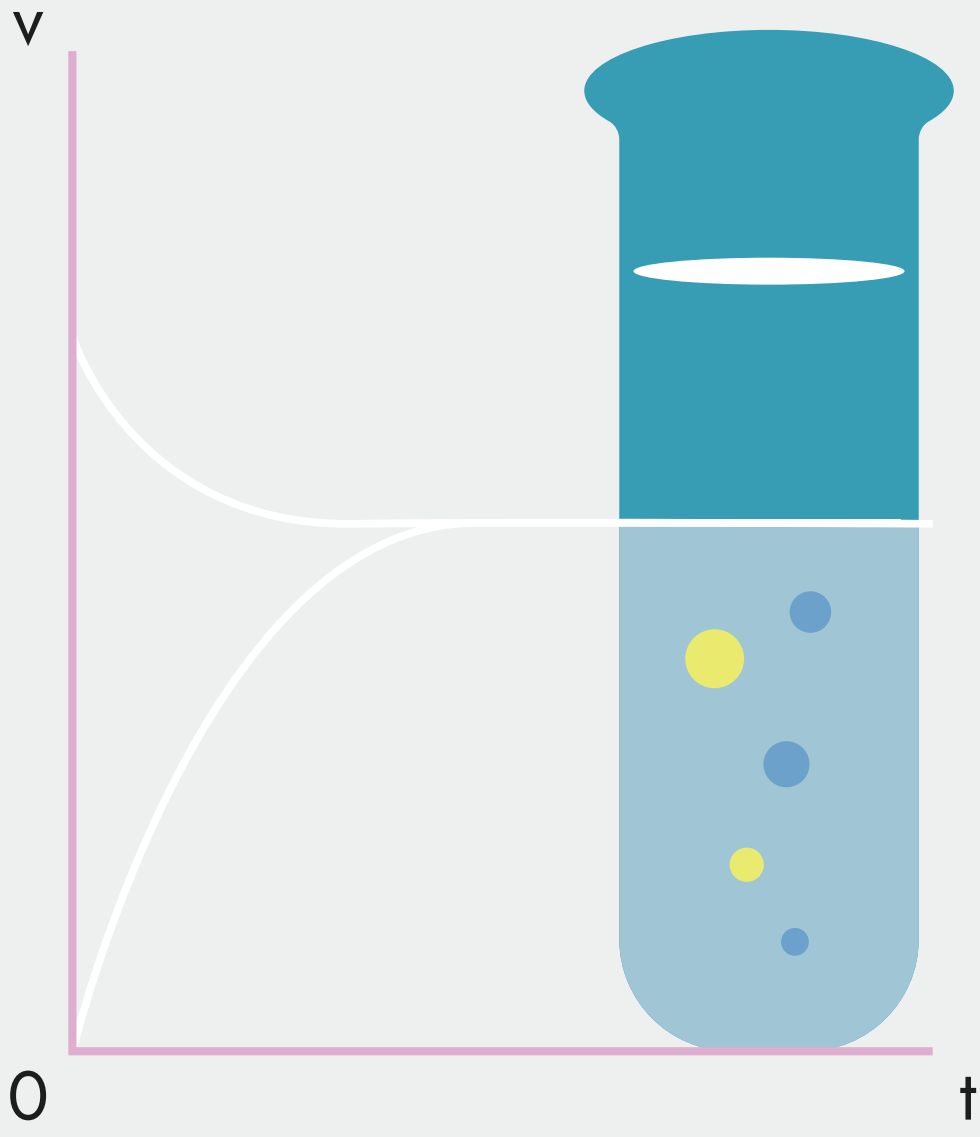
高中自然領域

雙語教學資源手冊

化學科 英語授課用語

A Reference Handbook for Senior High School Bilingual Teachers in the Domain of Natural Sciences (Chemistry): Instructional Language in English

〔高中選修(III)〕



國立彰化師範大學雙語教學研究中心 發行

目次 Table of Contents

★ 主題一 化學平衡 ★
Chemical Equilibrium

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■ 前言 Introduction

本章節主要定義化學平衡、探討影響化學反應性質的因素並將這些概念運用到化學實驗和生活中。所謂的化學平衡係指密閉系統中可逆反應的反應物與生成物達到一個穩定狀態的動態反應，一開始會藉由認識可逆反應的定義學習平衡條件對化學反應的重要性並利用平衡常數計算以了解平衡反應的行為。

此外，本章也會探討勒沙特列原理，指導學生對於外界條件改變時，系統如何對這些變化做出反應以維持平衡，透過實際案例，學生將學會如何應用這些原理來預測和解釋不同條件下的反應方向。

語言方面，教師可以帶入不同句型讓學生了解如何用英文定義、描述、比較化學反應的狀態等，例如在第二小節提及如何定義反應速率時，教師可以帶入簡易的定義類句型，如 stands for，而在提及物質之間的關聯性和因果關係時，也可以帶入句型讓學生試著用英文去描述。此外，如果課程中有做實驗需要描述實驗結果時，也可以選用合適的句型，例如 The correlation between_____ and_____ is positive/negative 讓學生用英文去描述在實驗中的觀察。

1-1 可逆化學反應
Reversible Chemical Reaction

■ 前言 Introduction

藉由生活上的例子來定義可逆與不可逆反應，同時用兩瓶水蒸發的例子讓學生了解何謂動態平衡。

語言方面，教師可以引導學生透過句型定義、描述並比較化學平衡的狀態，也能讓學生試著用英文講述造成目前平衡狀態的原因。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
equilibrium	平衡	reversible	可逆的
collision	碰撞	homogeneous	均相的/同質的
dynamic (v./adj.)	動態/ (動態的)	evaporate	蒸發
lid	蓋子	rate	速率
microscopic	微觀的	macroscopic	巨觀的

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ _____ be in accord with _____

例句：In reversible reaction conditions, if the forward reaction rate is **in** complete **accord with** the backward reaction rate, the reaction will be in dynamic equilibrium.

在可逆反應條件下，若正反應速率等於逆反應速率時，反應就會達成動態平衡。

❷ _____ depend on _____

例句：The equilibrium state of the chemical reaction **depends on** its equilibrium constant and initial condition.

這個反應的平衡狀態取決於它的平衡常數跟它的起始條件。

❸ no longer _____.

例句：The reaction will reach equilibrium when the concentration of product and reactant **no longer** change.

當產物與反應物的濃度不再改變，這個反應就會達到平衡。

❹ One_____, the other _____

例句：I have two cups of water here. **One** has a lid but **the other** doesn't.

我這邊有兩杯水，有一杯有加蓋，另一杯沒有。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After studying this chapter, students should be able to know that:

一、學生可以了解化學平衡的基本定義。

Students can understand the basic definition of chemical equilibrium.

❧ 例題講解 ☙

例題一

說明：學生可以學到如何判斷反應是否達到平衡。

Students can learn how to judge whether the reaction reaches equilibrium.

Which of the following characteristics can be used to judge whether a reaction is in equilibrium?

(A) The concentration of reactants and resultants remains constant.

(B) The limiting reagent is completely used.

(C) The concentration of the reactants is equal to that of the resultants.

(D) The total mass lost by the reactants is equal to that added by the resultants.

(E) The reaction in the forward and reverse directions completely stops.

下列何種反應特徵，可用來判斷反應是否達成平衡？

(A) 反應物與產物的濃度維持定值。

(B) 限量試劑完全用盡。

(C) 反應物濃度等於產物濃度。

(D) 反應物減少的總質量等於產物增加的總質量。

(E) 正、逆兩方向的反應完全停止。

Teacher: I put 2 cups of water on the table yesterday. One had a lid but the other didn't, right?

Student: Right.

Teacher: After a day, do you find any differences between these two cups of water?

Student: Some water in the cup without a lid evaporated while the water in the other cup didn't.

Teacher: Exactly, it means that in a confined space like the cup with a lid, the rate of water evaporation is in accord with that of condensation. We know that dynamic equilibrium is reached when forward reaction equals to reverse reaction. Macroscopically, the amount of water doesn't decrease. Microscopically, the amount of water evaporation is equal to that of water condensation.

Student: Ok, got it.

Teacher: Alright, now let's turn to page__ and look at example one.

（前一天老師在講桌上放了兩杯水，一杯有加蓋一杯沒加蓋）

老師： 老師昨天桌上的兩杯水，一杯有加蓋，一杯沒加蓋，而且都是滿的。

學生： 嗯，對。

老師： 你們有發現這兩杯放到今天有何差別嗎?

學生： 沒有加蓋的那杯蒸發一些，量有減少，而有加蓋的那杯，量沒有改變。

老師： 對，這可以表示在密閉環境下水的蒸發速率(正反應)等於凝結速率(逆反應)而我們知道正反應=逆反應就是動態平衡，巨觀上看起來水量沒有減少，微觀上是蒸發的量等於凝結的量。

(動作：老師把 $H_2O_{(l)} \leftrightharpoons H_2O_{(g)}$寫在黑板上)

學生： 好。

老師： 好，那麼就讓我們翻到第幾頁然後看範例一。

例題二

說明：學生可以了解化學平衡的原理。

Students can understand the principle of chemical equilibrium.

Chemical reaction of industrial ammonia synthesis is: $N_{2(g)} + 3H_2 \leftrightharpoons 2NH_{3(g)}$.

When one of the systems has reached equilibrium, which of the following is true?

(A) Nitrogen and Hydrogen will no longer become ammonia again.

(B) The overall number of the molecules on the left is equal to that on the right.

(C) The molar ratio of the nitrogen, hydrogen and ammonia is 1:3:2.

(D) The molar ratio of the nitrogen, hydrogen and ammonia is 1:1/3:1/2.

(E) The rate of nitrogen reacting with hydrogen to form ammonia equals that of ammonia decomposing into nitrogen and hydrogen.

工業上製氨的化學反應式: $N_{2(g)} + 3H_2 \leftrightharpoons 2NH_{3(g)}$，有一個此反應的系統達到平衡狀態時，下列敘述何者正確？

(A)　氮與氫不再反應成為氨。

(B)　反應式左側的分子總數等於右側的總數。

(C)　氮、氫、氨的莫耳數比為 1:3:2。

(D)　氮、氫、氨的莫耳數比為 1:1/3:1/2。

(E)　氮與氫反應成為氨的速率等於氨分解為氮跟氫的速率。

（110 上龍騰課本 CH01 P10 類題 1）

Teacher: Let me give you another example.

Student: Ok!

Teacher: The example I just mentioned is about water. What will happen during the equilibrium if I change it into a chemical reaction?

Student: I don't really know.

Teacher: Like the way ammonia is produced industrially, the Haber process. The equation of it is $N_{2(g)} + 3H_2 \leftrightharpoons 2NH_{3(g)}$. Now, I can say that during the equilibrium, the forward rate is equal to the reverse rate and the molar ratio of the nitrogen consumed, the hydrogen consumed and the ammonia produced will be 1:3:2.

Student: I still don't get it.

Teacher: In other words, the concentration ratio of the nitrogen consumed and the hydrogen consumed versus the ammonia produced is 1:3:2.

老師： 我再舉一個例子好了！

學生： 好！

老師： 前面舉水的例子，現在我改成一個化學反應，在平衡時會怎樣呢？

學生： 不清楚。

老師： 像是工業上製作氨的方式-哈伯法製氨，它的反應式是 $N_{2(g)} + 3H_2 \leftrightharpoons 2NH_{3(g)}$，此時我可以說它在平衡時正反應=逆反應，而氮消耗的莫耳數、氫消耗的莫耳數和氨生成的莫耳數，這三者的莫耳數比會是 1:3:2。

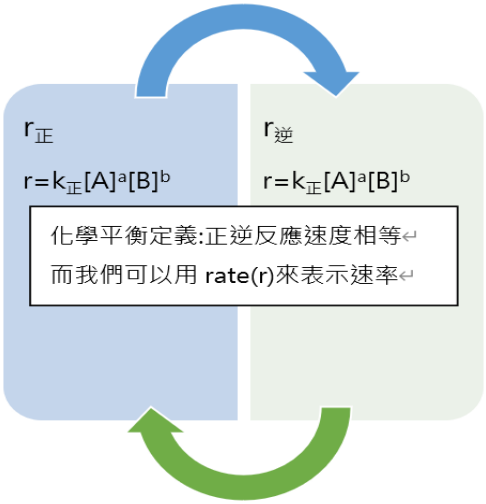
學生： 還是不懂。

老師： 也就是氮跟氫所消耗的濃度與氨生成的濃度比是 1:3:2。

1-2 平衡常數與計算
Equilibrium Constant and Calculation

■ 前言 Introduction

此小節老師可自行找尋網路上相關教學影片來複習同學們的化學平衡的概念-也就是正逆反應速度相等，再藉由速度帶到動力學的觀點去解釋何謂平衡常數（也就是 K＝k 正/k 逆，反應速率方程式裡面的速率常數 k 和平衡常數的 K 是不一樣的）：



語言方面，教師可以帶入句型，讓學生試著用英文定義反應速率、比較反應速率和溫度的關係，並表達關聯性。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
numerator	分子	dissociate	解離
denominator	分母	coefficient	係數
fraction	分數	significant	顯著的

reaction quotient	反應商	syringe	針筒
reaction mechanism	反應機構	constant	常數
dilute	低濃度的	product	乘積

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ _____ stands for _____.

例句：“r” **stands for t**he rate of reaction.

“r” 代表反應速率。

❷ On the contrary, _____

例句：For endothermic reaction, e reaction will be faster in higher temperature. **On the contrary,** the reaction will be slower in lower temperature.

對於吸熱反應，當提高溫度，反應速率會變快。相反的 ，當溫度降低，反應速率則會變慢。

❸ be/have (something) to do with _____.

例句：The equilibrium constant **has to do with** the concentration. The way to express this is: $K = [C]^C[D]^d/[A]^a[B]^b$, also called the law of mass action.

平衡常數與濃度有關。表示方式為：$K = [C]^C[D]^d/[A]^a[B]^b$，也稱為 the law of mass action!

❹ _____ as soon as _____.

例句：If the reactant side has a greater number of moles than does the product side, the gas will be compressed **as soon as** I push the piston in the syringe. Thus, it will proceed in the direction of the product.

如果生成物的係數和小於反應物的係數和，當我把在針筒裡的活塞往前推，裡面的氣體會被壓縮，故它會朝向生成物的方向。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After studying this chapter, students should be able to know that:

一、學生可以練習並熟悉平衡式的運算。

Students can practice and become familiar with the operation of the equilibrium constant expression.

❧ 例題講解 ☙

例題一

說明：學生可以熟悉平衡式的寫法。

Students will become familiar with the way of writing the equilibrium constant expression.

Try to write down the equilibrium constant expressions of the following reactions:

試寫出下列反應的平衡常數表示式:

(a) $PCl_{3(g)} + Cl_{2(g)} \leftrightarrows PCl_{5(g)}$

(b) $Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)} \leftrightarrows 2CrO_4^{2-}{}_{(aq)} + 2H^+{}_{(aq)}$

(c) $PbI_{2(s)} \leftrightarrows Pb^{2+}{}_{(aq)} + 2I^-{}_{(aq)}$

正解

(a) $K_c = [PCl_5]/[PCl_3][Cl_2]$

(b) $K_c = [CrO_4^{2-}]^2[H^+]^2/[Cr_2O_7^{2-}]$

(c) $K_c = [Pb^{2+}][I^-]$

（110 上龍騰課本 CH01 化學平衡 P.27 例 1-3）

Teacher: Does anyone remember the definition of equilibrium constant that we mentioned before?

