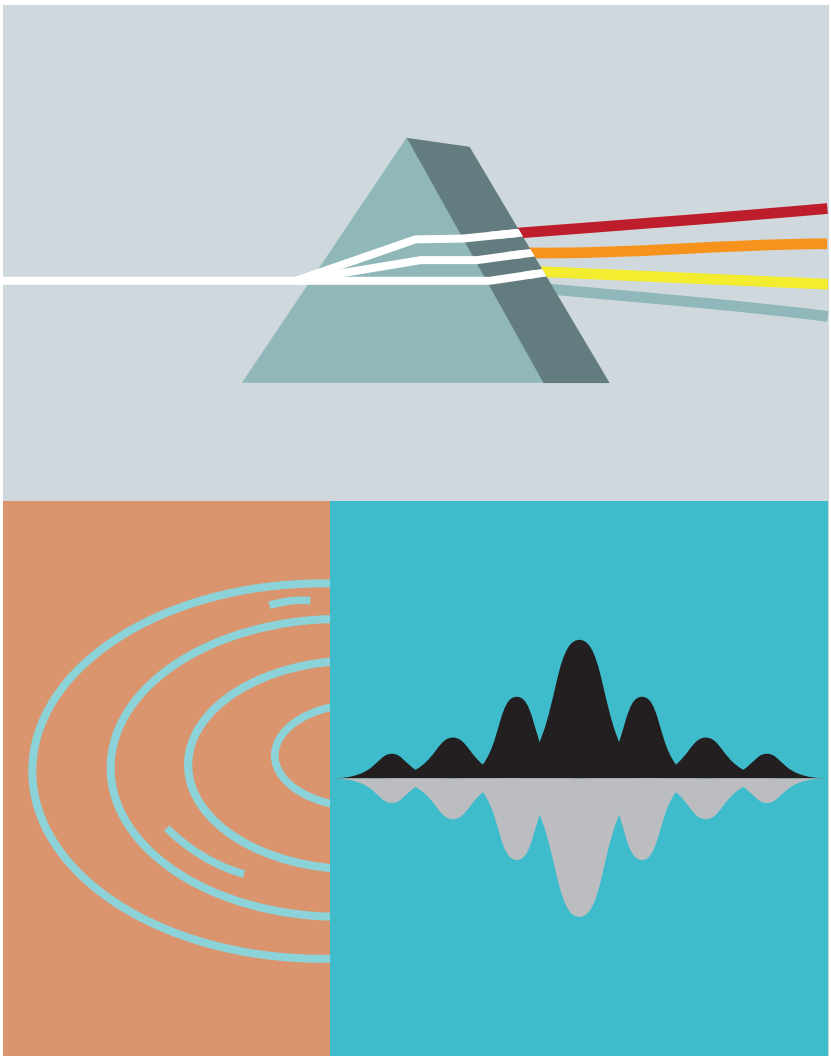
高中自然領域

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

〔高中選修(III)〕



國立彰化師範大學雙語教學研究中心 發行

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Wave

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■ 前言 Introduction

本章將介紹波動的基本概念，幫助學生理解不同類型的波及其主要特性，如波長、頻率、振幅和傳播方式。我們將探討水波、聲波、電磁波及地震波的特性，並分析它們在日常生活與科技應用中的重要性，例如聲音的傳播、光學現象、無線通訊及地震監測等。

此外，本章將透過實驗與圖像輔助教學，使學生能夠直觀地觀察波動的行為與影響。在雙語教學過程中，將適當引入英語專業術語，並透過對照與實例強化學生的理解，提升他們的科學素養與雙語能力。在雙語教學過程中，英語的使用應根據學生的語言能力適當調整。對於關鍵科學術語，如 "wave"（波）、"frequency"（頻率）、"amplitude"（振幅）等，應確保學生理解其含義，可以搭配實例或圖示進行說明。此外，可以透過對比中文與英語的表達方式，幫助學生理解專業詞彙的應用。

1-1 波的傳播
Propagation of Wave

■ 前言 Introduction

了解波動的基本特性，例如：波動可以傳遞能量但不能傳遞介質。並認識波動的種類，例如：依據傳遞時需要介質與否，分為力學波與電磁波；依據介質振動與傳遞方向之關係，可分為橫波與縱波兩種。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
characteristics of wave	波動的特性	medium	介質
direction of propagation	行進方向	propagation	傳播
direction of vibration	振動方向	rope wave	繩波
disturbance	擾動	tension	張力
electromagnetic wave	電磁波	transverse wave	橫波
energy	能量	wave speed	波速
frequency	頻率	waveform	波形
linear density	線密度	wave source	波源
longitudinal wave	縱波	water wave	水波
mechanical wave	力學波		

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

❶ _____ so that _____.

例句：The phenomenon where media are disturbed, affecting each other and transmitting energy, thus forming waves.
當介質因受到擾動，使其相互影響，進而傳遞能量，就形成波動。

❷ be classified into _____ based on _____.

