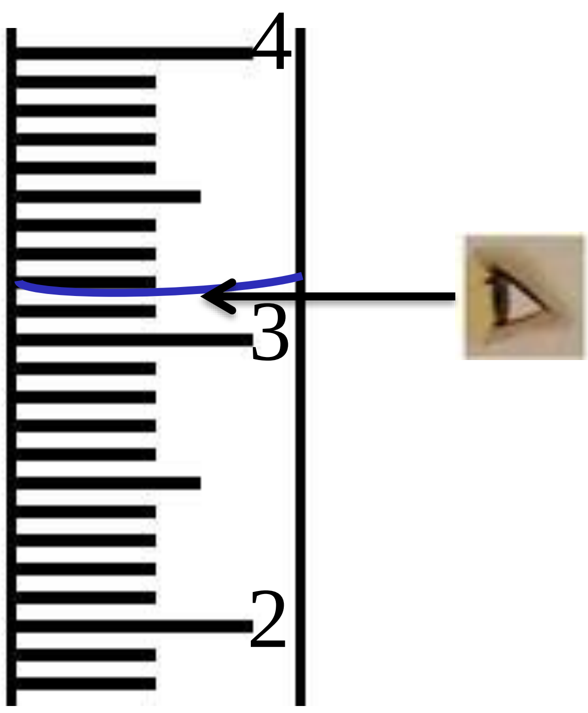
Guidelines for Lab Reports

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

Last revised: 2022/10/15

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**

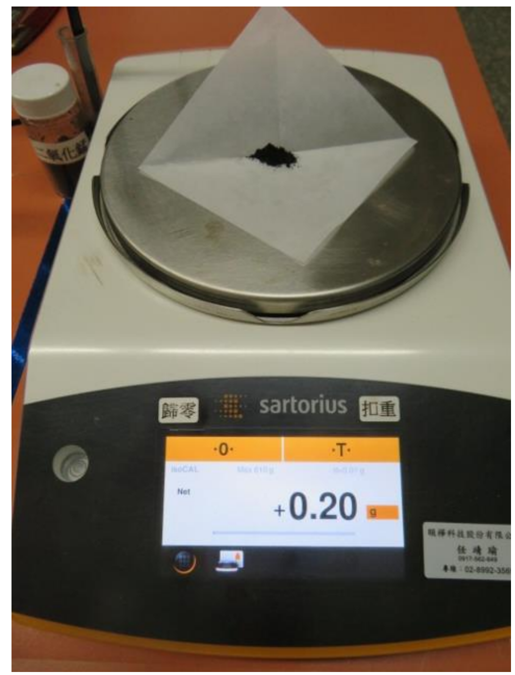
Prefix	Meaning
milli, m	10^{-3}
nano, n	10^{-9}
micro, μ	10^{-6}
mega, M	10^{6}

