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Development of Experimental Program for Acquisition of Mole Concept

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Abstract

Mole concept is applicable fundamental concept in chemistry to clarify the changes of the phenomena. However, instruction by teacher and understanding of the concept requires so much effort. Therefore, many studies were carried out. Two aspects exist in the concept as a "number" and a "scale". Most reports focus on one aspect of those. We developed an experimental program being integrated both aspects. A survey of present educational-research on “mole” was conducted, and related experiments were extracted and classified on the bases of the two aspects. Step with targets of attainments were set and corresponding contents of study were selected. Packing module type of experimental program was developed including, e.g. “Change of state in ethanol” of 4th grade (**g**4), “Determination of Avogadro constant, N_A, with crystalline NaCl ” (**g**11), and “Calculation in real gas” (**g**13). The program was composed of the text for experiments, experimental materials, background information, and explanatory power point file. The text was taken into consideration of insertion of numerous photographs in order for student himself to be able do each experiment smoothly.

Keywords: Mole concept, Number, Scale, Experimental program

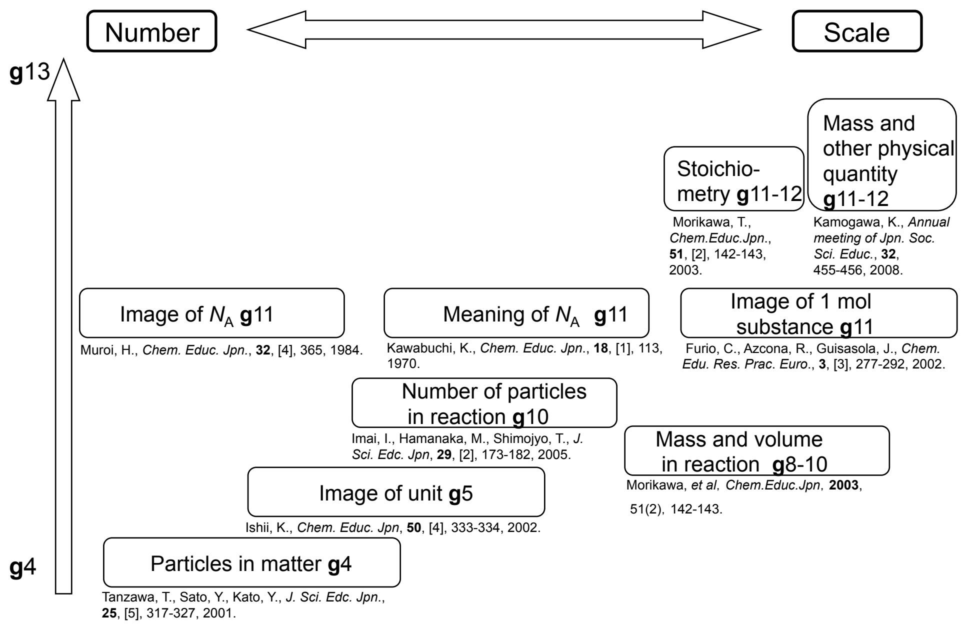
1 Introduction

The mole concept is applicable fundamental concept in chemistry to clarify the quantitative changes of the phenomena, stoichiometry. Therefore, the concept is essential topic in high school chemistry. However, learning the concept is not necessarily easy task for the beginner as pointed out in several studies (Baranski, 2012; Fang, 2014). It because the concept has two aspects namely "number" which counts the number of atoms or particles in terms of Avogadro’s constant, N_A (Muroi, 1984; Tanzawa, 2001), and "scale" which deals as a collection or unit of atoms (Furio, 2002; Morikawa, 2003). Most of studies focused on only one aspect of those, which sometime make students to have more efforts to integrate views of the concept.

In this paper, development of experimental program being integrated both aspects of the concept is reported. First, a survey of present educational-research on “mole” was conducted, and related experiments were extracted and classified on the bases of the two aspects. Step with targets of attainments were set and corresponding contents of study were selected. Finally, packing module type of experimental program was developed.

