General Chemistry

Chapter 3

Chapter 3 Stoichiometry

p1

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§ 3.1 Atomic Masses

1961 Modern System of Atomic Masses Established

^{12}C is assigned a mass of exactly 12 atomic mass units (amu), and the masses of all other atoms are given relative to the standard.

The most accurate method currently available :

mass Spectrometer 質譜儀

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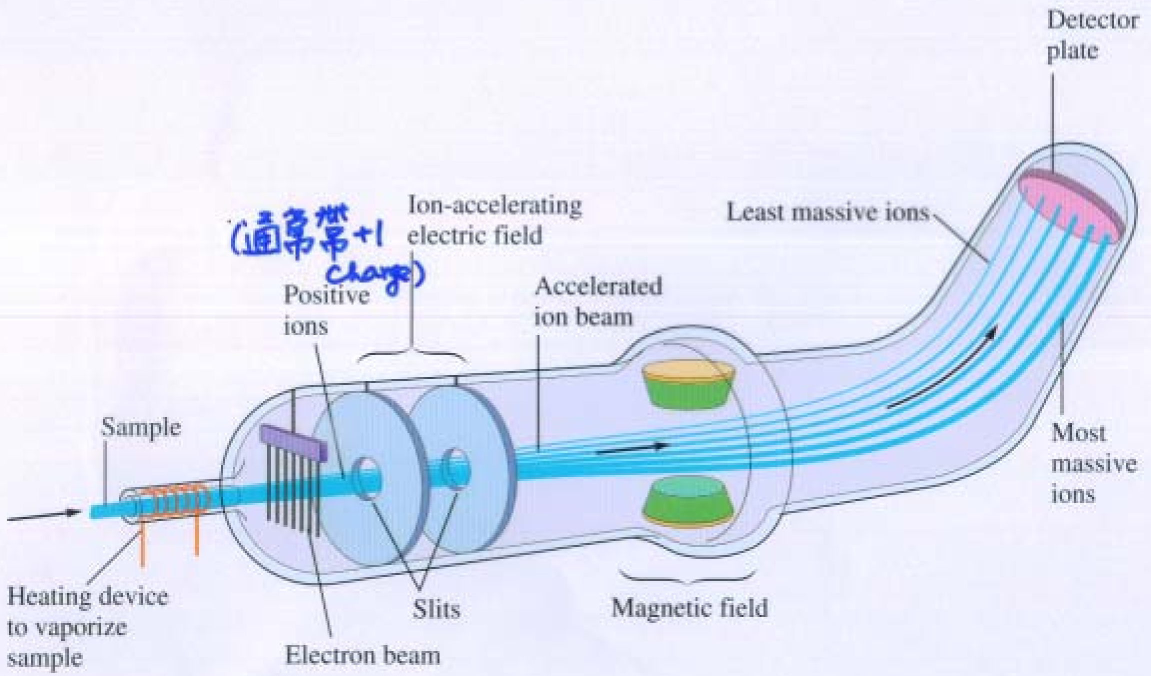
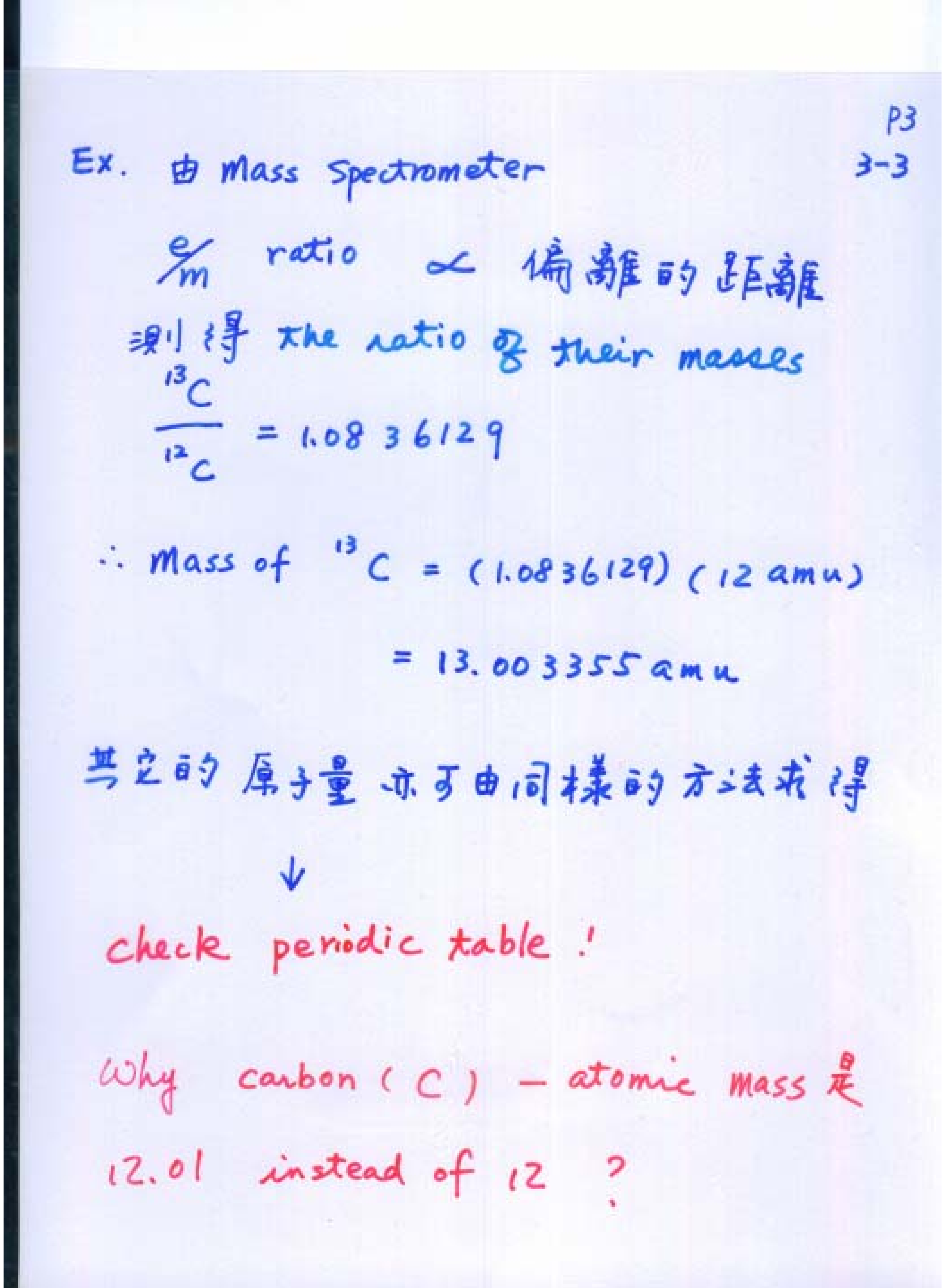


Zumdahl CHEMISTRY Fifth Edition
18 3.1 Diagram of a mass spectrometer



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Ex. 由 Mass Spectrometer

e/m ratio $\propto$ 偏離的距離

測得 the ratio of their masses

$$\frac{^{13}C}{^{12}C} = 1.0836129$$

$\therefore$ Mass of $^{13}C = (1.0836129)(12 \text{ amu})$

$= 13.003355 \text{ amu}$

其它的原子量亦可由同樣的方法求得

↓

check periodic table !

Why carbon (C) – atomic mass 是 12.01 instead of 12 ?

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Natural carbon :

98.89 % ^{12}C

1.11 % ^{13}C

∴ Average atomic mass :

98.89% · 12 amu + 1.11% · 13.0034 amu

= 12.01 amu

例题 3.1

Fig. 3.2 : Neon gas

62.93

~~63~~ amu × 69.09%

64.93

+ ~~65~~ amu × 30.91%

= ~~63.62~~ amu

63.55

§ 3.2 The Mole

Mole : the number equal to the number of carbon atoms in exactly 12 grams of pure ^{12}C.