Significant Figures in Measurements

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

Temp.: 27.<u>8</u> ^{o}C

3 significant figures



Weight: 0.2<u>0</u> g

2 significant figures

Precision of the Instruments

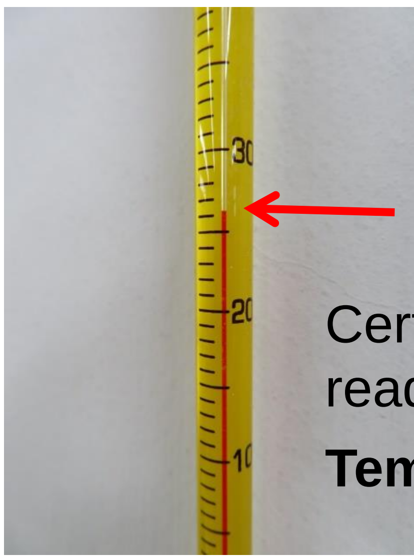
Wt.: 405.26 g — **± 0.01 g**

Wt.: 0.20 g — **± 0.01 g**

Wt.: 0.1439 g — **± 0.0001 g**

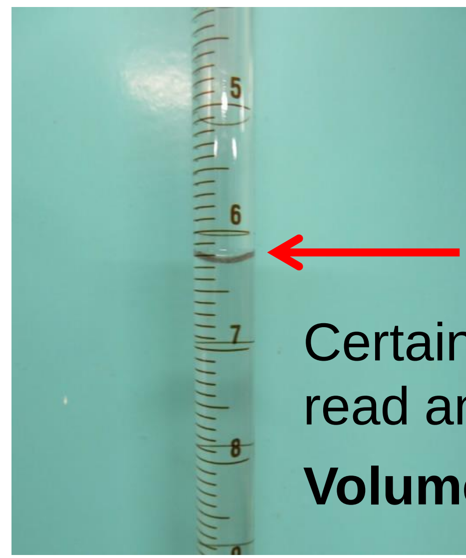
Significant Figures in Measurements

- 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 ^oC
read an uncertain digit
Temp.: 26.2 ^oC

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 infinite number of s.f.

- **1** atm
  = 101325 Pa
  = 760 torr
  = 76 cmHg
  = 760 mmHg

- **0** ^{o}C
  = 273.15 K

- 0.2786 g x **8** = 2.229 g

Significant Figures in Calculation

- In <u>addition and subtraction</u>, retain one uncertain digit in the sum or difference

$$\begin{array}{rr} & 1.7\underline{\mathbf{5}} \\ + & 9.\underline{\mathbf{1}} \\ \hline & 10.\underline{\mathbf{85}} \end{array} \qquad \begin{array}{rr} & 172.6\underline{\mathbf{3}} \\ - & 1.\underline{\mathbf{3}} \\ \hline & 171.\underline{\mathbf{33}} \end{array}$$

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

Ans: 171.<u>**3**</u>
(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

200.1 x 3.21 = (642.321) = 642

4 s.f. *3 s.f.* → *3 s.f. remains*

222 x 1.1 = (244.2) = 2.4 x 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"

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

$$= \frac{\overset{\text{four s.f.}}{727.3\ mmHg}}{\underset{\text{defined (infinite s.f.)}}{760\ mmHg}} \times \frac{\overset{\text{five s.f.}}{0.25796\ L} \times \overset{\text{defined (infinite s.f.)}}{273.15\ K}}{\underset{\text{five s.f.}}{1.0677 \times 10^{-2}\ mol} \times \underset{\text{four s.f.}}{302.1\ K}}$$

$$= 20.90\ L$$

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.

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

$$= 0.\mathbf{301} + (4.00000\ldots)$$

$$= 4.301$$

- 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

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

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

$$= \mathbf{1.8} \times 10^{-9}\ (M)$$ (round to the first decimal place)

E1: 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.)

E1: Determination of Chemical Formula

If less precise atomic weights are used in calculations:

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

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

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

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

Cu : O = 0.01313 : 0.01289

= 1.000 : 0.9817

Periodic Table (IUPAC dated 1 Dec 2018)

15	16
7 **N** nitrogen 14.007 [14.006, 14.008]	8 **O** oxygen 15.999 [15.999, 16.000]

Key:

atomic number **Symbol** **name** conventional atomic weight standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** hydrogen 1.008 [1.0078, 1.0082]																	2 **He** helium 4.0026
3 **Li** lithium 6.94 [6.938, 6.997]	4 **Be** beryllium 9.0122											5 **B** boron 10.81 [10.806, 10.821]	6 **C** carbon 12.011 [12.009, 12.012]	7 **N** nitrogen 14.007 [14.006, 14.008]	8 **O** oxygen 15.999 [15.999, 16.000]	9 **F** fluorine 18.998	10 **Ne** neon 20.180
11 **Na** sodium 22.990	12 **Mg** magnesium 24.305 [24.304, 24.307]											13 **Al** aluminium 26.982	14 **Si** silicon 28.085 [28.084, 28.086]	15 **P** phosphorus 30.974	16 **S** sulfur 32.06 [32.059, 32.076]	17 **Cl** chlorine 35.45 [35.446, 35.457]	18 **Ar** argon 39.95 [39.792, 39.963]
19 **K** potassium 39.098	20 **Ca** calcium 40.078(4)	21 **Sc** scandium 44.956	22 **Ti** titanium 47.867	23 **V** vanadium 50.942	24 **Cr** chromium 51.996	25 **Mn** manganese 54.938	26 **Fe** iron 55.845(2)	27 **Co** cobalt 58.933	28 **Ni** nickel 58.693	29 **Cu** copper 63.546(3)	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.723	32 **Ge** germanium 72.630(8)	33 **As** arsenic 74.922	34 **Se** selenium 78.971(8)	35 **Br** bromine 79.904 [79.901, 79.907]	36 **Kr** krypton 83.798(2)
37 **Rb** rubidium 85.468	38 **Sr** strontium 87.62	39 **Y** yttrium 88.906	40 **Zr** zirconium 91.224(2)	41 **Nb** niobium 92.906	42 **Mo** molybdenum 95.95	43 **Tc** technetium	44 **Ru** ruthenium 101.07(2)	45 **Rh** rhodium 102.91	46 **Pd** palladium 106.42	47 **Ag** silver 107.87	48 **Cd** cadmium 112.41	49 **In** indium 114.82	50 **Sn** tin 118.71	51 **Sb** antimony 121.76	52 **Te** tellurium 127.60(3)	53 **I** iodine 126.90	54 **Xe** xenon 131.29
55 **Cs** caesium 132.91	56 **Ba** barium 137.33	57-71 lanthanoids	72 **Hf** hafnium 178.49(2)	73 **Ta** tantalum 180.95	74 **W** tungsten 183.84	75 **Re** rhenium 186.21	76 **Os** osmium 190.23(3)	77 **Ir** iridium 192.22	78 **Pt** platinum 195.08	79 **Au** gold 196.97	80 **Hg** mercury 200.59	81 **Tl** thallium 204.38 [204.38, 204.39]	82 **Pb** lead 207.2	83 **Bi** bismuth 208.98	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** radium	89-103 actinoids	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium	113 **Nh** nihonium	114 **Fl** flerovium	115 **Mc** moscovium	116 **Lv** livermorium	117 **Ts** tennessine	118 **Og** oganesson

57 **La** lanthanum 138.91	58 **Ce** cerium 140.12	59 **Pr** praseodymium 140.91	60 **Nd** neodymium 144.24	61 **Pm** promethium	62 **Sm** samarium 150.36(2)	63 **Eu** europium 151.96	64 **Gd** gadolinium 157.25(3)	65 **Tb** terbium 158.93	66 **Dy** dysprosium 162.50	67 **Ho** holmium 164.93	68 **Er** erbium 167.26	69 **Tm** thulium 168.93	70 **Yb** ytterbium 173.05	71 **Lu** lutetium 174.97
89 **Ac** actinium	90 **Th** thorium 232.04	91 **Pa** protactinium 231.04	92 **U** uranium 238.03	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

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

International Year
of the Periodic Table
of Chemical Elements

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

E2: Molar Volume of Nitrogen Gas

Raw Measurement Results:

- Mass of H_2NSO_3H: 1.072<u>5</u> g **(five s.f.)**
- Molecular weight of H_2NSO_3H: 97.1<u>0</u> g/mol
- R.T.: 28.<u>0</u> ^oC **(thermometer, three s.f.)**
- P_{H_2O}: 28.<u>3</u> mmHg **(appendix, three s.f.)**
- P_{atm}: 76.5<u>7</u> cmHg **(barometer, four s.f.)**
- Mass of beaker: 154.6<u>6</u> g **(five s.f.)**
- Mass of beaker and water collected: 418.1<u>3</u> 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) = 97.1<u>0</u>

Use the equation provided in lab manual:

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

E2: 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**

$$V_{STP} = \frac{\left(\frac{737.4}{760}\right) \times 0.26347}{0.011045 \times 301.15} \times 273.15 = 20.99294 = 20.99\ (\text{L})$$

(four s.f.)

