Experiment 30C1 – Week 1

CHEMICAL CHANGE AND ENERGY:
What Fuel Makes the Best Energy Source?

MATERIALS: Week 1: 12 oz. Styrofoam cup with lid, thermometer, 100 mL graduated cylinder, 1.00 M HCl, 1.00 M NaOH, stir motor, stir bar.
Week 2: 12-oz. aluminum beverage can with top cut out and holes on side, thermometer, 100 mL graduated cylinder, 800 mL beaker, long-stem lighter, three fuel burners (filled with ethanol, n-octane, or 2-pentanol), steel wool, glass rod, ring stand, room-temperature water.

PURPOSE: The purpose of this experiment is to learn how chemical reactions transfer heat and to determine which fuels transfer the most heat during reaction with oxygen.

LEARNING OBJECTIVES: By the end of this experiment, the student should be able to demonstrate the following proficiencies:
1. Construct and use a calorimeter. – Week 1
2. Calculate the heat of a reaction from calorimetry data. – Week 1
3. Calculate the fuel value for several fuels. – Week 2
4. Compare the fuel value of an oxygenated and non-oxygenated fuel and explain differences in the values. – Week 2

DISCUSSION:
Energy is essential for life. We fill our cars with energy-rich fuels so that they can transport us across town. We burn fuel to create electricity to power the electronic gadgets on which we depend. We use fuel to heat the buildings where we live and work. It is also the essence of life; we eat foods made up of carbohydrates, proteins and fats to power our bodies.

Most of the fuels used today for power and heat are derived from petroleum oil, often referred to as crude oil, but these have limitations: they are non-renewable resources, and their combustion produces large amounts of pollution. Because of these problems, alternatives to petrol-based fuels are being developed, and their overall effectiveness is being investigated. Each alternative chemical fuel (1) has a different chemical composition and structure, (2) provides different amounts of energy, (3) produces different types and amounts of pollution, and (4) costs a different amount.

How do we decide what is the best possible energy source when we account for all of these aspects? This is one of the questions that you will investigate during the next two weeks as you explore the topic of chemical change and energy by investigating alternative fuel sources that produce energy via chemical changes. You will look at the energy content of different fuel sources as well as other issues that determine whether a fuel is a viable energy source.

During the first week of this laboratory module, you will conduct calorimetry experiments to measure the energy changes involved in the reaction between NaOH (aq) and HCl (aq) and to understand how chemical reactions transfer heat. In the second week, you will compare the combustion behaviors of different chemical compounds to determine which compound has the highest energy content per gram. Using the information from this module, you should be able to construct an argument to address the question “What fuel makes the best energy source?”
**WEEK 1:**

**How Do Chemical Reactions Transfer Heat?**

The neutralization of an acid with a base in aqueous solution is an exothermic process. The heat transferred in this process \( (q_{rxn}) \) can be measured using a coffee-cup calorimeter (see Figure 1). In this experiment, we will assume that no heat escapes or is absorbed by the coffee cup. Making this assumption, the energy transferred to the liquid inside the cup approximates the total energy released by the reaction. Therefore the heat of the calorimeter \( (q_{cal}) \) approximates the heat transferred to the liquid \( (q_{soln}) \) and it is the negative of \( q_{rxn} \).

\[
q_{cal} \approx q_{soln} \approx -q_{rxn}
\]

The heat evolved by the neutralization reaction is transferred to the solution and can be measured as a temperature change where:

\[
-q_{rxn} = q_{soln} = C_{soln} \cdot m_{soln} \cdot \Delta T_{soln}
\]

We will assume that the specific heat of the solution is the same as that of the solvent (water), therefore, \( C_{soln} = 4.184 \text{ J/g } ^\circ \text{C} \) (or \( 4.184 \text{ J/g } ^\circ \text{K} \)), \( m_{soln} \) is the mass of the solution, and \( \Delta T_{soln} = T_{final \ soln} - T_{initial \ soln} \). \( T_{final \ soln} \) is the maximum temperature reading on the thermometer during the reaction.

The enthalpy change of the reaction \( (\Delta H_{rxn}) \) in kJ/mol can be found using:

\[
q_{rxn} = n \cdot \Delta H_{rxn}
\]

where \( n \) is the number of moles of reaction that occurs.

![Figure 1: Coffee-cup Calorimeter](image_url)
PROCEDURE:

**Energy Changes During an Acid Base Reaction**

1. Rinse the graduated cylinder with water and then rinse it with about 10 mL of 1.00 M NaOH (coat the sides by turning the graduated cylinder). Discard the rinses. With the graduated cylinder, place 50.0 mL of 1.00 M NaOH into the calorimeter. Measure the temperature (in °C) of the NaOH solution using the thermometer provided. Record this value in the Data Section. Rinse the thermometer end after obtaining the temperature.