2 Procedure

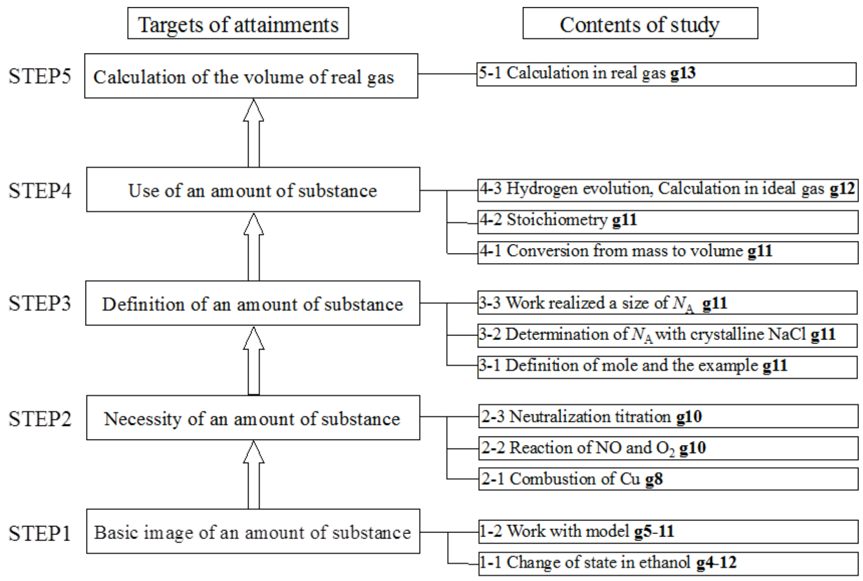
A survey of present educational-research on "mole" was conducted, and related experiments (Furio, 2002; Imai, 2005; Ishii, 2002; Kamogawa, 2008; Kawabuchi, 1970; Morikawa, 2003; Muroi, 1984; Tanzawa, 2001) were extracted and classified on the bases of the two aspects, "number" and an "scale" as shown in the scheme 1.



Scheme 1 "Number" and "Scale" of mole concept in previous research
g: grade(**g**4:4th in elementary～**g**13:1st in Univ.)

Degree in those two aspects was placed in horizontally and grade was placed vertically from **g**4, 4th grade in the elementally school, to **g**13, the first year of the university, level. At the lower level, aspect of "Number" is emphasized while at the higher level "scale" was emphasized more. There were many studies dealing with **g**11, senior high-school level.

In order to integrate both aspects of mole concept, step with targets of attainments were set and corresponding contents of study were selected from the survey as shown in the scheme 2.



Scheme 2 Steps and contents of study for experimental program

Basic image of an amount of substance was introduced in the step 1 where "Change of state in ethanol" of 4th grade (**g**4) was placed. Necessity of an amount of substance was introduced in the step 2 where "neutralization titration" (**g**10) and "combustion of Cu" (**g**8) were placed in the step. Definition of an amount of substance was introduced in the step3 where "Determination of Avogadro constant, N_A, with crystalline NaCl " (**g**11) was placed (Ikuo, 2004). Use of an amount of substance was introduced in the step 4 where stoichiometry or calculation of ideal gas was placed. "Calculation in real gas" (**g**13) was introduced in the step 5.

Packing module type of experimental program (Ikuo, 2008) was developed. The program was composed of the text for experiments, experimental materials, background information, and explanatory power point file. The text was taken into consideration of insertion of numerous photographs in order for student himself to be able do each experiment smoothly.

3 Results and Discussion

3.1 Basic image of an amount of substance

In the step 1-1, change of state in ethanol is introduced. Students are asked to measure the diameter of balloon, which contains different amount of ethanol, in the boiling water. From the activity of estimate volume of the balloon and correlate with amount of ethanol (Figure 1) students (**g**8) would obtain basic image of an amount of substance. To simplify the experiment ethanol was used although gaseous ethanol act slightly different from an ideal gas. In the case of students (**g**4), they could be asked to measure simply height of the balloon and correlate with amount of ethanol. In this manner, students do not need to calculate the volume.

