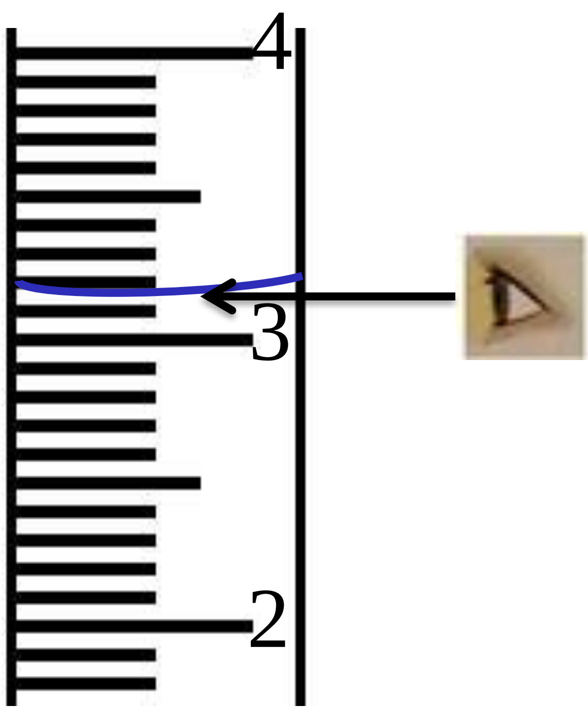
Guidelines for Lab Reports

- How to use significant figures (s.f.) correctly
- Example of prelab excercises and lab reports

Last revised: 2024/10/02

Uncertainty in Measurements



What is the most meaningful reading?

(A) 3.1 mL

(B) 3.2 mL

(C) 3.15 mL

(D) 3.16 mL

(E) 3.154 mL

SI Units

- **International System of Units, SI units**

Base quantity	Name of unit	Symbol
Length	meter	**m**
Time	second	**s**
Mass	kilogram	**kg**
Temperature	kelvin	**K**
Electrical current	ampere	**A**
Amount of substance	mole	**mol**
Luminous intensity	candela	**cd**

Prefix	Meaning
mega, M	10^{6}
kilo, k	10^{3}
milli, m	10^{-3}
micro, μ	10^{-6}
nano, n	10^{-9}

Significant Figures in Measurements

- When record raw data in the laboratory, always write down both **the value** (with correct s.f.) and **the unit**
- When reading values from instruments, take all the digits on display; the last digit is the uncertain digit

