# Heat of Reactions



Last revised: 2022/9/27

Groups on duty: TBA

# Preparation

**Collect the following items**

- ❑ Two Styrofoam cups and a plastic lid
- ❑ One 50 mL graduated cylinder
- ❑ One digital thermometer


**From your personal equipment**

- ❑ One 400 mL beaker
- ❑ One 50 mL graduated cylinder

- ✓ The TA will distribute one stop watch to each group
- ✓ Use the warm water in the fume hood for experiment (do not use the water fountain)

# Objective and Principles

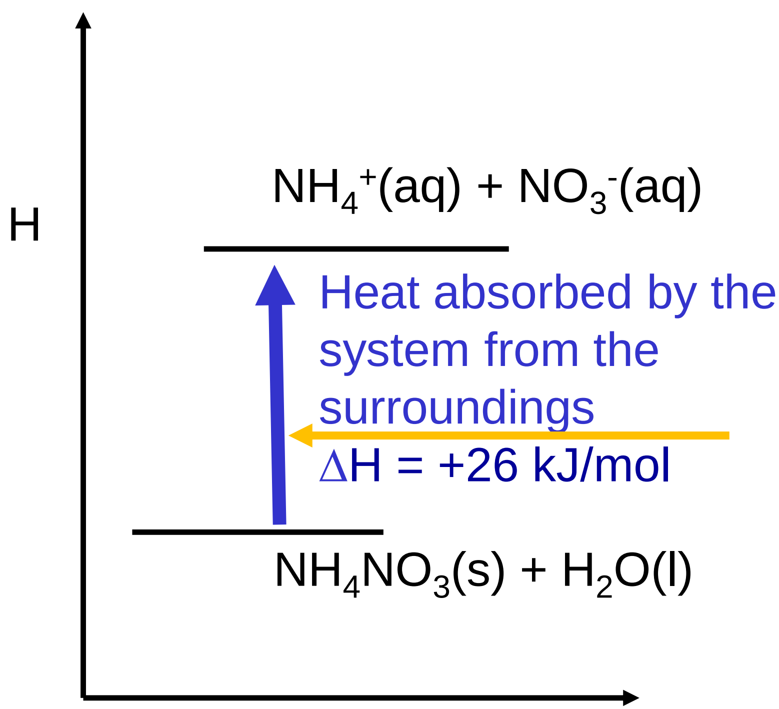
- **Objective:**
  - Determine the heat capacity of home-built calorimeter
  - Determine the heats of neutralization (HCl, $CH_3COOH$) and the heat of solution ($NH_4Cl$)
  - Use Hess' law to calculate $\Delta H_f$ (enthalpy of formation) of MgO

- **Lab techniques:**
  - Operate a simple calorimeter
  - Using a graduated cylinder to measure volume
  - Using a digital thermometer

