高等学校教材

# 化学概论

# GENERAL CHEMISTRY

▶ 张英珊　编

化学工业出版社
教材出版中心

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# GENERAL CHEMISTRY

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# 推荐书（代序）

化学工业出版社：

兹向你们推荐山东大学威海分校张英珊副教授编著的高等学校用书英语化学教科书《General Chemistry》，请考虑给予接受出版。

自国家教育部于2001年发布“提高高等学校教学水平的若干意见”的〈4〉号文件，提倡在高等学校实行双语教学、并将以有否实行双语教学作为评判教学质量的标准之一以来，高校各科特别是理工科课程的教师们纷纷设法开展汉-英双语教学。在此项工作中存在的实际困难主要是缺乏可用的英语教材。如果引用外国原版教科书，一是书价太贵（一般每部书价在一百美元以上），不是普通大学生可以承受得起的；购买国外版权国内印刷则版权费也是所费甚高的，不符合我国当前的经济水平条件。第二是外国教科书往往部头太大，与我国高等学校现行教学学时不相衬，也会造成浪费。最为理想的情况就是我国高等学校教师根据我国实际情况编著符合自己需要的英语教科书。这就需要作者有深厚的英语和业务根底，这也存在有一定困难，但这并不是力不可及的。

根据国际高校教学计划常规，本科第一门化学课，普遍都是General Chemistry（过去错误译名为“普通化学”，现经教育部高教司同意，正确译名为“化学概论”），不管当前大学一年级化学课的五花八门命名如何，它的英文名称总应该是General Chemistry，以此为名的教科书有很广的应用范围。

我很钦佩张英珊副教授有如此果敢的勇气和高超的英语及化学业务水平，自主编撰了这部英语化学教科书，适用于各类专业第一门化学课的双语教学或直用为教材。此书的出版将给广大高校化学师生解决一个困难，而且就其适用性之广泛，对出版社来说也有很大的市场价值。就此，我很愿意为此书的接受出版作出郑重的推荐。请予考虑，此致

敬礼！（如果接受出版，本函的文字可以用为该书的代序。）

推荐人

南开大学化学学院教授

中国科学院院士

申泮文

2003年12月

# 前　　言

编者长期从事无机化学及分析化学的基础教学与教研工作，并在一段时间内有幸接触和参与了大学英语的教学工作，在教学中对学生学习英语的艰辛深有感触。学生往往耗费了大量的时间和精力，结果却不尽如人意。这与应试教育异化了学习英语的目的有着千丝万缕的联系。正是这种深刻的体会促成了我在化学基础课上进行双语教学的尝试，并将双语教学的目的定位在提高学生英语的应用能力上。提出“将英语从英语教学的课堂上解放出来”，以此来强调语言的实用性，达到语言本质回归的目的。

这种尝试因与教育部提倡的“采用英文原版教材，实施双语教学”的精神相吻合，才有了拓展的空间。但在认真研读大量国外大学所使用的基础化学教材之后，在化学基础课上引入原版教材进行双语教学的初衷又产生了很大的变化。原版教材中所采用的教学方法令人耳目一新，坦率地说，与编者所熟悉的体系有很大的不同。看一看现代西方是如何进行基础化学教学的，他山之石可以攻玉，这恐怕是教育部提倡的引进原版教材、进行双语教学的真正意义之所在。学习语言仍然是目的之一，因为使用是学习语言的最佳途径，也是终极目的。这是极易达成共识的，在此无需多议，只想就感触最深的教学方法略谈一二。

杨振宁先生对中西方研究方法的差异体会颇深，他曾谈到过在西南联大读书时主要学到的研究方法是演绎，即从数学推演到物理；而到美国后所学的研究方法正好倒过来，是归纳法，即从物理现象引导出数学的表示，并渐渐地体会到这种思考方法的好处。“因为归纳法的起点是物理现象。从这个方向出发，不易陷入泥坑”。中国的大学若能“多增加一些不绝对严密的重视归纳法的课程，对于学生会有很多好处”。

