Heat of Reactions

Last revised: 2023/10/14

Preparation

Collect the following items

- Two Styrofoam cups and a plastic lid
- One digital thermometer
- The TA will distribute one stop watch to each group

From your personal equipment

- One 400 mL beaker
- One 50 mL graduated cylinder

✓ Use the warm water in the fume hood for experiment (do not use the water fountain)

Objective and Principles

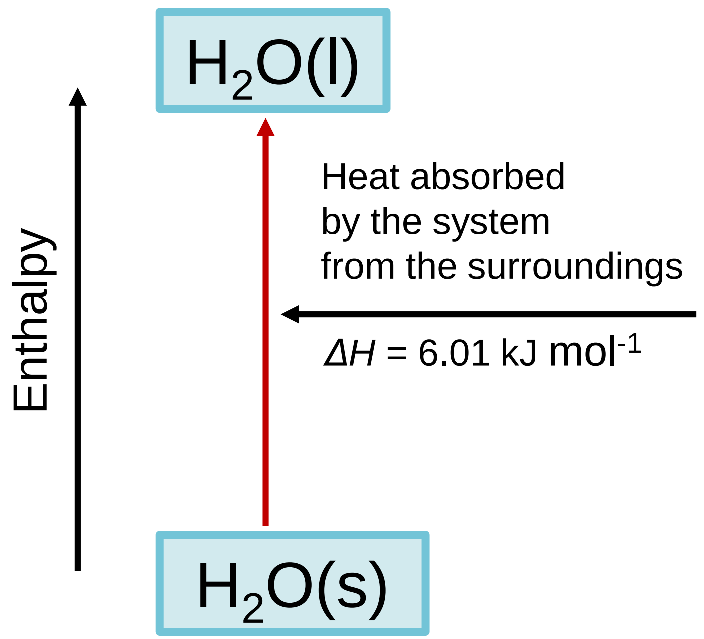
- **Objective:**
  - Determine the heat capacity of home-built calorimeter
  - Determine the heats of neutralization (HCl, CH_3COOH) and the heat of solution (NH_4Cl)
  - Use Hess' law to calculate ΔH_f (enthalpy of formation) of MgO

- **Lab techniques:**
  - Operate a simple calorimeter
  - Using a graduated cylinder to measure volume
  - Using a digital thermometer
  - Measure the weights of chemicals

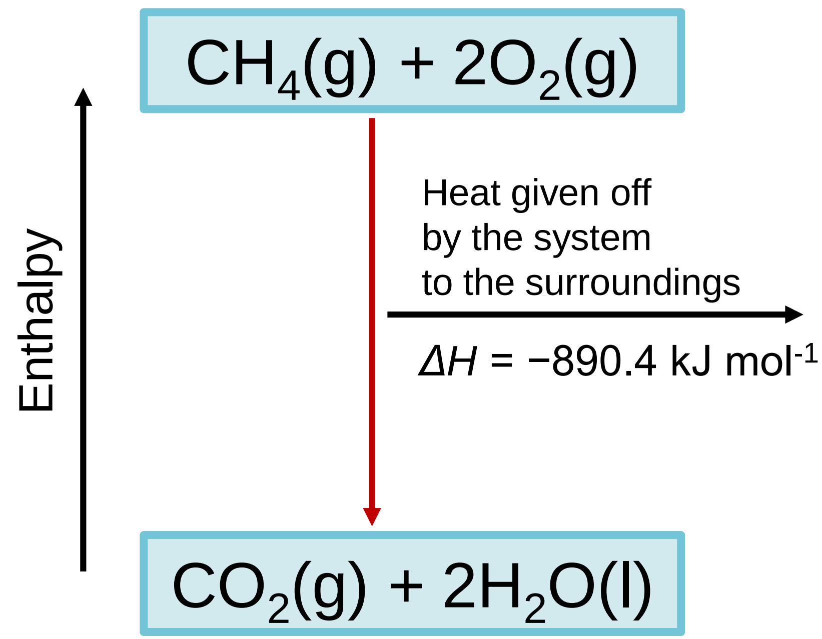
Enthalpy of Reaction

- At constant pressure, the change in enthalpy, **ΔH**, during a chemical reaction (***enthalpy of reaction***) equals to the heat gained or lost (q_p)
- $q_p = \Delta H = H(products) – H(reactants)$