2. Rinse the graduated cylinder with water and then rinse with 1.00 M HCl. Discard the rinses. Measure 50.0 mL of 1.00 M HCl into the graduated cylinder. Measure the temperature of the HCl solution in the graduated cylinder. Record this value in the Data Section. The initial temperature, $T_i$, will be defined as the average temperature of the two solutions. Record this average temperature in the Data Section.

3. Note the time (time = zero). Then add the HCl solution quickly to the NaOH solution in the calorimeter, swirl the solution then add the stir bar, and replace the lid on the calorimeter. Add the thermometer making sure it does not touch the stir bar. You can use a clamp to hold the thermometer at the proper height (in the solution but not touching the stir bar or sides of the calorimeter). Start the stir motor (on low) to gently mix the solution. Immediately begin collecting and recording temperature readings at 30-second intervals for 7 minutes (or until a minute after the maximum temperature has been reached). Keep the lid on the calorimeter.

4. When data collection is completed, rinse the calorimeter and the thermometer with distilled water and dry as completely as possible.

**Clean up:**

1. All solutions are dilute aqueous solutions and may be poured down the drain.
2. Wash all glassware. Rinse your calorimeter well and invert it on a paper towel to dry.
3. Turn OFF the thermometer.

**WEEK 1 DATA SECTION**

**Energy Changes During an Acid Base Reaction**

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Week 1 Data Analysis:

1. What was the maximum temperature you recorded after starting the acid-base reaction?  
   \[ T_f = \underline{________} \]

2. Calculate \( q_{\text{soln}} \) (in J) for this reaction between HCl (aq) and NaOH (aq). Show your work.  
   \( C_{\text{soln}} = 4.184 \, \text{J/g °C} \)

3. How many moles of HCl and how many moles of NaOH reacted in this reaction? Look at the amounts mixed.

4. Calculate \( \Delta H_{\text{rxn}} \) (in kJ/mol) for this reaction between HCl (aq) and NaOH (aq). Show your work.

5. Think about the qualitative observations you have made and the quantitative data that you have collected for the reaction between NaOH (aq) with HCl (aq).
   
a. Write the molecular, complete ionic, and net ionic equations for the chemical reaction that occurred.

   Molecular:

   Complete Ionic:

   Net Ionic:
b. Was the acid-base reaction you studied endothermic or exothermic? How do you know this? Explain using your experimental observations.

c. Draw a macroscopic-level* picture of what occurred during the calorimetry experiment including any experimental observations. Explain in words any macroscopic changes that occurred and how these are represented in your picture.

d. Draw a molecular-level* picture of the reactant and product species, and describe (in words) what is happening in the reaction from a molecular-level perspective. Review the net ionic equation on the previous page. On the molecular-level, what do you believe causes the macroscopic observations you noted in part c? Label clearly any representations or include a legend or key.

* Remember that a macroscopic-level description relates to what you observe (see, feel, notice, etc) during the experiment. A molecular-level description explains what you think the molecules, atoms and/or ions are doing that results in your macroscopic observations. You can’t see what’s happening on the molecular-level but it has a big effect (and explains) what you observe in the real world (macroscopically).
WEEK 1

PRE-LAB QUESTIONS
Experiment 30C1

1. When 100 mL of 0.500 M HCl is mixed with 100 mL of 0.500 M NaOH in a coffee-cup calorimeter, the final temperature of the mixture is measured to be 25.86 °C. The initial temperature of both solutions was 22.50 °C.
   a. Assuming that the densities and specific heat capacities of the solutions are the same as for water (1.00 g/mL and 4.184 J/g °C), calculate the heat released by this reaction ($q_{rxn}$) in kJ. Show your work.

b. Determine the enthalpy change for the reaction, $\Delta H_{rxn}$ (in units of kJ/mol HCl neutralized). Show work.

2. a. Determine whether the following are endothermic or exothermic.
   i. melting of ice (s $\rightarrow$ l) Endothermic Exothermic
   ii. condensation of water (g $\rightarrow$ l) Endothermic Exothermic
   iii. burning of gasoline (combustion rxn) Endothermic Exothermic
   iv. decomposition of potassium chlorate (KClO$_3$ to KCl and O$_2$) Endothermic Exothermic

b. Which of the following are TRUE regarding an exothermic process? Select all that apply.
   i. For an exothermic process, energy is transferred as heat from the system to the surroundings.
   ii. For an exothermic process, energy is transferred as heat from the surroundings to the system.
   iii. For an exothermic process, the surroundings will increase in temperature.
   iv. For an exothermic process, the sign for $\Delta H$ is positive.
   v. For an exothermic process, $q_{system} < 0$. 

E30C1-6