Heat of Reactions

Last revised: 2025/02/06

Preparation

Collect the following items

- ☐ Two Styrofoam cups and a plastic lid
- ☐ One digital thermometer
- ☐ One timer (TA distributed)

From your personal equipment

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

Note: Reduce the amount of chemicals

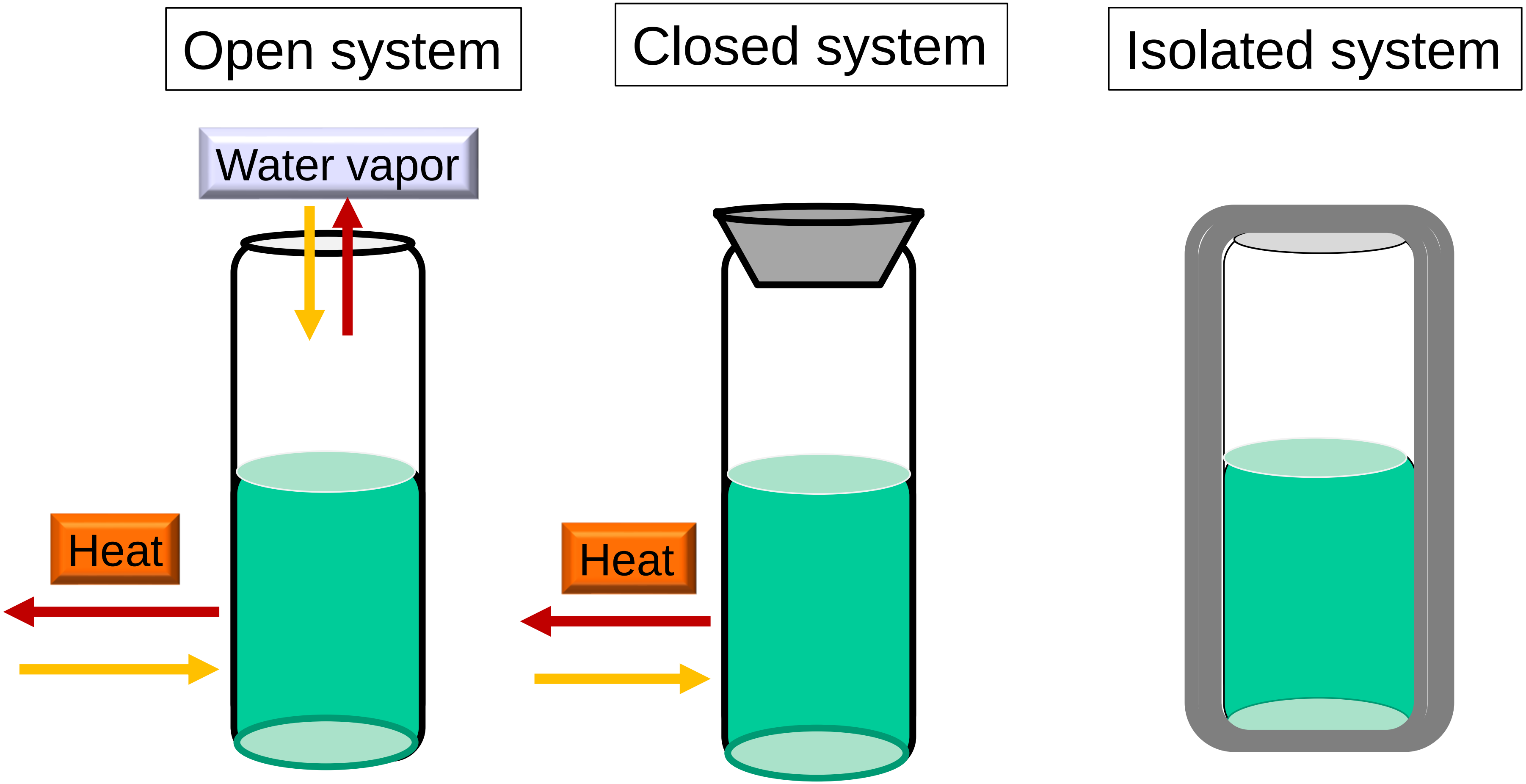
- ✓ **0.10-0.12 g** Mg reacts with **50 mL** HCl(aq)
- ✓ **0.3-0.4 g MgO reacts with 50 mL** HCl(aq)