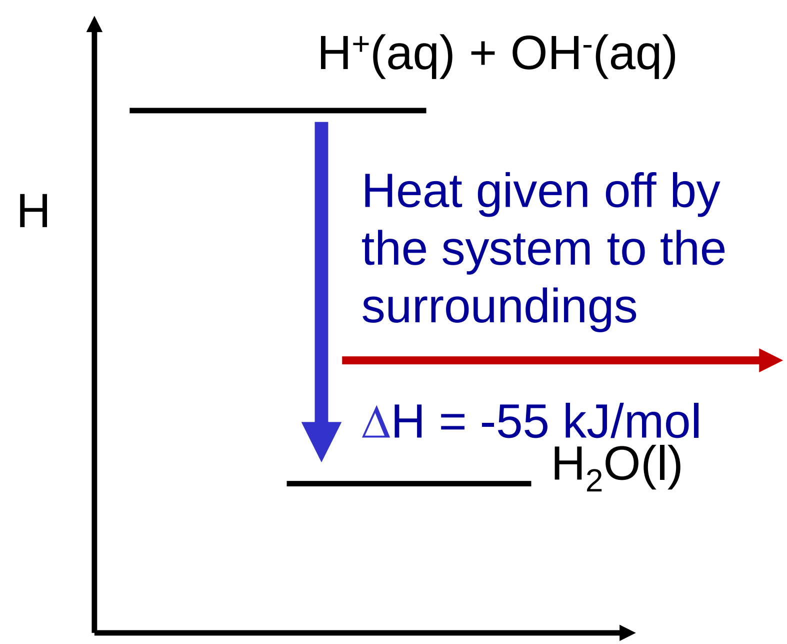
# Enthalpy of Reaction

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

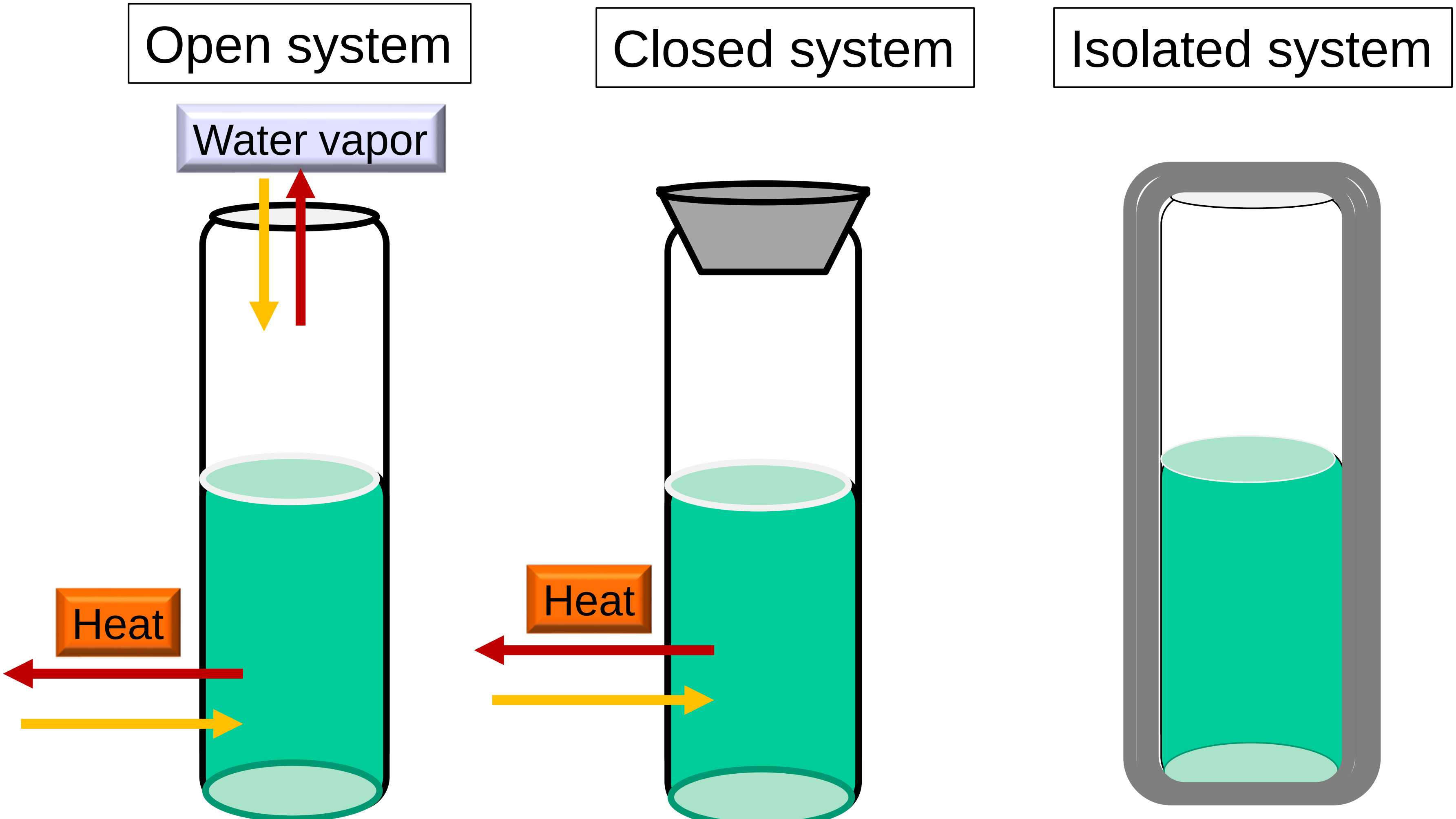
**Endothermic reaction (ΔH > 0)**




**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 ($q_{sys} = 0$)

$$q_{sys} = \Delta H_{rxn} + \underbrace{\underbrace{(q_{soln}}_{\text{heat transfer to solution}} + \underbrace{q_{cal})}_{\text{heat transfer to calorimeter}}}_{} = 0$$

*heat transfer to solution*

*enthaply of reaction*

*heat transfer to calorimeter*

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