Student: I only remember that the formula has something to do with the concentration of the reactant.

Teacher: That's fine. Since you are not that familiar with equilibrium constant now, it's good enough for you to define it roughly. Let's take a look at Item A. Take a reversible reaction $A_{(g)} \leftrightarrows B_{(g)}$ for example, the forward reaction rate will be k_f [A] and the backward reaction rate will be k_r [B]. When achieving dynamic balance, k_f [A] = k_r [B]. K_c represents k_f/k_r and the result of cross multiplication will be [B]/[A]. Thus, the answer to the first question can be written as $K_c = [PCl_5]/[PCl_3][Cl_2]$. So far so good?

Student: Yes!

Teacher: The power of A and B will be the reaction coefficients of A and B. For instance, $aA_{(g)} \leftrightarrows bB_{(g)}$ can be written as $[B]^b/[A]^a$. Let's look at Item B. For this one, please try it yourself!

Student: Is the answer $K_c = [CrO_4^{2-}]^2[H^+]^2/[Cr_2O_7^{2-}][H_2O]$?

Teacher: Almost there! Do you remember that the reactants or resultants of the reaction of nonaqueous solution contains water vapor or water? Since the concentration of water vapor or water will not affect the reaction equilibrium, we don't need to take its concentration into consideration. Then, the correct answer will be $K_c = [CrO_4^{2-}]^2[H^+]^2/[Cr_2O_7^{2-}]$. I will leave the last item to you. Remember that the solid state of PbI_2 will not affect the concentration, either. It will not be included in the equilibrium constant expression either.

Student: Ok, I got it!

（學生才剛剛聽完老師講完那麼多還存在著一頭霧水的狀態。）

老師： 大家還記得我們之前說的平衡常數的定義嗎？

學生： 我只記得那個公式與反應物的濃度有關。

老師： 沒關係，你們應該還不太熟，能講出大致定義已經很好了！那麼我們來看 a 部分，舉例說一個可逆反應 $A_{(g)} \leftrightarrows B_{(g)}$，正反應速率就會是 k_f [A]，逆反速率就會是 k_r [B]。在達到動平衡時，k_f [A] = k_r [B]，而 K_c 代表的就會是 k_f/k_r，同時交叉相乘的結果也會等於 [B]/[A]。像是第一小題我就可以寫成 $K_c = [PCl_5]/[PCl_3][Cl_2]$，到這邊，還跟得上嗎？

學生： 可以！

老師： 而 A 跟 B 的次方就會是 A 跟 B 的反應係數，舉例說 $aA_{(g)} \leftrightarrows bB_{(g)}$，它可以寫成 $[B]^b/[A]^a$，再來我們看第二小題，這題你們自己試著做做看！

學生： 答案是 $K_c = [CrO_4^{2-}]^2[H^+]^2/[Cr_2O_7^{2-}][H_2O]$嗎？

老師：對一半了！你們還記得非水溶液的反應中，反應物或產物含有水蒸氣或水嗎？因其濃度不會影響反應平衡，所以它的濃度不用考慮喔！$K_c = [CrO_4^{2-}]^2[H^+]^2/[Cr_2O_7^{2-}]$

剩下的第三小題你們再自己寫寫看，然後注意固體的 PbI_2 也不會影響濃度，所以同樣不會列入化學平衡式中。

學生：好，知道了！

例題二

說明：藉由一些小題練習，學生能理解平衡式的計算，並複習以前化學計量的基本運算。Through some practice exercises, students can review the basic calculation of stoichiometric amounts and know how to calculate equilibrium constant expression.

Put 1.0 mol of $CO_{(g)}$ and 1.0 mol of $H_2O_{(g)}$ in a 1.0 L vacuum container. When it's t °C, the 1.0 mol of $CO_{(g)}$ and 1.0 mol of $H_2O_{(g)}$ react and follow the equation:

$CO_{(g)} + H_2O_{(g)} \leftrightarrows CO_{2(g)} + H_{2(g)}$

There are 0.20 moles of $CO_{(g)}$ left when the reaction achieves equilibrium. Try to figure out the answers below:

(1) What is the equilibrium concentration of H_2?

(2) What is the equilibrium constant of this reaction?

(3) What is the percent yield of this reaction?

(4) Under the same condition, put 1.0 mol of $CO_{(g)}$ and 1.0 mol of $H_2O_{(g)}$ in a 1.0 L vacuum container respectively. What will the equilibrium concentration of H_2 be?

取 1.0 莫耳的 $CO_{(g)}$ 和 1.0 莫耳的 $H_2O_{(g)}$ 置於 1.0 升真空容器中，在 t °C 時依下列反應式發生反應：$CO_{(g)} + H_2O_{(g)} \leftrightarrows CO_{2(g)} + H_{2(g)}$，反應達平衡時，$CO_{(g)}$ 剩下 0.20 莫耳。試求：

(1) H_2 的平衡濃度。

(2) 此反應的平衡常數為何？

(3) 此反應的產率為何？

(4) 在相同條件下，分別將 0.10 莫耳的 $CO_{(g)}$和 $H_2O_{(g)}$ 充入此密閉容器中，求 H_2 的平衡濃度為何？

（110 上龍騰課本 CH01 P.34 例 1-6）

正解 (1) 0.80 M (2) 16 (3) 80% (4) 0.080 M

(1) $CO_{(g)} + H_2O_{(g)} \leftrightarrows CO_{2(g)} + H_{2(g)}$

初	1.0 M	1.0 M		
反應中	-0.8M	-0.8 M	+0.8 M	+0.8 M
平衡時	0.20 M	0.20 M	0.80 M	0.80 M

(2) $K_c = \frac{0.80 \times 0.80}{0.20 \times 0.20} = 16$

(3) 產率 (%) = $\frac{\text{實際產量}}{\text{理論產量}} \times 100\% = 0.8(80\%)$

$1.0 \times 100\% = 80\%$

(4)	$CO_{(g)}$	+	$H_2O_{(g)}$	$\leftrightarrows$	$CO_{2(g)}$	+	$H_{2(g)}$
初	0.10 M		0.10 M				
反應中	- x M		- x M		+x M		+x M
平衡時	0.10-x M		0.10-x M		x M		x M

$K_c = \frac{x \times x}{(0.10 - x) \times (0.1 - x)} = 16 \Rightarrow$

$\frac{x}{(0.1-x)} = 4 \Rightarrow x = 0.08 = [H_2]$

Teacher: Alright, let's move on to the next question. Do you remember how to calculate stoichiometric coefficients? Since this one is a chemical equation, we need to use concentration to calculate.

Student: Yes, I do. I remember that!

Teacher: As we can see in the question, when the reaction reaches equilibrium, there are 0.20 moles of $CO_{(g)}$ remaining. The coefficients of CO and H_2O are both 1. This means that there is also 0.2 M H_2O left when it is in equilibrium. In other words, both CO and H_2O will be consumed 0.8 M and the concentration of the products will be 0.8 M too. Now, try to calculate it with the chemical equation.

Student: I am done. Is the answer 16?

Teacher: That's right. Let's move on to question number three. Do you remember what percent yield is? Under normal circumstances, the chemical equation will not reach 100% completion. The formula is "Actual yield/Theoretical yield × 100%". Theoretical yield is the calculated perfect amount while actual yield is the amount obtained after experimentation.

Teacher: Let's look at question number two-1 M CO and 1 M H_2O. According to the coefficient ratio 1:1:1:1, the concentration of the product should be 1 M CO_2 and 1 M H_2 theoretically. However, after the calculation, we know that the concentration is only 0.8 M. Therefore, the percent yield can be written as:

Student: 0.8 M/1 M × 100% = 80%

Teacher: Excellent! We can use the answer to question number two, $k_c = 16$, to calculate the equilibrium concentration. But here comes the problem—we don't know how much the two reactants are consumed. Thus, we can suppose the consumption as x and substitute it with kc just like the way we did in question number one. Then, the x will be the equilibrium concentration of H_2 that the item is asking.

（已經幫學生複習了基本的平衡式觀念，現在要進到平衡式的計算）

老師： 好的我們進到下一題可以嗎？你們還記得化學計量係數的算法嗎？不過由於這個是化學反應式，所以我們要改用濃度去做計算。

學生： 還記得！

老師： （寫下板書如右圖）題目上跟我們說平衡時一氧化碳剩下了 0.2 M，一氧化碳及水在化學式的係數都是 1，這也代表著我們在平衡時水也會剩下 0.2 M，兩者都會消耗 0.8 M 且生成物們的濃度都會是 0.8 M，現在請同學們算一下並且代入化學反應式裡：$k_c = [CO][H_2]/[CO][H_2O]$，

學生： 寫完了，答案是 16 嗎？

老師： 沒錯，讓我們進到第三小題，那你們還記得什麼是產率嗎？在正常情況下，我們的化學反應式不會 100%生成，公式是「實際產量/理論產量×100%」，理論產量是計算出來完美的產量，實際產量是實驗後獲得的產量。而第二小題題目跟我們說取 1 M CO 跟 1 M H_2O，根據係數比 1:1:1:1，理論上生成物的濃度也應該是 1 M CO_2 跟 1 M H_2，而經由我們剛剛的運算我們卻只有得到了 0.8 M 而已，所以我們可以把產率寫成：

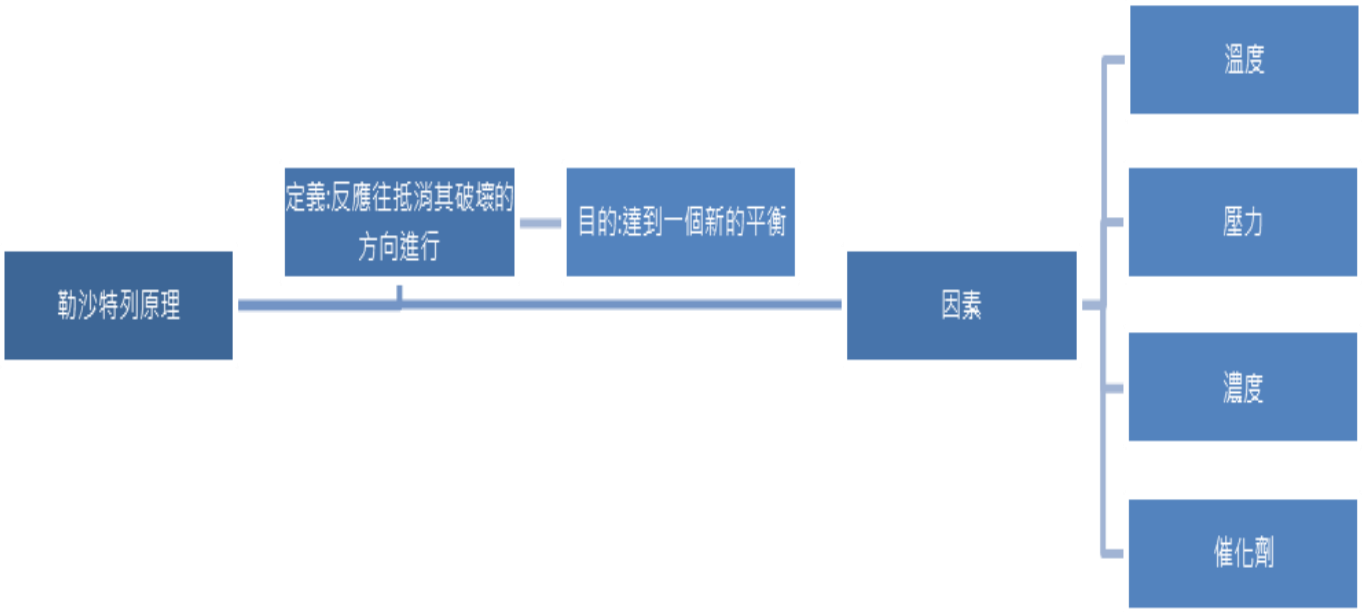
學生： 0.8M/1M × 100% = 80%

老師： 非常好！第三小題藉由第二小題求得的 k_c=16 就可以算出平衡濃度，但問題來了!我們不知道平衡的濃度因為我們並不知道兩個反應物消耗了多少，所以我們可以假設反應過程中消耗的 x M，再用第一小題同樣的方式代入 k_c 求得我們的 x，同時也就是題目問的 H_2 的平衡濃度。

1-3 勒沙特列原理
Le Chatelier Principle

■ 前言 Introduction

此小節教師引導學生了解基本勒沙特列的原理並讓他們知道影響反應破壞的因素。



語言方面，教師可以帶入句型，引導學生用英文將影響反應速率的因素分類、描述反應的目的和物質的功用，並學習如何用英文表示正／負相關。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
absorb	吸收	Haber process	哈伯法
colorimetry	比色法	industrial (adj.)	工業的
compress	壓縮	Le Chatelier principle	勒沙特列原理

dissociation	解離	nitrogen dioxide	二氧化氮
decomposition	分解	piston	活塞
dinitrogen tetroxide	四氧化二氮	reddish-brown	紅棕色

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ _____ be divided into _____.

例句：The factors that affect the reaction rate can **be divided into** temperature, concentration, pressure and catalyst.

影響反應速率的因素可以分為：溫度、濃度、壓力，和催化劑。

❷ in order to _____.

例句：When the equilibrium is disrupted by external factors, the system will move in the direction to counteract the disruption **in order to** achieve a new equilibrium.

當平衡狀態受到外在因素的破壞，系統會往抵消它破壞的方向移動，以達到新的平衡。

❸ use ____ as _____.

例句：Haber Process for ammonia synthesis is a way that **uses** iron **as** catalyst to produce NH_3. It is also a common example of Le Chatelier principle in action.

哈伯法製氨是工業上製造氨的方式並以鐵為催化劑，也是常見的勒沙特列應用實例。

❹ _____ be (directly) proportional to _____.

例句：The concentration of a solution **is** directly **proportional to** the depth of color. By measuring the intensity of light absorbed by a colored solution, we can determine the content in the solution. This is the principle of basic colorimetry.
溶液濃度與顏色深度呈正比，藉由測光被有色溶液吸收的強度，我們可以知道溶液物質內的含量，這就是基本比色法的原理。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：
After studying this chapter, students should be able to know that:
一、學生能了解影響平衡的因素及加入因素後反應的平衡方向。
Students can understand the factors in equilibrium and the direction of equilibrium shifts upon the addition of the factor(s).

❧ 例題講解 ☙

例題一

說明：學生可以把影響反應速率因素的概念代入問題中做應用。
Students can apply the concept of factors in reaction rates to solve problems.

After pressurization, which of the following reactions will shift to the right?

(A) $N_2O_{4(g)} \leftrightarrows 2NO_{2(g)}$

(B) $C_2H_{4(g)} + H_{2(g)} \rightleftarrows C_2H_{6(g)}$

(C) $2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$

(D) $H_{2(g)} + Cl_{2(g)} \rightleftarrows 2HCl_{(g)}$

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

下列這些反應加壓後，會使哪些選項反應向右移動？

(A) $N_2O_{4(g)} \leftrightarrows 2NO_{2(g)}$

(B) $C_2H_{4(g)} + H_{2(g)} \rightleftarrows C_2H_{6(g)}$

(C) $2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$

(D) $H_{2(g)} + Cl_{2(g)} \rightleftarrows 2HCl_{(g)}$

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

（110 上高中選修化學泰宇 第一章－化學平衡第 25 頁例題 10）

Teacher: Let's take a look at an example about how pressure affects reaction direction.

