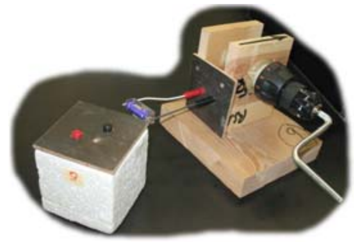
Energy and Energy Conversion

Minneapolis Community and Tech. College
Principles of Chemistry 1
v.9.15

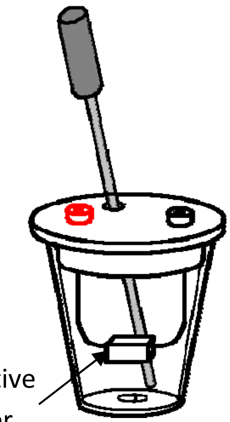


Energy

Energy is defined by most textbooks as the capacity to do work. However, the true usefulness of energy depends on its form. For example, food is a form of chemical potential energy that we need to live. Gasoline is another form of chemical potential energy that is useless as a food source but essential to transportation. Although it may seem obvious to you that gasoline is a form of chemical potential energy, it may not be as obvious to think of a charged battery in the same way. Neither can fuel our bodies but both are capable of propelling an automobile even though the mechanisms used to extract the stored energy and convert it into kinetic energy are quite different. Ultimately, all energy is eventually transformed into heat that warms the universe.

Energy cannot be lost or destroyed but only changes form. For example, when the driver of a conventional car pushes down on the brake pedal, the kinetic energy of the car is converted to heat energy via friction in the brakes which then radiates into the environment where it is unavailable for further use. Modern hybrid automobiles use a different braking mechanism that converts the car's motion during braking into electricity that charges a battery. Later, this stored electricity is used to propel the car. This hybrid system wastes much less energy than conventional brakes and makes for a more efficient automobile.

Generally, converting one form of energy into another involves loss. This doesn't mean that energy is really lost but rather that some significant part is converted into a form that is not useable. For example, only about 20-25% of gasoline's chemical potential energy is actually converted into useful motion of the car. The rest is lost as heat energy that is transferred into the surroundings (i.e. it warms you up on a cold winter day). This percentage, otherwise known as the conversion efficiency, is something automotive engineers are always trying to improve in their quest for a more efficient automobile.



In these experiments the heat energy produced is measured using calorimetry techniques. Since both water within the calorimeter and the cup assembly itself absorb any heat energy produced, it is necessary to treat these contributions separately. The heat transferred to the water is easily calculated using the water's measured temperature change and the equation:

$$q_{water} = m_{water} \times C_{water} \times \Delta T_{water} \qquad \textit{(Equation 1)}$$

Where the specific heat of water is known to be c_{water} = 4.184 J/g°C.
The heat transferred to the calorimeter apparatus is determined via

$$q_{cal} = C_{cal} \times \Delta T_{cal}. \qquad \textit{(Equation 2)}$$

where C_{cal} is the calorimeter constant equal to **90.5 J/°C .** $\Delta T_{cal} = \Delta T_{water}$ since the water and calorimeter are in contact with each other and experience the same change in temperature.

Together, the calorimeter (q_{cal}) and the water (q_{water}) account for most of the heat released in an experiment and we'll ignore any heat lost to the outside surroundings (air, countertop, etc). So, with those assumptions we can say that the total heat produced by an experiment will be q_{total}:

$$q_{total} = q_{water} + q_{cal} \qquad \textit{(Equation 3)}$$

Procedure:

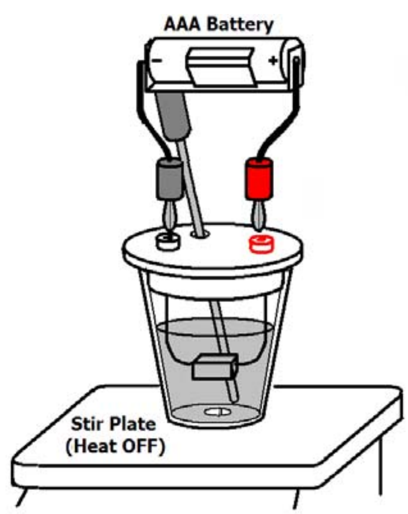
Materials List:

- Cubic Styrofoam Calorimeter, Lid and Heating Element
- Stir plate
- Magnetic Stir Bar (medium)
- LoggerPro temperature Probe
- LoggerPro data acquisition device (assorted cables and Power Supply)
- Computer
- 1 **black** 24" banana to banana wire
- 1 **red** 24" banana to banana wire
- 1 hand crank electrical generator
- 1 AAA battery holder
- 1 AAA Alkaline battery
- Stopwatch
- 2 100 mL graduated cylinders
- ~50 mL 1.00 M HCl
- ~50 mL 1.00 M NaOH

A. Conversion of battery's energy into heat.

In this procedure, we will attach a AAA battery to the calorimeter. The battery's stored chemical potential energy will be converted into heat that warms the water and calorimeter. By calculating the amount of heat energy produced, we determine the amount of energy available from the AAA battery.

Record the mass of the dry, empty calorimeter cup and lid using a top loading balance. You will use this "empty mass" throughout the entire series of calorimeter experiments. Use a 100 mL graduated cylinder to pour exactly 100mL of room temperature water into the cup and weigh. Record the mass in your data table and determine the water's mass.



Add a medium stirring bar to the water, replace the lid and place the calorimeter cup on top of the hot/stir plate (Heat is turned OFF). Insert the temperature probe through the hole in the lid and load the "Energy Conversion" file found in the share drive *(Path… S:\share\coureswork\boraas\C1151)*.

Stir the mixture at a setting of ~300 rpm. If you can hear the stir bar colliding with the temperature probe, adjust the position of the temperature probe and calorimeter cup on the hotplate .

Obtain a AAA ***alkaline*** battery and insert it into the battery holder **(positive = red).** **Don't attach the battery assembly to the calorimeter yet.** Use a top loading balance to measure the initial mass of the battery.

Now, click on the Logger Pro green "Collect" button and then connect the battery to the calorimeter. Continue collecting data until a maximum temperature has been reached (~700 seconds). Record the initial temperature and final maximum temperature for the trial in your data table with two decimal place accuracy. We will not be saving any other temperature data.

Record the amount of time the battery spent discharging in seconds and record this value in your data sheet.

Remove the battery from the battery holder and re-weigh it on the same top loading balance used previously.

Place the used battery in the recycling beaker at the front of the lab.

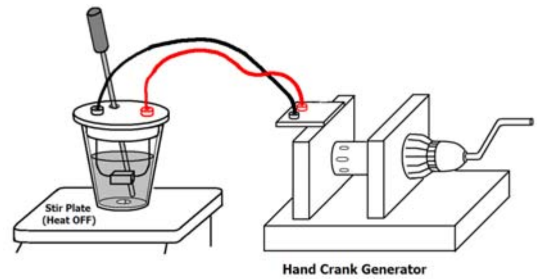
B. Generation of electrical energy and conversion to heat.

In this procedure, you will convert a small amount of stored chemical energy (…your breakfast/lunch) to kinetic energy as you crank the handle of a generator. The generator converts kinetic energy into electrical energy that is sent to the calorimeter where it is converted into heat by the resistive heater. By measuring the amount of heat released, we can determine approximately how much energy was originally available.

Use a 100 mL graduated cylinder to pour exactly 100mL of room temperature water into the cup and weigh your calorimeter. Record the mass in your data table and subtract to determine the actual mass of the water.

Add a medium stirring bar to the water (stir at 300), replace the lid and place the calorimeter cup on top of the hot/stir plate (Heat is turned OFF). Insert the temperature probe through the hole in the lid being VERY CAREFULL NOT TO POKE A HOLE IN THE CUP.