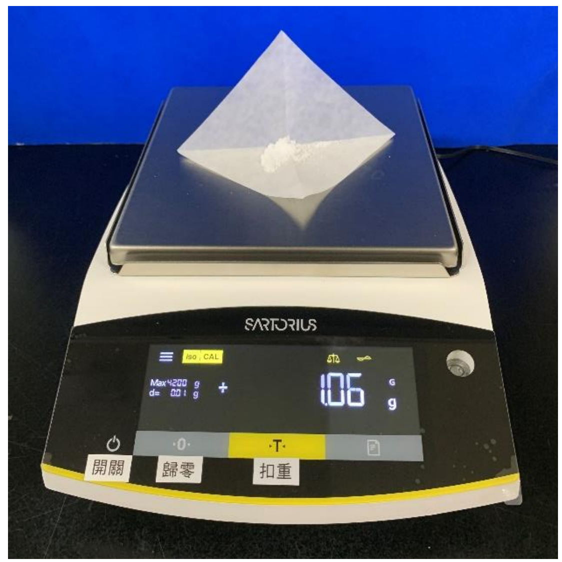
Temp.: 27.8 ºC

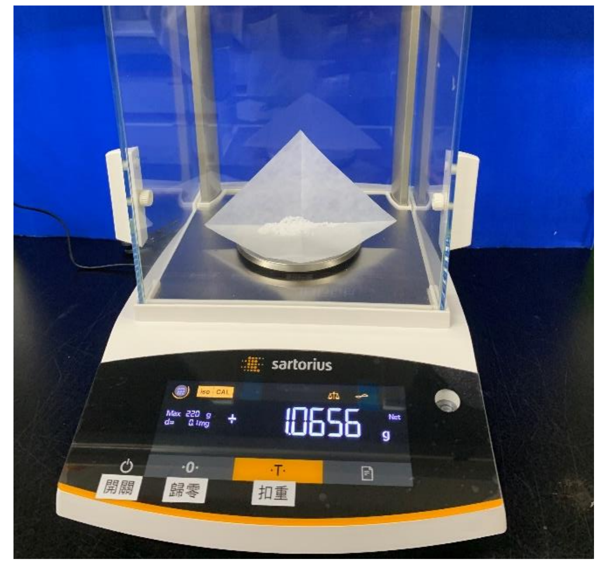
3 significant figures

Weight: 0.20 g

2 significant figures

Precision of the Instruments





Wt.: 405.26 g

± 0.01 g

Wt.: 1.06 g

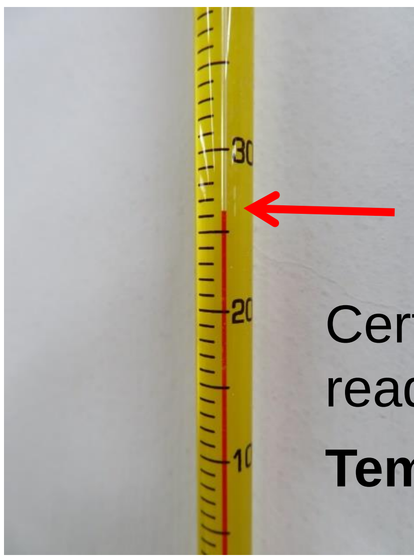
± 0.01 g

Wt.: 1.0656 g

± 0.0001 g

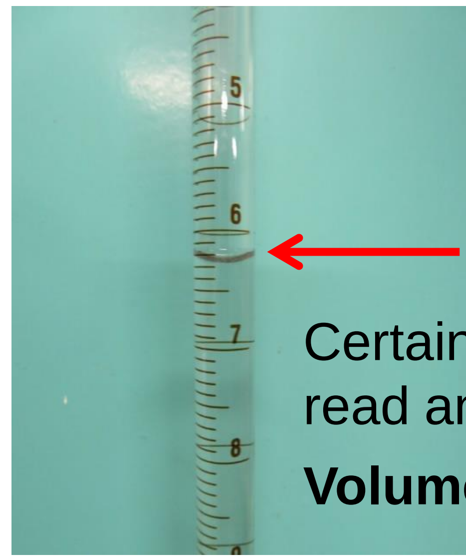
Significant Figures in Measurements

- When record raw data in the laboratory, always write down both **the value** (with correct s.f.) and **the unit**
- Leave only one uncertain digit
- The number of **significant figures** in a quantity is all of the certain digits plus the first uncertain one



Certain to 26 °C
read an uncertain digit
Temp.: 26.2 °C

3 significant figures
(2 certain + 1 uncertain)



Certain to 6.2
read an uncertain digit
Volume: 6.26 mL

3 significant figures
(2 certain + 1 uncertain)

Significant Figures in Measurements

- # of significant figures = All certain digits + one uncertain digit (estimated value)

Example: How many significant figures do the following values have?

- 21.5 ^{o}C — *3 s.f.*
- 0.02 L — *1 s.f.*
- 0.205 g — *3 s.f.*
- 0.50 M — *2 s.f.*
- 1000 mL — *? s.f.*

Rules:

1. **Disregard all initial zeros**
2. **Disregard all final zeros unless they follow a decimal point**
3. **All remaining digits including zeros between nonzero digits are significant**

Significant Figures in Measurements

- Pro tip: using scientific notation to write down values – this helps determine the significant figures easily

2500	2 significant figures	2.5×10^3
2.50×10^3	3 significant figures	2.50×10^3
2500.	4 significant figures	2.500×10^3

Significant Figures in Measurements

- Defined quantities, scientific constants, and counting numbers of objects have an <u>infinite number of s.f.</u>
  - **<u>1</u>** atm
    = 101325 Pa
    = 760 torr
    = 76 cmHg
    = 760 mmHg
  - **<u>0</u>** ^{o}C
    = 273.15 K
  - 0.2786 g x **<u>8</u>** = 2.229 g
  - Cl_2: 35.45 x 2 = 70.90

Significant Figures in Calculation

- In addition and subtraction, retain one uncertain digit in the sum or difference

1.7**5**	172.6**3**
+ 9.**1**	− 1.**3**
10.**85**	171.**33**

Ans: 10.**9**
(retain one uncertain digit
→ **three s.f.**)

Ans: 171.**3**
(retain one uncertain digit
→ **four s.f.**)