化学是一门实验学科，它的产生与发展点点滴滴都来自于对实验现象的观察与归纳，它的根基就是化学现象。杨振宁先生对于物理学研究方法的体会，对化学的学习与研究同样具有深刻的指导意义。现在国内大学化学基础课所采用的教学模式仍以演绎法为主，即先树立某一理论的权威性，然后在其指导下解释现象。在此必须指出的是，现阶段数学在化学上的应用远没有发展到像物理学那样完美。因此，以数学模型作为起点推演到化学现象，不仅抽象，还会出现很多无法解释的例外，在很大程度上挫伤了学生的学习兴趣和积极性，甚至有可能将化学这门鲜活的、充满生命力的学科变成一门僵死的学问。特别对于大学一年级的学生，刚一开始系统地接触化学科学，就形成这样一种思维习惯，会使他们误解化学的本质，混淆数学模型与事实的区别，误以为数学模型就是事实。于是一切思维都在某一数学模型的引导下展开，从而丧失了观察力和创造力，这种损失是巨大的。

化学不是灵感产生的结果，它是以无数次的观察与反复试验来解释所观察现象的产物。在原版教材中处处体现了这种观点，如引入化学概念时先展示观察到的现象，然后再讨论那些为解释观察现象所建立的模型（理论）。学生是通过仔细研究实验现象来把握整个思维过程，而不是跳过实验现象直接学习数学模型和理论。只有这样他们才能够真正学会“像一个化学家那样去思考”。事实上，就是用做科学研究的方法培养学生，让他们掌握从现象出发，通过归纳总结得到理论模型，然后再应用于实践当中，考验其正误，并对其进行修正。原版教材在内容和组织编排上无不显示出这种教学思想。如在气体一章中，首先通过实验再现当

初波义耳等科学家的实验结果，然后将这些结果合并得到理想气体定律。在此基础上引入分子运动论，从微观上建立理想气体模型，从而解释理想气体定律这一实验结果，解释其使用范围对条件的依赖，并在此模型的指导下对理想气体定律进行校正，得到实际气体定律。整个过程完全体现了化学发展史中科学家们从实验到理论，从仔细观察到总结归纳，最终建立理论模型的全过程。让学生认识到由实验所得到的结果是一种客观事实，但解释这种客观事实的理论模型却是人的主观想像，充满了人这一个体的创造。客观存在只有一种，但主观想像却可以有多种，理论模型仅是解释事实的方法，但绝不是事实本身。因此不难理解，理论模型有缺陷，而正因为有缺陷，才需要不断完善对客观事实的认识，改进理论模型。这样做的结果，不仅可以使学生理解理论与实验的关系，在遇到理论无法解释的情况时不再感到困惑，也会帮助他们在心理上克服科学的神秘感和对科学家的盲目崇拜。在他们开始系统地接近科学的时候，撩起科学的面纱——人类就是这样在向真理靠近，于是自己也产生了探索的欲望。这是归纳法与演绎法在被教育者心理上可能会造成的微妙差异。演绎法由于将所作的推演都建立在所使用的理论模型是正确的这一前提之下，无形当中将理论摆在了毋庸置疑、高高在上的位置，使被教育者对其产生了畏惧的心理，不敢对其权威性进行挑战，因此在一定程度上泯灭了受教育者在科学研究上的参与意识和创新精神。认识到这一点，离科学精神就又近了一步，原版教材的魅力也正在于此。

在此，并非否定演绎法在科学研究和教学中所起的作用。尤其对于学生而言，学会如何在一个前提下进行逻辑推理，演绎的能力是他们所受训练的一部分。但要想培养出有所发明、有所发现的创新性人才，离开了归纳法是不行的。

因此，在化学基础课上引入原版教材可以达到双赢的目的。但就目前情况而言，全盘引进尚有难度，具体实施起来也面临很多困难，总结起来有以下几个原因。

1. 基础课原版教材大多篇幅很大（上千页），全盘引入不仅造成学生经济上的压力，基础课上有限的学时也难以消化。

2. 基础课的对象是大学低年级的学生，必须考虑由于语言能力而造成的阅读困难。

3. 不同的原版教材在内容上差异很大。有的比较重视原理部分，而对元素性质的叙述则一带而过，甚至只字不提；有的则在元素性质的叙述方面占了大量的篇幅。这是缘于不同作者对基础教学的理解不同，而不同的学校都具有自己相对独立的教学体系，可以根据自己的教育思想自由选择的结果。相比之下，中国基础教育课程计划性太强，灵活不足；束缚太多，自主不足。特别是由于“考研”这一杠杆的存在，使得在基础课上引用原版教材面临着困难。