Objective and Principles

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

- **Lab techniques:**
  - Operating a simple calorimeter
  - Using a graduated cylinder to measure volume
  - Using a digital thermometer
  - Using the lab dispensers

Reaction System



Open system

Water vapor

Heat

Closed system

Heat

Isolated system

Both mass and energy can exchange

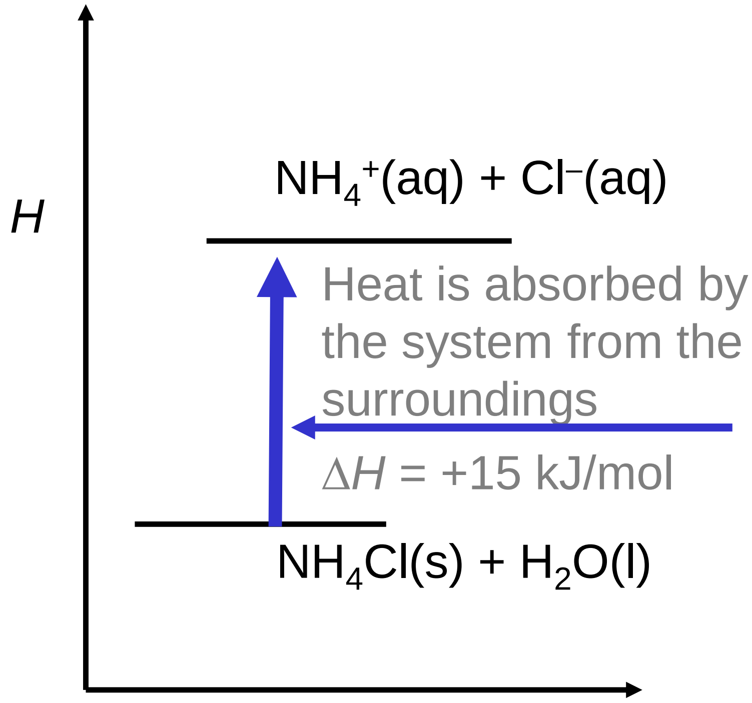
Only energy can exchange

Neither mass nor energy can exchange

Enthalpy of Reaction

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

Endothermic reaction ($\Delta H > 0$)



H

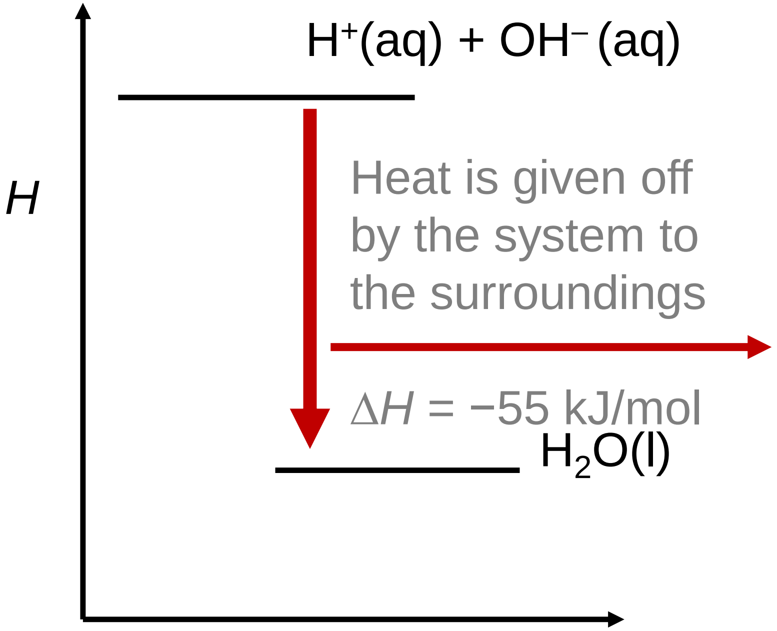
$NH_4^+(aq) + Cl^-(aq)$

Heat is absorbed by the system from the surroundings

$\Delta H = +15$ kJ/mol

$NH_4Cl(s) + H_2O(l)$

Exothermic reaction ($\Delta H < 0$)



$H^+(aq) + OH^-(aq)$

H

Heat is given off by the system to the surroundings

$\Delta H = -55$ kJ/mol

$H_2O(l)$

Constant-Pressure Calorimetry

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

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

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

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

    m: mass (g), s: specific heat (cal/g·^{o}C)

