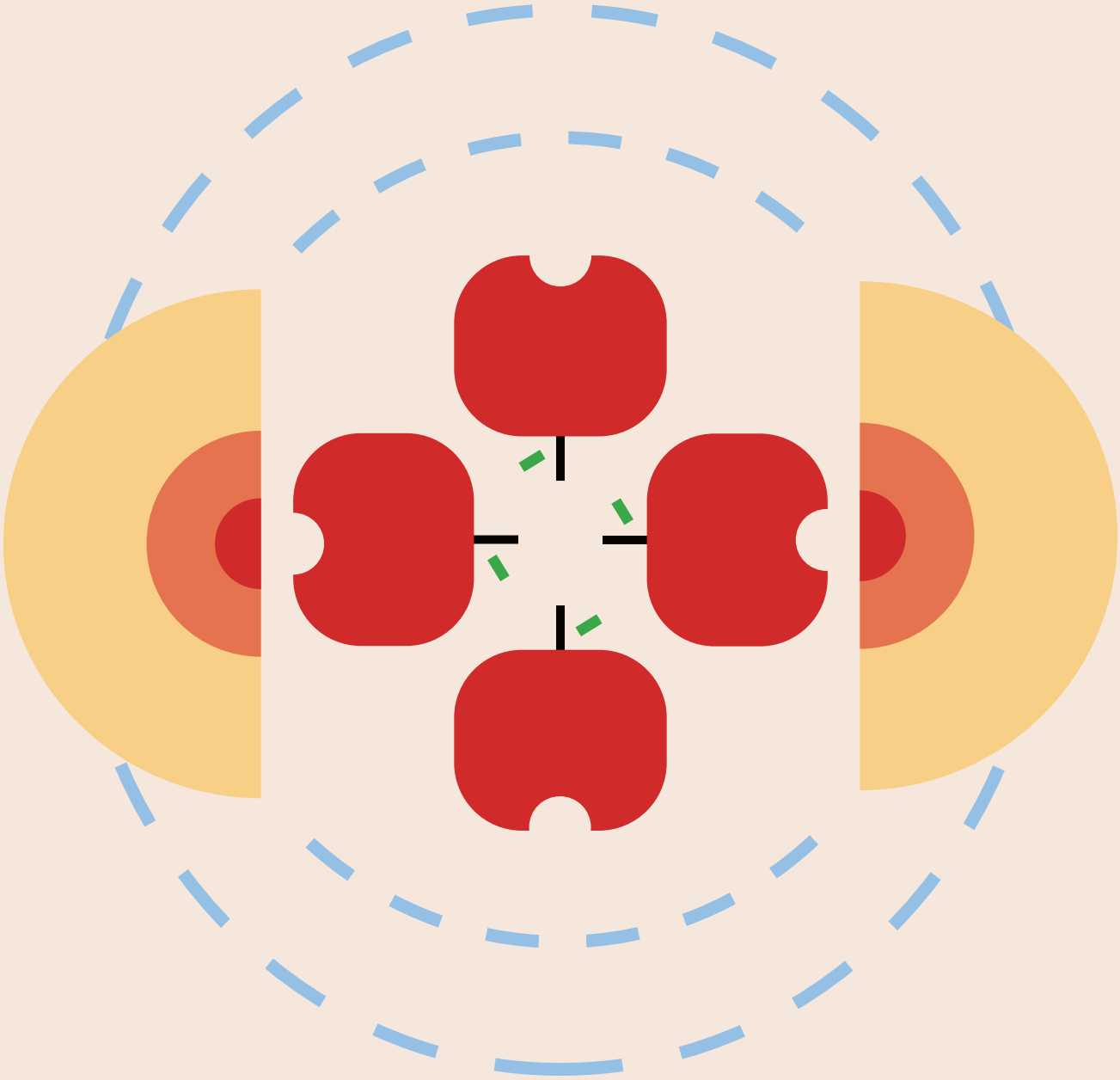
高中自然領域

雙語教學資源手冊 物理科英語授課用語

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

〔高中一年級〕



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　科學的態度與方法★
The Scientific Attitude and Method

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■ 前言 Introduction

本章介紹研究科學問題時，所應採取的態度、方法及測量時需要的單位及符號。最後簡介從希臘時期到 16 世紀後的物理學的發展，與相關科學家的貢獻。

1-1 科學態度
Scientific Attitude

■ 前言 Introduction

科學家研究問題時所採取的態度稱為「科學態度」，通常包含了理性、客觀、適當假設、觀察比較、運用嚴謹的數學推導或特定的實驗流程等科學方法，以獲得結論所遵行的態度。

舉例來說，到 17 世紀初我們仍不清楚光的本質是什麼。牛頓假設了光是由極小不同顏色的微粒組成；惠更斯則提出光具備如同水波的波動特性。此兩種假設具有截然不同的特性，卻都可以解釋當時觀察到的:反射及折射現象。直到楊氏完成雙狹縫干涉實驗後，只能以波動的理論解釋觀察到的現象，因此科學家相信光是波動的一種形式。但是到了 20 世紀初，愛因斯坦提出光量子假設，並成功解釋了光電效應實驗，從此，我們擴展了對光的認知，改以「波粒二象性」，兼容波動與粒子的雙重特性，來解釋光所呈現的不同現象。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
scientific attitude	科學態度	light	光
rationality	理性	corpuscular theory	微粒說
objectivity	客觀	wave model	波動說
hypothesis	假說	reflection	反射
observation	觀察	refraction	折射

comparison	比較	interference	干涉
mathematical derivation	數學推導	light quantum	光量子
experiment	實驗	wave-particle duality	波粒二象性

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

❶ _____ is made up of _____.

例句：People used to believe that light **was made up of** many tiny particles.
以前的人認為，光是由許多微小的粒子組成。

❷ from ____ to _____

例句：Reflection and refraction occur when light travels **from** one medium **to** another.
光從一種介質傳到另一種時，會發生反射及折射的現象。

❸ propose the hypothesis that S+V

例句：Huygens **proposed the hypothesis that** light behaved as wave motion.
惠更斯提出光是波動的假說。

❹ S+V by _____.

例句：Thomas Young observed the phenomenon of light interference **by** setting up the double-slit experiment.
楊氏透過雙狹縫實驗觀察到光的干涉現象。

■ 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、科學態度包含理性、客觀、多方假設、具體觀察、邏輯推理等。

the scientific attitude includes rationality, objectivity, multiple propositions, specific observations, logical reasoning, etc.

❧ 例題講解 ☙

例題一

說明：學生能掌握天平的使用方法與流程。

Students can use a balance and know the weighing process.

（英文）The scientific attitude means the attitude held by scientists when conducting scientific researches. Which of the following is not scientific attitude?

(A) Staying curious

(B) Staying rational

(C) Avoiding jumping right into conclusion

(D) Firmly believing the inference from the result of a single experiment

（中文）科學態度代表科學家進行科學探討時所持態度，下列何者不是科學態度？

(A)保持好奇心　　(B)保持理性

(C)避免妄下結論　　**(D)堅信單一實驗結果的推論**

（改編自 109 南二中期中考題）

解題 Solution：

科學態度應包含理性、客觀、好奇心及不妄下結論。舉例來說，以月亮高掛天空未落下來說，此結果為地球引力對月亮沒有作用，是堅信單一實驗結果但沒有多方比較與查證得到的結果所得的推論，不符合科學態度。故選(D)。

The scientific attitude should include rationality, objectivity, curiosity, and not jumping into conclusion too soon. For example, the assumption that the gravity doesn't work on the moon because the moon doesn't fall down from the sky, is the outcome of relying on one single experimental result without multiple comparisons and investigation. Such an attitude is not scientific, and therefore the answer is (D).

Teacher: How do we know that gravity exists through observation?
Student: Apples fall down to the ground because of gravity.
Teacher: Then does the gravity work on the moon? Otherwise why does the moon not fall down?
Student1: Since the moon is very far from the Earth and is little affected by gravity, it doesn't fall down.
Student 2: The moon is also affected by the gravity of the Sun. The summation force is zero so it doesn't fall down.
Teacher: Is the moon still or moving?
Student: The moon orbits around the Earth.
Teacher: Does an object need any force (centripetal force) to shift around a circle?
Student: Yes, it does.
Teacher: Since the moves around the Earth, it means that the moon needs centripetal force to pull it around. What is the source that provides this force?
Student: The Earth.
Teacher: The moon is affected by the gravity of the Earth. It is such force that keeps the moon moving around the Earth, instead of moving straight forward away from the Earth.

In sum, objects may not always fall down to the Earth when exerted by gravitational force. Thus, if we jump into a conclusion too soon with just one single experiment, we fail to follow the scientific attitude. Therefore, the answer is (D).

老師： 我們如何觀察到重力的存在？
學生： 因為蘋果掉下來是受到重力的作用。
老師： 那請問月亮是否受到地球的重力呢？不然月亮為什麼不會掉下來？
學生 1： 因為月亮距離地球較遠，受到的重力比較小，所以不會掉下來
學生 2： 月亮也受到太陽的吸引，所以合力等於 0 就不會掉下來。
老師： 月亮是靜止的，還是做哪種運動呢？

學生： 月亮繞著地球轉動。

老師： 轉動需要拉力（向心力）嗎？

學生： 轉動需要拉力。

老師： 因為月亮繞地球轉動，因此月亮需要拉力(向心力)，這個拉力是誰提供的？

學生： 地球。

老師： 因此月亮受到地球引力，也就是重力的作用，才可以繞著地球轉動，否則會沿著直線遠離地球。

物體受到重力不一定會掉下來，就像月球一樣，所以我們不能就單一結果，就遽下結論，這是不符合科學態度的。因此，答案選(D)。

1-2 科學方法
Scientific Method

■ 前言 Introduction

在探索科學的過程中，一開始的觀察與假設是必要的，接著，通過實驗的設計來得到數據以支持或反駁假設，並得出基本通則的過程，即稱為「科學方法」。

科學方法通常包含以下步驟，依序為：1.進行觀察、2.提出假設、3.實驗設計、4.分析資料與驗證、5.成果發表、6.分享/確認可重複性。

舉例來說：冉福得伯爵觀察到兵工廠，大砲在製作過程中砲身很燙，只要一直切削砲身，熱可以源源不斷產生。此現象與「熱質說」理論違背，於是提出「熱」是材料內某種形式的運動（能量），而不是一種物質（質量）。後來焦耳設計精巧的實驗裝置，再次證明「熱」是一種能量，可以與其他形式的能量（如動能）相互轉換。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
scientific method	科學方法	heat quantity/thermal energy	熱量/熱能
caloric theory of heat	熱質說	energy	能量
observation	觀察	motion	運動
hypothesis	假說	repeatability	可重複性
experiment	實驗	conversion/transformation	轉換
analysis	分析		

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

❶ _____ by + V-ing

例句：Children learn **by observing** adults.

小孩經由觀察大人來學習。

❷ S+V when S+V.

例句：He proposed the hypothesis stating that "**When** the color of fruit changes, it's ripe."

他提出「當水果變色表示成熟」的假說。

❸ _____ provide _____.

例句：Nothing can **provide** unlimited thermal energy.

沒有任何物體可以提供源源不斷的熱能。

■ 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、科學方法有一定的程序。

The scientific method has its certain procedures.

二、科學方法通常包含：觀察、假設、實驗設計、分析、驗證、歸納等過程。

The scientific method usually includes observation, formulating hypothesis, experiment design, verification, analysis, induction, etc.

例題講解

例題一

說明：讓學生了解科學方法的程序。

Make students understand the procedure of scientific methods.

（英文）Teachers asked students to design an experiment about the relationship between the time duration of chalks soaks in water and the hardness required to break the chalk. The method is to soak the chalk in the water for a while, and use the same method to find out the minimum force needed to break the chalk. Which of the following test recording sheets is most suitable for such experimental purpose?

(A)

Group	1	2	3	4
Color of chalk	white	white	white	white
Soaking time (s)	20	40	60	80
Length of chalk(cm)	8	8	8	8
Minimum external force(kgw)				

(B)

Group	1	2	3	4
Color of chalk	white	red	blue	yellow
Soaking time (s)	20	40	60	80
Length of chalk(cm)	5	6	7	8
Minimum external force(kgw)				

(C)

Group	1	2	3	4
Color of chalk	white	red	blue	yellow
Soaking time (s)	20	20	20	20
Length of chalk(cm)	8	8	8	8
Minimum external force(kgw)				

(D)

Group	1	2	3	4
Color of chalk	red	red	red	red
Soaking time (s)	40	40	40	40
Length of chalk(cm)	5	6	7	8
Minimum external force(kgw)				

（中文）老師要求同學，設計一個有關粉筆在水中浸泡時間，與粉筆斷裂難易度關係的實驗。實驗方法為先將粉筆浸泡水中一段時間，再以相同的方法，量出折斷粉筆所需的最小外力。由下列選項的實驗紀錄表，推測何者的實驗設計最符合前述的實驗目的？

(A)

實驗組別	一	二	三	四
粉筆顏色	白	白	白	白
浸泡時間(s)	20	40	60	80
粉筆長度(cm)	8	8	8	8
最小外力(kgw)				

(B)

實驗組別	一	二	三	四
粉筆顏色	白	紅	藍	黃
浸泡時間(s)	20	40	60	80
粉筆長度(cm)	5	6	7	8
最小外力(kgw)				

(C)

實驗組別	一	二	三	四
粉筆顏色	白	紅	藍	黃
浸泡時間(s)	20	20	20	20
粉筆長度(cm)	8	8	8	8
最小外力(kgw)				

(D)

實驗組別	一	二	三	四
粉筆顏色	紅	紅	紅	紅
浸泡時間(s)	40	40	40	40
粉筆長度(cm)	5	6	7	8
最小外力(kgw)				

（105 年國中會考 21）

解題 Solution：

實驗目的要測試粉筆濕度是否影響其斷裂之難度。因此設計實驗，觀察粉筆在水中浸泡時間，與粉筆斷裂難易度的關係，操縱變因是「粉筆在水中浸泡的時間」，其他因素不可以改變（不可改變的因素為控制變因）。由表格可看出(A)選項改變的因素是浸泡時間，其他因素固定。符合要探究的關係，因此選(A)。

This experiment aims to determine if the wetness of chalks may influence its stiffness. Therefore, we observe the relationship between the time of soaking chalk in water and the difficulty of breaking it. The independent variable is "the length of soaking time." Other factors cannot be changed (the unchangeable factors are controlled variables.) Table (A) shows that the changed variable is the length of soaking time, and the other factors are fixed. Its design is suitable for what the experiment aims to find out. Hence, the answer is (A).

Teacher: What are the factors that may affect the difficulty of breaking chalks?
Student: Material, temperature, wetness, length, and how hard it is pressed when being used.
Teacher: Good, let's assume that wetness of the chalk is one of the factor. If we want to investigate how the time duration the chalk soaks in water affects its stiffness, which factor should be changed?
Student: The length of time for soaking the chalk.
Teacher: In this experiment, the factor being changed is called the manipulated variable, while other unchanged factors are called controlled variables. In this experiment, what are the controlled variables?
Student: Material, temperature, length, color, and brand.
Teacher: Good. So what's the answer to this question?
Student: The answer is (A).

老師： 哪些因素，可能會影響粉筆斷裂的難易程度呢？
學生： 材質、溫度、濕度、長度、寫字的用力程度。
老師： 好，如果我們假設濕度會影響粉筆斷裂。讓我們來探討粉筆浸水時間與斷裂的難易程度的關係，應該改變哪個變因？
學生： 改變粉筆浸水時間。
老師： 在實驗中，改變的因素稱為操縱變因，其他不改變的因素就稱為控制變因。請問粉筆浸水時間與斷裂難易程度的關係中,哪些因素是控制變因？
學生： 材質、溫度、長度、顏色、廠牌。
老師： 很好，所以這題的答案要選什麼？
學生： 答案要選(A)。

1-3 國際單位制
International System of Units

■ 前言 Introduction

物理學是數量化的學科，所觀察到的物理量，都含有大小與單位。國際上最普遍使用的單位體制為「國際單位制」(法語：Système International d'Unités)，簡稱 SI。SI 包含七個基本物理量及單位，每個物理量及其單位皆各有其常用之英文符號，分別為：

(1) 時間(t)，單位：秒(s)

(2) 長度(L)，單位：公尺(m)

(3) 質量(m)，單位：公斤(kg)

(4) 電流(I)，單位：安培(A)

(5) 溫度(T)，單位：克耳文(K)

(6) 光強度(I)，單位：燭光(cd)

(7) 物質數量(n)，單位：莫耳(mol)

其他物理量，都可由這七個基本物理量推導而得，所有單位也可由上述七項基本量之單位，組合而成。例如：速度定義為長度除以時間，因此速度的單位是公尺/秒(m/s)。

為了描述生活中不同大小的數量，可用前綴詞(prefix)加在基本單位的前面。常見的前綴詞如：10^{12} 是 T、10^{9} 是 G、10^{6} 是 M、10^{3} 是 k，10^{-3} 是 m、10^{-6} 是 μ、10^{-9} 是 n、10^{-12} 是 p、10^{-15} 是 f 等。

例如：1 km 相當於 1000 m，中文稱 1 km 為 1 公里，相當於 1000 公尺。另外，皮秒雷射的皮秒就是 ps，相當於 10^{-12} 秒。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
International System of Units	國際單位制	amount of substance	物質數量
physical quantity	物理量	derived units	導出單位
base unit	基本單位	velocity/speed	速度/速率
length	長度	density	密度
time	時間	energy	能量
mass	質量	micrometer/micron	微米
electric current	電流	nanometer	奈米
thermodynamic temperature	熱力學溫度	femtosecond	飛秒
luminous intensity	光強度	millihertz	百萬赫茲

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

❶ _____ must _____(VR).

例句：Measurements **must include** quantity and unit.

測量值須包含數值及單位。

❷ _____ are _____.

例句：The SI units for mass, length, and time **are** kilogram(kg), meter(m), and second (s).

質量、長度及時間的國際基本單位，分別是公斤、公尺、秒。

❸ _____ **other than** _____.

例句：Combinations **other than** base units are called derived units.

基本單位以外的組合，稱為導出單位。

❹ _____ **the product of** _____

例句：The area of a rectangular is **the product of** its length and width.

長方形的面積是長與寬的乘積。

❺ _____ **is proportional to** _____.

例句：The mass of a cup of water **is proportional to** its volume.

一杯水的質量，與它的體積成正比。

❻ _____ **stand for** _____.

例句：Micro **stands for** 10 to the negative 6th power, represented by the symbol of ⌠.

「微」代表 10 的負 6 次方，以⌠的符號表示。

■ 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、測量值須包含數值與單位。

Understand that all measurements must include two parts: a numerical value and a unit of measurement.

二、SI 制規範了七個基本的物理量及其單位。

Understand that the SI system regulates seven basic physical quantities and each respective units.

三、將七項基本單位組合出其他物理單位。

Be able to combine basic units into other physical units.

四、能以 10 的次方表示，或使用前綴詞。

Be able to denote powers of tenor using correct prefixes.

例題講解

例題一

說明：了解 SI 制包含的七個基本量。

To understand the seven basic units of the SI system.

（英文）Quantum science has improved the quality of life with optoelectronic technology. It has also enhanced the precision and stability for the international standard of quality. Scientists discovered that quantizational units of electromagnetic quantities such as voltage, resistance, and electromagnetic wave energy are related to Planck's constant h, thus setting $h = 6.62607015 \times 10^{-34}\, J \cdot s$ as a new standard unit of mass. Engineers use an ampere balance similar to the one in Figure 26 to calibrate standardization of mass, and use the electromagnetic quantity corrected by the quantum unit to measure and convert electric voltage and electric current of the coil, thereby connecting the mass *M* to Planck's constant *h*.

A student used building blocks to make an equal-beam ampere balance similar to the one in Figure 26. The right side of the scale is the weighing pan, the left side is the coil and the magnet, and X and Y represent the poles of the fixed magnet. Take the fulcrum as the axis, and the coil and the weighing pan will be in a static mode that is kept horizontal, or a dynamic mode that vibrates slightly up and down.

Among the physical quantities mentioned in the question, which of the following is the basic unit?

(A) mass　　(B) electric resistance

(C) voltage　　(D) energy

(E) magnetic field

（中文）量子科學以光電科技改善了生活，也增進了質量國際標準的精密與穩定。科學家發現電壓、電阻與電磁波能量等電磁量的量子單元，與普朗克常數 h 相關，因此訂 $h = 6.62607015 \times 10^{-34}\ J \cdot s$ 為新的質量基準。工程師使用類似於圖 26 的電磁天平來校準質量，並利用經過量子單元校正的電磁量，來測量與換算線圈的電壓與電流，藉以連結質量 M 與普朗克常數 h。

某生利用積木製作一座類似於圖 26 等臂的電磁天平。圖中右側為秤盤，左側為線圈和磁鐵，X 與 Y 代表固定磁鐵的兩極。以支點為軸，線圈與秤盤可以是維持於水平的靜態模式，或上下微幅振動的動態模式。

關於文中提到的物理量，哪個為基本量？

(A)質量　(B)電阻

(C)電壓　(D)能量

(E)磁場

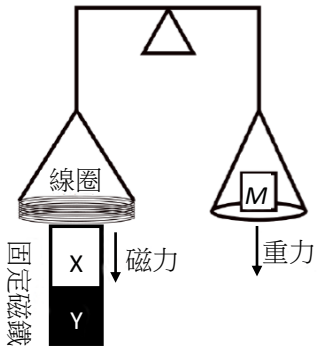

圖 26

（111 年學測 58）

解題 Solution：

物理量是用來描述某些物體特性，無法以其他物理量取代的稱為基本量。國際通用單位規範了七個基本量及基本單位。題目中提到的物理量有：電壓、電阻、能量、質量、電流、磁力、重力，其中質量、電流為基本量，其他都是導出量。

The physical quantity describes certain physical properties. For those quantities, which cannot be replaced by others are called the basic quantities. The International System of Units set the standard for seven basic quantities and its basic units. The physical quantities mentioned in the question are: voltage, resistance, energy, mass, electric current, magnetic force, and gravitational force, where mass and electric current are basic quantities, the others are derived quantities.

Teacher: What basic quantities does the International System of Units include?

Student: Mass, length, time, luminous intensity, thermodynamic temperature, electric current, and amount of substance.

Teacher: What's the basic unit of mass?

Student: The basic unit of mass is the kilogram.

Teacher: What physical quantities are the derived quantities?

Student: Velocity, density, energy, gravity, and so on.

Teacher: Good. So what's the answer to this question?
Student: The answer is (A).

老師： 國際單位系統包含哪幾個基本物理量？
學生： 質量、長度、時間、光強度、熱力學溫度、電流、物質數量。
老師： 質量的基本單位是什麼？
學生： 質量的基本單位是公斤。
老師： 哪些物理量是導出量？
學生： 速度、密度、能量、重力…等。
老師： 很好，所以這題的答案要選什麼？
學生： 答案要選(A)。

例題二

說明：了解常見輔助字首的符號表示。
To understand the symbols of common prefixes.

（英文）It was reported that a famous cellphone company has launched its latest flagship cellphone, which is equipped with the 7nm process A12 bionic chip manufactured by TSMC. The A12 chip adopts a 6-core design, with a clock rate of 2.49GHz. In the news mentioned above, 7 nanometers = _____m; and its frequency is 2.46 GHz=_____ Hz.

（中文）根據報載，某手機品牌大廠發表最新出廠旗艦手機，首度搭載台積電 7 奈米製程的 A12 Bionic 晶片。A12 晶片採用 6 核心設計，主時脈 2.49GHz。在上述新聞中，7 奈米=_____ m；其頻率為 2.49GHz = _____ Hz。

解題 Solution：

常見輔助字首有 10^{12}= T；10^{9}= G；10^{6}= M；10^{3}= k；10^{-3}= m；10^{-6}= μ；10^{-9}= n；10^{-12}= p；10^{-15}= f。

The common SI prefixes are: 10^{12}= T, 10^{9}= G, 10^{6}= M, 10^{3}= k, 10^{-3}= m, 10^{-6}= μ, 10^{-9}= n, 10^{-12}= p, 10^{-15}=f.

Teacher: What physical quantity does nanometer measure?
Student: Length.
Teacher: What's the value the prefix nano?
Student: 10 to the negative 9th power
Teacher: What physical quantity does hertz measure?
Student: Frequency.
Teacher: What power of 10 is the prefix of G?
Student: G means 10 to the 9th power.
Teacher: We come to know that 7 nanometers means 7 times 10 to the negative 9th power, (write down 7×10^{-9} m). So how many hertz are there in 2.49 G hertz?
Student: 2.49 times 10 to the 9th power of hertz, 2.49×10^{9} Hz.

老師： 奈米是哪個物理量的單位呢？
學生： 長度。
老師： 其中的「奈」表示多大的數值？
學生： 10 的−9 次方。
老師： 那麼，赫茲(Hz)又是哪個物理量的單位呢？
學生： 頻率。
老師： Hz 前面的 G 表示 10 的幾次方呢？
學生： G 等於 10 的 9 次方。
老師： 因此我們可以知道 7 奈米就是 7×10^{-9} 公尺(寫出 7×10^{-9} m)。那麼 2.49G 赫茲，相當於多少赫茲呢？
學生： 2.49 乘上 10 的 9 次方赫茲，2.49×10^{9} Hz。

1-4 物理學簡介
Introduction to Physics

■ 前言 Introduction

透過物理發展歷程所包含的幾位著名科學家的學說，讓學生了解從星體運動開始發展的運動學及力學，並延伸到電磁學。最後，簡介 20 世紀違背當時常識的理論內容，包括量子論，提出能量不連續概念，及狹義相對論打破時間與空間的絕對性。

語言方面，教師可以介紹幾項先進科技產品的英文，讓學生接軌生活科技英文。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
orbit	軌道	duality	雙重性
inclined plane	斜面	quantum theory	量子論
microscopic	微觀	special theory of relativity	狹義相對論
macroscopic	巨觀	laser	雷射
electromagnetic wave	電磁波	magnetic resonance imaging	核磁共振攝影
wave	波動	nuclear energy	核能
particle	粒子		

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

❶ _____ develop _____.

例句：Copernicus **developed** the heliocentric theory and published it in 1543.
哥白尼發展了日心說理論，並在 1543 年發表。

❷ As _____, first _____, then _____, and finally _____.

例句：**As** the temperature of an iron stick increases, **first** it glows red, **then** turns orange, **and finally** becomes "incandescent."
當物體的溫度升高時，一開始發出紅光，接下來變成橘黃色，最後呈現「白熾」。

❸ _____ such as _____.

例句：Several factors can affect chemical reaction rate, **such as** the materials of the reactants, temperature, concentration, cross section area, and adoption of catalyst.
有些因素會影響化學反應的速率，如：反應物的種類、溫度、濃度、接觸面積和催化劑的引用。

❹ _____ depend on _____.

例句：The radiation spectrum of a furnace **depends** only **on** its temperature.
熔爐發出的輻射光譜，僅取決於熔爐的溫度。

❺ _____ be independent of _____.

例句：The radiation spectrum of a black body **is independent of** its material.
黑體的輻射光譜與材質無關。

❻ _____ be different from _____. /Be _____ different from?

例句：**Is** the speed of light measured by a stationary observer **different from** that measured by a moving observer?
靜止的觀察者測量的光速，會與行進中的觀察者測量的光速不同嗎？

■ 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、量子論提出黑體輻射的能量，是不連續的。

the discrete nature of the energy of black body radiation proposed by the quantum theory.

二、狹義相對論認為光速是不變的，因而推得時間與空間，並非絕對，而是相對的。

speed of light is constant proposed by special theory of relativity, which therefore abandon the independency between space and time. Time and space are thus regarded as dependent on each other.

三、了解物理發展史上較重要的科學家及其貢獻，例如:伽利略、克卜勒、牛頓、惠更斯、法拉第、馬克士威、普朗克、愛因斯坦等。

about some major scientists and their contributions in the development of physics, such as: Galileo, Kepler, Newton, Huygens, Faraday, Maxwell, Planck, Einstein, etc.

例題講解

例題一

（英文）The development of physics is dependent on the effort made by many scientists. The following scientists (a) to (c) mark the important milestones in the development of physics:

(a): Concluded that the motion of planets follows certain clear laws.

(b): Derived the velocity of electromagnetic waves through the electromagnetic field equation.

(c): Concluded that the relative velocity between the wave source and the observer would affect the frequency of the wave being observed.

Which of the following options (A) to (E) is the correct correspondence between the scientists and their conclusions?

	Kepler	Doppler	Maxwell
(A)	(a)	(b)	(c)
(B)	(b)	(a)	(c)
(C)	(b)	(c)	(a)
(D)	(c)	(a)	(b)
(E)	(a)	(c)	(b)

（中文）物理學的發展有賴科學家的努力，下列甲至丙所述為物理學發展的重要里程碑：

甲：歸納出行星的運動遵循某些明確的規律。

乙：從電磁場方程式推導出電磁波的速率。

丙：波源或觀察者相對於介質的速度，會影響觀察到波的頻率。

上述發展與各科學家的對應，最恰當的為下列哪一選項？

	克卜勒	都卜勒	馬克士威
(A)	甲	乙	丙
(B)	乙	甲	丙
(C)	乙	丙	甲
(D)	丙	甲	乙
(E)	甲	丙	乙

（改編自 102 年學測 21）

解題 Solution：

克卜勒根據所觀察的行星數據，歸納出行星運動遵循的行星運動三個定律。馬克士威擴展並整合電磁學理論，且從中推導出電磁波方程式及電磁波的傳播速率（光速）。都卜勒

提出波源與觀察者，相對於介質的速度，會影響觀察到波的頻率。故選(E)。

Based on the data of observing planetary motion, Kepler concluded three laws regarding planetary motion. Maxwell integrated and extended the theories of electromagnetism and then derived the equation and transmission velocity of electromagnetic waves. Doppler proposed that the velocities of the wave source and the observer relative to the medium would affect the observed frequency. Therefore, the answer is (E).