6.02214×10^{23}

Avogadro's number

$$amu = \frac{1\,g}{6.022 \times 10^{23} (個\ atom)} = 1.670 \times 10^{-24}\,g$$

Ex. 3.2. 6 個 Americium 原子的重量

Americium

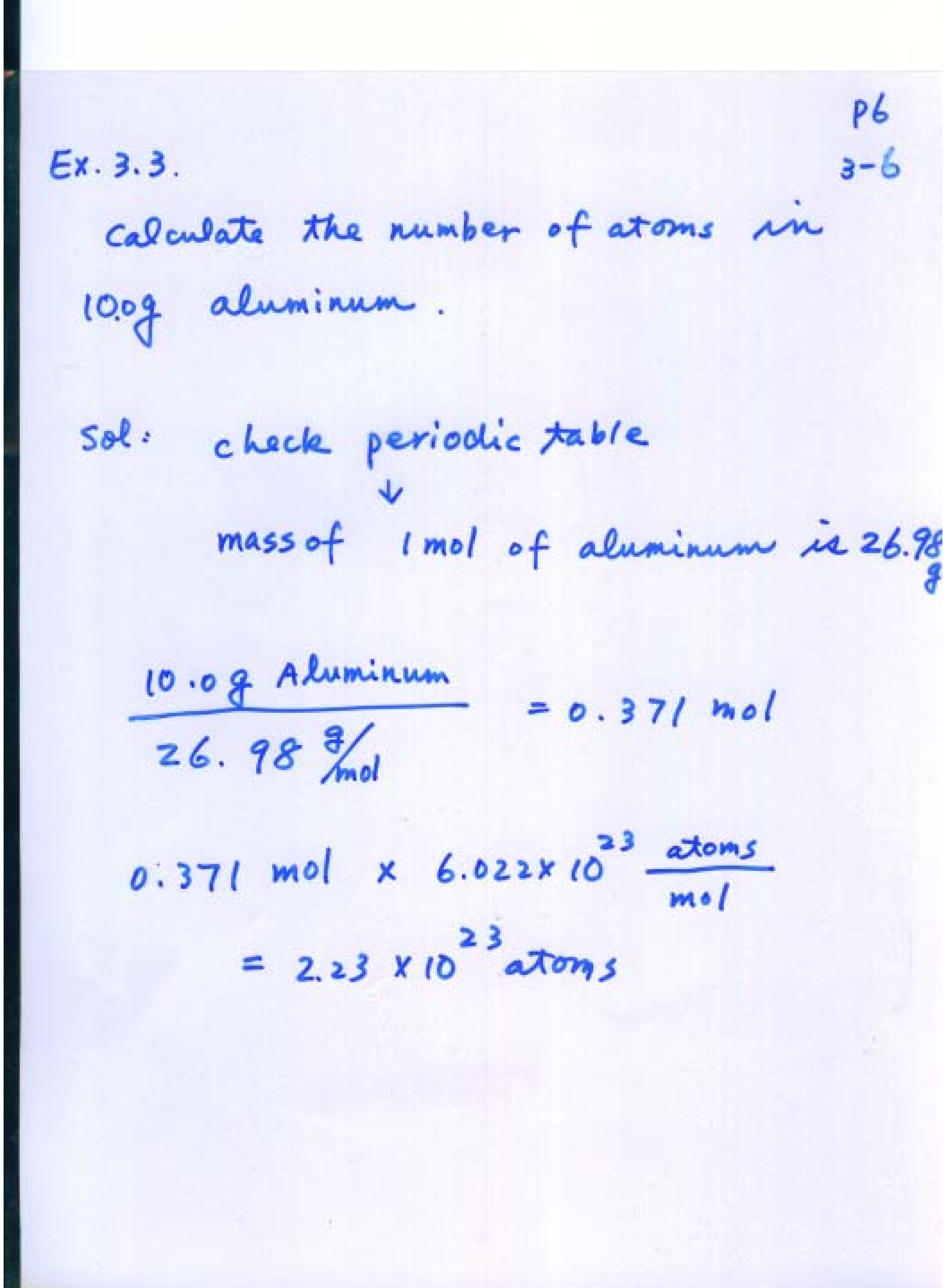
↓

check periodic table

1 Am = 243 amu

$$6\ atoms = 6 \times 243\ amu$$

$$= \underset{1458}{\cancel{1.46 \times 10^{2}}}\ amu = 2.42 \times 10^{-21}\,g$$



Ex. 3.3.

Calculate the number of atoms in 10.0g aluminum.

Sol: check periodic table

↓

mass of 1 mol of aluminum is 26.98 g

$$\frac{10.0\,\text{g Aluminum}}{26.98\,\text{g/mol}} = 0.371\ \text{mol}$$

$$0.371\ \text{mol} \times 6.022 \times 10^{23}\ \frac{\text{atoms}}{\text{mol}}$$

$$= 2.23 \times 10^{23}\ \text{atoms}$$

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Ex. 3.4 & Ex 3.5

silicon chip 5.68 mg = ? atoms

5.00×10^{20} Co atoms = ? mol

= ? g

Sol∵ (3.4)

$$5.68 \text{ mg} = 5.68 \times 10^{-3} \text{ g}$$

$$5.68 \times 10^{-3} \text{ g} \times \frac{1 \text{ mol}}{28.09 \text{ g}} = 2.02 \times 10^{-4} \text{ mol}$$

$$2.02 \times 10^{-4} \text{ mol} \times 6.022 \times 10^{23} \frac{\text{atoms}}{\text{mol}}$$

$$= 1.22 \times 10^{20} \text{ atoms}$$

(3.5)

$$5.00 \times 10^{20} \text{ atoms} \times \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ atoms}}$$

$$= 8.30 \times 10^{-4} \text{ mol}$$

$$8.30 \times 10^{-4} \text{ mol} \times \frac{58.93 \text{ g}}{1 \text{ mol}} = 4.89 \times 10^{-2} \text{ g}$$

§ 3.3 Molar Mass

Molar Mass: the mass in grams of one mole of the compound.

Ex. 甲烷 CH_4

Mass of 1 mol C = 12.01 g

4 mol H = 4x 1.008 g

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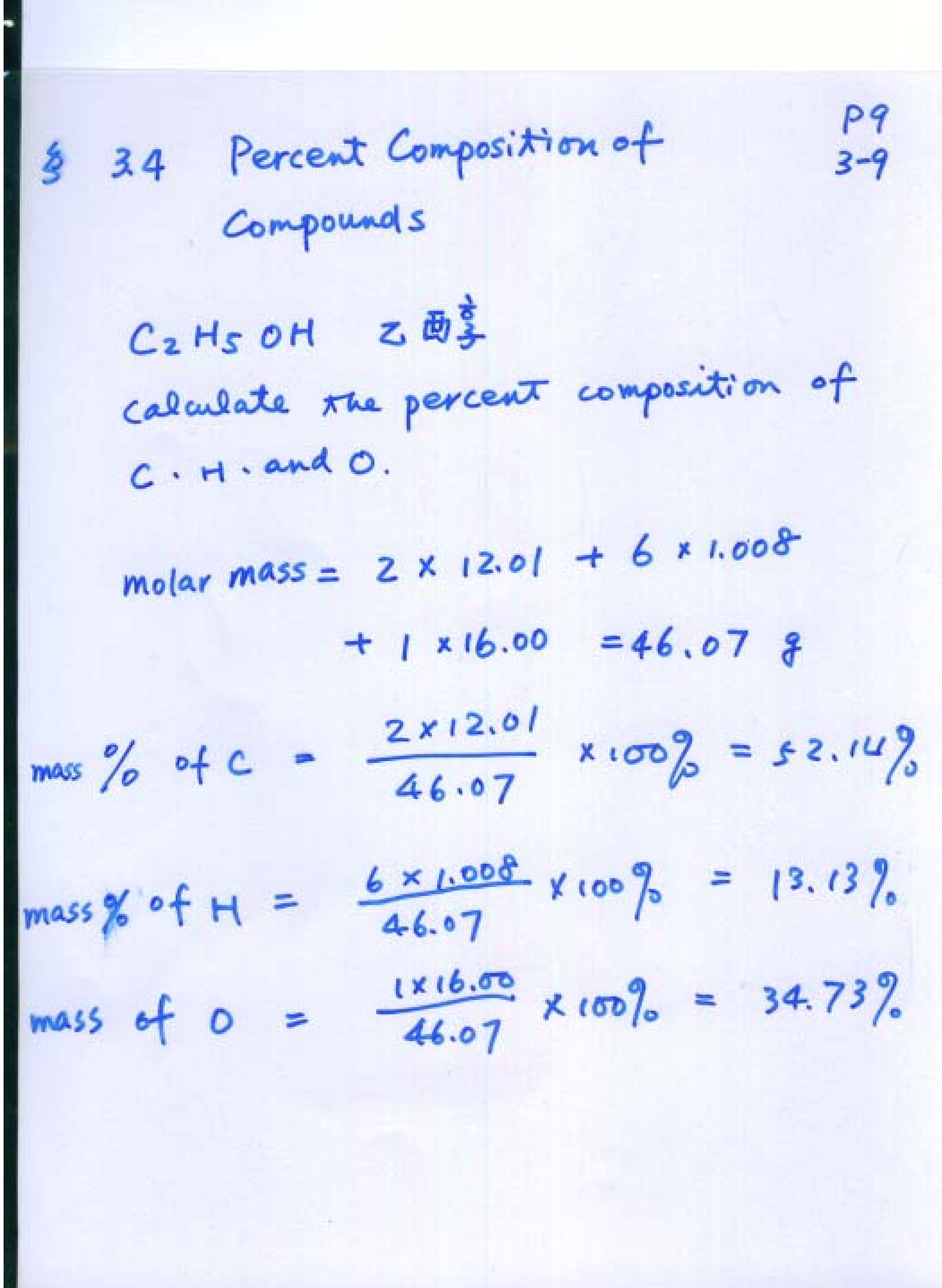
mass of 1 mol CH_4 = 16.04 g

Ex. 3 6

Calculate molar mass of Juglone.