例句：Waves **are classified into** transverse waves and longitudinal waves **based on** the distinction between the direction of medium vibration and that of wave propagation.
波動依「介質振動方向」與「波的行進方向」區分成橫波與縱波。

❸ _____ is perpendicular to_____.

例句：When the direction of medium vibration **is perpendicular to** that of wave propagation is called transverse wave.
「介質振動方向」垂直於「波的行進方向」：稱為橫波。

❹ _____ is parallel to _____.

例句：When the direction of medium vibration **is parallel to** that of wave propagation is called longitudinal wave.
「介質振動方向」平行於「波的行進方向」：稱為縱波。

❺ _____pass from _____ to _____.

例句：When wave **passes from** one medium **to** another, its frequency does not change.
波由一介質進入另一介質，頻率不會改變。

❻ the more _____ the more _____.

例句：**The more** the tension of the string is, **the faster** the wave velocity will be.
若弦線的張力愈大，波速就會愈快。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

一、了解波動會傳遞能量和動量，但介質本身不會傳遞。

To understand that waves involves the transmission of energy and momentum, but it does not transmit the medium itself.

二、認識波動可分成縱波與橫波，或力學波與電磁波，並能舉出生活中各種波動的實例。

To know that waves can be categorized as longitudinal and transverse waves, or mechanical and electromagnetic waves. And can give examples of each category from their daily life.

三、了解當波動由一介質進入另一介質時，頻率不會改變，但波速會改變的現象。

Understanding that waves can travel from one medium to another without changing its frequency, but the wave speed will change.

四、了解繩子波速與其張力與線密度有關，並能計算出波速。

Understanding that the wave speed of a rope is related to its tension and linear density, and can calculate it numerically.

例題講解

例題一

說明：了解橫波中介質如何振動。

To understand how media vibrate in transverse wave.

A periodic transverse wave travels in the horizontal direction on a thin rope, causing each point on the rope to undergo simple harmonic motion. At a certain moment, the waveform of a segment of the rope is shown in the diagram, where x and y represent the horizontal and vertical coordinates of each point (referred to as particles) on the rope, respectively. It is known that at this moment, the velocity of particle P is directed downward and its height is below the equilibrium position. As the wave continues to propagate, when particle P reaches the lowest point, which of the following statements is correct?

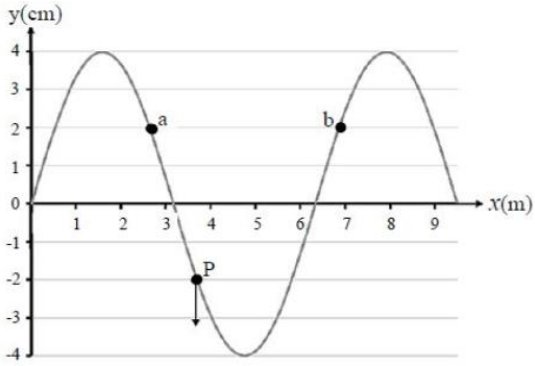
(A) y<0 for particle a　(B) y=0 for particle a　(C) y<0 for particle b

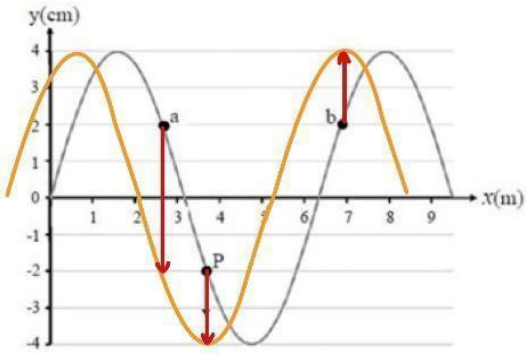
(D) y=0 for particle b　(E) Particle a reaches the highest point

一細繩上出現沿水平方向行進的週期性橫波，以致繩上各點均作簡諧振動，在某時刻其中一段的波形如圖所示，x 與 y 分 別代表繩上各點（簡稱質點）的水平位置坐標與垂直位置坐標，已知此時質點 P 的速度方向為垂直向下，高度低於其平衡位置。當波繼續行進，質點 P 位於最低點時，下列敘述何者正確？

(A) 質點 a 的 y<0　(B) 質點 a 的 y=0　(C)質點 b 的 y<0

(D) 質點 b 的 y=0　(E) 質點 a 到達最高點





（108 指考物理 6）

Teacher: This wave is transmitting, and particle P will reach the lowest point later. How will particles a and b move?

Teacher: First, I want to ask if particles a and b will propagate along with the wave or just vibrate nearby.

Student: Wave will transfer energy but not the medium, and this is a transverse wave. Therefore, the medium will vibrate up and down, perpendicular to the direction of wave propagation.

Teacher: That's correct. At this point, we can draw a wave shifting to the left or right that matches the waveform in the diagram to determine the direction of wave propagation. Since the problem states that particle P's velocity is downward, we can see that drawing a wave to the left corresponds to the downward displacement of particle P. This indicates that when the wave propagates to the left, particle P's velocity is indeed downward.