E2: 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.)**
- $P_{atm} - P_{H_2O} = 1.008 - 0.0372 = 0.9708$ (atm) **(three 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.)**

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 33

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, stuc
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 $PbCl_2$
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:

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

$$Hg_2Cl_2(s) + 2NH_3(aq) \rightarrow Hg(l) + \underset{\text{(black)}}{HgN_2Cl(s)\downarrow} + NH_4^+(aq) + Cl^-(aq)$$

Prelab Exercise: Chemicals

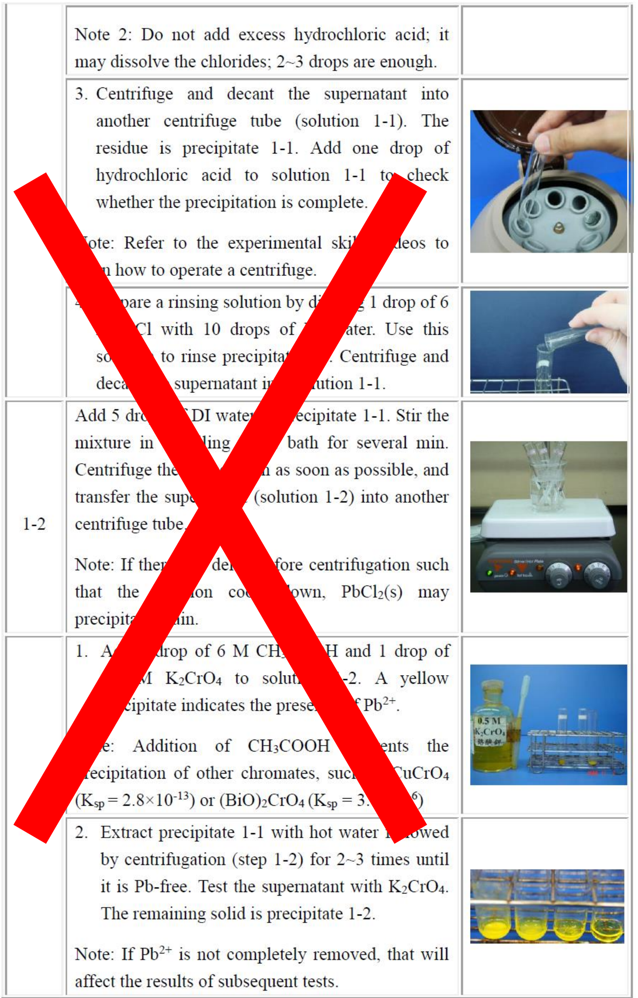
Include English names, chemical formulas, molecular/formula weights, physical properties (density, m.p./b.p., appearance), and chemical properties (esp. toxicities)

