Energy and Energy Conversion
MCTC Chemistry

v.9.17

Objective: Introduce you to calorimetry, energy conversion and heat-based calculations.

Prelab Questions: Read through this lab handout and answer the following questions before coming to lab. There will be a quiz at the beginning of lab over this handout and its contents.

1. What is released whenever energy transformation takes place?
2. In the first two experiments (battery and crank), how is heat generated in the calorimeter?
3. How much heat energy is required to raise the temperature of 75 g of water from 23.5ºC to 28.9ºC?
4. What is conversion efficiency?
5. How does the conversion efficiency of a gasoline engine compare to an electric motor?
6. Determining the heat gained by the calorimeter (q_{cal}) doesn't require the calorimeter's mass. Why?
7. Do you need to save the graphs produced in today's experiments?
8. What precautions are required when assembling the calorimeter apparatus?
9. Who is more powerful? You or your lab partner?
10. How many moles of HCl are there in 125 mL of 0.65 M solution?

Energy

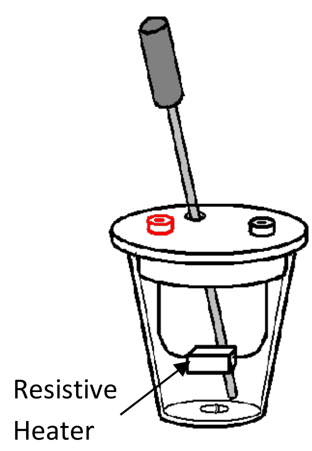
Energy is defined as the capacity to do work. However, the usefulness of energy depends on its form. For example, food is a form of chemical potential energy that we need to live. Gasoline is another form of chemical potential energy that is useless as a food source but essential to transportation. Although 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.

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.

Eventually, all forms of kinetic and potential energy are converted into heat that warms the universe.

Whenever one form of energy is transformed into another, waste heat is released. This doesn't mean that energy is lost but rather that some significant part is converted into heat that isn't 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. Electric motors that power electric and hybrid vehicles are approximately 50% efficient, meaning about half of the electrical energy is converted into motion.

This percentage is known as the conversion efficiency and is something engineers are always trying to improve as they design more efficient transportation. That is, convert as much of the stored energy (batteries or fuel) into motion with a minimum of heat loss.



In these experiments, electrical and chemical heat energy is converted into heat which is captured within a highly insulated cup referred to as a calorimeter; a device that contains water that absorbs much of the heat that is produced.

The heat transferred to the water (q_{water}) is calculated using the water's observed temperature change and the following 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 cup 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 q_{total}:

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

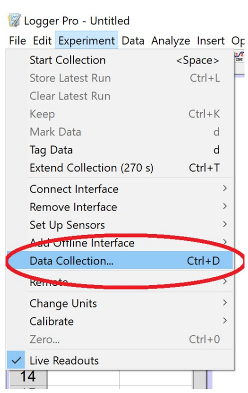
Experiment: Data Collection

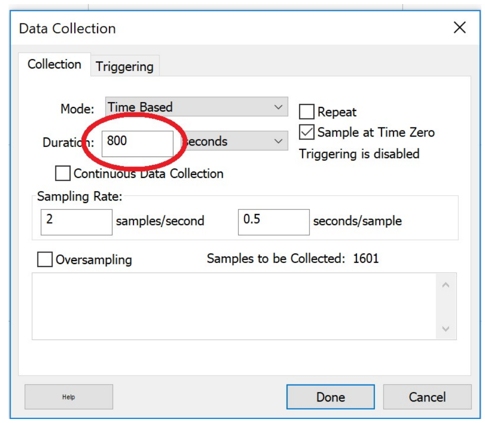
1. Assemble the LabPro data collection hardware.