Student: Got it! So when particle P reaches the lowest point with downward vibration, I can draw a waveform moving about one meter to the left.

Student: Makes sense! Referring to the subsequent waveform, we can see that particle a vibrates downward, indicating a vertical displacement $y<0$. Particle b, on the other hand, will vibrate upward, indicating a vertical displacement $y>0$.

Teacher: Excellent reasoning! Therefore, for this problem, we choose option A.

老師： 這個波在移動且待會質點 P 點會到最低點，那介質 a 與 b 會如何移動呢？

老師： 首先我想問質點 a 與 b 會隨著波傳遞出去，還是在附近來回振動。

學生： 波會傳遞能量，但不會傳遞介質，而且此為橫波，因此介質會上下振動，垂直於波的傳遞方向。

老師： 沒錯，這時候我們可以向左或向右畫出一個與圖上相同的波形，來判斷波的傳遞方向。由於題目說質點 P 速度向下，可看出向左畫的波形可以對應到質點 P 向下的位移。表示波往左傳遞時，質點 P 的速度是向下。

學生： 瞭解！所以如果這時質點 P 向下振動到最低點，我可以畫一個向左移動約一公尺的波形。

學生： 有道理!對應到後來的波形，可以看出質點 a 向下振動，即垂直位移 $y<0$。而質點 b 會往上振動，即垂直位移 $y>0$。

老師： 很棒的推理分析！所以此題我們選擇答案（A）。

例題二

說明：了解影響繩波波速之變因，並能根據公式算出波速。

To understand the variables that affect the wave speed of ropes, and being able to calculate its numerical value based on the corresponding formula.

John fixed one end of the rope to a tree and oscillated the other end vertically while applying a horizontal tension of 200 Newton, disregarding any changes in the length of the rope.
The rope has a mass of 2.0 kilograms and a length of 4.0 meters. What is the wave speed of the rope?

小明將繩子的一端固定綁在樹上，並於另一端上下振動，且施予水平拉力 200 牛頓，並忽略繩子長度的變化。此為一質量 2.0 公斤、長度 4.0 公尺的繩子。求繩子波速為何？

Teacher: Do you know what factors are related to the wave speed of a rope?

Student A: I remember that if the rope is pulled tighter and the tension is greater, the wave speed of the rope will increase.

Teacher: That's correct. Are there any other factors?

Student A: I know! If the rope is lighter, the speed of wave propagation will be faster!

Student B: Wait, I think it's linear density. Isn't mass the same as linear density?

Teacher: Great observation! Let me remind you that the weight of the rope and linear density are not the same. Mass and density are different concepts. For example, metals and cotton can have the same mass, but the density of metal is greater than that of cotton. This illustrates that mass and density are different concepts!

Teacher: So, we need to calculate the linear density first, which is the amount of mass per unit length. Remember to use meters for length and kilograms for mass units, so that we could obtain the wave speed with the unit of m/s. Therefore, the linear density is μ=2.0/4.0=0.5 kg/m.

Student A: I understand! Finally, we can plug in the values into the formula for rope waves: $v = \sqrt{\frac{T}{\mu}}$, where the rope tension T=200 N and the linear mass density of the string μ=0.5 kg/m. Therefore, the wave speed is $v = \sqrt{\frac{200}{0.5}} = 20$ m/s.

老師： 你們知道繩子的波速和什麼物理量有關嗎？

學生 1： 我記得如果繩子拉越緊、張力越大時，繩子波速就會變快。

老師： 沒錯，還有什麼因素嗎？

學生 1： 我知道！繩子越輕的話，波傳遞的速度也會越快！

學生 2： 我怎麼記得是線密度，質量和線密度一樣嗎？

老師： 思考細膩！提醒各位同學，繩子的輕重和線密度是不一樣的。質量與密度是不同概念喔！同樣質量的金屬和棉花，但密度卻是金屬大於棉花，這說明了質量和密度是不同概念！

老師： 所以我們需要先計算出線密度，就是每單位長度有多少質量，長度單位記得要用公尺、質量單位用公斤，才能推得 m/s 的波速單位。所以線密度為 μ=2.0/4.0=0.5 公斤/公尺。

學生 1： 我會了！最後再帶入繩波公式: $v = \sqrt{\frac{T}{\mu}}$，其中繩子張力 T=200 牛頓，線質量密度 μ=0.5 公斤/公尺，所以繩子之波速$v = \sqrt{\frac{200}{0.5}} = 20$ 公尺/秒。

1-2 振動與週期波
Vibration and Sinusoidal Wave

■ 前言 Introduction

說明如何產生正弦波，以及正弦波所涉及的變因，例如：波長、頻率、週期、振幅、波速等，並解釋正弦波之波形在時間與空間中均呈現週期性。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
amplitude	振幅	period	週期
crest	波峰	simple harmonic motion	簡諧運動
displacement	位移	sinusoidal wave	正弦波
equilibrium position	平衡位置	tension	張力
frequency	頻率	trough	波谷
linear density of mass	質量線密度	wavelength	波長
pulse	脈衝（波）		

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

❶ refer to _____.