Connect the generator to the calorimeter using the wires provided (match the colors).



Click on "Experiment" -----> "Store Latest Run".

Click on the "Collect" button and start cranking the generator. Crank as fast as you can for 5 minutes. Continue collecting data after you stop cranking for at least 15 more seconds to allow the temperature probe to reach its max. value. Record the initial and final temperatures in your data sheet with two decimal place accuracy. We will not be saving any other temperature data.

C. Chemical Energy: ΔH_{rxn} for Acid/Base Neutralization and collection of produced heat energy

Acid/Base Neutralization Reaction: $HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$ **ΔH_{rxn} = -55.7 kJ/mole**

In this experiment, you will combine equal volumes of aqueous hydrochloric acid and sodium hydroxide. Since both reactant solutions have the same concentration (1.00 M), they contain equal moles of both the acid and the base. The equal molar amounts react in a 1:1 mole ratio and are completely consumed (i.e. there is no limiting or excess reactant).

We will measure the heat produced by this reaction using techniques already described above. Then we will calculate the heat energy produced per mole of reactant and compare it to the tabulated ΔH_{rxn} value **above**.

Measure the mass of the empty calorimeter and lid using a top loading balance.

Measure out exactly 50 mL of 1.00 M NaOH and HCl in two, clean 100 mL graduated cylinders.

Pour the contents of the HCl solution into the calorimeter cup.

Carefully add a medium stirring bar to the HCl solution, replace the lid and place the calorimeter cup on top of the hot/stir plate (Heat is turned OFF). Insert the temperature probe through the hole in the lid and stir at 300.

Click on "Experiment" -----> "Store Latest Run". Click "Collect" and continue to collect data for approximately 60 seconds.

Carefully lift the calorimeter cup lid <u>keeping the temperature probe immersed in the solution</u>. Quickly pour the 50 mL of NaOH solution into the calorimeter. Replace lid.

Continue collecting data until the highest temperature is reached.

Use LoggerPro to identify the initial and final (maximum) temperatures. Record these temperatures on your data sheet. We will not be saving any other temperature data.

Important: Reweigh the calorimeter with its neutralized acid/base mixture on a top loading balance. This measurement will be used to determine the mass of the combined solutions. Dispose of the solution by carefully pouring down the drain. Rinse the calorimeter with distilled water.

C1151 Data Sheet
Energy Conversion
Instructor Initials_____

Name___________________________
Date of Exp. _________________
Lab Section _________________

Your *__individual__* *experimental report will be due at the beginning of your next lab.*
Data Tables: (All measurement entries must be in written in ink before you leave the lab).

Part A (Battery)		**Alkaline Battery**	
Empty Calorimeter mass	(grams)		
H_2O + Calorimeter Mass	(grams)		
Water Mass	(grams)		
Battery Mass	(grams)	Initial	Final
C_{cal}	(Joules/°C)	90.5	
Initial Temperature	(°C)		
Final Temperature	(°C)		
ΔT	(°C)		
Discharge Time	(minutes)		
q_{water} **...Eq. 1**	(Joules)		
q_{cal} **... Eq. 2**	(Joules)		
q_{total} **...Eq. 3**	(Joules)		

Part B (Generator)		
Empty Calorimeter mass	(grams)	
H_2O + Calorimeter Mass	(grams)	
Water Mass	(grams)	
C_{cal}	(Joules/°C)	90.5
Initial Temperature	(°C)	
Final Temperature	(°C)	
ΔT	(°C)	
q_{water} **...Eq. 1**	(Joules)	
q_{cal} **... Eq. 2**	(Joules)	
q_{total} **...Eq. 3**	(Joules)	