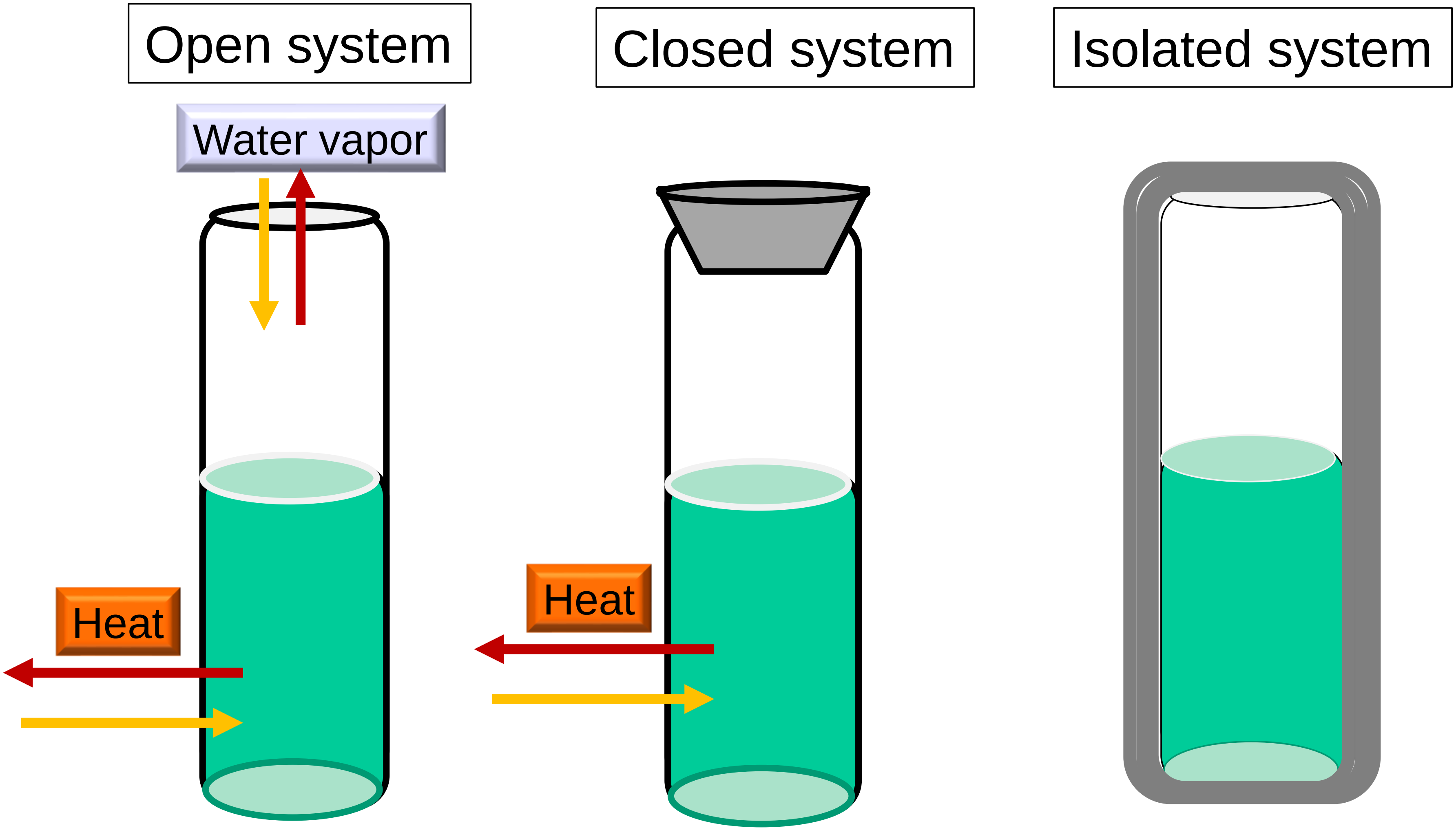
Endothermic reaction (ΔH > 0)