1-1 Change in state of ethanol g4-12

Charge ethanol in balloon and measure diameter of it on the boiling water

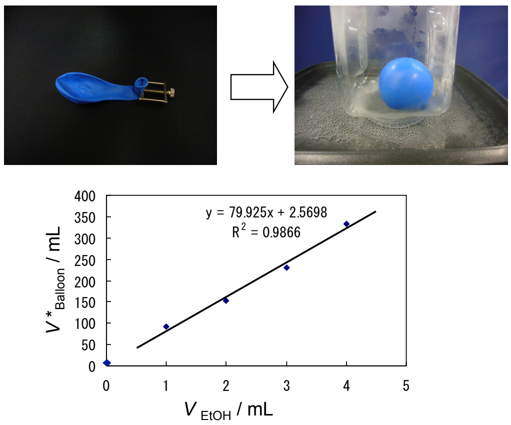
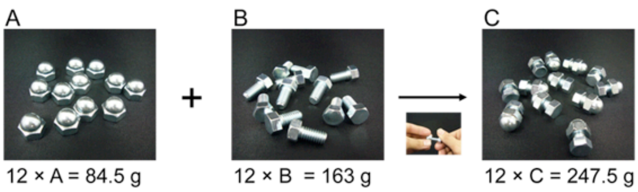


Figure 1 Example of experiment. Change in volume* of balloon by change in state of ethanol **g**8

＊calculated from diameter

In the step 1-2, model experiment with bolt and nut is introduced. Students (**g**5-11) are asked to calculate weight of one bolt or nut from the measurement of bolts and nuts (Figure 2). Students could obtain image of stoichiometry and mole weight.

1-2 Model experiment with bolt and nut g5-11



Calculate when 338 g of A is used to make C how many grams of B is required? and confirm it.

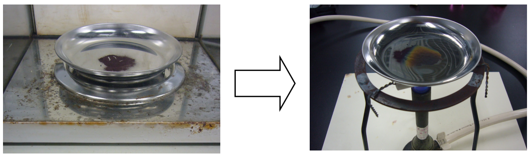
Figure 2 Example of experiment. Work with model **g**5-11

3.2 Necessity of an amount of substance

In the step 2, combustion of Cu (**g**8), reaction of NO and O_2 (**g**10), Neutralization titration (**g**10) are introduced. Students could obtain clear image of stoichiometry and an amount of substance through experiments (Figure 3-5).

2-1 Combustion of Cu g8

Measure weight change of Cu after combustion.
Each student use different amount of Cu eg. 0.5～1.0 g.



$$2Cu + O_2 \rightarrow 2CuO$$

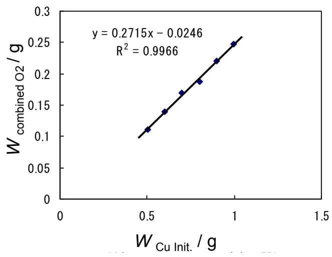


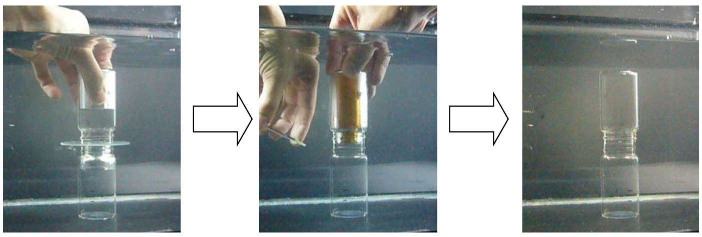
Fig. Weight of Cu and combined O_2

A fixed mass ratio is between reactants. which is determined by atomic mass. It is necessary to treat the quantity showing the number of particles.

Figure 3 Example of experiment. Combustion of Cu **g**8

2-2 Reaction of NO and O_2 g10

20 mL of NO is reacted with O_2 in water. Change volume of O_2 and observe the volume remained*.



$$2NO + O_2 \rightarrow 2NO_2$$

* NO: insol. in water, NO_2: sol. in water

Table volume of O_2 and gas remained

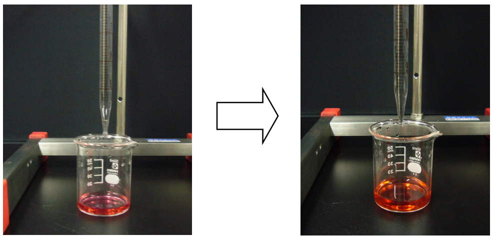
V_{O2} / mL	$V_{remained}$ / mL
10	Ca. 20
20	Ca. 0
40	Ca. 20

Same number of particles are contained in the gas of the same volume at the the same temperature and pressure. Since the ratio of volume is a ratio of the number of particles, a stoichiometry can be observed.

