJ}$ . On your diagram, label the following: both axes,  $E_a$ ,  $\Delta H$ , the activated complex, reactants, and products. What would be the  $E_a$  for the reverse reaction?



3) A certain reaction is described by:  $A + B + 80\text{kJ} \rightarrow AB$ . The activation energy is  $175\text{kJ}$ . Sketch a potential energy diagram for this reaction and label  $E_a$ ,  $\Delta H$ , the activated complex, reactants, and products. What is the  $E_a$  for the reverse reaction?



4) A reaction is given as follows:  $\text{CO} + \text{NO}_2 \rightarrow \text{CO}_2 + \text{NO} + 226\text{kJ}$   
 a) Sketch a potential energy diagram for the reaction. The activation energy is  $134\text{kJ}$ . Label reactants, products,  $E_a$ ,  $\Delta H$ , and the activated complex.



A catalyst is added and the  $E_a$  is reduced by  $54\text{kJ}$ . Use a dotted line on the above graph to sketch the catalyzed reaction. What is the value of  $E_a$  for this reaction? What is the value of  $\Delta H$ ? What benefit is there to us?

## Equilibrium Expressions Worksheet

### Equilibrium constant ( $K_{eq}$ )

1. Write the following equilibrium expressions in each box:

- a.  $O_3(g) + NO(g) \rightarrow O_2(g) + NO_2(g)$
- b.  $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$
- c.  $NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(l)$
- d.  $2H_2O(g) \rightarrow 2H_2(g) + O_2(g)$

a.

b.

c.

d.

### Calculations involving $K_{eq}$

1.  $PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$ . What is the equilibrium constant if the equilibrium concentrations are as follows:  $PCl_5$  is 0.0096 mol/L,  $PCl_3$  is 0.0247 mol/L and  $Cl_2$  is 0.0247 mol/L?

2. At  $1000^\circ C$ , a 1.00 L container has an equilibrium mixture consisting of 0.102 mol of ammonia, 1.03 mol of nitrogen, and 1.62 mol of hydrogen. Calculate the  $K_{eq}$  for the equilibrium system.



3. At a given temperature, the  $K_{eq}$  for the reaction  $2HI(g) \rightarrow H_2(g) + I_2(g)$  is  $1.40 \times 10^{-2}$ . If the concentration of both  $H_2$  and  $I_2$  at equilibrium are  $2.00 \times 10^{-4} M$ , find the concentration of HI.



## Le Chatelier's Principle

Balance the following equations. Write heat as a reactant or product, based on if the reaction is endothermic or exothermic. Predict which way equilibrium will shift, left or right.

### One

Consider the following exothermic reaction:  $\text{H}_2(\text{g}) + \text{F}_2(\text{g}) \rightleftharpoons \text{HF}(\text{g})$ .

- Which way will equilibrium shift if you add more hydrogen to the system?
- Which way will equilibrium shift if you add more hydrofluoric acid to the system?
- Which way will equilibrium shift if you decrease the amount of fluorine in the system?
- Which way will equilibrium shift if you increase the temperature?
- Which way will equilibrium shift if you decrease the volume of the container?

### Two

Consider the following exothermic reaction:  $\text{NaCl}(\text{aq}) + \text{Mg}(\text{NO}_3)_2(\text{aq}) \rightleftharpoons \text{NaNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq})$

- Which way will equilibrium shift if you add more NaCl to the system?
- Which way will equilibrium shift if you add more magnesium nitrate to the system?
- Which way will equilibrium shift if you decrease the amount of magnesium chloride in the system?
- Which way will equilibrium shift if you decrease the temperature?
- Which way will equilibrium shift if you decrease the amount of sodium nitrate in the system?

### Three

Consider the following endothermic reaction:  $\text{SbCl}_5(\text{g}) \rightleftharpoons \text{SbCl}_3(\text{g}) + \text{Cl}_2(\text{g})$ .

- Which way will equilibrium shift if you decrease the  $\text{SbCl}_5$  in the system?
- Which way will equilibrium shift if you add more chlorine to the system?
- Which way will equilibrium shift if you decrease the temperature of the system?
- Which way will equilibrium shift if you increase the volume of the container?
- Which way will equilibrium shift if you decrease the amount of  $\text{SbCl}_3$ ?

### Four

Consider the following endothermic reaction:  $\text{SO}_2(\text{g}) + \text{NO}_2(\text{g}) \rightleftharpoons \text{SO}_3(\text{g}) + \text{NO}(\text{g})$ .

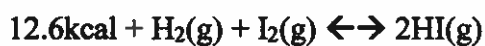
- Which way will equilibrium shift if you decrease the  $\text{SO}_3$  in the system?
- Which way will equilibrium shift if you add more NO to the system?
- Which way will equilibrium shift if you decrease the temperature of the system?
- Which way will equilibrium shift if you increase the volume of the container?
- Which way will equilibrium shift if you decrease the amount of  $\text{SO}_2$ ?

### Five

Consider the following exothermic reaction:  $\text{I}_2(\text{g}) + \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) \rightleftharpoons \text{NaI}(\text{aq}) + \text{Na}_2\text{S}_4\text{O}_6(\text{aq})$ .

- Which way will equilibrium shift if you decrease the NaI in the system?
- Which way will equilibrium shift if you add more  $\text{I}_2$  to the system?
- Which way will equilibrium shift if you increase the temperature of the system?
- Which way will equilibrium shift if you decrease the amount of  $\text{Na}_2\text{S}_2\text{O}_3$  in the system?
- Which way will equilibrium shift if you decrease the amount of  $\text{Na}_2\text{S}_4\text{O}_6$ ?

### Le Chatelier's Principle Practice



Stress	Equilibrium Shift	[H <sub>2</sub> ]	[I <sub>2</sub> ]	[HI]	K
1. Add H <sub>2</sub>		-----			
2. Add I <sub>2</sub>			-----		
3. Add HI				-----	
4. Remove H <sub>2</sub>		-----			
5. Remove I <sub>2</sub>			-----		
6. Remove HI				-----	
7. Increase Temperature					
8. Decrease Temperature					
9. Increase Pressure					
10. Decrease Pressure					



Stress	Equilibrium Shift	[HCl]	[O <sub>2</sub> ]	[H <sub>2</sub> O]	[Cl <sub>2</sub> ]	K
1. Add O <sub>2</sub>			-----			
2. Add H <sub>2</sub> O				-----		
3. Add Cl <sub>2</sub>					-----	
4. Remove HCl		-----				
5. Remove O <sub>2</sub>			-----			
6. Remove H <sub>2</sub> O				-----		
7. Increase Temperature						
8. Decrease Temperature						
9. Increase Pressure						
10. Decrease Pressure						