4. 原版教材涵盖了中国中学教育的某些内容，这也是其篇幅过大的原因之一。

以上种种，羁绊着在基础课上引用原版教材的步伐，使其举步维艰。因此，在上述思考的基础之上，决定结合双语教学的实践编写一本英语教材，在内容上既充分展示原版教材的特点，又可以与中国现行的教学体系相吻合，只有这样才可以扬长避短，取得较好的效果。于是就有了这本书。

与原版教材相比，此自编教材的优势体现在如下几方面。

1. 短小精练，在保持语言原汁原味的基础之上尽可能简化语言描述层次，使其简单易懂。并附有专业词汇表，配有汉语解释及国际音标，帮助学生掌握标准的专业词汇发音，消除在专业交流上的语言障碍。

2. 在内容和结构上对原版教材进行了大量的删改，使其更加适应现阶段中国化学教育

体系，包括与中学化学教育接轨的问题。达到既引入先进的教育理念和教学方法，又可与中国教育体系相融合的作用。是现阶段推行双语教学的最佳选择。

3. 按照中国的教学体系适当加强了元素性质部分的分量。

4. 集各家之所长，优势互补，将最精华的部分展现给读者。

此书的出版将为在基础课上推行双语教学提供一种新的尝试，为改革教学方法提出一种新的思路，希望能够起到抛砖引玉的作用，促使双语教学这一新生事物在基础教学领域开花结果，为培养与国际接轨的一流人才做出贡献。

这本书的完成得益于多人的鼎力相助。中科院院士、南开大学化学学院教授申泮文先生对此书的肯定给了编者极大的鼓励与鞭策，他所主持的教改项目将“化学概论”定位为化学的总纲，这也正是本书编写的宗旨。杜凯生先生在美国为优秀教材的遴选不辞辛劳，在此一并表示衷心的感谢。

最后感谢您选择本书，希望能对您的学习和工作有所帮助。由于编写时间仓促，书中可能会有一些不妥之处，请读者指正。

编者

2004年6月

# 内 容 提 要

本书是用英语编写的基础化学教材。之所以冠名为“General Chemistry”，是因为在教学改革不断深化的形势下，要求有一门课程能够承担引领学生进入化学科学领域的重要职责。“General Chemistry”是化学的总纲，在这本书上体现了这种认识和责任。大学一年级的学生不仅可以从这门课中得到对化学科学的系统化认识，更重要的是得到对化学研究科学方法的感知。

本书系统介绍了包括动力学、热力学、原子结构和周期表、化学键和分子结构、化学平衡等内容。纵观整部教材，编者在教学方法及理念上吸收了国外众多优秀教材的长处。如：将近代科学史贯穿于整部教材之中，使学生在学习过程中把握化学发展的脉络；灌输化学研究的科学理念；强调对实验结果归纳总结的重要性，明确指出理论模型是人的创造，其任务是对实验结果进行解释和演绎；在发展过程中必须经过不断的修正，才能使其趋近客观事实。这些均有助于提高学生的科学素养，也是在双语教学中特别应向先进的教学体系学习的。相信此书的出版将会推进化学教学体系的科学化进程。

基础课中引入双语教学会对学生的英语能力，特别是专业英语的能力产生极大的促进作用。

本书可作为大学教育的化学基础课教材，还可以作为教师以及对化学科学的研究方法有兴趣的各行业人员的参考书。本书还特别有助于学习科技英语的学生和从事科技翻译的人员掌握有关化学知识和相关的专业英语。

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# Chapter 1 Gases, Gas Phase Equilibria

Matter exists in three distinct physical states: gas, liquid and solid. It is interesting that it was not until the early years of the seventeenth century that the word "gas" was used. This word was invented by a Belgian physician, J. B. van Helmont (1577～1644), to fill the need caused by the new idea that different kinds of "airs" exist. Van Helmont discovered that a gas (the gas that we now call carbon dioxide) was formed when limestone was treated with acid, and that this gas differed from air in that it did not support life and was heavier than air.

During the seventeenth and eighteenth centuries other gases were discovered, including hydrogen, oxygen, and nitrogen, and many of their properties were investigated. It was not until nearly the end of the eighteenth century, however, that these three gases were recognized as elements. When Lavoisier recognized that oxygen is an element, and that combustion is the process of combining with oxygen, the foundation of modern chemistry was laid.