Teacher: What's the shape of the earth's orbit around the sun?
Student: The shape of oval.
Teacher: Who discovered the laws of planetary motion around the sun and proposed three laws of planetary motion?
Student: Kepler.
Teacher: Kepler discovered that the earth orbits the sun in an elliptical orbit, so is the sun at the center of the ellipse, or is it somewhere else?
Student: The sun is not at the center of the ellipse, but at one of the foci of the ellipse.
Teacher: Very good. This is the first law of planets summarized by Kepler.
Teacher: When an ambulance approaches, the frequency we hear is higher than the siren of the ambulance. Which phenomenon is this?
Student: Doppler effect.
Teacher: Who unified the relationship between electricity and magnetism, and came up with the concept of electromagnetic waves?
Student: Maxwell.
Teacher: So the answer is (E).
Teacher: When Maxwell deduced the electromagnetic wave equation, he also calculated that the wave speed of electromagnetic waves is always equal to the speed of light, regardless of the speed of the light source or the observer. This conclusion violates the relative motion view of Newton's mechanics and leads to the birth of Einstein's special theory of relativity.

老師： 地球繞著太陽的軌道並不是圓形，而是什麼形狀？
學生： 橢圓形。
老師： 哪位科學家歸納出行星繞著太陽運動的規律，並提出行星運動的三個定律呢？
學生： 克卜勒。
老師： 克卜勒發現地球繞太陽是橢圓形軌道，那麼太陽位置是否在橢圓中心，或是其他位置？

學生：太陽不在橢圓中心，而是在橢圓的其中一個焦點上。
老師：很好，這是克卜勒所歸納出的行星第一定律。
老師：當救護車接近時，我們聽到的頻率會比救護車發出的頻率高，這是哪個現象呢？
學生：都卜勒效應。
老師：誰擴展並整合了電與磁的關係，並推導出電磁波的理論呢？
學生：馬克士威。
老師：對，所以答案選(E)。
老師：馬克士威推導出電磁波方程式的同時，也算出電磁波的波速恆等於光速，與光源或觀察者的速度無關。此結論違背了牛頓力學的相對運動觀，並促成愛因斯坦狹義相對論的誕生。

例題二

（英文）The surface temperature of a star is related to the color of its starlight. When we watch the stars twinkling in the night sky, we can see the colors of the stars are white, blue, yellow, red, etc. Which of the following pairs have the same principle of color generation?

(A) The flare of stars and fireworks.
(B) Red stars and the redness of Mars.
(C) Blue stars and blue flowers.
(D) Red stars and the red light we see in volcanic lava.
(E) Blue stars and the blue light we see when gas is burning.

（中文）恆星的表面溫度與呈現的星光顏色有關，當我們觀賞夜空中閃爍的恆星，可看出恆星的顏色有白、藍、黃、紅等。下列選項中，顏色產生的原理何者相同？

(A)恆星與煙花的火光。
(B)紅色恆星與紅色的火星。
(C)藍色恆星與藍色的花。
(D)紅色恆星與火山熔岩發出的紅光。
(E)藍色恆星與瓦斯燃燒發出的藍光。

（108 年學測 3）

解題 Solution：

恆星發出的光與表面溫度有關，近似黑體輻射（一般所稱的熱輻射），火山熔岩的紅光，也是因為表面溫度夠高而發出紅光，與恆星發出紅光的原理相同。故選(D)。

The light illuminated by stars is determined by its surface temperature, which is similar to the black body radiation (or so-called thermal radiation). The volcanic lava looks red also because the surface temperature is so high that it generates red light, which is the same reason for stars that produce red light. Therefore, the answer is (D).

Teacher: Charcoal is originally black, and how does it change after being heated?
Student: Charcoal produces red light when heated.
Teacher: If the temperature is higher, will it also produce red light?
Student: It will turn orange and finally yellow.
Teacher: What factor is related to such color change?
Student: Temperature.
Teacher: Most things in our life don't produce light by themselves, but why can we see their different colors?
Student: Because the object reflects the light from its surroundings.
Teacher: Yes, most objects would absorb part of the light around them and reflect the rest. Therefore, what we see the colors are those reflect from the objects.
Teacher: Does the fluorescent lamp produce light because its temperature is high enough?
Student: No.
Teacher: Very well, the light produced by a fluorescent lamp is of a specific spectrum. The mercury vapor (mercury atoms) inside absorbs energy and emit light of a specific spectrum. ….
Teacher: So what are some other things that produce specific colored lights?
Student: Fireworks, the blue flame of gas, firefly.
Teacher: Very good, so the answer should be (D).

老師： 木炭原本是黑色的，加熱後有什麼變化？
學生： 木炭加熱後會發出紅光。
老師： 如果溫度再高一樣發出紅光嗎？
學生： 會變成橘色、甚至是黃色。
老師： 這樣的顏色變化跟木炭的哪個因素有關係？
學生： 溫度。

老師： 生活中多數的東西本身不發光，為何我們可以看到不同的顏色？

學生： 因為反射外界的光線。

老師： 日光燈發光，是因為溫度夠高嗎？

學生： 不是。

老師： 很好，日光燈發出的光是特定的光譜，主要是裡面的水銀蒸氣，也就是（汞原子）吸收能量後，其發出的光，在光譜上有特定的位置。產生這些特定光譜的單色光，屬於激發光，因此不需很高的溫度，只需要足夠動能的電子，超越光子的能階，就能激發出來。

老師： 那麼會發出特定顏色光線的東西，還有哪些呢？

學生： 煙火、瓦斯的藍色火焰、螢火蟲。

老師： 很好，所以答案要選(D)。

★主題二 物質的組成與交互作用★
Composition and Interaction of Substances

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■ 前言 Introduction

本章透過原子的介紹來說明物質的組成方式以及藉由三項圖判斷物質三態的變化。進而介紹物質間的四種基本交互作用，再介紹電磁力相關的電場、磁場，磁力線的概念。

2-1 物質的組成
Composition of Substances

■ 前言 Introduction

介紹生活中不同物質，是由哪些原子所組成，進而解釋微觀的原子排列狀態，及物質三態變化的關係。最後，再引入生活中的物理現象，如熱傳導，並以微觀的原子現象加以解釋。

語言方面，教師可以介紹生活中常見物質的英文，與描述三態改變的用語。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
diamond	鑽石	pressure	壓力
graphite	石墨	boiling point	沸點
carbon atom	碳原子	melting point	熔點
arrangement	排列方式	melt	熔化
characteristic (nature)	特性(性質)	solidification	凝固
periodic table of elements	週期表	thermal conductivity	熱傳導
temperature	溫度	shock/shake/tremble	震動

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

❶ _____ look like _____(N.).

例句：Diamond and graphite **look like** very different substances.
鑽石與石墨雖然是相同的元素，但看起來是截然不同的物質。

❷ ____ be surrounded with/by _____.

例句：Each carbon atom in diamond **is surrounded by** 4 carbon atoms.
鑽石中的每個碳原子周圍，緊鄰著 4 個碳原子。

❸ ____ be arranged in _____ structure.

例句：The carbon atoms of graphite **are arranged in** a two-dimensional honeycomb **structure**, and then stacked in layers.
石墨的碳原子排列成二維的蜂窩狀結構，再層層堆疊起來。

❹ _____ the way S. +V.

例句：Temperature and pressure can change **the way** atoms are arranged.
溫度與壓力可以改變原子的排列方式。

❺ _____ be not always fixed.

例句：The arrangement of atoms **is not always fixed**.
原子的排列方式並非一成不變。

❻ at _____ temperature

例句：Water is in liquid form **at** room **temperature**.
在室溫下，水呈現液態。

■ 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 completing this unit, students should acquire the following concepts:

一、分子是具有物質特性的最小單元，原子的排列不同，形成的物理性質也不同，但化學性質相同。

Molecules are the smallest unit that has material properties. Different arrangements of atoms have different physical properties but the same chemical properties.

二、溫度與壓力可以改變原子的排列方式，巨觀上是狀態（三態）的改變。

Temperature and pressure can change the arrangement of atoms, and the macroscopic phenomenon is the change of its state (three states).

❧ 例題講解 ☙

例題一

（英文）At present, the maximum data storage density that can be achieved by the memory technology is 108 byte/cm2 (1 byte=8 bits), but nanotechnology is very likely to break this limitation. In the design shown in the figure, the hydrogen and fluorine atoms on the surface of a diamond respectively represent 0 and 1 bits. If the atoms of the carbon nanotube probe head (such as nitrogen or boron) can attract or distract the hydrogen and fluorine atoms, the forces can be used to distinguish 0 and 1 byte. Which of the following statements about this nanotechnology is correct?

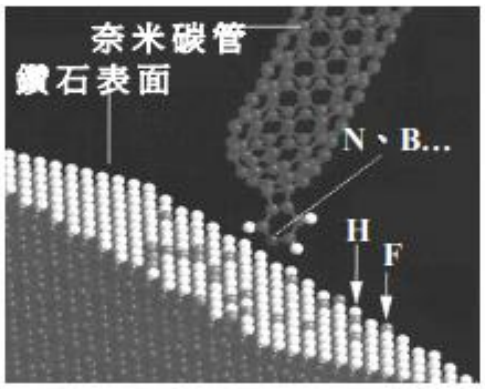
(A) The diameter of the hydrogen atom is about 10 nanometers.

(B) The larger the atomic diameter of the carbon nanotube probe head is, the easier it is to distinguish the difference between 0 and 1 bit.

(C) This nanotechnology is expected to increase the data storage density to more than tens of thousands of times the current highest density.

(D) There are two kinds of atoms representing 0 and 1 bits on the surface. The larger the diameter is, the easier it is to enlarge the data storage density.

（中文）目前記憶體技術可達到的資料儲存密度最高為 108 byte/cm2（1byte＝1 位元組＝8 位元），但奈米科技極可能突破此上限。如圖所示的設計，鑽石表面上的氫與氟原子，可分別代表 0 與 1 位元，若奈米碳管探針頭的原子（如氮或硼），對氫與氟原子分別具有吸引與排斥作用力，則可據以區別 0 與 1 位元。



下列與此奈米科技有關的敘述，何者正確？

(A) 氫原子的直徑大約為 10 奈米。

(B) 奈米碳管探針頭的原子直徑愈大愈有利於區別 0 與 1 位元。

(C) 此奈米科技預期可使資料儲存密度提高到目前最高密度的數萬倍以上。

(D) 位於表面上代表 0 與 1 位元的兩種原子，其直徑愈大愈有利於提高資料儲存密度。

（98 年學測 4）

解題 Solution：

原子的直徑大小約 1~3 埃(Å)，奈米碳管的**探針原子**直徑越小，較有利區分 0 與 1 位元。目前可記錄的資料儲存密度為 10^8 byte/cm^2，相當於 1 公分長度可紀錄 $\sqrt{10^8} = 10^4$ 位元組，1 cm = 10^8 Å，改以原子做為位元單位，則儲存密度可提高約 $10^8/10^4=10^4$ 倍，約數萬倍。代表 0 與 1 位元的原子直徑越小，越能增加儲存密度。故選(C)。

The diameter of an atom is about 1 angstrom to 3 angstroms. The smaller the diameter of the probe atom of carbon nanotubes, the better it is to distinguish 0 and 1 bit. The current recordable data storage density is 10^8 byte/cm^2, which means the length of 1 cm can record $\sqrt{10^8} = 10^4$ bytes。As 1 cm = 10^8Å, if atom is used as the unit for byte, then the storage density can be increased by about $10^8/10^4 = 10^4$ times, which is about tens of thousands of times. The smaller the diameter of the atoms representing the 0 and 1 bit, the larger the storage density is. Therefore, the answer is (C).

Teacher: What's the unit for the scale of atoms?

Student: It's Ångstrom (ANG/Å).

Teacher: How many nanometers are there in 1 Ångstrom?

Student: One nanometer is equal to 10 Ångstroms.

Teacher: When you use a pen, what kind of pen point can help you record more data?

Student: The finer one.

Teacher: If each character you write is 0.5 cm in length and width, how many characters can you put into a line on the paper that's the size of 10 cm × 10 cm?

Student: Twenty words in a line, as 10 divided by 0.5 is 20.

Teacher: So a total of 20 × 20 = 400 characters can be put onto a piece of paper. Then, how many Ångstroms is 1 cm equal to?

Student: One centimeter is equal to 10 to the 8th power of Ångstroms (1 cm = 10^8 Å).

Teacher: So if we use atoms to record data, how many atoms can be arranged in 1 cm?

Student: A total of 10 to the 8th power (10^8) of atoms can be arranged in 1 cm.

Teacher: When the atom is used as the storage unit, the storage density can be increased by tens of thousands of times, so the answer is (C).

老師： 原子的尺度使用哪個單位呢？

學生： 埃(Å)。

老師： 1 奈米等於幾埃呢？

學生： 1 奈米等於 10 埃 (1 nm = 10 Å)。

老師： 是的，那寫字的筆如果使用怎樣的筆頭，就可以記錄比較多的資料呢？

學生： 越細的可以寫越多資料。

老師： 1 張 10 公分 × 10 公分的白紙，如果上面的字長寬都是 0.5 公分，那麼一行可以紀錄幾個字呢？

學生： 一行可以記錄 10 除以 0.5 = 20 個字。

老師： 沒錯，所以一張紙總共可以記錄 20 × 20 = 400 個字，那 1 公分等於幾埃呢？

學生： 1 公分等於 10 的 8 次方埃，1 cm = 10^8 Å

老師： 很好，所以，如果以原子來紀錄資料，1 公分可以排列多少個原子呢？

學生： 1 公分可以排列 10 的 8 次方(10^8) 個原子。

老師： 所以，原子做為儲存的單位時，儲存的密度就可以增加數萬倍，答案選(C)。

例題二

（英文）Based on the concepts of atoms and molecules, which of the following statements regarding the three states of matter (solid, liquid, gas) are correct?

(A) When a substance melts, the types of atoms making up the substance do not change.

(B) The density of iron is so large that it can't exist as a gas.

(C) The microscopic meaning of temperature represents the speed of particle motion.

(D) The change of matter's three states is related to temperature, which has nothing to do with pressure.

(E) When a substance vaporizes, the distance between neighboring molecules increases.

（中文）以原子與分子的觀點，來看物質的三態變化，下列敘述哪些正確？

(A)物質熔化時，組成原子的種類不會改變。

(B)鐵的密度大，無法以氣態存在。

(C)溫度的微觀意義代表粒子運動的劇烈程度。

(D)三態變化與溫度有關，與壓力無關。

(E)物質汽化的過程中，分子間的距離增大。

（取自 108 年中一中段考 18）

解題 Solution：

物質的三態會隨溫度與壓力之改變而改變，但原子種類不變，改變的只是原子間的排列方式，及原子運動的活躍程度。溫度夠高的話，所有物質都可轉變為氣態。故選(D)。

The three states of matter may change when the temperature or pressure change, but the types of atom species remain the same. What changes are the arrangement of atoms and the degree of active atomic motion. When the temperature is high enough, all substances can transform into gas. So the answer is (D).

Teacher: How do you melt an iron stick?

Student: Heat the iron stick to make its temperature exceed the melting point, and then the iron stick will begin to melt.

Teacher: What happens to the atoms of iron after they absorb heat?

Student: The movement of the atoms will intensify.

Teacher: Very well. Besides temperature, what other factors will change a substance's state of matter?

Student: Pressure.

Teacher: That's correct. The process of evaporation turns the substance from what state to what state?

Student: From liquid to gaseous.

Teacher: That's right. Then among the three states of a material, under what circumstances can the atoms of iron have the largest distance?

Student: The distance is the largest between gaseous iron atoms.

Teacher: Very good, so the answer is (D).

老師： 生活中如何使鐵棒熔化？

學生： 把鐵棒加熱，讓鐵棒的溫度超過熔點，鐵棒就會開始熔化。

老師： 是的，鐵原子吸收熱量後，鐵原子有什麼變化？

學生： 鐵原子的運動會變的比較劇烈。

老師： 很好，除了溫度，還有哪個因素能改變物質的狀態？

學生： 壓力。

老師： 正確，那麼汽化是由哪種狀態改變成哪種狀態呢？

學生： 液態變成氣態。

老師： 沒錯，三態中，哪種狀態下的鐵原子間距離最大？

學生： 氣態的鐵原子間，距離最大。

老師： 很好，所以答案要選 (D)。

2-2 原子的結構
Atomic Structure

■ 前言 Introduction

透過原子模型的發展史，探討組成物質之基本粒子。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
scale	尺度	rebound	反彈
internal structure	內部結構	cannonball	砲彈
element	元素	plum pudding model	葡萄乾布丁模型
embed	鑲嵌	planetary model	行星模型
electrical neutrality	電中性	proton	質子
electron	電子	neutron	中子
hit/collide	撞擊	nucleus	原子核
deflection	偏折	elementary particle	基本粒子
alpha particle	α 粒子	quark	夸克
gold foil	金箔		

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

❶ During _____ reaction, _____ will not change, but_____ would change.

例句：Atomic Theory assumes that the constituent particles-atoms of different elements are different. **During** chemical **reaction,** the type and number of atoms **will not change, but** the arrangement and combination of atoms **would change.**

「原子論」假設不同的元素，其組成的粒子-原子，是不一樣的。而化學反應前後，原子種類、個數，皆不會改變，但化學反應會改變原子的排列組合。

❷ The positive charge inside an atom is_____ such as_____.
The negatively charged particles of electrons are_____ like _____.

例句：**The positive charge inside an atom is** distributed uniformly throughout the volume of the sphere **such as** pudding. **The negatively charged particles of electrons are** embedded inside the atoms **like** raisins.

原子內的正電荷像布丁一樣均勻分布，帶負電的電子則像葡萄乾一樣，鑲嵌在原子內部。

❸ Most of _____, but a very small number of _____.

例句：**Most of** the alpha particles deflect at a small angle when they hit the gold foil, **but a very small number of** alpha particles bounce back more than 90 degrees after hitting the gold foil.

大部分 α 粒子撞擊到金箔只有小角度偏折，但極少數的 α 粒子撞擊金箔後，以超過 90 度的反彈。

❹ _____ be made up of _____.

例句：Protons and neutrons **are made up of** much smaller particles, called quarks.

質子與中子是由更小的夸克所組成。

■ 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、知道探討原子內部結構的科學史。

Know the history of how the internal structure of atoms was developed.

二、了解原子內部結構（組成及表示法）。

Understand the internal structure of atoms (composition and notation).

❧ 例題講解 ☙

例題一

說明：讓學生了解科學方法的程序。

Make students understand the procedure of scientific methods.

（英文）Rutherford hit gold foil with particles and found occasional large-angle scattering, suggesting that electrons orbit around the nucleus of an atom, similar to how the planets orbit around the sun. Which of the following statements about Rutherford's experiment and its atomic model is correct? (2 options should be selected)

(A) There is no electrostatic force between the electrons of a particle and an atom.

(B) The electrostatic force between the particle and the nucleus is an attractive force.

(C) If the electrons in the atom lose energy, the electrons can be brought closer to the nucleus.

(D) Particles occasionally scatter at large angles, mainly due to collisions with multiple electrons.

(E) Particles occasionally scatter at large angles, mainly because the positive charge of the atom is concentrated in the extremely small nucleus.

（中文）拉塞福以粒子撞擊金箔，發現偶爾會有大角度的散射，因而提出電子繞原子核運行，正如行星繞行太陽。下列關於拉塞福實驗與其原子模型的敘述，哪些正確？（應選 2 項）

(A)粒子與原子的電子間沒有靜電力。

(B)粒子與原子核間的靜電力為吸引力。

(C)原子中的電子若損失能量，可使電子更接近原子核。

(D)粒子偶爾會有大角度的散射，主要是因為與多個電子發生碰撞。

(E)粒子偶爾會有大角度的散射，主要是因為原子的正電荷集中於極小的原子。

（106 年學測 32）

Teacher: What kind of particle did Rutherford use to hit gold foil? What charge does this particle carry?

Student: He hit gold foil with alpha particles, which have a positive charge.

Teacher: Yes, what was the result of Rutherford's experiment?

Student: Most alpha particles deflected at small angles, but a few alpha particles bounce backward with more than 90 degrees.

Teacher: What kind of the evidence can the backward bouncing alpha particles show?

Student: The over 90-degree backward bounce reveals that since the alpha particles interact with the positive charge, a very small degree of bounce lets us know that the positive charge is concentrated in a very small area.

Teacher: Good, so, is there an electrostatic force between the particle and electrons or nuclei in an atom?

Student: The particles in the question are alpha particles with positive charge, so there is an attractive force between the particles and the electron, and there is a repulsive force between the particles and the nucleus.

Teacher: The Rutherford model proposes that negatively charged electrons revolve around positively charged nuclei. What is this model called?

Student: Atomic planetary model, like a planet orbiting the sun.

Teacher: So if the mechanical energy of the planet decreases, do you think the planet will be closer to the sun or farther away from the sun?

Student: It should be closer, just like when a satellite is orbiting around the earth, if its mechanical energy decreases, it would fall instead of drifting away from the earth.

Teacher: So which two should you choose?

Student: The answers should be (C) and (E).

老師： 拉塞福以哪種粒子撞擊金箔？這種粒子帶什麼電？
學生： 他用 α 粒子撞擊金箔，α 粒子帶正電。
老師： 好，拉塞福的撞擊實驗結果如何？
學生： 多數的 α 粒子以小角度偏折，極少數的 α 粒子以超過 90 度反彈。
老師： 反彈的 α 粒子顯示了哪種證據？
學生： 超過 90 度反彈，顯示 α 粒子應該是撞擊到正電，極少數的反彈，可以讓我們推測正電是集中在極小的區域。
老師： 很棒，因此題目中的粒子與原子中的電子或原子核之間，是否有靜電力？
學生： 題目中的粒子是 α 粒子帶有正電，因此與電子之間有吸引力，與原子核之間有排斥力。
老師： 是的，那拉塞福模型提出帶負電的電子，繞著帶正電的原子核運轉，這個模型被稱為什麼？
學生： 原子行星模型，如同行星繞太陽運轉。
老師： 很好，那麼如果行星的力學能減少，你認為行星會接近太陽還是遠離太陽？
學生： 應該會接近，就像衛星繞地球運轉，如果力學能減少，應該會墜落，而不是遠離地球。
老師： 正確，所以答案要選哪兩個？
學生： 答案要選(C)跟(E)。

例題二

（英文）Which of the following statements about atoms $_{84}$Po (mass number 210) and $_{88}$Ra (mass number 226) are correct?

(A) The number of neutrons inside the nuclei of $^{210}_{84}$Po and $^{226}_{88}$Ra differ by 16.

(B) The number of protons in the nuclei of $^{210}_{84}$Po and $^{226}_{88}$Ra differ by 16.

(C) The number of electrons in the atoms of $^{210}_{84}$Po and $^{226}_{88}$Ra differ by 4.

(D) Both polonium and radium do not exist in nature.

(E) The radioactivity of both polonium and radium come from the X-rays emitted by their nuclei.

（中文）下列關於 $_{84}$Po（質量數 210）原子及 $_{88}$Ra（質量數 226）原子的敘述，何者正確？

(A) $^{210}_{84}$Po 和 $^{226}_{88}$Ra 兩種原子核中的中子數相差 16。

(B) $^{210}_{84}$Po 和 $^{226}_{88}$Ra 兩種原子核中的質子數相差 16。

(C) $^{210}_{84}$Po 和 $^{226}_{88}$Ra 兩種原子中的電子數相差 4。

(D) 釙和鐳兩個元素，在自然界都不存在。

(E) 釙和鐳的放射性都是源自其原子核釋出 X 光。

（101 年學測 47）

Teacher: What element does $_{84}$Po stand for, and what's its atomic composition?

Student: Po means polonium, and 84 means polonium atom has 84 protons, or the neutral polonium atom has 84 electrons.

Teacher: What does the mass number in $_{84}$Po (mass number 210) represent?

Student: The mass number is the sum of the number of protons plus the number of neutrons in an atom.

Teacher: Yes, so $^{210}_{84}$Po means how many protons, electrons, and neutrons, respectively, are there in the polonium atom?

Student: The number of protons in the polonium atom can be found from the number in the lower left corner, 84. The number of electrons in a neutral polonium atom is equal to the number of protons. The number of neutrons can be found by subtracting the mass number of 210 by the number of protons, 84, which is 116.

Teacher: Great!

Teacher: Who was the first to discover radium?

Student: Madame Curie was the first scientist to discover that the element was radioactive by extracting radium from asphalt.

Teacher: What kind of rays do radioactive elements usually emit?

Student: Radioactive elements usually emit three types of rays, namely alpha rays, beta rays, and gamma rays.
Teacher: So what's the answer?
Student: The answer is (C).

老師： $_{84}$Po 這個符號表示哪種元素及其原子組成呢？
學生： Po 表示釙元素，84 表示釙原子有 84 個質子，或者中性的釙原子外面有 84 個電子。
老師： $_{84}$Po（質量數 210）質量數的數字代表的意思是什麼呢？
學生： 質量數是原子內的質子數加上中子數的總和。
老師： 是的，所以 $^{210}_{84}$Po 表示釙原子內部有質子、電子、中子分別多少個呢？
學生： 釙原子內部結構，可以直接讀取左下角數字，84 代表質子數量，再由質量數 210 減去質子數 84，得到中子數有 116 個。
老師： 很好，完全正確。
老師： 第一個發現鐳的是誰呢？
學生： 居禮夫人從瀝青提煉出鐳，是第一個發現元素具有放射性的科學家。
老師： 是的，放射性元素通常會放射那些射線？
學生： 放射性元素通常會放射三種射線，分別是 α 射線、β 射線、γ 射線。
老師： 因此答案要哪個呢？
學生： 答案是(C)。

2-3 基本交互作用
Fundamental Interaction

■ 前言 Introduction

介紹物質間的四種基本交互作用，分別為：重力、電磁力、強核力、弱核力，並引入生活中常見的重力現象及定律公式。再介紹電磁力相關的電場、磁場、磁力線等概念。最後利用強核力及弱核力的特性，解釋原子何以穩定存在，又為何會發生自發性的放射現象。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
gravity	重力	distribute	分布
electrostatic force	靜電力	electric charge	電荷
magnetic force	磁力	electromagnetic force	電磁力
gravitational acceleration	重力加速度	contact force	接觸力
gravitational field	重力場	strong nuclear force	強核力
iron powder	鐵粉	strong interaction	強交互作用
magnet	磁鐵	weak nuclear force	弱核力
magnetic field line	磁力線	beta decay	β 衰變

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

❶ **_____ have discovered _____ kinds of _____ in nature, namely: _____, _____, _____, and _____.**

例句：Scientists **have discovered** four **kinds of** forces **in nature, namely**: gravity, electromagnetism, strong nuclear force, **and** weak nuclear force.
科學家發現自然界有四種力，分別是：重力、電磁力、強核力、弱核力。

❷ **_____ with mass**

例句：There must be attractive gravitational force between any two objects **with mass**.
任何兩個具有質量的物體之間，都存在吸引的萬有引力。

❸ **_____ is (directly) proportional to _____.**

例句：The magnitude of gravitational force **is proportional to** the product of their masses, and inversely proportional to the square of the distance between them.
重力的量值與兩物體之質量乘積成正比，與兩者距離之平方成反比。

❹ **such as_____, _____, _____**

例句：Contact forces in life **such as** stretching a rubber band, closing a door, standing on a scale, etc., are, on a microscopic scope, caused by electrostatic force.
生活中的接觸力，例如：拉長橡皮筋、關門、站上體重計等力量，在微觀尺度都屬於靜電力。

❺ **_____ is proportional to _____.**

例句：The mass of a cup of water **is proportional to** its volume.
一杯水的質量，與它的體積成正比。

❻ _____ is a brand-new effect, _____.

例句：The weak nuclear force **is a brand-new effect.** In this process, both the mass number and charge numbers keep conserved.

弱核力是最近發現的作用，在此過程中，質量數守恆，電荷數守恆。

■ 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、了解重力及靜電力，與距離皆成平方反比的關係。

Understand the inverse-square law of distance regarding gravitational and electrostatic forces.

二、了解四種基本作用力的作用範圍，及強度與作用情況。

Understand the scale, strength and effect of the four basic interactional forces.

❧ 例題講解 ☙

例題一

（英文）The gravitational force between two particles is proportional to the product of their masses and inversely proportional to the square of the distance between them. Xiaojun wants to estimate the earth's mass M from the gravitational constant G, the acceleration of gravity g on Earth's surface, and the radius of Earth R. Which of the following should be the correct calculation?

（中文）兩質點間的萬有引力與其質量的乘積成正比，而與其距離的平方成反比。小君想從萬有引力常數 G、地球表面的重力加速度 g、和地球半徑 R 去估算地球的質量 M，她寫出的正確計算式應為下列何者？

(A) $\boldsymbol{M=\frac{gR^2}{G}}$　(B) $M=\frac{GR^2}{g}$　(C) $M=\frac{Gg}{R^2}$　(D) $M=\frac{R^2}{gG}$　(E) $M=gGR^2$

（100 學測 68）

解題 Solution：

學生需要知道萬有引力公式，並知道重力加速度(g)，與萬有引力常數(G)間的關係，兩式整合，就能得到解答。

Students need to know Newton's Universal Law of Gravitation, and the relationship between gravitational acceleration (g) and the gravitational constant (G). Then we can obtain the answer by combining the two formulas.

Teacher: What is Newton's law of gravitation?

Student: $F = \frac{GMm}{R^2}$.

Teacher: Then what's the relationship between gravity and acceleration due to gravity?

Student: Gravity equals to the mass of an object times the acceleration due to gravity!

Teacher: That is correct! $F_g = mg$.

Teacher: So what's the mathematical form of gravitational acceleration in related to the gravitational constant G?

Student: $g = \frac{GM}{R^2}$.

Teacher: That's correct.

Teacher: Now the question wants you to estimate the mass M of the earth. How do you derive the answer?

Student: $M = \frac{gR^2}{G}$.

Teacher: Yes, so the answer is (A).

老師： 請問萬有引力公式為何？

學生： $F = \frac{GMm}{R^2}$。

老師： 那麼重力與重力加速度之間有何關係呢？

學生： 重力等於物體質量乘重力加速度！

老師： 是的，$F_g = mg$。

老師： 因此，重力加速度與萬有引力常數的關係應如何？

學生： $g = \frac{GM}{R^2}$。

老師： 答對了。

老師： 那麼，現在題目是要估算地球的質量 M，要如何得到解答呢？

學生： $M = \frac{gR^2}{G}$。

老師： 是的，因此答案要選(A)。

例題二

（英文）The reaction rate of nuclear fusion inside the sun is fairly steady, and is enough to continuously supply Earth's energy needed for 10 billion years. According to research, the main interactional force that affects the reaction rate of nuclear fusion, is the same fundamental interaction as the process by which neutrons decay into protons, electrons, and another electrically neutral particle called an antineutrino.