    ΔT: temperature change (^{o}C)

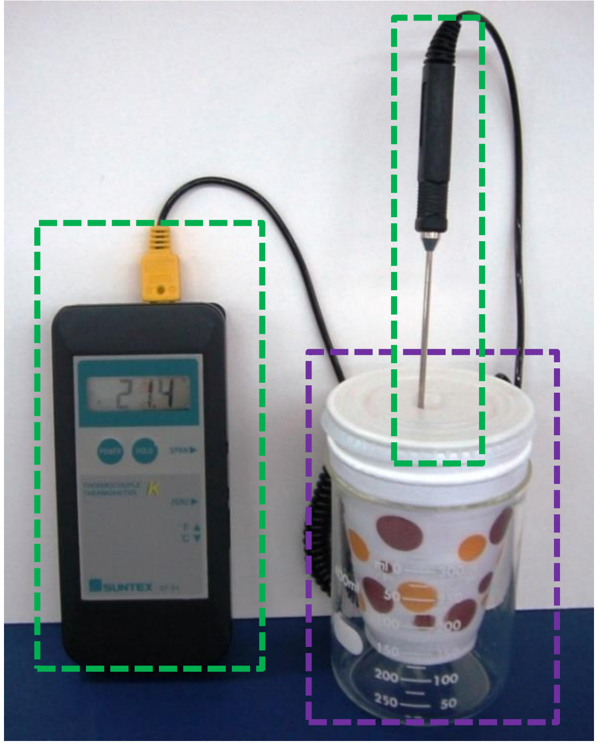
  - $q_{cal} = C_{cal} \times \Delta T$

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

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

  n: number of mole of limiting reagent

Thermometer and probe



Two Styroform cups and a 400 mL beaker stacked together

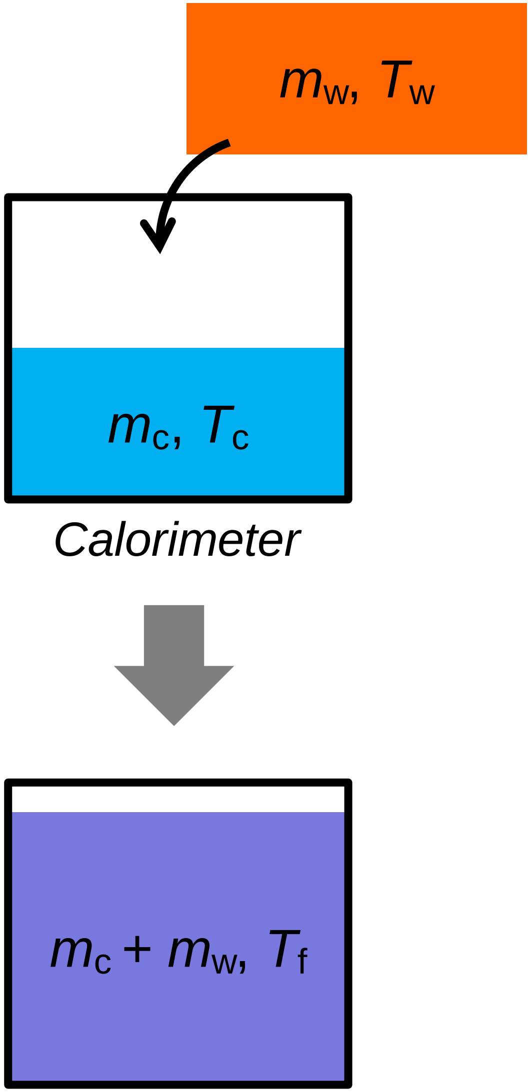
✓ Assume the density and specific heat of solutions are identical to that of H_2O