When the first discarded digit is equal or more than five (5 in this case), increase the last significant digit by 1

When the first discarded digit is less than five (3 in this case), retain the last significant digit as is

Significant Figures in Calculation

- In multiplication and division, the number of significant figures in the product or quotient equals the number in the factor with the least significant figures

$$200.\underline{1} \times 3.2\underline{1} = (642.321) = 64\underline{2}$$

4 s.f. *3 s.f.* → *3 s.f. remains*

$$22\underline{2} \times 1.\underline{1} = (244.2) = 2.\underline{4} \times 10^2$$

3 s.f. *2 s.f.* → *2 s.f. remains*

Significant Figures in Calculation

- Example: In the experiment "The Molar Volume of Nitrogen Gas"

$$V_{STP} = (P_{atm} - P_{H_2O}) \times \frac{\Delta V \times 273.15}{n_1 \times T_1}$$

four s.f. — five s.f. — defined (infinite s.f.)

$$= \frac{727.3\ mmHg}{760\ mmHg} \times \frac{0.25796\ L \times 273.15\ K}{1.0677 \times 10^{-2}\ mol \times 302.1\ K}$$

defined (infinite s.f.) — five s.f. — four s.f.

$$= 20.90\ L$$

Because the smallest number of significant figures in this multiplication/division operation is four s.f., the answer is rounded to **four s.f.**

Significant Figures in Calculation

- When taking a logarithm of a number, keep as many digits to the right of the decimal point as there are significant figures in the original number

three s.f.

$$\log(\mathbf{2.00} \times 10^4) = \log(\mathbf{2.00}) + \log(10^4)$$

$$= 0.\mathbf{301} + 4$$

$$= 4.301$$

- When taking an antilogarithm of a number, keep as many digits as there are digits to the right of the decimal point in the original number

$$pH = 8.74 = -\log[H^+]$$

$$[H^+] = \text{antilog}(-8.\mathbf{74}) = 1.819 \times 10^{-9}\ (M)$$

$$= \mathbf{1.8} \times 10^{-9}\ (M)$$ (rounded to two s.f.)

Example
Determination of Chemical Formula

Mass of empty test tube: 42.495**3** g (six s.f.)

Mass of test tube and CuO: 43.536**1** g (six s.f.)

Mass of test tube and Cu: 43.330**0** g (six s.f.)

Mass of CuO: 43.536**1** - 42.495**3** = 1.040**8** (g) (five s.f.)

Mass of Cu: 43.330**0** - 42.495**3** = 0.834**7** (g) (four s.f.)

Mass of O: 1.040**8** - 0.834**7** = 0.206**1** (g) (four s.f.)

Alternative way:

Mass of O: 43.536**1** – 43.330**0** = 0.206**1** (g) (four s.f.)

Example
Determination of Chemical Formula

If less precise atomic weights are used in calculations:

Moles of Cu: $\frac{0.8347}{63.55} = 0.01313454 = 0.01313 \text{ (mol)}$

$\frac{0.8347}{63.6} = 0.0131$

Moles of O: $\frac{0.2061}{15.99} = 0.01288931 = 0.01289 \text{ (mol)}$

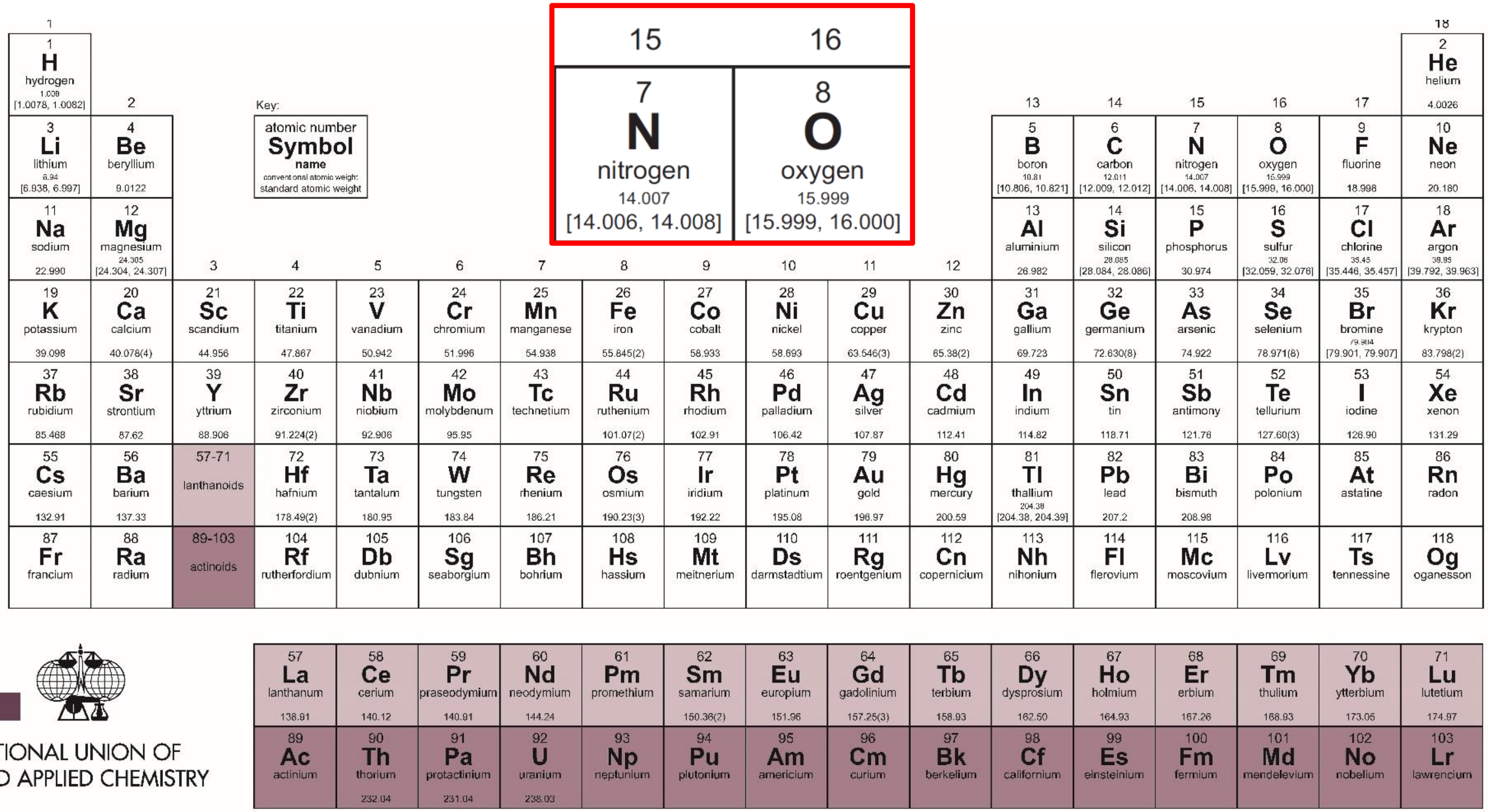
$\frac{0.2061}{16} = 0.013$

Cu : O = 0.01313 : 0.01289

= 1.000 : 0.9817

= 1.019 : 1.000

Periodic Table (IUPAC dated 1 Dec 2018)



INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2018.

United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

IUPAC

- The square brackets inform the lower and upper bounds of the standard atomic weight of that element

Example
Molar Volume of Nitrogen Gas

Raw Measurement Results:

- Mass of H_2NSO_3H: 1.0725 g **(five s.f.)**
- Molecular weight of H_2NSO_3H: 97.10 g/mol
- R.T.: 28.0 ºC **(thermometer, three s.f.)**
- P_{H_2O}: 28.3 mmHg **(appendix, three s.f.)**
- P_{atm}: 76.57 cmHg **(barometer, four s.f.)**
- Mass of beaker: 154.66 g **(five s.f.)**
- Mass of beaker and water collected: 418.13 g **(five s.f.)**

1. Use the formula weight written in the prelab

   OR

2. Calculate by adding the atomic weights from the periodic table in the Appendix

   e.g. (1.008 x 3) + (14.01 x 1) + (32.07 x 1) + (16.00 x 3) = 97.10

Use the equation provided in lab manual:

$$\frac{1(atm) \times V_{STP}(L)}{1(mol) \times 273.15(K)} = \frac{P_{N_2} \times V_1}{n_1 \times T_1} = \frac{\left(P_{atm} - P_{H_2O}\right) \times \Delta V}{n_1 \times T_1}$$