Which of the following is the main force affecting the reaction rate of nuclear fusion?

(A) Electrostatic force　(B) Strong force　**(C) Weak force**

(D) Gravity (universal gravitation)　(E) Electricity and magnetism

（中文）太陽內部核熔合的反應速率相當穩定，足以持續提供地球 100 億年的能源需求。根據研究，影響核熔合反應速率的主要作用力，與中子衰變成質子、電子和另一個稱為反微中子的電中性粒子的過程，屬於同一種基本交互作用。由此可知下列何者為影響核熔合反應速率的主要作用力？

(A)靜電力　(B)強力　**(C)弱力**　(D)重力（萬有引力）　(E)電力與磁力

（103 年學測 21）

解題 Solution：

透過四種基本作用力的特性，與涉及的粒子種類的辨識，可以判斷此題的作用力種類。

We can determine the type of interaction of this question by means of distinguishing the differences of the characteristics and associated particles among the four types of fundamental interactional forces.

Teacher: What are the four basic interactional forces?

Student: Gravity, electromagnetism, strong force, and weak nuclear force.

Teacher: Good! What are the situations in which gravity take place? Could you give me an example?

Student: The satellites orbiting around the earth is the result of gravity.

Teacher: That's right. Gravitational force exists owing to masses, which force is always attractive.

Teacher: What about the electromagnetic force? Could you give me a few examples?

Student: Most of the contact forces in life are electromagnetic forces, such as the force of pushing objects, the force of hitting a ball with a bat, buoyancy, and so on.

Teacher: Very good! So, electromagnetic force exists due to interaction between charges, which can be either attractive or repulsive.

Teacher: Then, can the strong nuclear force and the weak nuclear force be observed in daily life?

Student: The strong nuclear force and the weak nuclear force cannot be observed in our daily life.

Teacher: So what's the effect of strong nuclear force?

Student: It's a force that allows atoms to maintain its stability.

Teacher: What about the weak nuclear force? What does it act on?

Student: The weak nuclear force is the beta decay process of nuclear decay, which changes the atoms.

Teacher: Correct. So in this question, what kind of force should be the main factor that affects the reaction rate of nuclear fusion?

Student: The weak nuclear force, because it is mentioned in the question that this force is the same basic fundamental interaction as the process of neutrons decaying into protons, electrons and antineutrinos, and that's so-called weak force.

Teacher: Correct, so the answer is (C).

老師： 請問四種基本作用力分別是哪四種？

學生： 重力、電磁力、強核力、弱核力。

老師： 重力作用的情況為那些，可以舉例嗎？

學生： 衛星繞著地球轉，就是重力作用的結果。

老師： 沒錯，所以，重力的原因是質量，重力必為吸引力。

老師： 那麼電磁力呢？可以舉幾個例子嗎？

學生： 生活中大多數的接觸力都是電磁力，例如：推東西的力，球棒打球的力、浮力等等。

老師： 很好，所以，電磁力的原因是電荷之間的排斥或吸引力。

老師： 那麼強核力跟弱核力生活中，可以在日常經驗中觀察到嗎？

學生： 強核力與弱核力生活中觀察不到。

老師： 那麼強核力的作用是什麼呢？

學生： 讓原子可以維持穩定的力。

老師： 很好，那麼弱核力呢？它如何作用？

學生： 弱核力是核衰變的 β 衰變過程，它會使原子發生變化。

老師： 正確，因此題目中，影響核熔合反應速率的主要作用力，應該是哪種力呢？

學生： 弱核力，因為題目中提到這種力與中子衰變成質子、電子與反微中子屬於同一種基本交互作用，這種作用就是弱核力。

老師： 是的，所以答案為(C)。

★主題三 物體的運動★
Movement of Objects

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■ 前言 Introduction

在本章教師應先簡單介紹運動所需的名詞定義，並讓學生能了解運動關係圖中的 X-T 圖，V-T 圖，a-t 圖表示的意義。再引入牛頓運動三大定律，讓學生了解物體運動與作用力之間的關係。最後介紹生活中常見的力：如正向力、彈力、摩擦力，再由天體運動的歷史發展，引入克卜勒三大行星定律，並延伸到牛頓重力的發現。

3-1 物體的運動
Movement of Objects

■ 前言 Introduction

介紹描述運動現象，所需的幾個基本物理量，例如：路徑長、位移、平均速度、平均速率、瞬時速度、及加速度……等。同時，說明路徑長與位移的區別，在科學常使用位移，而生活中較常使用路徑長。並由常見的運動關係圖，探討其運動狀態。

語言方面，教師可以介紹生活中描述運動的英文，與描述運動狀態改變的語法。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
curved	彎曲的	acceleration	加速度
straight	直線的	instantaneous velocity	瞬時速度
path length	路徑長	free fall	自由落體
vector	向量	circular motion	圓周運動
distance	距離	gravity	重力
displacement	位移	parachute	跳傘
average velocity	平均速度	Taiwan High Speed Rail	台灣高鐵
average speed	平均速率		

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

❶ The distance between ___ and ___ is _____.

例句：**The distance between** my house **and** the train station **is** 1500 meters.
從我家到車站的距離是 1500 公尺。

❷ from _____ to _____

例句：The displacement vector is the vector of an object moving **from** its initial point **to** the final point.
位移是連接出發點到終點的向量。

❸ divide ___ by ___.

例句：When we **divide** the displacement **by** the elapsed time, we obtain the average velocity.
我們將位移除以經過的時間，可得到該時段內的平均速度。

❹ faster and faster

例句：At the moment of skydiving, due to gravity, the speed of falling goes **faster and faster**.
剛跳傘時，因重力的作用，使得落下的速度越來越快。

❺ _____ reach _____.

例句：A rain drop will finally **reach** its terminal velocity, due to the balance of gravity and air resistance.
由於重力與空氣阻力的平衡，雨滴最後可達到終端速度。

■ 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：

By the end of this section, students should understand:

一、定義物體運動狀態的物理量，包含：位移、路徑長、平均速度、瞬時速度、加速度。

The definitions of physical quantities that describe the motion of objects, including displacement, path length, average velocity, instantaneous velocity, and acceleration.

二、根據運動之關係圖，判斷物體的運動狀態。或由物體運動狀態的描述，畫出不同類型的關係圖。

Determine the states of motion of an object based on the kinematics graphs. Or depict correct kinematics graphs with respect to the given states of motion.

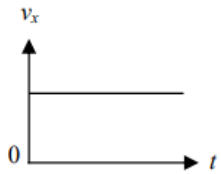
❧ 例題講解 ☙

例題一

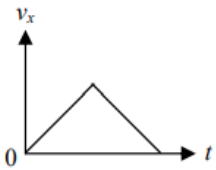
（英文）In a baseball game, the batter hits a high-flying home run by swinging the bat diagonally upward. If the air resistance is not considered, so the baseball is not affected by external force when flying in the horizontal direction in the air. Which of the following graphs can represent the relationship between the horizontal speed v_x of the baseball and its elapsed flying time t before landing?

（中文）棒球比賽中，打擊者用力向斜上方揮棒，擊出高飛全壘打。若不考慮空氣阻力，因此棒球在空中飛行時水平方向不受外力作用，則下列圖形何者可以代表棒球的水平方向速度 v_x 與其落地前飛行時間 t 的關係？

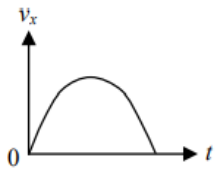
(A)



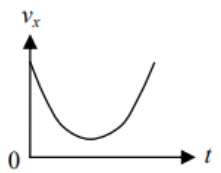
(B)



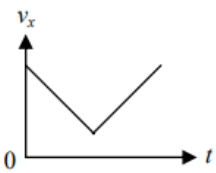
(C)



(D)



(E)



（101 年學測 66）

解題 Solution：

由題目敘述中可知，棒球在空中飛行時水平方向不受外力作用，根據牛頓第一定律，不受外力的物體，可以維持等速度運動。因此，棒球在水平方向的速度大小，不隨時間改變，因此選答案(A)，圖中，Vx 維持在固定的高度，不隨時間而改變。

From the description above, we know that the baseball is not affected by external force in the horizontal direction when flying in the air. So, the baseball moves at the same speed in the horizontal direction, and its speed does not change with time, so the answer is (A).

Teacher: When an object is not acted upon by any external forces, what's its motion state like?
Student: It remains at rest or in constant velocity motion.
Teacher: Good, which physical law is the above assertion based on?
Student: Newton's First Law of Motion.
Teacher: Yes, then what's the gravity direction of the baseball in the air?
Student: It's downward.
Teacher: Correct, is the baseball in the air exerted upon by any horizontal force?
Student: No.
Teacher: True, then how does the baseball's horizontal velocity change in the air?
Student: The horizontal velocity does not change; it is a constant.
Teacher: Very good, in the graph of velocity vs. time, what should be the curve to depict the motion of constant velocity?
Student: A horizontal line.
Teacher: Great, so which graph is correct for the baseball's horizontal velocity vs. time?
Student: It should be a straight horizontal line, so the answer should be (A).

老師： 物體不受外力作用時，其運動會保持怎樣的狀態呢？
學生： 靜止或者等速度運動。
老師： 很好，這是根據哪一條定律呢？
學生： 牛頓第一運動定律。
老師： 沒錯，那麼，棒球在空中受到的重力方向為何？
學生： 棒球受到的重力方向向下。
老師： 那棒球在空中是否受到水平方向的力呢？
學生： 沒有。
老師： 正確，因此，棒球在空中的水平速度，會如何變化呢？

學生：水平速度沒有變化，是固定值。

老師：是的，那麼，在速度對時間的關係圖中，維持等速度運動，其關係會是什麼形狀？

學生：一條水平直線。

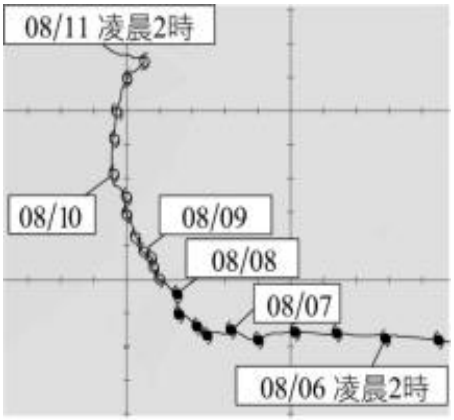
老師：很好，因此棒球的水平速度對時間關係圖，應該是哪種？

學生：水平直線的關係，應該選(A)。

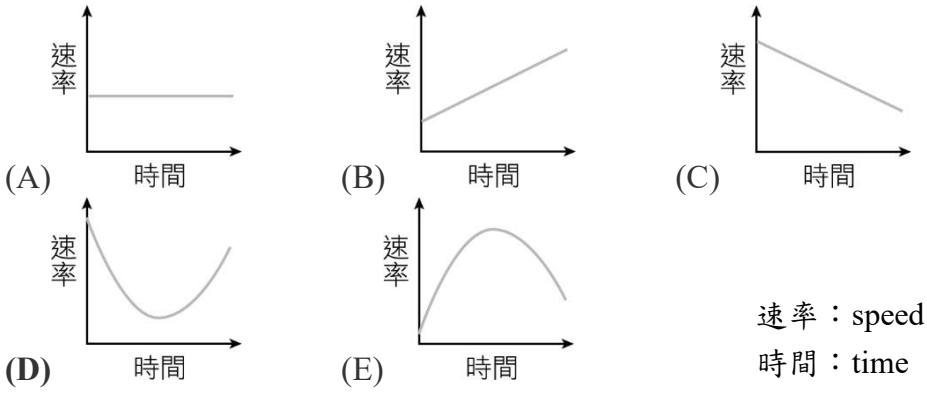
例題二

（英文）Typhoons often cause huge damage to Taiwan, so it is important to understand the characteristics of typhoons. The picture tracks the path of the center position of a typhoon with the date (recording starts at 2 am every day and is recorded every 6 hours). From 2:00 a.m. of 08/06 to 2:00 a.m. of 08/11, which trend curve is closest to the average speed of the typhoon center changing with time?

（中文）颱風之風雨往往對臺灣造成巨大災害，因此對颱風特性的了解是重要的。如圖為某次颱風中心位置隨著日期變化的路徑圖（每日凌晨 2 時開始記錄，每 6 小時記錄一次）。自 08/06 凌晨 2 時至 08/11 凌晨 2 時期間，該颱風中心移動的平均速率隨著時間變化的趨勢曲線，最接近下列何者？



實心點表示強烈或中度颱風
空心點表示輕度颱風



速率：speed
時間：time

（108 年學測 37）

解題 Solution：

由題目知道此為颱風路徑圖，且每 6 小時記錄一次，因此可知圖上的每個點之間時間差為 6 小時。由路徑長除以時間差，可得到兩點間的平均速率。因時間差固定，可推論兩點之間的距離越大，則兩點間的移動速率也越大。由圖片可觀察到，8/6 期間的點與點之間的間隔比較大，8/7、8/8 的兩點間隔逐漸變小，8/9~8/11 間隔逐漸變大。因此可知 8/6~8/8 速率逐漸變慢，8/9~8/11 速率又漸增。因此，可知道速率是先漸減，再漸增。所以，速率對時間的關係圖，應該是先往下，後往上，呈現上凹曲線，在 8/8~8/9 期間速率出現最小值。

From the question we know that this is a typhoon track map, and it is recorded every 6 hours, so it can be seen that the time difference between each point on the map is 6 hours. The average velocity between two points can be obtained by dividing the path length by the time difference. Since the time difference is fixed, it can be deduced that the greater the distance between two points, the greater the speed of movement between the two points. It can be observed from the pictures that the intervals between points during 8/6 are relatively large, the intervals between 8/7 and 8/8 gradually become smaller, and the intervals between 8/9~8/11 gradually become larger. Therefore, it can be seen that the rate of 8/6~8/8 gradually slows down, and the rate of 8/9~8/11 increases gradually. Therefore, it can be known that the rate decreases gradually and then increases gradually. Therefore, the graph of the relationship between speed and time should first go down and then go up, showing an upward concave curve, and the speed has a minimum value and a minimum value during 8/8~8/9.

Teacher: The dots in the typhoon track map represent the current position, so what can be used to judge the speed of the typhoon?

Student: The distance between two points.

Teacher: That's right. The larger the distance between two points, the faster the moving speed at that time.

Observe the distance between 8/6 and 8/9. How does it change?

Student: The distance between two points is getting shorter and shorter.

Teacher: Very good, so how does the movement speed of the typhoon change from 8/6 to 8/10?

Student: Slower and slower.

Teacher: That's right, and so on, how does the rate change from 8/9 to 8/11?

Student: It gradually become faster.

Teacher: Very good, so in the whole process, the speed slowed down first, and then speeded up.

Teacher: Therefore, what kind of curve should the relationship diagram of speed versus time be?

Student: Student: A curve that goes down first and then goes up.

Teacher: Exactly, so the answer is (D).
This kind of concave curve means that its extreme value is the minimum value.
Around 8/9, the distance between two points is the shortest, so the speed at that time is the slowest.

老師： 這個颱風路徑圖當中的點，表示當時的位置，那麼速率的快慢，可由甚麼來判斷？

學生： 兩點間的距離。

老師： 沒錯，兩點間的距離越大，代表當時移動的速率越快。
觀察 8/6 到 8/9 之間的距離，是如何變化呢？

學生： 兩點間的距離越來越短。

老師： 很好，所以代表颱風在 8/6 到 8/10 的移動速率如何變化？

學生： 越來越慢。

老師： 沒錯，依此類推，那麼 8/9~8/11 的速率如何變化？

學生： 逐漸變快。

老師： 很好，所以全部的過程，速率是先變慢，再變快。

老師： 因此，速率對時間的關係圖，應該是哪一種曲線呢？

學生： 先往下，後往上的曲線。

老師： 完全正確，所以答案是(D)。
這種上凹的曲線代表，它的極值是最小值。
在 8/9 附近，兩點間的距離最短，所以當時的速率最慢。

3-2 牛頓三大運動定律
Newton's Laws of Motion

■ 前言 Introduction

介紹牛頓三大運動定律的定義及概念，並透過生活實例，體會加速度與合力之間的關係。再將牛頓定律應用在生活實例中，藉由生活實例的探討，深入了解牛頓三大運動定律的意義及用法。如：自由落體的等加速度運動現象。

語言方面，教師需注意關鍵術語，在物理之定義及生活上意義之區別，例如：「力」及「加速度」。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
logical	邏輯的	rapidly/quickly	迅速地
inclined plane/ ramp	斜面	Newton’s Laws of Motion	牛頓運動定律
free fall	自由落體	resultant force	合力
regularity	規律性	action force	作用力
inertia	慣性	reaction force	反作用力
hammer	鐵鎚	cancel out	抵銷

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

❶ Although S. + V, S. + V.

例句：**Although** he introduced the logical framework of analysis and reasoning, his hypothesis was not qualified as modern scientific attitude and method.
雖然他引入分析與推理的邏輯架構，但他的假說不符合現代科學的態度與方法。

❷ By _____(V.-ing), S. + V.

例句：He designed a series of inclined plane experiments. **By** adjust**ing** the angle of the inclined plane, he could observe the change of acceleration, and then verified the regularity of falling objects.
他設計一系列的斜面實驗，藉由調整斜面的角度，觀察到加速度的變化，進而驗證了落體運動的規律。

❸ The more/-er + S.1 + V.1 …, the more/-er + S.2 + V.2

例句：**The steeper** the incline, **the greater** the object's acceleration when sliding down.
斜面越斜，物體下滑的加速度越大。

❹ ____ is called _____.

例句：The tendency of an object to resist a change in motion **is called** inertia.
物體有維持原有運動的傾向，稱為慣性。

❺ ____ be referred to as_____.

例句：The first of Newton's Law of motion **is** often **referred to as** the law of inertia.
牛頓第一運動定律，常被稱為慣性定律。

❻ ____ act on/upon _____.

例句：Since action and reaction forces **act on/upon** different objects, the forces don't cancel each other out.
作用力與反作用力的作用對象不同，因此力不會抵銷。

❼ unless S. + V.

例句：An object remains in its state of motion **unless** it is acted upon by an external force.
物體會保持原來的運動狀態，除非有受到外力影響。

■ 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 section, students should understand the following concepts:

一、物體若維持靜止或等速度運動，表示不受外力或合力等於零。

When an object is at rest or in uniform motion, it means it is not acted upon by an external force, or the resultant force is zero.

二、物體運動狀態(速度)若改變，必受外力作用，且質量不變的情況下，加速度與所受合力成正比。

When an object changes its motion, there must be an external force acting upon it. The motion and the external forces are proportional if the mass of the object remains the same.

三、作用力與反作用力同時產生，同時消失，大小相等方向相反，作用在不同物體上，故無法抵銷。

Action and reaction forces always appear and disappear simultaneously. Action-reaction pairs don’t cancel each other out because they always act on different objects.

例題講解

例題一

（英文）An exploration submarine loses its propulsion power, and can only dive or surface through the control of water displacement. During the process of ascending, the crew have to decelerate the submarine, in order to prevent the people in the submarine from being harmed by the sudden change of pressure.

The water body of the area is known to be stationary, and the total masses of the submarine before and after the water displacement are both considered m, the magnitude of the buoyancy force is F_B, the magnitude of the vertical resistance is F_R, and the magnitude of the gravitational acceleration is g. In the process of decelerating and ascending vertically, which of the following equations is correct?

（中文）一艘探勘潛艇失去推進動力，只能利用進水、排水以控制潛艇的下潛或上浮。在上浮過程中，為了避免上升速度過快，導致人體難以承受壓力驟變，工作人員於是進行潛艇減速。已知該水域水體靜止，且潛艇在進水或排水後的總質量皆可視為 m，所受浮力的量值為 F_B、垂直阻力的量值為 F_R，而重力加速度的量值為 g，則在潛艇沿垂直方向減速上升的過程中，下列關係何者正確？

(A) $F_B + F_R = mg$　(B) $F_B - F_R = mg$　**(C) $F_B - F_R < mg$**

(D) $F_B + F_R < mg$　(E) $F_B - F_R > mg$

（108 年學測 50）

解題 Solution：

此問題要找出，潛艇減速上升過程，所受外力之間的關係。因題目已知潛艇「減速上升」，所以加速度向下。透過牛頓第二運動定律($\Sigma\vec{F} = m\vec{a}$)，可知潛艇的合力也應向下。

此時，合力包含：浮力 F_B 向上，重力 mg 向下，垂直阻力與速度方向相反，故為 F_R 向下，因此，可得合力：（配合加速度方向，以向下為正。）$\Sigma F = mg + F_R - F_B > 0$，因此得到 $F_B - F_R < mg$。

First find out the relationship between the process of the submarine decelerating and vertical ascending and the external face. According to the question, the submarine decelerates and moves upward, so the acceleration is downward.

According to Newton's Second Laws of Motion ($\Sigma\vec{F} = m\vec{a}$), the resultant force of the submarine should also be downward. At this time, the resultant force includes: the buoyancy F_B is upward, the gravity mg is downward, and the vertical resistance is opposite to the direction of the velocity, so F_R is downward. Therefore, the resultant force can be obtained: (according to the acceleration direction, downward is positive). $\Sigma F = mg + F_R - F_B > 0$, so $F_B - F_R < mg$.

Teacher:	The submarine decelerates and moves upwards. Can we know where the acceleration of the submarine is heading?
Student:	Acceleration is going down.
Teacher:	So, in which direction is the resultant force going?
Student:	the resultant force is also downward
Teacher:	Yes, which law is this based on?
Student:	Newton's second law of motion.
Teacher:	Very good. Is the direction of gravity, buoyancy and resistance of the submarine in the water fixed?
Student:	The gravity is always downward, the buoyancy is always upward, and the vertical resistance is opposite to the direction of motion. So when the submarine is upward, the vertical resistance is downward.
Teacher:	Very good. The upward force is only buoyancy, while the downward force is gravity and vertical drag. The upward force is smaller than the resultant downward force, so what is the inequality between these forces?
Student:	$F_B < mg + F_R$.
Teacher:	So which is the answer?
Student:	The answer is (C) $F_B - F_R < mg$.

老師： 潛艇減速向上運動，可知道潛艇的加速度向哪裡？

學生： 加速度向下。

老師： 所以，合力往哪個方向？

學生： 合力也向下。

老師： 是的，這是根據哪個定律呢？

學生： 牛頓定二運動定律。

老師： 很好，潛艇在水中受到的重力、浮力、阻力方向是否固定？

學生： 重力恆向下，浮力恆向上，垂直阻力與運動方向相反，因此當潛艇向上時，垂直阻力向下。

老師： 很好。向上的力只有浮力，而向下的力有重力及垂直阻力。向上的力又小於向下的合力，那麼這些力之間的不等式為何？

學生： $F_B < mg + F_R$。

老師： 所以答案是哪個呢？

學生： 答案選 (C) $F_B - F_R < mg$。

例題二

（英文）A metal ball, whose mass is negligible, is suspended from the ceiling by a thin wire, as shown in the right figure. The relevant forces of this system are as follows: W_1 is the gravitational force acting upon the metal ball, W_2 is the gravitational force of the metal ball acting upon the earth, T_1 is the force exerted by the suspension wire on the metal ball, T_2 is the force exerted by the suspension wire on the ceiling, and T_3 is the force exerted by the metal ball on the suspension wire. Which of the following statements are correct? (3 answers)

(A) T_1 and T_2 are action-reaction pair forces.

(B) W_1 and W_2 are action-reaction pair forces.

(C) T_1 and T_3 are action-reaction pair forces.

(D) T_1 and W_1 are action-reaction pair forces.

(E) T_1, T_2, T_3, W_1 and W_2 all have the same magnitude.

（中文）一金屬球以質量可忽略的細線靜止懸掛於天花板，如右圖所示。此系統相關的受力情況如下：W_1 為金屬球所受的重力，W_2 為金屬球對地球的引力，T_1 為懸線施於金屬球的力，T_2 為懸線施於天花板的力，T_3 為金屬球施於懸線的力。下列敘述哪些正確？（應選 3 項）

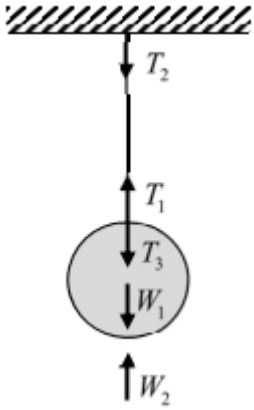
(A) T_1 與 T_2 互為作用力與反作用力。

(B) W_1 與 W_2 互為作用力與反作用力。

(C) T_1 與 T_3 互為作用力與反作用力。

(D) T_1 與 W_1 互為作用力與反作用力。

(E) T_1、T_2、T_3、W_1 與 W_2 的量值均相等。



（103 年學測 66）

解題 Solution：

判斷是否為作用力與反作用力，需要看施力體與受力體，是否為一對相互作用的關係。而判斷力的量值是否相等，除了根據是否為作用力與反作用力，還可透過平衡來決定。故選(B)(C)(E)。

To determine whether the forces are an action-reaction pair, the key is whether the two objects have a direct interaction relationship. To decide whether the magnitudes of forces are equal or not, we can rely on whether the forces are action-reaction or balance forces. Therefore, the answers are (B)(C), and (E).

Teacher: The gravitational force that the metal ball receives from the earth is called gravity, so what is the reaction force of this force?
Student: It is the attraction of the metal ball to the earth.
Teacher: Yes. Then, what is the relationship between action force and reaction force?
Student: Two forces are equal in magnitude, opposite in direction, and act on different objects.
Teacher: Yes, then how to judge whether the two forces are action and reaction force?
Student: The force-exerting object and the force-receiving object of the two forces must be a pair of directly acting objects.
Teacher: Very good. If the objects receiving the two forces are the same, can these two forces be action force and reaction force?
Student: Impossible.
Teacher: That's right, if an object is acted on by two forces in different directions and remains stationary, what should be the relationship between the magnitudes of these two forces?
Student: These two forces are equal in magnitude and opposite in direction.
Teacher: Very good, so what is the reaction force of W_1?
Student: The reaction force of W_1 is W_2.
Teacher: Yes. Which one is the reaction force of T_1?
Student: The reaction force of T_1 is T_3.
Teacher: So, among T_1, T_2, T_3, W_1 and W_2, what is the magnitude relationship of these forces?
Student: The magnitudes of these five forces are all equal.
Teacher: So, which three options are correct?
Student: The answers are (B)(C)(E).

老師： 金屬球受到地球的吸引力稱為重力，那麼這個力的反作用力是什麼呢？
學生： 是金屬球對地球的吸引力。
老師： 是的，那麼，作用力與反作用力之間的關係，是什麼？
學生： 兩個力的大小相等，方向相反，作用在不同的物體上。
老師： 沒錯，如何判斷兩力，是否為作用力與反作用力的關係呢？

學生： 兩力的施力物體與受力物體，必須是一對直接作用的物體。

老師： 很好，如果兩個力的受力物體是相同的，這兩個力可能是作用力與反作用力嗎？

學生： 不可能。

老師： 沒錯，那如果一個物體受到兩個方向不同的力作用，且保持靜止狀態，那麼這兩力的大小關係，應該如何？

學生： 這兩力的大小相等，且方向相反。

老師： 很好，那麼 W_1 的反作用力是哪個？

學生： W_1 的反作用力是 W_2。

老師： 對，T_1 的反作用力是哪個？

學生： T_1 的反作用力是 T_3。

老師： 所以，T_1、T_2、T_3、W_1 及 W_2，這幾個力的量值關係為何？

學生： 這五個力量值都相等。

老師： 因此答案是哪三個？

學生： 答案是(B)(C)(E) 。

3-3 生活中常見的力
Forces Commonly Seen in Daily Life

■ 前言 Introduction

教師可利用生活中的例子，讓學生認識生活中常見的接觸力（包含正向力、摩擦力，及彈力）與超距力（包含重力、磁力、電力），並探討這些作用力在生活實例中的推理與應用。語言方面，教師可以提供生活實例，來訓練學生的表達能力，且要注意各項術語間的關係，如：連接詞或轉折語的使用。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
contact force	接觸力	rough	粗糙的
force at a distance	超距力	smooth	光滑的
magnetic force	磁力	brakes	煞車
electrostatic force	(靜)電力	critical value	臨界值
normal force	正向力	return to its former shape	回復
friction	摩擦力	spring	彈簧
static friction	靜摩擦力	elasticity	彈性
kinetic friction	動摩擦力		

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

❶ _____ include _____, _____, etc.

例句：Common contact forces in life **include** friction force, tension, normal force, **etc**.
生活中常見的接觸力有摩擦力、彈力、正向力等。

❷ _____ be perpendicular to _____.

例句：Normal force **is perpendicular to** the contact surface.
正向力會垂直於接觸面。

❸ _____ be parallel to _____.

例句：Frictional force **is parallel to** the contact surface.
摩擦力會與接觸面平行。

❹ _____ is more likely to + _____(V.R.).

例句：When a road is wet or slippery, a car **is more likely to** skid.
路面濕滑時，車子較容易打滑。

❺ _____ return to _____.

例句：When the external force is removed, the rubber band will **return to** its original shape due to its elasticity.
當移除外力後，橡皮筋會因自身的彈性而恢復原狀。

❻ _____ increases from _____.

例句：A force that pushes the object slowly **increases from** zero.
推動物體的力，從零開始慢慢增加。

❼ _____ is applied to _____(V.R.).

例句：Hooke's law **is applied to** devise pointer scales used in everyday life.
生活中的指針式磅秤，是應用虎克定律製成的。

■ 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：

By the end of this section, students will:

一、認識生活中常見的接觸力，並了解正向力會垂直於接觸面，摩擦力平行於接觸面。

Knowing contact forces commonly existed in everyday life. And to understand that the normal force is perpendicular to the contact surface, while the friction force is parallel to the contact surface.

二、在彈性限度內，彈簧改變的長度，與外力大小成正比。

Knowing that within the elastic limit, the change of spring's length is proportional to the external force applied.

❧ 例題講解 ☙

例題一

（英文）Under normal conditions, less friction is better for which of the following situations?

(A) The friction between the sole and the ground when we walk.

(B) The friction between the snowboard and the snow when we ski.

(C) The friction between the hand and the handle of a tool when we use it.

(D) The friction between the brake pads and the wheels when we brake on a bike.