$C_{10}H_6O_3$.



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§ 3.4 Percent Composition of Compounds

C_2H_5OH 乙醇

calculate the percent composition of C · H · and O.

$$\text{molar mass} = 2 \times 12.01 + 6 \times 1.008 + 1 \times 16.00 = 46.07\ g$$

$$\text{mass \% of C} = \frac{2 \times 12.01}{46.07} \times 100\% = 52.14\%$$

$$\text{mass \% of H} = \frac{6 \times 1.008}{46.07} \times 100\% = 13.13\%$$

$$\text{mass of O} = \frac{1 \times 16.00}{46.07} \times 100\% = 34.73\%$$

Ex. 3.10

Penicillin 盤尼西林

抗生素

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Penicillin F $C_{14}H_{20}N_2SO_4$

$$\text{molar mass} = 14\times(12.01) + 20\times(1.008) + 2\times(14.01) + 1\times(32.07) + 4\times(16.00) = 312.4\ g$$

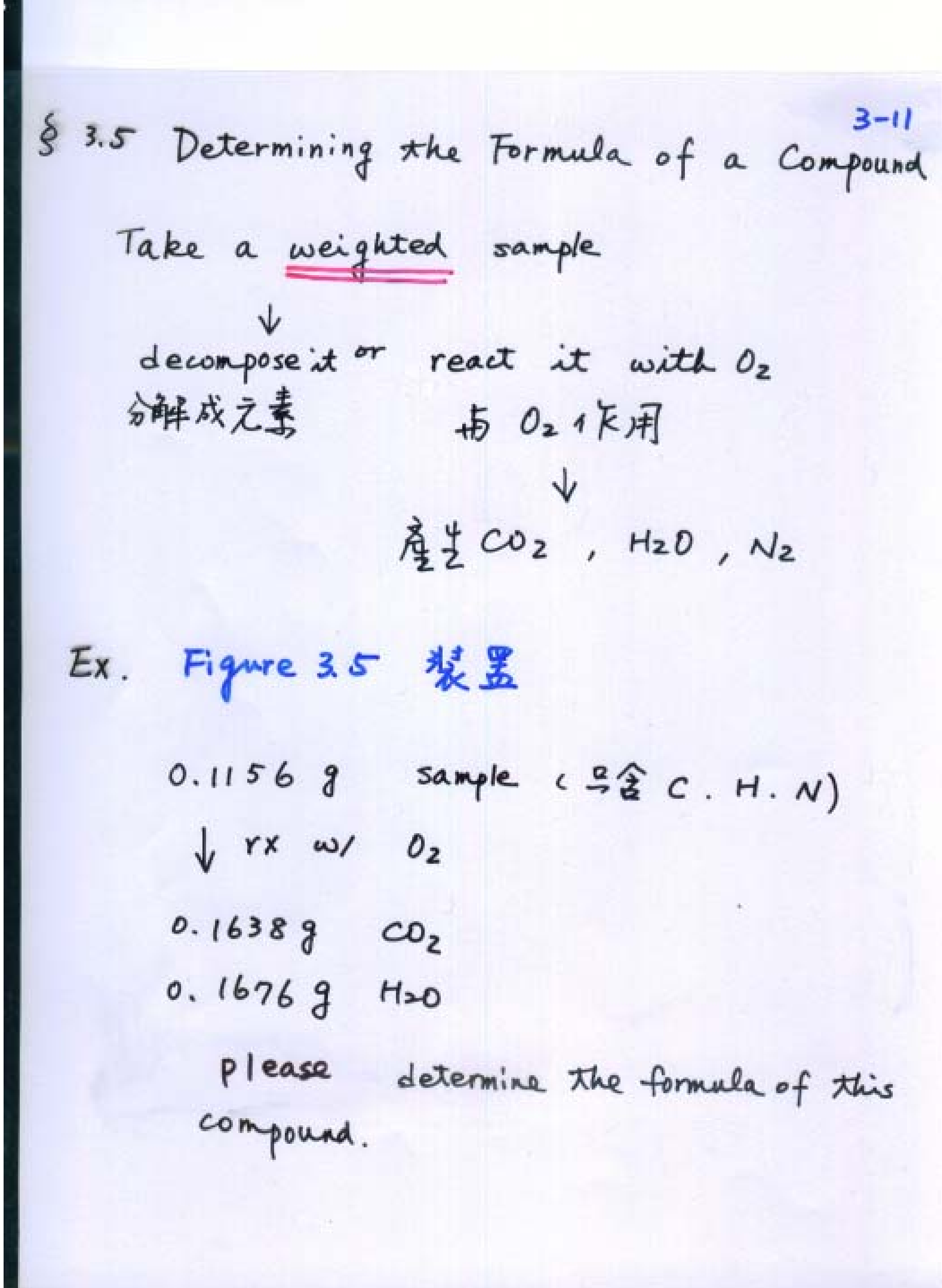
$$\text{mass\% of C} = \frac{14\times(12.01)}{312.4}\times100\% = 53.81\%$$

$$\text{mass \% of H} = \frac{20\times(1.008)}{312.4}\times100\% = 6.453\%$$

$$\text{mass\% of N} = \frac{2\times(14.01)}{312.4}\times100\% = 8.969\%$$

$$\text{mass\% of S} = \frac{1\times(32.07)}{312.4}\times100\% = 10.27\%$$

$$\text{mass \% of O} = \frac{4\times(16.00)}{312.4}\times100\% = 20.49\%$$



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§ 3.5 Determining the Formula of a Compound

Take a weighted sample

↓

decompose it or react it with O_2

分解成元素 与 O_2 作用

↓

產生 CO_2 , H_2O , N_2

Ex. Figure 3.5 裝置

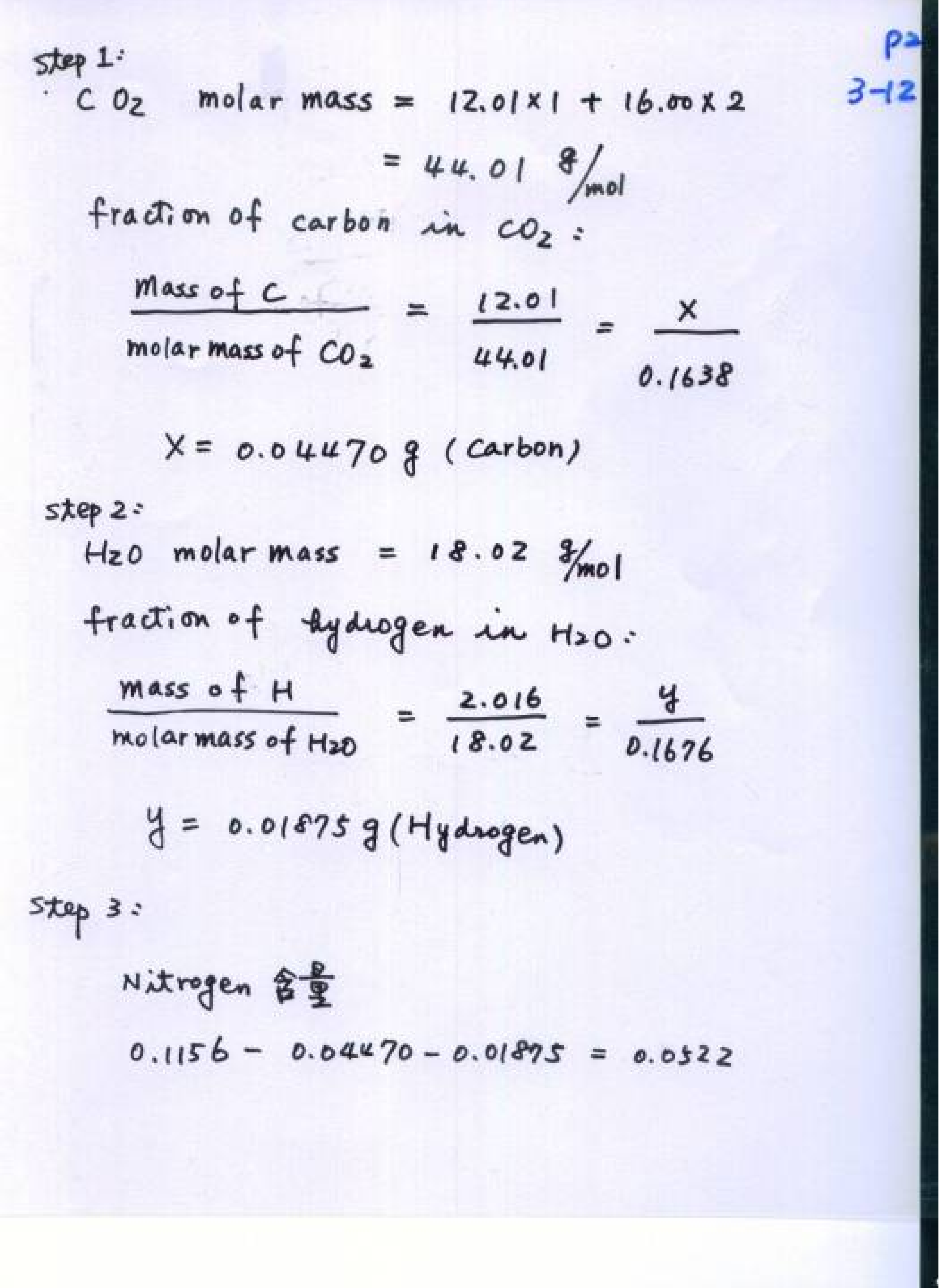
0.1156 g sample (只含 C. H. N)