Figure 4 Example of experiment. Reaction of NO and O_2 g10

2-3 Introduce molarity to neutralization g10

Estimate volume of 1wt.% NaOH soln. to neutralize 5 mL of 1wt.% HCl soln. and conduct experiment.
Understand necessity of using the concentration handling the number of particles.



$$HCl + NaOH \rightarrow H_2O + NaCl$$

Result of titration

	$V_{1\ wt\%NaOH}$ / mL
1	5.45
2	5.47
3	5.51
Av.	5.48

Figure 5 Example of experiment. Introduce molarity to neutralization **g**10

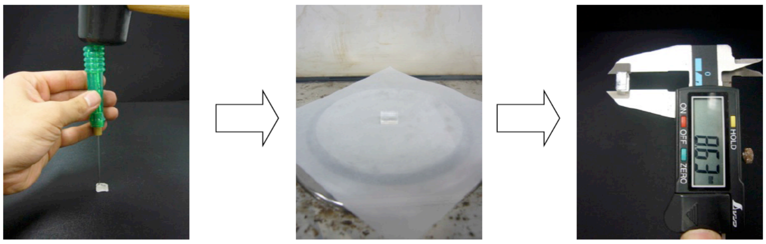
3.3 Definition of an amount of substance

In the step 3, Definition of mole is introduced. Students will see real example of one mole substance (**g**11), calculate Avogadro's constant (**g**11) from measured density of NaCl crystal and lattice constant (Figure 6, 7), and conduct activity to realize size of Avogadro's constant. Student could obtain image of number of particles in the substance.

Figure 6 Example of experiment. One mole of popular substance. From top left to bottom right: oxygen (in PET bottles), carbon (rod), sodium chloride, water, iron (nut), aluminum (coins), copper (wires).

3-2 Determination of Avogadro's constant

1. Cleave large bay salt to a rectangular shape.
2. Measure it's weight and size to obtain density.
3. Calculate N_A using lattice constant of NaCl



Size of cleaved bay salt and density

	l_1 /mm	l_2 /mm	l_3 /mm	m /g	ρ /g cm^{-3}
1	4.26	3.46	3.27	0.1066	2.212
2	4.41	3.62	2.72	0.0939	2.162
3	4.24	2.55	2.21	0.0513	2.147
Av.	–	–	–	–	2.174

$$\rho = 2.174\ \mathrm{gcm^{-3}} \qquad a = 5.640\times10^{-8}\ \mathrm{cm}$$

$$N_A = \frac{4\times58.45\ \mathrm{gmol^{-1}}}{a^3\ \mathrm{cm^3}\times\rho\ \mathrm{gcm^{-3}}} = 6.025\times10^{23}\ \mathrm{mol^{-1}}$$

Figure 7 Example of experiment. Determination of Avogadro's constant

3.3 Use of an amount of substance

In the step 4-3, Calculation of ideal gas is introduced (Figure 8). Students (**g**12) are asked to measure weight of magnesium and placed in the syringe, and then asked to suck up hydrochloric acid. After completion of the reaction they are asked to measure volume of gas formed. For the students in the g13, calculation in real gas can be introduced (Appendix 7). The program can be adopted for different grade of students.

4-3 Hydrogen evolution g12

Estimation* of hydrogen evolved form amount of Mg ribbon used * and compare with the experimental value reacting with 1 mol L^{-1} HCl in the cyringe.

＊ 1 atm, 25 ℃

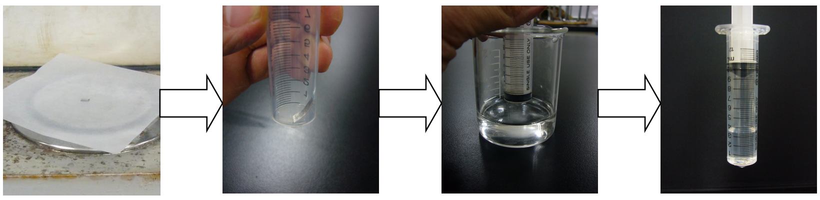


Table Amount of Mg and evolved H_2

#	W_{Mg} / g	V_{H2} Calc. /mL	V_{H2} Obs. /mL
1	0.0045	4.5	4.56
2	0.0056	5.6	5.73
3	0.0051	5.1	5.15

$$Mg + 2HCl \rightarrow H_2 + MgCl_2$$

Figure 8 Example of experiment. Hydrogen evolution, Calculation in ideal gas **g**12

Conclusion

A survey of present educational-research on “mole” was conducted, and related experiments were extracted and classified on the bases of the two aspects, "number" and an "scale". Step with targets of attainments were set and corresponding contents of study were selected. We were able to develop an experimental program being integrated both aspects. The program could be applied for students from elementary school to university and teachers in-service.