Gases differ remarkably from liquids and solids in that the volume of a sample of gas depends in a striking way on the temperature of the gas and the applied pressure. Particularly, the study of gases provides an excellent example of the scientific method in action. It illustrates how observations lead to natural laws, which in turn can be accounted for by models. Then, as more accurate measurements become available, the models are modified.

Therefore, It is important to understand the behavior of gases. The goals are pursued by studying the properties of gases, the laws and models that describe the behavior of gases.

A reaction mixture that ceases to change and consists of reactant and products in definite concentrations is said to have reached *chemical equilibrium*. In this chapter we will see how to determine the composition of a gaseous reaction mixture at equilibrium and how to alter this composition by changing the conditions for the reaction.

## 1.1 The Perfect-gas Law

### Boyle's Law——The dependence of Gas Volume on Pressure

The first quantitative experiments on gases were performed by an Irish chemist, Robert Boyle (1627～1691). Using a J-shaped tube closed at one end (Fig. 1.1), Boyle studied the relationship between the pressure of the trapped gas and its volume. The experiments have shown that, for nearly all gases the product of the pressure and volume is constant. This behavior can be represented by the equation

$$pV=k\text{(temperature constant, moles of gas constant)}$$

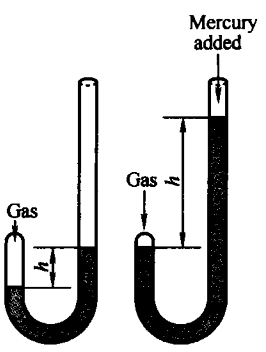

Fig. 1. 1 A J-tube similar to the one used by Boyle

which is called **Boyle's law.** A gas that obeys Boyle's law is called **ideal gas.**

Boyle's law only approximately describes the relationship between pressure and volume for a gas. Highly accurate measurements on various gases at a constant temperature have shown that the product $pV$ is not quite constant but changes with pressure. The small changes occur in the product $pV$ as the pressure is varied. Such changes become very significant at pressures much higher than normal atmospheric pressure. We will discuss these deviations and the reasons for them in detail in Section 1. 5.

**Charles's Law——The Dependence of Gas Volume on Temperature**

In the century following Boyle's findings, a French physicist, Jacques Charles (1746~1823), who was a pioneer in hot-air and hydrogen-filled balloons, found in 1787 that the volume of a gas at constant pressure increases linearly with the temperature of the gas. That is, a plot of the volume of a gas (at constant pressure) versus its temperature (℃) gives a straight line. This behavior is shown for several gases in Fig. 1. 2. This fact can be expressed mathematically by the following equation:

$$V = a + bt$$

where $t$ is the temperature in degrees Celsius, and $a$ and $b$ are constants that determine the straight lines for gases.

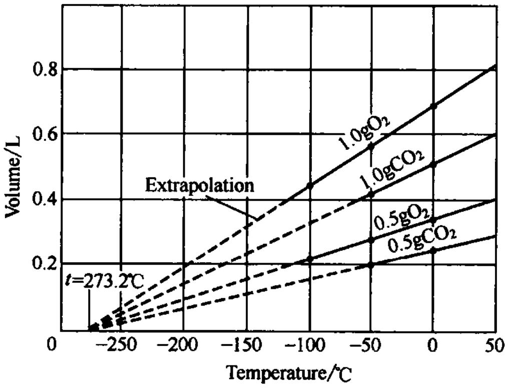

Fig. 1. 2 Plots of $V$ versus $T$ for several gases

One very interesting feature of these plots is that the volumes of all the gases extrapolate to zero at the same temperature, −273. 2℃. On the Kelvin temperature scale ( an absolute temperature scale) this point is defined as 0 K, which leads to the following relationship between the Kelvin and Celsius scales

$$\text{Temperature(K)} = 0^\circ\text{C} + 273.2$$

Let us write $T$ for the temperature on the Kelvin scale. Then we get

$$V = bT$$

This equation is a mathematical form of **Charles's law.** We can state this law as follows: *The volume of a gas at a constant pressure is directly proportional to the absolute temperature.*

Although most gases follow Charles's law fairly well, they deviate from it at high pressures and low temperatures——as we will see later in this chapter.