2. Attach the stainless steel temperature probe to Channel 1

3. Activate the Logger Pro software

4. Adjust the experiment length to 800 seconds
   a. Click on Experiment ---> Data collection
   b. Change the "Duration" to 800 seconds and click "Done"





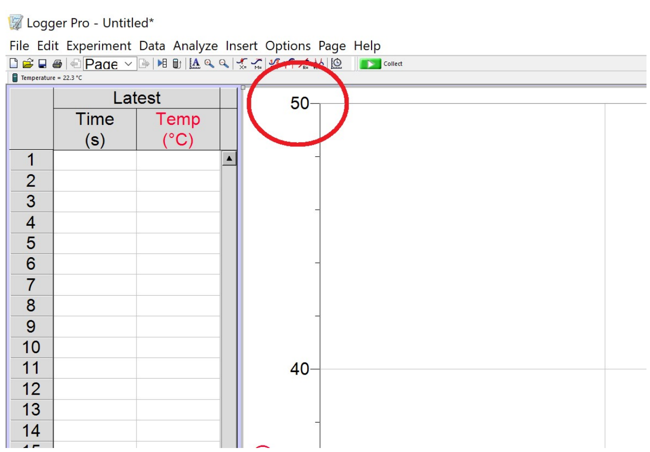
5. Graph axis adjustment

   a. Click on the maximum Y axis value (50: figure at right)

   b. Enter 30 as the new maximum Y axis value

   c. Press "Enter"

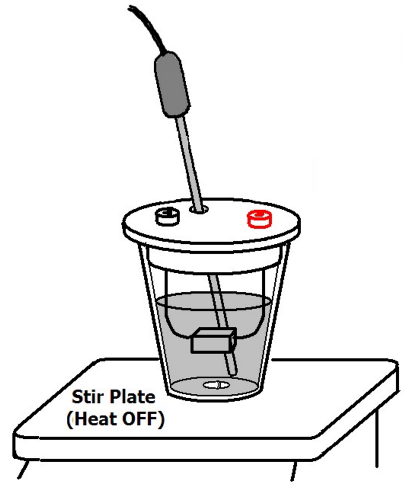
   d. Repeat the procedure to change the minimum Y axis value to 20 degrees.



Experiment: How much stored chemical potential energy is there in a AAA battery?

In this procedure, you will attach a AAA battery to the calorimeter.
Do not plug the battery assembly into the calorimeter until AFTER you collect data for 30 seconds.

1. Place a medium sized magnetic stirring rod in your empty calorimeter cup.



2. Weigh the empty apparatus (calorimeter cup, lid and stirring bar) using a top loading balance.

   You will use this "empty mass" throughout the entire series of calorimeter experiments. Record it in all three data tables.

3. Fill the 100 mL graduated cylinder to the 100 mL mark with distilled water. We're using distilled water because it's at room temperature.

4. Weigh the apparatus & water on the top loading balance and record this measurement in your data table.

5. Make sure that the heat is turned off for your stir plate.

6. Place the calorimeter in the very center of the stir plate.

   The stirring function works best when the stirring rod is lined up with the rotating magnet in the stir plate located in the center of the surface.

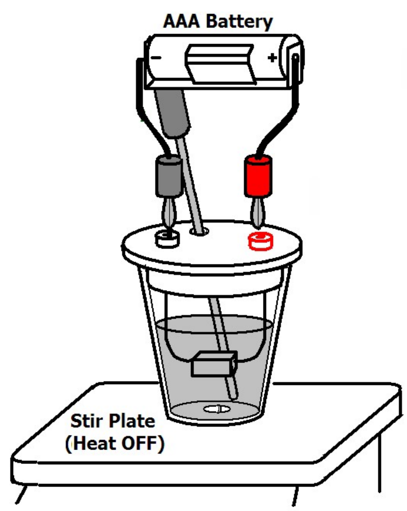
7. Carefully insert the temperature probe through the hole in the lid. The tip of the temperature probe must be completely immersed in water.

   Be careful not to punch a hole in the bottom of the calorimeter cup with the temperature probe!