Student: Ok.

Teacher: Now that you know that pressure is one of the factors in the reaction direction, do you know which way pressure will cause the reaction to shift, right or left?

Student: Left.

Teacher: Well, nice try, but it's not the correct answer. Do you remember the Ideal Gas Law PV = nRT?

Student: We can take the reaction coefficient as the number of moles that increases or decreases. The sum of reaction coefficients on the left can be seen as the number of moles that the reactant consumes, while the sum of reaction coefficients on the right can be seen as the number of moles that the product produces.

Student: Teacher, I still don't get it.

Teacher: For example, in item (A) "$N_2O_{4(g)} \leftrightarrows 2NO_{2(g)}$", I can say that the ratio of reactant and product is 1:2 because the ratio of reaction coefficient is 1:2.

Student: The number of moles increases as the reaction heads to right in (A). According to the Ideal Gas Law, moles are directly proportional to pressure. So, the pressure will be higher, the answer is (B)(C)(E).

Teacher: Excellent, that's right! If I can make sure that all the reactions go right, then the pressure will increase when the coefficient decreases.

老師： 我們來看一個壓力影響反應方向的例子。

學生： 好。

老師： 你們知道既然壓力是影響反應方向一個大的因素，你們知道壓力會使反應向右還是向左呢？

學生： 向左。

老師： 不對，但是個好的嘗試。你們還記得理想氣體方程式 PV = nRT 嗎？

學生： 我們可以把反應係數視為增加或減少的莫耳數，而左邊的反應係數和可以視為反應物消耗的莫耳數，右邊可以視為生成物生成的莫耳數。

學生： 老師我還是聽不懂。

老師： 像是你們看題目的(A) $N_2O_{4(g)} \leftrightarrows 2NO_{2(g)}$我就可以說反應物：生成物比是 1:2。因為反應係數比是 1:2。

學生： 所以我可以說莫耳數在(A)反應向右過程中變大，根據理想氣體方程式，莫耳數跟壓力呈正相關，壓力因此變大，所以答案是(B)(C)(E)！

老師： 太棒了！就是這樣！如果我可以確定反應都是往右的情況下，係數變小壓力就會變大喔！

例題二

說明：學生能藉學習均相與非均相來了解濃度對反應方向的影響

Students can understand the impacts of concentration on reaction direction by learning about homogeneous and heterogeneous reactions.

In the chemical equation "$2CrO_4^{2-}{}_{(aq)} + 2H^+ \rightleftarrows Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$", which of the following factors can shift the reaction towards the forward direction?

(A) Add $K_2CrO_{4(s)}$

(B) Add concentrated $NH_{3(aq)}$

(C) Add $BaCl_{2(s)}$

(D) Add $H_2O_{(l)}$

(E) Add concentrated $HNO_{3(aq)}$

$2CrO_4^{2-}{}_{(aq)} + 2H^+ \rightleftarrows Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$ 平衡反應式中，下列哪些因素可以使反應向正反應方向移動？

(A) 加入 $K_2CrO_{4(s)}$

(B) 加入濃 $NH_{3(aq)}$

(C) 加入 $BaCl_{2(s)}$

(D) 加入 $H_2O_{(l)}$

(E) 加入濃 $HNO_{3(aq)}$

（110 上課本（選修化學 I）第一章 第 10 頁 範例 2-2）

Teacher: (Write on the blackboard: $Fe^{3+}_{(aq)} + SCN^{-}_{(aq)} \rightleftarrows FeSCN^{2+}_{(aq)}$)
We just mentioned that pressure and volume can have an influence on the direction of equilibrium. Do you know that concentration can also affect the direction of equilibrium?

Student: Yes. If I add $Fe(NO_3)_3$, the Fe^{3+} concentration of the reactant will increase.
To counteract this concentration, the reaction will move in the direction of the product. Besides, if I cut down the concentration of $FeSCN^{2+}$, the reactant will move to the right in order to make up for the concentration of the product and the reaction will shift to the right.

Teacher: Excellent! Now let's do exercise 1-7. Forward reaction direction refers to moving to the right. Do you know what causes the reaction to proceed to the right?

Student: I need to increase concentration on the side of the reactant, which means to increase the concentration of [CrO_4^{2-}] and [H^+]. Thus, I need to add K_2CrO_4, acids to provide the needed concentration.

Teacher: That's right, so we can choose (A) and (E). Now, can you explain why (B), (C) and (D) are incorrect?

Student: For (B), adding $NH_{3(aq)}$will neutralize the reactant H^+ and cut down the amount of H^+, so the reaction will go left when the reactant decreases. In (C), when $BaCl_2$ is added, it will form a precipitate $BaCrO_4$ with the reactant CrO_4^{2-}, reducing the concentration of CrO_4^{2-} and thus making the reaction go left.

Teacher: Great! Then you are supposed to know why (D) is false, right?

Student: In (D), adding water means the amount of the product will increase. It will move to the direction of the reactant to counteract the concentration of water, so the reaction goes left.

老師： (在黑板寫下：$Fe^{3+}_{(aq)} + SCN^{-}_{(aq)} \rightleftarrows FeSCN^{2+}_{(aq)}$)
剛剛我們提到壓力跟體積可以影響反應平衡方向，那你們知道濃度也可以影響平衡方向嗎？

學生： 知道，如果我加了硝酸鐵，反應物的鐵離子濃度增加，為了抵銷這個濃度，反應會往生成物的方向移動。此外，當我減少 $FeSCN^{2+}$的濃度，會使得反應物往右去彌補生成物的濃度，也會使得反應往右。

老師： 太棒了！那我們現在來做這一題範例 1-7，所謂的正反應方向就是往右，那你們知道哪些因素可以使反應往右了吧！

學生：我需要在反應物的那一邊增加濃度-也就是增加[CrO_4^{2-}]以及[H^+]濃度，所以我需要藉由加入 K_2CrO_4、酸類物質來提供所需的濃度！

老師：沒錯，所以我們可以選(A)、(E)。你們可以解釋(B)(C)(D)錯的地方在哪裡嗎？

學生：(B)加入氨會去中和反應物的 H^+，會減少 H^+的量，所以反應物減少時反應會往左；(C)加入 $BaCl_2$ 時會和反應物的 CrO_4^{2-}形成沉澱 $BaCrO_4$，進而減少 CrO_4^{2-}的濃度，反應向左。

老師：學得很好喔！那你們應該知道 D 為何錯吧！

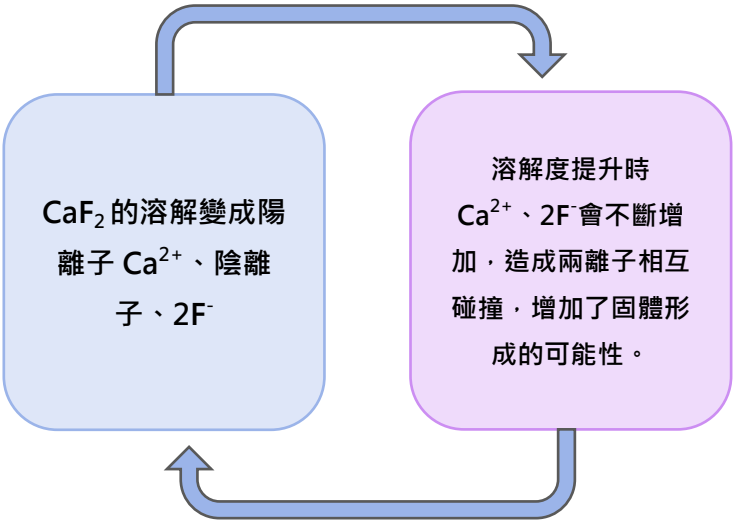
學生：(D)加入水代表生成物增加，會往反應物方向去抵銷水的濃度，所以反應向左。

1-4 溶解平衡與溶度積的關係
The Relationship between Dissolution Equilibrium and Solubility Product

■ 前言 Introduction

溶解是生活中一個非常常見的現象。經由前面平衡的概念我們可以說此反應是達到了溶解平衡：

舉例說 $CaF_{2(S)}$溶於水中：$CaF_{2(S)} \rightleftarrows Ca^{2+}_{(aq)} + 2F^{-}_{(aq)}$



語言方面，教師可以透過句型引導學生用英文表達達成目的的方法或手段，並試著用英文描述別稱。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
common-ion effect	同離子效應	precipitation	沉澱
dissolve	溶解	qualitative analysis	定性分析

enamel	琺瑯質	quantitative analysis	定量分析
filtration	濾液	solubility	溶解度
ion product	離子積	solubility product	溶度積
kidney stones	腎結石	soluble/insoluble	可溶/不可溶的
lime	石灰	spectrometry	光譜法

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ By _____, _____.

例句：**By** knowing the solubility of ions or the concentration of ions**,** we can determine the solubility product of this salt.

我們可以藉由知道離子的溶解度或是離子濃度以求得此鹽類的溶度積。

❷ _____, also referred to as _____.

例句：The solubility product constant is the equilibrium constant for the dissolution equilibrium**, also referred to as** the "solubility product" in the equilibrium equation.

溶解度積常數是溶解度平衡的平衡常數，也被稱為平衡方程式中的「溶解度積」。

❸ _____ include __(N/V-ing)__.

例句：Examples of common ion effects **include** the salting out of saponification, gout and kidney stones.

常見同離子效應的例子包含、皂化反應的鹽析、痛風、腎結石。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After this lesson, students should be able to know:

一. 學生能了解溶度積。

Students can understand the solubility product.

❧ 例題講解 ☙

例題一

說明：學生能藉由鹽類的溶解度差異的性質來做沉澱分離的應用。

Students can apply the differences in solubility properties of salts for precipitation and separation purposes.

During blood collection, it is common to see nurses using tubes of various colors. Each color represents a different medical purpose. For example, the gray tube contains calcium oxalate as an anticoagulant. Sodium fluoride can be used to prevent the glycolysis of red blood cells and is commonly used in glucose and lactic acid testing. In order to prevent clotting of extracted blood from the body, calcium ions must be removed from the plasma. Therefore, the function of anticoagulants such as oxalate ions ($C_2O_4^{2-}$) is to remove calcium ions from the blood. When the concentration of $C_2O_4^{2-}$ is high enough, the reaction between calcium ions and oxalate ions will form solid CaC_2O_4 precipitate. It is known that $[Ca^{2+}]$ in the serum sample is 2.2×10^{-3} M. Try to answer the following questions:

(CaC_2O_4 $K_{sp} = 1.96\times10^{-8}$, $K_2C_2O_4$ molar mass 166 g/mol)

(1) At what concentration of $[C_2O_4^{2-}]$ in the blood will calcium ions precipitate?

(2) At least how many milligrams of potassium oxalate ($K_2C_2O_4$) are needed in a 3.0 mL vacuum blood collection tube to inhibit blood clotting?

抽血的時候，常常會看到護理師拿著五顏六色的採血管。不同顏色的採血管分別代表不同的醫療用途。例如：灰色的管中含有草酸鈣當作抗凝血劑，氟化鈉可避免紅血球糖解，常被用於檢驗血液中葡萄糖和乳酸。為了避免抽出人體的血液凝結，必須從血漿中除去鈣離子，所以抗凝劑的作用就是去除血液中鈣離子，如草酸根($C_2O_4^{2-}$)。當 $C_2O_4^{2-}$濃度夠高時，鈣離子和草酸根會形成固體 CaC_2O_4 沉澱。已知血清樣品中$[Ca^{2+}] = 2.2\times10^{-3}$ M。試回答下列問題：

(CaC_2O_4 $K_{sp} = 1.96\times10^{-8}$，$K_2C_2O_4$ 莫爾質量 166 g/mol)

(1) 血液中的鈣離子在$[C_2O_4^{2-}]$大於多少時，會產生沉澱？

(2) 一支 3.0 mL 的真空抽血管中，最少須含有多少毫克的草酸鉀($K_2C_2O_4$)才可抑制血液凝固？

Ans:(1) 8.9×10^{-6} M (2) 4.4×10^{-3} mg

(1) 需要讓血液沉澱的前提是要讓 $Q > K_{sp}$ 而已知 $[Ca^{2+}] = 2.2\times10^{-3}$M ∴ 設$[C_2O_4^{2-}] = X$

$Q = [Ca^{2+}][C_2O_4^{2-}] = (2.2\times10^{-3}\ M) \times X > K_{sp} = 1.96\times10^{-8}$

$1.96\times10^{-8}/2.2\times10^{-3}$ ∴$X = 8.9\times10^{-6}$ M

(2) M × V = mole ∴8.9×10^{-6} M×(3×10^{-3}) = 2.67×10^{-8} mole

mole =克數/$K_2C_2O_4$ 分子量 (設克數為 y), y/166.7 = 2.67×10^{-8} mole = 4.45×10^{-6} g = 4.45×10^{-3} mg

（110 上 龍騰課本 高中選修化學 第二章沉澱反應 範例 2-6 p.86)

Teacher: Let's take a look at example 2-6. Don't be intimidated by the length of the question. Please read the entire question carefully.

Student: We finished reading it.

Teacher: All right. Then what conditions are required for oxalate to precipitate?

Student: (Students point out the key points of precipitation judgment on page 92 of the textbook)
To let the reaction proceed in the direction of precipitation, Q needs to achieve the solubility product. So, Q needs to be greater than $K_{sp} = 1.96\times10^{-8}$ here.

Teacher: Great job! We can then substitute the known concentration to get our answer 8.9×10^{-6} M.

Teacher: How about question number two?

Student: Multiply the concentration obtained in the first question by the volume of 3 mL to get the number of moles, and then deduce the number of grams from the number of moles.

Teacher: Remember what the answer wants is milligrams, not grams. So, we have to multiply that by 1000.

Student: Thanks for your reminder!

老師： 請看例題 2-6，不要看這題目很長就不敢寫。請同學們把題目用心讀完！

學生： 讀完了！

老師： 好！那我想要問一下大家，我們剛剛所說的草酸根沉澱需要什麼條件？

學生： (學生指出課本第 92 頁沉澱判斷處的重點整理)

2-3 溶解平衡：

1. 溶度積：

2. 沉積的判斷：離子商以 Q 表示

(1) $Q < K_{sp}$ 時：表示此時仍為未飽和溶液且無沉澱產生。

(2) $Q > K_{sp}$ 時：反應往產生沉澱物的方向進行，直到重新產生沉澱。

3. 銅離子效應：於含有某鹽類的溶液中，加入與此鹽類相同的離子時，會降低溶液中此鹽類的溶解度。

Q 要達於溶度積才會使反應往沉澱方向進行!所以我們的 Q 需要大於 $K_{sp} = 1.96\times10^{-8}$

老師： 學得很好喔！那我們就可以把已知濃度代入就可以得到我們的答案 8.9×10^{-6} M。

老師： 第二小題怎麼算呢？

學生： 把第一小題求得的濃度乘體積 3 毫升得到莫耳數，再從莫耳數推得克數。

老師： 記得答案是要毫克不是要克！所以還要再乘 1000！

學生： 謝謝老師的提醒！

例題二

說明：學生能了解同離子的定義與計算。

Students can understand the definition and calculation of common-ions.

At 25 °C, the K_{sp} of $Mg(OH)_2$ is 3.2×10^{-11}, try to answer the following questions:

(1) What is the solubility of $Mg(OH)_2$ in pure water in Molarity?

(2) What is the solubility of $Mg(OH)_2$ in a 0.01M $Mg(NO_3)_2$ solution?