How to Determine C_{cal}

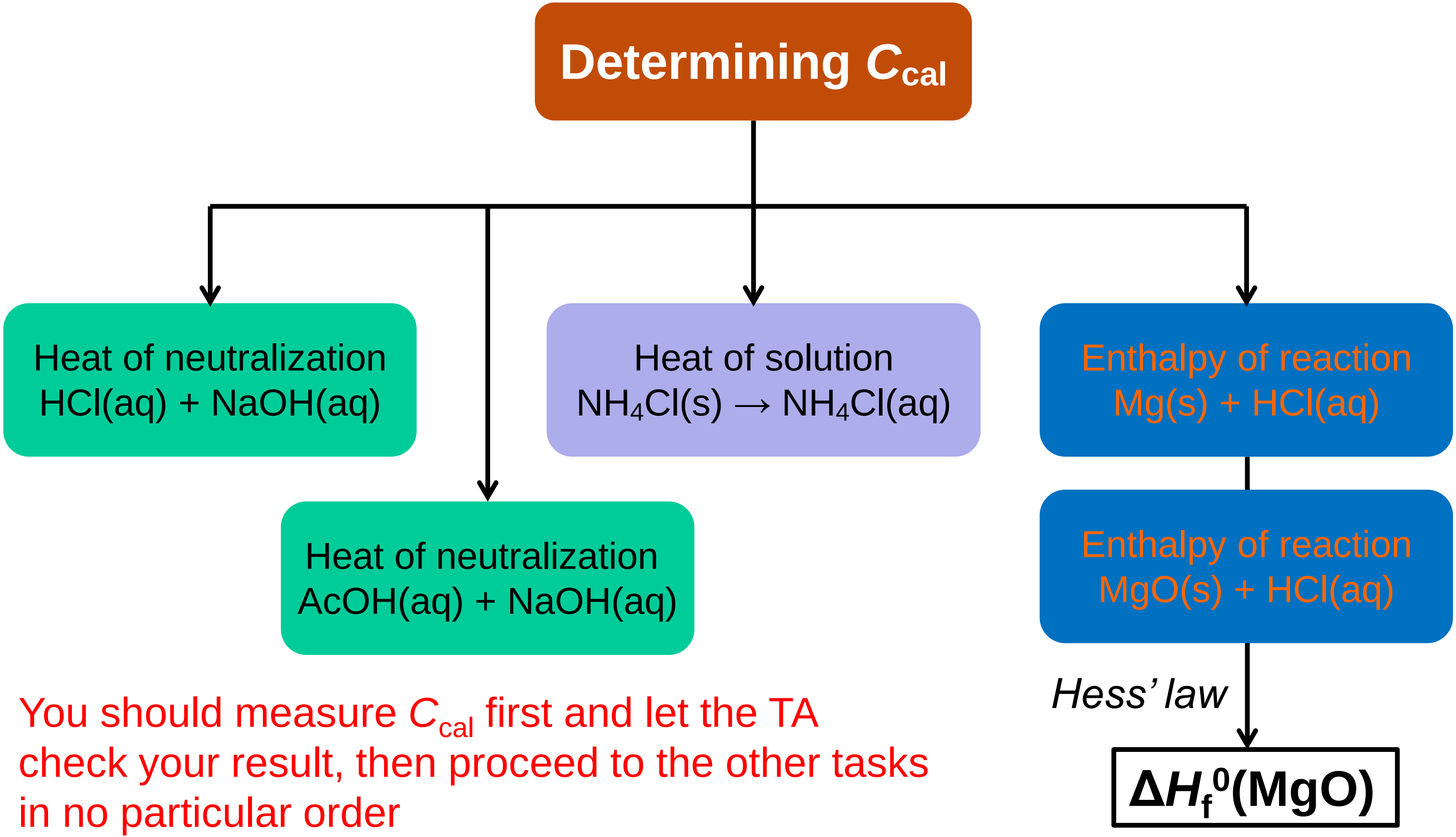
- m_w grams of warm water (temperature T_w) is added to m_c grams of cold water (temperature T_c) in a calorimeter
- The final temperature at equilibrum: T_f
- For an isolated system:

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

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



Experiment Tasks



Determining C_{cal}

Heat of neutralization
$HCl(aq) + NaOH(aq)$

Heat of neutralization
$AcOH(aq) + NaOH(aq)$

Heat of solution
$NH_4Cl(s) \rightarrow NH_4Cl(aq)$

Enthalpy of reaction
$Mg(s) + HCl(aq)$

Enthalpy of reaction
$MgO(s) + HCl(aq)$

Hess' law

$\boxed{\Delta H_f^0(MgO)}$

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) $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H_3 = \Delta H_f(H_2O) = -285.8$ kJ/mol

$$\underbrace{Mg(s) + \tfrac{1}{2}O_2(g) \rightarrow MgO(s)}_{\text{This rxn = (1) − (2) + (3)}}$$