Before we illustrate the uses of Charles's law, let us consider the importance of 0 K. At temperatures below this point, the extrapolated volumes would become negative. The fact that a gas cannot have a negative volume suggests that 0 K has a special significance. 0 K is called **absolute zero**, which has never been reached. The lowest temperature that has been produced so far in laboratories is approximately $1\times10^{-6}$K.

**Standard Temperature and Pressure** (STP)

Since the volume of a gas changes with both pressure and temperature, a gas sample has a particular volume only as the pressure and the temperature are specified. To simplify comparisons, the volume of a given sample of gas is normally reported at **standard temperature and pressure (STP).** They are reference conditions for gases, chosen by convention to be 0℃ (273.2 K) and 1 atm (101.33 kPa).

**Avogadro's Law**

In 1809 Gay-Lussac measured the volumes of gases that reacted with each other under the same conditions of temperature and pressure. He found that 2 volumes of hydrogen react with 1 volume of oxygen to form 2 volumes of gaseous water and 1 volume of hydrogen reacts with 1 volume of chlorine to form 2 volumes of hydrogen chloride. Some simple diagrams illustrating these results are given in Fig. 1.3.

Three years later, the Italian chemist Avogadro interpreted these results and proposed that *equal volumes of gases at the same temperature and pressure contain the same number of "particles."* This assumption is called Avogadro's law, which can be stated mathematically as

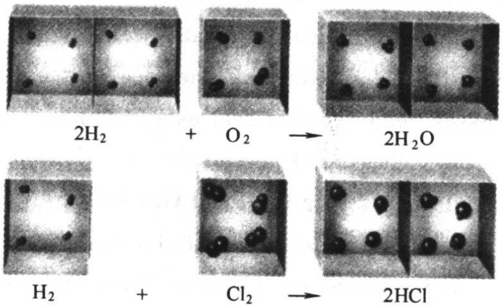

Fig. 1.3 The relative volumes of gases involved in chemical reaction

$$V=a\,n$$

where $V$ is the volume of the gas, $n$ is the number of moles, and $a$ is a proportionality constant. This equation states that for a gas at constant temperature and pressure the volume is directly proportional to the number of moles of gas. This relationship is obeyed closely by gases at low pressures.

One mole of any gas contains the same number of molecules (Avogadro's number $=6.022\times10^{23}$) and must occupy the same volume at a given temperature and pressure. This volume of one mole of gas is called the **molar gas volume.** At STP, the molar gas volume is found to be 22.41L/mol. So we can get another mathematical expression of Avogadro's law

$$V=nV_\mathrm{m}$$

where $V_\mathrm{m}$ is the molar gas volume.

**The Ideal Gas Law**

Boyle's law and Charles's law can be combined as follows

$$V=\text{constant}(T/p) \quad \text{(for a given amount of gases)}$$

For one mole of gas, the equation is changed into the following form

$$V_\mathrm{m}=RT/p$$

where $R$ is the value of the constant for one mole of gas. Because its value is the same for all gases, $R$ is called the **universal gas constant**. When the pressure is expressed in atmospheres and the volume in liters, $R$ has the value 0.08206 $\mathrm{L \cdot atm \cdot K^{-1} \cdot mol^{-1}}$. In SI units, we have $R=8.31441\ \mathrm{J \cdot K^{-1} \cdot mol^{-1}}$ which is equivalent to 8.31441 $\mathrm{dm^3 \cdot kPa \cdot K^{-1} \cdot mol^{-1}}$.

The above equation can be written for $n$ moles of gas if we multiply both sides by $n$.

$$nV_m = nRT/p$$

According to Avogadro's law, we can write

$$V=nRT/p$$

The equation can be rearranged to the more familiar form of the **ideal gas law**.

$$pV=nRT$$

It is important to recognize that the ideal gas law is an empirical equation——it is based on experimental measurements of the properties of gases. A gas that obeys this equation is said to behave ideally. That is, this equation defines the behavior of an ideal gas, which is a hypothetical substance. The ideal gas equation is best regarded as a limiting law——it expresses behavior that real gases approach at low pressures and high temperatures. Most gases obey this equation closely enough at pressures below 1 atmosphere.