（中文）在正常狀況下，下列何者的摩擦力愈小愈好？

(A)走路時，鞋底與地面之間的摩擦力。

(B)滑雪時，滑雪板與雪地之間的摩擦力。

(C)使用工具時，手與工具把手之間的摩擦力。

(D)騎腳踏車煞車時，煞車板與輪子之間的摩擦力。

（94 年學測 33）

解題 Solution：

摩擦力可使物體減速，也可以使物體加速。走路須靠向前的靜摩擦力，才能向前進。而使用工具時，手與工具也不能打滑，這兩種都是靠靜摩擦力，帶動物體運動，摩擦力越大，越不容易打滑。而煞車需要動摩擦力，使物體快速減速，所以也是越大越快剎車。只有滑雪板與雪地間，動摩擦越小，越方便前進。

Frictional force can either decelerate or accelerate objects. As we walk we need static friction to move forward. We also need static friction when using tools so that our hands will not slip. Both of the examples above are static friction that drive objects to move. The greater the friction, the less likely it is to slip. On the other hand, the brake needs greater kinetic frictional force to decelerate the object quickly to achieve the purpose of braking. Only the kinetic friction between snowboard and snow need to be small to allow skiing quickly.

Teacher:	What kind of external force does the action of walking rely on?
Student:	Friction.
Teacher:	Yes. So when we walk, should the direction of the friction force be forward or backward?
Student:	Backward.
Teacher:	No, we rely on friction to move forward.
Teacher:	So, when the friction force is greater, should the walking speed be faster or slower?
Student:	When we walk, the greater the friction force, the faster the speed is.
Teacher:	Very good, if we grip the screwdriver tighter when we turn it, which forces will increase?
Student:	Normal force and friction force.
Teacher:	Great. We rely on friction to drive the screwdriver to turn.
Teacher:	So, is the friction force during brakes a dynamic friction force or a static friction force?
Student:	When we step on a brake, the car still moves forward but decelerates, so it is kinetic friction.
Teacher:	No, the area of motion friction and static friction is whether the contact surface is sliding, not just whether there is movement. Therefore, when braking, the friction of the wheels should be static friction.
Teacher:	If the kinetic friction force is small when we brake, can the car stop in time?
Student:	No. Larger kinetic friction is needed for the car to decelerate as quickly as possible.
Teacher:	Correct, then when we ski, what is the main driving force?

Student: Skiing is usually carried out on slopes, relying on the component force of gravity to accelerate people forward.

Teacher: Very good, so when we ski, is the frictional force kinetic or static?

Student: It is kinetic friction.

Teacher: Yes, then when we ski, should the friction force between the skis and the snow be smaller or larger to slide faster?

Student: The smaller the friction force, the faster the acceleration of forward sliding.

Teacher: So which one is the answer?

Student: The answer is (C).

老師： 走路前進靠的是那種外力？

學生： 摩擦力。

老師： 是的，那走路時摩擦力的方向，應該是向前還是向後？

學生： 向後。

老師： 不對喔，我們的腳向後踩，所以地面對腳的摩擦力向前，才能前進。
所以，摩擦力越大，走路速度可以越快或越慢？

學生： 走路時，摩擦力越大，則速度可越快。

老師： 很好，那麼轉動起子時，握得越緊，哪些力增加呢？

學生： 正向力及摩擦力。

老師： 很棒，我們是靠摩擦力帶動螺絲起子轉動的。

老師： 那麼剎車時的摩擦力，是動摩擦力還是靜摩擦力呢？

學生： 煞車時，車子仍向前運動但減速，所以是動摩擦力。

老師： 不對喔，動摩擦與靜摩擦的區別，是在於接觸面是否滑動，而不能僅以是否有在動來判斷。所以，剎車時，輪子的摩擦應該是靜摩擦。
若剎車時，靜摩擦力太小，則車子可以及時煞車嗎？

學生： 不行。需要足夠的靜摩擦力，車子才能盡快減速。

老師： 正確，否則車子就會超過最大靜摩擦，變成動摩擦而打滑。

老師： 那麼滑雪時，前進的動力主要靠什麼呢？

學生： 滑雪通常在有坡度的地方進行，是靠重力平行於斜坡的分力，使人加速前進。

老師： 很好，因此滑雪時的摩擦力，是動摩擦力還是靜摩擦力呢？

學生： 是動摩擦力。

老師： 很好，因為此時滑雪板與地面有相互的滑動。那麼滑雪時，滑雪板與雪地間的動摩擦力，應該要越小還是越大，才會滑得快呢？

學生： 摩擦力越小，向前滑的加速比較快。

老師： 因此答案選哪個？

學生： 答案選(C)

例題二

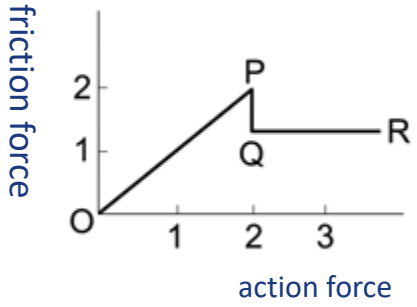
（英文）An object is stationary on a horizontal plane initially, and then it is acted upon by a force begging from small to large. The relationship between the friction force and the action force is shown in the diagram. Which of the following statements about friction is correct, based on the diagram (choose three answers)?

(A) The object begins to move immediately as soon as the force acts on it.

(B) When the force goes from O to P, the object remains at rest.

(C) When the acting force is at point P, the friction force on the object is the largest.

(D) When the acting force is at point P, the acceleration for the object is the largest.



(E) When the force moves from Q to R, the acceleration for the object becomes larger and larger.

（中文）一物體在某水平面上開始時為靜止，後來物體受一由小而大的作用力作用，其所受摩擦力與作用力的關係如圖所示。依據此圖，下列有關摩擦力的敘述何者正確？（應選三項）

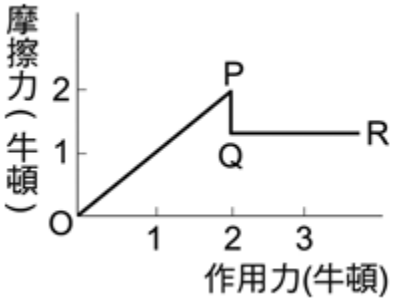
(A)物體受力作用後立即開始運動。

(B)作用力如圖從 O 到 P 點時，物體維持靜止。

(C)作用力如圖 P 點時，物體所受摩擦力最大。

(D)作用力如圖 P 點時，物體的加速度最大。

(E)作用力如圖從 Q 到 R 點時，物體運動的加速度越來越大。



（96 年學測 43）

解題 Solution：

由摩擦力對作用力的關係圖，可以看到 OP 過程，摩擦力隨作用力變大而變大，且摩擦力=外在作用力，合力=0，故物體保持靜止，此過程的摩擦力為靜摩擦力。PQ 線段對應到相同的外在作用力，表示此時物體運動狀態發生改變，由靜止變成滑動，可知 P 點對應到的摩擦力是最大靜摩擦力，此時作用力恰可使物體移動，因此 QR 線段對應到物體已經運動的狀態。QR 段對應到的摩擦力就是動摩擦力，而動摩擦力在運動過程約為定值，不因外力的大小，或物體的速度大小而改變。因此，隨著作用力越大，物體受到越大的合力，因此產生越大的加速度。故選(B)(C)(E)。

From the diagram of frictional force versus acting force, we can see that, based on the OP line segment, the friction force increases with the increase of the acting force. Since the friction force at this moment is static friction force, the object remains stationary. The PQ line segment corresponds to the same reaction force, which means that the motion state of the object changes from static to sliding. Therefore, it can be seen that the friction force corresponding to the P point is the maximum static friction force. At this time, the force is just enough to make the object start to move, so the QR line segment means the object is moving. The friction force corresponding to the QR segment is kinetic frictional force, which keep constant during the moving process. So the answers are (B), (C), and (E).

Teacher: When an object is at rest, is it necessarily acted upon by friction?

Student: Not necessarily. If the object is not acted on by other forces in the parallel direction, then the frictional force is zero when the object is at rest.

Teacher: For the same object, is the magnitude of static friction fixed?

Student: No. When objects keep stationary, the frictional force would change according to the parallel component of external force acted on them. When the action force is greater than the maximum static frictional force, the object begins to slide.

Teacher: Does the kinetic friction force increase as the object moves faster?

Student: No. The frictional force of an object in motion is a fixed value.

Teacher: Yes, from this diagram of the relationship between frictional force and acting force, we can see that PQ corresponds to the same acting force. What does this mean?

Student: The PQ line segment corresponds to the same action force, indicating that the object starts to slide from a state of rest.

Teacher: So what does the OP line segment represent?

Student: The OP line segment indicates that when an object is at rest, the frictional force of the object increases with the increase of the action force, but the object remains at rest, so this is the static frictional force.

Teacher: Is the motion of the QR line segment uniform motion?

Student: No. It's the acceleration motion.

Teacher: Is it a uniform accelerated motion?

Student: No, it's variable accelerated motion. Since the frictional force at this time is kinetic frictional force, the magnitude keeps constant, but the action force continues to increase, the resultant force would increase. Therefore, it is a kind of variable accelerated motion with increasing acceleration.

Teacher: So which answers are correct?

Student: The answers are (B), (C), and (E).

老師： 物體靜止必受到摩擦力嗎？

學生： 不一定。如果物體沒有受到其他沿著平行方向的力作用，則物體靜止時，摩擦力等於零。

老師： 很好，對同一個物體來說，靜摩擦力大小是固定的嗎？

學生： 不一定。物體若維持靜止，摩擦力會隨平行外力的改變而改變，直到作用力大於最大靜摩擦力時，物體就會開始滑動。

老師： 運動時的動摩擦力，會隨物體運動速度變快而增大嗎？

學生： 不會。物體運動時的摩擦力是固定值。

老師： 很好，所以從這個摩擦力對作用力的關係圖，我們可以看出 PQ 對應到同樣的作用力，這代表什麼意思？

學生： PQ 線段對應到相同的作用力，表示物體恰好由靜止變成運動（滑動）狀態。

老師： 那麼 OP 線段是代表什麼意義呢？

學生： OP 線段是靜止時，物體的摩擦力隨作用力增加而變大，但物體仍保持靜止狀態，因此這為靜摩擦力。

老師： 那 QR 線段的運動是等速度運動嗎？

學生： 不是。此時是加速度運動。

老師： 是等加速度運動嗎？

學生： 不是，是變加速度運動。因為這時候的摩擦力是動摩擦力，大小維持固定，但是作用力持續變大，因此合力也變大，是加速度逐漸增大的變加速度運動。

老師： 因此答案要選哪些？

學生： 答案是(B)(C)(E)。

3-4 天體運動
Celestial Movement

■ 前言 Introduction

教師可利用日月星辰移動的現象來提問，引導學生了解地心說與日心說的差異，進而說明為何用日心說，來說明一天中所看到的周日運動，及周年運動。最後介紹克普勒行星三大運動定律的科學史。

語言方面，教師可以提供學生各種星球的英文，以及描述星體運動及軌跡的用語。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
geocentric theory	地心說	focal point/focus	焦點
heliocentric theory	日心說	be proportional to	正比於
popular/prevailing	風行	constant	常數
fix/modify	修正	square	平方
ellipse	橢圓	cubed	立方
circular	圓形的	analyze	分析
violate	違背	perihelion distance	近日距離
orbit	軌道	aphelion distance	遠日距離

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

❶ _____ because of _____(N.).

例句：Ptolemy's geocentric model was widely accepted **because of** the church's support.
因為教會的支持，托勒米的地心說廣被接受。

❷ _____ move around _____ in circular orbits

例句：Heliocentric theory holds that all planets, including the Earth, **move around** the Sun **in circular orbits**.
日心說認為，包括地球在內的行星，都以圓形軌道繞太陽運動。

❸ _____ violate _____.

例句：Copernicus's heliocentric theory **violated** the teachings of the Catholic Church at that time.
哥白尼的日心說，違背當時天主教會的教義。

❹ a large amount of _____

例句：Kepler used **a large amount of** data left by Tycho and discovered that the orbit of Mars revolve around the Sun is elliptical.
克卜勒透過第谷留下的大量資料，發現火星繞太陽是橢圓軌道。

❺ one of the _____ (a plural noun).

例句：The Sun is at **one of the** foci of the ellipse orbit of its planets.
太陽位在行星橢圓軌道的其中一個焦點位置。

❻ _____ in the same period of time.

例句：The line connecting the planet and the Sun sweeps the same area **in the same period of time.**
在相同時間內，行星與太陽的連線掃過的面積相同。

❼ the average of _____

例句：The orbital radius is **the average of** the perihelion distance and the aphelion distance.
平均軌道半徑，是近日距與遠日距的平均值。

❽ _____ be proportional to _____.

例句：Kinetic energy of objects **is proportional to** the square of their speed.
物體的動能，與其速率平方成正比。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

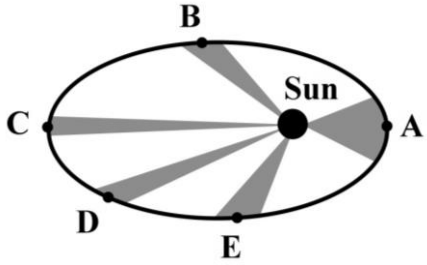
在學習完本單元後，學生應習得以下觀念：
By the end the section, students should:
一、了解每天看到的星體移動，主要是地球自轉造成，但地球也同時繞太陽公轉。
understand that the movement of the stars you see every day is mainly caused by the rotation of the Earth, but the Earth also revolves around the Sun.
二、了解克普勒三大行星運動定律。
understand the three Kepler's Laws of planetary motion.

❧ 例題講解 ☙

例題一

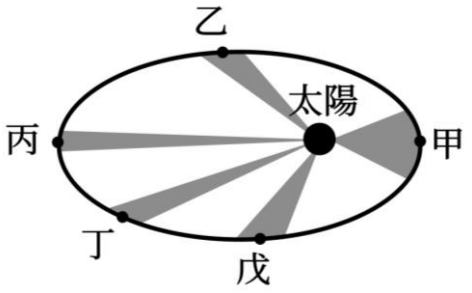
（英文）Kepler introduced the Law of Areas by analyzing the data left by Tycho: a line connecting a planet to the Sun sweeps out equal areas in equal times, as shown like the gray areas in the figure. It is known that the Sun is the focus on the right, and then for the planets on the points A, B, C, D, E, which position the planet at has the greatest kinetic energy?

(A) A　(B) B　(C) C　(D) D　(E) E



（中文）克卜勒分析第谷的行星觀測資料發現等面積定律，即一個行星與太陽的連線，在等長的時間內，於行星軌道所掃過的面積必相等，如圖中的五個灰色區域所示。已知太陽在右邊焦點上，則此行星在甲、乙、丙、丁、戊五點上，哪一點的動能最大？

(A)甲　(B)乙　(C)丙　(D)丁　(E)戊



（103 年學測 19）

解題 Solution：

由克普勒第二定律知道在相同時間內，行星與太陽連線掃過的面積相同。由題目可知五個灰色區域面積相同，且時距相同。因甲的掃過的弧長最長，可知甲點速率最快，又動能與速率平方成正比，因此甲點的動能最大。

According to Kepler's Second Law, a line connecting a planet to the Sun sweeps out equal areas in equal times. It is known from the question that the five gray areas cover the same area within the same time interval. Since the arc length of area A is the longest, we can know that the speed of the planet on point A is the fastest. Besides, since the kinetic energy is proportional to the square of the speed, the kinetic energy of point A is the largest.

Teacher: What's the shape of a planet's orbit around the Sun?

Student: Elliptical.

Teacher: Yes, does a planet move around the Sun at the same speed?

Student: No.

Teacher: From which of Kepler's laws can we find the speed of a planet?

Student: From the law of equal areas.

Teacher: Very good. The law of equal area tells us that when a planet orbits the Sun, the area swept by the line connecting the planet and the Sun is the same within the same period of time. As can be seen from the figure, the elapsed time of the five gray areas is the same, so the gray areas are also the same. So how to identify the fastest point that the planet moves at?

Student: The motion of a planet is the path of the elliptical orbit. The longer the path passes within the same period of time, the faster the speed is.

Teacher: Great, at which point does the planet move the fastest?

Student: At point A

Teacher: Yes, what is the relationship between kinetic energy and velocity?

Student: Kinetic energy is proportional to the square of velocity.

Teacher: At which point does the planet have the greatest kinetic energy?

Student: Point A.

Teacher: So which answer is (A).

老師： 行星繞太陽的軌道，是什麼形狀？

學生： 橢圓形。

老師： 答對了，那麼行星繞太陽運動的速率會一樣快嗎？

學生： 不會。

老師： 行星的速率，可以由克卜勒的哪個定律得知？

學生： 可以由等面積定律得知。

老師： 很好，等面積定律告訴我們：行星繞太陽時，相同時間內，行星與太陽連線掃過的面積相同。由圖中可以知道，五個灰色區域的經過時間相同，因此灰色面積也相同。那麼如何知道在哪一個點速率最快呢？

學生： 行星運動為橢圓軌道上的軌跡，相同時間經過的軌跡越長，則速率越快。

老師： 正確，所以哪一點速率最快？

學生： 甲點速率最快。

老師： 沒錯，那麼動能與速率的關係為何呢？

學生： 動能與速率的平方成正比。

老師： 很好，所以動能最大的是哪一點呢？

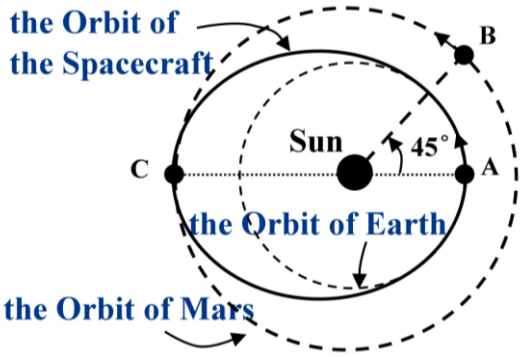
學生： 甲點。

老師： 因此答案選(A)。

例題二

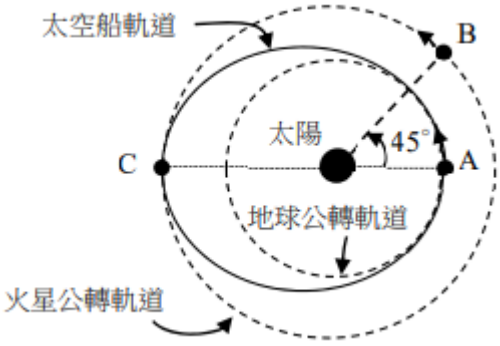
（英文）In July 2020, three spacecraft left Earth for Mars. At this time, Earth is at A and Mars is at B. The spacecraft is propelled into an elliptical orbit by a rocket and sails under gravity, as shown in the figure. It doesn't enter the orbit of Mars until it is about to meet with Mars, and finally meets Mars at C. Given that the orbital period of Mars is 1.9 times that of Earth, the time required for a spacecraft to travel from Earth to meet with Mars is the closest to which of the following?

(A) 600 days
(B) 360 days
(C) 300 days
(D) 260 days
(E) 180 days



（中文）2020 年 7 月有 3 艘太空船從地球出發前往火星，此時地球在 A 處、火星在 B 處。太空船由火箭推動進入橢圓軌道後在重力下航行，如圖所示，直到要與火星會合時，再進入繞行火星的軌道，最後於 C 處會合。已知火星公轉週期為地球公轉週期的 1.9 倍，則太空船由地球出發到與火星會合，所需時間最接近下列何者？

(A) 600 天
(B) 360 天
(C) 300 天
(D) 260 天
(E) 180 天



（110 年學測 56）

解題 Solution：

根據克卜勒行星第三定律，繞同一恆星公轉之各行星，之軌道半徑三次方與週期平方成正比。太空船由 A 處到達 C 處時，火星也由 B 處到達 C 處，此段軌跡佔火星繞太陽週期運動軌跡的 135 度(= 180 度 − 45 度)，而火星繞日公轉週期為地球公轉周期的 1.9 倍，由此可知火星繞日一周需 693.5 日(= 365 日 × 1.9)， B C 的角度約為 135 度，依比例可估算出火星由 B 處到 C 處需 260 日(= 693 日 × $\frac{135\text{ 度}}{360\text{ 度}}$)。

According to Kepler's Third Law of planetary motion, the squares of the orbital periods of the planets are directly proportional to the cubes of the semi-major axes of their orbits. When the spacecraft arrives at C from A, Mars also arrives at C from B. This trajectory accounts for 135 degrees (= 180 degrees − 45 degrees) of Mars' orbit around the Sun, while the orbit of Mars around the Sun is 1.9 times the e*arth's revolutionary period*. It takes 693.5 days for Mars to circle around the Sun (= 365 days × 1.9), and the angle of B and C is about 135 degrees. According to the ratio, it can be estimated that it takes 260 (= 693 days × $\frac{135 \text{ degrees}}{360 \text{ degrees}}$) days for Mars to travel from B to C.

Teacher: When a spacecraft travels from the Earth to Mars, can it go directly from A to B?

Student: No.

Teacher: Correct, but why not?

Student: Because when the spacecraft moves, Mars also moves around the Sun. When the spacecraft reaches B, Mars has already moved to other positions.

Teacher: Yes, in this question, what does it mean when it states that the spacecraft starts from the earth at A and finally reaches C?

Student: It means Mars also reaches C from B at the same time.

Teacher: Good, from the diagram, can you tell the time required for the spacecraft to travel from point A to point C?

Student: No, because the distance from the Sun will affect the speed of the movement, if the spacecraft relies on the action of gravity only. Therefore, it requires the movement of Mars to help us find out how much time it takes.

Teacher: So how do we know the time it takes for the spacecraft to get from point A to point C?

Student: When the spacecraft reaches C from A, Mars also reaches C from B at the same time.

Teacher: How long is the rotation period of Mars around the Sun?

Student: The period of Mars' revolution around the Sun is 1.9 times that of the earth's rotation period, so it's 365 days × 1.9 = 693.5 days.

Teacher: Correct, then how do we know how long it takes for Mars to reach C from B?

Student: BC is the movement trajectory of Mars, which can be simplified as a circular motion with constant velocity, and the time required is proportional to the angle. The angle of Mars from B to C is 135 degrees, and the entire circular motion is 360 degrees. It can be calculated that the time needed is $\frac{693.5\times135}{360}=260$ days.

Teacher: Great, so the answer should be (B).

老師： 太空船要由地球到火星，可以直接由 A 處到 B 處嗎？

學生： 不行。

老師： 為什麼？

學生： 因為太空船移動時，火星也會繞太陽持續運動，當太空船到達 B 的時候，火星已經運轉到其他位置了。

老師： 非常好，那根據題目，如果太空船由 A 處的地球出發最後到達 C 處，表示什麼意思？

學生： 火星在同樣的時間由 B 處也到達 C 處。

老師： 是的，那麼可以由圖直接看出，太空船由 A 處到 C 處軌跡所需的時間嗎？

學生： 不行，因為僅靠重力作用的話，與太陽的距離會影響運動太空船的速率。所以要由火星的運動來判斷所需要的時間。

老師： 好的，那麼可以從哪邊得知太空船由 A 處到達 C 處需要的時間？

學生： 太空船由 A 處到 C 處時，同時間火星也由 B 處到達 C 處。

老師： 是的，那火星繞太陽的公轉週期多久呢？

學生： 火星繞太陽公轉的週期，是地球公轉周期的 1.9 倍，所以是 365 日 × 1.9 = 693.5 日。

老師： 正確，那怎麼知道火星由 B 處到 C 處，需要多久呢？

學生： BC 是火星的運動軌跡，可以簡單化視為等速圓周運動，則需要的時間與角度成正比。火星由 B 到 C 的角度是 135 度，而整個圓周運動是 360 度。就可以算出時間需要 $\frac{693.5\times135}{360}=260$ 日。

老師： 很棒，因此答案要選(B)。

★主題四 電與磁★
Electricity and Magnetism

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■ 前言 Introduction

本章介紹電與磁之間的關聯。包含電流磁效應、電磁感應、電與磁的統整及光波特性。首先引入厄斯特發現電流磁現象的歷史，接著探討如何利用安培右手定則，判斷電流方向與所產生的磁場方向之關係。除了原理，也將介紹電磁原理在生活中的應用，包含：電磁鐵、馬達、發電機、變壓器、電磁爐等。最後，探討光波的特性及相關原理，如：惠更斯原理、光的反射、折射、干涉、繞射、都卜勒效應等。

4-1 電流磁效應
Magnetic Effect of Electric Current

■ 前言 Introduction

藉由厄斯特發現通有電流的導線，會造成磁針偏轉的故事，介紹電流磁效應現象的發現，及電與磁之間首次的關聯。接著，透過安培右手定則，判斷電流方向與產生的磁場方向間的關係，並引入三種形狀之載流導線的磁場分佈：1.長直導線周圍的磁場 2.圓形線圈的磁場 3.螺縣管的磁場。最後，說明電流磁效應的應用，包含：電磁鐵及馬達。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
electric current	電流	four fingers	四指
wire	導線	ring	環形
magnetic field	磁場	perpendicular	垂直的
magnetic needle	磁針	emit	射出
deflect	偏轉	inject	射入
be linked to/be associated to	關聯	solenoid	螺線管
nearby	附近	electromagnet	電磁鐵
concentric circles	同心圓	motor	馬達
distribute	分佈	hair dryer	吹風機
Ampere’s right-hand rule	安培右手定則	washing machine	洗衣機
thumb	拇指		

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

❶ In _____, sb. discovered that _____(S.+V.).

例句：**In** 1820, Ørsted **discovered that** a wire with electric current in the north-south direction would deflect a nearby magnetic needle.
1820 年厄斯特發現通有電流，且為南北方向的導線，會造成附近磁針的偏轉。

❷ point to _____

例句：A magnetic needle would **point to** the north, if there are no current flowing nearby.
若沒有電流在附近通過，則磁針會指向北方。

❸ with the use of _____

例句：The motor in a hair dryer rotates **with the use of** the magnetic effect by electric current.
吹風機內的馬達，是運用電流磁效應的原理，產生轉動。

■ 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：
一、了解電流磁效應的現象，與安培右手定則。
二、認識電流磁效應在生活上的應用實例。

By the end of the session, students should be able to：

1. Understand the phenomenon of the magnetic effect of electric current and Ampere's right-hand rule.
2. Know the application examples of the magnetic effect of electric current in our daily life.

例題講解

例題一

說明：能由安培右手定則，根據電流方向判斷產生的磁場方向。
Can utilize Ampere's right-hand rule to determine the direction of the magnetic field from the given direction of the electric current.

（英文）As shown in the figure, two circular coils with a steady current passing through them stand opposite each other. If the influence of geomagnetism is ignored, what is the direction of the magnetic field caused by the two current-carrying coils at the midpoint of the line connecting the centers of the coils?

(A) To the east

(B) To the west

(C) To the north

(D) Upward

(E) The magnetic fields generated by the two coils are in opposite directions.

（中文）兩個通有穩定電流的圓形線圈相對而立，如圖所示。若忽略地磁的影響，則兩載流線圈在線圈圓心連線中點處造成的磁場方向為何？

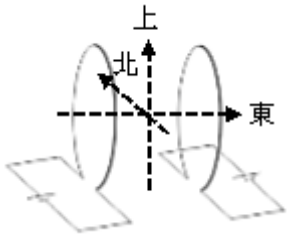
(A)向東

(B)向西

(C)向北

(D)向上

(E)兩線圈產生的磁場方向相反



（107 年學測 17）

解題 Solution：

先判斷題目中的電流方向，再利用安培右手定則，判斷出左右線圈產生的磁場方向分別為何，再加總出最後線圈圓心連線，中點處的磁場方向。

First determine the direction of the current of the two coils, and then use Ampere's right-hand rule to determine the direction of the magnetic field generated by the left and right coils. Finally, sum up the direction of the magnetic field at the middle of the line connecting the center of the coils.

Teacher: How do we use Ampere's Right-Hand Rule when determining the magnetic field of a circular coil? Is the direction of the thumb point to the direction of the current, or the direction of the magnetic field?

Student: With respect to a circular coil, the direction of the four bending fingers is the direction of the current, and the direction of the thumb is the direction of the magnetic field.

Teacher: That's right! If the current direction is not known, how do you find out the current direction of the coils on the left and right sides?

Student: The positive and negative electrodes of the battery can be used to determine the direction of the current, and the current flows from the positive electrode of the battery back to the negative electrode.

Teacher: Good, could you please tell me, according to Ampere's right-hand rule, which direction is the thumb on the left pointing to?

Student: The thumb is pointing at the east.

Teacher: Going to the original question. According to the right-hand rule, which direction is the magnetic field of the right coil facing?

Student: The magnetic field faces east.

Teacher: Yes, the magnetic fields of the two coils are both facing east, so which direction should the magnetic field at the center of the line connecting the centers of the coils be directed?

Student: To the East.

Teacher: Great, so which is the correct answer?

Student: (A). The correct answer is (A).

老師： 判斷圓形線圈的磁場時，如何利用安培右手定則？大拇指方向是電流方向，還是磁場方向？

學生： 判斷圓形線圈時，四指彎曲方向是電流的方向，大拇指方向是磁場方向。

老師： 沒錯！如果未標示電流方向，那麼左右兩邊的線圈的電流方向，如何判斷呢？

學生： 利用電池的正負極可以判斷電流方向，電流由電池的正極流出，回到負極。

老師： 是的，那請告訴我，依照安培右手定則，左邊的線圈是大拇指是朝向哪個方向？

學生： 大拇指朝向東。

老師： 答對了，再回到原先的問題，利用安培右手定則，右邊線圈的磁場朝向哪個方向呢？

學生： 磁場朝向東。
老師： 很好，兩個線圈的磁場都朝向東，那麼線圈圓心連線中心處的磁場，方向應該向哪個方向？
學生： 向東。
老師： 很棒，因此正確答案是哪個呢？
學生： (A)，正確答案是(A)。

例題二

說明：此題不僅需了解電流磁效應，同時也需理解在磁場環境中，載有電流的導線，會受到磁力作用，而發生轉動或震動。
This question requires not only understanding the magnetic effect of electric current, but also knowing that wire carrying current in magnetic field could rotates by the effect of magnetic force.

（英文）Which of the following electric appliances is associated with the magnetic effect of magnetic current?
(A) heating effect of microwave ovens.
(B) speakers in the classroom for amplification.
(C) motors of washing machines.
(D) electromagnets in a car recycling yard.