$$\Delta H = \Delta H_f(MgO)$$

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

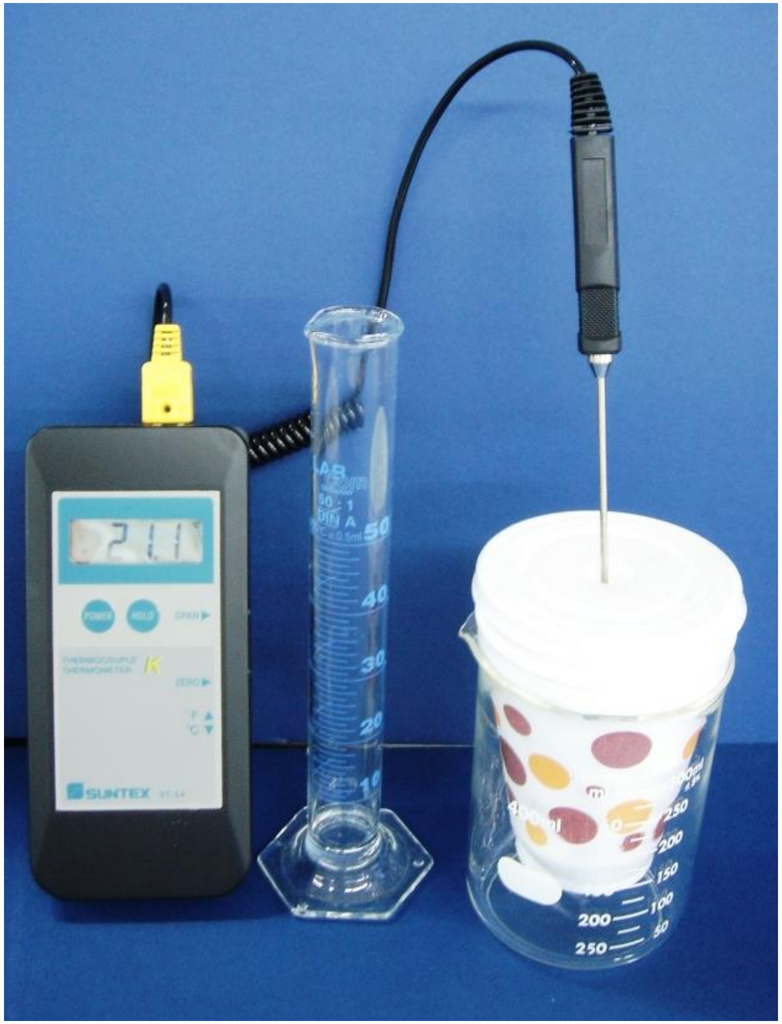
ΔH_1 and ΔH_2 are measured experimentally in this lab

