國立中正大學

National Chung Cheng University

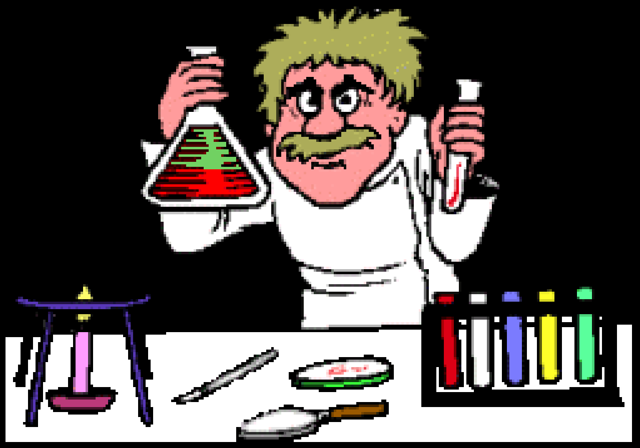
積極創新　修德澤人

114-2
Expt. 12 – Buffer Solution

March 14, 2026 (time required: 2.5 hours)

1. Objectives

- Understand and prepare buffer solutions.
- Investigate factors affecting buffer capacity.
- Learn the use of a pH meter.



2. Principle (1/7)

Buffer Solutions

- A buffer resists large pH changes upon dilution or small additions of acid/base.

- Composed of a weak acid/base and its conjugate base/acid.
  - weak acid + limited strong base
  - weak base + limited strong acid

2. Principle (2/7)

Conjugate acid–base pairs maintain a dynamic equilibrium in solution

$$HA_{(aq)} \rightleftharpoons H^{+}_{(aq)} + A^{-}_{(aq)} \qquad \text{(eq. 12-1)}$$

$$K_a = \frac{[H^+][A^-]}{[HA]} \qquad \text{(eq. 12-2)}$$

K_a : Dissociation constant

2. Principle (3/7)

pH Response of Buffers

Addition of acid:

$A^{-}_{(aq)} + H^{+}_{(aq)} \rightarrow HA_{(aq)}$ (eq. 12-3)

Addition of base:

$HA_{(aq)} + OH^{-}_{(aq)} \rightarrow H_2O_{(l)} + A^{-}_{(aq)}$ (eq. 12-4)

2. Principle (4/7)

Henderson - Hasselbalch Equation

- $[H^+] = \dfrac{K_a[HA]}{[A^-]}$ (eq. 12-5)

- $pH = -\log[H^+] = -\log K_a - \log \dfrac{[HA]}{[A^-]}$ (eq. 12-6)

- $pH = pK_a + \log \dfrac{[A^-]}{[HA]}$ (eq. 12-7)

2. Principle (5/7)

Buffer Capacity

- **The amount of strong acid or base required to change the pH of 1.0 liter of the buffer solution by one unit.**
- **A buffer solution with a high concentration and an $[A^-]/[HA]$ ratio of 1 has a large buffer capacity.**
- **In this experiment, a buffer solution is prepared using acetic acid and sodium acetate. Strong acid or base is then added, and the pH is measured to observe its change and compare the buffer capacity.**

2. Principle (6/7)

The relationship between solution pH and the measured potential

$$E_m = \frac{\mathrm{K}-2.3RT(\mathrm{pH})}{nF}$$

since R, n, and F are constants, this can be simplified to

$$E_m = mT(\mathrm{pH}) + \mathrm{K}$$

Where T is constant, m is also a temperature-related constant, E_m shows a linear relationship with pH value.

2. Principle (7/7)

- E_m : The measured potential
- K : Constant (the value depends on the electrode)
- R : Gas constant
- T : Absolute temperature of the solution
- pH: The pH of the solution
- n : Number of electrons transferred in the electrode reaction
- F : Faraday constant

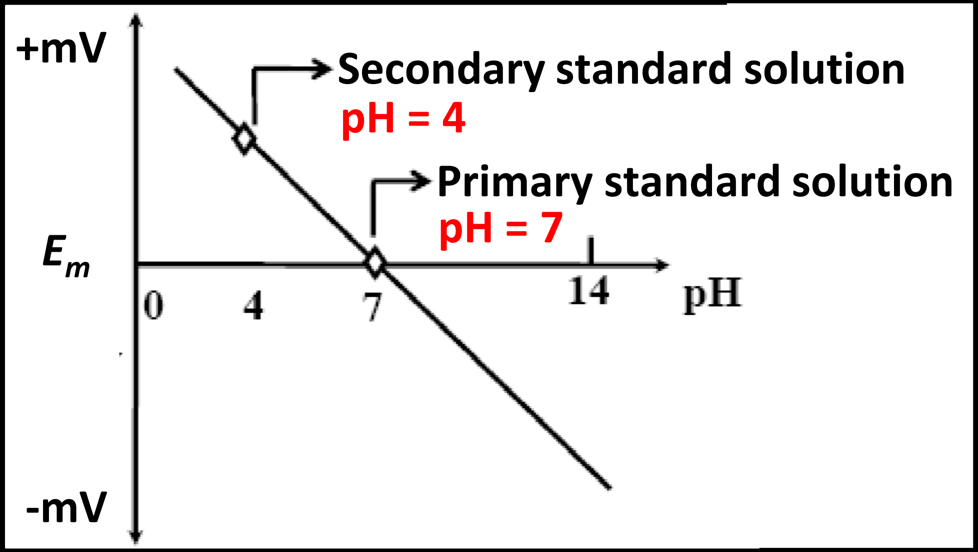


Figure 1. Relationship between the measured potential and the pH of the solution.