（中文）以下哪個電器用品的必要元件，「並非」利用電流磁效應原理製成？
(A)加熱用的微波爐。
(B)教室擴音用的喇叭。
(C)洗衣機的馬達。
(D)汽車回收場的電磁鐵。

解題 Solution：
生活中發出聲音的喇叭、利用電能轉動的馬達、用電能控制磁力開關的電磁鐵等，都是利用電流磁效應的物件。
In our daily life, speakers that create sound, motors that utilize electrical energy to rotate, and electromagnet that control magnetic switches are all that use magnetic effect of electric current.

Teacher: What are the applications of motors in life?
Student: Fans, blenders, washing machines, hair dryers, range hoods, etc.
Teacher: Good, what products have speakers in them?

Student: Audio, headphones, mobile phones, TVs...etc.

Teacher: Yes, where is the electromagnet used?

Student: In car recycling yards, container handling, electromagnetic locks, and electronic locks.

Teacher: Great, then by which principle are motors, horns, and electromagnets made?

Student: Motors, horns, and electromagnets are all components made using the magnetic effect of current.

Teacher: Excellent, what is the purpose of the magnetron, the main component of the microwave oven?

Student: The magnetron emits microwaves.

Teacher: Correct, so which answer should you choose?

Student: The correct answer is (A).

老師： 同學們知道馬達應用在生活中，有哪些東西呢？

學生： 電風扇、果汁機、洗衣機、吹風機、抽油煙機……。

老師： 很好，那麼那些產品裡面有喇叭呢？

學生： 音響、耳機、手機、電視……等。

老師： 沒錯，而電磁鐵用在那些地方呢？

學生： 汽車回收廠、貨櫃搬運、電磁鎖、電子鎖。

老師： 馬達、喇叭、電磁鐵，都是利用哪個原理製成的元件呢？

學生： 馬達、喇叭、電磁鐵，都是利用電流磁效應製成的元件。

老師： 是的，那微波爐主要的元件：磁控管，是什麼用途呢？

學生： 磁控管會發出微波。

老師： 很棒，因此答案要選哪個？

學生： 正確答案是(A)。

4-2 電磁感應
Electromagnetic Induction

■ 前言 Introduction

法拉第發現線圈進入或離開磁場時，線圈上會感應出電流，所產生的電流稱為感應電流。再利用「冷次定律」，可判斷感應電流的方向。冷次定律：感應電流所產生的磁場，會抵抗線圈中磁力線數的變化。電磁感應的應用，有發電機、變壓器、電磁爐、麥克風、無線充電器、無線感應刷卡……等。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
induction	感應	wireless	無線的
coil	線圈	switch	開關
oppose	抵抗	stable	穩定的
magnetic line of force	磁力線	a period of time	一段時間
generator	發電機	moment	瞬間
transformer	變壓器	Lenz's Law	冷次定律
induction cooker	電磁爐	induced current	感應電流
microphone	麥克風	Faraday	法拉第

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

❶ ____ have trouble when _____(V.-ing).

例句：Faraday initially **had trouble when** conduct**ing** experiments of generating electricity from magnetism.

法拉第一開始，在磁產生電的實驗上，遭遇困難。

❷ _____; on the contrary, _____.

例句：Electric current can result in magnetic field; **on the contrary,** can magnetic field cause electric current?

電流會產生磁場，相反的，磁場可以產生電流嗎？

❸ figure out that _____.

例句：Faraday finally **figured out that** only change of magnetic fields can cause electric currents.

最終，法拉第理解到，只有變化的磁場才能產生電流。

■ 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 section, students should understand the following concepts:

一、了解電磁感應現象及發生原因。

Understand what electromagnetic induction is and how it happens.

二、認識電磁感應的應用。

Know the applications of electromagnetic induction.

例題講解

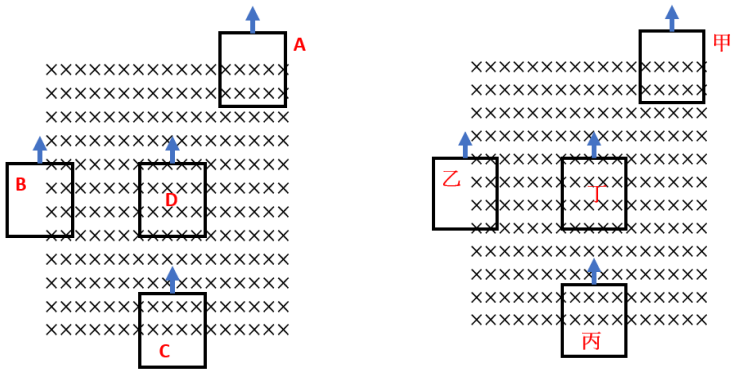
例題一

說明：此題利用四個封閉線圈，等速通過均勻磁場的不同狀況，檢視四個線圈，是否都會產生應電流？

This problem uses four closed coils passing through a uniform magnetic field at the same speed to determine whether the four coils generate induced current.

（英文）There are four rectangle closed coils through a homogeneous magnetic field at the same speed. Which two coils will generate the current?

（中文）四個矩形線圈，以共同等速度通過一個均勻磁場，試問哪兩個線圈，會產生應電流？



解題 Solution：

學生需判斷，封閉線圈內，磁力線數場是否發生變化，以確定線圈上是否產生應電流。根據圖示，只有 A 與 C 線圈移動過程，內部有磁力線的變化，因此只有 A 與 C 線圈上。會產生感應電流。至於 B 與 D 線圈，雖然有移動，但線圈內的磁力線數不變，所以不會出現感應電流。

Students need to determine if the magnetic lines of force changes, in order to decide if there are induced electric current being generated.

Teacher: In this figure, what do the crosses in the magnetic field represent? Do they mean that the magnetic lines of force are entering or going out of the paper?

Student: The crosses symbolize that the magnetic field is entering the paper.

Teacher: How will the number of magnetic lines of force change in the coil A?

Student: Coil A leaves the magnetic field upwards, and the number of magnetic lines of force in the coil decreases!

Teacher: That's right, so will the coil A generate an induced current?

Student: Yes.

Teacher: That's right. Then when the coil B moves and when the coil of magnetic lines of force moves, will the number of magnetic lines of force change?

Student: Half of the area of coil B is within the range of the magnetic field, and half of the area is outside the range of the magnetic field. When coil B moves, the lines of magnetic force do not change.

Teacher: So will there be an induced current on the coil B?

Student: The number of magnetic lines of force in the coil B has not changed, so there will be no induced current on the B coil.

Teacher: What about the coil C?

Student: The coil C is entering the range of the magnetic field, and the number of magnetic lines of force increases, so the C coil will have an induced current.

Teacher: Very good. What about the coil D?

Student: The coil D moves at a constant speed in the magnetic field, and the number of magnetic force lines does not change, so there is no induced current.

Teacher: Excellent! So which coil will generate induced current?

Student: Coil A and Coil C.

Teacher: Perfect!

老師： 在圖中的磁場是叉叉符號，代表磁力線，出紙面或進入紙面？

學生： 叉叉符號表示磁場進入紙面。

老師： 是的，A 線圈內的磁力線數目，會有什麼變化呢？

學生： A 線圈向上離開磁場，線圈內的磁力線數目減少！

老師： 沒錯，所以 A 線圈會產生感應電流嗎?

學生： 會。

老師： 答對了，那麼 B 線圈移動時，磁力線線圈移動時，磁力線數目會改變嗎？

學生： B 線圈一半面積在磁場範圍內，一半面積在磁場範圍外，B 線圈的移動方向，磁力線不會改變。

老師： 很好，因此 B 線圈上，有感應電流嗎？

學生： B 線圈內的磁力線數目沒有改變，所以 B 線圈上不會有感應電流。

老師： 正確，那麼 C 線圈的情況呢？

學生： C 線圈正在進入磁場範圍，磁力線數量增加，因此 C 線圈會有感應電流。

老師： 很好。那麼 D 線圈呢?

學生： D 線圈在磁場內移動，磁力線數目不改變，因此也沒有感應電流。

老師： 很棒，所以會產生感應電流的，是哪些線圈呢？
學生： A 與 C 線圈。
老師： 完全正確！

例題二

說明：知道電磁感應的應用，有變壓器、發電機、電磁爐、無線充電器、麥克風等，都是利用磁力線數的變化，產生感應電流的產品。

Know that the applications of electromagnetic induction include transformers, generators, induction cookers, wireless chargers, microphones, etc. These are applications that utilize change of magnetic lines of force to induce electric current.

（英文）A transformer has a main coil of 10 turns, the secondary coil of 20 turns. Now a stable direct current is input to the input end. Which of the following statement about the output end is correct?

(A) The output voltage is 0.

(B) It generates direct current with constant output voltage.

(C) It generates alternating current with output voltage halved.

(D) The output voltage becomes direct current with twice the original.

(E) The output voltage is alternating current with twice the original.

（中文）有一變壓器，主線圈有 10 匝，副線圈有 20 匝，今於輸入端輸入穩定的直流電，則下列有關輸出端的敘述何者正確？

(A)輸出電壓為零　(B)輸出電壓不變的直流電　(C)輸出電壓減半的交流電　(D)輸出電壓變為原來 2 倍的直流電　(E)輸出電壓為原來 2 倍的交流電

（台南二中段考）

解題 Solution：

了解變壓器需利用交流電輸入，才能產生變化的磁場，以便能產生感應電壓輸出。因此，答案為(A)。

Understand that transformers need to use alternating current input in order to generate changing magnetic field, which is essential for producing induced output electric voltage.

Teacher: A transformer is an application of electromagnetic induction. How many loops does it have?

Student: Two loops.

Teacher: What kind of power supply is the input and output of the input circuit and output circuit?

Student: They're both alternating current.

Teacher: The ratio of the number of coils in the transformer will affect what characteristics of the output?

Student: The ratio of the number of coils will affect the output voltage and current.

Teacher: That's right. If a stable direct current is input, will the transformer have an output?

Student: No, because the transformer needs a changed magnetic field to generate induce current.

Teacher: So which is answer?

Student: The answer is A, and the output voltage is 0.

老師： 變壓器是電磁感應的應用，它有幾個迴路？

學生： 2 個迴路。

老師： 是的，一邊是輸入迴路，另一邊是輸出迴路。輸入的，應是哪種電源？是直流還是交流電？

學生： 變壓器的輸入及輸出都是交流電。

老師： 變壓器的線圈數量比值會影響輸出的那些特性？

學生： 線圈數量的比值會影響輸出的電壓及電流。

老師： 沒錯，如果輸入穩定的直流電，變壓器會有輸出嗎？

學生： 不會，因為變壓器需要變化的磁場才能產生感應電流。

老師： 因此答案要選哪個呢？

學生： 答案是 A，輸出電壓為 0。

4-3 電與磁的統整
Integration of Electricity and Magnetism

■ 前言 Introduction

馬克士威統整了電與磁相關的四個方程式，並利用此推導出電磁波的存在。由推導出的電磁波波動方程，顯示電磁波的傳遞速度等於光速，因而推論光就是電磁波的一種。接著，赫茲藉由實驗，證實了電磁波的存在。發展至今，電磁波的各項應用，在生活中已不可或缺。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
equation	方程式	infrared	紅外線
integration	統整	visible light	可見光
vacuum	真空	ultraviolet	紫外線
propagate/travel	傳播	X-ray	X 射線
magnetic dipole	磁偶極	γ-ray	γ射線
electric charge	電荷	electric field	電場
electromagnetic spectrum	電磁波譜	oscillation	震盪
radio waves	無線電波	(v.) rub (n.) friction (摩擦力)	摩擦
microwave	微波	Maxwell's Equations	馬克士威方程式

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

❶ _____ integrate _____ into _____.

例句：Maxwell **integrates** four laws of electricity and magnetism **into** a set of equations.
馬克士威將四個電磁相關定律，統整成一組方程式。

❷ Based on the fact that _____, _____.

例句：**Based on the fact that** the speed of electromagnetic waves is the same as the speed of light, Maxwell believed that light is a kind of electromagnetic wave.
基於電磁波的速度與光速相同，馬克士威認為，光是電磁波的一種。

❸ _____ are effective for ___(V.-ing).

例句：Microwave ovens **are effective for** heat**ing** food.
微波爐加熱食物的效果很好。

■ 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 section, students should understand the following concepts:

一、知道馬克士威由電與磁的定律，統整出的方程式，進而理解電磁波的性質。
Know the equations integrated by Maxwell from four laws of electricity and magnetism, in order to understand the concepts of electromagnetic waves.

二、認識電磁波，光譜的分布與分類，及在生活中的應用。
Know the classification of the electromagnetic spectrum and its applications in daily life.

例題講解

例題一

說明：認識馬克士威在電磁學的重要貢獻

To know about the major contributions of Maxwell in electromagnetism.

（英文）Which of the following statements about Maxwell's contributions to electromagnetism is correct? (2 options should be selected)

(A) He was the first to discover electromagnetic induction.

(B) He was the first to discover that electric current can generate a magnetic field.

(C) He is the first to predict the existence of electromagnetic waves.

(D) He is the first to experimentally confirm the existence of electromagnetic waves.

(E) He was the first to theoretically derive the propagation velocity of electromagnetic waves.

（中文）下列關於馬克士威在電磁學上貢獻的敘述，哪些正確？(應選 2 項)

(A)是第一位發現電磁感應者。

(B)是第一位發現電流可產生磁場者。

(C)是第一位預測電磁波存在者。

(D)是第一位實驗證實電磁波存在者。

(E)是第一位理論導出電磁波傳播速率者。

（103 年學測 34）

解題 Solution：

請同學先回答，以下電磁相關原理的發現，之科學家是誰。

Ask the students to describe the important electromagnetic-related phenomena and who the scientist who discovered them was.

Teacher: Who was the first to discover that an electric current can generate a magnetic field?

Student: Hans Christian Ørsted.

Teacher: Who was the scientist who found out the relationship between the direction of electric current and the direction of the induced magnetic field?

Student: André-Marie Ampère.

Teacher: Who discovered that the changes in the magnetic field can cause a current to flow in a closed coil?

Student: Michael Faraday.

Teacher: Who was the scientist who derived the equation of electromagnetic wave?

Student: James Clerk Maxwell.

Teacher: Who was the scientist who determined the speed of electromagnetic waves and found that the speed is the same as the speed of light, and that light is electromagnetic waves?

Student: James Clerk Maxwell.

Teacher: Who conducted experiments to prove the existence of electromagnetic waves?

Student: Heinrich Rudolf Hertz.

Teacher: So which two are the answers?

Student: (C) and (E).

老師： 第一位發現電流可以產生磁場的，是誰呢？

學生： 厄斯特。

老師： 找出電流方向，與其所感應之磁場方向，的科學家是誰呢？

學生： 安培。

老師： 發現磁場的變化，可以使封閉線圈上產生電流的，是誰呢？

學生： 法拉第。

老師： 藉由理論，推導出電磁波的科學家，是誰呢？

學生： 馬克士威。

老師： 算出電磁波傳遞速度，並發現電磁波速度與光速相同，因而認為光就是電磁波的科學家，是誰呢？

學生： 馬克士威。

老師： 誰利用實驗，證實電磁波的存在？

學生： 赫茲。

老師： 所以答案選哪兩個？

學生： (C)與(E)。

例題二

說明：認識電磁波在生活中的應用，及其可在真空中傳播的特性。

Learn about the applications of electromagnetic waves in daily life and its property of being able to propagate in a vacuum.

（英文）Which of the following waves cannot propagate in a vacuum?

(A) Radio waves from mobile phones.

(B) Infrared light waves radiated by the human body.

(C) Sound waves.

(D) Microwaves from microwave ovens.

（中文）下列哪一種波動，無法在真空中傳播？

(A)手機的無線電波 (B)人體輻射出的紅外光波 **(C)聲波** (D)微波爐的微波。

（小港高中期中考）

解題 Solution：

請學生說出電磁波的特性，及電磁波分類名稱，並分辨電磁波與力學波之不同。

Ask students to name the characteristics of electromagnetic waves and the names of electromagnetic waves, and to distinguish the difference between electromagnetic wave and mechanical wave.

Teacher: What are some examples of electromagnetic waves?

Student: Radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and r-rays.

Teacher: What devices use radio waves?

Student: Wireless TV and radio.

Teacher: What devices use microwaves?

Student: Mobile communication, Bluetooth, WIFI, and microwave oven.

Teacher: What kind of electromagnetic waves are emitted by the human body?

Student: Infrared.

Teacher: What is the function of ultraviolet rays?

Student: Sterilization and disinfection.

Teacher: What kind of electromagnetic wave was used to understand the double helix structure of DNA at the earliest?

Student: W-ray.

Teacher: What kind of rays are used in radiation therapy for cancer treatment?

Student: r-rays.
Teacher: What characteristics do the above electromagnetic waves have in common?
Student: They can all travel at the speed of light in a vacuum.
Teacher: Can sound waves travel in a vacuum?
Student: No, it can't.
Teacher: So which answer is correct?
Student: (C).

老師： 電磁波包含哪幾種？
學生： 無線電波、微波、紅外線、可見光、紫外線、X 射線、r 射線。
老師： 那些裝置使用無線電波？
學生： 無線電視、廣播。
老師： 那些裝置使用微波？
學生： 手機通訊、藍芽、WIFI、微波爐。
老師： 人體發出的電磁波，屬於哪種呢？
學生： 紅外線。
老師： 紫外線有什麼作用呢？
學生： 殺菌消毒。
老師： 最早了解 DNA 的雙螺旋結構，是利用哪種電磁波？
學生： x 射線。
老師： 癌症治療的放射線治療，是利用哪種射線？
學生： r 射線。
老師： 以上的這些電磁波，都具有什麼相同的特性？
學生： 都可以在真空中，以光速行進。
老師： 聲波可以在真空中傳播嗎？
學生： 聲波無法在真空中傳播。
老師： 所以答案選哪個？
學生： (C)。

4-4 光波的特性
The Properties of Light

■ 前言 Introduction

本節介紹人們對光的認識之歷史演進，並由波動的基本特性，探討光的基本原理，包含：光的反射、折射、繞射、干涉、等。也引入惠更斯的波動說，解釋光的干涉及繞射現象。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
consider	認為	mirror	鏡子
stream	束	concave mirror	凹面鏡
particle	粒子	convex mirror	凸面鏡
geometric	幾何的	spherical mirror	球面鏡
reflection	反射	wavefront	波前
refraction	折射	wavelet	波源
interfere (v.) interference (n.)	干涉	ripple	漣漪
diffraction	繞射	medium	介質
scattering	散射	immerse	沉浸
diffuse	漫射	straw	吸管
specular	鏡面反射	bend/deflection	偏折

real image	實像	prism	稜鏡
virtual image	虛像		

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

❶ _____ consider _____ to be _____.

例句：Newton **considered** light **to be** a stream of particles.

牛頓認為光束是微粒組成的。

❷ _____ travel in _____.

例句：In diffuse reflection off a rough surface, the reflected light **travels in** all directions.

在粗糙表面的漫射中，反射光向所有方向傳播。

❸ the nature of _____

例句：Young's double-slit experiment demonstrates **the** wave **nature of** light.

楊式雙狹縫實驗，證明了光的波動性。

■ 問題講解 Explanation of Problems

ଓ 學習目標 ଓ

在學習完本單元後，學生應習得以下觀念：

After studying this section, students should understand the following concepts:

一、了解光的本質，包含：光的直線前進、反射、折射、干涉、繞射現象等。Understand the nature of light, including the linear progression, reflection, refraction, interference and diffraction phenomena of light, etc.

例題講解

例題一

說明：瞭解光的折射原理。
Understand the principle of light refraction.

（英文）FIG. 1 is a schematic diagram of a wave entering from medium A into medium B. The wave has a slower speed in medium A and a faster wave speed in medium B. The solid line with arrows represents the incident ray, and the dashed line is the extension line. Draw in the answer area on the answer sheet

(1) Normal; (1 point)

(2) The refraction line after the wave enters medium B. The refraction line only needs to be drawn to the upper right, lower left, or along the dotted line without deflection. (1 point)

（中文）圖 1，為波自介質 A 射入介質 B 的示意圖。波在介質 A 中波速較慢，在介質 B 中波速較快。箭號實線代表入射線，虛線為延伸線。在答題卷中的作答區畫出：

(1) 法線；（1 分）

(2) 波進入介質 B 之後的折射線。折射線只需要畫出示意的偏右上、偏左下、或沿虛線不偏折。（1 分）

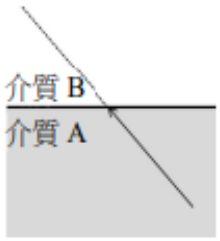


圖 1

（110 年學測 51）

解題 Solution：

光在均勻介質中會直線前進，進入光疏介質會偏離法線。如圖 1 所示。

Light travels in a straight line when it's within a homogeneous medium, and when it enters an optically thinner medium, it will deviate from the normal. Shown as Figure 1.

Teacher:	Could you name a daily life example which is similar to a medium A entering a medium B?
Student:	The speed of light is slower in water and faster in air, so it is similar to the situation where light shoots from water to air.
Teacher:	Yes, Then how do you draw the normal (lines)?
Student:	The normal should be perpendicular to the interface of the medium.

Teacher: Right. So how can normal lines be drawn?

Student: From the point where the incoming ray meets the interface, draw a vertical line perpendicular to the interface between medium A and medium B.

(The teacher uses a dotted line to draw the normal line in picture 1, following the student's answer).

Teacher: Very good! Then when light enters medium B from medium A, should it be deviated to or away from the normal line?

Student: Because it enters a medium with fast wave speed, it should be far away from the normal.

Teacher: Wonderful! When the light goes from the slow medium A to the fast medium B, the refracted light path should deviate from the normal.

(The teacher draws a refracted line in picture 1, following the student's answer).

老師： 同學可以舉出，類似介質 A 進入介質 B 的生活實例嗎？

學生： 光在水中的速度較慢，在空氣中的速度較快，所以類似光從水射向空氣的情況。

老師： 是的，那麼法線怎麼畫呢？

學生： 法線要垂直介質的交界面。

老師： 沒錯，所以法線可以怎麼畫？

學生： 生從入射線與介面交界的點，劃一條垂直線垂直介質 A 與介質 B 的交界面。

（老師順著學生作答，在圖 1 中，以虛線畫出法線。）

老師： 很好，那光由介質 A 進入介質 B，應該偏向法線或遠離法線？

學生： 因為進入波速快的介質，所以應該遠離法線。

老師： 很好，光由速度慢的介質 A 進入速度快的介質 B，折射光路線應偏離法線。

（老師順著學生作答，在圖 1 畫出折射的線。）

例題二

說明：了解繞射現象，隨波長或頻率之不同，所出現的差異。

Understand the effects of diffraction phenomenon at different wavelengths and varied frequency.

（英文）Wang Wei, a poet from the Tang Dynasty, once wrote in his poem: "No one was seen in the empty mountain, but one can hear people's voices". It means that though you can't see anyone in the forest, yet you can still hear the conversation between people in the woods. Which of the following is the reason for such a phenomenon?

(A) The speed of sound waves is greater than that of light waves, so the sound can be heard before the sound maker is seen.

(B) The energy intensity of sound waves is greater than that of light waves, so they can and travel out through the woods.

(C) The wavelength of the sound waves is close to the scale of the distance between trees, so it is easy to diffract and transmit out.

(D) The frequency of sound waves is higher than that of light waves, so there is a greater chance for sound waves to reach the observer.

(E) The wavelength of sound waves is shorter than that of light waves, so it is easier for wound waves to travel out through the woods.

（中文）唐朝王維的詩中寫道：「空山不見人，但聞人語響」。在山林中看不見人，卻可以聽到樹林間人的對話聲，其原因為下列何者？

(A)聲波的速率比光波大，故未見人而先聞聲。

(B)聲波的能量強度比光波大，故可穿透過樹林傳出。

(C)聲波的波長與林木間距的尺度較接近，故容易發生繞射而傳出。

(D)聲波的頻率比光波大，故有較大的機率傳到觀察者。

(E)聲波的波長比光波短，故較容易穿透過樹林傳出。

（102 年學測 22）

解題 Solution：

本題利用古詩例子，說明生活中光波與聲波，因波長不同，在繞射現象的差別比較。學生須先能分辨，光波與聲波的差異，再推論其現象之不同。

This problem uses the example of a classical poem to illustrate the differences between the diffraction phenomenon of light waves and sound waves in daily life, because of their different wavelengths. Students should firstly fully distinguish the characteristic differences between light and sound waves, then determine their phenomena differences.

Teacher: In a mountain where the forests are dense, you may hear people's voices without seeing them. What kind of sound wave phenomenon is this?

Student: Diffraction.

Teacher: Do all fluctuations produce diffraction?

Student: Yes.

Teacher: Why is it not easy to see the diffraction of light waves in life?

Student: Since the wavelength of light is too short, it is not easy to find suitable holes compatible with the wavelength to allow the diffraction phenomena observable.

Teacher: Which is faster, the speed of sound waves or the speed of light waves?

Student: The speed of light is relatively faster.

Teacher: What is the approximate frequency of sounds that the average person can hear?

Student: From 20 Hz to 20,000 Hz.

Teacher: The wavelength of visible light is about 400 nanometers to 780 nanometers. If the speed of light is $3 \cdot 10^8$ m/s, then on what scale is the frequency of visible light?

Student: The frequency of visible light is about the scale of 10^{15} Hz.

Teacher: If the speed of sound is about 340 m/s, then what is the wavelength of the sound wave?

Student: The wavelength of sound waves is about 0.17 cm~17 meters.

Teacher: The sound can be heard by people in the distance through the woods; is it because the energy of sound waves is relatively strong?

Student: No, it is because the sound waves are diffracted when encountering trees. Because the diameter of the trunk is close to the wavelength scale of the sound waves, there will be a more obvious diffraction phenomenon.

Teacher: So which answer should you choose?

Student: The answer is (C).

老師： 在樹林茂密的山裡，看不到人卻可以聽到人的聲音，這個是聲波的哪種現象？

學生： 繞射。

老師： 所有波動都會產生繞射現象嗎？

學生： 是的。

老師： 為何生活中不容易看到光波的繞射現象呢？

學生： 因為光的波長太短，需要非常窄的孔縫，才能觀察得到。

老師： 聲波速度跟光波速度，哪個比較快呢？

學生： 光速比較快。

老師： 一般人可聽到的聲音頻率，大約是多少呢？

學生： 20 赫茲到 20000 赫茲。

老師： 那可見光的波長大約 400 奈米到 780 奈米，如果光速為 $3 \cdot 10^8$m/s，那麼可見光的頻率大約在哪個尺度呢?

學生： 可見光的頻率大約在 10^{15} Hz 的尺度。

老師： 如果聲速大約 340m/s，那聲波的波長大概是多少呢？

學生： 聲波的波長大約 0.17cm~17 公尺。

老師： 那聲音可以通過樹林被遠處的人聽到，是因為聲波的能量比較強嗎？

學生： 不是，是因為聲波遇到樹木產生繞射，因為樹幹的直徑與聲波的波長尺度接近，所以會有較明顯的繞射現象。

老師： 所以答案要選哪個？

學生： 答案選(C)。

4-5 都卜勒效應
Doppler Effect

■ 前言 Introduction

介紹都卜勒效應原理，及生活中都卜勒效應的現象及應用。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
single	單一	away from	遠離
relative motion	相對運動	ambulance	救護車
pitch	音調	police car	警車
note	音符	siren	響笛
source	波源	horn	喇吧
rest	靜止	honk (v.)	鳴笛
toward	向...靠近		

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

❶ either _____ or_____.

例句：The observed frequency will change when **either** the source **or** the observer moves.
波源或觀察者移動時，被觀測的頻率都會改變。

❷ _____ **move toward** _____.

例句：The observer **moves toward** the source S at the speed of V.

觀察者以速度 V，接近波源 S。

❸ _____ **move away from** _____.

例句：The observer **moves away from** the source S at the speed of V.

觀察者以速度 V，遠離波源 S。

■ 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 section, students should understand the following concepts:

一、了解觀察者接收到的頻率改變情況。

Understand how the frequency changes received by an observer.

二、了解速度的方向不同，或快慢不同，所造成的頻率改變。

Understand how frequency changes due to change of directions or magnitudes of velocities.

❧ 例題講解 ☙

例題一

說明：由反射時間，推算距離，並掌握回音頻率的變化。

To estimate the distance and the motion of echo by means of reflection time, and determine the frequency variation of echo.

（英文）A stationary ship at sea sends out sound waves to detect where the school of fish are. After 50 milliseconds, the echo signal of the sound is measured, and the frequency of the echo is found to drop. If the speed of sound in the sea at that time was 1520 m/s, which of the following is the distance and motion between the fish and ship when the sound waves are reflected?

(A) 38 meters apart approaching.

(B) 76 meters apart, approaching.

(C) 38 meters apart, moving away.

(D) 76 meters apart, moving away.

(E) 76 meters apart, relatively stationary.

（中文）海上靜止的船隻，發出聲波以偵測魚群位置，經過 50 毫秒測得聲波的回聲訊號，且發現回聲的頻率下降。若當時海中聲波速率為 1520 公尺/秒，則下列何者為該魚群在反射聲波時，其相對於船隻的距離與運動狀態？

(A)相距 38 公尺，接近中。

(B)相距 76 公尺，接近中。

(C)相距 38 公尺，遠離中。

(D)相距 76 公尺，遠離中。

(E)相距 76 公尺，相對靜止。

（104 年學測 38）

解題 Solution：

先判斷聲源與觀察者的運動狀態及方向，再利用都卜勒效應，判斷觀測到的頻率增加、降低、或不改變。當波源相對於觀察者是靠近時，頻率增加，反之，則頻率減小。

First determine the motion state and direction of the sound source and the observer, and then use the Doppler Effect to determine whether the observed frequency increases, decreases, or remain the same. When the sound source is approaching to the observer, the observed frequency increases. On the other hand, the observed frequency decreases.

Teacher: Is it the sound source or the observer that moves in this question?

Student: It is the sound source that moves.

Teacher: When the car is at point O, which person is relatively closer to the car?

Student: The person standing at a.

Teacher: How is the frequency heard by the person at location a?

Student: The frequency heard will become higher.

Teacher: Who is relatively farther away from the car?

Student: The person standing at b.

Teacher: Then what is the frequency heard by the person at b like?

Student: The frequency heard will become lower.

Teacher: For the people standing at c and d, are they getting closer or further when the car passes point o?

Student: They're neither getting closer nor further, since the tangential velocity of the car is perpendicular to the line connecting the person and the car.