↓ rx w/ O_2

0.1638 g CO_2

0.1676 g H_2O

please determine the formula of this compound.



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step 1:

CO_2 molar mass = $12.01 \times 1 + 16.00 \times 2$

= 44.01 g/mol

fraction of carbon in CO_2:

$$\frac{\text{Mass of C}}{\text{molar mass of } CO_2} = \frac{12.01}{44.01} = \frac{x}{0.1638}$$

x = 0.04470 g (Carbon)

step 2:

H_2O molar mass = 18.02 g/mol

fraction of hydrogen in H_2O:

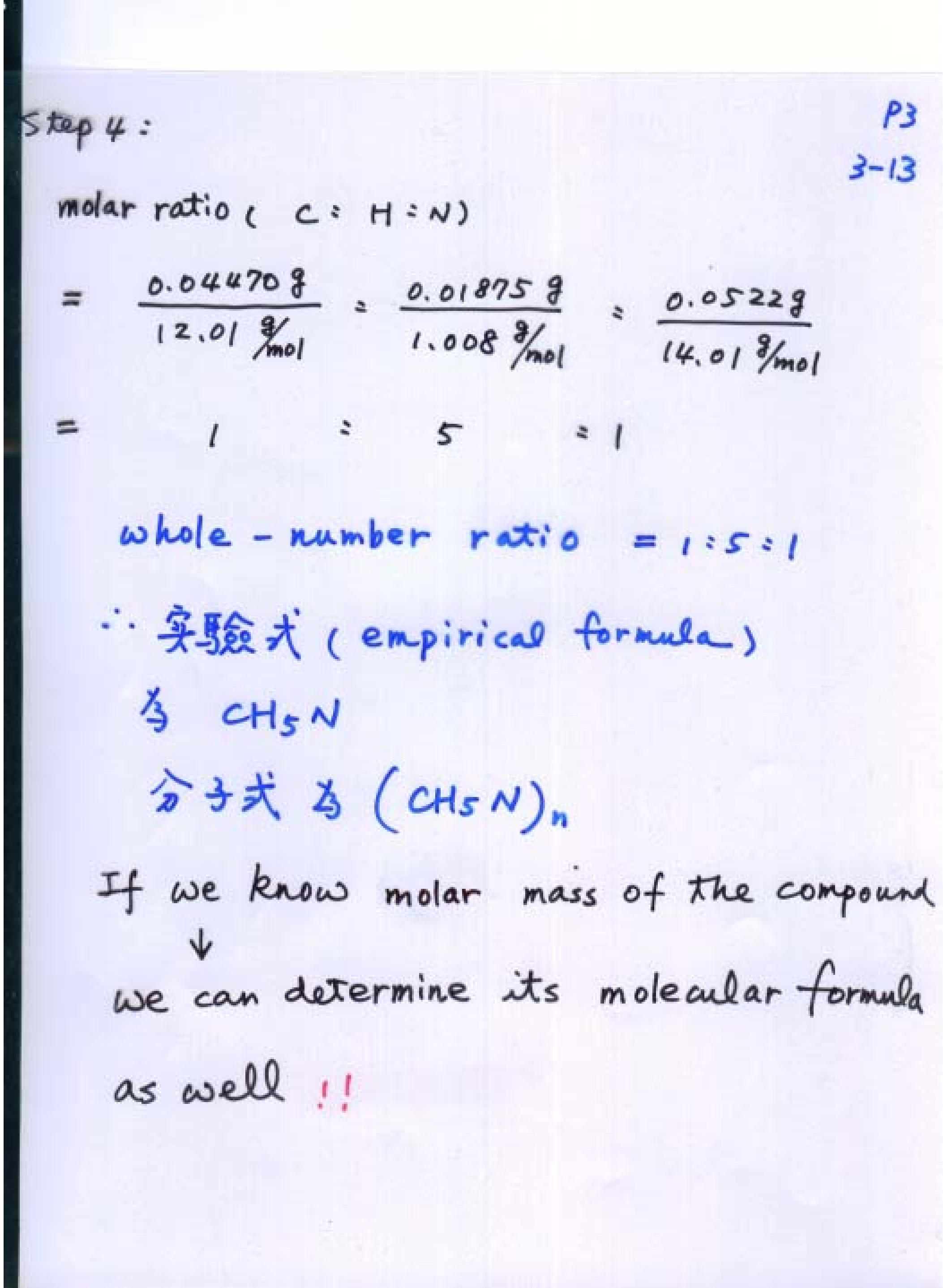
$$\frac{\text{mass of H}}{\text{molar mass of } H_2O} = \frac{2.016}{18.02} = \frac{y}{0.1676}$$

y = 0.01875 g (Hydrogen)

step 3:

Nitrogen 含量

$0.1156 - 0.04470 - 0.01875 = 0.0522$



Step 4:

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molar ratio (C : H : N)

$$= \frac{0.04470\,g}{12.01\,g/mol} : \frac{0.01875\,g}{1.008\,g/mol} : \frac{0.0522\,g}{14.01\,g/mol}$$

$$= 1 : 5 : 1$$

whole-number ratio = 1:5:1

∴ 实驗式 (empirical formula)

为 CH_5N

分子式 为 $(CH_5N)_n$

If we know molar mass of the compound

↓

we can determine its molecular formula

as well !!

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Ex : 3.11

Determine the empirical and molecular formula for a compound that gives the following analysis (元素分析結果)

71.65% Cl

24.27% C

4.07% H

molar mass = 98.96 g/mol

Sol :

$$71.65\text{ g Cl} \times \frac{1\text{ mol Cl}}{35.45\text{ g Cl}} = 2.021\text{ mol Cl}$$

$$24.27\text{ g C} \times \frac{1\text{ mol C}}{12.01\text{ g C}} = 2.021\text{ mol C}$$

$$407\text{ g H} \times \frac{1\text{ mol H}}{1.008\text{ g H}} = 4.04\text{ mol H}$$

molar ratio (C : H : Cl)

$$= 2.021 : 4.04 : 2.021 = 1 : 2 : 1$$

∴ Empirical formula = CH_2Cl

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molecular formula $= (CH_2Cl)_n$

Molar mass $= n \times (12.01 + 1.008 \times 2 + 35.45)\ g/mol$

$= 98.96\ g/mol$

$n = 2$

$\therefore$ molecular formula $= C_2H_4Cl_2$

Ex : 3.13

咖啡因的分子式

Sol :

C $49.48\% \times 194.2\ g/mol = 96.09\ g/mol$ of caffeine 的 C

4位 S.F.

H $5.15\% \times 194.2\ g/mol = 10.0\cancel{013}\ g/mol$ 的 H

3位 S.F.

