OBJECTIVES:

(1) Set up a cup calorimeter
(2) Determine the heat capacity of a cup calorimeter, C_{cal}.
(3) Determine the molar enthalpy change, $\Delta H/n$ for the neutralization reaction of hydrochloric acid, HCl and sodium hydroxide, NaOH.

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

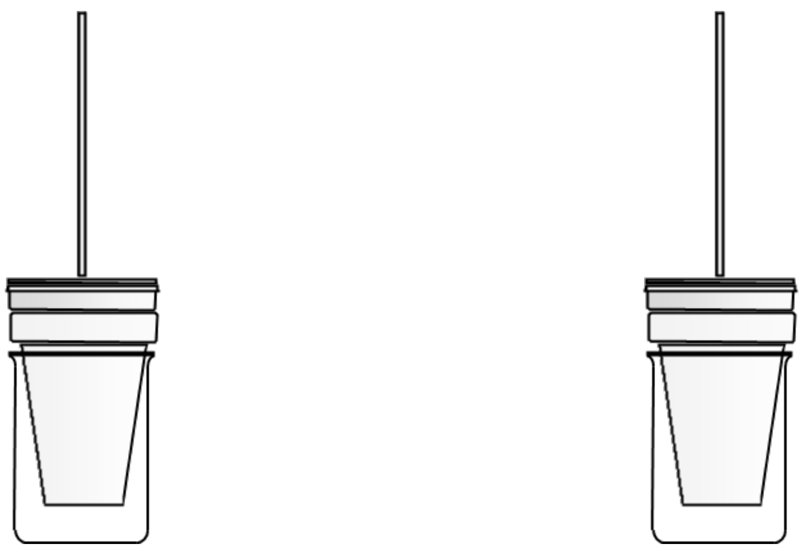
(4) Determine the molar enthalpy change, $\Delta H/n$, associated with the neutralization of acetic acid, $HC_2H_3O_2$, with sodium hydroxide, NaOH.

$$HC_2H_3O_2\ (aq) + NaOH(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l)$$

(5) Determine the specific heat of a metal, $C_{metal.}$

PROCEDURE:

(1) Construct 2 set-ups as shown in Figure 1
   a. Label the set-ups as "A" and "B" on the outside of the beaker. (Do not write on the foam cups). Set-up "A" will serve as your calorimeter. Set-up "B" is simply a well-controlled staging point.



"A"
(use as your calorimeter)

"B"
(Use as a staging point)

Figure 1 – Cup calorimeter set-up. For each set-up, use 2 nested coffee cups with a lid and thermometer. Stabilize each set-up in a beaker as shown.

(2) Determine the heat capacity of the cup calorimeter (set-up "A"), C_{cal}, as follows:

a. Use a 100mL graduated cylinder to transfer 50.0mL of **COLD** tap water into "A".
b. Use a 100mL graduated cylinder to transfer 50.0mL of **HOT** water into "B".
c. Wait a couple minutes for the temperatures of A and B to stabilize. Then, record the temperatures, T_{cold} and T_{hot}.
d. Pour and swirl the contents of "B" into "A" and record the temperature every 15 seconds for a couple minutes. record the highest observed temperature, $T_{mixture}$.
e. Calculate the heat released by the hot water, q_{hot}
   $q_{hot} = mc_w\Delta T$
   m = mass of the hot water = 50.0g
   c_w = specific heat of water = 4.18 J/(g°C)
   $\Delta T = T_{hot} - T_{mixture}$
f. Calculate the heat absorbed by the cold water, q_{cold}
   $q_{cold} = mc_w\Delta T$
   m = mass of the cold water = 50.0g
   c_w = specific heat of water = 4.18 J/(g°C)
   $\Delta T = T_{mixture} - T_{cold}$
g. Calculate the heat absorbed by the calorimeter, q_{cal}
   $q_{cal} = q_{hot} - q_{cold}$
h. Calculate the heat capacity of the calorimeter, C_{cal}
   $C_{cal} = q_{cal}/\Delta T$
   $\Delta T = T_{mixture} - T_{cold}$

Table 1 – Heat capacity of calorimeter "A"

Quantity	Trial		
	1	2	3
T_{cold} (°C)			
T_{hot} (°C)			
$T_{mixture}$ (°C)			
q_{hot} (J)			
q_{cold} (J)			
q_{cal} (J)			
C_{cal} (J/°C)			

Average C_{cal} = ________________________J/°C

Standard Deviation of C_{cal} = ________________________J/°C

95% CI of C_{cal} = ________________________J/°C

(3) Determine the molar enthalpy change, $\Delta H/n$, associated with the neutralization of hydrochloric acid, HCl, with sodium hydroxide, NaOH.

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

a. Clean and dry the cups of both set-ups, A and B.
b. Use a 100 mL graduated cylinder to transfer 50.0mL of 1.0M NaOH into set-up "A".
c. Use a 100mL graduated cylinder to transfer 50.0mL of 1.0M HCl into set-up "B".
d. Wait a couple minutes for the temperatures of A and B to stabilize. They should stabilize at the same or close to the same temperature (room temp). Record the average temperature of the two set-ups, $T_{initial}$.
e. Pour and swirl the contents of "B" into "A" and record the temperature every 15 seconds for a couple minutes. record the highest observed temperature, T_{final}.
f. Calculate the heat absorbed by the solution, $q_{soln.}$
   $q_{soln} = m\ c_{soln}\ \Delta T$
   m = mass of the solution = 100.0g
   $c_{sol'n}$ ~ specific heat of water = 4.18 J/(g°C)
   $\Delta T = T_{final} - T_{initial}$
g. Calculate the heat absorbed by the calorimeter, $q_{cal.}$
   $q_{cal} = C_{cal}\ \Delta T$
   C_{cal} = (use average value of C_{cal} from Table 1)
   $\Delta T = T_{final} - T_{initial}$
h. Calculate the heat released by the reaction, $q_{rxn.}$
   $q_{rxn} = q_{soln} + q_{cal}$
i. Calculate the enthalpy change of the reaction, ΔH.
   $\Delta H = -q_{rxn}$.
j. Calculate the moles of water produced, n_{water}.
   0.050moles of each reactant is consumed, which produces 0.050mole of water, n_{water}.
k. Calculate the molar enthalpy change of the reaction, $\Delta H/n$.
   $\Delta H/n$ = "molar enthalpy change" or "molar heat of reaction" = $\Delta H/n_{water}$.