Teacher: Then how does the frequency of the sound heard by the people in these two place change?

Student: The received frequencies at c and d are the same as the emitted frequencies. They don't change because there is no relative movement in the radial direction.

Teacher: Good. Which two should you choose for the answer?

Student: (B) and (C).

老師： 在這個題目中移動的，是聲源還是觀察者呢？

學生： 移動的是聲源。

老師： 當車子在 O 點時，那些人相對於車子是接近的嗎？

學生： 站在 a 處的人。

老師： 因此在 a 處的人聽到的頻率會如何呢？

學生： 聽到的頻率會變高。

老師： 那些人相對於車子是遠離的呢？

學生： 站在 b 處的人。

老師： 因此在 b 處的人聽到的頻率會如何呢？

學生： 聽到的頻率會變低。

老師： 站在 c 處及 d 處的人，在車子通過 o 點的瞬間，屬於接近或遠離呢？

學生： 對 c 處及 d 處的人來說，車子的切線速度與人車的連線垂直，所以不屬於接近也不屬於遠離。

老師： 因此這兩處的人聽到的聲音頻率有什麼變化呢？

學生： c 與 d 處接收到的頻率與發出頻率相同，沒有變化，因為沒有徑向方向的相對運動。

老師： 那麼答案應該選哪兩個？

學生： (B)及(C)。

★主題五 能量★
Energy

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■ 前言 Introduction

本章介紹能量有哪些形式，及微觀尺度下的能量如何傳遞與呈現，以及能量形式的轉換。由施力作功引入能量的轉移，並介紹動能、位能以及力學能，了解力學能守恆的生活實例。本章也探討不同溫標如何轉換，及溫度與能量的差異。並由不同舉例了解生活中，各種形式的能量轉換，並由此了解能量守恆的限制與應用。最後介紹愛因斯坦的質能守恆定律，了解核能反應的過程、核能發電及輻射安全。

5-1 能量的形式
Forms of Energy

■ 前言 Introduction

由作功的定義，了解能量的轉移。依序介紹生活中常見的能量型態:動能與位能，並引入力學能的定義，及生活中常見的力學能守恆現象。最後探討生活中常見的能量形式及其轉換。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
work	功	oscillation	震盪
joule	焦耳	conservation	守恆
positive work	正功	precipitous	陡峭
potential energy	位能	slope	坡度
gravitational potential energy	重力位能	ignore	忽略
adiabatic expansion	絕熱膨脹	convert	轉換
elastic potential energy	彈力位能	chemical energy	化學能
mechanical properties	力學能	light energy	光能
kinetic energy	動能	nuclear energy	核能

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

❶ _____multiplied by_____.

例句：The gravitational potential energy is equal to the weight of an object **multiplied by** the change in height.

重力位能等於物體重量乘上高度變化。

❷ do work

例句：(1) When energy is accumulated as gravitational potential energy, we are **doing** positive **work**.

當能量以重力位能的型態累積，即為作正功。

(2) In adiabatic expansion of the gas, the gas **does** positive **work** to the environment without absorbing heat, so the gas's temperature decreases.

在絕熱膨脹過程,氣體膨脹對外作正功，且不吸熱，所以氣體溫度會下降。

❸ _____ convert into _____

例句：Different forms of energy may be **converted** from one form **into** another.

不同形式的能量，可能可以彼此轉換。

■ 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 section, students should be able to know that:

一、了解不同形式的能量。

Understand different forms of energy.

二、知道不同形式的能量轉換過程且能計算。

Know the conversion among different forms of energy and calculate them.

例題講解

例題一

說明：學生能了解各種形式的能量，並能計算作功、位能、動能及力學能。

Students can understand various forms of energy and can calculate work, potential energy, kinetic energy and mechanical energy.

（英文）If a sphere with a mass of 720 kg has a kinetic energy of 3600 kJ, what is the approximate velocity of the sphere?

(A)10^2 (B) 10^3 (C) 10^4 (D) 10^5 (E) 10^6

（中文）若質量為 720 公斤的球體，具有 3600 千焦耳的動能，則此球體的速率約為多少公尺/秒？

(A)10^2 (B) 10^3 (C) 10^4 (D) 10^5 (E) 10^6

（111 年學測 5）

解題 Solution：

物體的動能 $E_k=\left(\frac{1}{2}\right)mv^2$。因此，物體速率 $v=\sqrt{\frac{2E_k}{m}}$ 。

The kinetic energy of an object $E_k=\left(\frac{1}{2}\right)mv^2$. So, the speed of the object $v=\sqrt{\frac{2E_k}{m}}$.

Teacher: What factors are related to the kinetic energy of an object?

Student: The mass and velocity of the object.

Teacher: Do you directly multiply the mass of the object by the speed of the object?

Student: No. The kinetic energy of an object is equal to the mass of the object multiplied by the square of its velocity, and then multiplied by one-half.

Teacher: Very good, $E_k=\left(\frac{1}{2}\right)mv^2$. If the kinetic energy of the object is already known, how do we find the speed of the object?

Student: Multiply the kinetic energy of the object by 2 times, divide the mass of the object, and then take the square root of the obtained value.

老師： 物體的動能與那些因素有關？

學生： 物體的質量及速率。

老師： 將物體質量直接乘上物體速率嗎？

學生： 不是。物體的動能相當於將物體的質量乘上其速率的平方後，再乘上二分之一。

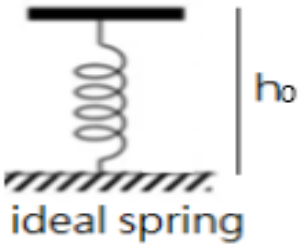
老師： 很好，$E_k=\left(\frac{1}{2}\right)mv^2$，如果已經知道物體的動能，要如何知道物體的速率呢？

學生： 將物體的動能乘上 2 倍，再除物體的質量後，再將得到的數值開方。

例題二

說明：了解能量守恆定律，包含作功、熱能、重力位能、及彈力位能的定義及計算。
Understand the law of conservation of energy, including the definitions and calculations of work, thermal energy, gravitational potential energy, and elastic potential energy.

（英文）The ideal spring system shown in the figure can only expand and contract along its central axis, its bottom end is fixed, and its top end is connected to a flat plate. Under the external force only gravity, the system stands still and is in equilibrium. The height of the top is h. Now, after the weight armor is placed on the top of the spring system, the spring continues to vibrate, and the maximum height that the top can reach is h′. Which of the following statements about the spring system is correct?



(A) h′may be greater than h_o

(B) h′ must be equal to h_o

(C) h′may be less than h_o

(D) h′ may be greater than h_o if the temperature of the spring rises due to expansion and contraction.

(E) If the temperature of the spring increases due to expansion and contraction, then h′ will still be equal to h_o

（中文）如圖的理想彈簧系統只能沿其中心軸伸縮，其底端固定，頂端連接一塊平板。在外力只有重力下，系統靜止豎立處於平衡狀態。頂端的高度都為 h_o。今將重物甲靜置於彈簧系統的頂端後，彈簧持續震盪，其頂端可達到的最大高度為 h'。下列關於彈簧系統的相關敘述何者正確？

(A) h'可能大於 h_o。

(B) h'必等於 h_o。

(C) h'可能小於 h_o。

(D) 若彈簧伸縮導致其溫度上升，則 h'可能大於 h_o。

(E) 若彈簧伸縮導致其溫度上升，則 h'仍會等於 h_o。

（改編自 112 年學測 35）

解題 Solution：

外界可透過作功，給予或抽取系統的能量。藉由能量形式之間的轉換，仍可達到能量守恆。

Work from outside is a process of delivering or extracting energy to/from a system. By means of the transformation or various energy forms, energy conservation still holds.

Teacher: By putting down a heavy object on the spring, it can compress the spring for a certain distance. What kinds of energy conversion are involved there?

Student: Gravitational potential energy, elastic potential energy, and kinetic energy.

Teacher: Very good. Then in our daily life, will the spring oscillation always maintain the original vibration amplitude?

Student: No, the spring oscillation range will become smaller and smaller.

Teacher: That's right. Does it obey the conservation of energy?

Student: It does. Only part of the energy is turned into heat energy.

Teacher: Correct, is it possible that the vibration amplitude of the spring is larger than before?

Student: That’s impossible.

Teacher: That’s right. Then what are the possible relationships between h’ and h?

Student: If no energy is lost as heat, then h' will be equal to h_o. But if there is energy lost to heat, then h' must be less than h_o.

Teacher: Great. The temperature of the spring rises. Is it possible because the external air resistance does positive work on the spring?

Student: Resistance will be opposite to the direction of motion, so negative work is done instead of positive work.

Teacher: Yes. The resistance does negative work in the spring. Does it mean that the energy of the spring system increases or decreases?

Student: Doing negative work on an object means that the energy of the object is reduced.

Teacher: Correct. So if the temperature of the spring increases, what will happen to h'?

Student: h' will be less than h_o.

Teacher: Good. Then which answer should you choose?

Student: C.

老師： 放下重物使彈簧壓縮一段距離，這裡面有哪些能量的形式轉換？

學生： 重力位能、彈力位能及動能。

老師： 很好，那麼生活中彈簧振盪會一直維持原來的振動幅度嗎？

學生： 不會，生活中彈簧振盪範圍會越來越小。

老師： 沒錯，這樣是否遵守能量守恆呢？

學生： 這樣仍遵守能量守恆。只是能量有部分變成熱能了。

老師： 是的，彈簧振動幅度可能比原來還大嗎？

學生： 不可能。

老師： 沒錯，那 h’與 h 之間的關係可能為那些情況？

學生： 如果沒有能量損失變成熱能，那麼 h’會等於 h。但如果有能量損失變成熱能，那麼 h’必定會小於 h。

老師： 很棒，那彈簧溫度上升，可能是外界空氣阻力對彈簧作正功嗎？

學生： 空氣阻力會與運動方向相反，所以做負功，而非正功。

老師： 是的，阻力對彈簧做負功，表示彈簧系統能量增加還是減少呢？

學生： 外界對物體做負功，則物體的能量會減少。

老師： 正確，所以如果彈簧溫度升高，那麼 h’有什麼變化？

學生： h’會小於 h。

老師： 很好，所以答案要選哪個？

學生： (C)。

5-2 微觀尺度下的能量
Energy at the Microscopic Scale

■ 前言 Introduction

當純物質狀態轉變時，系統的能量變化，皆用於改變分子之間的束縛能，不影響系統的溫度。理想氣體系統在微觀尺度下，溫度增加時，氣體的速度變快，因此動能增加。同時，理想氣體的微觀模型，因忽略氣體分子之間的作用力，故可忽略位能（位能不因氣體之間的距離變化有明顯改變）。所以氣體系統的熱能相當於總動能(因為不需考慮位能變化)。溫度是常用來衡量熱能變化的物理量，常用的溫標包含生活上常使用的攝氏 (ºC)，或華氏溫標 (ºF)，以及科學上常用的絕對溫標。攝氏與絕對溫標間的關係為：絕對溫度（K）＝攝氏溫度（℃）＋273．15。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
microscopic	微觀	heat conduction	熱傳導
scale	尺度	thermal equilibrium	熱平衡
molecular	分子	Celsius temperature scale	攝氏溫標
barometric pressure	氣壓	absolute temperature scale	絕對溫標

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

❶ with both A and B

例句：Atoms or molecules of solid materials are always in vibration; thus **with both** kinetic energy and potential energy.

固態物質的原子或分子總是不停地振動，因而帶有動能及位能。

❷ _____ can be determined by _____.

例句：Internal energy changes in an ideal gas **can be determined by** changes in its kinetic energy.

理想氣體的內能變化，可透過其動能變化來確定。

❸ On _____ scale, _____.

例句：**On** a microscopic **scale,** collisions between molecules cause changes in velocity.

從微觀的尺度來看，分子間的碰撞會造成速度的改變。

■ 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 section, students should be able to know that:

一、了解微觀尺度的熱能包含動能及位能。

Understanding that thermal energy on the microscopic scale includes kinetic energy and potential energy.

二、能轉換攝氏溫度與絕對溫度。

Being able to convert between Celsius temperature and absolute temperature.

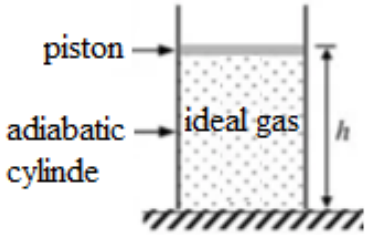
例題講解

例題一

說明：了解活塞系統在絕熱過程，理想氣體系統的能量轉換。

Understanding the energy conversion of the piston system in an adiabatic process for an ideal gas system.

（英文）The diagram shows that an adiabatic cylinder system (including piston) is filled with ideal gas, and there is no friction between the piston and the cylinder wall. The original height of the piston is h when it is at rest. If no other external forces are considered and only gravity is applied, a heavy object is placed on the piston, and the cylinder system starts to vibrate repeatedly until the piston stops at the height h'. Which of the following statements is correct?



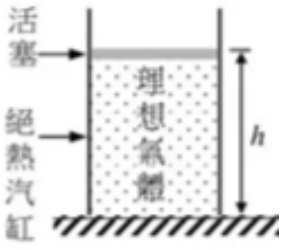
(A) This cylinder system obeys the law of conservation of energy, so the final height h'= h.

(B) This cylinder system does not follow the law of conservation of energy, so the final height h'≠h.

(C) This cylinder system obeys the law of conservation of energy, so the final height h'< h.

(D) This cylinder system does not the law of conservation of energy, so the final height h'> h.

（中文）如圖示為一個絕熱汽缸系統(含活塞)，內充有理想氣體，且活塞與缸壁無摩擦。其活塞原靜止時高度為 h，若不考慮其他外力僅有重力的作用下，將重物靜置在活塞上，汽缸系統開始反覆震盪，直到最後活塞停在高度 h'，請問以下敘述何者正確？



(A)此汽缸系統適用能量守恆，故最後高度 h'= h。

(B)此汽缸系統不適用能量守恆，故最後高度 h'≠h。

(C)此汽缸系統適用能量守恆，故最後高度 h'< h 。

(D)此汽缸系統不適用能量守恆，故最後高度 h'> h。

（改編 112 年學測 35）

解題 Solution：

根據能量守恆概念，理解絕熱過程及外力作正功時，理想氣體會獲得能量，並換轉為氣體的內能，以微觀尺度來看就是動能的增加。

Based on the principle of energy conservation, understanding the adiabatic process and positive work done by external forces, an ideal gas will gain energy and convert it into internal energy, which can be observed on the microscopic scale as an increase in kinetic energy.

Teacher: Energy in nature can appear in various forms, and different energies can be converted from one to another. Will the total energy before and after conversion maintain a constant value?

Student: The conversion between different energies will maintain a constant value.

Teacher: Good. If a heavy object is placed on a piston without friction, what effect does the change of the piston position of the cylinder system have on the gas pressure?

Student: The piston will go down due to the downward gravity of the heavy object, and the gas volume will become smaller, and the pressure will increase! Eventually the piston will stop at the point where the object reaches the force balance.

Teacher: Will the final height h' be equal to the original height h?

Student: No. The final height h' will be less than the original height h.

Teacher: Very good. Does the weight downwards do positive work on the cylinder system? So should the energy of the cylinder system increase or decrease?

Student: The weight does positive work on the cylinder system, so the energy of the cylinder system increases.

Teacher: Very good. The energy of the cylinder system increases. What kind of energy increase is it?

Student: It’s gas kinetic energy.

Teacher: Correct. The gas in the cylinder gets these energies, so how will the speed of the gas molecules change?

Student: The average speed of gas molecules becomes faster, but the gas is compressed, so the distance between gas molecules becomes smaller.

Teacher: Then which answer should you choose?

Student: C.

Teacher: Exactly!

老師： 自然界的能量會以各種形式出現，不同的能量間可以彼此轉換，轉換前後的總能量會維持定值嗎？

學生： 不同的能量互相轉換，會維持定值。

老師： 很好，那麼重物放置在沒有摩擦力的活塞上，汽缸系統的活塞位置變化會對氣體壓力造成什麼影響？

學生： 活塞受到重物向下的重力作用會向下，氣體體積變小時，壓力會變大！最後活塞會停在使重物力平衡的位置。

老師： 是的，那最後的高度 h'會等於原來的高度 h 嗎？

學生： 不會，最後高度 h'會小於原來高度 h。

老師： 很好，重物向下對汽缸系統做正功嗎？因此汽缸系統的內能，應增加還是減少？

學生： 重物對汽缸系統做正功，因此汽缸系統的內能增加。

老師： 很好，汽缸系統的內能增加，我們說這是哪種能量增加呢？

學生： 這是氣體動能。

老師： 正確，另外，汽缸內的氣體分子速率有什麼變化？

學生： 氣體分子的平均速率變快，但因為最後達到力平衡，顯示氣體被壓縮，因此氣體分子彼此間距離變小。

老師： 所以答案應該選哪個？

學生： C。

老師： 完全正確！

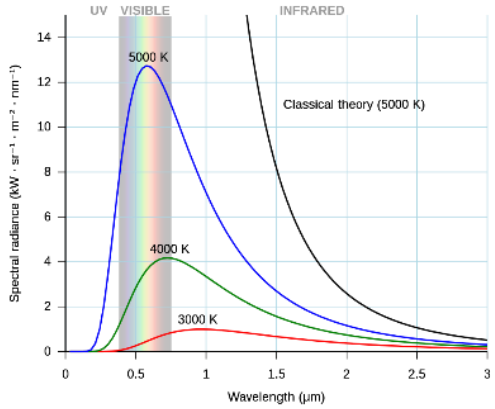
例題二

說明：轉換攝氏溫度與絕對溫度的數值關係。

Convert between Celsius and absolute temperature values.

（英文）The figure shows the relationship between the radiation intensity and wavelength of blackbody radiation. Wien's displacement law specifies that the wavelength at which the blackbody radiation intensity reaches its maximum at a temperature T is λ_{max}, which meets the following: $\lambda_{max} \cdot T \sim 2.9 \times 10^{-3} (m \cdot K)$. While a person's body temperature is 36.5°C, what is the wavelength of the maximum intensity electromagnetic wave that it emits in meters?

（中文）如圖為黑體輻射的輻射強度與波長關係，維恩位移定律給定溫度 T 的其黑體輻射強度達到最大時的波長為λ_{max}，滿足以下關係：$\lambda_{max} \cdot T \sim 2.9 \times 10^{-3} (m \cdot K)$，已知人體溫為 36.5℃，則其發出的最大強度電磁波波長為多少公尺？



A: $\lambda_{max} = 9.4 \times 10^{-6} m$

解題 Solution：

維恩位移定律需使用絕對溫度，故需先將攝氏溫度換算為絕對溫度帶入關係式中，才可得出答案。

Wien's Law needs to adopt the absolute temperature unit, so we should first convert the Celsius temperature into the absolute temperature, and put the number into the formula, and then obtain the answer.

Teacher: From Wien's Law, how do we calculate the maximum intensity of the wavelength λ_{max}?

Student: $\lambda_{max} = \frac{9.4 \times 10^{-3}}{T}$.

Teacher: So do we substitute the temperature 36.5°C directly to get this wavelength?

Student: No, because the temperature unit of this relationship is K, not ℃.

Teacher: Then tell me how to convert ℃ into K.

Student: Add 273.15 to the Celsius temperature to get the absolute temperature.

Teacher: Right, so 36.5°C=309.65K. What is the wavelength that can be obtained after putting it into the equation?

Student: The wavelength can be obtained as $\lambda_{max} = 9.4 \times 10^{-6} m$.

老師： 由題目的維恩位移關係，可以知道最大強度的波長 λ_{max} 應怎麼表示呢？

學生： $\lambda_{max} = \frac{9.4 \times 10^{-3}}{T}$。

老師： 可以直接將溫度 36.5℃，代入嗎？

學生： 不行，因為這個關係式，溫度單位是 K 不是℃。

老師： 那怎麼將℃轉換成 K 呢？

學生： 將攝氏溫度加上 273.15 即為絕對溫度。

老師： 沒錯，所以 36.5℃=309.65K。代入關係式後可以得到波長為多少呢？

學生： 可以得到波長為$9.4 \times 10^{-6} m$。

5-3 能量守恆
Conservation of Energy

■ 前言 Introduction

不同形式的能量可以互相轉換，巨觀的能量形式與微觀的能量形式描述上可能有所不同，例如用瓦斯爐加熱一壺水，是將化學能轉換為熱能，而使用手機時，內建的電池則是將化學能轉換成電能，再經由發光元件如 LED 將電能轉換為光能。雖然能量間的轉換，皆可滿足能量守恆定律，但有些種類的能量，無法完全轉換為作功（力學能）。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
lithium battery	鋰電池	fossil fuel	化石燃料
ATP	ATP	power generation	發電量
dam	水壩	ordered energy	有序能量
dynamo	發電機	disordered energy	無序能量
photosynthesis	光合作用	pumped storage	抽蓄式
engine	引擎	waste heat	廢熱
thermal work equivalent	熱功當量	turbine	渦輪機

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

❶ S.+ convert _____ into _____.

例句：Photosynthesis **converts** the sun's light energy **into** the chemical energy of glucose.
光合作用將太陽的光能，轉換成葡萄糖的化學能。

❷ In the process of _____, _____.

例句：**In the process of** hydroelectric power generation, energy is transformed into different forms multiple times.
水力發電的過程，能量的形式經過多次轉換。

❸ _____ for more than 70% of _____.

例句：From October to the coming March every year, Taiwan's wind power output accounts **for more than 70% of** the annual wind power output.
每年 10 月到隔年 3 月，台灣風力發電量輸出，占整年度風力發電量的 70%以上。

■ 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 section, students should be able to know that:
一、知道不同形式的能量轉換過程。
Know the different forms of energy conversion processes.
二、了解能量與能源的不同，且知道熱能無法完全轉換為作功。
Understand the difference between energy and energy resources, and know that thermal energy cannot be completely converted into work.

例題講解

例題一

說明：知道不同形式的能量轉換過程。

To know the conversion processes of different forms of energy.

（英文）The following A-E are five statements related to energy:

A: The generators in thermal power plants can directly convert thermal energy into electrical energy.

B: The power output of wind power generation varies with seasons.

C: The electric appliances powered through a transformer, even if they are turned off, still consume electricity when the transformer is plugged with electric current.

D: The energy conversion efficiency of solar power generation is extremely high, with a small-area panel being able to provide a large amount of power supply.

E: Hydroelectric power generation requires a large amount of water to drive the generator, so it is mostly installed at the estuary.

Among the above 5 statements, which two of the following statements are correct?

(A)A　**(B) B**　**(C) C**　(D) D　(E) E

（中文）下列甲~戊為 5 個與能源有關的敘述：

甲：火力發電廠的發電機，能夠直接將熱能轉換為電能。

乙：風力發電的電能輸出，隨著季節變化有所差異。

丙：以變壓器供電的電器，即使關機，只要變壓器接在插座上而通有電流就會耗電。

丁：太陽能發電能量轉換效率極高，小面積的面板即可提供大量供電。

戊：水力發電需要大量水推動發電機，因此設置地點多為下游出海口處。

在上述 5 項敘述中，正確的為哪兩項？

(A)甲　**(B)乙**　**(C)丙**　(D)丁　(E)戊

（改編自 112 年學測 34）

解題 Solution：

了解目前常見的發電型態，及其發電程序中能量形式如何轉換，並了解變壓器的能量轉換原理。

Understanding the current common power generation types and how the energy form is converted in the power generation process, and knowing how a transformer converts forms of energy.

Teacher: What are the common sources of electricity generation in Taiwan?

Student: Thermal power generation, wind power generation, solar power generation, and nuclear power generation.

Teacher: Correct. Which of the above power generation forms need electric motors?

Student: Thermal power generation, wind power generation and nuclear power generation.

Teacher: Good. Can you briefly describe the process of thermal power generation?

Student: The chemical energy of fossil fuels converted into heat energy with the use of coal or gas. Then its heat energy is converted into kinetic energy when water vapor drives a turbine. When the turbine drives a generator, the generator converts kinetic energy into electrical energy and then transmits it to each household.

Teacher: Very good. Will the process energy be lost during the process? How can we reduce the loss?

Student: As long as there is current, there will be a thermal effect, so the process of transmission will lose electric energy. In order to reduce the loss of electric energy, a transformer can be used to increase the voltage and make the current smaller, which can reduce the energy loss.

Teacher: Great, which principle is the transformer based on to change the voltage?

Student: The transformer changes the voltage based on the principle of electromagnetic induction.

Teacher: Does the transformer have only one single circuit?

Student: The transformer has two loops: one for input and the other for output.

Teacher: So the output circuit is not connected to electrical appliances, but when the input circuit has current, will the transformer lose power?

Student: The heating effect happens when the current passes through the wire, so a little waste heat will be generated.

Teacher: What are the situations where wind power generation or solar power generation is unstable?

Student: Wind and sunlight will vary with seasons and geographical locations, so it is difficult to provide stable energy continuously.

Teacher: At present, the energy conversion efficiency of solar power generation is only about 15%~18%. How can we get a large amount of power supply?

Student: People can choose a place with a lot of sunshine and not too hot, and build a large-scale solar field to get a larger amount of power supply.

Teacher: What is the source of energy for a hydroelectric power plant?

Student: It's the gravitational potential energy of water falling from a high place, converting into kinetic energy to drive the generator and electrical energy.

Teacher: Is it suitable for a hydroelectric power plant to be located near the sea estuary?

Student: No, because the water level difference at the sea estuary is smaller, the power plant should be built in a place with a larger water level difference.

Teacher: Very good! So which two should be chosen for the answer?

Student: B, C.

老師： 台灣目前常見的發電來源有哪些？

學生： 火力發電、風力發電、太陽能發電、核能發電。

老師： 沒錯。以上這些發電形式，需要發電機的有那些？

學生： 火力發電、風力發電及核能發電。

老師： 很好。你可以簡單敘述火力發電的過程嗎？

學生： 利用燃煤或燃氣，將石化燃料的化學能轉換成熱能，再利用水蒸氣推動渦輪機，將熱能轉成動能，渦輪機帶動發電機時，發電機將動能轉成電能，再輸送到各戶。

老師： 很好。輸送的過程能量會損失嗎?要如何減少損失？

學生： 只要有電流就會產生熱效應，因此輸送的過程會損失電能，為了減少電能的損失可以利用變壓器提高電壓，使電流變小，就可以減少損失的能量。

老師： 很棒，變壓器利用什麼原理改變電壓？

學生： 變壓器利用電磁感應原理改變電壓。

老師： 很好，變壓器只有單一迴路嗎？

學生： 變壓器有兩個迴路，一個輸入，一個輸出。

老師： 所以輸出的迴路沒有連接電器，但輸入的迴路有電流的時候，變壓器會有電能的損耗嗎？

學生： 有電流通過導線就有熱效應，所以會產生少許的廢熱。

老師： 風力發電、或太陽能發電的發電量不穩定的原因有哪些？

學生： 風力與陽光會隨季節變化、地理位置不同有所差異，所以較無法持續提供穩定的能量。
老師： 目前太陽能發電的能量轉換效率大約只有 15%~18%，如何要得到大量的供電？
學生： 選擇多日照且不會太熱的地點，建置大範圍的太陽能場址，就可以得到較大的供電量。
老師： 水力發電廠的能量來源是什麼呢？
學生： 利用水從高處落下的重力位能轉換為動能推動發電機，轉換為電能。
老師： 水力發電廠如果設置在出海口附近適合嗎？
學生： 不適合，因為出海口的水位落差較小，應該要設置在水位落差大的地點。
老師： 很好！因此答案要選哪兩個？
學生： 乙、丙。

例題二

說明：能夠計算能量轉換效率。

Being able to calculate energy conversion efficiency.

（英文）A reservoir utilizes a water level drop of about 25 meters to generate electricity, and its flow rate is about 40 cubic meters per second. If it is known that its power generation is 9000 kilowatts, what is its energy conversion efficiency? (Assume gravitational acceleration is 10 m/s ^{2})

(A) 100% **(B) 90%** (C) 80% (D) 70% (E)60%

（中文）某水庫利用水位落差約 25 公尺進行發電，其流量約為每秒 40 立方公尺，若已知其發電功率為 9000 千瓦，請問其能量轉換效率為以下何者(設重力加速度值為 10 公尺/秒 ^{2})？

(A)100% **(B)90%** (C)80% (D)70% (E)60%。

（改編自龍騰版 110 課本(物理全)第六章 第 178 頁 例題 6-5）

解題 Solution：

依據水位落差及水流流速，推算力學能的輸出功率，再比對發電功率，以求出能量轉換效率。

Based on the difference in water level and the flow velocity, the mechanical output power of the potential energy is calculated, and then compared with the generated power to determine the energy conversion efficiency.

Teacher: Tell me about the energy conversion process of hydroelectric power generation.

Student: The gravitational potential energy converts into kinetic energy from the water falling from a high place, propelling the generator to convert it into electrical energy.

Teacher: How do we calculate gravitational potential energy?

Student: The gravitational potential energy is equal to the mass of an object multiplied by the gravitational acceleration and the height difference.

Teacher: Correct, how do we define the energy conversion efficiency of hydropower?

Student: The power output per second is divided by the gravitational potential energy of water.

Teacher: Correct, so how much gravitational potential energy does water flow have per second?

Student: The water flow rate of 40 cubic meters per second is equivalent to 40 times the water flow rate of 1000 kilograms per second, then multiplied by the acceleration of gravity value of 10 m/s2, and then multiplied by the height drop of 25 meters to get 10^7 joules/ seconds of input power.

Teacher: Great, so dividing the output power by the input power is the energy conversion efficiency. What is the approximate efficiency of hydroelectric power generation?

Student: Divide 9000 kilowatts by 10^7 watts, and the efficiency is equal to 90%.

Teacher: Exactly, so which answer should I choose?

Student: B.