3. Equipment and Chemicals (1/2)

Equipment

In cabinet	Provided by TA
Beaker 500 mL × 1	Dropper
Beaker 250 mL × 2	pH meter
Beaker 100 mL × 2	Cleaning wipes
Glass rod × 1	(one box shared by two groups)
Pipet filler × 1	
Graduated pipet 10 mL × 1	
Graduated cylinder 10 mL × 1	
Wash bottle × 1	

3. Equipment and Chemicals (2/2)

Chemicals

0.05 M CH_3COOH * * *	0.05 M CH_3COONa *
1.00 M HCl * * *	1.00 M NaOH * * *
Standard buffer solutions * (Primary standard buffer solution, pH = 7.00) (Secondary standard buffer solution, pH = 4.00)	

* : Corrosive * : Irritant * : Flammable * : Toxic

Ref. : https://pubchem.ncbi.nlm.nih.gov/

4. Experimental Procedures

1. Obtain 250 mL each of 0.05 M HOAc and NaOAc aqueous solutions prepared by the TA.
2. Obtain 20.0 mL each of 1 M NaOH and HCl aqueous solutions prepared by the TA.
3. Using a 10 mL graduated cylinder, add several drops of HCl and NaOH solutions separately; measure the volume added and record the number of drops.

- Buffer capacity (meq/L · pH)

$$= \frac{1\ (\text{drop})}{\text{slope (pH)}} \times \boxed{V\ (\text{mL/drop})} \times N\ (eq/\text{L}) \times \frac{1000\ (\text{mL/L})}{30\ (\text{mL})}$$

Figure 2. Schematic diagram of the dropper and graduated cylinder.

Old Model pH Meter

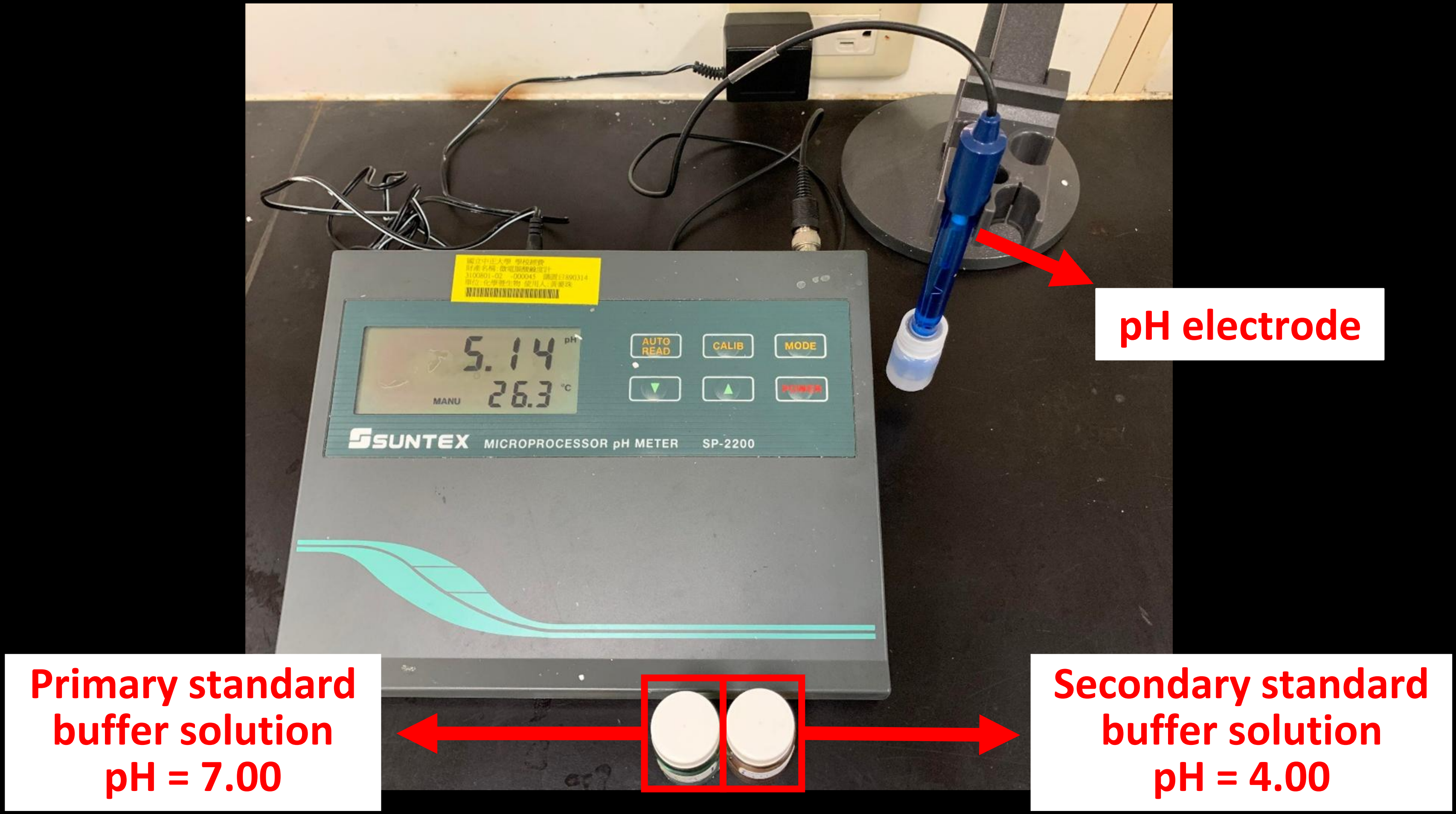


Figure 3. Schematic diagram of the old model pH meter.