例句：In a sinusoidal wave, the point with the maximum positive displacement **refers to** the crest, and the point with the maximum negative displacement **refers to** the trough.
正弦波波形中，最大正位移處稱為波峰，最大負位移處稱為波谷。

❷ the distance from _____ to _____.

例句：The magnitude of the maximum displacement of medium is called amplitude, which is **the distance from** the equilibrium point **to** the crest or that to the trough.
介質中最大位移的量值稱為振幅，即平衡點到波峰或波谷的距離。

❸ the distance between two _____.

例句：**The distance between two** adjacent crests or two adjacent troughs is called wavelength.
相鄰兩個波峰或相鄰兩個波谷間的距離，稱為波長。

❹ thereby increasing _____

例句：When tightening a guitar string, its tension is increased, **thereby increasing** the wave speed along the string.
拉緊琴弦時，增加弦上的張力，藉此提高弦線之波速。

❺ greater _____ result in larger _____.

例句：When swinging the end of a rope with **greater** force, it **results in a larger** amplitude and transmits more energy with the wave, without increasing the wave speed.
手持繩子的一端上下甩力越大，造成的振幅越大，波所傳遞的能量越大，但不會提高波速。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、了解波動的傳遞，與介質振動的關係。

Understand the relation between the wave transmission and the vibration of the medium.

二、認識週期波的相關物理名詞，例如：波長、波速、週期、頻率等。

Know the physical terminologies related to periodical waves, such as wavelength, wave speed, period, frequency, etc.

三、了解週期波的波形，在時間與空間上均具有週期性。

Understand that the forms of periodic waves exhibit periodicity in both time and space.

四、能選擇並應用適當的公式來推算波速。

Can select and apply valid formulas to determine wave speed.

❧ 例題講解 ☙

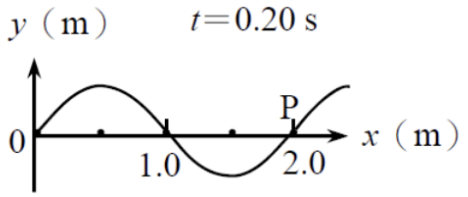
例題一

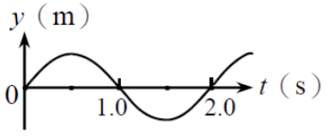
說明：了解週期波之波形，在時間與空間上均具有週期性。

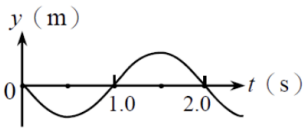
Understand that the forms of periodic waves exhibit periodicity in both time and space.

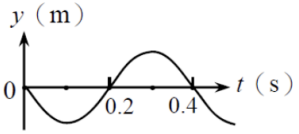
A sinusoidal wave travels along -x direction at speed of 5.0 m/s, causing a thin rope to vibrate in y direction. Let y represents the displacement of the thin rope from its equilibrium position. At t=0.2s, the displacements of various points on the rope are shown in the diagram below. The relationship between the displacement y of point P at x=2.0 m and the time t is depicted in the following figures. Which of the following figures is more correct?

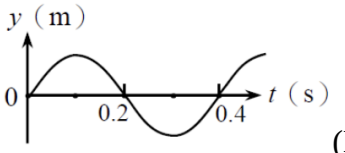
一列正弦繩波以 5.0 m/s 之速度，沿 −x 方向傳播時，以致質輕細繩沿著 y 方向振動。若以 y 代表細繩偏離平衡位置的位移，則在 t=0.2s 時，繩上各點的位移，如下圖所示，則在 x=2.0 m 處之 P 點的位移 y 隨時間 t 的變化關係，以下列何圖所示較為正確？

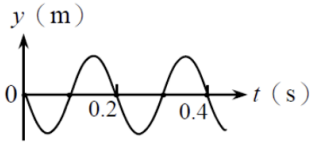


(A) 

(B) 

(C) 

(D) 

(E) 

（104 指考物理 17）

Teacher: In this chapter, you'll commonly come across two types of graphs regarding transmitting wave. The vertical axis always represent displacement of medium while the horizontal axis can represent position (displacement of wave) or time. The vertical axis represents the displacement of a particle from its equilibrium position. If the horizontal axis represents position, you can think of it as a photograph taken at a specific time.

Student: So, we can see that the wavelength is 2 meters according to the given diagram.

Teacher: That's right. Now, if the horizontal axis represents time, as all the options shown, it means that the particle at P is continuously oscillating up and down from the equilibrium point.

Student: So, we can read that the time taken for one complete oscillation from the x-axis, which is one period. For example, in option (A), the period is 2 seconds.