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Appendix 1　STEP1-1 Change of state in ethanol, model experiment with bolt and nut

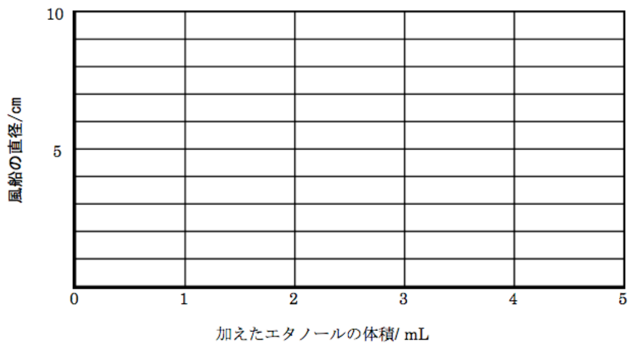
物質量（モル）

Ⅰ　「物質量」の基礎イメージの構築

1 実験　エタノールの状態変化

95 w%エタノール 1～5 mL を風船に入れ口をクリップでしばり、ホットプレートの上で熱する

どのような変化が起こったかを観察・図示する。また，風船の直径を測定し，グラフ化する



2 ボルトとナットを使ったモデル実験

A:1ダース(12個)で84.5 g　B:1ダース(12個)で163 g　C:1ダース(12個)で247.5 g

上図のようにナット A とボルト B を組み合わせて C をつくるとき，338 g の A をすべて使って C をつくるには何 g の B が必要か計算してみよう。

338 g の A は $\frac{338}{84.5}$ =①＿＿＿＿ダース

①ダースの A をすべて使うには②＿＿＿＿ダースの B が必要

②ダースの B は②× ＿＿＿＿ ＝ ＿＿＿＿ g

使用器具
・ゴム風船
・ホットプレート
・プラスチックの筒
・クリップ

材料
・95 w%エタノール
・水

エタノール
（エチルアルコール）
CH_3CH_2OH、分子量 46.1
特有のにおいと味のある無色の液体
凝固点 -114.15 ℃
沸点　78.3 ℃
密度　0.7892 g cm^{-3}
（化学大辞典，東京化学同人）

材料
・ボルト
・ナット
・天秤

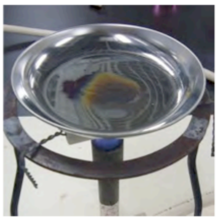
1

Appendix 2　STEP2-1 Combustion of Cu

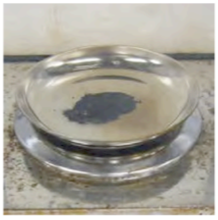
Ⅱ　物質量の導入の必要性の理解

1　実験　銅の燃焼

ⅰ）指定された質量の銅粉をステンレス皿上に電子天秤ではかりとる



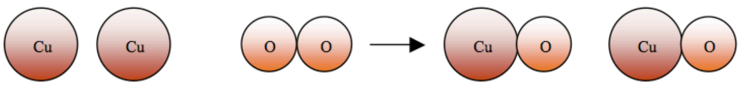
ⅱ）銅粉をステンレス皿ごと三脚・三角架の上でガスバーナーで３分間強熱する



ⅲ）火を消し、十分に冷却させたらステンレス皿ごと質量を測り、記録する

ⅳ）薬さじでまんべんなく参加されるように試料を混ぜ、再びガスバーナーの火にかける
質量が一定になるまでⅱ）～ⅲ）の操作を繰り返す

担当する銅粉の質量 ＿＿＿＿＿＿ g



2Cu　＋　O_2　→　2CuO

結果

回目	①ステンレス皿の質量	②酸化銅＋ステンレス皿の質量	②−①酸化銅の質量	備考
1	＿＿＿＿ g	＿＿＿＿ g	＿＿＿＿ g	
2	＿＿＿＿ g	＿＿＿＿ g	＿＿＿＿ g	
3	＿＿＿＿ g	＿＿＿＿ g	＿＿＿＿ g	
4	＿＿＿＿ g	＿＿＿＿ g	＿＿＿＿ g	
5	＿＿＿＿ g	＿＿＿＿ g	＿＿＿＿ g	