pH Meter Control Panel (Old Model)

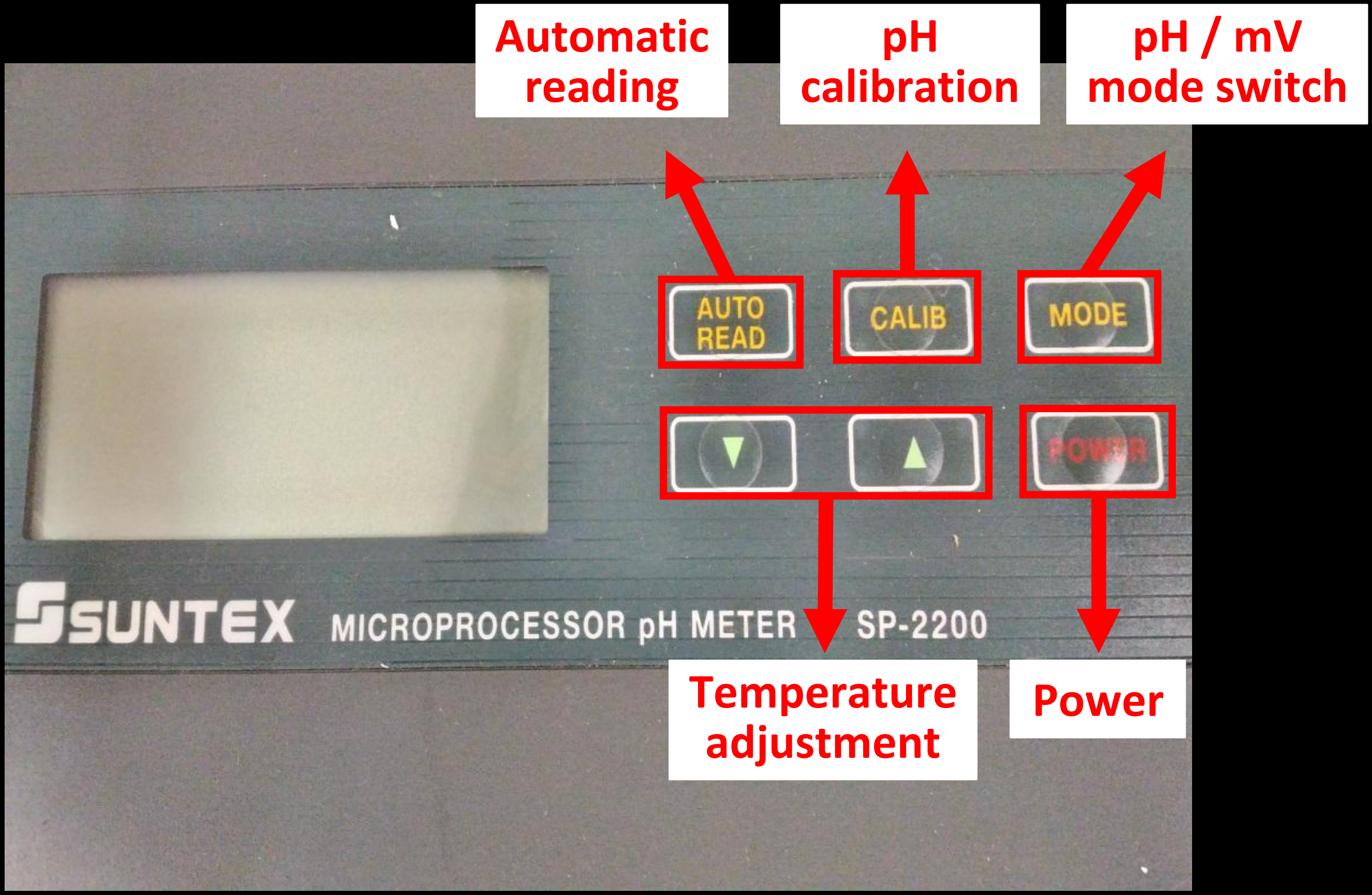


Figure 4. The Control panel of the old model pH meter.