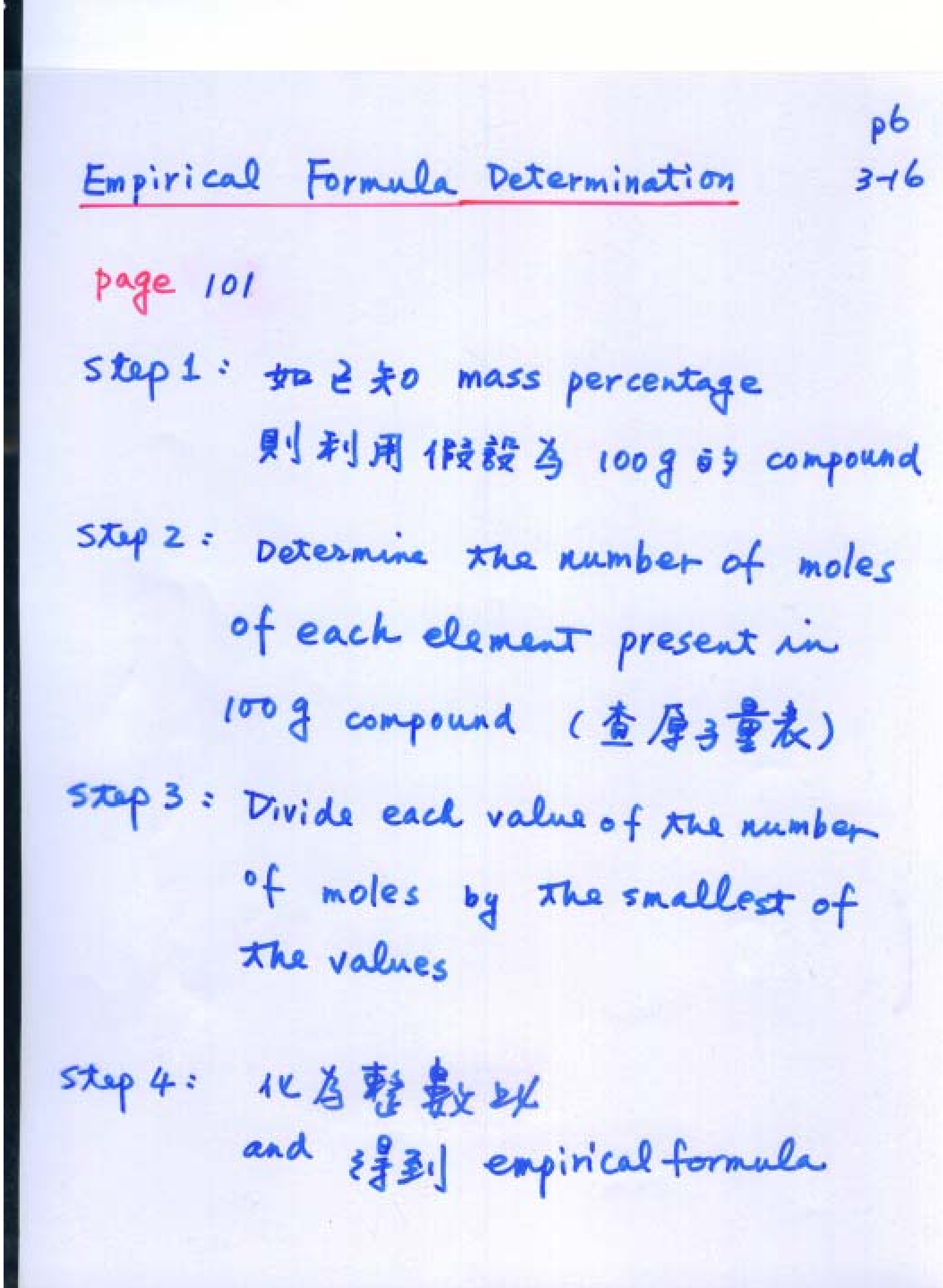
N $28.87\% \times 194.2\ g/mol = 56.07\ g/mol$ 的 N

O $16.49\% \times 194.2\ g/mol = 32.02\ g/mol$ 的 O

↓

Convert to # of mol

$96.09 \frac{g\ of\ C}{mol\ of\ Caffeine} \div 12.01\ g/mol\ of\ C = 8.001 \frac{mol\ C}{mol\ of\ caffine}$



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Empirical Formula Determination

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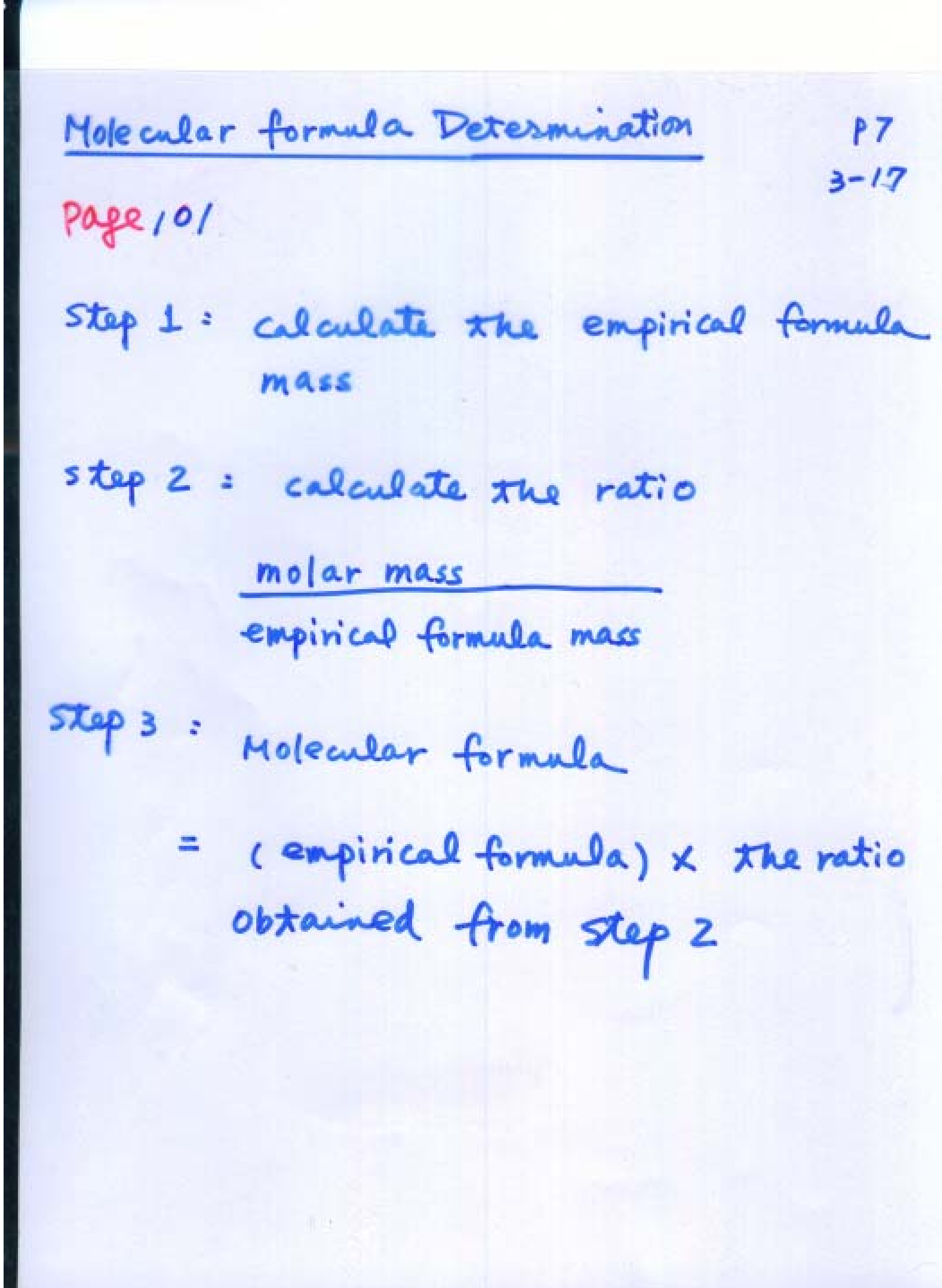
step 1: 如已知 mass percentage
則利用假設為 100g 的 compound

step 2: Determine the number of moles of each element present in 100g compound (查原子量表)