Example
Molar Volume of Nitrogen Gas

- n_1 = 1.0725 / 97.10 = 0.011045314109 (mol) **(four s.f.)**
- T_1 = 28.0 + 273.15 **(infinite s.f.)** = 301.15 (K) **(four s.f.)**
- $P_{atm} - P_{H_2O}$ = 765.7 - 28.3 = 737.4 (mmHg) **(four s.f.)**
- 1 atm = 760 mmHg **(infinite s.f.)**
- ΔV：418.13-154.66 = 263.47 g ÷ 1 g/mL

  = 263.47 mL = 0.26347 L **(five s.f.)**

Tips:

1. Do the **rounding** only after all calculation steps are completed
2. Carry at least **one extra digit** beyond the significant figures through all of the calculation steps in order to avoid **rounding errors**

$$V_{STP} = \frac{\left(\frac{737.4}{760}\right) \times 0.26347}{0.01104_5 \times 301.1_5} \times 273.15 = 20.99294 = 20.99\ (\mathrm{L})$$

(four s.f.)

Example
Molar Volume of Nitrogen Gas

- n_1 = 1.072$\underline{5}$ / 97.1$\underline{0}$ = 0.0110$\underline{45314109}$ (mol) **(four s.f.)**
- T_1 = 28.$\underline{0}$ + 273.15 **(infinite s.f.)** = 301.$\underline{15}$ (K) **(four s.f.)**
- $P_{atm} - P_{H_2O}$ = 1.00$\underline{8}$ – 0.037$\underline{2}$ = 0.97$\underline{08}$ (atm) **(three s.f.)**
- 1 atm = 760 mmHg **(infinite s.f.)**
- ΔV：418.1$\underline{3}$-154.6$\underline{6}$ = 263.4$\underline{7}$ g ÷ 1 g/mL

  = 263.4$\underline{7}$ mL = 0.2634$\underline{7}$ L **(five s.f.)**

If P_{atm} and P_{H2O} are converted to atm unit first → Still correct but s.f. is different

Tips:
1. Do the **rounding** only after all calculation steps are completed
2. Carry at least **one extra digit** beyond the significant figures through all of the calculation steps in order to avoid **rounding errors**

$$V_{STP} = \frac{0.9708 \times 0.26347}{0.011045 \times 301.15} \times 273.15 = 21.\mathbf{00455844} = 21.\mathbf{0}\ (L)$$

(three s.f.)

Prelab Exercise: Principles

Experiments 5 and 6

QUALITATIVE ANALYSIS OF CATIONS

Objective

The purpose of this experiment is to learn the techniques to separate and identify some common cations, and to understand the principles for the equilibria of precipitation and complex formation.

Lab techniques

- Using litmus and universal indicator paper.
- Operating of the centrifuge.

Introduction

Analysis of the identity and quantity o
samples is an integral part of chemical rese
analytical instruments (such as the atomic abs
cations were analyzed with a simple method in
and basic instruments, as well as the applica
precipitation, dissolution, and complex formatic
of cations covers a very wide range of fields, in
and materials research. In this experiment, stud
and procedures for separating and identifying c
usually consists of three stages. First, based on
cations are separated into 5 groups through
precipitating reagents. Second, within each gro
through selective dissolution processes. Last, tl
through different identification tests. The catio
groups:

Group 1 cations (Hg_2^{2+}, Ag^+, and Pb^{2+}; insolul

Among the common metallic cations,
insoluble chlorides with hydrochloric acid. Wh
white precipitates of Hg_2Cl_2, AgCl and PbCl
remain in solution.

Introduce relevant theories and chemical reactions concisely (less than one page)

- Objective
  1. Learn how to seperate and identify cations
  2. Understand the equilibria of precipitation & complex formation

- Principles
  1. All of the common cations are separated into 5 groups, and by adding selective precipitating agents we can know which group the cations belong to.
  2. Within each group, we have special techniques respectively to seperate each group member and thus know what exactly the cations are.
  3. In the 1 Group, there is precipitation of Hg_2Cl_2, AgCl, $PbCl_2$. We separate $PbCl_2$ by add hot water (Using it high solubility in hot water), and then separate Hg_2Cl_2 and AgCl by adding ammonia water:

$$AgCl(s) + 2NH_3(aq) \rightarrow Ag(NH_3)_2^+(aq) + Cl^-(aq) \quad \text{(dissolved)}$$

$$Hg_2Cl_2(s) + 2NH_3(aq) \rightarrow Hg(l) + HgNH_2Cl(s)\downarrow + NH_4^+(aq) + Cl^-(aq)$$

(black)