Teacher: Exactly! The problem provides us with the wave speed, and we also know the wavelength. Therefore, we can calculate the period of this wave. Because [wave speed(v) = wavelength(λ) /period(T)], the period T=λ/v= 2/5 = 0.4 seconds.
So, options (A), (B), and (E) can be eliminated.

Student: From the graph, we can also see that since the wave is travelling towards the direction of –x. As a result, the next moment after t=2.0s, point P will move above the equilibrium position.

Teacher: So, looking at option (C), in the next moment after t=2,0s, point P indeed moves upward. Therefore, it's crucial to note that the diagram provided in this question starts the discussion from t=0.2s!

老師： 波動單元常探討兩種關係圖，縱軸都代表介質的位置，橫軸可能代表位置（波的位移）或是時間。縱軸就代表質點偏離平衡位置的位移，如果橫軸代表位置時，關係圖相當於某個特定時間所拍出的一張照片 。

學生： 所以在題目給的那張圖中，可以看出波長為 2 公尺。

老師： 那如果橫軸是時間，像是選項中那些圖的話，就代表繩上某個質點在距離平衡點不斷上下振動。

學生： 所以我們可以看得出來，完整一次振動所花的時間，也就是週期。所以以選項（A）為例，週期就是 2 秒。

老師： 沒錯！那題目有給我們波速，我們也知道波長，所以可以計算出此波的週期，因為[波速(v)=波長(λ)/週期(T)]，所以週期 T=λ/v=2/5=0.4 秒。所以（A）、（B）、（E）項可以先刪除。

學生： 從圖中也可以看出因為波往-x 傳遞，所以在 t=0.2s 下一個瞬間，質點 P 會偏離平衡位置往上振動。

老師： 所以從選項（C）看到在 t=0.2s 下一個瞬間，P 點確實位移往上振動。所以要特別注意題目給的圖是從 t=0.2s 開始討論的！

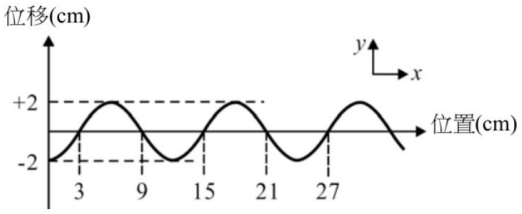
例題二

說明：認識週期波的物理名詞，例如：波長、波速、週期、頻率等，並能推算出波速。
Know the physical terms related to periodic waves, such as wavelength, wave speed, period, frequency, etc., and be able to derive the wave speed.

A continuous periodic wave is shown in the diagram below. If each particle on the thin rope oscillates up and down 12 times in its original position within a minute, which of the following statements is correct?

(A) The wavelength of this periodic wave is 15 cm.
(B) The amplitude of this periodic wave is 4 cm.
(C) The frequency of this periodic wave is 12 Hz.
(D) The wave speed of this periodic wave is 2.4 cm/s.
(E) It takes 18 seconds for this periodic wave to propagate from a position of 3 cm to a position of 27 cm.

一個連續的週期性繩波，如下圖所示，若細繩上的各質點在原位置每分鐘上下振盪 12 次，則下列敘述何者正確？



(A) 此週期波的波長為 15 cm。
(B) 此週期波的振幅為 4 cm。
(C) 此週期波的頻率為 12 Hz。
(D) 此週期波的波速為 2.4 cm/s。
(E) 此週期波由位置 3 cm 處傳播到 27 cm 處需時 18 s。

（101 指考物理 2）

Teacher: The first task of reading the diagram of wave is to figure out what the horizontal and vertical axes represent. Since both axes represent position, you can think of this diagram as a photograph. Can you find the wavelength and amplitude of the wave from the diagram?

Student A: Yes, we can directly determine the wavelength, which is 15−3 = 12 (centimeters).

Student B: And the amplitude is the distance from the equilibrium position to the crest or trough, so the amplitude should be 2 centimeters.

Student A: I know! If the rope is thinner, the wave will travel faster!

Student B: But, how can we determine the frequency from the diagram?

Teacher: We can't directly determine the frequency from the diagram. But you may derive the frequency from the statement of "each particle on the thin rope oscillates up and down 12 times in its original position within a minute."

Student A: I see! But the definition of frequency is how many times it oscillates per second, so the frequency is f=12/60 = 0.2 (1/sec = Hz).

Student A: And then, based on the frequency and wavelength, I can calculate the wave speed (v), which is the frequency (f) multiplied by the wavelength (λ), that is, v=f·λ=0.2·12 = 2.4 cm/s.

Teacher: Finally, since wave speed is constant, the time required to transmit is equal to the distance divided by the wave speed. For a wave with a speed of 2.4 cm/s, delivering a distance of 27 - 3 = 24 cm, how much time does it take?

Student B: It's just distance divided by wave speed to find the time! So the needed time is t=v/s=24/2.4 = 10 seconds.