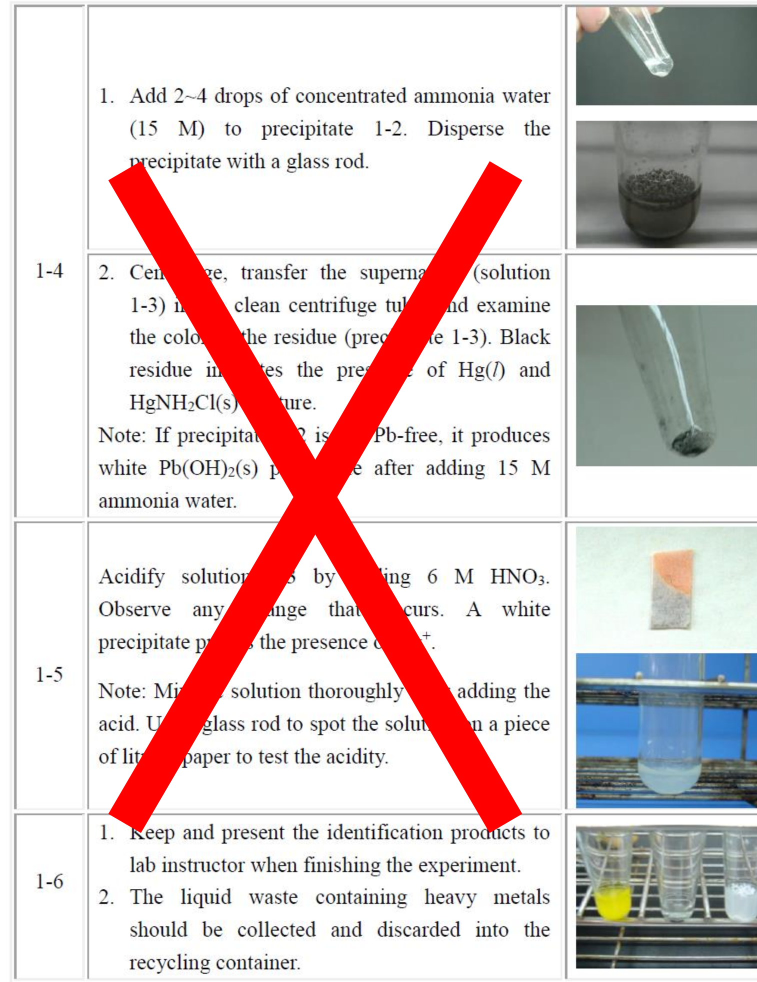
• Chemicals:

Name	Formula	Formula wt.	density (g/cm³)	b.p./m.p. (°C)	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 NA (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