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

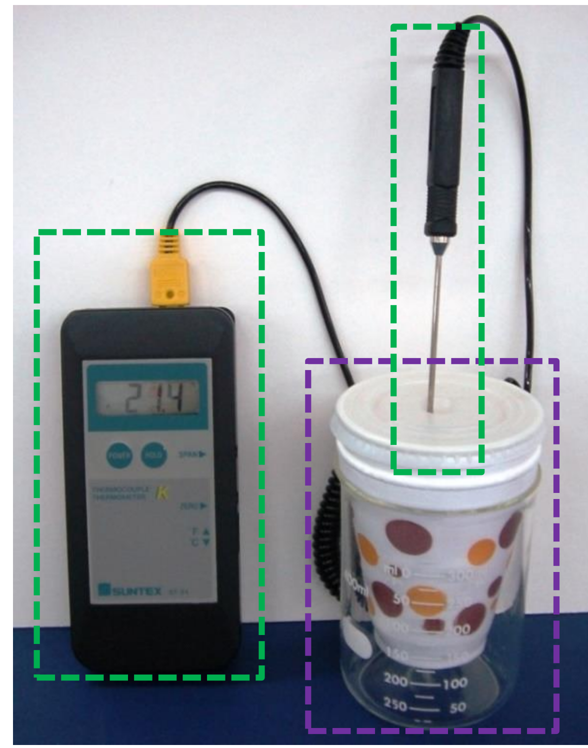
  m: mass (g), s: specific heat (cal/g·˚C)

  ΔT: temperature change (˚C)

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

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

Thermometer and probe



Two Styroform cups and a 400 mL beaker stacked together

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

# 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:

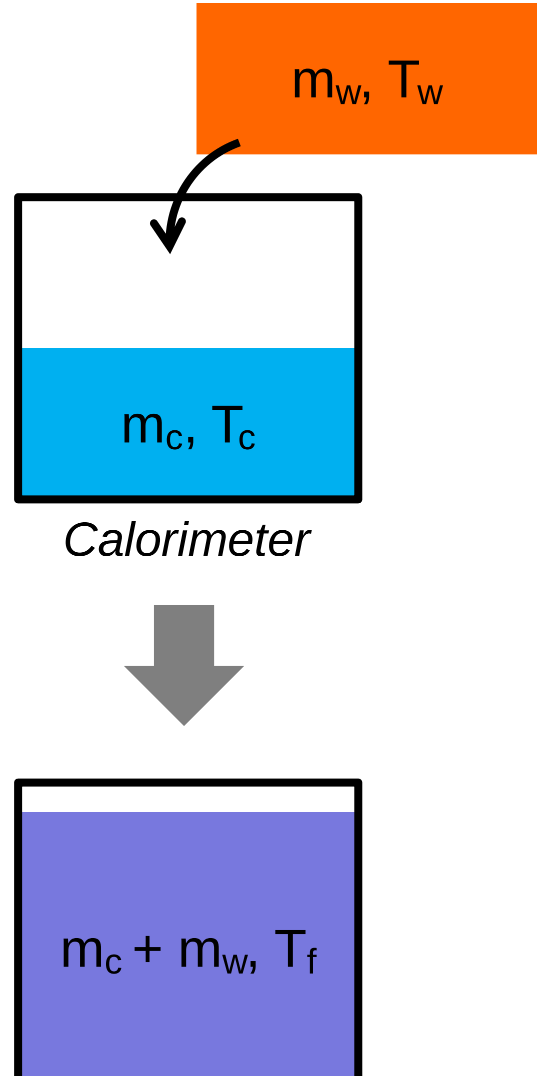
  0 = $q_1$ (heat released by the warm water)