step 3: Divide each value of the number of moles by the smallest of the values

step 4: 化為整數比
and 得到 empirical formula



Molecular formula Determination

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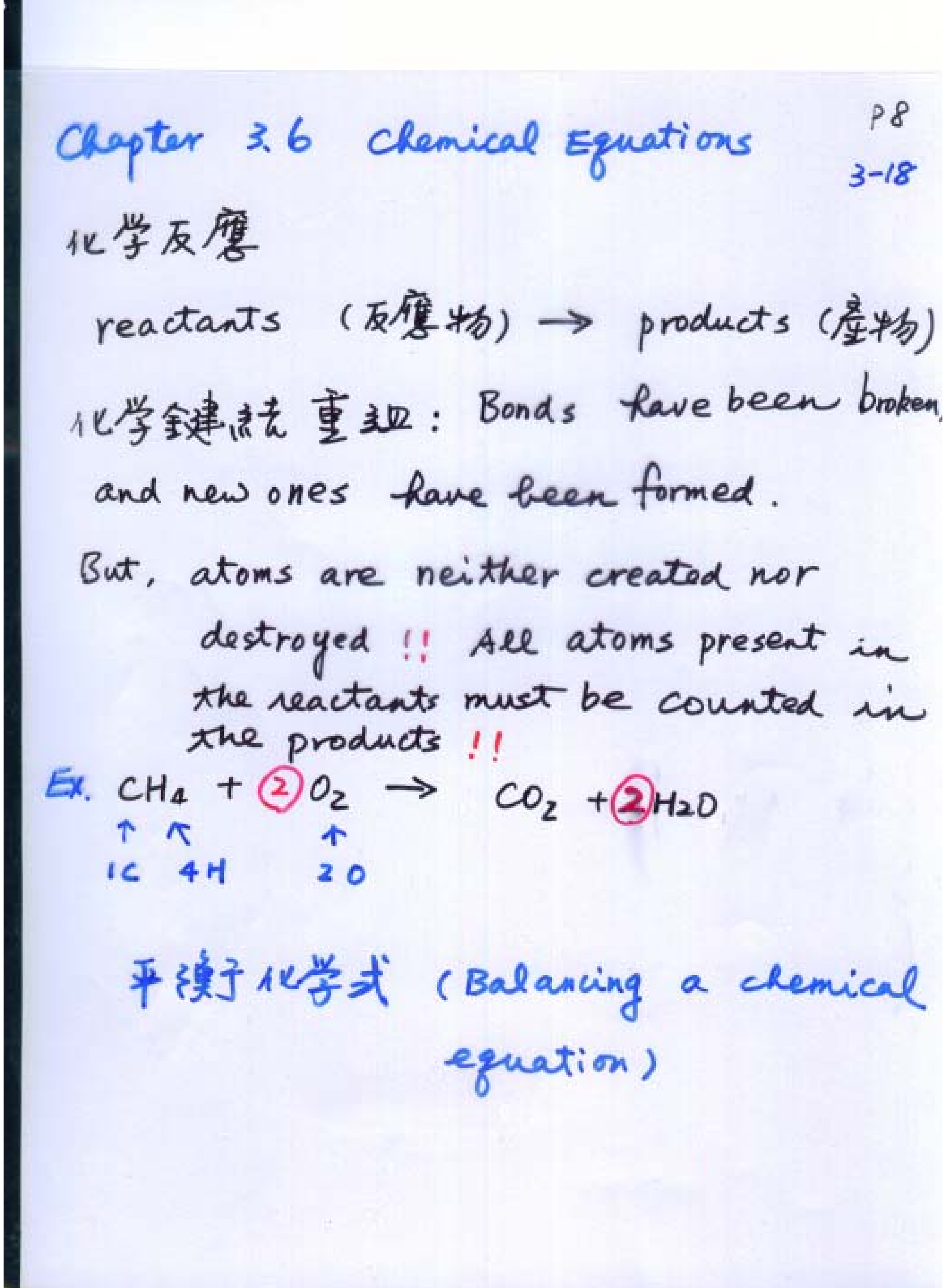
Step 1 : calculate the empirical formula mass

step 2 : calculate the ratio

$$\frac{\text{molar mass}}{\text{empirical formula mass}}$$

Step 3 : Molecular formula

= (empirical formula) × the ratio obtained from step 2



Chapter 3.6 Chemical Equations

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化学反應

reactants (反應物) → products (產物)

化学鍵結 重組: Bonds have been broken, and new ones have been formed.

But, atoms are neither created nor destroyed !! All atoms present in the reactants must be counted in the products !!

Ex. $\underset{\substack{\uparrow \\ 1C}}{C}\underset{\substack{\nwarrow \\ 4H}}{H_4} + \textcircled{2} \underset{\substack{\uparrow \\ 2O}}{O_2} \rightarrow CO_2 + \textcircled{2} H_2O$

平衡化学式 (Balancing a chemical equation)

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physical state (狀態)

Solid	(s)
Liquid	(l)
gas	(g)
Dissolved in water	(aq)

Ex :

$$HCl_{(aq)} + NaHCO_{3\,(s)} \rightarrow CO_{2\,(g)} + H_2O_{(l)} + NaCl_{(aq)}$$

$$CH_{4\,(g)} + 2O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2H_2O_{(g)}$$

Table 3.2 (page ~~104~~ 98)

化学平衡的意義

Chapter 3.7 Balancing Chemical Equations

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Step 1:

Determine what reaction is occurring. What are the reactants, the products, and the physical states involved?

Step 2:

Write the unbalanced equation that summarizes the reaction describ in step 1

Step 3:

Balance the equation, starting with the most complicated molecules

Ex. 3.14 $1\ (NH_4)_2Cr_2O_7 \rightarrow 1\ Cr_2O_{3(s)} + 1\ N_{2\ (g)} + 4\ H_2O_{(g)}$

§ 3.8 Stoichiometric Calculation :

amounts of Reactants and Products

coefficients in chemical equations :

represent numbers of molecules

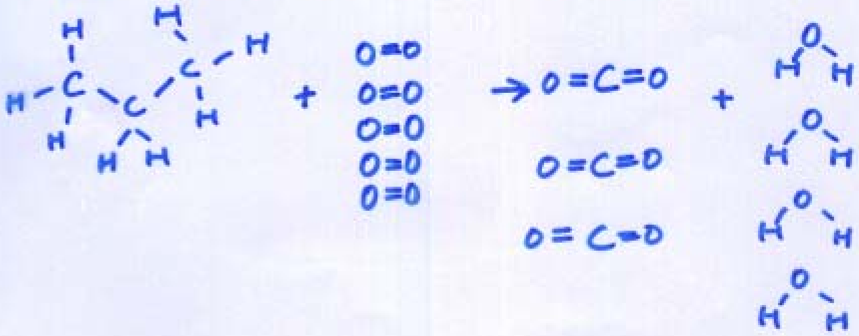
↓

masses ?

Ex : what mass of oxygen will react with 96.1 grams of propane (C_3H_8) ?

Sol : step 1 : Write the equation for the reaction , then balance it .

$$1\,C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$$



Step 2: Convert the known mass of reactant or product to moles!

$$\frac{96.1\ g}{44.1g\ g/mol} = 2.18\ mole\ C_3H_8$$

step 3: Use the balanced equation to set up the appropriate mole ratios.