(3) What is the solubility of $Mg(OH)_2$ in a 0.01M NaOH solution?

(4) Compare the answers to questions two and three. Given equal concentrations of $[Mg^{2+}]$ and $[OH^-]$, which one will cause a greater decrease in the solubility of sodium hydroxide?

25 °C 時，$Mg(OH)_2$ 的 K_{sp} 為 3.2×10^{-11}，試求出：

(1) $Mg(OH)_2$ 在純水中的溶解度為多少 M？

(2) $Mg(OH)_2$ 在 0.01 M $Mg(NO_3)_2$ 溶液中的溶解度。

(3) $Mg(OH)_2$ 在 0.01 M NaOH 的溶解度。

(4) 比較題(2)、(3)的答案，在溶液中，同濃度的$[Mg^{2+}]$、$[OH^-]$存在，何者會使氫氧化鈉的溶解度降低程度較大？

（龍騰版 110 上課本（選修化學 I）第一章 第 88 頁 範例 2-7）

Ans:(1) 2.0×10^{-4} (2) 2.8×10^{-5} (3) 3.2×10^{-7} (4) $[OH^-]$

詳解：設$[OH^-]$、$[Mg^{2+}]$的濃度為 X

(1) $Mg(OH)_{2(S)} \rightleftarrows Mg^{2+}_{(aq)} + 2OH^-_{(aq)}$

-X M　　+X M　　+2X M

$\therefore K_{sp} = [Mg^{2+}][OH^-]^2 = 3.2\times10^{-11} \Rightarrow X\times4X^2 = 3.2\times10^{-11} \quad \therefore X = 2\times10^{-4}$

(2) $Mg(OH)_{2(S)} \rightleftarrows Mg^{2+}_{(aq)} + 2OH^-_{(aq)}$

-X M　　0.01 M+X M　　+2X M

(0.01 來自於 $Mg(NO_3)_2 \rightleftarrows Mg^{2+}+2NO_3^-$的$[Mg^{2+}]$)

$\therefore K_{sp} = [Mg^{2+}][OH^-]^2 = 3.2\times10^{-11} \Rightarrow (0.01+X)\times4X^2 = 3.2\times10^{-11} \quad \therefore X = 2.83\times10^{-5}$

(3) $Mg(OH)_{2(S)} \rightleftarrows Mg^{2+}_{(aq)} + 2OH^-_{(aq)}$

-X M　　+X M　　0.01 M+2X M

(0.01 來自於 $NaOH \rightleftarrows Na^+ + OH^-$的$[OH^-]$)

$\therefore K_{sp} = [Mg^{2+}][OH^-]^2 = 3.2\times10^{-7} \Rightarrow X\times(0.01+2X)^2 = 3.2\times10^{-11} \quad \therefore X = 3.1995\times10^{-7}$

Teacher: Now let's take a look at the example of the common-ion effect. Before doing this practice, please recall the definition of common-ion effect.

Student: By adding ions that have the same properties as salt, according to Le Chatelier's principle, an increase in ion concentration will cause the reaction to move to the left, thereby suppressing the dissociation of the salt and leading to a decrease in solubility.

Teacher: Right, can you help us solve these questions?

Student: The way to solve the first question is to assume $[Mg^{2+}]$ and $[OH^-]^2$ as X, multiply them and get the solubility product.

Teacher: Remember the coefficient of OH^- in question number one is 2, so it needs to be quadratic. That's great. The calculation of common-ion effect is used in questions two and three. You know how to solve them, right?

Student: Due to the high concentration of ions, I need to include the concentrations in the equilibrium equations. So in the second question, $[Mg^{2+}]$ with the addition of 0.01 M $Mg(NO_3)_2$ would be 0.01+X, and in the third question, $[OH^-]$ with the addition of NaOH would be 0.01+2X. In the fourth question, $[OH^-]$ will bring a larger impact because it is 2X, while $[Mg^{2+}]$ is X. Therefore, $[OH^-]$ has a greater effect on decreasing solubility compared to $[Mg^{2+}]$.

Teacher: Clear explanation. Would you like to come to the stage and write down the answer for everyone?

Student: Ok!

老師： 現在我們來看同離子效應的例題。做這題之前，請大家回憶一下同離子效應的定義。

學生： 藉由加入具有與鹽類相同的離子，根據勒沙特列原理，離子濃度的增加會造成反應向左，進而抑制鹽類的解離-溶解度就會下降！

老師： 沒錯，那麼你可以幫我們解題嗎？

學生： 第一小題就是把$[Mg^{2+}]$、$[OH^-]^2$ 假設為 X 相乘等於溶度積。

老師： 你還記得第一小題的 OH^-係數是 2 所以要兩次方，非常好！
第二跟三小題就是用到同離子的計算！你應該會吧！

學生： 由於離子的濃度很大，我需要在我的平衡式中加上我的濃度。所以現在第二小題[Mg^{2+}]在加入 $Mg(NO_3)_2$ 的 0.01 M 就會是 0.01+X，而第三小題的[OH^-]在我加入 NaOH 時就會是 0.01+2X

而第四小題影響較大者會是[OH^-]因為它是 2X 而[Mg^{2+}]是 X，所以它使溶解度下降的影響較[Mg^{2+}]來得大。

老師： 講解得很詳細，要不要上台寫給大家看？

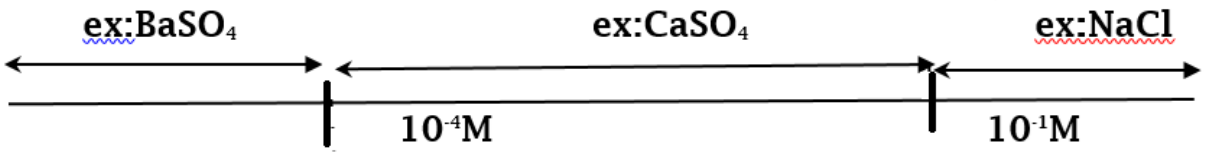
學生： 好！

1-5 離子之沉澱、分離及確認
Precipitation, Separation and Confirmation of Ions

■ 前言 Introduction

我們知道當 K_{sp} 越小時，反應會傾向往左使得鹽類的濃度增加，在鹽類已經超過其溶解度時則會有部分的鹽類析出，這就叫做沉澱反應。

不同的鹽類都有不同的 K_{sp} 取決於陰離子與陽離子結合的種類。



語言方面，教師可以利用句型讓學生使用英文表達因果關係，並試著描述狀態發生的可能性。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
anion	陰離子	ion exchange	離子交換
cation	陽離子	predict	預測
clarify	澄清	reagent	試劑
coral	珊瑚	saturated	飽和
electrolyte	電解質	selectivity	選擇性
hydrolysis	水解	slightly soluble	微溶性
identification	鑑定	turbid	混濁

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ on the basis of _____

例句：Salts can be divided into soluble, slightly soluble and insoluble salts **on the basis of** the difference in solubility.

鹽類依照溶解度的差異可以區分為可溶、微溶及難溶性鹽類。

❷ due to +N

例句：Soap loses its cleaning effectiveness in hard water **due to** the formation of a precipitate with calcium ions at its hydrophilic end.

肥皂在硬水中因為其親水端和鈣離子形成沉澱而失去洗滌的效果。

❸ have the potential/chance/opportunity to ____

例句：When the concentration of salts exceeds their solubility, they **have the potential to** precipitate.

當鹽類濃度高於溶解度時它就有機會產生沉澱。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After this lesson, students should be able to know:

一、學生藉所學的沉澱表來判斷離子沉澱的先後順序。

Students can use the precipitation table they learned to determine the order of ion precipitation.

❧ 例題講解 ☙

例題一

說明：學生學習在多種離子時可以藉由加入適當試劑使離子依序發生沉澱反應。

Students can learn that when dealing with multiple ions, they can sequentially precipitate ions by adding appropriate reagents

The table below shows the results of the interaction between solutions of $Pb(NO_3)_2$, $Mg(NO_3)_2$ and $Ni(NO_3)_2$, and solutions of NaOH, Na_2SO_4 and Na_2S. In this table, "+" indicates precipitation occurred, and "-" indicates no precipitation.

A certain solution includes three cations: Pb^{2+}, Mg^{2+} and Ni^{2+}. If NaOH, Na_2SO_4, and Na_2S solutions are used as reagents for separation, what is the correct order of adding these three reagents?

(A) NaOH, Na_2SO_4, Na_2S (B) Na_2S, NaOH, Na_2SO_4

(C) Na_2SO_4, Na_2S, NaOH (D) Na_2SO_4, NaOH, Na_2S

(E) NaOH, Na_2S, Na_2SO_4

	$Pb(NO_3)_2$	$Mg(NO_3)_2$	$Ni(NO_3)_2$
NaOH	+(white precipitate)	+(white precipitate)	+(green precipitate)
Na_2SO_4	+(white precipitate)	-	-
Na_2S	+(black precipitate)	-	+(black precipitate)

下表示硝酸鉛、硝酸鎂、硝酸鎳三種溶液與氫氧化鈉、硫酸鈉、硫化鈉三種溶液作用的結果，表中的「+」表示發生沉澱、「-」表示沒有沉澱。

某水溶液中含 Pb^{2+}、Mg^{2+}及 Ni^{2+}三種陽離子，若以 NaOH、Na_2SO_4 及 Na_2S 溶液作為試劑使分離，則滴加三種試劑的先後順序，何者正確?

(A) NaOH, Na_2SO_4, Na_2S　(B) Na_2S, NaOH, Na_2SO_4

(C) Na_2SO_4, Na_2S, NaOH　(D) Na_2SO_4, NaOH, Na_2S

(E) NaOH, Na_2S, Na_2SO_4

	$Pb(NO_3)_2$	$Mg(NO_3)_2$	$Ni(NO_3)_2$
NaOH	+(白色沉澱)	+(白色沉澱)	+(綠色沉澱)
Na_2SO_4	+(白色沉澱)	-	-
Na_2S	+(黑色沉澱)	-	+(黑色沉澱)

（110 上龍騰課本 高中選修化學 第二章沉澱反應 範例 2-3 p.80)

Ans: (C)

首先要判斷的就是發生沉澱反應最少種類的，**要在第一**次滴加陰離子試劑時只和一種陽離子產生一種沉澱物，如果陰離子會和兩種陽離子產生沉澱時就無法達到沉澱的效果：∵第一次選擇分離時我們要選擇試劑與陽離子反應最少種的.∴我們要選擇 Na_2SO_4，我們已經扣除了 Pb^{2+}，因此在第二次我們可以選擇 Na_2S 來分離 Ni^{2+}，最後才會分離 Mg^{2+}。顏色順序為：白色沉澱→黑色沉澱→綠色沉澱，藉由顏色的順序我們可以明顯地辨別沉澱的先後順序。

Teacher: After doing the experiment in the laboratory, now you all know how to separate and identify the ions, right?

Student: Yes!

Teacher: The so-called separation means it can only produce one precipitate at a time. So, if it produces more than one kind of precipitates after adding the reagent, the goal of separation will not be achieved, right?

Student: Right!

Teacher: So, which solution should be added first?

Student: Na_2SO_4, because it will only react with $Pb(NO_3)_2$ and form a precipitation of $PbSO_4$.

Student: Then we have to choose Na_2S because $Pb(NO_3)_2$ is removed and only Ni^{2+} and Mg^{2+} are left in the reagent. Only Na_2S will react with $Ni(NO_3)_2$ and produce a precipitation of NiS. The last one we have to choose is NaOH and it will produce $Mg(OH)_2$.

Teacher: Great! You are good at learning by analogy. The conclusion is that the reagent that produces the least precipitation will be our priority.

老師： 各位在實驗室做完實驗後，大家知道要怎麼分離並鑑定離子的吧！

學生： 知道！

老師： 所謂的分離，就是一次只會產生一種沉澱物，如果再滴加試劑後產生超過一種沉澱物，就無法達到了分離的目的了對不對？

學生： 對！

老師： 所以我們應該選？

學生： Na_2SO_4，因為它只會和 $Pb(NO_3)_2$ 的 Pb^{2+}產生 $PbSO_4$ 的沉澱。

學生： 接著就要選 Na_2S，因為 $Pb(NO_3)_2$ 已經被剔除了!試劑內只會剩下 Ni^{2+}、Mg^{2+}，只有 Na_2S 會與 $Ni(NO_3)_2$ 產生 NiS，最後才是 NaOH，產生 $Mg(OH)_2$。

老師： 很好！會舉一反三，所以結論就是我們要選擇產生最少沉澱的試劑為優先。

例題二

說明：學生能了解常見陰離子和陽離子所生成化合物的溶解性及顏色。

Students can understand the solubility and color of chemical compounds formed by common anions and cations.

In analytical chemistry, there is a qualitative analysis method that identifies ions in a solution through chemical reactions, based on the possible color changes, precipitations or other observable phenomena that related to specific ions. The table below is the result of the "anion and cation precipitation experiment". The concentration of each ion is 0.1 M. Equal volumes are taken and mixed to record the precipitate situation. Please try to answer questions one and two.

(1) In how many cells of A, B, C, D, E, and F will not produce precipitation?

(A) 1 (B) 2 **(C) 3** (D) 4 (E) 5

(2) Which of the following colors is closest to the color recorded in cell E?

(A) White

(B) Black

(C) Yellow

(D) Red

(E) Green

Ions	Ag^{+}	Pb^{2+}
CrO_4^{2-}	A	D
SO_4^{2-}	B	E
NO_3^{-}	C	F

在分析化學中，有一種定性分析是通過化學反應，針對特定離子可能出現的顏色變化、沉澱或其他可觀現象，以鑑定出溶液中的離子。下表是「陰、陽離子沉澱實驗」之實驗結果，各種離子的濃度均為 0.1 M，取等體積混合紀錄沉澱情形。請回答第(1)、(2)題：

(1) 甲、乙、丙、丁、戊、己 6 格當中、沒發生沉澱反應的有幾格？

(A) 1　(B) 2　**(C) 3**　(D) 4　(E) 5

(2) 戊格中所記錄的顏色，最接近下列何種顏色？

(A) 白色

(B) 黑色

(C) 黃色

(D) 紅色

(E) 綠色

離子	Ag^+	Pb^{2+}
CrO_4^{2-}	甲	丁
SO_4^{2-}	乙	戊
NO_3^-	丙	己

（翰林版 110 上課本（選修化學 I）第一章 第 109 頁 練習 1-12）

Teacher: Since you all know the basic definition of ion separation, do you remember the colors of different kinds of precipitates?

Student: No!

Teacher: Alright, then let's review what you have learned on page 108.

Teacher: Do you know what will produce precipitations?

Student: NO_3^- is an ion that will not produce precipitation, so C and D will not produce any precipitation with Ag^+ and Pb^{2+}.

Teacher: You are half right. Actually, there is another answer.

Teacher: What ions will SO_4^{2-} react with?

Student: 劉氏被簽蓋！So, it will react with Pb^{2+} but not Ag^+. B will not produce precipitation, the answer is (C)!

Teacher: Let's look at question number two. According to the color of the precipitate on page 108, do you know the color of the D precipitate?

Student: I remember that the color of $PbSO_4$ is white.

Teacher: It seems that you remember it very well! Then, do you remember the colors of the precipitates for compound A and compound D?

Student: Ag_2CrO_4 is brick red and $PbCrO_4$ is yellow!

Teacher: Exactly!