Prelab Exercise: Chemicals

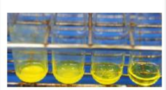
Include English names, chemical formulas, molecular/formula weights, physical properties (density, m.p./b.p., appearance), and chemical properties, and toxicities

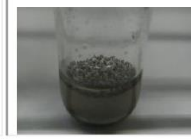
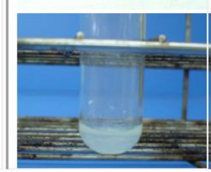
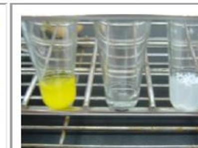
• Chemicals:

Name	Formula	Formula wt.	density (g/cm^3)	b.p./m.p. (℃)	Solubility	Appearance	Toxicity
mercury (I) nitrate dihydrate	$Hg_2(NO_3)_2 \cdot 2H_2O$	561.22	4.78	−/70	13 (parts H_2O)	colorless crystal	Fatal if swallowed, inhaled or in contact with skin
silver nitrate	$AgNO_3$	169.87	4.352	−/212	2.16×10^2 ($g/100g\ H_2O$)	colorless rhombic crystal	Fatal if swallowed, causes serious skin burn and eye damage
lead (II) nitrate	$Pb(NO_3)_2$	331.21	4.53	−/470	Soluble	white/colorless translucent crystals	Causes eye, skin irritation
Hydrochloric acid (6M)	$HCl_{(aq)}$	36.46	−	−/−	67.3 (30°) ($g/100g\ H_2O$)	clear colorless liquid	Causes serious skin burn, eye damage, may cause respiratory irritation

- Tabulate the content (can use two rows for each chemical)
- Indicate the sources (Wikipedia is often not the most correct source)
- Write N/A (not available) if a chemical has no toxicity data (though almost all chemicals are irritating to skin/eyes to an extent)
- Molecular/formula weights should have at least four significant figures

Prelab Exercise: Procedures

	Note 2: Do not add excess hydrochloric acid; it may dissolve the chlorides; 2~3 drops are enough.	
	3. Centrifuge and decant the supernatant into another centrifuge tube (solution 1-1). The residue is precipitate 1-1. Add one drop of hydrochloric acid to solution 1-1 to check whether the precipitation is complete. Note: Refer to the experimental ski[illegible]deos to [illegible]n how to operate a centrifuge.	
	4[illegible]pare a rinsing solution by d[illegible] 1 drop of 6 [illegible]Cl with 10 drops of [illegible]ater. Use this so[illegible] to rinse precipita[illegible]. Centrifuge and deca[illegible] supernatant i[illegible]ution 1-1.	
1-2	Add 5 dr[illegible] DI water[illegible]ecipitate 1-1. Stir the mixture in [illegible]ling [illegible] bath for several min. Centrifuge the[illegible]n as soon as possible, and transfer the sup[illegible] (solution 1-2) into another centrifuge tube[illegible] Note: If the[illegible] de[illegible]fore centrifugation such that the [illegible]on co[illegible]own, $PbCl_2(s)$ may precipit[illegible]in.	
	1. A[illegible]drop of 6 M CH[illegible]H and 1 drop of [illegible]M K_2CrO_4 to solut[illegible]-2. A yellow [illegible]cipitate indicates the prese[illegible]f Pb^{2+}. [illegible]e: Addition of CH_3COOH [illegible]ents the [illegible]ecipitation of other chromates, suc[illegible]$CuCrO_4$ ($K_{sp} = 2.8\times10^{-13}$) or $(BiO)_2CrO_4$ (K_{sp} = 3.[illegible])	
	2. Extract precipitate 1-1 with hot water f[illegible]owed by centrifugation (step 1-2) for 2~3 times until it is Pb-free. Test the supernatant with K_2CrO_4. The remaining solid is precipitate 1-2. Note: If Pb^{2+} is not completely removed, that will affect the results of subsequent tests.	