8. 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 stir plate.

9. Obtain a AAA battery and weigh it on a top loading balance.
   Insert the battery into the battery holder

   Don't connect the battery to the calorimeter yet.



10. Click on the Logger Pro green "Collect" button.

11. Connect the battery to the calorimeter (figure at right).

12. When the temperature no longer rises, continue collecting data for 30 more seconds and then click on "Stop."

    At this point, all the potential energy stored in the battery has been converted into heat which is collected by the calorimeter.

13. Record the initial temperature and final <u>maximum</u> temperature for the trial in your data table with one decimal place accuracy.

    We will not be saving any other temperature data.

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

15. Remove the battery from the battery holder and re-weigh it on the top loading balance.

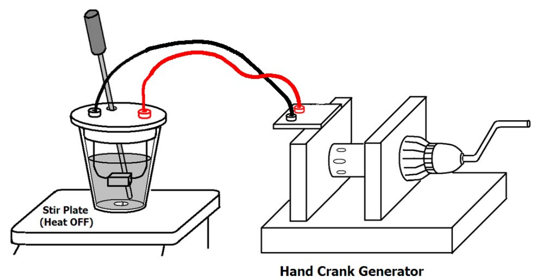
16. Dispose of the used battery in the recycling beaker at the front of the lab.

Experiment: How much energy can your arm produce in 3 minutes?

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 your kinetic energy into electrical energy that is sent to the calorimeter where it is converted into heat by the resistive heater.

Both you and your partner will perform this experiment but you are responsible for only your data.

1. Empty and carefully dry your calorimeter.
2. Place the medium sized magnetic stirring rod in your empty calorimeter cup.
3. Use the 100 mL graduated cylinder to measure out 100 mL of distilled water and pour it into the calorimeter.
4. Weigh your apparatus and record the measurement in your data table.
5. Place the calorimeter in the very center of the stir plate and stir at ~ 300 rpm. (Heat turned off!)
6. Carefully insert the temperature probe through the hole in the lid. The tip of the temperature probe must be completely immersed in water.
7. Carefully insert the temperature probe through the hole in the lid. Be careful not to punch a hole in the cup.
8. Connect the hand crank generator to the calorimeter using the wires provided (match the colors…figure at right).



9. Click on "Experiment" -----> "Store Latest Run".
10. Click on the "Collect" button and wait 15 seconds.
11. Begin cranking the generator as fast as you can for 3 minutes.
12. After 3 minutes, stop cranking but continue collecting data for another 15 seconds to allow the temperature probe to reach its max. value.
13. Click "Stop" and record the initial and maximum final temperatures in your data sheet with one decimal place accuracy.

    We will not be saving any other temperature data.
14. Repeat this experiment for your lab partner.

Experiment: How much energy is generated by an acid-base neutralization reaction?

The acid/base reaction below is exothermic, meaning that it produces heat energy:

$$HCl_{(aq)} \quad + \quad NaOH_{(aq)} \quad \rightarrow \quad H_2O_{(l)} \quad + \quad NaCl_{(aq)} \qquad \Delta H_{rxn} = \ -55.7 \text{ kJ/mole}$$

ΔH *values for exothermic reactions are negative since in losing heat, the reaction's energy goes down. Also notice that like most acid-base neutralization reactions, this one produces water and a salt (NaCl).*

1. Empty and carefully dry your calorimeter.
2. Place the medium sized magnetic stirring rod in your empty calorimeter cup.
3. Measure out 50.0 mL of 1.00 M NaOH and 50.0 mL of HCl in two, clean 100 mL graduated cylinders.
4. Pour the contents of the HCl solution into the calorimeter cup.
5. Place the lid on the calorimeter and carefully insert the temperature probe through the hole in the lid.