老師： 既然大家知道分離離子的基本定義了，那麼大家還記得各種沉澱物的顏色嗎？

學生： 不記得！

老師： 好，那麼們就做這題來複習一下觀念，還記得當時老師有請你們背 P.108 的內容嗎？

(老師叫同學翻開 P.108)

老師： 你們知道會產生沉澱的有哪幾種嗎？

學生： NO_3^-是不會產生沉澱的離子，所以丙、丁不會與 Ag^+、Pb^{2+}產生任何沉澱。

老師： 答案對一半，其實還有另一個答案。

老師： 硫酸根會和哪些離子做反應？

學生： 劉氏被簽蓋！所以是和 Pb^{2+}產生反應不跟 Ag^+產生反應，乙也不會產生沉澱，答案要選(C)！

老師： 再看一下第二小題，根據 P.108 的沉澱顏色，你們知道戊格沉澱物的顏色嗎？

學生： 我記得硫酸鉛的顏色是白色。

老師： 看來你記得非常熟呢！那麼你們還記得甲跟丁沉澱物的顏色嗎？

學生： Ag_2CrO_4 是磚紅色而 $PbCrO_4$ 是黃色的！

老師： 沒錯！

★ 主題二 酸鹼反應 ★
Acid-base Reaction

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■ 前言 Introduction

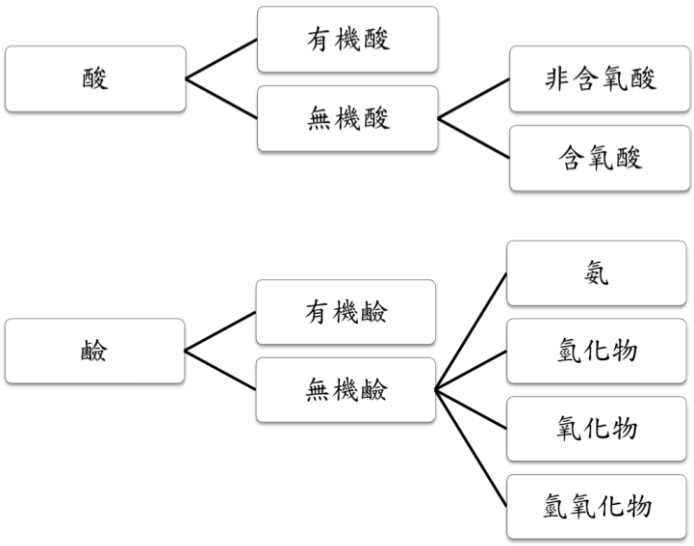
本章節中，希望學生能延續高一化學（全）已學過的酸和鹼的解離反應，更深入認識酸鹼學說及其科學史，從中學習判斷化合物的酸鹼性及相對強度。再進一步了解水的解離反應，與如何計算水溶液的 pH 值，並應用此概念理解弱酸與弱鹼的解離，和緩衝溶液的組成與性質。老師在課程中除了讓學生有系統性的認識酸與鹼的意義與計算，也可以進行實驗比較相同 pH 值的緩衝溶液與一般溶液的差異，讓學生親身體驗緩衝溶液的特性。語言方面，本章節較多酸與鹼的命名與專有名詞，以系統性地介紹字首字尾，幫助學生記憶複雜的命名規則。在課堂中以問題引導學生回答，透過思考幫助學生理解計算過程，強化學生對學習內容的認知。

2-1 酸與鹼的命名
Naming of Acids and Bases

■ 前言 Introduction

此小節教師引導學生認識酸與鹼的命名規則，藉由酸與鹼溶於水後會產生氫離子與氫氧根離子，舉數個化合物溶於水的化學反應為例，讓學生理解化合物溶於水後的酸鹼性，並藉由舉例整理出酸與鹼的命名規則。

語言方面，授課中老師可以根據酸與鹼的命名，介紹英文字彙的字首字尾規則，幫助學生記憶專有詞彙，同時輔助學生以英文表達酸鹼物質之相關性質。



■ 詞彙 Vocabulary

單字	中譯	單字	中譯
hydracid	非含氧酸	carboxylic acid	羧酸
polybasic acid	多元酸（多質子酸）	dioxide	氧化物

polybasic base	多元鹼	organic base	有機鹼
oxyacid	含氧酸	organic acid	有機酸
hydride	氫化物	inorganic base	無機鹼
hydroxide	氫氧化物	inorganic acid	無機酸

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ _____ can be divided into _____ and _____.

例句：Acids **can be divided into** inorganic acids **and** organic acids.
酸可分為無機酸和有機酸。

❷ _____ contain _____ groups and are called _____.

例句：Organic acids **contain** carboxyl **groups and are called** carboxylic acids.
有機酸含有羧機，稱為羧酸。

❸ dissolve in water to form _____.

例句：Non-metal oxides **dissolve in water to form** oxyacids.
非金屬氧化物溶於水形成含氧酸。

❹ ____ dissociate in water to produce _____, making the solution ____.

例句：Oxyacids **dissociate in water to produce** hydrogen ions**, making the solution** acidic.
含氧酸會在水中解離產生氫離子，使溶液呈酸性。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After studying this chapter, students should be able to know that:

一、學生能了解酸與鹼的命名規則。

Students can understand the naming rules of acids and bases.

❧ 例題講解 ☙

例題一

說明：學生能判斷化合物的酸鹼性。

Students can judge the acidity and alkalinity of compounds.

Of the following solutions of compounds, which ones are basic?

(A) $NH_{3(g)}$ (B) $SO_{3(g)}$ **(C) $CaO_{(s)}$**

(D) $P_4O_{6(s)}$ **(E) $Ba(OH)_{2(s)}$**

下列化合物的水溶液，那些呈鹼性？

(A) $NH_{3(g)}$ (B) $SO_{3(g)}$ **(C) $CaO_{(s)}$**

(D) $P_4O_{6(s)}$ **(E) $Ba(OH)_{2(s)}$**

（龍騰版 11_上課本（選修化學 III）第三章 第 111 頁 練習 3-5）

Teacher: When hydroxide is dissolved in water, hydroxide ions will be produced. Is the aqueous solution acidic or alkaline?

Student: It would be alkaline.

Teacher: Very good. Which substance's oxide will become alkaline when dissolved in water?

Student: Metal oxides are alkaline when dissolved in water.

Teacher: Good. Do you have any other questions?

Student: I would like to ask a question. Why is NH_3 aqueous solution alkaline?

Teacher: Good question. When NH_3 dissolves in water it will form NH_4^+ ions and OH^- ions, making the solution alkaline.
(The teacher can write down the reaction equation on the blackboard:
$NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$)
Student: Got it!

老師： 氫氧化物溶於水後，會產生氫氧根離子，請問此時水溶液酸鹼性為何？
學生： 鹼性。
老師： 很好。請問哪種物質的氧化物溶於水後會呈現鹼性呢？
學生： 金屬氧化物溶於水呈現鹼性。
老師： 非常好。同學們還有問題嗎？
學生： 老師，請問為什麼 NH_3 水溶液呈現鹼性呢？
老師： 同學的問題非常好，NH_3 溶於水會形成 NH_4^+離子與 OH^-離子，使溶液呈現鹼性。
（可在黑板上寫下反應式：$NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$）
學生： 老師我懂了！ 謝謝老師。

例題二

說明：學生能判斷非金屬氧化物溶於水，使溶液呈酸性。
Students can tell that non-metal oxides dissolve in water to make the solution acidic.

Many physiological reactions in organisms require the catalytic ability of enzymes to proceed smoothly. When the pH value of blood is unstable, it will affect the ability of enzymes. It is known that the concentration of CO_2 in the blood will affect the pH value of the blood, and breathing rate will affect the concentration of CO_2 in the blood. When breathing accelerates, the expulsion of CO_2 from the body also speeds up.
Which of the following statements is correct?

(A) When the pH level of the blood is higher than the normal value, breathing will slow down to increase the CO_2 concentration in the blood and bring it back to normal.
(B) When the pH level of the blood is lower than the normal value, breathing will slow down to increase the CO_2 concentration in the blood and bring it back to normal.
(C) When the pH level of the blood is lower than the normal value, breathing will become faster to increase the CO_2 concentration in the blood and bring it back to normal.

(D) When the pH level of the blood is lower than the normal value, breathing will slow down to decrease the CO_2 concentration in the blood and bring it back to normal.

(E) When the pH level of the blood is higher than the normal value, breathing will become faster to decrease the CO_2 concentration in the blood and bring it back to normal.

生物體內許多生理反應均需要酵素的催化能力才能順利進行。當血液的酸鹼值不穩定時，會影響酵素的能力。已知血液中的 CO_2 濃度會影響血液的酸鹼值，而呼吸的快慢會影響血液中的 CO_2 濃度，當呼吸加快時，體內排出 CO_2 則變快。

下列敘述哪一項正確？

(A) 當血液中的酸鹼值較正常值高時，呼吸會變慢，以增加血液 CO_2 濃度，使其回復正常。

(B) 當血液中的酸鹼值較正常值低時，呼吸會變慢，以增加血液 CO_2 濃度，使其回復正常。

(C) 當血液中的酸鹼值較正常值低時，呼吸會變快，以增加血液 CO_2 濃度，使其回復正常。

(D) 當血液中的酸鹼值較正常值低時，呼吸會變慢，以降低血液 CO_2 濃度，使其回復正常。

(E) 當血液中的酸鹼值較正常值高時，呼吸會變快，以降低血液 CO_2 濃度，使其回復正常。

（109 年大學指定考試化學考科 第 12 題）

Teacher: What is the acidity and alkalinity of the solution after non-metal oxides dissolve in water?

Student: It would be acidic.

Teacher: When the pH value in the blood is higher than the normal value, what would the pH level of the blood be? Is it alkaline or acidic?

Student: Alkaline.

Teacher: Good! Then would the CO_2 concentration in the blood be higher or lower?

Student: It would be lower.

Teacher: Very good. When the CO_2 concentration in the blood is low, should the CO_2 concentration in the blood increase or decrease in order to restore it to a normal value?

Student: It should increase.

Teacher: Great. When breathing accelerates, the expulsion of CO_2 from the body also speeds up. Therefore, when the CO_2 concentration in the blood is low, should breathing be faster or slower to return to the normal value?

Student: It should be slower! I got it!

老師： 非金屬氧化物溶於水後，溶液的酸鹼性為何？

學生： 酸性。

老師： 當血液中的酸鹼值較正常值高時，表示血液的酸鹼性為何呢？是鹼性還是酸性？

學生： 鹼性。

老師： 很好！那表示血液中的 CO_2 濃度較高還是較低呢？

學生： 較低。

老師： 非常好。此時血液中的 CO_2 濃度較低時，為使其回復正常值，應該增加還是減少血液中的 CO_2 濃度？

學生： 增加。

老師： 很好。當呼吸加快時，體內排出 CO_2 則變快。因此當血液中的 CO_2 濃度較低時，呼吸應變快還是變慢，才能使其回復正常值？

學生： 變慢！老師我懂了！

2-2 布-洛酸鹼學說
Bronsted-Lowry Theory of Acid and Base

■ 前言 Introduction

在此小節，學生學習布-洛酸鹼學說內容、布-洛酸鹼之定義。教師透過得失質子說明如何判別共軛酸鹼對，使學生能夠從化學反應式中找出共軛酸、鹼，並從共軛酸鹼對酸鹼性之強弱判斷反應方向。

語言方面，學生能夠使用比較級比較物質不同的酸鹼性，以及各酸鹼性的強弱之分。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
The Brønsted-Lowry acid-base theory	布-洛酸鹼學說	conjugate base	共軛鹼
Brønsted-Lowry acid	布-洛酸	strong base	強鹼
Brønsted-Lowry base	布-洛鹼	strong acid	強酸
amphoteric substance	兩性物質	proton	質子
conjugate acid-base pair	共軛酸鹼對	weak base	弱鹼
conjugate acid	共軛酸	weak acid	弱酸

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ **_____ donates protons and is called Brønsted-Lowry acid; while _____ accepts protons and is called Brønsted-Lowry base.**

例句：Hydrogen chloride **donates protons and is called Brønsted-Lowry acid; while** water **accepts protons and is called Brønsted-Lowry base**.
氯化氫提供質子稱為布-洛酸，水接受質子稱為布-洛鹼。

❷ **_____ loses a proton after the reaction and becomes _____; while _____ gains a proton and becomes _____.**

例句：The acid (HA) **loses a proton after the reaction and becomes** a base (A^-) **; while** the base (B^-) **gains a proton and becomes** an acid (HB).
酸(HA)反應後失去質子變成其共軛鹼(A^-) ；而鹼(B^-)獲得質子變為其共軛酸(HB)。

❸ **_____ and _____ are conjugate acid-base pairs, _____ is the conjugate acid of _____, and _____ is the conjugate base of _____.**

例句：HA **and** A^- **are conjugate acid-base pairs,** HA is the conjugate acid of A^-, and A^- **is the conjugate base of** HA.
HA 和 A^-互為共軛酸鹼對，HA 為 A^-的共軛酸，A^-為 HA 的共軛鹼。

❹ **Substances that can _____ protons _____ are called _____ acids.**

例句：**Substances that can** donate **protons** better **are called** strong **acids.**
提供質子能力強之分子，稱為強酸。

❺ **The --er/more …, the -er/more ….**

例句：**The stronger** the acid**, the weaker** its conjugate base.
越強的酸，其共軛鹼為越弱的鹼。

❻ A substance that can act as both an acid and a base is called an amphoteric substance, such as _____.

例句：**A substance that can act as both an acid and a base is called an amphoteric substance, such as** H_2O.

既可扮演酸，亦可扮演鹼的物質，稱為兩性物質，例如 H_2O。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After studying this chapter, students should be able to know that:

一、學生能理解、應用布-洛酸鹼學說理論。

Students can understand and apply the Brønsted-Lowry acid-base theory.

❧ 例題講解 ☙

例題一

說明：學生能從化學式中找出共軛酸鹼對，並從反應方向判斷物質酸鹼性的強弱。

Students can identify conjugate acid-base pairs from chemical formulas and determine the relative strengths of acids and bases from the direction of the reaction.

Given the reaction $H_3PO_{4(aq)} + HCO_3^-{}_{(aq)} \rightleftharpoons H_2PO_4^-{}_{(aq)} + H_2CO_{3(aq)}$ tends to proceed towards the right, which of the following statements are correct?

(A) H_3PO_4 is acid, and HCO_3^- is base.

(B) H_3PO_4 is the conjugate acid of $H_2PO_4^-$.

(C) H_3PO_4 and HCO_3^- are a conjugate acid-base pair.

(D) H_2CO_3 is more acidic than H_3PO_4

(E) HCO_3^- is more alkaline than $H_2PO_4^-$

已知 $H_3PO_{4(aq)} + HCO_3^-{}_{(aq)} \rightleftharpoons H_2PO_4^-{}_{(aq)} + H_2CO_{3(aq)}$，此反應方向趨向右，下列敘述哪些正確？

(A) H_3PO_4 為酸，HCO_3^-為鹼

(B) H_3PO_4 為 $H_2PO_4^-$ 的共軛酸

(C) H_3PO_4 與 HCO_3^- 互為共軛酸鹼對

(D) H_2CO_3 的酸性較 H_3PO_4 強

(E) HCO_3^- 的鹼性較 $H_2PO_4^-$ 強

（翰林版_高中選修化學 III 課本 2-2 第 82 頁 範例 2-2）

Teacher: In this reaction, which two substances lose protons?