老師： 觀察關係圖時，首先須確定橫軸與縱軸代表什麼，因為兩軸都代表位置，所以你可以把此圖想像成一張照片。從圖中，我們可以讀出波長及振幅各為何呢？

學生 1： 波長是 15−3=12 (公分)。

學生 2： 而振幅是看平衡位置到波峰或波谷之距離，所以振幅應該是 2 公分。

學生 1： 我知道！繩子越輕的話，波傳遞的速度也會越快！

學生 2： 那要怎麼從圖上知道頻率呢？

老師： 從這張關係圖應該看不出來頻率的，要從題目「細繩上的各質點在原位置每分鐘上下振盪 12 次」這句話得出！

學生 1： 了解！但是頻率的定義是每秒鐘振動幾次，所以頻率是 12/60=0.2(1/sec=Hz)。接著，有了頻率和波長，我可以計算出波速，波速(v)=頻率(f)·波長(λ)，也就是 v=f·λ=0.2·12=2.4(cm/s)。

老師： 很好，最後，因為波速保持固定，所以所需花的時間就等於距離除以波速即可，也就是波速為 2.4cm/s 的波，傳遞距離 27−3=24 公分，需要花多少時間呢？

學生 2： 就是距離除上波速就可以知道時間了！
所以需要花的時間(t) :t=v/s =24/2.4=10 秒。

1-3 繩波的反射與透射
The Reflection and Transmission of Rope Waves

■ 前言 Introduction

說明繩波為波動的一種實例，因此繩波在不同繩子中傳遞，就如同光波遇到不同介質，同樣會產生部分反射與部分透射的現象。並說明反射波、透射波與入射波之間的關係。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
fixed end	固定端	reaction force	反作用力
free end	自由端	reflection	反射
incident wave	入射波	transmission	透射

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

❶ reach _____first reflects first/reach ____ later reflects later.

例句：The part that **reaches** the endpoint **first reflects first,** while the part that **reaches** the endpoint **later reflects later.**

由先到達端點的部分先反射，後到達端點的部分後反射。

❷ _____ be bilateral symmetry with _____.

例句：The waveform of the reflected wave **is bilateral symmetry with** that of the incident waveform.

繩波之反射波與入射波形必左右對稱。

❸ _____ be relative to _____.

例句：The reflected waveform **is** flipped upside down **relative to** the incident waveform when transmitted from a lighter to a heavier rope.

若繩波由較輕的繩子傳到較重的繩子，則其反射波形相對於入射波形會上下顛倒。

❹ from _____ to _____.

例句：The incident wave travels **from** a heavier rope **to** a lighter rope just like achieving the free end, so the reflected waveform will not be inverted.

入射波由重繩往輕繩傳遞，就好像到達自由端，反射波形不會翻轉。

❺ be the same as_____.

例句：When a rope wave is incident on another rope of the same density, the properties of the transmitted wave **are the same as** those of the incident wave.

當繩波入射於相同密度的另一繩時，則透射波與入射波的各種性質均不改變。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、了解繩波傳到不同介質時，會發生部分反射與部分透射的現象。

Understand the phenomenon that when a rope wave transmits to different mediums, partial reflection and partial transmission occur.

二、分析入射波與反射波、透射波之間物理性質（例如:波速、頻率、波長、振幅）與波形（例如:上下顛倒、左右相反）的差異與相關性。

Analyze the differences and correlations in physical properties (such as wave speed, frequency, wavelength, amplitude) and waveform (such as upside-down, reversed) between incident waves, reflected waves, and transmitted waves.

三、了解波傳遞到自由端與固定端時，入射波與反射波的各種特性。

Understand the characteristics of incident waves and reflected waves when wave propagation reaches a free end or a fixed end.

四、了解繩波由重繩（線密度大）傳遞到輕繩（線密度小），反射波的特性可以視為波傳遞到自由端的效果。

Understand that when a heavy rope (high linear density) travels to a light rope (low linear density), the characteristics of the reflected wave can be considered as similar to those of the wave reaching a free end.

∞ 例題講解 ∞

例題一

說明：了解繩波在不同繩子（線密度）間傳遞的特性。

Understand the characteristics of rope wave propagating between different ropes (with different linear densities).

Ming created a pulse wave, which traveled from Rope A to Rope B. Observing that the waveform of the reflected wave and the incident wave are flipped upside down, which of the following descriptions is correct?

(A) The waveform of transmitted wave and the incident wave is an upside-down shape.

(B) The frequency of the reflected wave is the same as the frequency of the incident wave.

(C) The wavelength of Rope A is smaller than the wavelength of Rope B.

(D) The linear density of Rope A is greater than the linear density of Rope B.

(E) The mass of Rope A is greater than the mass of Rope B.

(F) The wave speed of Rope A is smaller than the wave speed of Rope B.

小明製造一個脈衝波，此波由甲繩傳遞至乙繩，觀察反射波與入射波波形為上下顛倒，則下列何者正確？

(A) 透射波與入射波波形上下顛倒。

(B) 反射波與入射波頻率相同。

(C) 甲繩波長小於乙繩波長。

(D) 甲繩線密度大於乙繩線密度。

(E) 甲繩質量大於乙繩質量。

(F) 甲繩波速小於乙繩波速。

Teacher: We know that since the reflected wave is flipped upside down, same as the wave encountered a fixed end, which means it traveled from a lighter rope to a heavier rope.