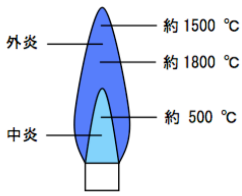
2

材料
- 3 mol L^{-1} 硝酸
- 蒸留水
- 酸素（ボンベ入り）
- 銅粉
- 水（水道水）

使用器具
- ステンレス皿
- ガスバーナー
- 三脚
- 三角架
- 薬さじ
- 電子天秤

銅の物性
Cu. 原子番号 63.54
赤色で金属光沢を持つ。乾燥した空気中では常温で安定で変化しない。空気中で加熱すれば 1000 ℃以下では黒色の酸化銅（Ⅱ）を、それ以上の高温では赤紫色の酸化銅（Ⅰ）を生ずる。
（化学大辞典，東京化学同人）

ガスバーナーの炎の温度



（サイエンスビュー　化学総合資料，実教出版）

Appendix 3 STEP2-2 Reaction of NO and O_2

2 実験 NO と O_2 の反応

ⅰ）40 mL のところに印をつけたはかりびんに水上置換で NO を 40 mL 捕集する

ⅱ）20 mL のところに印をつけたはかりびんに水上置換で O_2 を 20 mL 捕集する

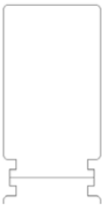
ⅲ）O_2 を捕集したびんにガラス板でふたをし、気体が漏れないように抑えながらひっくり返し、その上に NO を捕集した便をのせ、手で押さえる

ⅳ）ガラス板をゆっくりと引き抜き、O_2 を上のびんにもれないように移し、その時のびんの様子を観察・図示する
O_2 の体積を 10 mL、40 mL と変えⅰ）～ⅳ）の操作を行う

反応

$$2NO + O_2 \rightarrow 2\ NO_2$$

※NO_2 は水に溶ける気体

O_2 : 20 mL	O_2 : 40 mL	O_2 : 60 mL
		
（容器内の様子を図示）	（容器内の様子を図示）	（容器内の様子を図示）

化学反応式の係数と反応する気体の体積比の関係からわかること

使用器具
- はかりびん（60mL×4）
- 油性ペン
- 水層
- 二股試験管
- ゴム栓（穴を開けたもの）
- 誘導管
- ガラス板

酸素の物性 3-974
O_2, 原子番号 8 原子量 16.00
無色、無臭の気体。
融点 −218.76 ℃
沸点 −182.97 ℃
溶解度
4.8 mL/100 mL (100 ℃)
（化学大辞典，東京化学同人）

一酸化窒素（反応物）の物性
NO, 分子量 30.01
無色の気体。反応性が大きく、酸化されて二酸化窒素 (NO_2) になりやすい。
融点 −161 ℃
沸点 −151 ℃
溶解度
水 0 ℃ 0.00984 g $(100\ g)^{-1}$
水 50 ℃ 0.00376 g $(100\ g)^{-1}$
（化学大辞典，東京化学同人）

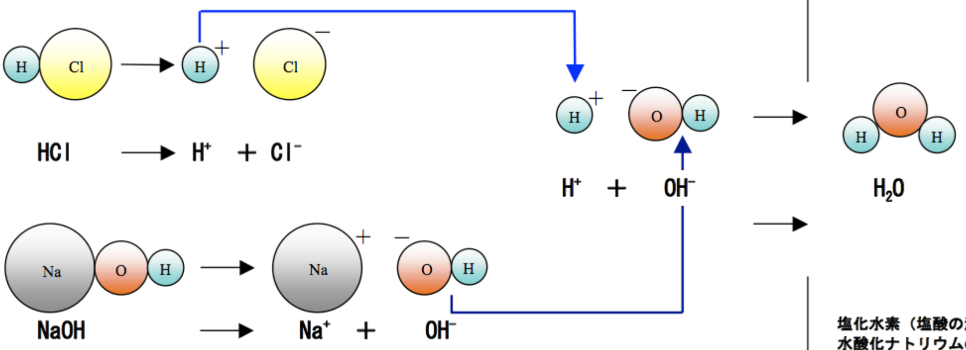
二酸化窒素（生成物）の物性
NO_2, 分子量 46.01
赤褐色の気体。固体は無色、液体は黄色。水と反応して硝酸および亜硫酸を生ずる。
融点 −9.3 ℃
沸点 21.3 ℃（分解）
（化学大辞典，東京化学同人）