Student: H_3PO_4 and H_2CO_3.

Teacher: Correct! So, are H_3PO_4 and H_2CO_3 acids or bases?

Student: They are acids.

Teacher: Which two substances gain protons, and are Brønsted-Lowry bases?

Student: $H_2PO_4^-$ and HCO_3^-.

Teacher: Very good! So, which two are a conjugate acid-base pair?

Student: H_3PO_4 and $H_2PO_4^-$ are a conjugate acid-base pair. H_2CO_3 and HCO_3^- are another conjugate acid-base pair.

Teacher: That's right! Since the reaction tends to proceed to the right, which one is the stronger acid?

Student: H_3PO_4.

Teacher: Which one is the stronger base?

Student: HCO_3^-.

Teacher: Good!

老師： 在此反應式中，哪兩個物質失去質子？

學生： H_3PO_4、H_2CO_3

老師： 沒錯！因此 H_3PO_4、H_2CO_3 是酸還是鹼？

學生： 是酸。

老師： 那是哪兩個物質獲得質子，為布-洛鹼？

學生： $H_2PO_4^-$、HCO_3^-

老師： 很好！因此哪兩者間互為共軛酸鹼對？

學生： H_3PO_4、$H_2PO_4^-$互為共軛酸鹼對。H_2CO_3、HCO_3^-互為共軛酸鹼對。

老師： 沒錯！此反應方向趨向右，表示何者酸性較強？
學生： H_3PO_4。
老師： 何者鹼性較強？
學生： HCO_3^-。
老師： 非常好！

例題二

說明：學生能從布-洛酸鹼學說判斷各反應方向，並結合過去所學決定出平衡常數最小的反應。

Students can use the Brønsted-Lowry acid-base theory to determine the directions of various reactions, and combine it with what they have learned before to identify the reaction with the smallest equilibrium constant.

Under the same temperature, the order of acidity of the following five substances in water is $HClO_4 > CH_3COOH > HCN > H_2O > NH_3$. Which of the following reactions has the smallest equilibrium constant?

(A) $HClO_{4(aq)} + CN^-_{(aq)} \rightleftharpoons HCN_{(aq)} + ClO_4^-{}_{(aq)}$

(B) $HClO_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + ClO_4^-{}_{(aq)}$

(C) $CH_3COOH_{(aq)} + OH^-_{(aq)} \rightleftharpoons H_2O_{(l)} + CH_3COO^-_{(aq)}$

(D) $NH_2^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + OH^-_{(aq)}$

(E) $HCN_{(aq)} + CH_3COO^-_{(aq)} \rightleftharpoons CN^-_{(aq)} + CH_3COOH_{(aq)}$

相同的溫度下，下列五種物質在水中之酸性強弱順序為 $HClO_4 > CH_3COOH > HCN > H_2O > NH_3$。試問下列哪一個反應式的平衡常數最小？

(A)$HClO_{4(aq)} + CN^-_{(aq)} \rightleftharpoons HCN_{(aq)} + ClO_4^-{}_{(aq)}$

(B)$HClO_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + ClO_4^-{}_{(aq)}$

(C)$CH_3COOH_{(aq)} + OH^-_{(aq)} \rightleftharpoons H_2O_{(l)} + CH_3COO^-_{(aq)}$

(D)$NH_2^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + OH^-_{(aq)}$

(E)$HCN_{(aq)} + CH_3COO^-_{(aq)} \rightleftharpoons CN^-_{(aq)} + CH_3COOH_{(aq)}$

（107 年大學指定考試化學考科 第 2 題）

Teacher: Do you remember the equilibrium constant formula? If you do, please write it down.

Student: Equilibrium Constant = [Products]/[Reactants]

Teacher: Great, you all remember it very well! The question indicates that the equilibrium constant is at its minimum. Then which would be lower, the concentration of reactants or the concentration of the products?

Student: The concentration of the products would be lower.

Teacher: Perfect! So, in which direction should the reaction proceed?

Student: Towards the left.

Teacher: As mentioned in this chapter, does the reaction tend to proceed from a strong acid toward a weak acid or from a weak acid toward a strong acid?

Student: From a strong acid towards a weak acid.

Teacher: Excellent! Therefore, the answer must satisfy both the condition that the reaction proceeds from a strong acid towards a weak acid and the condition that the reaction proceeds towards the left. Only option E satisfies these conditions, with the acidity: HCN<CH_3COOH, the reaction proceeding towards the left, and the equilibrium constant being at its minimum. Hence, the answer is option E.

老師： 大家還記得平衡常數公式嗎？若還記得，請寫下平衡常數公式。

學生： 平衡常數＝[產物]/[反應物]

老師： 大家都還記得，非常好！題目中表示平衡常數最小，代表反應物還是產物濃度要較低？

學生： 產物。

老師： 很好！因此反應是要向哪邊進行呢？

學生： 向左。

老師： 在本章節提到，反應趨向為強酸往弱酸的方向進行還是弱酸往強酸方向進行呢？

學生： 強酸往弱酸。

老師： 太棒了！因此答案必須同時符合反應由強酸往弱酸方向進行且反應向左。選項中只有 E 選項，酸性：HCN<CH_3COOH，反應向左，平衡常數最小，故答案選 E。

2-3 酸鹼的解離平衡
Acid-base Dissociation Equilibrium

■ 前言 Introduction

在此小節，學生學習酸與鹼的解離平衡，理解酸鹼解離常數的定義及應用公式計算弱酸、弱鹼的 pH 值；了解同離子效應及計算緩衝溶液之 pH 值，並認識多質子酸的酸鹼平衡。語言部分，學生將學會以比較級呈現「越...(形容詞)，則越...(形容詞)」的句型用法。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
ion product constant	離子積常數	common-ion effect	同離子效應
complete dissociation	完全解離	polyprotic acid	多質子酸
partially dissociation	部分解離	charge balance	電荷平衡
degree of dissociation	解離度	mass balance	質量平衡
percent dissociation	解離百分比	buffer solution	緩衝溶液
hydrolysis	水解		

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ The -er/more …, the -er/more ….

例句(1)：The strength of an acid can be determined by the magnitude of its dissociation constant. The larger the K_a value, the stronger the acidity
酸的強弱可由酸的解離常數大小判斷，K_a 值愈大者，其酸性愈強.

例句(2)：At the same temperature and concentration**, the larger** the K_a value of different acids**, the larger** the dissociation percentage**,** and **the higher** the hydrogen ion concentration**.**
同溫度下，同濃度的不同酸，K_a 值愈大，解離百分比愈大，氫離子濃度也愈大。

例句(3)：**For the same** weak acid **at different** concentrations**, the greater** the concentration**, the** higher the hydrogen ion concentration, but the lower the dissociation percentage.
不同濃度的同一種弱酸，濃度愈大，氫離子濃度愈大，但解離百分比愈小。

❷ _____ is called/is known as _____.

例句(1)：When a weak acid reaches equilibrium on dissociation, the ratio of the concentration of dissociated hydrogen ions to the initial concentration of the weak acid **is called** the degree of dissociation of the weak acid.
當弱酸解離達平衡時，將解離出的氫離子濃度，與弱酸初濃度相除所得之比值，稱為弱酸的解離度。

例句(2)：The total charge of cations in aqueous solution must be equal to the total charge of anions**,** which **is known as** charge balance.
在水溶液中陽離子的總電荷量必等於陰離子的總電荷量，稱為電荷平衡。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After studying this chapter, students should be able to know that:

一、學生能理解酸鹼平衡反應，並利用酸鹼解離平衡公式求得答案。

Students can understand acid-base equilibrium reactions and use the acid-base dissociation equilibrium formula to find the answer.

❧ 例題講解 ☙

例題一

說明：學生能利用過去所學求得氫氧根離子，並利用酸鹼解離平衡公式求得答案。

Students can use what they have learned to determine the hydroxide ion concentration, and use the acid-base dissociation equilibrium formula to acquire the answer.

At 25 °C, the test results of the lake water samples showed that the pH value of the lake water was 7.98. Assuming that this value is completely affected by a certain basic compound A in the lake water, and the concentration of compound A at that time was 0.01 M. Which of the following values is closest to its base dissociation constant?

(A) 10^{-4} (B) 10^{-6} (C) 10^{-8} **(D) 10^{-10}** (E) 10^{-12}

在 25 °C 時，湖水樣品化驗結果顯示湖水之 pH 值為 7.98，假設此數值完全受湖水中某鹼性化合物甲的影響，而當時化合物甲的濃度為 0.01 M，則其鹼解離常數應最接近下列哪一數值?

(A) 10^{-4} (B) 10^{-6} (C) 10^{-8} **(D) 10^{-10}** (E) 10^{-12}

（107 年大學指定考試化學考科 第 17 題）

Student:	Sir, how do we find the dissociation constant of a base?
Teacher:	First, use pH + pOH = 14 to find out the pOH value of the lake water. What is the value?
Student:	7.98 + pOH = 14, so pOH = 6.02.

Teacher: Now that we know that pOH = 6.02, what is the [OH^-] concentration approximately？

Student: 10^{-6}.

Teacher: Very good. Therefore, the lake water is weakly alkaline. Now, what is the dissociation formula of the weak base?

Student: $[OH^-]=\sqrt{C_0K_b}$

Teacher: Then bring the [OH^-] obtained just now and the initial concentration C_0 in the title into the formula to find K_b.

Student: $K_b = 10^{-10}$.

Teacher: Good!

學生： 老師，要如何求得鹼的解離常數呢？

老師： 請大家先利用 pH + pOH = 14，求出湖水的 pOH 值是多少呢？

學生： 7.98 + pOH = 14，所以 pOH = 6.02

老師： 再由 pOH = 6.02，求出[OH^-]大約為多少呢？

學生： 10^{-6}。

老師： 很好。因此湖水屬於弱鹼性，大家回想弱鹼的解離公式為何呢？

學生： $[OH^-]=\sqrt{C_0K_b}$

老師： 再將剛剛求得[OH^-]及題目中的初濃度 C_0 帶入公式中，求出 K_b。

學生： $K_b = 10^{-10}$

老師： 非常好！

例題二

說明：學生能夠判斷溶液混合後溶液的性質，並利用酸鹼解離平衡公式、酸鹼中和反應式求得答案。

Students can determine the properties of the solution after mixing, and use the acid-base dissociation equilibrium formula and acid-base neutralization reaction formula to obtain the answer.

It is known that the K_a of HCOOH and CH_3COOH are 1.8×10^{-4} and 1.8×10^{-5}, respectively. There are 4 cups of aqueous solutions on the laboratory table, which are (1) 0.1 M CH_3COOH, (2) 0.1 M CH_3COONa, (3) 0.1 M HCOOH and (4) 0.1 M HCOONa.

If equal volumes of (1) and (2) are mixed to obtain solution A, equal volumes of (1) and (3) are mixed to obtain solution B, and equal volumes of (1) and (4) are mixed to obtain solution C, then what is the order of [CH_3COOH] of solutions A, B, and C from small to large?

(A) A<B<C　(B) B<A<C　**(C) C<B<A**　(D) A<C<B　(E) C<A<B

已知 HCOOH 與 CH_3COOH 的 K_a 分別為 1.8×10^{-4} 與 1.8×10^{-5}。實驗桌上有 4 杯水溶液，分別為(1) 0.1 M 的 CH_3COOH、(2) 0.1 M 的 CH_3COONa、(3) 0.1 M 的 HCOOH 與(4) 0.1 M 的 HCOONa。

若將等體積(1)與(2)混合得溶液甲，等體積(1)與(3)混合得溶液乙，等體積(1)與(4)混合得溶液丙，則溶液甲、乙與丙的[CH_3COOH]由小至大的順序為何？

(A)甲<乙<丙　(B)乙<甲<丙　**(C)丙<乙<甲**　(D)甲<丙<乙　(E)丙<甲<乙

（來源：110 年大學指定考試化學考科 第 14 題）

Teacher: Think about it, equal volumes of (1) and (2) are mixed to get solution A. What kind of solution is solution A?

Student: It is a buffer solution.

Teacher: That's right. Now use the acid dissociation equilibrium formula and bring the initial concentrations of HCOOH and CH_3COOH into the formula to obtain the dissociated [H^+]. Note that when solutions are mixed in equal volumes, the concentration is halved.

$$[H^+]=K_a\times\left(\frac{[CH_3COOH]}{[CH_3COO^-]}\right)$$

Student: $[H^+] = 1.8\times10^{-5}$.

Teacher: Then subtract the initial concentration of CH_3COOH from the concentration after the solution is mixed to determine the concentration of CH_3COOH in solution A.

Student: $0.05-1.8\times10^{-5}$. It roughly equals 0.05 M.

Teacher: What kind of solution is solution B formed by adding weak acid to weak acid?

Student: The solution is weakly acidic.

Teacher: Very good, so let's use the weak acid-base dissociation formula to find the dissociated $[H^+]$.

$$[H^+]=\sqrt{C_1K_1+C_2K_2}$$

Student: $[H^+] = 3.14\times10^{-3}$

Teacher: Then subtract the initial concentration of CH_3COOH from the concentration after the solution is mixed to determine the concentration of CH_3COOH in solution B.

Student: $0.05-(3.14\times10^{-3}$. It roughly equals 0.047 M.

Teacher: What reaction occurs in solution C when a weak acid is mixed with a weak base?

Student: It would reach acid-base neutralization.

Teacher: Very good. Therefore, we have to write the acid-base neutralization reaction formula. Use stoichiometry to find the consumption of CH_3COOH and find the dissociation constant K_c of this reaction formula.

$$\underset{0.05-x}{CH_3COOH}+\underset{0.05-x}{HCOO^-}\rightarrow \underset{x}{CH_3COO^-}+\underset{x}{HCOOH}$$

$$K_c=\frac{1.8\times10^{-5}}{1.8\times10^{-4}}=0.1$$

What is the value of x obtained through the dissociation constant formula?

Student: x = 0.012.

Teacher: Then subtract the concentration of acid-base neutralization consumption of the solution from the initial concentration of CH_3COOH to obtain the concentration of CH_3COOH in solution C.