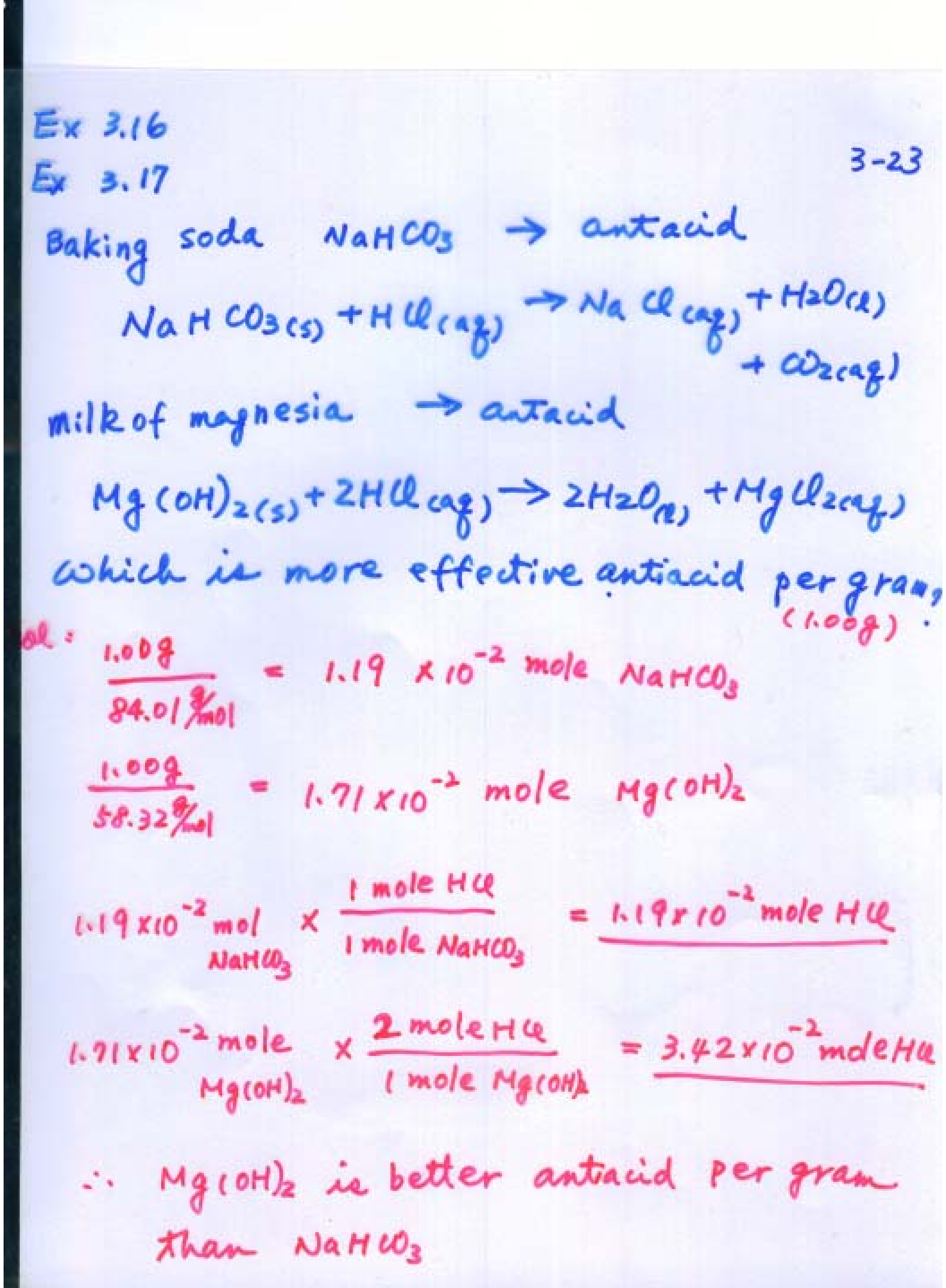
$5\ mole\ O_2 : 1\ mol\ C_3H_8$

Step 4: Use the mole ratios to calculate the number of moles of the desired reactant or product

$$\therefore \quad \frac{5\ mole\ O_2}{1\ mole\ C_3H_8} = \frac{x}{2.18\ mole} \qquad X = 10.9\ mole\ O_2$$

step 5: Convert from moles to masses

$$10.9\ mole \times 32.0\ g/mole = 349\ g\ O_2$$



Ex 3.16

Ex 3.17

3-23

Baking soda $NaHCO_3$ → antacid

$$NaHCO_{3(s)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)} + CO_{2(aq)}$$

milk of magnesia → antacid

$$Mg(OH)_{2(s)} + 2HCl_{(aq)} \rightarrow 2H_2O_{(l)} + MgCl_{2(aq)}$$

which is more effective antiacid per gram, (1.00g).

ol:

$$\frac{1.00g}{84.01\,g/mol} = 1.19 \times 10^{-2} \text{ mole } NaHCO_3$$

$$\frac{1.00g}{58.32\,g/mol} = 1.71 \times 10^{-2} \text{ mole } Mg(OH)_2$$

$$1.19 \times 10^{-2} \underset{NaHCO_3}{\text{mol}} \times \frac{1 \text{ mole } HCl}{1 \text{ mole } NaHCO_3} = \underline{1.19 \times 10^{-2} \text{ mole } HCl}$$

$$1.71 \times 10^{-2} \underset{Mg(OH)_2}{\text{mole}} \times \frac{2 \text{ mole } HCl}{1 \text{ mole } Mg(OH)_2} = \underline{3.42 \times 10^{-2} \text{ mole } HCl}$$

∴ $Mg(OH)_2$ is better antacid per gram than $NaHCO_3$

§3.9 Calculations Involving a Limiting Reactant

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Chemicals are mixed together →

they are often mixed in stoichiometric quantities !

(all the reactants " run out ")

用盡所有反應物

Ex. Haber Process

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

$$CH_{4(g)} + H_2O_{(g)} \rightarrow 3H_{2(g)} + CO_{(g)}$$

$$\underset{\times 10^3}{2.50}\ \text{kg } CH_4 \rightarrow ?\ \text{kg } H_2O$$

$$\frac{2.50\times10^6 \text{ g } CH_4}{16.04 \text{ g/mol } CH_4} \times \frac{1 \text{ mole } H_2O}{1 \text{ mole } CH_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mole } H_2O}$$

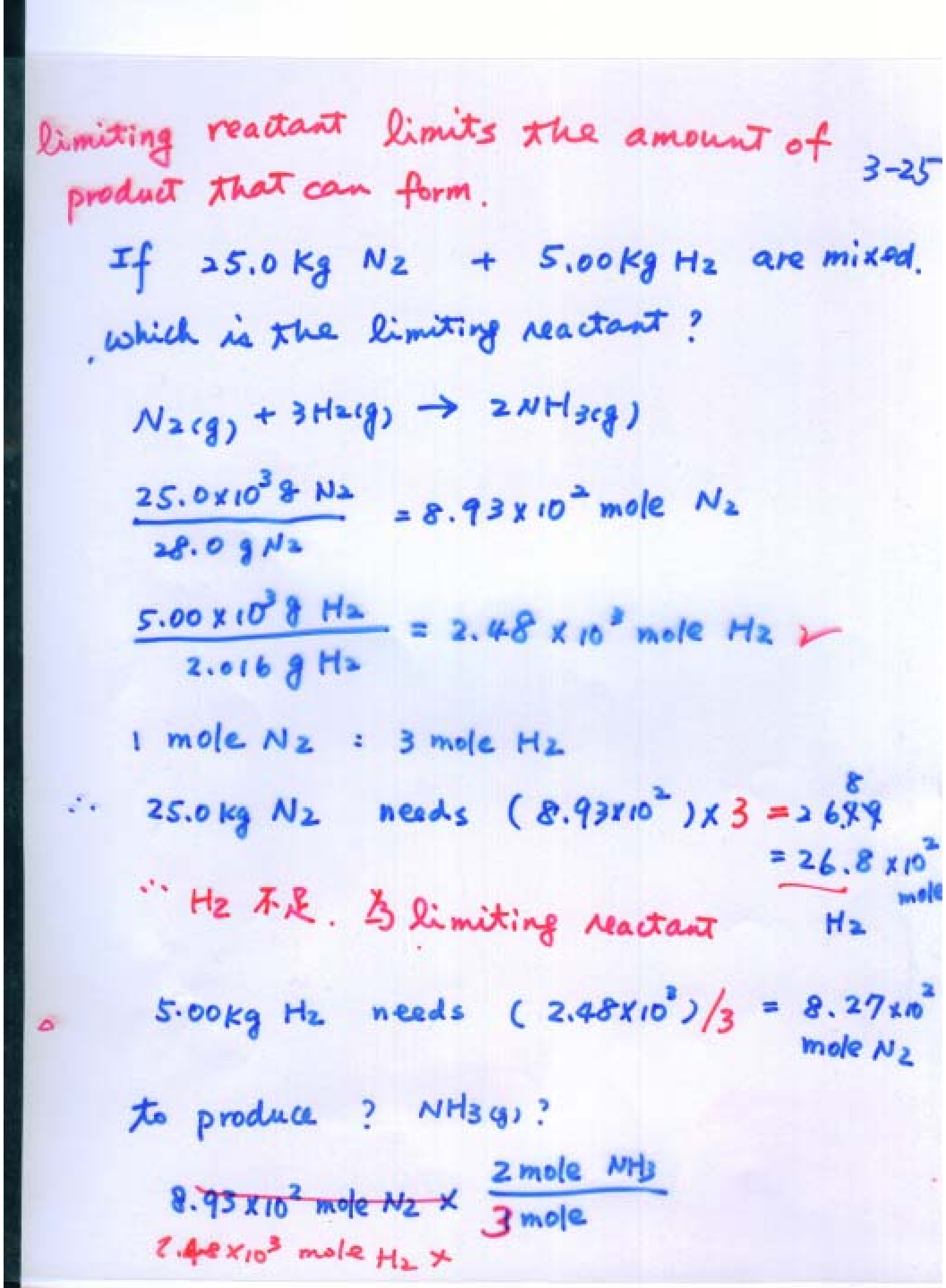
$$= 2.81\times10^6 \text{ g } H_2O$$

$$= 2.81\times10^3 \text{ Kg } H_2O$$

If we mix 3×10^3 Kg H_2O w/ 2.50×10^3 kg CH_4

H_2O is in excess

水过量. ∴ CH_4 (甲烷) is the limiting reactant !!



limiting reactant limits the amount of product that can form.