4

Appendix 4　STEP2-3 Neutralization titration

３ 実験　質量パーセント濃度を使った中和反応実験

水中でのイメージ：HCl ひとつぶと NaOH ひとつぶがちょうど中和する



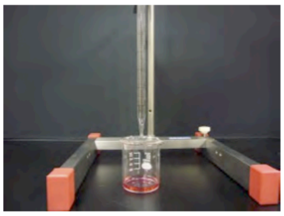
問題 質量パーセント濃度 1 %の塩酸 10 mL とちょうど中和する質量パーセント濃度 1 %の水酸化ナトリウム水溶液は何 mL か。

〈予想〉（○をつける）　　〈理由〉＿＿＿＿＿＿＿＿＿＿＿＿

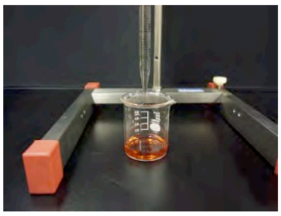
・10 mL
・10 mL より多い
・10 mL より少ない

実験 塩酸と水酸化ナトリウム水溶液の中和滴定

1 w%の塩酸 10 mL を 100 mL ビーカーに計りとり、そこに薬さじでメチルオレンジを少量加える



50 mL メスピペットに 1 w%水酸化ナトリウム水溶液を入れ、最初の水位をよみ記録し、滴下していく



滴定前の目盛①　　　　mL

滴定後の目盛②　　　　mL

滴下量②−①　　　　mL

＜予想が当たっていたか＞

＿＿＿＿＿＿＿＿＿＿＿＿

＜どのような濃度を使用すればよいか＞

＿＿＿＿＿＿＿＿＿＿＿＿

塩化水素（塩酸の溶質）と水酸化ナトリウムの分子量

HCl　= 36.64
NaOH = 40.00

材料
・1 w%塩酸
・1 w%水酸化ナトリウム
・メチルオレンジ

使用器具
・100 mL ビーカー
・薬さじ
・50 mL メスピペット

塩酸の物性
塩化水素(HCl)の水溶液。胃酸の成分。濃厚なものは湿った空気中で著しく発煙する刺激性のある無色の溶液。非金属とはあまり反応せず、多くの金属を常温で溶解して水素を発生する。
濃塩酸は劇物。
（化学大辞典, 東京化学同人）

水酸化ナトリウムの物性

（化学大辞典, 東京化学同人）

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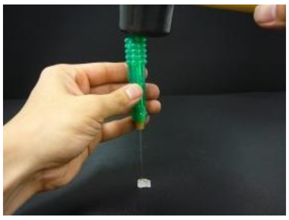
Appendix 5　STEP3-2 Determination of N_A with crystalline NaCl

実験 アボガドロ定数の測定

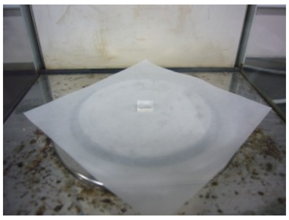


岩塩をアイスピックとラバーハンマーを使ってへき開する

カッターとラバーハンマーを使い、さらにへき開し、なるべく正確な直方体に形を整える

（へき開した試料）

へき開した試料の三辺の長さを電子ノギスで精密に測定し、記録する



へき開した試料の質量を電子天秤で測定し、記録する

$w =$ ＿＿＿＿＿ cm　　質量 ＿＿＿＿＿ g

$d =$ ＿＿＿＿＿ cm

$h =$ ＿＿＿＿＿ cm

$$\text{密度} = \frac{\text{試料の質量/g}}{\text{試料の体積/cm}^3} = ① \underline{\qquad\qquad} \text{ g cm}^{-3}$$

モル質量　② 58.44 g mol^{-1}

単位格子（面心立方格子）の一辺の長さ　$a =$ ③ ＿＿＿＿＿ cm

単位格子中に NaCl ④ 4 個相当の原子を含む

$$\text{アボガドロ定数：} N_A = \frac{④\times②}{①\times(③)^3} = \underline{\qquad\qquad} \text{ mol}^{-1}$$