Student: 0.05-0.012, which approximately equals 0.05 M. I understand! $[CH_3COOH]$: C<B<A

老師： 請大家想一想，相等體積的(1)與(2)混合得溶液甲，溶液甲是什麼樣的溶液呢？

學生： 緩衝溶液。

老師： 沒錯，因此利用酸的解離平衡公式，將 HCOOH 與 CH_3COOH 初始濃度帶入公式中，求得解離出的$[H^+]$。提醒大家溶液等體積混合，濃度減半。

$$[H^+]=K_a\times\left(\frac{[CH_3COOH]}{[CH_3COO^-]}\right)$$

學生： $[H^+] = 1.8\times10^{-5}$

老師： 很好。再將 CH_3COOH 初始濃度減去溶液混合後解離的濃度，求出溶液甲的 CH_3COOH 濃度。

學生： $0.05-1.8\times10^{-5}$，大約等於 0.05 M。

老師： 請大家想一想，由弱酸加弱酸形成的溶液乙是什麼樣的溶液呢？

學生： 溶液呈弱酸性。

老師： 很好，因此利用弱酸鹼離公式，求出解離出的$[H^+]$。

$$[H^+]=\sqrt{C_1K_1+C_2K_2}$$

學生： $[H^+]=3.14\times10^{-3}$

老師： 再將 CH_3COOH 初始濃度減去溶液混合後解離的濃度，求出溶液乙的 CH_3COOH 濃度。

學生： $0.05-(3.14\times10^{-3})$，大約等於 0.047 M。

老師： 請大家想一想，由弱酸加弱鹼形成的溶液丙，是發生什麼反應？

學生： 酸鹼中和。

老師： 非常好。因此我們要寫出酸鹼中和反應式，利用化學計量求出 CH_3COOH 的消耗量，求出此反應式的解離常數 K_c。

$$\underset{0.05-x}{CH_3COOH}+\underset{0.05-x}{HCOO^-}\rightarrow\underset{x}{CH_3COO^-}+\underset{x}{HCOOH}$$

$$K_c=\frac{1.8\times10^{-5}}{1.8\times10^{-4}}=0.1$$

透過解離常數公式求出 x 為多少呢？

學生： x = 0.012

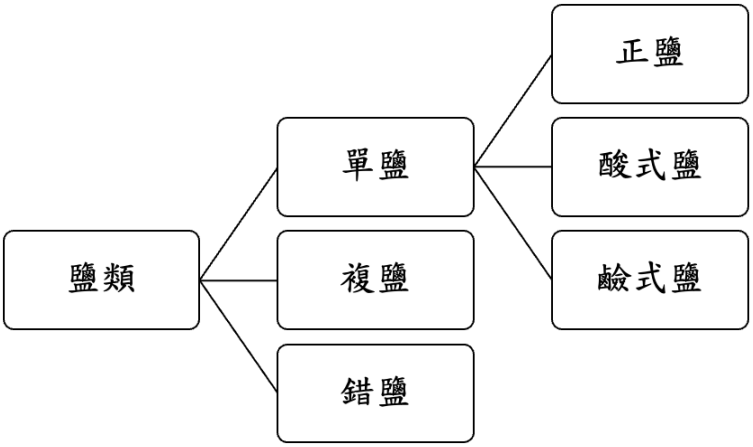
老師： 再將 CH_3COOH 初始濃度減去溶液酸鹼中和消耗的濃度，求出溶液丙的 CH_3COOH 濃度。

學生： $0.05-0.012$，大約等於 0.05 M。老師我懂了！$[CH_3COOH]$：丙<乙<甲

2-4 鹽類
Salt

■ 前言 Introduction

此小節，學生了解鹽的特性、種類及其水解方程式，並透過方程式與水解作用程度來得知鹽的酸鹼性，可將此概念結合先前學習的酸鹼解離常數計算出鹽類溶於水的 pH 值。語言方面，學生可練習被動式與假設語氣等相關句型。



■ 詞彙 Vocabulary

單字	中譯	單字	中譯
simple salt	單鹽	acid salt	酸式鹽
double salt	複鹽	basic salt	鹼式鹽
complex salt	錯鹽	normal salt	正鹽

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ _____ can be replaced by _____.

例句：The dissociable H^+ in the acid **can be replaced by** a metal cation or NH_4^+.

酸中可解離的 H^+被金屬陽離子或 NH_4^+取代。

❷ A combination of _____ is called _____.

例句：**A combination of** two or more cations or anions **is called** a double salt.

由兩種或兩種以上的陽離子或陰離子組合而成的稱為複鹽。

❸ If only _____ undergo _____ reaction in the aqueous solution _____ will _____, making [OH^-] _____ [H^+]. As a result, the aqueous solution is _____.

例句：**If only** anions **undergo** hydrolysis **reaction** in an aqueous solution, the concentration of **[OH^-] in the solution** will increase**, making [OH^-]** greater than **[H^+]**. **As a result, the aqueous solution** is alkaline.

若水溶液中僅陰離子發生水解反應，則水溶液中的[OH^-]會增加，使[OH^-]大於[H^+]，因此水溶液呈鹼性。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After this lesson, students should be able to know:

一、學生能理解並應用鹽類的概念，包含鹽的水解與反應。

Students can understand and apply the concept of salts, including salt hydrolysis and reactions.

❧ 例題講解 ☙

例題一

說明：學生能夠理解鹽的水解，並透過鹽類解離出的陰陽離子推出水溶液的酸鹼性。

Students can understand the hydrolysis of salt, and determine the acidity or alkalinity of an aqueous solution through the anions and cations dissociated from the salts.

Which of the following aqueous solutions with a concentration of 0.1 M is acidic?

(A) NaBr

(B) CH_3COONa

(C) NH_4Cl

(D) $NaHCO_3$

(E) Na_2CO_3

濃度均為 0.1 M 的下列各水溶液，何者呈酸性？

(A) NaBr

(B) CH_3COONa

(C) NH_4Cl

(D) $NaHCO_3$

(E) Na_2CO_3

（來源：翰林版課本選修化學 III 2-4 第 102 頁 範例 2-9）

Teacher: Do the cations and anions of NaBr undergo hydrolysis when dissolved in water?

Student: Neither Na^+ nor Br^- does.

Teacher: So, what is the acidity or alkalinity of the solution?

Student: Neutral.

Teacher: Very good. Do cations or anions undergo hydrolysis to make the solution acidic when salts are dissolved in water,

Student: Cations.

Teacher: That's right. How about the salts in options B-E. Which cation will undergo hydrolysis?

Student: NH_4Cl and NH_4^+ in option C will hydrolyze.

Teacher: Very good! Therefore, the answer is option C.

老師： NaBr 溶於水後，陰陽離子是否會水解？

學生： Na^+與 Br^-都不水解。

老師： 因此溶液的酸鹼性為何？

學生： 中性。

老師： 非常好。請問大家鹽類溶於水後，是陽離子還是陰離子發生水解作用，使溶液呈酸性呢？

學生： 陽離子。

老師： 沒錯。接著，請思考選項 B~E 的鹽類，何者的陽離子會發生水解作用？

學生： 選項 C 的 NH_4Cl，NH_4^+會發生水解。

老師： 很好！因此答案為 C。

例題二

說明：學生能夠從題幹與鹽的化學式中，推得加熱反應後的產物。

Students can deduce the products of reaction after heating from the given information and the chemical formula of the salt.

In the process of making bread, baking soda ($NaHCO_3$) is often used as a leavening agent. However, before the use of baking soda, ammonium bicarbonate (NH_4HCO_3) was also used as a leavening agent for this type of food. When ammonium bicarbonate is used, three gases, A, B, and C, will be released during the baking process of bread (approximately 190 to 230 °C). A has a pungent smell, while B and C are tasteless. If baking soda is used to bake bread within the same temperature range, two gases and sodium carbonate (Na_2CO_3) will be produced.

Which of the following statements about these two baking processes are correct?

(A) Each mole of ammonium bicarbonate will produce 4 moles of gas.
(B) Each mole of baking soda will produce 3 moles of gas.
(C) When baking soda is used, gas A will not be produced.
(D) When baking soda is used, gases B and C will be produced.
(E) When ammonium bicarbonate is used, the gas produced is urea ($(NH_2)_2CO$).

在麵包的製作過程中，常以小蘇打($NaHCO_3$)做為膨鬆劑，然而在使用小蘇打之前，碳酸氫銨(NH_4HCO_3)亦曾是這類食品的膨鬆劑。使用碳酸氫銨時，於麵包烘焙過程中（約 190 至 230 °C）會釋出甲、乙與丙三種氣體，其中甲有刺鼻味，而乙與丙均沒有味道。若於同溫度範圍內使用小蘇打烘焙麵包時，則會產生兩種氣體及碳酸鈉(Na_2CO_3)。
下列有關此兩種烘焙過程的敘述，哪些正確？
(A) 每 1 莫耳的碳酸氫銨會產生 4 莫耳的氣體。
(B) 每 1 莫耳的小蘇打會產生 3 莫耳的氣體。
(C) 使用小蘇打時，不會產生甲。
(D) 使用小蘇打時，會產生乙與丙。
(E) 使用碳酸氫銨時，所產生的甲是尿素($(NH_2)_2CO$) 。

（來源：107 年指考 24）

Teacher: When NH_4HCO_3 is heated, three gases will be produced. What is the pungent-smelling gas produced?
Student: NH_3.
Teacher: Good. The odorless gases will contain carbon atoms or hydrogen atoms, so what are the odorless gases B and C?
Student: CO_2 and H_2O.
Teacher: Now please try to write the reaction equation of NH_4HCO_3.
Student: $NH_4HCO_3 \rightarrow NH_{3(g)} + CO_{2(g)} + H_2O_{(g)}$.
Teacher: Very good! Now, if 1 mole of ammonium bicarbonate is used, how many moles of gas will be produced?
Student: A total of 3 moles.
Teacher: Yes. Next, what two gases will be produced after $NaHCO_3$ is heated?
Student: CO_2 and H_2O.
Teacher: That's right. Now please try to write the reaction equation of $NaHCO_3$.

Student: $2NaHCO_3 \rightarrow Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$.

Teacher: Correct! So, when 1 mole of baking soda is used, how many moles of gas will be produced?

Student: A total of 1 mole.

老師： NH_4HCO_3 加熱後會產生三種氣體，其中會產生有刺鼻味的甲氣體為？

學生： NH_3。

老師： 很好。那沒有味道的氣體會含有碳原子或氫原子，因此沒有味道的乙與丙氣體為何？

學生： CO_2 與 H_2O。

老師： 現在請大家嘗試寫出 NH_4HCO_3 的反應方程式。

學生： $NH_4HCO_3 \rightarrow NH_{3(g)} + CO_{2(g)} + H_2O_{(g)}$。

老師： 非常好！因此使用 1 莫耳的碳酸氫銨，會產生幾莫耳氣體呢？

學生： 總共 3 莫耳。

老師： 答對！接下來 $NaHCO_3$ 加熱後會產生哪兩種氣體呢？

學生： CO_2 與 H_2O。

老師： 沒錯，現在請大家嘗試寫出 $NaHCO_3$ 的反應方程式。

學生： $2NaHCO_3 \rightarrow Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$。

老師： 正確！因此當使用 1 莫耳的小蘇打，會產生幾莫耳氣體呢？

學生： 總共 1 莫耳。

2-5 緩衝溶液
Buffer Solution

■ 前言 Introduction

本節，學生理解緩衝溶液的定義與原理，與了解緩衝效果與能力的應用，再結合先前所學，統整出計算緩衝溶液的 pH 值，並應用公式計算出不同緩衝溶液的 pH 值。課堂中老師結合生活常見的緩衝溶液，例如：血液，使學生能夠將緩衝溶液與生活結合，深化課堂中學習到的原理及應用。

語言方面，學生將練習假設語氣的相關用法。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
buffer solution	緩衝溶液	sodium hydroxide	氫氧化鈉
buffer capacity	緩衝能力	muriatic acid	鹽酸
acetic acid	醋酸	ammonia	氨
sodium acetate	醋酸鈉	ammonium chloride	氯化銨

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ The -er/more _____, the -er/more _____

例句：**The higher** the concentration of the buffer solution**, the better** its buffering effect.
當緩衝溶液的濃度愈濃，緩衝效果愈佳。

❷ **The _____ of a solution consisting of _____ and _____ does not change significantly by the _____ of acid or base.**

例句：**The** pH value **of a solution consisting of** acetic acid **and** sodium acetate **does not change significantly by the** addition **of acid or base.**

由醋酸與醋酸鈉組成的溶液，其 pH 值不會因為加入的酸或鹼而大幅改變。

❸ **If a strong base, such as _____, is added to a _____, the _____ will react with almost all the _____ in the _____.**

例句：**If a strong base, such as** sodium hydroxide**, is added to a** buffer solution**, the** hydroxide ions **will react with almost all the** hydrogen ions **in the** solution.

若在緩衝溶液中加入強鹼，例如氫氧化鈉，則氫氧離子會與溶液中的氫離子發生反應幾乎用完。

❹ **In order to maintain the _____, the _____ will dissociate in a _____ amount to restore the _____ to its original concentration.**

例句：**In order to maintain the** dissociation balance**, the** original weak acid in the buffer solution **will dissociate in a** small **amount to restore the** hydrogen ion concentration to **its original concentration.**

緩衝溶液中原有的弱酸為了維持解離平衡，會少量解離，使氫離子濃度恢復至原本濃度。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After this lesson, students should be able to know:

一、學生能理解緩衝溶液的定義與配置，了解緩衝溶液的濃度與緩衝能力之間的關係，並應用先前所學計算出緩衝溶液的 pH 值。

Students can understand the definition and configuration of buffer solutions and the relationship between the concentration and buffering capacity of buffer solutions, and calculate the pH value of buffer solutions using what they have learned previously.

❧ 例題講解 ☙

例題一

說明：學生能理解緩衝溶液的定義與組成。

Students can understand the definition and composition of buffer solutions.

Take 1 mole of the following substances to form a mixed solution. Which ones are buffer solutions?

(A) CH_3COOH and NH_3.

(B) CH_3COOH and CH_3COONa.

(C) HCl and NaOH.

(D) KH_2PO_4 and K_2HPO4.

(E) NH_3 and NH_4Cl.

下列各物質皆取 1 莫耳形成混合溶液，哪些為緩衝溶液？

(A) CH_3COOH 和 NH_3.

(B) CH_3COOH 和 CH_3COONa.

(C) HCl 和 NaOH.

(D) KH_2PO_4 和 K_2HPO4.

(E) NH_3 和 NH_4Cl.

（翰林版課本選修化學 III 2-5 第 107 頁 範例 2-10）

Teacher: Everyone, what is a buffer solution?

Student: A buffer solution is a solution where the pH value does not change significantly when a strong acid or strong base is added.

Teacher: Very good, then how do we configure the buffer solution?

Student: We use weak acids and their salts, or weak bases and their salts.

Teacher: That's right! You are all quite familiar with the definition and configuration of buffer solutions! Next, please choose the combination that can be configured as a buffer solution among the options.

Student: B, D, and E!

Teacher: Correct!

老師： 同學們，請問緩衝溶液的定義為何？

學生： 將強酸、強鹼加入緩衝溶液，溶液的 pH 值不會大幅改變。

老師： 非常好，那請問要如何配置緩衝溶液呢？

學生： 使用弱酸與其鹽類，或是弱鹼與其鹽類配置。

老師： 沒錯！大家都相當熟悉緩衝溶液的定義與配置！接下來，請大家選出選項中可配置成緩衝溶液的組合。

學生： B、D、E！

老師： 正確！

例題二

說明：學生能夠利用公式計算緩衝溶液的 pH 值。

Students can calculate the pH value of a buffer solution using a formula.

If you want to prepare a buffer solution at pH = 4.3, which mixture of the following weak acid and its conjugate base at the same concentration would be most suitable?

(A) Nitrous acid, HNO_2 ($K_a = 5.1\times10^{-4}$)

(B) Hydrofluoric acid, HF ($K_a = 6.6\times10^{-4}$)

(C) Benzoic acid, C_6H_5COOH ($K_a = 6.4\times10^{-5}$)

(D) Hypochlorous acid, HOCl ($K_a = 3.1\times10^{-8}$)

(E) Hydrocyanic acid, HCN ($K_a = 4.9\times10^{-10}$)

若想製備 pH = 4.3 的緩衝溶液，使用相同濃度下列哪種弱酸及其共軛鹼鹽的混合溶液最合適？

(A) 亞硝酸 HNO_2 ($K_a = 5.1\times10^{-4}$)

(B) 氫氟酸 HF ($K_a = 6.6\times10^{-4}$)

(C) 苯甲酸 C_6H_5COOH ($K_a = 6.4\times10^{-5}$)

(D) 次氯酸 HOCl ($K_a = 3.1\times10^{-8}$)

(E) 氫氰酸 HCN ($K_a = 4.9\times10^{-10}$)

（來源：龍騰版課本選修化學 III 3-6 第 142 頁 範例 3-14）

Teacher: What is the optimal ratio of the concentration of weak acid or weak base to its salt in a buffer solution to achieve the best buffering effect?