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If 25.0 Kg N_2 + 5.00 Kg H_2 are mixed. which is the limiting reactant ?

$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$

$\frac{25.0 \times 10^3 g\ N_2}{28.0\ g\ N_2} = 8.93 \times 10^2$ mole N_2

$\frac{5.00 \times 10^3 g\ H_2}{2.016\ g\ H_2} = 2.48 \times 10^3$ mole H_2 ✓

1 mole N_2 : 3 mole H_2

∴ 25.0 kg N_2 needs $(8.93 \times 10^2) \times 3 = 26\overset{8}{8}9$

$= \underset{\sim}{26}.8 \times 10^2$ mole H_2

∵ H_2 不足. 為 limiting reactant

5.00 kg H_2 needs $(2.48 \times 10^3)/3 = 8.27 \times 10^2$ mole N_2

to produce ? $NH_{3(g)}$?

~~8.93×10^2 mole N_2~~ × $\frac{2\ \text{mole}\ NH_3}{3\ \text{mole}}$

2.48×10^3 mole H_2 ×

Ex. 3.18

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nitrogen gas can be prepared by passing ammonia over solid copper (II) oxide at high temperature.

$2NH_{3(g)} + 3\,CuO \longrightarrow N_{2(g)} + 3\,Cu_{(s)} + 3H_2O_{(g}$

If a sample containing 18.1 g of NH_3 is reacted w/ 90.4g of CuO, which is the limiting reactant ? How many grams of N_2 will be forme ?

$$18.1\,g\ NH_3 \times \frac{1\ mole\ NH_3}{17.03\,g\ NH_3} = 1.06\ mole\ NH_3$$

$$90.4\,g\ CuO \times \frac{1\ mole\ CuO}{79.55\,g\ CuO} = 1.14\ mole\ CuO$$

$$\frac{mole\ CuO}{mole\ NH_3}\ (required) = \frac{3}{2} = 1.5$$

$$\frac{mole\ CuO}{mole\ NH_3}\ (actual) = \frac{1.14}{1.06} = 1.08$$

∴ CuO is the limiting reactant

$$1.14\ mole\ CuO \times \frac{1\ mole\ N_2}{3\ mole\ CuO} \times \frac{28.0\,g\ N_2}{1\ mole\ N_2} = 10.6\,g\ N_2$$

Theoretical yield: The amount of a product 3-27 formed when the limiting reactant is completely consumed.

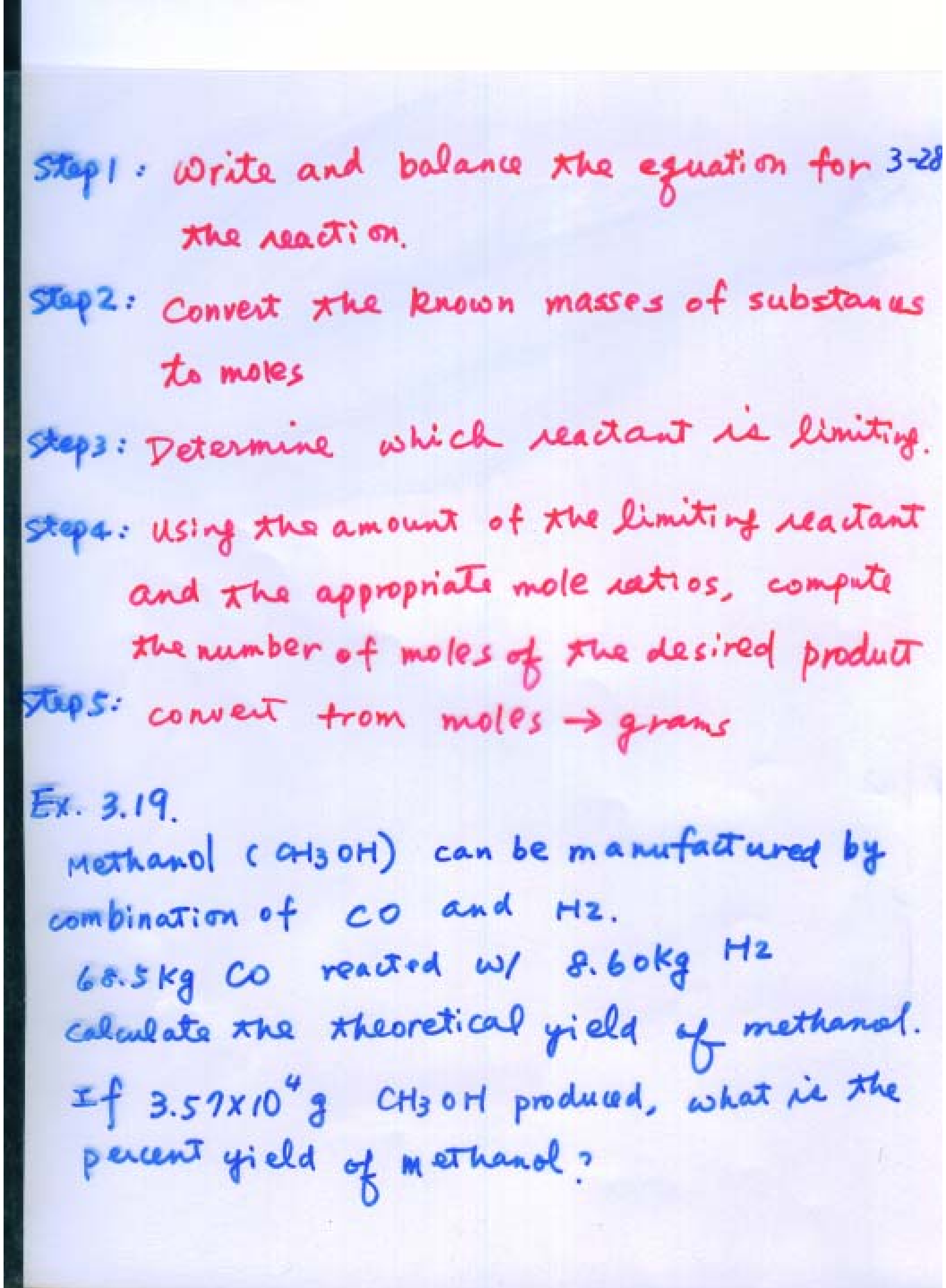
percent yield:

$$\frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\% = \text{percent yield}$$

Ex. (from Ex 3.18)

If only 6.63 grams produced, please calculate the percent yield.

$$\frac{6.63\ g\ N_2}{10.6\ g\ N_2} \times 100\% = \underline{62.5\%}$$



Step1: Write and balance the equation for the reaction. 3-28

Step2: Convert the known masses of substances to moles

Step3: Determine which reactant is limiting.

Step4: Using the amount of the limiting reactant and the appropriate mole ratios, compute the number of moles of the desired product

Step5: convert from moles → grams

Ex. 3.19.

Methanol (CH_3OH) can be manufactured by combination of CO and H_2.

68.5 kg CO reacted w/ 8.60 kg H_2

Calculate the theoretical yield of methanol.

If 3.57×10^4 g CH_3OH produced, what is the percent yield of methanol?

Ex. 3.19

Sol:

step 1:

$$2H_{2(g)} + CO_{(g)} \rightarrow CH_3OH_{(l)}$$

step 2 & 3

$$\frac{68.5\times10^3 \text{ g CO}}{28.02 \text{ g/mole CO}} = 2.44\times10^3 \text{ mole CO}$$

$$\frac{8.60\times10^3 \text{ g } H_2}{2.016 \text{ g/mole } H_2} = 4.27\times10^3 \text{ mole } H_2$$

$$\frac{\text{mole } H_2}{\text{mole CO}} \text{ (required)} = \frac{2}{1} = 2$$

actual: $$\frac{4.27\times10^3 \text{ mole } H_2}{2.44\times10^3 \text{ mole CO}} = 1.75$$

∴ H_2 is the limiting reactant

step4: $$4.27\times10^3 \text{ mole } H_2 \times \frac{1 \text{ mole } CH_3OH}{2 \text{ moles } H_2} \times 32.04 \text{ g } CH_3OH/\text{mole}$$

$$= 6.86\times10^4 \text{ g } CH_3OH$$ theoretical yield

step5: $$\frac{3.57\times10^4 \text{ g } CH_3OH \text{ (actual yield)}}{6.86\times10^4 \text{ g } CH_3OH \text{ (theoretical yield)}} \times 100\% = 52.0\%$$