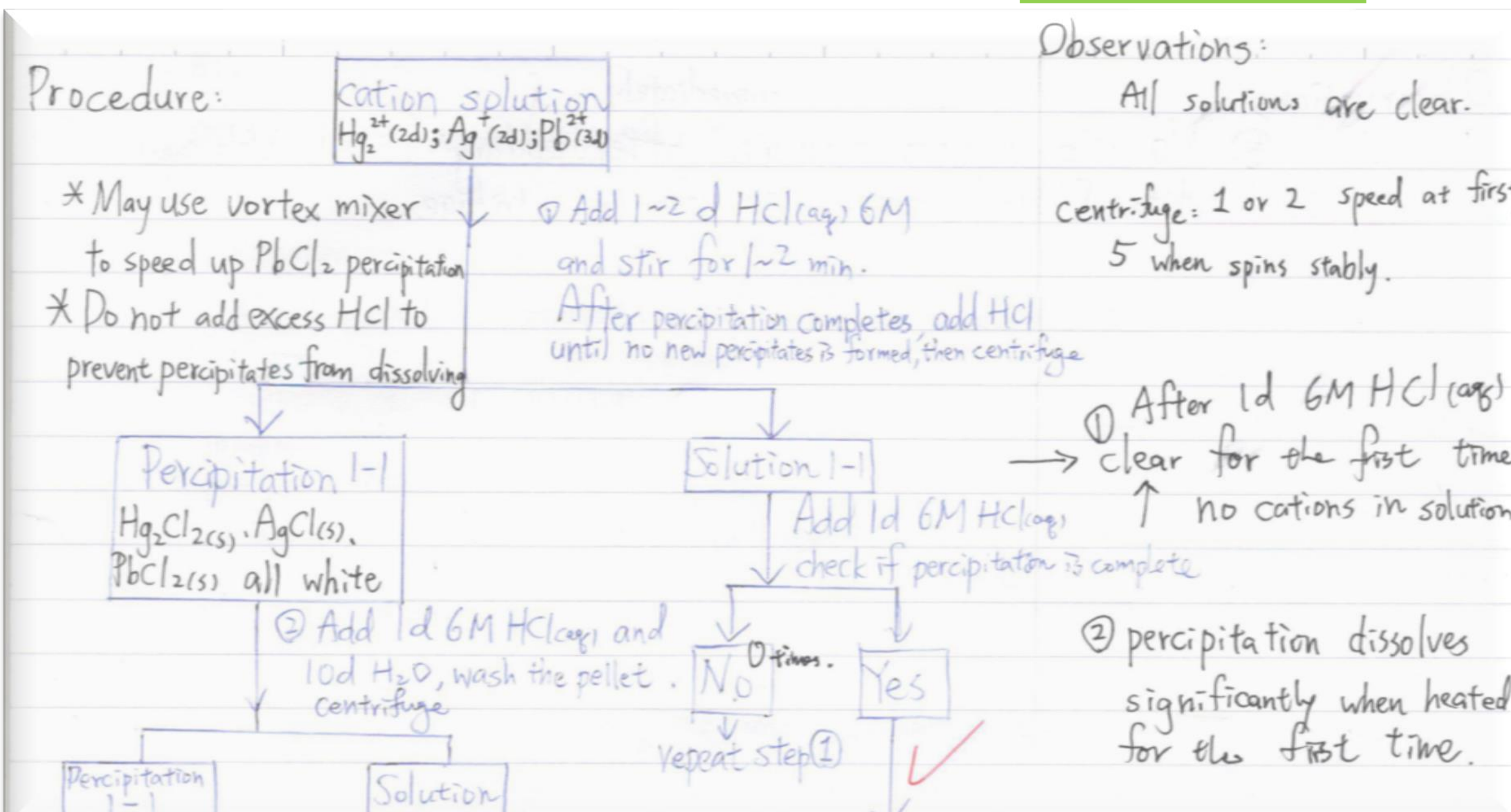
1-4	1. Add 2~4 drops of concentrated ammonia water (15 M) to precipitate 1-2. Disperse the precipitate with a glass rod.	 
	2. Ce[illegible]ge, transfer the superna[illegible] (solution 1-3) i[illegible] clean centrifuge tu[illegible]nd examine the colo[illegible] the residue (prec[illegible]e 1-3). Black residue i[illegible]es the pre[illegible]e of Hg(*l*) and $HgNH_2Cl(s)$[illegible]ture. Note: If precipita[illegible]2 is[illegible] Pb-free, it produces white $Pb(OH)_2(s)$ p[illegible]e after adding 15 M ammonia water.	
1-5	Acidify solution[illegible] by [illegible]ing 6 M HNO_3. Observe any[illegible]ange tha[illegible]curs. A white precipitate p[illegible] the presence [illegible]. Note: Mi[illegible] solution thoroughly [illegible] adding the acid. U[illegible] glass rod to spot the solut[illegible]n a piece of lit[illegible] paper to test the acidity.	 
1-6	1. Keep and present the identification products to lab instructor when finishing the experiment. 2. The liquid waste containing heavy metals should be collected and discarded into the recycling container.	