Student: 1 to 1.

Teacher: That's right! Good. Next, how do we calculate the pH value of the buffer solution?

Student: We have no idea.

Teacher: Recall that the formula for calculating the pH value of a buffer solution is $pH = pK_a + \log(\frac{[A^-]}{[HA]})$. Just now everyone answered that the concentration ratio of a weak acid or a weak base to its salt should be 1:1, which will have the best buffering effect. Substitute the formula $pH = pK_a + \log(1) = pK_a$, so $pH = pK_a$ at this time. Please calculate the pH values of options A to E and choose a solution with pH = 4.3.

Student: The answer is option C!

老師： 請大家思考緩衝溶液中弱酸或弱鹼與其鹽類濃度比例要為多少，會具有最好的緩衝效果呢？

學生： 1:1。

老師： 沒錯！非常好，接下來請問要如何計算緩衝溶液的 pH 值呢？

學生： 不知道。

老師： 大家回想計算緩衝溶液 pH 值的公式：$pH = pK_a + \log(\frac{[A^-]}{[HA]})$，剛剛大家回答弱酸或弱鹼與其鹽類濃度比例要為 1:1，會具有最好的緩衝效果，因此代入公式 $pH = pK_a + \log(1) = pK_a$，因此此時 $pH = pK_a$。請大家計算 A 到 E 選項的 pH 值，選出 pH = 4.3 的溶液。

學生： 答案是 C 選項！

2-6 酸鹼滴定與滴定曲線
Acid-base Titration and Titration Curve

■ 前言 Introduction

本節，學生理解酸鹼滴定時溶液中的化學反應以及離子濃度的改變，並將酸鹼滴定的過程繪製成滴定曲線圖，從圖中判斷各點的 pH 值，再進一步瞭解強酸-強鹼、弱酸-強鹼、強酸-弱鹼滴定曲線的差異，認識弱酸-強鹼、強酸-弱鹼滴定時在半當量點會形成緩衝溶液。語言方面，學生可練習數字計算的相關用語。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
acid-base indicator	酸鹼指示劑	phenolphthalein	酚酞
methyl orange	甲基橙	universal test paper	廣用試紙
methyl red	甲基紅	equivalence point	當量點
litmus	石蕊	half-equivalence point	半當量點
bromothymol blue	溴瑞香草酚藍	end point	滴定終點
phenol red	酚紅	titration curve	滴定曲線

■ 教學句型與實用句子 Sentence Frames and Useful Sentences

❶ **When the pH value is less than _____, the _____ appears _____.**

例句：**When the pH value is less than** 6.8**, the** phenolphthalein indicator **appears** colorless.
當 pH 值小於 6.8 時，酚酞指示劑呈現無色。

❷ **Near the equivalence point, the pH value changes very obviously, and the curve at pH=___~___ is almost vertical, so an indicator whose color change range falls around pH=___~___ can be selected.**

例句：**Near the equivalence point, the pH value changes very obviously, and the curve at** pH = 4~10 **is almost vertical, so an indicator whose color change range falls around** pH = 3~11 **can be selected.**
在當量點附近，pH 值變化非常明顯，在 pH = 4~10 的曲線幾乎垂直，因此可以選用變色範圍落在 pH = 3~11 左右的指示劑。

❸ **When _____ mL of _____ M _____ solution is titrated with _____ M _____, the pH value is _____ at the half-equivalence point.**

例句：When 25.0 mL of 0.10 M ammonia solution (K_b = 1.8×10^{-5}) is titrated with 0.10 M hydrochloric acid, the pH value is 9.26 at the half-equivalence point.
以 0.10 M 的鹽酸滴定 25.0 毫升的 0.10 M 氨水溶液 (K_b = 1.8×10^{-5})，達半當量點時，pH = 9.26。

❹ **When titrating _____ mL of _____ M _____ $_{(aq)}$ with _____ M _____ $_{(aq)}$, _____ can be used as the indicator.**

例句：**Titrate** 40.0 **mL of** 0.100 **M** $NH_{3(aq)}$ **with** 0.100 **M** $HCl_{(aq)}$. Methyl red **can be used as the indicator.**
以 0.100 M $HCl_{(aq)}$滴定 0.100 M $NH_{3(aq)}$ 40.0 mL，可選用甲基紅為指示劑。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

After this lesson, students should be able to know:

一、學生能夠理解滴定曲線圖的意義，及透過滴定曲線圖計算出溶液的濃度、pH 值、解離常數等。

Students can understand the meaning of titration curves and calculate the concentration, pH value, dissociation constant, etc. of a solution through titration curves.

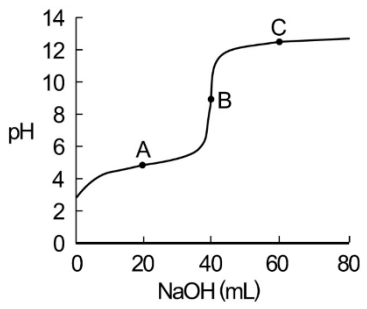
❧ 例題講解 ☙

例題一

說明：學生能理解滴定曲線圖的意義，並透過圖例計算出溶液的濃度、解離常數等。

Students can understand the meaning of titration curve diagrams and calculate the concentration and dissociation constant of the solution through the graph.

A 20 mL organic monoprotic acid solution of unknown concentration is titrated with 0.1 M NaOH aqueous solution. The titration curve is shown in the figure on the right. Which of the following statements about this titration experiment is correct?



(A) Methyl red (color change range is pH 4-6) can be selected as the indicator for this titration reaction.

(B) The concentration of this organic acid is 0.05 M.

(C) The mole number of H^+ in the solution at point B is equal to the mole number of OH^-.

(D) The solution at point C is a buffer solution.

(E) The dissociation constant of this organic acid is less than 1.0×10^{-4}.

以 0.1 M 的 NaOH 水溶液滴定某一體積為 20 mL、濃度未知的有機單質子酸溶液，其滴定曲線如右圖所示。下列有關此滴定實驗的敘述，哪一選項正確？

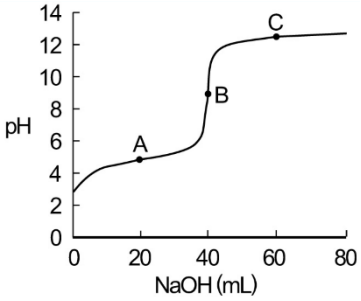
(A) 此滴定反應可選擇甲基紅(變色範圍為 pH 4-6)為指示劑。

(B) 此有機酸的濃度為 0.05 M。

(C) 在 B 點之溶液中 H^+的莫耳數等於 OH^-的莫耳數。

(D) 在 C 點之溶液為一緩衝溶液。

(E) 此有機酸的解離常數小於 1.0×10^{-4}。



（107 年指考 4）

Student: Sir, why is the concentration of organic acid 0.05 M?

Teacher: At the equivalence point, the volume of sodium hydroxide consumed is 40 mL, so the following formula can be applied

$n_AM_AV_A = n_BM_BV_B$

$1 \times M_A \times 20 = 1 \times 0.1 \times 40$

$M_A = 0.05$ M

Student: I see! Why is the dissociation constant of organic acids less than 1.0×10^{-4}?

Teacher: The dissociation constant of organic acid needs to be obtained from the buffer point A, using the buffer solution formula:

$$[H^+] = K_a \times \frac{[HA]}{[A^-]}$$

At buffer point A, half of [HA] is used up, so $[HA]=[H^+]=[A^-]$, and $K_a=[H^+]=10^{-5}$, 10^{-5} is less than 1.0×10^{-4}.

Student: I see!

學生：老師，為什麼有機酸的濃度是 0.05 M 呢？

老師：在達當量點時，消耗氫氧化鈉體積 40 mL，因此可以帶入下列公式。

$n_AM_AV_A = n_BM_BV_B$

$1 \times M_A \times 20 = 1 \times 0.1 \times 40$

$M_A = 0.05$ M

學生：原來如此！那為什麼有機酸的解離常數小於 1.0×10^{-4} 呢？

老師：　有機酸的解離常數需從緩衝點 A 求得，緩衝溶液公式：

$$[H^+] = K_a \times \frac{[HA]}{[A^-]}$$

在緩衝點A時，[HA]用掉一半，因此[HA]=[H^+]=[A^-]，因此 K_a=[H^+]=10^{-5}，10^{-5} 小於 1.0×10^{-4}。

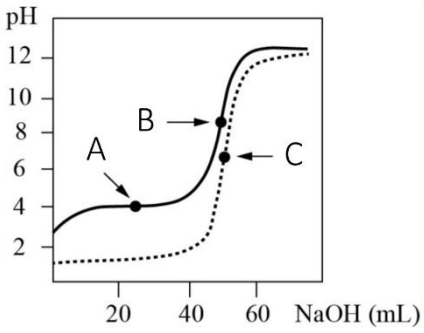
學生：　這樣我懂了！

例題二

說明：學生能從滴定曲線圖中，判斷溶液的酸鹼性並計算出濃度，及弱酸-強鹼或強酸-弱鹼滴定中，到達半當量點時形成緩衝溶液。

Students can determine the acidity or alkalinity of a solution from the titration curve and calculate the concentration, and in weak acid-strong base or strong acid-weak base titration, a buffer solution is formed at the half-equivalence point.

Li found two bottles of acidic solution of the same volume in the laboratory. To determine the concentration and strength of the acids in the two bottles, he titrated each acid with 0.2 M sodium hydroxide solution. Taking the volume (mL) of the added sodium hydroxide solution as the X-axis and the pH value of the solution as the Y-axis, the resulting titration curve is shown in the diagram on the right.



Which of the following statements is wrong?

(A) The concentrations of the two bottles of acid are similar.

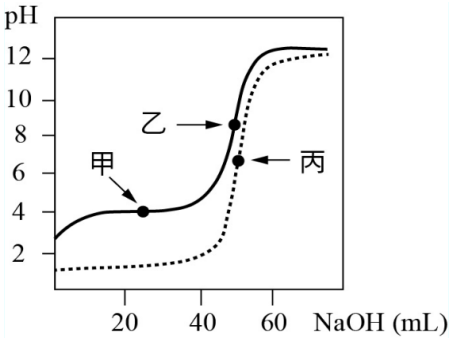
(B) The gently sloping region near point A in the diagram is the buffer solution.

(C) The pH value of point A in the diagram is the pK_a value of this acid.

(D) The solid line titration curve represents a strong acid, and the dashed line titration curve represents a weak acid.

(E) Points B and C in the diagram represent the equivalent points of the two bottles of acid solution respectively.

李同學在實驗室發現兩瓶相同體積的酸性溶液，為了獲知兩瓶溶液的濃度及酸的強度，於是用 0.2 M 的氫氧化鈉溶液分別對兩瓶酸進行滴定。以所加入氫氧化鈉溶液的體積(毫升)為 X 軸，溶液的 pH 值為 Y 軸，得到的滴定曲線如右圖所示。下列敘述，哪一項錯誤？



(A) 兩瓶酸的濃度相近。

(B) 圖中甲點附近平緩曲線區是緩衝溶液。

(C) 圖中的甲點 pH 值即為此酸的 pK_a 值。

(D) 實線的滴定曲線是強酸，虛線的滴定曲線是弱酸。

(E) 圖中的乙、丙兩點分別代表這兩瓶酸溶液的滴定當量點。

（108 年指考 9）

Teacher: When two acidic solutions are titrated with NaOH, the volumes at the equivalence point are both about 50 mL. Therefore, when the number of protons dissociated from the two acidic solutions is the same, their concentrations are the same. Got it?

Student: Got it! Then why is the solid line titration curve for a strong acid, and the dashed line titration curve for a weak acid?

Teacher: This is a great question! Please observe the pH values of the equivalence points of the solid line and the dotted line.

Student: The equivalence point of the solid line has a pH of approximately 8, and the equivalence point of the dotted line has a pH of 7.

Teacher: Good! From the pH values of the equivalence points, it can be determined that the solid line represents a weak acid-strong base titration, so the pH value is greater than 7, and the dashed line represents a strong acid-strong base titration, with a pH of 7.

Student: Got it!

老師： NaOH 滴定兩種酸性溶液，在當量點時體積皆約為 50 mL，因此當兩種酸性溶液解離出的質子數量相同時，兩者濃度相同，這樣了解嗎？

學生： 了解！那為什麼實線的滴定曲線是強酸，虛線的滴定曲線是弱酸呢？

老師： 這是個很好的問題！請大家觀察實線與虛線的當量點 pH 值各為多少？

學生： 實線的當量點 pH 約為 8，虛線的當量點 pH 為 7。

老師： 很好！從當量點 pH 值可以判斷實線為弱酸-強鹼滴定，因此 pH 值大於 7，虛線為強酸-強鹼滴定，pH = 7。

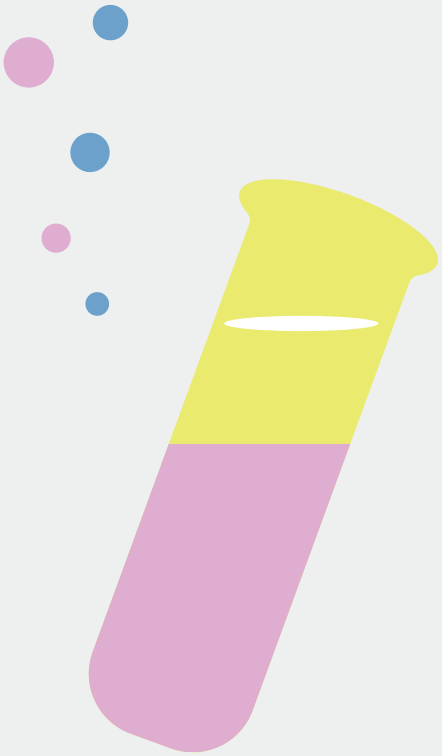
學生： 我懂了！

國內外參考資源 More to Explore

Ward's Science featuring Ward's World 提供國中及高中年齡層學生及教師使用，也有影片。也有其他自然科。 https://wardsworld.wardsci.com/chemistry	
Middle School Chemistry 提供國中教師完整教學指引，學習單，教學影片。 https://www.middleschoolchemistry.com/	
American Association of Chemistry Teachers 美國教師化學協會，提供個階段教師資源分享。 https://teachchemistry.org/	
Khan Academy 可汗學院，有分年級的化學教學影片及問題的討論。 https://www.khanacademy.org/	
Interactive Simulations, University of Colorado Boulder 互動式電腦模擬，除了化學，還有其他自然科。 https://phet.colorado.edu/	

自然領域雙語教學資源手冊：化學科英語授課用語
[選修化學(III)]
A Reference Handbook for Senior High School Bilingual Teachers in the Domain of Natural Sciences (Chemistry): Instructional Language in English
[Elective Chemistry (III)]

- 研編單位：國立彰化師範大學雙語教學研究中心
- 指導單位：教育部師資培育及藝術教育司
- 撰稿：周鈺庭、陳瑞安、林心怡、陳郁暄
- 語言諮詢：龔慧懿
- 綜合規劃：曾松德
- 排版：吳依靜
- 封面封底：JUPE Design



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