Student: Does that mean Rope A has less mass than Rope B?

Teacher: We are not sure. The heavy rope and the light rope only means larger and smaller linear densities. We only know that the linear density of Rope A is smaller than that of Rope B. Therefore, options (D) and (E) are incorrect.

Student: Regarding option (A), since the transmitted wave can be thought of as passing straight through, the waveform won't be flipped upside down or reversed left and right. This option is incorrect either.

Teacher: Exactly! The wave speed is equal to the square root of the tension divided by the linear density. In this case, Rope A is connected to Rope B, so the tension is the same. We can know that the wave speed is inversely proportional to the square root of linear density. As Rope A has lower linear density, we can infer that its wave speed is faster. Option (F) is incorrect.

Student: Teacher, I also know that the frequency is dependent only on the source of the wave, so the frequency of Rope A is equal to the frequency of Rope B. Option (B) is correct.

Teacher: That's right! When Rope A and Rope B are connected in series, their frequencies will be the same. Now, let's discuss the wavelengths in option (C). According to the formula of wave speed $v = f\lambda$, with fixed frequency, where the faster the wave speed (v) is (as in Rope A), the larger the wavelength (λ) will be. Therefore, option (C) is incorrect.

老師： 我們從反射波的波形上下顛倒，可以推測此繩波相當於遇到固定端，即由輕繩傳遞到重繩。

學生： 所以甲繩質量應小於乙繩嗎？

老師： 我們不確定喔，這邊的重繩與輕繩是代表線密度大小，僅知道甲繩線密度小於乙繩線密度，但無法確定繩子的總質量大小。所以（D）、（E）選項不正確。

學生： 關於（A）選項，因為透射波可以想成直接穿過去，所以波形不會上下顛倒也不會左右相反。因此，（A）也是錯誤的。

老師： 沒錯！而波速等於線密度除以繩上張力，再開根號。而甲繩與乙繩是串在一起，所以張力會相同，所以波速應該只與線密度開根號成反比。因為甲繩線密度較小，所以甲繩的波速較快，（F）是錯的。

學生：老師我還知道頻率僅由波源決定，所以甲繩頻率應等於乙繩。（B）選項正確。

老師：對的！所以串接起來的甲繩與乙繩，頻率會相同。那剩下（C）選項，波長的比較，由波速的公式 v=fλ，在頻率相同的情況下，波速越快的甲繩，波長也越大，所以選項（C）也是錯的。

例題二

說明：了解繩波傳遞到自由端與固定端的反射波特性。

Understand the characteristics of reflected waves when wave propagation reaches a free end or a fixed end.

A string is fixed at its left end and free to slide up and down at its right end. When t=0, a wave travels to the right as shown in diagram (A). After t>0, due to reflections at the endpoints, the first appearance order of the waveforms (B), (C), and (D) is: [Note:甲=A, 乙=B,丙=C,丁=D]

(A) BCD

(B) BDC

(C) CDB

(D) DBC

(E) DBC

一弦左端固定，右端可自由上下滑動。在 t=0 時，一波向右行進如(甲)圖所示。

則 t>0 後，由於波在兩端點的反射，下列(乙)、(丙)及(丁)各波形首次出現的先後順序為：

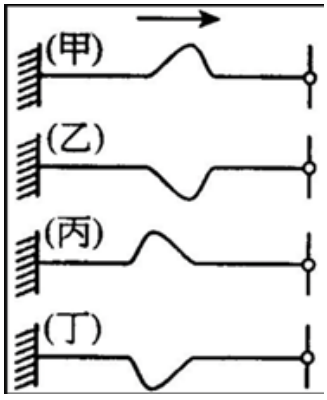
(A) (乙)(丙)(丁)

(B) (乙)(丁)(丙)

(C) (丙)(乙)(丁)

(D) (丙)(丁)(乙)

(E) (丁)(乙)(丙)



【80 日大】

Teacher: This pulse wave first meets a free end, so how should its reflected wave look like?

Student: Comparing with the incident wave, the reflected wave should be reversed left and right, but not flipped upside down. The wave is traveling to the left, and the waveform is steep on the left and gentle on the right. So, I think option (丙) would appear first.

Teacher: That's right. Next, the wave encounters a fixed end, and the earliest part reflects first. Therefore, the reflected wave's waveform will be reversed left and right, and the fixed end will provide an reaction force, causing it to be flipped upside down, which matches option (乙)

Student: And then, when the wave travels to the right and meets a free end again! So I know that the waveform is reversed left and right, but not flipped upside down.
Since the original displacement of the oscillation was a downward waveform, it will continue to move downward. Reversed left and right means steep on the left and gentle on the right, which is depicted in diagram (丁).