→ **ΔH_f(MgO) can then be calculated**

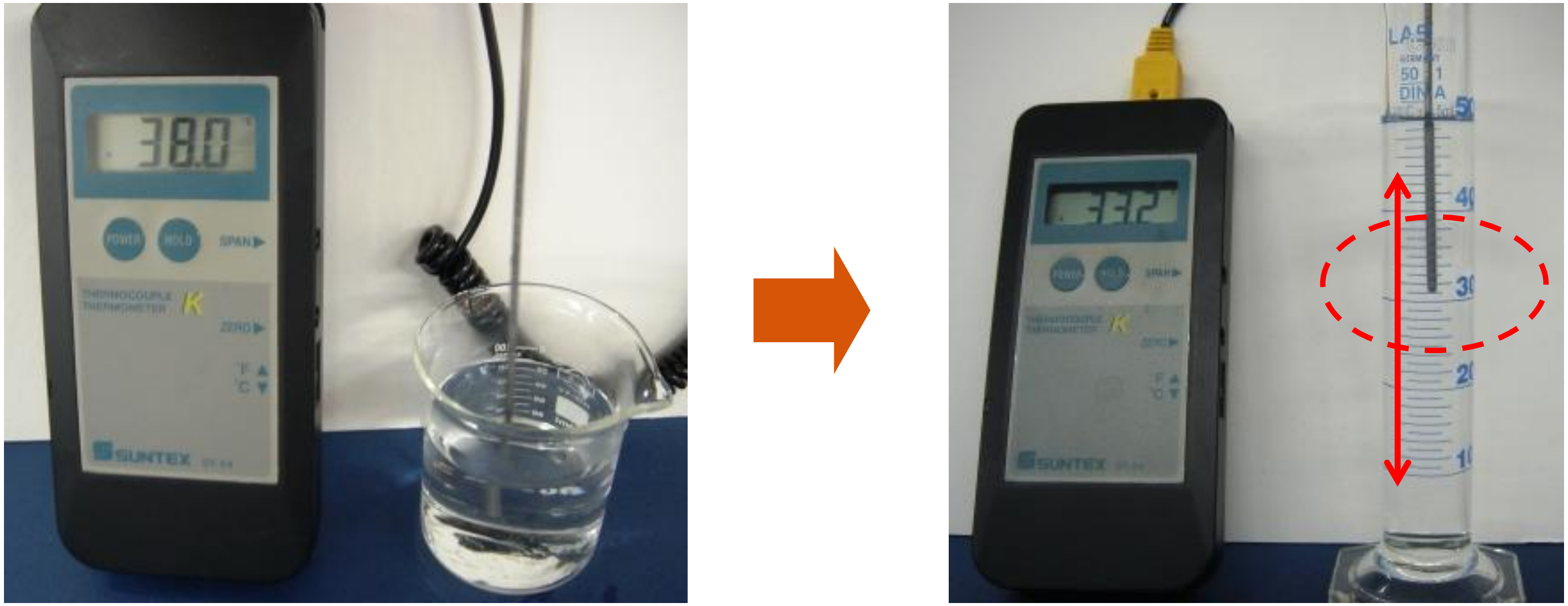
Task 1.1: Determining C_{cal}

- Use a graduated cylinder to measure 50 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 1~2 minutes, then record the water temperature

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



Task 1.2: 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 ^{o}C higher than the cold water

✓ Use the hot water in the fume hood

- Use a graduated cylinder to measure 50 mL of warm water
- Use the thermoprobe to check whether the water temperature is even at different heights
- Record the water temperature in the middle section

Task 1.3: Determining C_{cal}

Example:

Time (s)	**Temp.** (^oC)
0	**27.5**
5	**33.3**
10	**33.3**
15	**33.2**

- Quickly pour the warm water into the calorimeter, then close the plastic lid
- Insert the thermoprobe
- Swirl the calorimeter to mix the water
- Record the temperature readings at a fixed time interval, and 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)

- Use a lab dispenser to measure 50.0 mL of 1.0 *M* HCl into the calorimeter, then record its equilibrium temperature
- Use a graduated cylinder to measure 50 mL of 1.0 *M* NaOH, then record its equilibrium temperature
- Quickly pour NaOH into the calorimeter, close the plastic lid, and insert the thermoprobe
- Mix the solution; record the temperature evolution

Example:

Time (s)	Temp.(^{o}C)
0	27.9
5	32.3
10	33.6
15	33.7
20	33.6

Task 3: Heat of Neutralization (AcOH+NaOH)

AcOH(aq)

NaOH(aq) **AcOH(aq)**

- Use a lab dispenser to measure 50.0 mL of 1.0 *M* CH_3COOH into the calorimeter, then record its equilibrium temperature
- Use a graduated cylinder to measure 50 mL of 1.0 *M* NaOH, then record its equilibrium temperature
- Quickly pour NaOH into the calorimeter, close the plastic lid, and insert the thermoprobe
- Mix the solution; record the temperature evolution

Task 4: Heat of Solution (NH_4Cl)

Example:

Time (s)	Temp.(°C)
0	27.8
30	24.7
60	24.0
90	24.0
120	24.1

- Measure 50 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
- ✓ Take the lowest temp. reading as the equil. temp

Task 5.1: Enthaply of Reaction (Mg + HCl)

- Measure **50.0 mL** of 1.0 *M* HCl into the calorimeter, then record its equilibrium temperature
- Use analytical balance to weigh ca. **0.1-0.12 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

50.0 mL

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

✓ Solid reactants must be mixed and reacted completely

Task 5.2: Enthaply of Reaction (MgO + HCl)