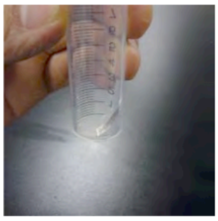
（アボガドロ定数の文献値：6.022 × 10^{23} mol^{-1}）

Appendix 6　STEP4-3 Hydrogen evolution, Calculation in ideal gas

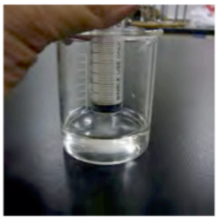
Ⅳ　物質量の利用

２ 実験 塩酸とマグネシウムの反応実験（水素の発生）

マグネシウムリボンを５mm程度切り、電子天秤で質量を測定する



先をカッターで切り取った注射器のピストンをはずし、マグネシウムリボンを入れ、ピストンをもどす



注射器内から空気を追い出し、ビーカーに入れた１mol L^{-1} 塩酸を勢いよく 10 mL 程度吸い上げる
気体発生とともに注射器内の塩酸が追い出されるので、ビーカーで受ける

マグネシウムリボンがすべて反応したらピストンを押し下げちょうどいい目盛にあわせ、その目盛と液面の目盛を記録する

材料
・マグネシウムリボン
・1 mol L^{-1} 塩酸

使用器具
・注射器
・100 mL ビーカー

マグネシウムの物性　8-842
Mg, 原子番号 12、原子量 24.32。
銀白色の軽い金属で、かなり延性に富む。かわいた空気中では表面がうすい酸化膜で覆われているので室温では参加が進行しないが、湿った空気中では速やかに光沢を失って鈍い色になる。

マグネシウムリボンの質量　①＿＿＿＿＿＿＿＿g

ピストンの目盛　②＿＿＿＿＿＿＿＿mL　**液面の目盛**　③＿＿＿＿＿＿＿＿mL

発生した水素の体積　③－②＿＿＿＿＿＿＿＿mL

計算から求められる体積（理想気体）

$$2HCl \quad + \quad Mg \quad \rightarrow \quad MgCl_2 \quad + \quad H_2$$

質量　　　①

↓

物質量　$\frac{①}{24.32}$ ────→ $\frac{①}{24.32} \times \frac{1}{1}$

↓

$$\frac{①}{24.32} \times \frac{1}{1} \times 27\cdots$$

＝＿＿＿＿＿＿＿＿

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Appendix 7　STEP5-1 Calculation in real gas

V　ファンデルワールスの式を使った実在気体の体積の計算

ファンデルワールスの式

$$p=\frac{RT}{V_m-b}-\frac{a}{V_m^{\ 2}}$$

を変形して

$$V_m^{\ 3}-\left(b+\frac{RT}{p}\right)V_m^{\ 2}+\left(\frac{a}{p}\right)V_m-\frac{ab}{p}=0$$

各数値

$R=$ ① 8.20574×10^{-2} L atm K^{-1} mol^{-1}

$T=$ ② 298 K(25℃)

$p=$ ③ 1 atm

$a=$ ④ 0.2476 atm L^2 mol^{-2}※（H_2に固有の値）

$b=$ ⑤ 2.661×10^{-2} L mol^{-1} ※（H_2に固有の値）

を代入すると

$$V_m^{\ 3}-\left(⑤+\frac{①\times②}{③}\right)V_m^{\ 2}+\left(\frac{④}{③}\right)V_m-\frac{④\times⑤}{③}=0$$

V_mについての三次方程式となるが、複雑で手計算で解くのが困難なので、Excel などの表計算ソフトを使用して計算をする（ゴールシーク機能を活用する）。

V_m = ______________

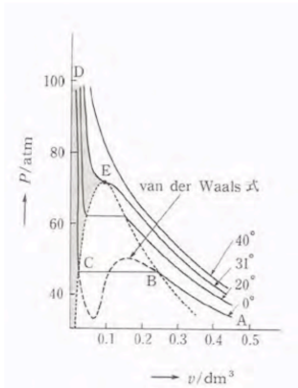

図 CO_2の P-V 曲線

Kita, H., Ichikawa, K., **1995**, *Daigakun kisokagaku,* Gakujyututosyo syuppannshya

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