Startup Procedures

1. Press the “POWER” button.

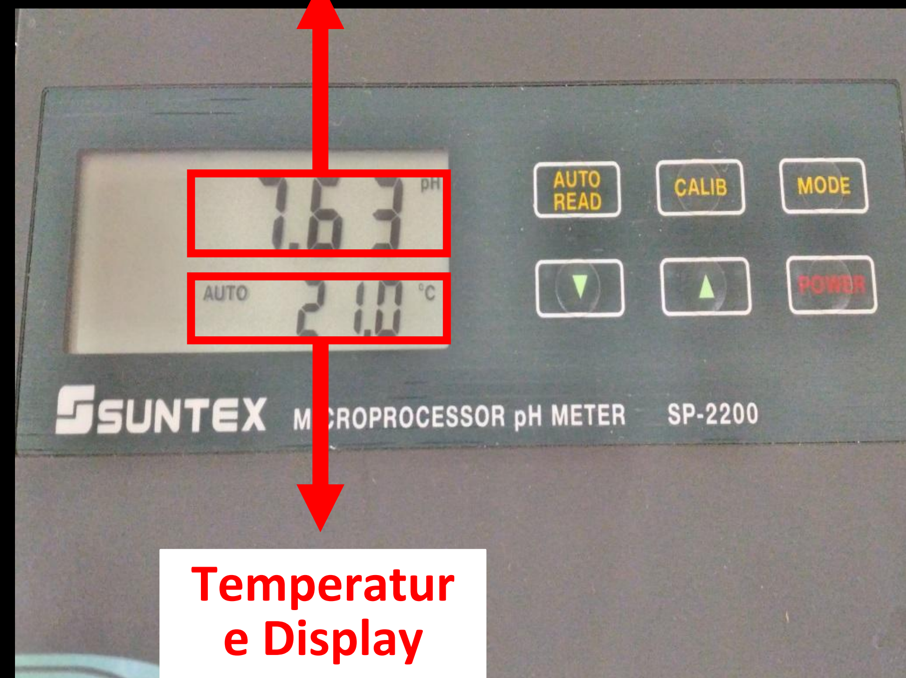


Figure 5. Startup procedures for the old model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 7.00)

2. Rinse the electrode with DI water and gently blot it dry with cleaning wipes.
3. Press the “CALIB” button once; “CAL1” will appear.

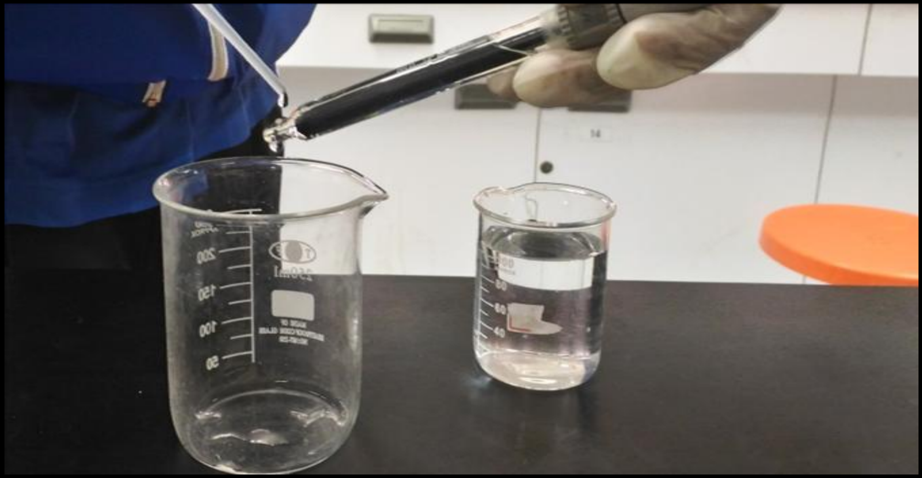


Figure 6. Schematic diagram of electrode cleaning.

Figure 7. Calibration schematic diagram of the old model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 7.00)

4. Immerse the temperature probe and pH electrode in the primary standard buffer solution (pH = 7.00).
5. Press and hold the "CALIB" button until "CAL1" flashes.
6. When the display switches to "CAL2," measure the standard buffer solution at pH = 4.00.

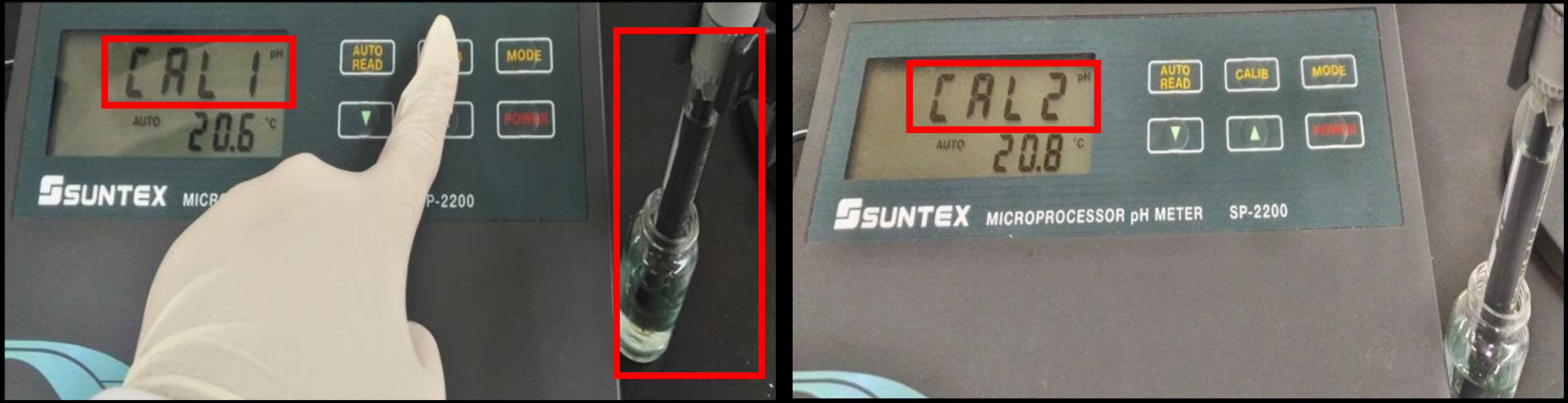


Figure 8. Calibration schematic diagram of the old model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 4.00)

7. Immerse the temperature probe and pH electrode in the secondary standard buffer solution (pH = 4.00).
8. Press and hold the “CALIB” button until “CAL2” stops flashing and the electrode slope is displayed.
9. Record the electrode slope; it must be greater than 80% before proceeding with the experiment.