  + $q_2$ (heat gained by the cold water)

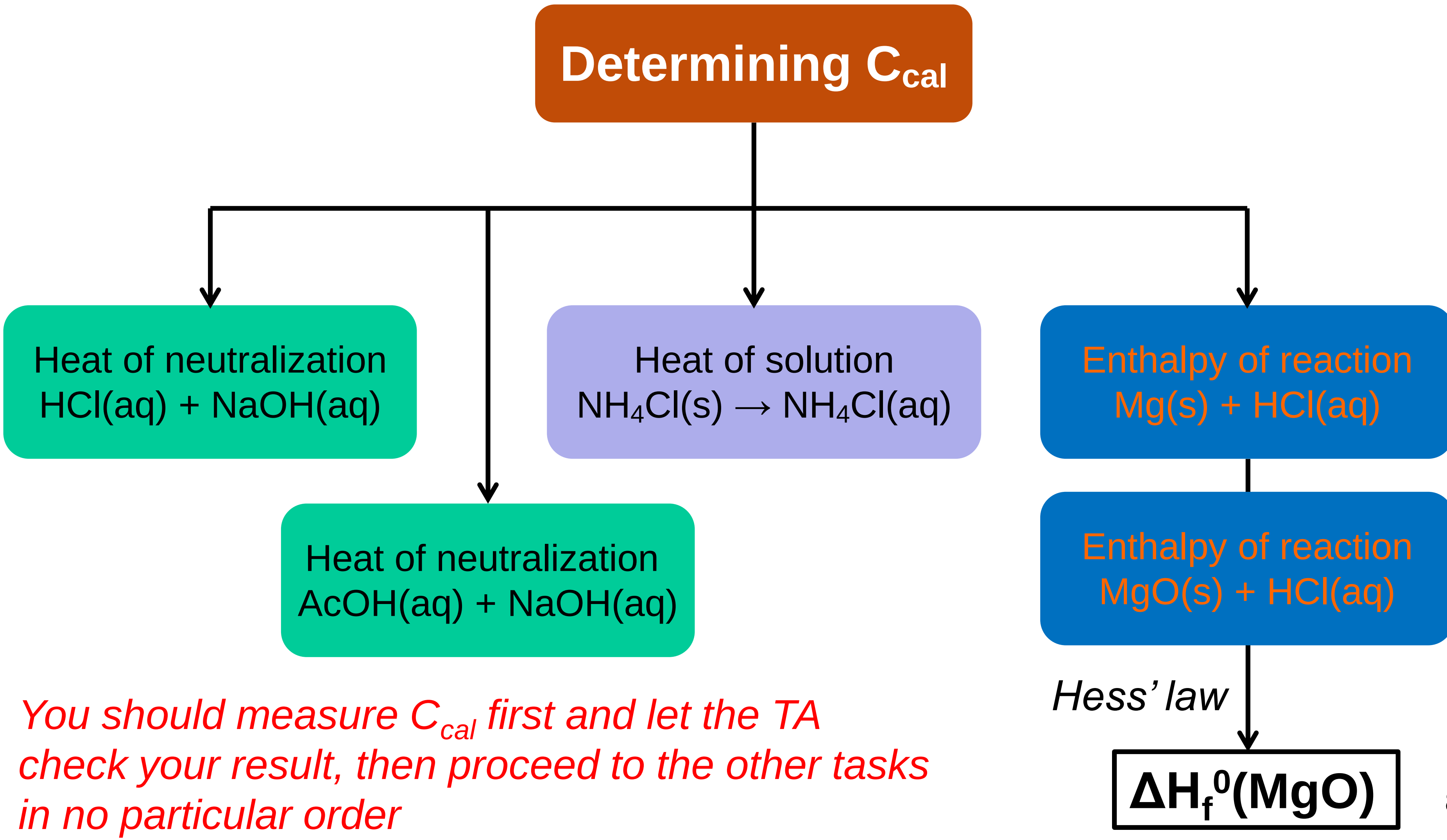
  + $q_3$ (heat gained by the calorimeter)