Exothermic reaction (ΔH < 0)



System & Surroundings



Both mass and energy can exchange

Only energy can exchange

Neither mass nor energy can exchange

Constant-Pressure Calorimetry

- The simple home-built calorimeter is treated as an isolated system ($q_{sys} = 0$)

heat transfer to solution

$$q_{sys} = \mathbf{q_{rxn}} + (q_{soln} + q_{cal}) = 0$$

Heat of reaction *heat transfer to calorimeter*

$$\rightarrow \mathbf{q_{rxn}} = -(q_{soln} + q_{cal})$$

- $q_{soln} = m \times s \times \Delta T$

  m: mass (g), s: specific heat (cal/g·˚C)

  ΔT: temperature change (˚C)

- $q_{cal} = \mathbf{C_{cal}} \times \Delta T$

  C_{cal}: heat capacity of calorimeter (cal/˚C)

- **$\Delta H = q_{rxn}$ /n (molar heat of reaction)**

  n: mole of limiting reagent

(here we assume the density and specific heat of solutions are identical to that of H_2O)

Thermometer and probe

Two Styroform cups and a 400 mL beaker stacked together

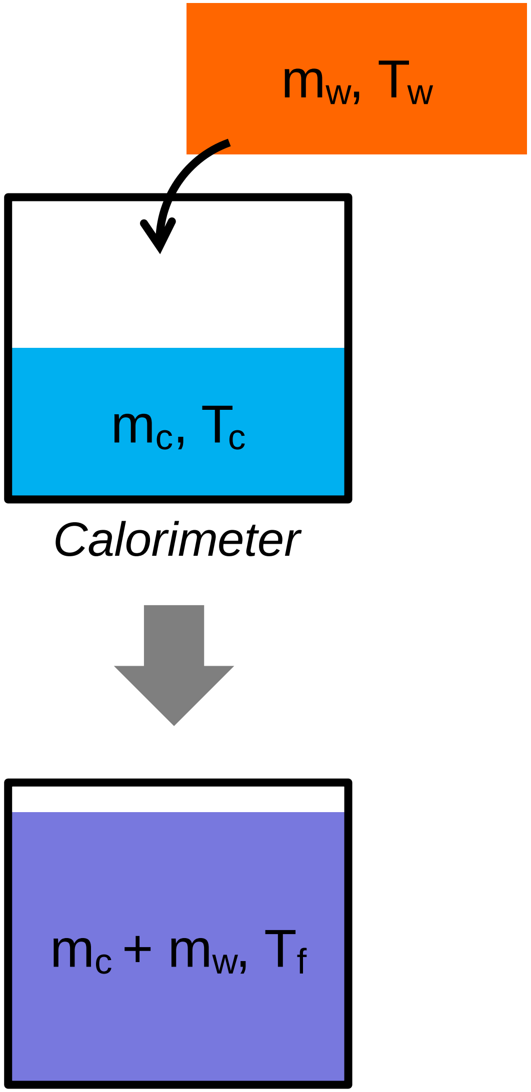
How to Determine C_{cal}

- m_w grams of warm water (temperature T_w) is added to m_c grams of cold water (temperature T_c) in a calorimeter
- The final temperature at equilibrum: T_f
- For an isolated system:

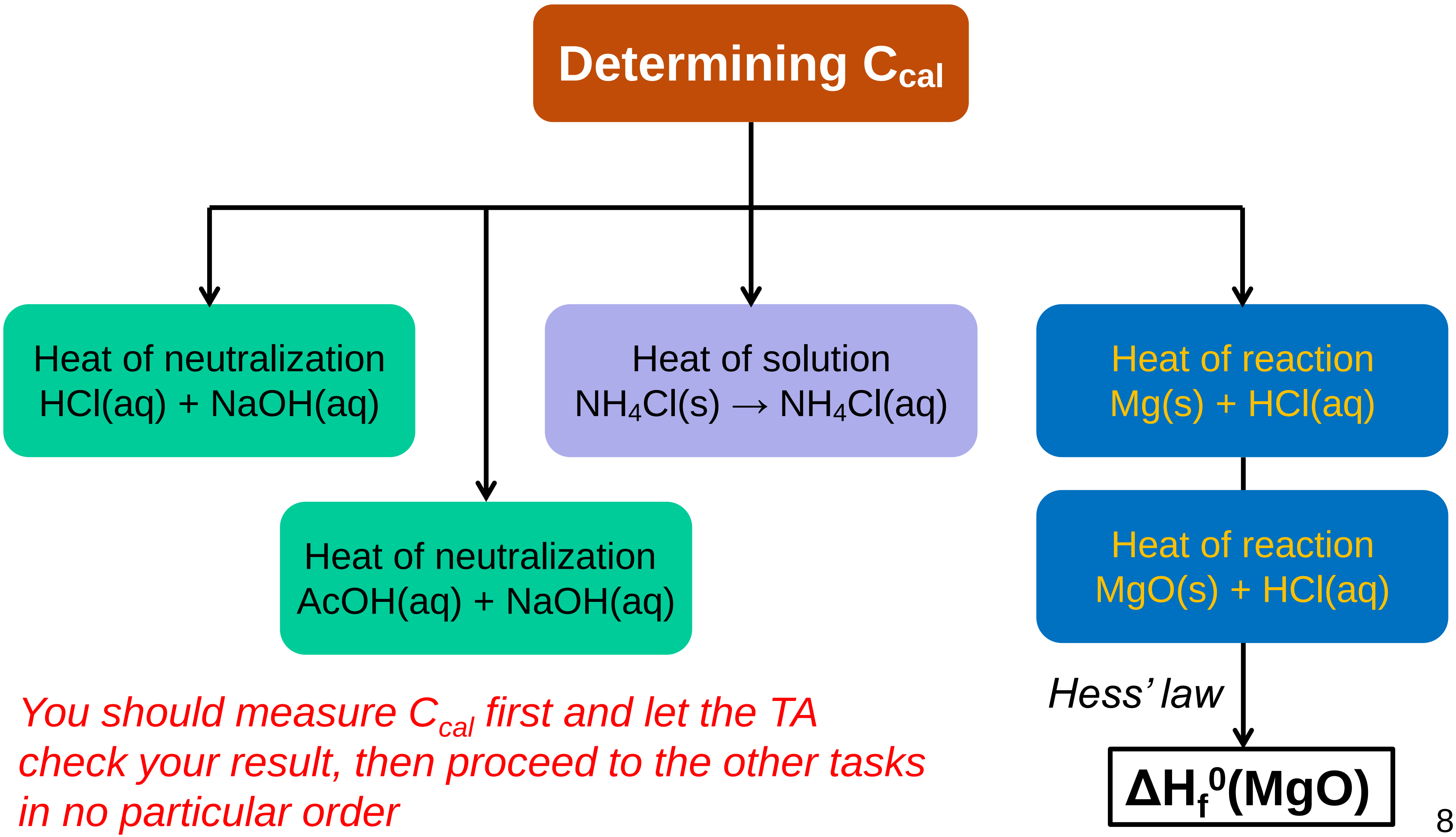
$$0 = q_1 \text{ (heat released by the warm water)}$$
$$+\, q_2 \text{ (heat gained by the cold water)}$$
$$+\, q_3 \text{ (heat gained by the calorimeter)}$$

- $0 = [m_w \times s \times (T_f - T_w)] + [m_c \times s \times (T_f - T_c)] + [C_{cal} \times (T_f - T_c)]$

- Measure T_w, T_c, T_f → Calculate C_{cal}



Experiment Tasks



You should measure C_{cal} first and let the TA check your result, then proceed to the other tasks in no particular order

Hess' Law

1. $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$ ΔH_1
2. $MgO(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2O(l)$ ΔH_2
3. $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H_3 = \Delta H_f(H_2O) = -68.4$ kcal/mol

$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$ $\Delta H = \Delta H_f(MgO)$

This rxn = (1) − (2) + (3)