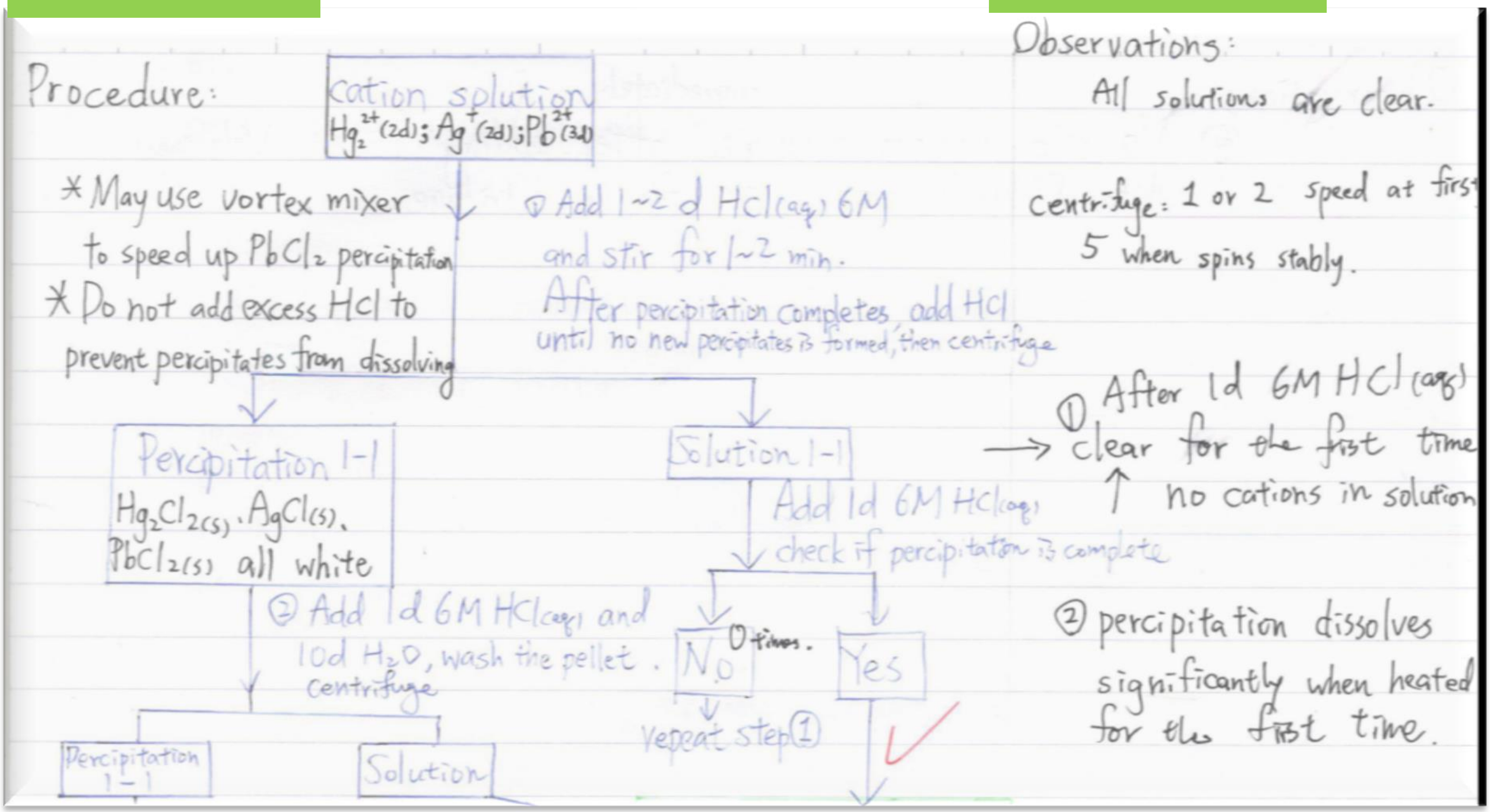


Do not copy the procedures from the lab manual as it is

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, E4, E5, E7)
- Complete the data analysis and calculation 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

Name: ____________________ Student ID: ____________________
Department: ________________ Group No.:__________ Date: __________

Experiment 1

DETERMINING THE CHEMICAL FORMULA OF A COMPOUND

I. Experimental Results (list all calculations)

1. Weight of empty 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 ____________________

- 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
- ~~✓ Questions and discussion~~

15 pts + 10 pts + 10 pts

Final Report (Full Version)

- Four experiments for this semester (E3, E8, E10, E13)
- 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**

Experimental Error Analysis

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

誤差討論：

誤差討論：可針對實驗誤差做合理的討論。

本實驗誤差 $\frac{21.6-22.4}{22.4} \times 100\% = -3.57\%$（負偏差）

Positive or negative deviation in your result

造成本實驗負偏差的原因：

統漏氣 → 排開水量少（但本組未在實驗中觀察到漏氣，故排除此因）

$_2NSO_3H$ 稱重誤差 → H_2NSO_3H 在稱後，可能因拿取時不當，造成部分 H_2NSO_3H 損失，故高估實際反應量，造成負偏差。

③ 反應不完全：若反應不完全，則會低估排開水量

測量 ΔV 之誤差。

Possible causes of negative deviation

Rule out certain possible cause based on the acutal procedures or observations

若實驗結果為正偏差，可能原因有：

① NO_2 的影響：若 NO_2 沒有完全溶於 H_2O，則可能造成 ΔV 較大造成正偏差。

② 溫壓未回復：高溫時，氣体体積大，造成 ΔV 大而產生正偏差。

③ H_2NSO_3H 誤差：若天平未校準，則可能造成 H_2NSO_3H 在稱重時低估其重量而造成正偏差。

Possible causes of positive deviation

Discuss other potential sources of error even though they may lead to positive deviation

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*