- Measure **50.0 mL** of 1.0 *M* HCl into the calorimeter, then record its equilibrium temperature
- Use analytical balance to weigh ca. **0.3-0.4 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 placed in the center of the solution, as it may give an 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 pretty fast, so you should start recording the temperature immediately after mixing
- Wash and dry the Styrofoam cups after each experiment
- Solid reactants (NH_4Cl, Mg, MgO) must be reacted completely → observe and note 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 the **highest reading** and then start to decrease
  - Endothermic reactions: the solution temperature would decrease to the **lowest reading** and 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 the solution is identical to that of water (1 cal/g·^{o}C) ← this is an exact value (infinite s.f.)
- List calculations in detail in the lab report (including the amount of heat, # moles of reactants, and enthalpy of reactions) → **The unit of heat should be in J or kJ**
- Use correct significant figures and units

Clean-Up and Check-Out

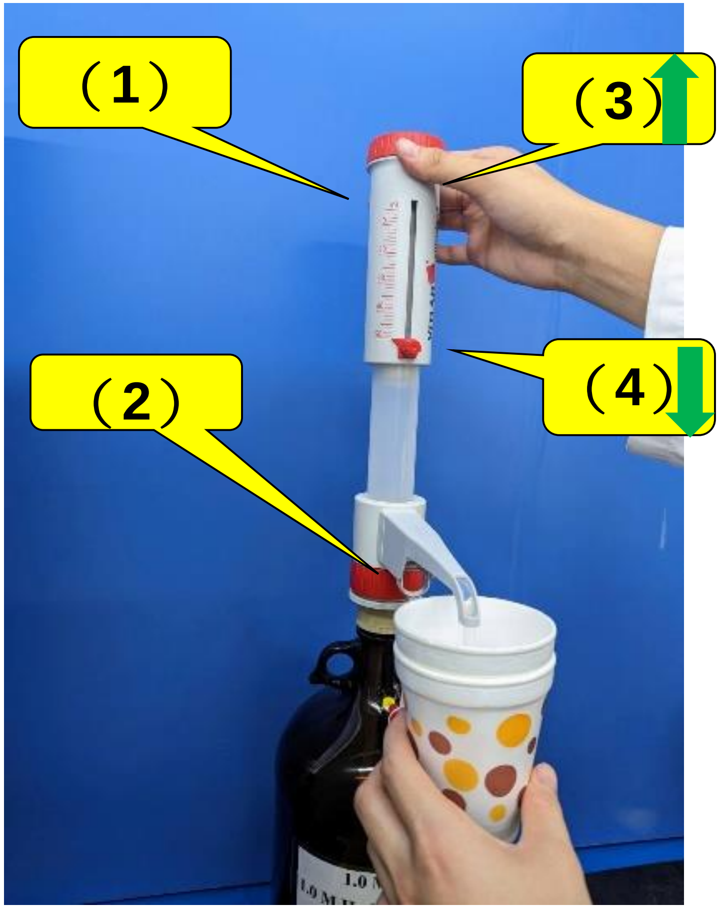
- Salt solutions resulting from acid-base neutralization can be disposed into the sink
- Clean the Styrofoam cups and plastic lid for reuse
- Return the stopwatch to TA
- Clean up the lab bench and check personal equipment inventory (have an associate TA sign the check list)

- 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

Dispenser

1. Check the pre-set volume and do not change the volume setting afterwards
2. Position the flask under the tip of dispenser
3. Lightly pull the piston pump up and down several times to get rid of the bubbles
4. Lightly pull piston pump up to the top, then slowly push down to obtain the measured solution



Electronic Balance

Video on YouTube (Click)

- To maintain calibration, never move the balance.
- Do not overload the balance. Maximum load of an electronic balance in lab is usually 610 g.
- Check to see that the balance is level and clean before use.
- Warm up the balance for 30 min before use.

Electronic Balance
(s.f. only contains two decimal places)

Analytical Balance
(s.f. contains four decimal places)

- Put weighed object in the center of weighing pan. Read digital readout for mass.
- Use folded weighing paper, beaker or bottle as container while weighing. Do not put chemicals on the pan directly.
- Always allow an object that has been heated to return to room temperature before weighing it. The buoyancy of convective airflow around the pan will affect object’s apparent mass.
- Keep the balance and its case scrupulously clean. The balance area has a soft brush for this purpose.
- Do not invert balance upside down to avoid damage to the parts inside.
- Analytical balance is an instrument with high precision with maximum load of 210 g. Close its windshields while zeroing and weighing, otherwise the reading is fluctuated and inaccurate.