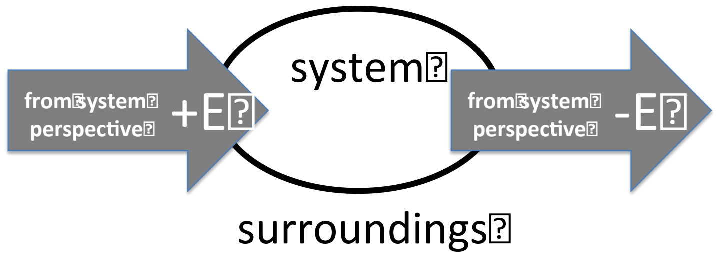
Thermodynamics: Understanding the Difference between Heat of Reaction, Temperature Changes, and Enthalpy of Reaction v110414

Objective: The student will be able to differentiate between the concept of heat and temperature. The students will also be able to determine the enthalpy of reaction using a coffee cup calorimeter.

Background:



The overall energy change of the system is equal to the final energy of the system minus the initial energy of the system. (Chapter 6, Section 3 of Tro 3rd Edition) All reactions require an energy investment. This is the energy that must be added to the system represented here by a +E. Also, all reactions generate energy, represented here by a –E. The difference in these two energies is the change in energy (ΔE) of the system. The **first law of thermodynamics** states that the total energy of the universe is constant. In other words, energy cannot be created nor destroyed. Therefore, energy changes in the system are directly related to energy changes in the surroundings. The system and surroundings simply have opposite signs because energy gained by the system will have been lost by the surroundings.

$$\Delta E_{system} = - \Delta E_{surroundings}$$

For a chemical reaction, the energy is mostly associated with the bonds of the reactants and the bonds of the products. Energy must be added to the reactants to break the bonds (+E) and energy is generated as a result of the formation of new bonds leading to products (-E). The difference in these energies describes the energy of the reaction. The primary form of energy for a reaction is in the form of heat.

The terms heat and temperature are often used incorrectly. **Heat** is the flow of energy caused by a temperature difference in two substances. **Temperature** is a measure of the average kinetic energy of the atoms or molecules that compose a sample of matter (Chapter 6, Section 4 of Tro 3rd Edition). To help you understand the difference between heat and temperature, picture the following scenario.

1. You have a glass of hot water and you have a thermometer, both sitting on the laboratory bench.
2. The water molecules in the glass have a high kinetic energy because they are at a high temperature. The alcohol molecules in the thermometer have a lower kinetic energy since they are at room temperature.
3. The thermometer is then added to the glass of hot water. The heat from the water is transferred to the alcohol in the thermometer by collision from the hot water molecules. This causes the average kinetic energy of the alcohol molecules to increase.
4. The increase in kinetic energy of the alcohol causes the alcohol to expand providing an observed change in the temperature.

A second example that will help you understand the difference in heat and temperature can be illustrated with a teacup of water and a bathtub of water. The water in the teacup and the bathtub are heated so that the water in the two containers is at the same temperature. To get the water in these two containers to the same temperature, did you have to add the same amount of energy? No, to get the water in the bathtub to the same temperature as that in the teacup, the water in the bathtub had to absorb more energy and therefore it contains a greater amount of heat.

Heat will always be transferred from the hotter object to the colder object until the two objects reach thermal equilibrium. Experiments show that the heat transferred and the temperature change observed for an object are directly proportional. The amount of energy needed to cause a change in temperature depends on the specific heat capacity of the substance, which is a constant (Table 6.4 on page 257 of Tro 3rd Edition). For example: specific the heat capacity of water is 4.18 J / (g · ^oC) and that of aluminum is 0.903 J/(g^oC). These heat capacities indicate that 4.18 J of energy must be absorbed by 1 g of water to raise the temperature by 1^oC and that 0.903 J of energy must be absorbed by aluminum to raise 1 g of aluminum by 1^oC. These specific heat capacities explain why an aluminum pan gets hot quickly while water in the pan takes a longer time to become hot. The relationship of heat to the change in temperature observed can be calculated using the equation:

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

where: q = heat transferred, m = mass of substance, c = specific heat capacity of the substance, and ΔT = change in temperature ($T_{final} - T_{initial}$)

If the reaction occurs at constant pressure, then the heat of the reaction equals the **enthalpy change (ΔH)** of the reaction (Chapter 6, Section 6 of Tro 3rd Edition). If a greater amount of energy must be supplied to the system to break the bonds of the reactants than is given off upon the formation of the bonds in the products, then the reaction will be **endothermic (+ΔH)**. If a greater amount of energy is produced upon the formation of the bonds in the products than was required to break the bonds of the reactants, then the reaction is **exothermic (-ΔH)**. Since the energy is directly related to the number and types of bonds, the quantity of reactants and type of reagents will have a direct impact on the amount of heat produced. (Limiting reagent rules will apply to the amount of heat produced.) The energy produced is therefore a stoichiometric value, it can be a limiting reactant or a product.

$CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$ $\Delta H = -179.2$ kJ
$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ $\Delta H = 179.2$ kJ (reversed reaction, changed sign)
$\frac{1}{2} CaO(s) + \frac{1}{2} CO_2(g) \rightarrow \frac{1}{2} CaCO_3(s)$ $\Delta H = -89.6$ kJ (½ moles of compounds, ½ ΔH)

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ $\Delta H = -55.4$ kJ
$H^+(aq) + OH^-(aq) \rightarrow H_2O(g)$ $\Delta H = -11.8$ kJ (alter state of matter, change enthalpy)

In a laboratory setting, the enthalpy of reaction can be calculated using the equation:

$$\Delta H = q \;/\; \text{moles of product produced}$$

where: q = heat and the moles of product produced takes into account the stoichiometric needs of enthalpy.

Procedure:

Experiment I

1. Construct a coffee-cup calorimeter as directed by the instructor.
2. Using a graduated cylinder, add 50-mL of 1 M HCl (record the concentration and volume of the acid on your data sheet) to the coffee cup calorimeter.
3. Monitor the temperature for 1 minute and record as initial temperature. (This assumes that the initial temperature of both starting materials is the same. This assumption is fairly accurate given that both the acid and base have been stored at room temperature.)
4. Measure out 50-mL of 1 M NaOH (record the concentration and volume of the base on your data sheet) and add it to the HCl in the coffee cup calorimeter.
5. Stir the solution for 1 min while monitoring the temperature.
6. Record the temperature after 1 minute as the ending temperature.
7. Pour the reaction mixture down the drain with excess water, rinse with tap water then with distilled water, and dry.

Experiment II

8. Repeat steps 2-7, but use 100-mL of 1 M HCl and 100-mL of 1M NaOH instead.

Experiment III

9. Repeat steps 2-7, but use 50-mL of 2 M HCl and 50-mL of 2 M NaOH instead.

Experiment IV

10. Repeat steps 2-7, but use 25-mL of 1 M HCl and 75-mL of 1 M NaOH instead.

Experiment V

11. Repeat steps 2-7, but use 25-mL of 1 M H_2SO_4 and 75-mL of 1 M NaOH instead.

Names of student: ______________________________ Name of Partner:____________________________

DATA SHEET FOR LAB

Experiment No.	Initial moles H^+	Initial moles OH^-	Limiting Reactant	Theo. yield moles of H_2O from neutralization reaction	ΔT_{avg}* (°C)	Mass of resulting solution (g)	q absorbed by the solution (J)	q released by the reaction (J)	$\Delta H_{neutralization}$ (kJ/mol)
1 50 mL 1 M HCl + 50 mL 1 M NaOH									
2 100 mL 1 M HCl + 100 mL 1 M NaOH									
3 50 mL 2 M HCl + 50 mL 2 M NaOH									
4 25 mL 1 M HCl + 75 mL 1 M NaOH									
5 25 mL 1 M H_2SO_4 + 75 mL 1 M NaOH									

* Averaged from several runs and other class data

Name: ______________________________

Pre-Laboratory Assignment

1. Define heat.

2. Define temperature.

3. Define enthalpy.

4. Draw a coffee cup calorimeter. (p 269 of Tro 3rdEdition)

5. A hydrochloric acid spill occurred on Lucky Bear's property. The HAZMAT team was directed to use 50-mL of 1 M NaOH for every 50-mL of 1 M HCl spilled to neutralize the acid spill. A temperature increase of 6.7^{o}C results from the reaction as described.

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

   a. Is this reaction endothermic or exothermic?

   b. Given that the density of water is 1.00 g/mL and that HCl and NaOH are aqueous solutions, calculate the change in heat expected for the surroundings.

   c. What is the change in heat associated with the reaction?

d. Calculate the moles of water produced by this reaction (limiting reagent problem).

e. Calculate the enthalpy change associated with this reaction.

6. Write the balanced chemical equation and the net ionic equation for the following two reactions.

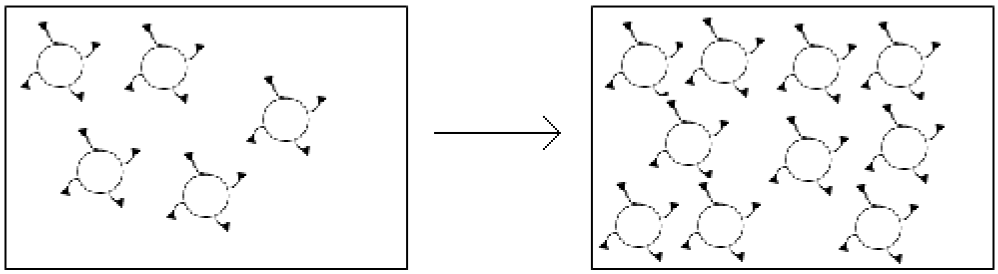
   a. $HCl(aq) + NaOH(aq) \rightarrow$

   b. $H_2SO_4(aq) + NaOH(aq) \rightarrow$

   c. Would you expect the two reactions in (a) and (b) to have the same enthalpy change? Explain.