Part C (ΔH_{rxn})					
Empty Calorimeter mass	(grams)		q_{water} **...Eq. 1**	(Joules)	
Solution + Calorimeter Mass	(grams)		q_{cal} **... Eq. 2**	(Joules)	
Total Solution Mass	(grams)		q_{total} **...Eq. 3**	(Joules)	
C_{cal}	(Joules/°C)	90.5			
Initial Temperature	(°C)		**Moles HCl**		
Final Temperature	(°C)		**Moles NaOH**		
ΔT	(°C)		ΔH_{rxn}	**(kJ/mol_{HCl})**	
			ΔH_{rxn}	**(kJ/mol_{NaOH})**	

Calculations and questions. (SHOW ALL WORK FOR ALL CALCULATIONS)

Part A: In the space below, determine the heat gained by the water (equation #1) the calorimeter (Equation #2)and the total heat released (equation #3) for the alkaline battery. Record your results with the correct number of significant figures in the data table.

In the space below, divide the heat produced by the battery's discharge time in seconds. This value is the energy discharge rate (power rating) of the battery and has units of Watts (J/sec).

Does your battery have sufficient power rating to light a 60 Watt light bulb?

Chemists always assume that the mass of reactants equals the mass of products. Compare the initial and final battery masses. Has the battery mass changed considering the accuracy of the top loading balance (+/- 0.01 g)? Does this support the chemist's mass assumption?

Part B: In the space below, calculate, the heat gained by the water (equation #1) the calorimeter (Equation #2)and the total heat released (equation #3) when cranking the generator.

Divide the heat produced when cranking by the time spent cranking in seconds. This value is the energy delivery rate you achieved whilst cranking the generator in units of Watts (J/sec).

Convert the energy delivery rate of your arm in Watts into horsepower using the conversion factor:

1 watt = 0.00134102209 Horsepower (hp)

Now consider the following machines and their horsepower ratings:

Electric Hand Mixer	: 0.25 Horsepower	Electric food Processor	: 1.0 Horsepower
Gas lawn mower	: 5.0 Horsepower	Small Motorcycle	: 20.0 Horsepower
Small Car	: 150 Horsepower	Single 747 Jet turbine	: 30,000 Horsepower

What machine comes closest to your horsepower rating? Are you very powerful?

Part C: *In this experiment, we will assume that the solutions used are enough like water that we can use the specific heat of water (4.184 J/g°C) in all calculations.*

In the space below, calculate, the heat gained by the total solution (equation #1) the calorimeter (Equation #2)and the total heat released (equation #3) when the two solutions are mixed.

Use the solution volumes and molarities to determine the number of moles of NaOH and HCl of each used in the experiment. Report these values in your data table with the correct number of significant figures.

Divide the heat released by the number of moles of NaOH and report this result with the correct number of significant figures in the data table for ΔH_{rxn}.

Divide the heat released by the number of moles of HCl and report this result with the correct number of significant figures in the data table for ΔH_{rxn}.

Why doesn't it matter in these experiments which reactant we choose when calculating ΔH_{rxn}?

The "Δ %" calculation is used to compare an experimental result to the known value. Use one of your ΔH_{rxn} values above and the known ΔH_{rxn} = -55.7 kJ/mole to determine Δ % value for your experiment. Be sure to report the sign of the result as it tells us whether the experimental value is higher or lower than the known value.

$$\Delta \% = \frac{\text{Experimental} - \text{Known}}{\text{Known}} \times 100$$

Use your value of ΔH_{rxn} to determine the heat released when 50.0 mL of 1.0 M HCl is mixed with 150.0 mL of 1.25 M NaOH. If the temperature of the two solutions initially is 22.4 °C, use the steps below to determine the final temperature of the combined solutions.

Step 1: Determine the moles of HCl and NaOH present and identify the limiting reactant.

Step 2: Use the limiting reactant and your ΔH_{rxn} value to determine the heat released by the reaction.

Step 3: Use the heat you determined in Step 2 to calculate the temperature change using the equation $q = m_{solution} \times C_{solution} \times \Delta T + C_{cal} \times \Delta T$.

Assume the resulting solution has the density and specific heat of pure water.

Step 4: Assuming the initial temperature of the two solutions is 22.4 °C, determine the final temperature of the total solution.