***Note:** Before each measurement, rinse the electrode with DI water and dry it with cleaning wipes before proceeding.*

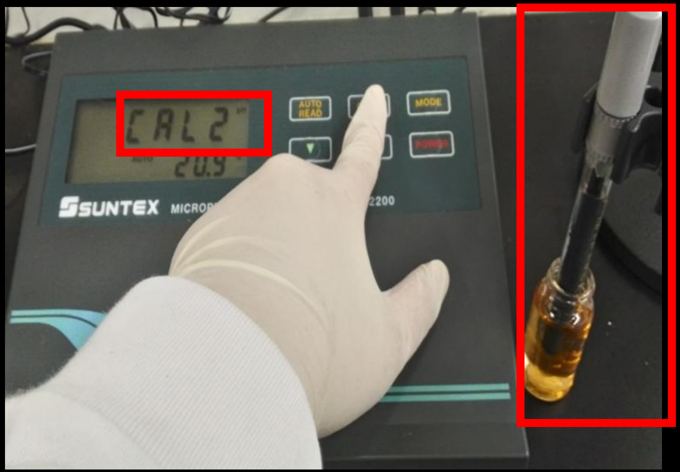


Figure 9. Calibration procedures for the old model pH meter.

New Model pH Meter

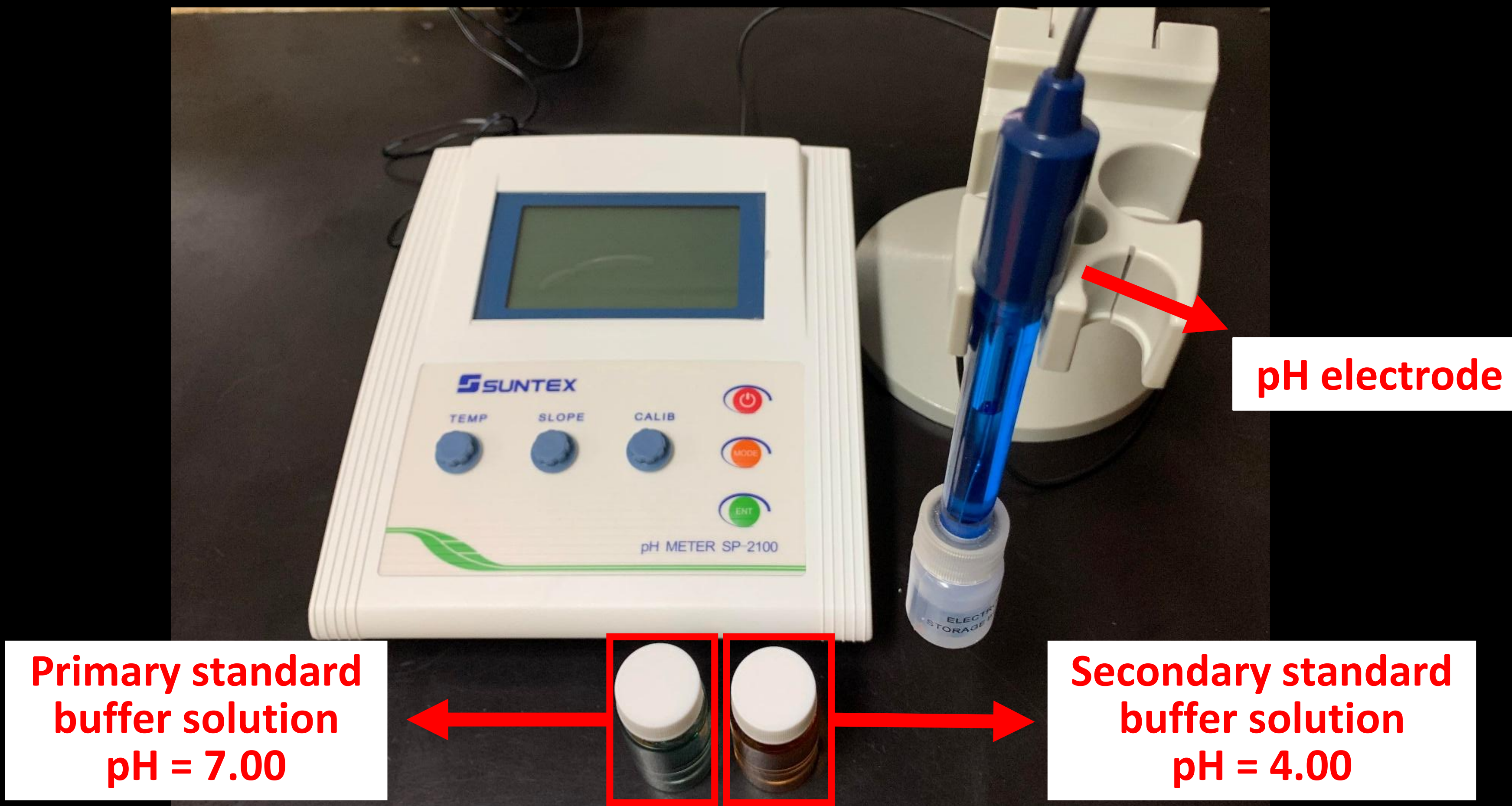


Figure 10. Schematic diagram of the new model pH meter

New Model pH Meter Control Panel

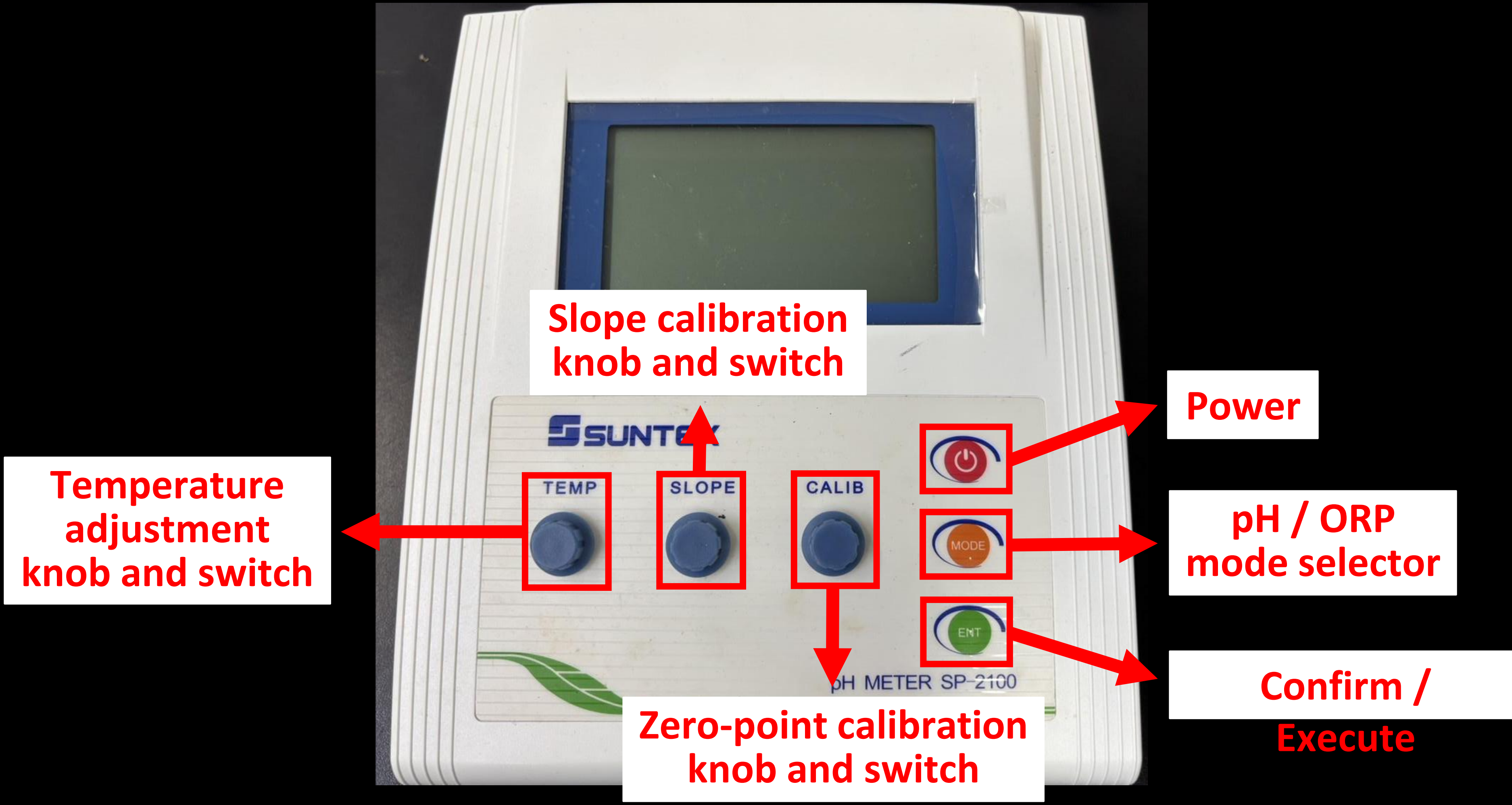


Figure 11. The Control panel of the new model pH meter..

Power on

1. Press the “POWER ” button.

Figure 12. Startup procedures for the new model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 7.00)

2. Rinse the electrode with DI water and dry it by cleaning wipes.
3. Press the “MODE ” button; “Ct 1” will appear.

Figure 13. Schematic diagram of electrode cleaning

Figure 14. Calibration schematic diagram of the new model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 7.00)

4. Immerse the temperature probe and pH electrode in the primary standard buffer solution (pH = 7.00).
5. Press the "ENT " button and wait; once stabilized, the pH value for the first calibration point will be displayed.
6. The system will automatically proceed to the second calibration point. Rinse the electrode with DI water and (ani

Figure 15. Calibration schematic diagram of the new model pH meter.

Calibrate the pH meter (standard buffer solution, pH = 4.00)

7. Immerse the temperature probe and pH electrode in the primary standard buffer solution (pH = 4.00).
8. Press the “ENT ” button and wait; once stabilized, the pH value for the second calibration point will be displayed.
9. The system will automatically proceed to the third calibration point; press the “MODE ” button.