Mass of $1m^3$ water=1000kg

gravitational potential energy=mgh=$40*1000*10*25=10^7$(J)

efficiency=$\frac{output\ power}{input\ power}=\frac{9000*10^3}{10^7}=90\%$

老師： 說說看水力發電的能量轉換過程。

學生： 利用水由高處落下的重力位能轉換成動能後，推動發電機轉換成電能。

老師： 重力位能如何計算？

學生： 重力位能等於質量乘上重力加速度再乘上高度差。

老師： 是的，那如何定義水力發電的能量轉換效率呢？

學生： 可以將每秒輸出的發電量，除以水的重力位能變化速率。

老師： 正確，因此每秒水流的重力位能有多少呢？

學生： 每秒 40 立方公尺水流量，相當於每秒 40 乘上 1000 公斤的水流量，再乘上重力加速度值 10 公尺/秒 2，再乘上高度落差 25 公尺就可以得到 10^7 焦耳/秒的

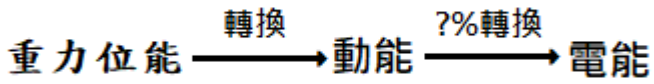
輸入功率。

老師：　師：很好，所以將輸出功率除以輸入功率就是能量轉換效率，可以得到水力發電效率大約多少呢？

學生：　將 9000 千瓦除以 10^7 瓦等於 90%。

老師：　所以答案要選哪個？

學生：　B。



1立方公尺水的質量=1000kg

每秒流下的水產生的重力位能=mgh=40*1000*10*25=10^7(J)

$$\text{轉換效率}=\frac{\text{輸出的電功率}}{\text{每秒流下的水的重力位能}}=\frac{9000*10^3}{10^7}=90\%$$

。

5-4 質能互換
Mass-Energy Equivalence

■ 前言 Introduction

本節介紹愛因斯坦的質能互換定律。由此引入核能反應中的核融合與核分裂反應，及能量轉換。最後介紹核能發電過程及輻射安全。使學生了解生活中的安全輻射劑量計算及家庭用電安全應注意事項。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
equivalence	等價	core meltdown	爐心熔毀
nuclear fusion	核融合	radiation leak	輻射外洩
fuse	融合	nuclear waste	核廢料
neutrino	微中子	hidden costs	隱形成本
deuterium	氘	cadmium	鎘
helium	氦	boron	硼
positron	正電子	control rod	控制棒
nuclear power plant	核電廠	radiation dose	輻射劑量
tritium	氚	cement	水泥
nuclear fission	核分裂	loop	迴路
chain reaction	連鎖反應	distribution box	配電箱

reactor	反應爐	overload	過載
cooling system	冷卻系統		

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

❶ _____ a small amount of _____.

例句：Through nuclear reactions, **a small amount of** mass can be converted into enormous amounts of energy.

藉由核反應，少許的質量可轉化為巨大的能量。

❷ _____ interact with _____.

例句：Alpha particles can **interact with** nitrogen nuclei to produce protons and oxygen isotopes.

α粒子可以與氮原子核反應，產生質子和氧同位素。

❸ _____ undergo nuclear fission.

例句：When a large fissile atomic nucleus such as uranium-235 or plutonium-239 absorbs a neutron, it may **undergo nuclear fission**.

當一個較大，易裂變的原子核（例如 U-235 或 Pu-239）吸收一個中子後會發生核分裂。

❹ _____ be specified by _____.

例句：A nucleus **is specified by** *ZAXZAX*, where A is the mass number, and Z is the atomic number, which is the number of protons.

一個原子核的表示法為 *ZAXZAX*，其中 A 是質量數，而 Z 是原子序，代表質子的數量。

■ 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 section, students should be able to know that:

一、了解核反應，包含核融合與核分裂。

To understand nuclear reactions, including nuclear fusion and nuclear fission.

二、了解輻射安全。

To understand radiation safety.

❧ 例題講解 ☙

例題一

說明：瞭解核能反應的過程。

To understand the process of nuclear reaction.

（英文）Which of the following statements about nuclear energy is correct? (choose 3 items)

(A) Quarks are released during nuclear fission, so electricity can be generated.

(B) Both atomic bombs and nuclear power plants use nuclear fission to release energy.

(C) Uranium-235 can release energy through nuclear fission for people to use.

(D) The principle of power solar power generation is to directly convert nuclear energy into electrical energy.

(E) The sun shines through nuclear fusion; the longer the sun shines, the smaller its total mass is.

（中文）下列關於核能的敘述，哪些正確？（應選 3 項）

(A)核分裂時都會放出夸克，故可發電。

(B)原子彈和核能電廠都可利用核分裂來釋出能量。

(C)鈾-235 可經由核分裂釋出能量， 以供人類使用。

(D)太陽能板的發電原理是直接將核能轉為電能。

(E)太陽藉由核融合得以發光，太陽發光越久，其總質量就越小。

（110 年學測 33）

解題 Solution：

核能反應可以分為核分裂和核融合兩種。兩種反應都利用了質量-能量轉換，質量減少時會轉化為能量。目前，核能發電使用核分裂產生熱能，再利用發電機產生電能。核電廠不會像原子彈那樣爆炸。

Nuclear energy reactions can be categorized as nuclear fission and nuclear fusion. Both of which use mass-energy exchange, and the mass reduction is converted into energy. At present, nuclear power generation uses nuclear fission to generate thermal energy, which activates a generator to generate electric energy. The nuclear power plant will not explode like an atomic bomb.

Teacher: There are mainly two types of nuclear energy reactions. Which two are they?
Student: Nuclear fusion and nuclear fission.
Teacher: Yes, so which method is used by the nuclear power plants currently?
Student: Nuclear fission.
Teacher: Yes, how does the mechanism of nuclear fission work?
Student: The neutron hit the unstable heavy nuclear atom, splitting it into two lighter atoms. The total mass will be reduced in this process, and the reduced mass will be converted into heat energy and released.
Teacher: When the nucleus splits, apart from splitting into lighter atoms, what else is released?
Student: It also releases neutrons and radiation.
Teacher: Very good. So what kind of atom do we currently use for nuclear fission?
Student: Uranium 235.
Teacher: The atomic bomb material is also uranium 235, so will the nuclear power plant explode like an atomic bomb?
Student: No, the concentrations of both uranium raw materials are different.
Teacher: Good, then how does the sun shine and heat up?
Student: The sun emits light and heat through nuclear fusion reactions.
Teacher: So will the mass of the sun become smaller and smaller?
Student: Yes.
Teacher: Solar panels in our daily life also use the energy of the sun. Is it based on the principle of converting nuclear energy into electricity?
Student: No, the solar panel is similar to the reverse process of LED's light emission. It is the conversion of sunlight energy into electrical energy, not a nuclear reaction.
Teacher: So which three should be chosen for the answer?
Student: B, C, and E.
Teacher: Very good!

老師： 核能反應主要分為兩種，是哪兩種呢？
學生： 核融合與核分裂。
老師： 是的，那麼目前的核能電廠採用哪種方式？
學生： 核分裂。
老師： 沒錯，核分裂的機制如何作用？
學生： 讓中子撞擊不穩定的重核原子，使其分裂為兩個較輕的原子，此過程總質量會減少，減少的質量就換變成熱能釋放。
老師： 很好，那核分裂的時候除了分裂成較輕的原子，還會釋放什麼嗎？
學生： 還會釋放中子及輻射。
老師： 很好。那目前我們使用哪種原子進行核分裂呢？
學生： 鈾 235。
老師： 原子彈材料也是鈾 235，那麼核電廠會像原子彈一樣爆炸嗎？
學生： 不會，兩者鈾原料濃度不同。
老師： 師：那太陽是怎麼發光發熱的？
學生： 太陽是藉由核融合反應而發光發熱。
老師： 所以太陽的質量會越來越小嗎？
學生： 是的。
老師： 生活中的太陽能面板也是利用太陽的能量。它的發電原理是把核能轉成電能嗎？
學生： 不是，太陽能面板類似 LED 的發光的相反過程。是將太陽的光能，轉換成電能，不是核反應。
老師： 所以答案應該選哪 3 項？
學生： B、C、E。
老師： 很好！

例題二

說明：了解家中的電路配置及其用電安全。

Understand the circuit configuration at home and the safety of using electricity.

（英文）In Taiwan, three power transmission lines are generally used to supply power to household electricity users, one of which is a grounded neutral line. Which of the following statements about the voltage of these three power transmission lines is correct?

(A) The voltage on the neutral wire is sometimes +110 volts, and sometimes 110 volts.

(B) The voltage of the neutral line is always lower than the voltage of the other two transmission lines.

(C) The output voltage of the two-hole sockets in most households is 110 volts.

(D) The mobile phone charger has the function of converting alternating current into direct current.

（中文）國內一般都用三條電力輸送線供電給家庭用電戶，其中有一條是接地的中性線。下列有關此三條電力輸送線電壓的敘述，何者正確？

(A)中性線的電壓，有時 為+110 伏特，有時則為 110 伏特。

(B)中性線的電壓永遠低於其他兩條輸電線的電壓。

(C)多數家庭的兩孔插座輸出電壓恆為 110 伏特。

(D)手機充電器具有將交流電轉換為直流電的作用。

（改編自 98 年學測 7）

解題 Solution：

由家庭配電及電力輸送轉換，了解家庭用電常識及安全。

Learn about household electricity usage and safety through household power distribution and power transmission conversion.

Teacher: Common household sockets have two holes and three holes. Is there any difference between them?

Student: Two-hole sockets output 110 volts of alternating current, and air conditioners use three-hole sockets that output 220 volts of alternating current.

Teacher: The purpose of the third hole is for safety. Is it the neutral wire of Taipower?

Student: No.

Teacher: Very good. The third hole is connected to the ground wire of each household. But are all three-hole outlets 220 volts?

Student: No.

Teacher: Then how can we judge which is which?

Student: In order to prevent incorrect plugging, two holes of the 110-volt three-hole socket are parallel holes, and the two holes of the 220-volt three-hole socket are arranged vertically or diagonally.

Teacher: The electricity transmission line from Taipower to the home has two live wires and a neutral wire. What is the difference between the neutral wire and the other two live wires?

Student: Because the neutral line is grounded, the voltage is maintained at 0 volts. The voltage of the other two live wires is the output of alternating current. The average voltage output of the two live wires is 220 volts.

Teacher: Is the charging of the mobile phone directly converted by the transformer?

Student: No, because the battery must be charged with direct current.

Teacher: Very good. A general mobile phone charger has the functions of a transformer and a rectifier, which can reduce the voltage and convert it into direct current to charge a 3.7-volt lithium battery. So which one should be the answer?

Student: D.

Teacher: That's right!

老師： 一般家庭的插座有兩孔跟三孔，它們有什麼不一樣嗎？

學生： 兩孔插座是輸出 110 伏特的交流電，冷氣機使用的是輸出 220 伏特的交流電的三孔插座。

老師： 第三孔的目的是為了安全，它是台電的中性線嗎？

學生： 不是。

老師： 很好，第三孔是接到各戶的接地線。但所有三孔插座都是 220 伏特嗎？

學生： 不是。

老師： 那怎麼判斷呢？

學生： 為了防止誤插，所以 110 伏特的三孔插座其中的兩孔為平行孔，220 伏特的三孔插座的輸電兩孔為垂直排列或斜向排列。

老師： 台電輸送到家裡的電力輸送線有兩條火線，有一條中性線。中性線跟其他兩條火線有何差異？

學生： 中性線因為接地，所以電壓維持為 0 伏特。其他兩條火線電壓則為交流電的輸出。兩條火線的電壓輸出平均為 220 伏特。

老師： 那手機的充電，是直接以變壓器轉換充電嗎？

學生： 不是，因為電池必須以直流電充電。

老師： 很好，一般的手機充電器具有變壓器及整流器的作用，可以將電壓降低並轉換為直流電，才能為 3.7 伏特的鋰電池充電。因此答案應該選哪個呢？

學生： D。

老師： 答對了!

★主題六 量子現象★
Quantum Phenomenon

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■ 前言 Introduction

本章介紹量子論的誕生歷史，及量子論的能量不連續概念。包含愛因斯坦以光量子論，來解決電磁波理論無法解釋的光電效應。因此，光除了具有波動性，也兼具粒子性。接著，德布羅意提出物質波假說，並透過科學家觀察到電子繞射及干涉條紋而得到證實。因此，物質具有波動與粒子的二象性，最後，由波耳提出氫原子模型假說，也透過氫原子光譜的實驗而證實。

6-1 量子論的產生
The Birth of Quantum Theory

■ 前言 Introduction

物體因不同溫度發出的輻射，其本質為電磁波，且各波長的強度有特定的分布曲線，與物質的材質無關，只與溫度有關，以 19 世紀末電磁波理論，無法解釋該曲線特性。普朗克提出的量子論，認為釋放與吸收的電磁波能量並非連續，而是頻率的整數倍能量，即為 E=nhf，其中 E 為輻射能量，n 為正整數，f 為電磁波頻率。量子論成功解釋了黑體輻射曲線，被認為是量子力學的開端。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
tungsten bulb	鎢絲燈泡	energy level	能階
heat radiation	熱輻射	Planck's constant	普朗克常數
stepped	階梯狀		

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

❶ a variety of _____

例句：**A variety of** objects placed in a high-temperature oven would radiate the same electromagnetic wave.

放置在高溫烤箱裡的各種物體，都輻射出相同的電磁波。

❷ at a given temperature, _____

例句：Different objects **at a given temperature**, the distributions of wavelengths-intensity of their thermal radiation are the same.
所有物體在相同溫度時，所輻射的波長-強度分布曲線會相同。

❸ In practice _____.

例句：**In practice**, a cavity with a small hole is just like a blackbody.
實務上，一個帶有小孔的空腔表現如同黑體。

❹ in dependent of _____

例句：The spectrum of cavity radiation is **in independent of** the cavity wall material.
空腔輻射的光譜與空腔壁的材質無關。

❺ no matter what _____

例句：All objects, **no matter what** their temperatures are, would radiate electromagnetic waves.
一切物體，不論其溫度高低，都會輻射出電磁波。

■ 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 section, students should be able to know that:

一、 認識量子論發展的歷史。
Know the history and development of quantum theory.

二、 了解黑體輻射曲線只與溫度有關。
Understand that the black body radiation distribution depends only on its temperature.

例題講解

例題一

說明：認識近代物理起源:量子論的發展歷史。

To know the history and development of quantum theory in modern physics.

（英文）Which of the following statements about scientific history is correct?

(A) Maxwell uses Maxwell's equation to explain the distribution of black body radiation curves.

(B) Einstein first successfully explained the distribution of the black body radiation curve with the photon model.

(C) Planck uses continuous electromagnetic wave energy radiation and absorption, which fits the black body radiation curve distribution.

(D) Bohr first used the hydrogen atom spectrum to explain the distribution of the black body radiation curve.

(E) According to Planck's quantum theory, electromagnetic radiation energy is related to frequency and is absorbed or released in integer multiples of energy units.

（中文）下列關於科學史實敘述，何者正確？

(A) 馬克士威以馬克士威方程式解釋黑體輻射曲線分布。

(B) 愛因斯坦以光子模型首先成功解釋黑體輻射曲線分布。

(C) 普朗克利用連續的電磁波能量輻射與吸收，吻合黑體輻射曲線分布。

(D) 波耳首先利用氫原子光譜解釋黑體輻射曲線分布。

(E) 普朗克量子論認為電磁輻射能量與頻率有關，且以整數倍的能量單元吸收或釋放。

（改編自 111 年學測 9）

解題 Solution：

19 世紀末電磁波理論，無法解釋黑體輻射的曲線分布，普朗克量子論是首先成功吻合黑體輻射曲線分布的理論，該理論認為物質釋放出的能量並非連續的，與帶電粒子振動頻率 f 有關，物體吸收或釋放能量為能量單元 hf 的整數倍。

At the end of the 19th century, the electromagnetic wave theory could not explain the curvilinear distribution of black body radiation. Planck's quantum theory was the first theory that successfully fit the curvilinear distribution of black body radiation. This theory holds that the energy released by matter is not continuous and is related to the vibration frequency f of charged particles of matter. The energy absorbed or released by an object is an integer multiple of the energy unit hf.

Teacher: If at room temperature, an object absorbs all the radiation from the outside world, then what color would it look like?

Student: Black.

Teacher: If this object is heated high enough, will it still remain black?

Student: No. Objects often turn red or yellow, or even look white when heated.

Teacher: We call an object a black body if it absorbs external radiation without reflecting it, and only emits its own radiation. So what factors are the color of a black body related to?

Student: The color of a blackbody is only related to its temperature.

Teacher: That's correct, so is the color of the black body related to the material of the black body?

Student: No, it doesn't matter.

Teacher: Who was the first scientist to explain the distribution of the black body radiation curve?

Student: Planck.

Teacher: Did Planck use electromagnetic wave theory to explain the phenomenon of black body radiation?

Student: No.

Teacher: So what theory did Planck propose?

Student: Quantum theory.

Teacher: Yes, it is the quantum theory of electromagnetic waves. What are the main concepts of quantum theory?

Student: The absorption or release of electromagnetic wave energy is discrete; that is, the absorption or release of energy must be an integer multiple of a certain energy unit.

Teacher: Which element of the electromagnetic wave is related to this energy unit?

Student: The energy unit is related to the frequency f of the electromagnetic wave.

Teacher: Very good. Which scientist then quoted Planck's concept to propose the quantum theory of light?

Student: Einstein.

Teacher: Very good. So which one option is the answer?

Student: E.

Teacher: Right!

老師： 若在室溫下，一個物體會吸收所有來自外界的輻射，那麼它看起來會是什麼顏色？

學生： 黑色。

老師： 如果將這個物體加熱到足夠的高溫，那麼還是保持黑色嗎？

學生： 不是。物體加熱後通常會呈現紅色或黃色或甚至看起來像白色。

老師： 我們把會吸收外界輻射不反射，只發出自己輻射的物體稱為黑體，那麼黑體的顏色跟什麼因素有關？

學生： 黑體的顏色只會跟溫度有關。

老師： 答對了，那麼黑體顏色跟黑體的材質有關嗎？

學生： 無關。

老師： 最早解釋黑體輻射曲線分布的科學家，是哪位呢？

學生： 普朗克。

老師： 普朗克是利用電磁波理論，解釋黑體輻射的現象嗎？

學生： 不是。

老師： 那麼普朗克提出什麼理論呢？

學生： 量子論。

老師： 沒錯，是電磁波的量子論，其主要概念是什麼呢？

學生： 電磁波能量的吸收或釋放是不連續的，也就是能量的吸收或釋放必須是某個能量單元的整數倍。

老師： 這個能量單元跟電磁波的哪個因素有關呢？

學生： 能量單元與電磁波的頻率 f 有關。

老師： 很好。後來是哪位科學家引用普朗克的概念提出光量子論呢？

學生： 愛因斯坦。

老師： 非常棒。所以答案應該選哪個呢？

學生： E。

老師： 沒錯！

6-2 光的粒子性
Particle Nature of Light

■ 前言 Introduction

光照在金屬板上，可能使其電子脫離表面，此現象稱為「光電效應」。而電子脫離表面的因素，只與光的頻率有關，與光的強度無關。如果照射光的頻率低於底限頻率時，不論照射多久或改用亮度更強的光，仍然無法促使電子脫離金屬表面，此現象無法以當時的電磁波理論解釋，愛因斯坦因而提出光量子說，並成功解釋光電效應。

光量子論認為電磁波是由許多光量子組成，簡稱光子，每個光子的能量等於普朗克常數 h 乘上頻率 f，及 E=hf。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
photoelectric effect	光電效應	work function	功函數
threshold frequency	底限頻率	electron volt	電子伏特
light quantum	光量子	cutoff voltage	截止電壓
photon	光子		

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

❶ A be illuminated with B

例句：When a zinc plate **is illuminated with** ultraviolet light, electrons take off the metal surface, and the metal plate becomes positively charged.

以紫外光照射鋅板，電子脫離金屬表面，會使金屬板帶正電。

❷ depend on_____, but has nothing to do with _____.

例句：The maximum kinetic energy of electrons **depends on** the frequency of light and the type of metal plate, **but has nothing to do with** the intensity of light.

理想氣體的內能變化，可透過其動能變化來確定。

❸ emit A from B

例句：The work function is the minimum energy required to **emit** an electron **from** the surface of the material.

功函數是讓電子脫離金屬表面，所需的最小能量。

■ 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 section, students should be able to know that:

一、了解光電效應實驗結果及解釋。

Understand the experiment results of the photoelectric effect and their explanations.

二、了解光量子論。

Understand the quantum theory of light.

例題講解

例題一

說明：理解光電效應實驗結果及其解釋。

Understand the experimental results of the photoelectric effect and their explanations.

（英文）The photoelectric effect is the experimental evidence that light has particle nature. When monochromatic light is irradiated on the metal surface, the electrons on the metal surface absorb the energy of the incident light, part of the energy is used to overcome the bondage of the metal surface to the electrons, and the remaining energy is converted into electronic kinetic energy, escaping from the metal surface and becoming photoelectrons. Which of the following statements about the photoelectric effect experiment are correct? (choose 2 items)

(A) **The energy of the incident photon is determined by the frequency; the higher the frequency, the greater the energy.**

(B) The energy of the incident photon is determined by the light intensity; the greater the intensity, the higher the frequency.

(C) **The higher the frequency of the incident photons, the higher the kinetic energy of the photoelectrons.**

(D) The greater the intensity of the incident light, the higher the kinetic energy of the photoelectrons.

(E) When irradiated with the same monochromatic light, the kinetic energy of photoelectrons has nothing to do with the type of metal material to be irradiated.

（中文）光電效應是光具有粒子性的實驗證據，今以單色光照射金屬表面後，金屬表面的電子吸收入射光的能量，部分能量用於克服金屬表面對電子的束縛，剩餘能量則轉為電子動能，自金屬表面逸出，成為光電子。下列有關此光電效應實驗的敘述，哪些正確？ (應選 2 項)

(A) 入射光子的能量由頻率決定，頻率越高，能量越大。

(B) 入射光子的能量由光強度決定，強度越大，頻率越高。

(C) 入射光子的頻率越高，光電子的動能會隨之增加。

(D) 入射光的強度越大，光電子的動能會隨之增加。

(E) 以同一單色光照射時，光電子的動能與被照金屬材料的種類無關。

（102 年學測 32）

解題 Solution：

學生須知道光電效應的實驗結果:入射光需要超過底限頻率，才能使電子脫離金屬表面。若入射光頻率低於底限頻率，不論是增加光強度或延長照射時間都無法產生光電子。底限頻率與金屬材料的功函數有關，與入射光之強度無關。

Students are required to know the experimental results of the photoelectric effect; for example, the incident light needs to exceed the threshold frequency in order for the electrons to detach from the metal surface. If the frequency of the incident light is lower than the threshold frequency, photoelectrons cannot be produced either by increasing the light intensity or prolonging the irradiation time. The threshold frequency is related to the work function of the material of metal, and has nothing to do with the intensity of incident light.

Teacher: When a potassium metal plate is illuminated with green light, photoelectrons cannot be produced. Then can photoelectrons be produced with red light?

Student: No.

Teacher: Can photoelectrons be produced if the intensity of red light is increased or the irradiation time is prolonged?

Student: No.

Teacher: Is it possible to generate photoelectrons if blue light is used instead?

Student: Maybe.

Teacher: In the electromagnetic wave theory, if the energy of the wave is increased, which property of the wave can be changed?

Student: Increasing the amplitude of the wave can increase the energy of the wave.

Teacher: According to the theory of electromagnetic waves, increasing the intensity of light means increasing the amplitude of light waves and increasing the energy of light, right?

Student: Yes.

Teacher: Therefore, it means that the electromagnetic wave theory cannot explain the phenomenon of the photoelectric effect, so who proposed the theory to explain the experimental results of the photoelectric effect?

Student: Einstein

Teacher: What is the content of Einstein's quantum theory of light?

Student: Light is a discontinuous wave packet, and each wave packet is a photon. The energy of a photon is Planck’s constant multiplied by its frequency, which can be expressed as $E=hf$.

Teacher: Therefore, according to Einstein's light quantum theory, the energy of incident light

is only related to the frequency, and the higher the frequency, the greater the energy, right?

Student: Yes.

Teacher: Then Einstein's photoelectric equation $hf = \frac{1}{2}mv_{max}^2 + \phi$. What do they represent?

Student: hf represents the incident photon energy, $\frac{1}{2}mv_{max}^2$ is the maximum kinetic energy of the detached electron, and ϕ is the work function.

Teacher: This means that if the energy of the incident photon (hf) is large enough and is absorbed by the electron, the minimum energy required to detach from the metal surface, that is, the work function (ψ), is deducted, and the remaining energy is the maximum kinetic energy of the electron. So which factor is the work function related to?

Student: The work function is related to the type of metal.

Teacher: So which two should be chosen as the answer?

Student: A and C

Teacher: Great!

老師： 如果用綠光照射鉀金屬板，無法產生光電子，那麼用紅光照射可以產生光電子嗎？

學生： 不行。

老師： 如果增加紅光的強度，或延長照射的時間，可以產生光電子嗎？

學生： 不行。

老師： 如果改用藍光照射，可能可以產生光電子嗎？

學生： 可能可以。

老師： 在電磁波理論中，如果要讓波的能量增加，可以改變波的哪個特性呢？

學生： 增加波的振幅，可以使波的能量變大。

老師： 依照電磁波理論，增加光強度，就是使光波的振幅變大，光的能量也會增加，對嗎？

學生： 是的。

老師： 因此表示電磁波理論無法解釋光電效應的現象，那麼是誰提出理論解釋光電效應實驗結果？

學生： 愛因斯坦。

老師： 愛因斯坦的光量子論內容是什麼？

學生：光是不連續的波包，每個波包就是光子，光子的能量為普朗克常數乘上其頻率，可表示成 E=hf。

老師：因此根據愛因斯坦的光量子論，入射光的能量只與頻率有關，且頻率越高，能量越大，是嗎？

學生：是的。

老師：那愛因斯坦的光電方程式 $hf=\frac{1}{2}mv_{max}^2+\phi$ ，分別代表什麼？

學生：hf 表示入射的光子能量，$\frac{1}{2}mv_{max}^2$ 是脫離的電子的最大動能，是功函數。

老師：這表示如果入射的光子能量 (hf)，足夠大且被電子吸收，扣除脫離金屬表面所需要的最低能量，也就是功函數 (ψ)，剩餘的能量就是電子的最大動能。那麼功函數與哪個因素有關呢？

學生：功函數與金屬種類有關。

老師：因此答案要選哪兩個？

學生：A 與 C。

老師：非常棒！

例題二

說明：計算光量子能量及數量。

Calculate the energy and quantity of light quantum.

（英文）In the laboratory, there is a laser light source with a wavelength of 200 nm and a power of 3.0W. It is known that the speed of light is 3×10^{8}m/s, and Planck's constant h is 6.6×10^{-34}Js. What is the approximate energy of each photon emitted by this light source?
A: 9.9×10^{-19}J

（中文）在實驗室中有一台可發出波長 200nm 為的雷射光源，功率為 3.0W。已知光速為 3×10^{8}m/s，普朗克常數 h 為 6.6×10^{-34}Js。此光源發出的每個光子能量約為多少？
A: 9.9×10^{-19}J

（改編自 105 年指考 19）

解題 Solution：

由[光子能量=普朗克常數頻率]，以及[光速=頻率波長]，即可算出每個光子的能量。

單一光子能量=普朗克常數普朗克常數頻率= $h\times\frac{\text{光速 C}}{\text{波長 }\lambda}=6.6\times10^{-34}\times\frac{3\times10^{8}}{200\times10^{-9}}=9.9\times10^{-19}$J。

Students can calculate the energy of each photon by photon energy = Planck's constant times frequency, and the speed of light =frequency times wavelength. photon energy= Planck's constant×frequency=$h\times\frac{the\ speed\ of\ light\ C}{wavelength\ \lambda}=6.6\times10^{-34}\times\frac{3\times10^{8}}{200\times10^{-9}}=9.9\times10^{-19}$J.

Teacher: According to Einstein's light quantum theory, how can we calculate the energy of photons?

Student: The energy of a photon is equal to Planck's constant times the frequency.

Teacher: Then how can we get the frequency from the speed of light?

Student: The speed of light is equal to the wavelength times the frequency.

Teacher: So how many Hertz is the frequency of a photon? Can the speed of light be directly divided by 200 nanometers?

Student: No, it needs to be converted first. 200 nanometers is equivalent to 2 times 10 to the power of −7 meters. Then multiply the speed of light 3 by 10 to the 8th power, and divide by the wavelength to get the frequency equal to 1.5×10^{15} Hz.

Teacher: So what is the energy of a photon?

Student: The energy of a photon is equal to Planck's constant 6.6×10^{-34} multiplied by the frequency 1.5×10^{15} equals 9.9×10^{-19} joules.

Teacher: Excellent! That's right.

老師： 愛因斯坦光量子論，提出光子能量如何計算呢？

學生： 光子能量等於普朗克常數乘上頻率。

老師： 那如何由光速得到頻率呢？

學生： 光速等於波長乘上頻率。

老師： 所以光子的頻率等於多少赫茲？可以直接將光速除以 200 奈米嗎？

學生： 不行，要先換算。200 奈米相當於 2 乘上 10 的−7 次方公尺。再將光速 3 乘上 10 的 8 次方，除以波長就可以得到頻率等於 1.5×10^{15} 赫茲。

老師： 所以光子的能量等於多少呢？

學生： 光子的能量等於普朗克常數 6.6×10^{-34} 再乘上頻率 1.5×10^{15} 等於 9.9×10^{-19} 焦耳。

老師： 讚！沒錯。

6-3 物質的波動性
The Wave Nature of Particles

■ 前言 Introduction

愛因斯坦提出光粒子概念，解釋了光電效應，引發德布羅意反向思考，具質量的粒子是否也具有波動性質，提出物質波模型。後續由其他科學家以實驗分別得到電子繞射及干涉條紋，證明了電子確實具有波動性，因而驗證了物質波理論。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
matter waves	物質波	pattern	圖案
nickel	鎳	X-ray	X 射線
crystal	晶體	probability distribution	機率分布

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

❶ Diffraction of _____.

例句：**Diffraction of** matter waves is only observable for extremely small particles, like electrons, neutrons, atoms and small molecules.
物質波的繞射現象，只能在極小的粒子（例如電子、中子、原子和小分子）上被觀察到。

❷ _____ shared _____ Nobel Prize for the discovery of _____ by _____.

例句：Davisson **shared** 1937 **Nobel Prize for the discovery of** the diffraction of electrons **by** crystals.
戴维森利用晶體發現電子的繞射，獲得 1937 年的諾貝爾獎。

❸ The wave nature of _____.

例句：**The wave nature of** the electron was experimentally confirmed in 1927 by C J Davisson.
電子的波動性在 1927 年被 CJ 戴維森以實驗驗證。

■ 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 section, students should be able to know that:
一、知道電子的物質波如何透過實驗驗證。
Know that how matter waves of electrons were verified via experiments
二、了解所有物質都有波動性質，但只有質量較小的粒子，容易被觀察到波動性質。
Understand that all materials have wave properties, but only the less massive particles are easily observed.