**Calculations Using the Ideal Gas Law**

1. Determinations of molar mass

If we know any three of the variables $P$, $V$, $n$ and $T$, the fourth can be calculated by using the ideal gas equation. If we also know the mass of the gas, we can calculate its molar mass.

**Example 1.1**

A flask of 0.300L volume was weighed after it had been evacuated. It was then filled with a gas of unknown molar mass at 1.00 atm pressure and a temperature of 300 K. The increase in the mass of the flask was 0.977 g.

(1) What is the molar mass of the gas?

(2) Assuming that the gas molecules contain only sulfur and oxygen, what is the molecular formula of the gas?

**Solution**

(1) We first find the number of moles of the gas

$$n=\frac{pV}{RT}=\frac{1.00\mathrm{atm}\times 0.300\mathrm{L}}{0.0821\mathrm{atm \cdot L \cdot mol^{-1} \cdot K^{-1}}\times 300\mathrm{K}}=0.0122\mathrm{mol}$$

Then we can find the molar mass $M$

$$M=\frac{m}{n}=\frac{0.977\mathrm{g}}{0.0122\mathrm{mol}}=80.1\mathrm{g \cdot mol^{-1}}$$

Thus the molar mass is 80.1 $\mathrm{g \cdot mol^{-1}}$.

(2) The molecular formula could be either $SO_3$ ($M=80.06\mathrm{g \cdot mol^{-1}}$) or $S_2O$ ($M=80.12\mathrm{g \cdot mol^{-1}}$). Any other combinations of sulfur and oxygen have molar masses quite different from 80 g.

2. Gas density

Recall that density equals mass divided by volume. Because the volume of a gas depends on both its temperature and its pressure, the density of the gas must depend on these variables.

**Example 1. 2**

The density of a gas was found to be $2.06 \mathrm{g \cdot L^{-1}}$ at STP. What is its molar mass?

**Solution**

At STP

$$p = 1.00 \mathrm{atm} \quad T = 273 \mathrm{K}$$

Substituting in the equation $M = dRT/p$, we have

$$M = \frac{(2.06 \mathrm{g \cdot L^{-1}})(0.0821 \mathrm{atm \cdot L \cdot mol^{-1} \cdot K^{-1}})(273 \mathrm{K})}{1.00 \mathrm{atm}} = 46.2 \mathrm{g \cdot mol^{-1}}$$

## 1. 2 The Partial Pressures of Components of a Gas Mixture

### Dalton's Law of Partial Pressures

While studying the composition of air, John Dalton concluded in 1801 that each gas in a mixture of unreactive gases acts as though it were the only gas in the mixture; the total pressure exerted is the sum of the pressures that each gas would exert if it were alone. This statement is known as **Dalton's law of partial pressures.** It can be expressed as follows

$$p_{\mathrm{Total}} = p_{\mathrm{A}} + p_{\mathrm{B}} + p_{\mathrm{C}} + \cdots$$

$p_{\mathrm{A}}$, $p_{\mathrm{B}}$, $p_{\mathrm{C}}$, and so on are **partial pressures** of component gas A, gas B, gas C, etc. in a mixture; each one refers to the pressure that an individual gas would exert if it were alone in the container.

To illustrate, consider two 1L flasks. One flask is filled with helium to a pressure of 3 atm at a given temperature. The other flask is filled with hydrogen to a pressure of 2. 4 atm at the same temperature. Suppose all of the helium in the one flask is put in with the hydrogen in the other flask (Fig. 1. 4). According to Dalton, each gas exerts the same pressure it would exert if it were the only gas in the flask. Thus the pressure exerted by helium in the mixture is 3 atm, and the pressure exerted by hydrogen in the mixture is 2. 4 atm. The total

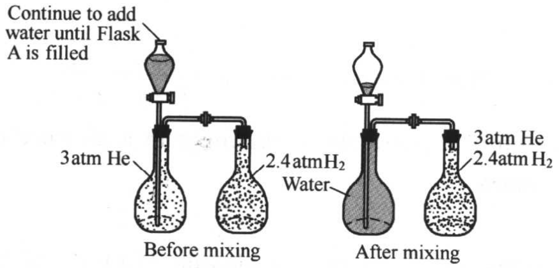

Fig. 1. 4 A demonstration of Dalton's law of partial pressures