Figure 16. Calibration schematic diagram of the new model pH meter.

Calibrate the pH meter

10. "PASS" will appear on the display.
11. After a brief moment, the calibration is complete.

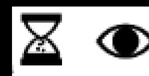
Figure 17. Calibration schematic diagram of the new model pH meter.

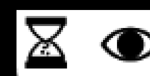
New model pH meter (pH measurement procedure)

1. Place the cleaned and dried electrode into the sample solution and press the "ENT " button.
2. When the  symbol appears and the reading is locked, press the "ENT " button again.

Figure 18. Measurement schematic diagram of the new model pH meter.

New model pH meter
(pH measurement procedure)

3. At this stage, the  symbol flashes; begin reading and wait for the measurement to stabilize.

3. Once the reading stabilizes, the  symbol stops flashing and the value is locked.

3. Record the value, rinse the electrode with DI water, dry it with cleaning wipes, and repeat steps 1–4.

Precautions for using the pH meter

1. Ensure the electrode tip is fully immersed in the sample solution and does not touch the container walls.
2. After adding HCl or NaOH, lift the electrode and stir the solution with a glass rod before measuring.
3. Each time the sample solution is changed, rinse the electrode with ***DI water*** and dry it with ***cleaning wipes***.
4. ***Never*** invert or lay the electrode flat.
5. When not in use temporarily, keep the electrode immersed in clean ***DI water***.
6. For long-term storage, soak the electrode in ***3.0 M KCl*** solution.

Formulations of solutions (a) – (i)

Solution	0.050 M HOAc (mL)	0.050 M NaOAc (mL)	DI water (mL)
(a)	30.0	0	0
(b)	0	30.0	0
(c)	15.0	15.0	0
(d)	5.0	5.0	20.0
(e)	0	0	30.0
(f)	5.0	25.0	0
(g)	10.0	20.0	0
(h)	20.0	10.0	0
(i)	25.0	5.0	0

Measure the pH value

1. Measure the pH of the solution before any drops are added (0 drops).
2. Use a dropper to draw 1.0 M $HCl_{(aq)}$.
3. Add one drop to solution (a).
4. Mix thoroughly and record the pH value.
5. Continue by adding a total of five drops incrementally.

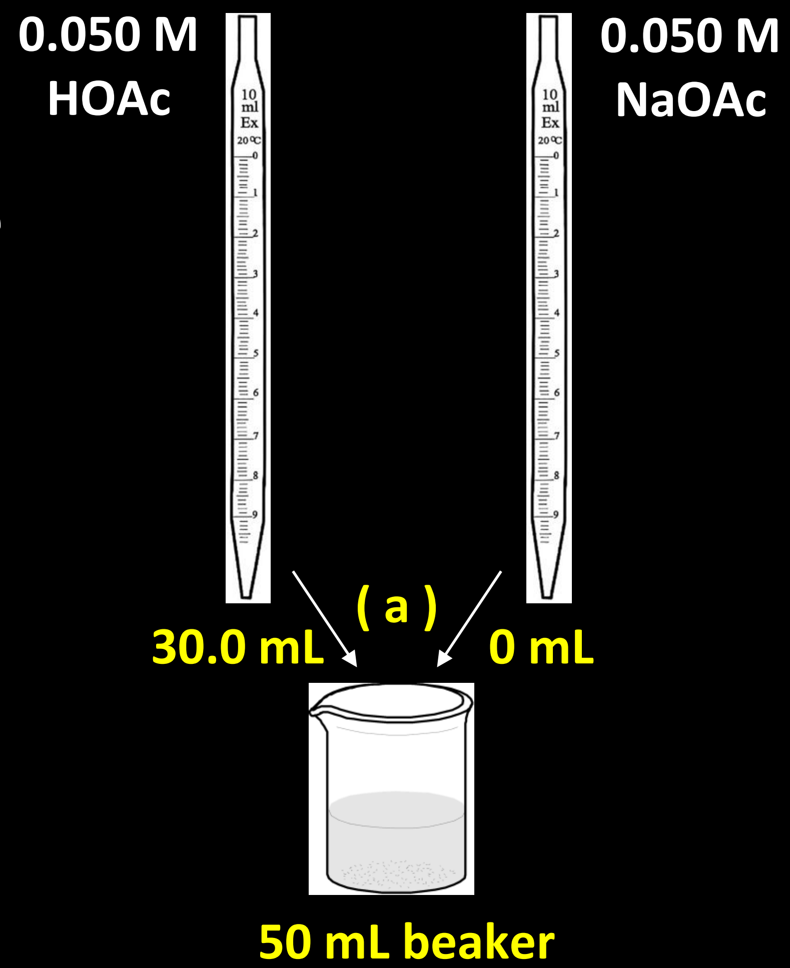


Figure 19. Schematic diagram of the preparation of solution (a).

Measure the pH value

6. Prepare a fresh portion of solution (a).
7. Measure the pH of the solution before any drops are added (0 drops).
8. Use a dropper to draw 1.0 M $NaOH_{(aq)}$.
9. Add the solution dropwise while measuring the pH.
10. Repeat steps 1–8 for solutions (b) ~ (i).