例題講解

例題一

說明：知道電子的物質波相關概念。
Know the concept of matter waves associated with electrons.

（英文）Which of the following statements about matter waves is correct?

(A) Elementary particles in motion do not have the properties of matter waves.

(B) A baseball moves at a speed of 150 km/h, and its matter wave properties are significant and easy to observe.

(C) Electrons are charged particles. In the experiment where the electron beam penetrates the metal lattice, due to the Coulomb electrostatic force, although the diffraction pattern of the electrons is obtained, it may not prove that the electrons have the nature of waves.

(D) The nature of matter waves only exists in uncharged particles; for example, neutrons are uncharged particles, and the experiment of neutrons irradiating crystals can reveal the nature of matter waves.

(E) **Single electrons with appropriate energy pass through the double slits. When we observe the screen behind the double slits, each time the electron leaves a bright spot on the screen and repeat the same experiment many times, then the accumulated bright spots on the screen can form bright and dark stripes.**

（中文）下列有關物質波的敘述何者正確？

(A) 運動中的基本粒子不具有物質波的性質。

(B) 棒球以 150 公里/小時的速率運動，其物質波的性質顯著且易於觀察。

(C) 電子是帶電粒子，電子束穿透金屬晶格的實驗中，由於庫侖靜電力的作用，雖然得到電子的繞射圖案，但未必能證明電子具有波的性質。

(D) 物質波的性質僅存在於不帶電的粒子；例如，中子是不帶電的粒子，由中子照射晶體的實驗，才能顯現物質波的性質。

(E) 以適當能量的單電子通過雙狹縫，觀察雙狹縫後方屏幕，每次電子在屏幕上留下一個亮點，重複多次相同實驗，在屏幕上累積留下的亮點可形成亮暗條紋。

（109 年(補考)指考 1）

解題 Solution：

了解物質波是所有具有質量物體的特性，且質量極小的粒子，其波長才可達到容易觀察的尺度。

Understand that matter waves are the characteristics of all objects with mass, and only particles with extremely small masses can reach a scale that is observable.

Teacher: Does de Broglie's matter wave claim that only electrons have wave properties?
Student: No, all matters have the property of wave.
Teacher: Why can't we observe the phenomenon of interference or diffraction of matter waves in our daily life?
Student: Because the wavelength of the matter wave is related to the mass: the greater the mass, the smaller the wavelength. Objects in life, even when it's sand, have matter waves whose wavelengths are too small to be measured by any instrument. Therefore, they cannot be observed.
Teacher: Can we use an electron beam to penetrate a metal lattice and get the diffraction pattern to prove that the electron has the property of fluctuation?
Student: Yes, if diffraction or interference patterns are observed, it can be confirmed that it has wave nature.
Teacher: Very good. So which should be the answer?
Student: E.
Teacher: Great!

老師： 德布羅意的物質波，是主張電子才有波動性質嗎？
學生： 不是，所有的物質都具有波動性質。
老師： 為什麼生活中，觀察不到物質波的干涉或繞射現象？
學生： 因為物質波的波長與質量有關，質量越大，波長越小。生活中的物體，即使是沙子，其物質波的波長都小到任何儀器無法測量的尺度，因此無法觀察到。
老師： 我們可以利用電子束穿透金屬晶格後，得到繞射圖案就可以證明電子具有波動的性質嗎？
學生： 是的，如果觀測到繞射或干涉圖樣，就可以證實具有波動性質。
老師： 很好。所以答案應該選哪個？
學生： E。
老師： 很棒！

例題二

說明：了解物質波的意義，並與日常生活所觀察到的波動現象相比較。
Understand the meaning of matter waves and compare them to the wave phenomena observed in daily life.

（英文）Which of the following phenomena can verify de Broglie's matter wave theory?

(A) When the water waves pass through the leaves on the surface of a lake, the leaves shake up and down with the waves and do not follow the direction of the waves.

(B) The damper of the 101 building can reduce the vibration amplitude of the building shaking during the earthquake.

(C) Noise-canceling headphones use the reverse electronic signal input to cause disruptive interference and reduce noise interference.

(D) The charge-coupled device (CCD) of a digital camera uses the photoelectrons, which appear when light reaches it, and then convert light waves into digital signals.

(E) The electron beam passes behind an aluminum foil, showing the same diffraction pattern as that of X-rays.

（中文）下列現象哪個可以驗證德布羅意的物質波理論？

(A) 水波通通湖面上的葉子時，葉子隨波上下晃動，不隨水波傳遞方向前進。

(B) 101 大樓的阻尼器可以降低地震時的大樓隨地震搖晃的震動幅度。

(C) 降噪耳機利用輸入的反向電子訊號，造成破換性干涉，減少噪音的干擾。

(D) 數位相機的感光元件利用光打到感光元件後，產生光電子，將光波轉換成數位訊號。

(E) 電子束通過鋁箔後方，出現與 X 射線相同的繞射圖樣。

解題 Solution：

觀察生活上的各種波動現象的特性，並區分其與物質波概念的不同。

Observing the properties of various wave phenomena in daily life and distinguishing those with the concept of matter waves.

Teacher: Can you tell me some common wave phenomena in daily life?

Student: Moving straight forward, reflection, refraction, diffraction, interference, and Doppler effect.

Teacher: Very good. Can all of these phenomena be explained by the particle properties?

Student: Only diffraction and interference can be explained by wave properties. The phenomena of moving straight forward, reflection, refraction, and Doppler effect can be explained by the particle properties.

Teacher: What is the concept of matter waves?

Student: All matters have wave properties.

Teacher: So, can we observe the interference or diffraction of matter waves in everything?

Student: No.

Teacher: Why not?

Student: Only particles with very small mass, such as electrons, have wavelengths large enough to observe.

Teacher: So, are all interference or diffraction fringes generated by electrons considered a phenomenon of matter waves?

Student: Yes.

Teacher: The photosensitive part of a digital camera uses light to emit electrons. What effect is it?

Student: It is the photoelectric effect.

Teacher: Dampers can reduce the vibration amplitude during an earthquake. Is it using the concept of matter waves?

Student: No, the vibration reduction is achieved by using the properties of mechanical waves.

Teacher: So, what is the correct answer?

Student: E.

Teacher: Excellent!

老師： 說說看生活中有那些常見的波動現象？

學生： 直線前進、反射、折射、繞射、干涉、都卜勒效應。

老師： 很好，這些現象，也可以用粒子性質解釋嗎？

學生： 只有繞射與干涉能用波動解釋，直線前進、反射、折射、都卜勒效應等現象都可以粒子性質解釋。

老師： 物質波的概念是什麼呢？

學生： 所有物質都有波動的性質。

老師： 所以，所有東西都可以觀察到，物質波的干涉或者繞射現象嗎？

學生： 不行。

老師： 為什麼？

學生： 只有質量很小，例如電子，其物質波的波長，才足夠大到能觀察的等級。
老師： 所以只要是以電子為來源，產生干涉或繞射條紋，都是屬於物質波的現象嗎？
學生： 是的。
老師： 那數位相機的感光元件利用光打出電子，這是什麼效應呢？
學生： 光電效應。
老師： 阻尼器可降低地震時的震動幅度，是利用物質波的概念嗎？
學生： 不是，減振是利用力學波，來降低振幅。
老師： 所以答案應該選哪個？
學生： E。
老師： 很棒！

6-4 波粒二象性
Wave-Particle Duality

■ 前言 Introduction

本節介紹電子雙狹縫實驗的結果，一次發射一顆電子，使其經過雙狹縫在後面屏幕成像。隨著累計的電子數量逐漸增加，原本一點一點出現，呈現粒子性質，當達到數萬顆電子時，卻呈現類似光波的雙狹縫干涉特徵。由此電子雙狹縫實驗，可了解到電子的確兼具波動及粒子性，但卻無法同時呈現。也可呼應物質波的空間機率分布概念。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
to cast dice	擲骰子	electron gun	電子槍
discrete	離散的	interference fringes	干涉條紋
wave-particle duality	波粒二象性		

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

❶ Whether A or B, or C _____

例句：**Whether** electrons **or** light, **or** even all matter, has wave-particle duality.

不論是電子或光，甚至所有的物質，都具有波粒二象性。

❷ A behave like B.

例句：Electrons **behave like** waves in a large number of electron-beam double-slit experiments.

大數量的電子束，透過雙狹縫實驗，則電子束會表現得如同波。

❸ _____ play dice.

例句：God does not **play dice**!

上帝不擲骰子。

■ 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 section, students should be able to know that:

一、了解波粒二象性的概念。

Understand the concept of wave-particle duality.

二、了解電子雙狹縫實驗，可驗證物質波機率分布的主張。

Understand the electron double-slit experiment can underpin the assertion of the probability distribution of matter waves.

例題講解

例題一

說明：了解哪些物質或現象，具有波粒二象性。

To Know what substances or phenomena have wave-particle duality.

（英文）Which of the following statements about quantum phenomena is correct?

(A) Light is a continuous electromagnetic wave, while electrons are discrete particles.

(B) A laser light can produce interference fringes after passing through double slits, and an electron can also produce interference fringes after passing through double slits.

(C) Only light waves can produce diffraction fringes, while electron beams cannot produce diffraction fringes.

(D) The photoelectric effect can explain that light has wave-particle duality.

(E) All matter has wave-particle duality, but cannot be observed simultaneously.

（中文）下列關於量子現象的敘述，哪個正確？

(A)光是連續的電磁波，而電子是不連續的粒子。

(B)一道雷射光通過雙狹縫後可以產生干涉條紋，一個電子通過雙狹縫後也可以產生干涉條紋。

(C)只有光波能產生繞射條紋，電子束無法產生繞射條紋。

(D)光電效應可以驗證光的波粒二象性。

(E)所有物質都有波粒二象性，但無法同時被觀測到。

解題 Solution：

所有物質與電磁波都具有波粒二象性，但必須經過特定實驗才能觀察到另一個面向。光電效應展現出光的粒子性，而電子雙狹縫的干涉條紋，則可以證實電子具有波動性。

All matters and electromagnetic waves have wave-particle duality, but either aspect can only be observed through specific experiments. The photoelectric effect illustrates the particle nature of light, while the interference fringes of electron double slits demonstrate the wave nature of electrons.

Teacher: According to Einstein's quantum theory of light, the energy of each photon is equal to Planck's constant multiplied by the frequency. Does this mean that Einstein believed that light is a particle and does not have the characteristics of a wave?

Student: No, light still has the characteristics of waves, wavelength and frequency, so the energy of photons is related to the frequency of light waves.

Teacher: Yes, then can the photoelectric effect verify the properties of particles or waves?

Student: The photoelectric effect can only be explained by the particle model of light.

Teacher: That's right, so what phenomena can verify that light has wave nature?

Student: Wave nature of light can be demonstrated from phenomena such as single-slit diffraction or double-slit interference.

Teacher: So light has wave properties and particle properties at the same time. Can these two properties be observed at the same time?

Student: No.

Teacher: Very good. According to de Broglie's matter-wave hypothesis, does all matter have wave properties?

Student: Yes, all matters have wave properties.

Teacher: Then why can't we see the interference phenomenon of particles in our daily life?

Student: Just like the interference fringes of light are related to the size of the slits, the wavelength of the objects in life, even as tiny as sand, is still too small. It is impossible to observe via daily life experiences.

Teacher: So what kind of particles are we using to observe matter waves now?

Student: Electronics.

Teacher: In most observations, is the property of an electron classified as a particle or a wave?

Student: Particles.

Teacher: How does the current electron double slit experiment confirm the wave nature of electrons?

Student: Interference patterns can be obtained by using a large number of electrons to pass through double slits.

Teacher: Can we observe the particle nature and wave nature of the same particle at the same time?

Student: No.

Teacher: Very good! So which answer should I choose?

Student: E.

Teacher: Very good!

老師： 根據愛因斯坦的光量子論，每個光子的能量等於普朗克常數乘上頻率，這表示愛因斯坦認為光是粒子，不具備波的特性嗎？

學生： 不是，光仍具有波的特性，如:波長及頻率，因此光子的能量與光波的頻率有關。

老師： 是的，那麼光電效應，可以驗證粒子性質或波動性質？

學生： 光電效應只能展現光的粒子性。

老師： 沒錯，那由那些現象可以驗證光具有波動性質？

學生： 可以由單狹縫繞射，或雙狹縫干涉等現象，驗證光的波動性質。

老師： 所以光同時具有波動性及粒子性，那麼可以同時觀察到這兩個特性嗎？

學生： 不行。

老師： 很好。另外，根據德布羅意的物質波假說，所有物質都具有波動性質嗎？

學生： 是的，所有物質都具有波動性質。

老師： 為何生活中看不到粒子的干涉現象？

學生： 如同光的干涉條紋與狹縫大小有關，生活中的物體，即使是沙子，它的波長仍然太小，無法透過日常經驗觀測到。

老師： 那我們現在是藉由哪種粒子觀測到物質波？

學生： 電子。

老師： 電子在多數的觀察中，它的屬性是被歸類為粒子或波動？

學生： 粒子。

老師： 目前的電子雙狹縫實驗，如何確認電子的波動性質？

學生： 利用大量電子通過雙狹縫，可得到干涉圖樣。

老師： 很好，那我們可以同時觀測到電子的粒子性及波動性嗎？

學生： 不行。

老師： 很好！所以答案要選哪個？

學生： E。

老師： 很好！

例題二

說明：知道電子雙狹縫干涉，可展現電子的波動性，如同光的雙狹縫干涉。

Know the double-slit electron interference experiment can demonstrate the wave nature of electrons, same as that of double-slit light interference.

（英文）Which of the following statements about the double slit experiment is correct?

(A) The interference fringes of light can be observed through the use of double slits, but the interference fringes of electrons cannot be observed.

(B) The interference fringes after an electron passes through the slits can be observed through the use of double slits.

(C) As long as a few electrons pass through the double slit, the interference fringes can be observed.

(D) Double-slit interference fringes of electrons, which can confirm the concept of probability distribution of matter waves.

（中文）以下關於雙狹縫實驗的敘述，何者正確？

(A) 利用雙狹縫可以觀察到光的干涉條紋，但無法觀察到電子的干涉條紋。

(B) 利用雙狹縫，可以觀察到一顆電子通過狹縫後的干涉條紋。

(C) 只要少數幾顆電子通過雙狹縫，即可觀察到干涉條紋。

(D) 電子的雙狹縫干涉條紋，可以證實物質波的機率分布概念。

解題 Solution：

雙狹縫干涉可以驗證波動性質，電子雙狹縫的干涉條紋需大量數以萬計的電子通過雙狹縫才能呈現。而一開始電子逐一通過，螢幕出現亮點則是電子的粒子性質。由電子束的雙狹縫實驗，可以驗證物質波的機率分布概念。

Double-slit interference can verify the nature of the wave. The interference fringes of the electron double-slit need a large number of thousands of electrons to pass through the double slit. At the beginning, the electrons pass through one by one, and bright spots appear on the screen, which is the particle nature of the electron. The concept of the probability distribution of matter waves can be verified by the double-slit experiment of the electron beam.

Teacher: Why can the phenomena of diffraction and interference verify the wave nature of the objects?

Student: Because the nature of particles cannot explain the diffraction and interference phenomena, which can only be explained by the wave theory.

Teacher: Are matter waves the same as water waves or sound waves? Are the matter waves of electrons the waves that transmit energy through electrons?

Student: No. Matter waves are not waves transmitted through matter.

Teacher: Very well, what the matter wave describes is the probability distribution concept of matter appearing in space. Can you explain the probability of a dice?

Student: The dice has 6 sides, and the probability of each side showing is $\frac{1}{6}$. If you only throw it three times, the same number may appear, but if you throw it many times, such as 30,000 times, then the number of times each number will appear will be nearly 5,000 times.

Teacher: How do you explain the probability distribution of electron double slits?

Student: A single electron hitting the screen will produce a bright spot, and the appearance of each bright spot is independent. However, after accumulating thousands of electrons, there will be a lot of bright spots in some positions on the screen, and a small number of bright spots in some positions, similar to the distribution of interference fringes. So the final interference pattern of electron double slit can explain the probability distribution of the matter wave of electrons.

Teacher: Very good, so which answer should we choose?

Student: D。

Teacher: Wonderful!

老師： 為何繞射及干涉現象，可以驗證該物體屬性為波動？

學生： 因為粒子性無法解釋繞射及干涉現象，只能以波動說解釋。

老師： 物質波跟水波或聲波，是相同的嗎？電子的物質波，就是藉由電子傳遞能量的波動？

學生： 不是。物質波不是藉由物質傳遞的波動。

老師： 很好，物質波描述的，是物質在空間出現的機率分布概念。可以舉一個骰子的機率說明看看嗎？

學生： 骰子有 6 面，每面出現的機率是六分之一，如果只擲三次，可能出現同一個數字，但是如果投擲次數非常多次，例如三萬次，那麼每個數字出現的次數會接近五千次。

老師： 那電子雙狹縫實驗的機率分布怎麼解釋呢？

學生： 單一顆電子打到螢幕會產生一個亮點，每個亮點的出現都是獨立的。但累積幾萬顆以上的電子後，螢幕就會出現某些位置特別多亮點，某些位置亮點數偏少，類似干涉條紋分布的樣貌。所以電子雙狹縫最後的干涉圖樣，可以解釋電子的物質波機率分布。

老師： 很好，所以答案要選哪個？

學生： D。

老師： 讚！

6-5 原子光譜
Spectra of Atoms

■ 前言 Introduction

本節介紹光譜的分類及其形成原因。再引入波爾之氫原子模型，來了解氫原子光譜實驗與理論吻合，進一步鞏固量子力學的發展。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
continuous spectrum	連續光譜	transition	躍遷
emission spectrum	發射光譜	ionization	游離化
absorption spectrum	吸收光譜	ground state	基態
line spectra	明線光譜	excited state	激發態
stationary state	穩定態	prism	三稜鏡
quantized	量子化的	assume(v.) assumption (n.)	假設

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

❶ correspond to _____

例句：A particular spectrum line **corresponds to** a certain light wavelength.
任一特定的光譜線，對應著特定的光波長。

❷ be produced by _____.

例句：Each isolated bright or dark line in the spectrum **is produced by** light emitted or absorbed by electrons.
光譜中每條獨立的亮線或暗線，都是由電子發射或吸收光產生的。

❸ be caused by _____

例句：Some certain absorption lines in the spectrum of the Sun **are caused by** the absorption in the Earth's atmospheric molecules.
太陽光譜中的某些吸收線，是由地球大氣分子的吸收所引起。

❹ _____ only when _____

例句：Radiation occurs **only when** an electron goes from the orbit in an excited state to another orbit of lower energy.
只有當電子從一個激發的軌道，進入另一個能量較低的軌道時，才會發生輻射。

■ 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 section, students should be able to know that:

一、認識原子光譜的分類及其特性。

Know the classification of atomic spectrum and their properties.

二、了解波耳氫原子模型的假說及能階的概念。

Understand the hypothesis of the Bohr hydrogen atomic model and the concept of energy levels.

例題講解

例題一

說明：瞭解原子光譜的特性。

To understand the properties of atomic spectra.

（英文）Figure 1 shows the emission spectra of hydrogen, helium, and mercury atoms. After observation, the three students expressed their opinions as follows:

Student A: Just as barcodes can be used to identify different commodities, the spectral lines produced by different atoms can be used to identify the types of atoms.

Student B: Different atoms produce different wavelengths of spectral lines, which is the main reason for the different colors of substances.

Student C: Atoms only emit spectral lines of specific wavelengths, which is evidence that atoms have discrete energy levels.

Whose statements are correct?

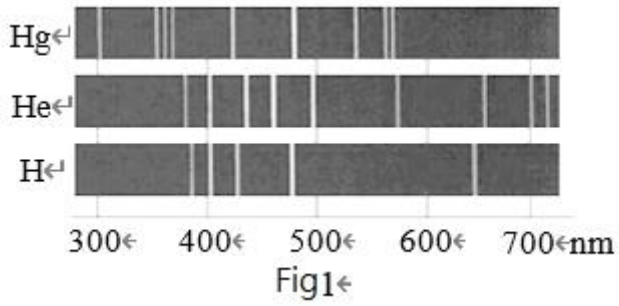

Fig1

(A) Only A (B) Only B (C) Only C **(D) Only A and C** (E) Only B and C

（中文）圖 1 為氫、氦、汞原子的發射光譜，三位同學觀察後發表見解如下：

甲生：正如條碼可用來辨識不同商品，不同原子產生的譜線，可用來辨識原子的種類。

乙生：不同原子產生的譜線波長不同，是物質呈現不同顏色的主因。

丙生：原子僅發射特定波長的光譜線，這是原子具有不連續能階的證據。

哪幾位同學的說法是正確的？

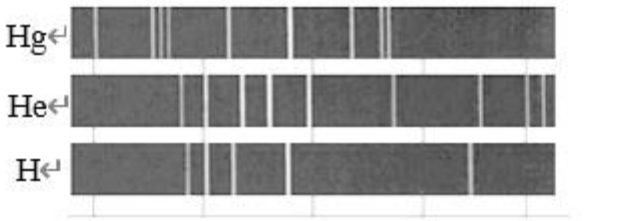

圖 1

(A)僅有甲　(B)僅有乙　(C)僅有丙　**(D)僅有甲丙**　(E)僅有乙丙

（108 年學測 7）

解題 Solution：

原子的發射光譜為特徵光譜，因為不同元素的原子譜線不一樣。任何元素的原子只能發射特定波長的光，且光子能量為兩能階之能量差。

The emission spectrum of atoms is a characteristic spectrum, since the spectral lines of different elements' atoms are different. Atoms can only emit light of a specific wavelength, and the photon energy is the energy difference between two orbits.

Teacher: What kind of spectrum are these diagrams? Are they emission spectrum or absorption spectrum?

Student: Emission spectrum.

Teacher: Yes, how can we get the emission spectrum?

Student: The light emitted by the thin and high-temperature gas is separated via dispersion of a prism.

Teacher: Yes, what can we know about the spectral lines emitted by these different atoms?

Student: Different atoms have different energy levels because of the different numbers of electrons and nuclear charges. Therefore, the spectral lines of different atoms are also different, just like the lines of different barcodes are different.

Teacher: Can Rutherford's hydrogen atom similar to planetary model theory explain these spectral lines?

Student: No, because the theory related to electromagnetic waves, there should be continuous spectral lines, not discrete spectral lines.

Teacher: Very good. Could Bohr's hydrogen atom model hypothesis explain these spectral lines?

Student: Yes.

Teacher: What did Bohr's hydrogen atom model assume?

Student: The first assumption is that electrons can only stay in specific orbits. The second assumption is that electrons absorb or emit light at the energy difference between orbitals when they transition from one orbital to another.

Teacher: Good! So does Bohr's hydrogen atom model correspond to discontinuous energy levels?

Student: Yes.

Teacher: So which students' statements are correct?

Student: A and C.

Teacher: Then which is the correct answer?

Student: D.

Teacher: Very good!

老師： 這個圖屬於哪種光譜?發射光譜或是吸收光譜？

學生： 發射光譜。

老師： 是的，我們可以怎麼得到發射光譜？

學生： 將稀薄高溫的氣體發出的光，經過稜鏡色散後分離。

老師： 沒錯，由這些不同原子發出的光譜線，我們可以知道什麼呢？

學生： 不同原子因為電子數及原子核帶電量不同，所以會有不同的能階，因此不同原子的光譜線也都不一樣，就像不同條碼的線是不一樣的。

老師： 那拉塞福的氫原子行星模型理論，可以解釋這些譜線嗎？

學生： 不行，因為依照電磁波理論，應該會是連續的譜線，而不是離散的譜線。

老師： 很好。那波耳的氫原子模型假說可以解釋這些譜線嗎？

學生： 可以。

老師： 波耳的氫原子模型假設了什麼？

學生： 第一個假設是，電子只能在特定的軌道運行。第二個假設是電子在不同軌道躍遷時，會吸收或釋放軌道能量差值的光。

老師： 很好，所以波耳的氫原子模型，可對應到不連續的能階現象嗎？

學生： 是的。

老師： 所以那些學生說法正確？
學生： 甲和丙。
老師： 所以正確答案是哪個？
學生： D。
老師： 很好！

例題二

說明：了解波耳氫原子模型，及對應的光譜線。
To understand the Bohr hydrogen atomic model and the corresponding spectral lines.

（英文）Which of the following statements about the Bohr hydrogen atom model is correct?
(A) Electrons can orbit in arbitrary radii.
(B) Electrons can only orbit in certain radii.
(C) Electrons can jump between different orbits.
(D) When an electron transitions in different orbits, it will definitely emit photons.
(E) When electrons transition in different orbits, the energy of the emitted photon is equal to the energy level difference between the two orbits.

（中文）以下關於波耳氫原子模型的敘述，何者正確？ (應選三項)
(A)電子可以在任意半徑的軌道運行。
(B)電子只能在某些特定半徑的軌道運行。
(C)電子可以在不同的軌道間躍遷。
(D)電子在不同軌道躍遷，一定會釋放光子。
(E)電子在不同軌道躍遷時，釋放的光子能量等於兩個軌道能階差值。

（自編）

解題 Solution：

了解波耳氫原子模型的假設，並推得氫原子發射光譜與氫原子能階的關係。
Understand the assumptions of the Bohr hydrogen atom model, and then derive the relationship between the emission spectrum of hydrogen atoms and the energy levels of hydrogen atoms.

Teacher: Could the scientists at the end of the 19th century determine the orbit of electrons?
Student: No.
Teacher: Can we know the structure of atoms through Rutherford's scattering experiment?
Student: It can be known that the positive charge is concentrated in the atomic nucleus in a

very small range, and the electrons move in the periphery.

Teacher: Very good! Is it easy to determine the position of electrons?

Student: No.

Teacher: So the orbits of electrons proposed by Rutherford are like planets orbiting the solar system, which can be in any radius. But Bohr put forward the hypothesis that electrons can only move in specific orbits. According to Bohr's hypothesis, the transition of electrons in two orbitals will release light of a specific wavelength. What is the relationship between the energy of this light and the two orbits?

Student: If a photon is released from a high energy level to a low energy level, the energy of the photon is equal to the difference between the two energy levels. To transition from a lower energy level to a higher energy level, a photon of energy equal to the energy level difference needs to be absorbed.

Teacher: So the transition may absorb photons or release photons?

Student: Yes.

Teacher: Which three should you choose as the answer?

Student: B, C, E.

Teacher: Right!

老師： 19 世紀末，科學家已經能確定電子的軌道了嗎？

學生： 不行。

老師： 通過拉塞福的散射實驗，可以知道原子的結構嗎？

學生： 可以知道正電集中在極小範圍的原子核，電子在外圍運動。

老師： 很好，那電子的位置容易確定嗎？

學生： 不容易。

老師： 所以拉塞福提出的電子軌道是像行星一般，可以在任意半徑。但波耳卻提出電子只能在特定的軌道運行的假設。根據波耳的假設，電子在兩個軌道躍遷，會釋放特定波長的光，這個光的能量跟兩個軌道有什麼關係？

學生： 如果從高能階，躍遷到較低能階會釋放光子，光子的能量等於兩能階的差值。如果從低能階躍遷到較高能階，那麼需要吸收與能階差值相等能量的光子。

老師： 所以躍遷可能會吸收光子也可能會釋放光子嗎？

學生： 是的。

老師： 那答案應該選哪三個呢？

學生： B、C、E。

老師： 答對了！

國內外參考資源 More to Explore

PBS LearingMedia 有科學類的影片，分年級分類別，推薦影片及提供影片內可詢問學生的問題，部分影片有閱讀材料。 https://www.pbslearningmedia.org/	
MIT opencourseware 此網站為 MIT 的開放式課程，包含講義及課程設計及實驗設計。 https://ocw.mit.edu/	
Khan Academy 可汗學院，有分年級的物理教學影片及有問題的討論。 https://www.khanacademy.org/	
Interactive Simulations, University of Colorado Boulder 互動式電腦模擬，除了物理，還有其他自然科。 https://phet.colorado.edu/	
Collection of Physics Experiments, Charles University in Prague 探究物理實驗設計及結果，並包含原理解說。 https://physicsexperiments.eu/en/physics	

PhysPort, PER	
物理教育研究資源庫，分享評量相關工具，包含迷思概念，情意成效，學習觀等。 https://www.physport.org/assessments/	
泛科學	
介紹自然科學相關的知識。 https://pansci.asia/	
ISLE Physics	
此網站是以設計給學生學習物理相關知識為目的。 https://www.islephysics.net/	

雙語教學資源手冊：物理科 英語授課用語

[十年級]

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

[10th grade]

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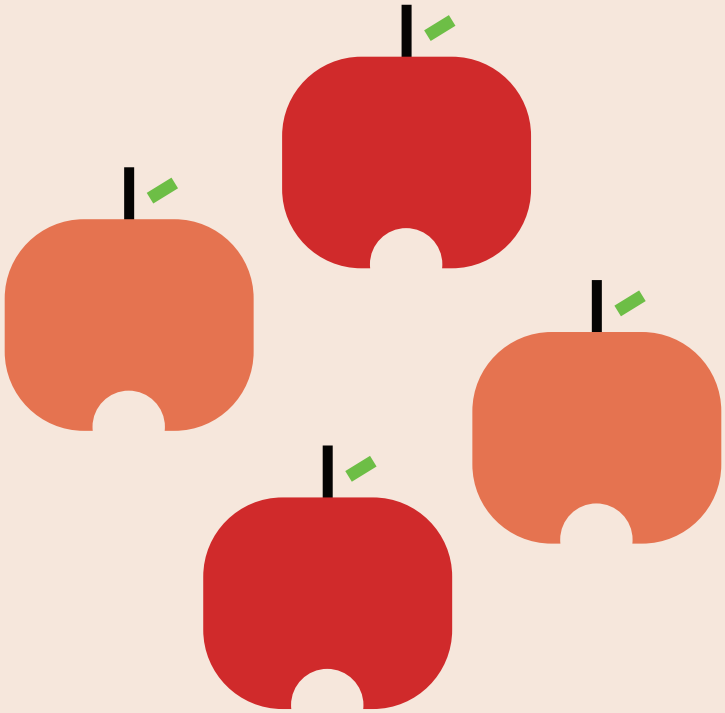

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