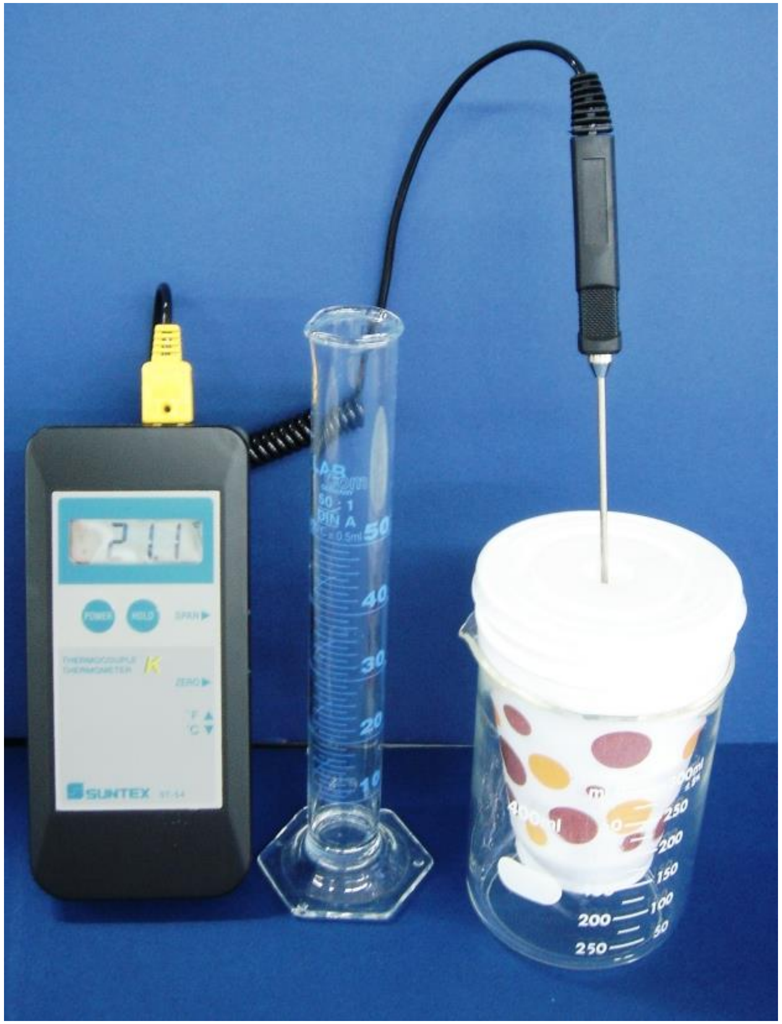
$= \Delta H_1 - \Delta H_2 + \Delta H_3$

ΔH_1 and ΔH_2 are measured experimentally in this lab
→ **ΔH_f(MgO) can then be calculated**

Task 1: Determining C_{cal}

- Use a graduated cylinder to measure 50.0 mL room temperature DI water (use a drop pipet to adjust the liquid level if needed)
- Transfer the water into the calorimeter, close the plastic lid, and insert the thermoprobe
- Wait 3 minutes, then record the water temperature

✓ Place the graduated cylinder away from the bench edge to avoid knocking it over accidentally



Task 1: Determining C_{cal}

- Use a beaker to take some hot water from the fume hood
- Adjust the water temperature with cold water until it is 10 – 15 °C higher than the cold water

- Use a graduated cylinder to measure 50.0 mL warm water
- Use the thermoprobe to check whether the water temperature is even at different heights
- Record the water temperature at the middle part

Task 1: Determining C_{cal}

Example:

Time (s)	**Temp.** (^{o}C)
0	**23.5**
5	**31.3**
10	**31.3**
15	**31.0**

- Pour the warm water quickly into the calorimeter, close the plastic lid
- Insert the thermoprobe
- Swirl the calorimeter to mix the water
- Record the temperature readings at a fixed time interval, find out what the equilibrium temperature is (take the highest reading for exothermic reactions and the lowest point for endothermic reactions)

Task 2: Heat of Neutralization (HCl+NaOH)

NaOH(aq) HCl(aq)

- Measure 50.0 mL of 1.0 M HCl into the calorimeter, then record its equilibrium temperature
- Measure 50.0 mL of 1.0 M NaOH, then record its equilibrium temperature in the graduated cylinder
- Pour NaOH quickly into the calorimeter, close the plastic lid and insert the thermoprobe
- Mix the solution; Record the evolution of temperature

Example:

Time (s)	Temp.(^oC)
0	23.9
5	29.8
10	29.8
15	29.7
20	29.7

✓ Wash the graduated cylinder thoroughly between use, or use separate graduated cylinder for measuring HCl(aq) and NaOH(aq)

Task 3: Heat of Neutralization (AcOH+NaOH)

NaOH(aq) HOAc(aq)

- Measure 50.0 mL of 1.0 M CH_3COOH into the calorimeter, then record its equilibrium temperature
- Measure 50.0 mL of 1.0 M NaOH, then record its equilibrium temperature in the graduated cylinder
- Pour NaOH quickly into the calorimeter, close the plastic lid and insert the thermoprobe
- Mix the solution; Record the evolution of temperature

Task 4: Heat of Solution (NH_4Cl)

$H_2O(l)$

$NH_4Cl(s)$

Example:

Time (s)	Temp.(^oC)
0	23.4
30	20.7
60	19.5
90	19.6
120	19.6

- Measure 50.0 mL of DI water into the calorimeter, then record its equilibrium temperature
- Weigh ca. **3 g ammonium chloride (NH_4Cl)** and record the exact weight
- Add $NH_4Cl(s)$ to the calorimeter, close the plastic lid and insert the thermoprobe
- Swirl the calorimeter to mix the solution thoroughly, record the time evolution of temperature

✓ All solid must be dissolved completely

Task 5.1: Enthaply of Reaction (Mg + HCl)

- Measure **100.0 mL** of 1.0 M HCl into the calorimeter, then record its equilibrium temperature
- Weigh ca. **0.2 g** magnesium (Mg) and record the exact weight
- Add Mg(s) into the calorimeter, close the plastic lid and insert the thermoprobe
- Swirl the calorimeter to mix the solution thoroughly, record the time evolution of temperature

50 mL twice

$$Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$$

✓ Solid reactants must be mixed and reacted completely

Task 5.2: Enthaply of Reaction (MgO + HCl)

- Measure **100.0 mL** of 1.0 M HCl into the calorimeter, then record its equilibrium temperature
- Weigh ca. **0.7 g** magnesium oxide (MgO) and record the exact weight
- Add MgO(s) into the calorimeter, close the plastic lid and insert the thermoprobe
- Swirl the calorimeter to mix the solution thoroughly, record the time evolution of temperature

$$MgO(s) + 2H^{+}(aq) \rightarrow Mg^{2+}(aq) + H_2O(l)$$

✓ Solid reactants must be mixed and reacted completely

Additional Notes

- The tip of the thermoprobe should be in the center of the solution, as it may give inaccurate reading when touching the container wall
- After measuring the temperature of warm water, rinse the thermoprobe with tap water (so it can cool down) before inserting it into the calorimeter
- The reactions between cold and warm water and acid-base neutralization occur quite fast, so the temperature recording should start immediately after mixing
- Wash and dry the Styrofoam cups after each experiment
- Solid reactants (NH_4Cl, Mg, MgO) must be reacted completely → observe if any solid remains in the calorimeter after each experiment

Additional Notes

- How to determine the equilibrium temperatures:
  - Exothermic reactions: the solution temperature would increase to a **highest reading** then start to decrease
  - Endothermic reactions: the solution temperature would decrease to a **lowest reading** then start to increase
- Assume the solution density is identical to that of water (1.0 g/cm^3) ← this is an experimental value (two s.f.)
- Assume the specific heat of solution is identical to that of water (1 $cal/g \cdot {}^oC$) ← this is an exact value (infinite s.f.)
- List calculations in details in the lab report (including amount of heat, # moles of reactants, and enthalpy of reactions)
- Use correct significant figures and SI units (kJ/mol)

Clean-Up and Check-Out

- Salt solutions resulted from acid-base neutralization can be disposed into the sink
- Clean the Styrofoam cups and plastic lid for reuse
- Return the stop watch to TA
- Clean up the lab bench and check personal equipment inventory (<u>have an associate TA sign the check list</u>)

- This is a **Full Report** experiment:
  - **Have the lab notes and results checked by the TA**
  - **Hand in the report next week**

- Groups on duty shall stay and help clean up the lab