5. Precautions (1/2)

1. After completing the experiment, clean and dry the glass electrode, then place the electrode cap filled with 3.0 M $KCl_{(aq)}$ on it.
2. The glass electrode used in this experiment is expensive; handle it with care. Any damage will require compensation.
3. If the 3.0 M $KCl_{(aq)}$ in the electrode cap is less than half full, ask the TA for assistance to refill it (Fig. 20).

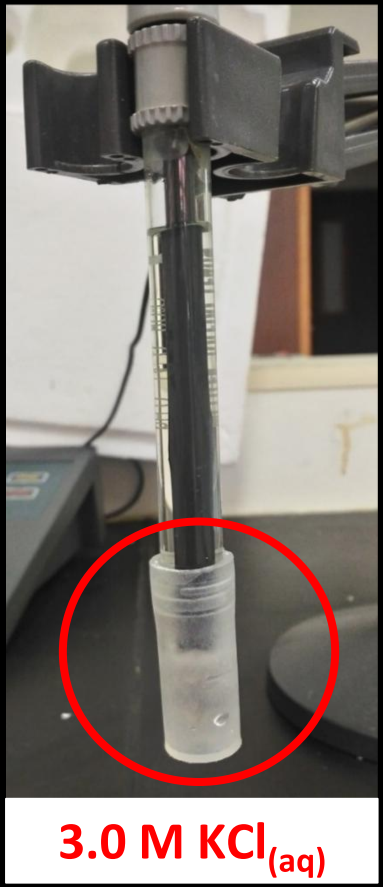


Figure 20. Schematic diagram of the KCl electrode cap.

5. Precautions (2/2)

4. At the end of the experiment, dispose of the waste solutions in the designated waste container.
5. Odd-numbered groups perform experiments (a) – (e); even-numbered groups perform experiments (f) – (i).
6. Standard Personal Protective Equipment (PPE) is mandatory: lab coat, safety goggles, gloves, and a mask.
7. All chemicals used in the laboratory are toxic and potentially hazardous. Please follow all laboratory safety regulations to ensure a safe working environment.
8. Removal of any chemicals or laboratory equipment from the lab is strictly prohibited.

6. Experimental data

Number of drops / **pH value**		(a) 0.05 M HOAc	(b) 0.05 M NaOAc	(c) 0.05 M HOAc/NaOAc	(d) 0.017 M HOAc/NaOAc	(e) DI water
1.0M HCl	-5					
	-4					
	-3					
	-2					
	-1					
	0					
Average (0)						
1.0M NaOH	0					
	1					
	2					
	3					
	4					
	5					

Plots of pH versus number of acid/base drops for (a) – (e)

Plot of pH values for (c) and (d)

Effect of the $[OAc^-]/[HOAc]$ ratio on buffer capacity

pH value **Number of drops**		(f) 0.05 M HOAc/NaOAc (1:5)	(g) 0.05 M HOAc/NaOAc (1:2)	(h) 0.05 M HOAc/NaOAc (2:1)	(i) 0.05 M HOAc/NaOAc (5:1)
1.0M HCl	-5				
	-4				
	-3				
	-2				
	-1				
	0				
Average (0)					
1.0M NaOH	0				
	1				
	2				
	3				
	4				
	5				

Plots of pH versus number of acid/base drops for (f) – (i)

7. Questions (1/4)

1. For the solutions prepared in this experiment—(c) 0.050 M acetic acid/sodium acetate (1:1) and (d) 0.017 M acetic acid/sodium acetate (1:1)—what are their theoretical pH values? Derive and explain using the appropriate equations.

7. Questions (2/4)

2. **If a buffer solution is prepared using NaH_2PO_4 and Na_2HPO_4, what is its optimal buffering pH range? Write the reaction equations showing how this buffer neutralizes added H^+ and OH^- ions.**

7. Questions (3/4)

3. **Discuss the buffer capacities of the buffer solutions at different concentrations used in this experiment, and explain the reasons for the observed differences.**

7. Questions (4/4)

4. **The pH of human blood is approximately 7.4, and the bicarbonate ($NaHCO_3$) / carbonic acid (H_2CO_3) system is the primary blood buffer system. In a patient with metabolic acidosis, the blood pH decreases to 7.1. How does the human body compensate for this pH change through the respiratory system? Describe the mechanism in detail and write the relevant chemical reaction equations related to increased respiration.**

Plotting requirements

1. **pH vs. number of acid/base drops (a) – (e):**
   The x-axis represents the number of HCl/NaOH drops, and the y-axis represents the pH value.
2. **Plots of pH for solutions (c) and (d):**
   Solutions (c) and (d) are plotted separately, with the x-axis as the number of HCl/NaOH drops and the y-axis as the pH value. Linear regression is performed using five data points for each, from which the equation and R^2 value are obtained, and the buffer capacity is calculated.
3. **pH vs. number of acid/base drops (f) – (i):**
   The x-axis represents the number of HCl/NaOH drops, and the y-axis represents the pH value. Linear regression is performed using five data points for each solution to obtain the equation and R^2 value, and the buffer capacity is calculated.

National Chung Cheng University
Department of Chemistry and Biochemistry

Prepared by: TA Y.-W. Lu (盧昱瑋)

Edited by: TA Y.-C. Tseng (曾盈臻)

Instructor: Prof. Joyce S. Yu (于淑君)

Last Updated: Feb 26, 2026