Table 2 – Molar Enthalpy Change, $\Delta H/n$, of the neutralization of hydrochloric acid with sodium hydroxide.

Quantity	Trial		
	1	2	3
T_{intial} (°C)			
T_{final} (°C)			
q_{soln} (J)			
q_{cal} (J)			
q_{rxn} (J)			
ΔH (J)			
n_{water} (mol)			
$\Delta H/n$ (J/mol)			

Average $\Delta H/n$ = ________________________J/mol

Standard Deviation of $\Delta H/n$ = ________________________J/mol

95% CI of $\Delta H/n$ = ________________________J/mol

(4) Determine the molar enthalpy change, $\Delta H/n$, associated with the neutralization of acetic acid, $HC_2H_3O_2$, with sodium hydroxide, NaOH.

$$HC_2H_3O_2\,(aq) + NaOH(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l)$$

a. Clean and dry the cups of both set-ups, A and B.
b. Use a 100 mL graduated cylinder to transfer 50.0mL of 1.0M NaOH into set-up “A”.
c. Use a 100mL graduated cylinder to transfer 50.0mL of 1.0M $HC_2H_3O_2$ into set-up “B”.
d. Wait a couple minutes for the temperatures of A and B to stabilize. They should stabilize at the same or close to the same temperature (room temp). Record the average temperature of the two set-ups, $T_{initial}$.
e. Pour and swirl the contents of “B” into “A” and record the temperature every 15 seconds for a couple minutes. record the highest observed temperature, T_{final}.
f. Calculate the heat absorbed by the solution, $q_{soln.}$
   $q_{soln} = m\, c_{soln}\, \Delta T$
   m = mass of the solution = 100.0g
   $c_{sol'n}$ ~ specific heat of water = 4.18 J/(g°C)
   $\Delta T = T_{final} – T_{initial}$
g. Calculate the heat absorbed by the calorimeter, $q_{cal.}$
   $q_{cal} = C_{cal}\, \Delta T$
   C_{cal} = (use average value of C_{cal} from Table 1)
   $\Delta T = T_{final} – T_{initial}$
h. Calculate the heat released by the reaction, $q_{rxn.}$
   $q_{rxn} = q_{soln} + q_{cal}$
i. Calculate the enthalpy change of the reaction, ΔH.
   $\Delta H = -q_{rxn}$.
j. Calculate the moles of water produced, n_{water}.
   0.050moles of each reactant is consumed, which produces 0.050mole of water, n_{water}.
k. Calculate the molar enthalpy change of the reaction, $\Delta H/n$.
   $\Delta H/n$ = “molar enthalpy change” or “molar heat of reaction” = $\Delta H/n_{water}$.

Table 3 – Molar Enthalpy Change, ΔH, the neutralization of acetic acid with sodium hydroxide.

Quantity	Trial		
	1	2	3
T_{intial} (°C)			
T_{final} (°C)			
q_{soln} (J)			
q_{cal} (J)			
q_{rxn} (J)			
ΔH (J)			
n_{water} (mol)			
$\Delta H/n$ (J/mol)			

Average $\Delta H/n$ = ________________________J/mol

Standard Deviation of $\Delta H/n$ = ________________________J/mol

95% CI of $\Delta H/n$ = ________________________J/mol

(5) Determine the specific heat of a metal, c_{metal}.

a. Fill the calorimeter (set-up "A") with 100.0mL of cold tap water. Allow the temperature to stabilize.

b. Weigh and record the mass of a sample of metal, m_{metal}.

c. Heat the metal in a beaker of boiling water for a few minutes. This will raise the temperature of the metal to the boiling point of water (100°C). Record this temperature as T_{metal}.

d. Record the stabilized temperature of the water in the calorimeter, T_{water}.

e. Use a pair of crucible tongs to quickly transfer the metal from the boiling water into the calorimeter.

f. Gently swirl the calorimeter.

g. Monitor and record the temperature of the water every 15 seconds for a few minutes. Record the highest temperature as T_{final}.

h. Calculate the specific heat of the metal, C_{metal}.

$$q_{metal} = q_{water} + q_{cal}$$
$$m_{metal}\, C_{metal}\, \Delta T_{metal} = m_{water}\, C_{water}\, \Delta T_{water} + C_{cal}\, \Delta T_{water}$$
$$m_{metal}\, C_{metal}\, (T_{metal} - T_{final}) = m_{water}\, C_{water}\, (T_{final} - T_{water}) + C_{cal}\, (T_{final} - T_{water})$$

Substitute numbers into the equation and solve for C_{metal}

Table 4 – Specific heat of a metal, C_{metal}.

Quantity	Trial		
	1	2	3
T_{metal} (°C)			
T_{water} (°C)			
T_{final} (°C)			
m_{metal} (g)			
m_{water} (g)			
C_{water} , J/(g°C)			
C_{cal} , J/°C			
C_{metal} , J/(g°C)			

Average C_{metal} ________________________________ J/(g°C)

Standard Deviation of C_{metal} = _________________________J/(g°C)

95% CI of C_{metal} = _________________________J/(g°C)