For the following questions the size of the box refers to the volume and the symbol is a substance radiating heat to the surroundings. The amount of heat generated by each of the above representations is identical.

7. If you double the quantity of substance but the volume remains the same:

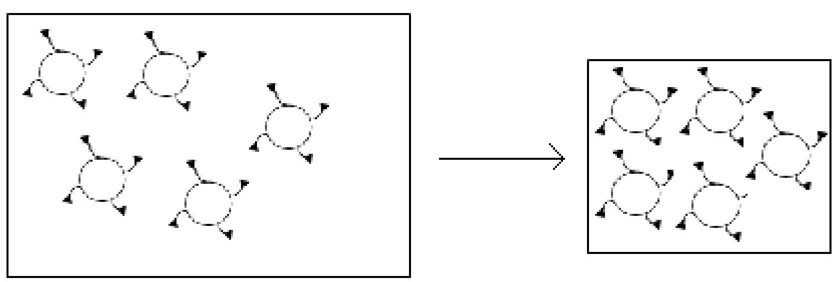


   a. Heat: increases decreases remains the same

   b. Temperature: increases decreases remains the same

   c. Explain the reasoning behind your answers.

8. If you keep the quantity of the substance constant but you reduced the volume by half:

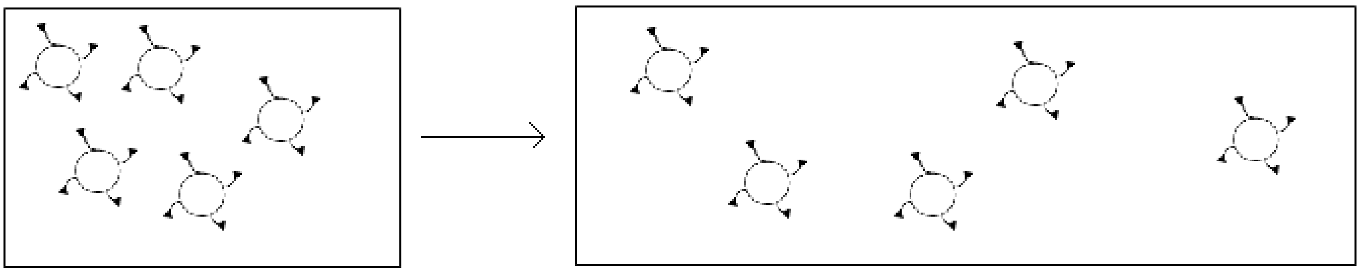


   a. Heat: increases decreases remains the same

   b. Temperature: increases decreases remains the same

   c. Explain the reasoning behind your answers.

9. If you keep the quantity of the substance constant but double the volume:

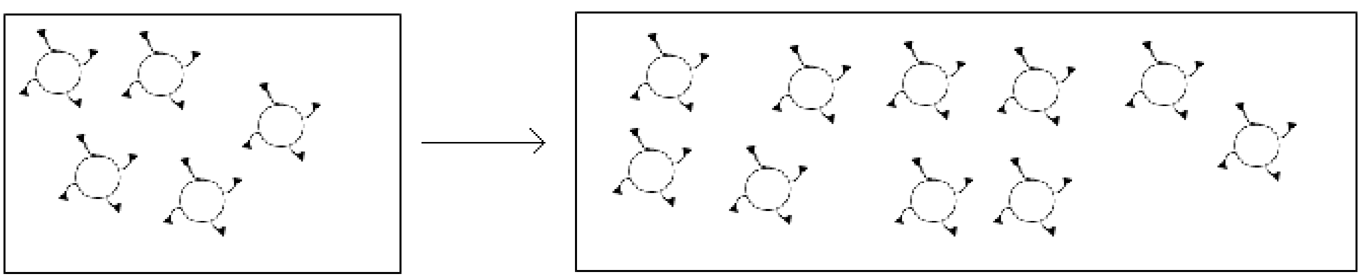


a. Heat: increases decreases remains the same

b. Temperature: increases decreases remains the same

c. Explain the reasoning behind your answers.

10. If you double the quantity of the substance and double the volume:



a. Heat: increases decreases remains the same

b. Temperature: increases decreases remains the same

c. Explain the reasoning behind your answers.

Name: ______________________________

Post-Laboratory Questions

1. Experiment I to Experiment II is an example of question 10 from the pre-lab. Did your experimental results reflect your prediction in the pre-lab? Explain.

2. Experiment I to Experiment III is an example of question 7 from the pre-lab. Did your experimental results reflect your prediction in the pre-lab? If not, explain.

3. Explain the difference between heat and temperature.

4. What experimental parameters affected the temperature of the solution?

5. What experimental parameters affect the enthalpy of the reaction?