Do not copy the procedures from the lab manual as it is

Prelab Exercise: Procedures

Use flow chart and cartoon to explain the crucial operations in this experiment

Procedures **Observations**



Final Report (Brief Version)

- Five experiments for this semester (E1, E2, E3, E6, E7)
- Complete the data analysis, calculation and conclusion part in the lab manual (not including the Questions and Discussion)
- Hand in the report at the end of the class together with the prelab and lab records

Experiment 2

DETERMINATION OF THE CHEMICAL FORMULA OF A COMPOUND

I. Experimental Data and Results (show all calculations)

1. Weight of empty large test tube (W_1) ____________
2. Weight of test tube and copper oxide (W_2) ____________
3. Weight of copper oxide ($W_2 - W_1$) ____________
4. Weight of test tube and copper (W_3) ____________
5. Weight of copper ($W_3 - W_1$) ____________
6. Weight of oxygen ($W_2 - W_3$) ____________
7. Empirical formula of copper oxide ____________

II. Conclusion

____

____

- 35 points per experiment
- 5 pts deduction for late submission within one week
- 0 points for reports handed in more than one week late

Final Report (Brief Version)

I. Prelab exercise

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

II. Lab Notes

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

III. Final report

- ✓ Data analysis
- ✓ Conclusion
- ~~✓ Questions and discussion~~

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

Final Report (Full Version)

- Four experiments for this semester (E5, 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
- ✓ Conclusion
- ~~✓ Questions and discussion~~

15 pts + 10 pts + 25 pts

Experimental Error Analysis

$$Error = \frac{Exp.value\ - theo.value}{theo.value} \times 100\%$$

- ✓ Positive or negative deviation
- ✓ Possible causes of deviation
- ✓ Give the conclusion depending on your experimental results

Error analysis and conclusions

Data analysis and error analysis

We have to calculate the theoretical value of each exp first.

By the Hess' law, we have: $\Delta H^\circ_{rxn} = \sum_n n \Delta H_f^0 \text{ product} - \sum_n n \Delta H_f^0 \text{ reactants}$ with n being the stoichiometric coefficients and ΔH_f° being the enthalpy of formation.

exp	ΔH_f° of each compound (kJ/mol)	theoretical value of ΔH°_{rxn} (kJ/mol)
2. $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$	(-167.15, -469.15, -407.27, -285.830)	[(-407.27)+(-285.830)] - [(-167.15)+(-469.15)] = -56.8
3. $CH_3COOH_{(aq)} + NaOH_{(aq)} \rightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$	(-486.34, -469.15, -726.13, -285.830)	[(-726.13)+(-285.830)] - [(-486.34)+(-469.15)] = -56.4
4. $NH_4Cl_{(s)} \rightarrow NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$	(-314.5, -133.26, -167.08)	[(-133.26)+(-167.08)] - (-314.5) = 14.16
5-1. $Mg_{(s)} + 2H^+{}_{(aq)} \rightarrow Mg^{2+}{}_{(aq)} + H_{2(g)}$	(0, 0, -467.0, 0)	-467.0 ✓
5-2. $MgO_{(s)} + 2H^+{}_{(aq)} \rightarrow Mg^{2+}{}_{(aq)} + H_2O_{(l)}$	(-601.6, 0, -467.0, -285.830)	[(-285.830)+(-467.0)] - (-601.6) = -151.2 ✓
5-3. $Mg_{(s)} + \frac{1}{2}O_2 \rightarrow MgO_{(s)}$	(0, 0, -601.6)	-601.6 ✓

Ref: Lange's Handbook of Chemistry - Fifteen Edition

Good to sh[ow] detai[l]

Compare the theoretical value of ΔH°_{rxn} with the expirimental value and calculate its relative error: $\frac{\text{Absolute Error}}{\text{Actual Value}} = \frac{\text{Measured value} - \text{expected value}}{\text{Actual value}}$ (expressed in %)

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, units, and conclusion sentences	5
	8. Plot the results with correct XY axes and labeling*	***5***
	9. Analyze the results with appropriate error discussions*	***5***
	10. Elaborate findings and provide constructive suggestions*	***5***

***Only for full reports**