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

- 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. $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$ $\Delta H_1$
2. $MgO(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2O(l)$ $\Delta H_2$
3. $H_2(g) + ½O_2(g) \rightarrow H_2O(l)$ $\Delta H_3 = \Delta H_f(H_2O) = -68.4$ kcal/mol

$$\underbrace{Mg(s) + ½O_2(g) \rightarrow MgO(s)}_{\textit{This rxn} = (1) - (2) + (3)} \qquad \Delta H = \Delta H_f(MgO)$$

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

$\Delta H_1$ and $\Delta H_2$ are measured experimentally in this lab
→ **$\Delta H_f$(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.** ($^oC$) |
|---|---|
| **0** | **17.5** |
| **5** | **25.3** |
| **10** | **25.3** |
| **15** | **25.0** |

- 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 | 17.9 |
| 5 | 22.3 |
| 10 | 23.6 |
| 15 | 23.7 |
| 20 | 23.6 |

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

# Task 3: Heat of Neutralization (AcOH+NaOH)

NaOH(aq) AcOH(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 ($NH_4Cl$)

*Example:*

| Time (s) | Temp.(ºC) |
|---|---|
| 0 | 29.4 |
| 30 | 26.7 |
| 60 | 25.5 |
| 90 | 25.6 |
| 120 | 25.6 |

- 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

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

✓ 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

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

✓ 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 $cal/g\cdot{}^{o}C$) ← 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 units

# 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:
  - Member A: **Hand in prelab to the TA**
  - Member B: **Have the lab notes and results checked by the TA, and hand in the report next week**

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

# Final Report (Full Version)

- Four experiments (E3, E8, E10, E12)
- Complete the data analysis and calculation part in the lab manual
- Plot data correctly and discuss potential sources of errors
- Hand in the report in the following week together with the prelab and lab records
- 50 points per report (5 pts deduction for late submission < 1 week)

**I. Prelab exercise**

- ✓ Objectives
- ✓ Principles
- ✓ Chemicals
- ✓ Procedures

**II. Lab Notes**

- ✓ Observation
- ✓ Operation
- ✓ Reaction condition
- ✓ Data and results

**III. Final report**

- ✓ Data analysis
- ✓ Elaborate results
- ✓ Error analysis
- ~~✓ Questions and discussion~~

**15 pts + 10 pts + 25 pts**

# Lab Report Grading Rubrics

| Category | Guidelines | Pts |
|---|---|---|
| I. Prelab exercise | 1. Briefly summarize main principles and relevant equations | 5 |
| | 2. List the chemicals' toxicity and physical and chemical properties | 5 |
| | 3. Use flow chart to explain the experimental procedures | 5 |
| II. Lab notes | 4. Record data with correct significant figures and units | 5 |
| | 5. Record observations, operations, and reaction conditions in details | 5 |
| III. Final report | 6. Process data correctly (calculation included) | 5 |
| | 7. Present final results with correct significant figures and units | 5 |
| | *8. Analyze the results with appropriate error discussions** | *5* |
| | *9. Plot the results with correct XY axes and labeling** | *5* |
| | *10. Elaborate findings and provide constructive suggestions** | *5* |

**Only for full reports*