   Be careful not to punch a hole in the bottom of the calorimeter cup with the temperature probe!
6. Stir at the 300 rpm setting. (Heat turned off!)
7. Click on "Experiment" -----> "Store Latest Run".
8. Click "Collect" and continue to collect data for approximately 60 seconds.
9. Carefully lift the calorimeter cup lid <u>but keep the temperature probe immersed in the solution</u>.

   You should be still collecting temperature data.
10. Quickly pour the 50 mL of NaOH solution into the calorimeter and replace the lid.
11. Continue collecting data until 30 seconds after the highest temperature is reached. Then click "Stop."
12. 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.
13. Weigh the calorimeter apparatus with its neutralized acid/base mixture on a top loading balance.
14. Record this measurement in your data table.
15. Dispose of the neutralized solution by carefully pouring it down the drain.

When finished, rinse the calorimeter cup and resistive heater thoroughly 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).

Energy produced by a Battery			
Empty Calorimeter	(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)		

Energy produced by You		
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)	

Energy produced by an acid/base reaction		
Empty Calorimeter mass	(grams)	
Solution + Calorimeter Mass	(grams)	
Total Solution 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)	
HCl Concentration	M	
HCl Volume	mL	
HCl Moles	moles	
ΔH_{rxn}	kJ/mol_{HCl}	
NaOH Concentration	M	
NaOH Volume	mL	
HaOH moles	moles	
ΔH_{rxn}	kJ/mol_{NaOH}	

Prelab Questions: Answers

1. Waste heat
2. A resistive heater converts electrical energy into heat that is transferred to the water and calorimeter cup
3. 1694 Joules.
4. Conversion efficiency tells us what percentage of the energy has been used to perform useful work. The remaining energy is wasted as heat.
5. Electric motors are approximately twice as efficient as gasoline engines.
6. Heat capacity includes the masses of the calorimeter components. All you need is the change in temperature to determine heat gained/lost by the calorimeter. Specific heat (…for water) requires the mass of the water to determine heat gained/lost.
7. No. You only need the initial and final temperatures in each experiment.
8. Keep the hotplate heat turned off. Don't poke a hole in the calorimeter with the temperature probe. Center the calorimeter on the stir-plate.
9. You won't know until you both perform the hand-crank generator experiment.
10. 0.08125 moles HCl

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

Energy produced by a AAA battery:

In the space below, determine

- heat gained by the water
- heat gained by the calorimeter
- total heat produced for the battery.

Record your results in the data table with the correct number of significant figures.

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).

Can your battery supply enough power to light a 60 Watt light bulb?

Oxidation/reduction chemical reactions take place in the battery as it releases electrical energy and we know the mass of the reactants always equals the mass of the products. This principle is known as "Conservation of Mass."

Compare the initial and final battery masses. Has the battery's mass changed considering the accuracy of the top loading balance (+/- 0.01 g)? Has "Conservation of Mass" been verified?

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Energy produced by you (Electrical Generator):

In the space below, determine

- heat gained by the water
- heat gained by the calorimeter
- total heat produced while hand-cranking the generator.

Record your results in the data table with the correct number of significant figures.

Divide the heat produced when cranking by the time spent cranking in seconds. This value is the energy delivery rate you achieved while 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)

Consider the following machines and circle the one that comes closest to your horsepower rating.

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

Energy released by an acid-base neutralization reaction:

For these calculations, we will use the specific heat of water (4.184 J/g°C) as the specific heat of the solutions.

In the space below, determine

- heat gained by the water
- heat gained by the calorimeter
- total heat produced when HCl and NaOH solutions are reacted.

Record your results in the data table with the correct number of significant figures.

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 in the data table for ΔH_{rxn}.

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

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

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Problem: 60.0 mL of 1.0 M HCl is mixed with 60.0 mL of 1.25 M NaOH.

The initial temperatures of the two solutions is 22.4°C

Use your value of ΔH_{rxn} to determine the final temperature of the solutions.

Step 1: Determine the moles of HCl and NaOH present and *clearly* 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 solution has the same density and specific heat as pure water.

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