Teacher: Great, so the overall sequence is (丙)(乙)(丁), thus the answer is option (D).

老師： 這個脈衝波首先遇到自由端，所以它的反射波應該如何？

學生： 反射波與入射波相比，應該要左右相反，但上下不顛倒。波往左傳遞，且波形左邊陡峭右邊平緩，應該選擇(丙)。

老師： 沒錯，接下來波遇到固定端，先到先反彈，所以反射波波形一定會左右相反，而固定端會給繩波反作用力，所以上下顛倒，符合(乙)。

學生： 之後，波又往右傳遞遇到自由端！所以波形應左右相反，上下不顛倒。所以既然原本振動的位移就是向下的波形，一樣會維持向下。左右相反後左邊陡峭右邊平緩，也就是圖(丁)。

老師： 很好，所以整體順序為(丙)(乙)(丁)，答案應選(D)。

1-4 波的疊加原理
Principle of Superposition of Waves

■ 前言 Introduction

說明波動的疊加原理，並以繩波的干涉現象，透過繪圖方式加以解釋。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
interference	干涉	destructive interference	破壞性干涉
constructive interference	建設性干涉	speed of medium oscillation	介質的振動速度

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

❶ First _____, and then _____.

例句：When drawing a graph, **first** depict the individual waveforms of the two waves at a specific moment, **and then** find the respective displacements of each wave at that point. Then sum up their displacements, which represents the displacements of the composite wave at various points.

繪製圖形時，先把兩個波在某時刻的個別波形畫出，再將兩個波在該處的位移加總繪出，即為合成波在各點之位移。

❷ **_____ do not change after _____.**

例句：The independence of waves means that the waveform, wave speed, frequency, period, and wavelength **do not change after** two waves interfere with each other.
波的獨立性為兩波交會後的波形、波速、頻率、週期、波長，不會因疊加過程而發生改變。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、了解線性波的疊加原理，並能繪製與計算出疊加後的位移與波速。
Understand the principles of linear wave superposition and be able to depict and calculate the superposition of displacement and wave velocity.

二、了解波動的獨立性是疊加原理的依據。
Understand that the superposition principle is based on the independence of waves.

三、認識波的干涉，可分為建設性及破壞性干涉兩種。
Know that wave interference may be categorized as constructive and destructive interferences.

例題講解

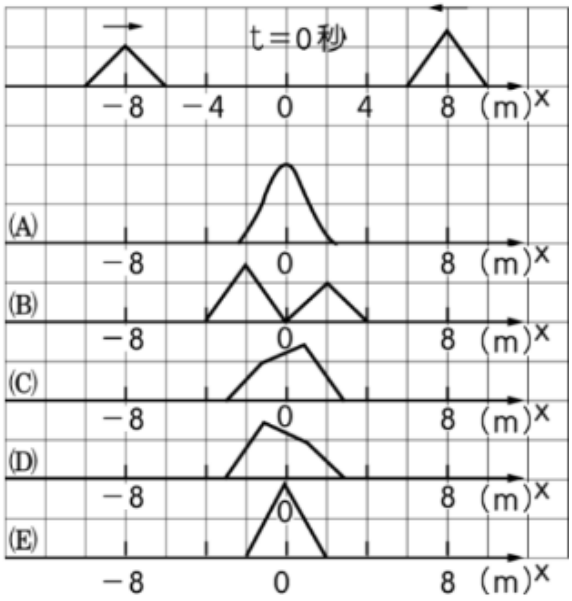
例題一

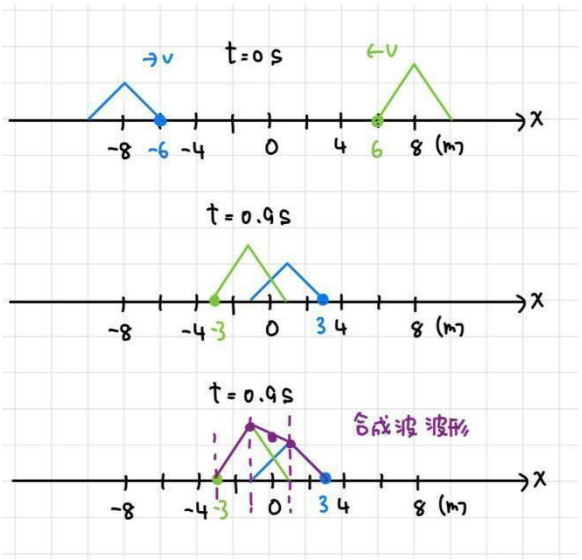
說明：了解波的疊加原理，並能繪製出合成波波形。

Understand the principle of wave superposition and be able to depict the waveform of composite waves.

When t=0, two unequal-height pulse waves are traveling in opposite directions on a taut rope, as shown in the diagram. Given that the wave speed on the rope is 10 m/s, which of the following describes the shape of the rope wave at t=0.9 seconds? **Ans:(D)**

時間 t=0 秒時，在一條拉緊的長繩上有兩個不等高的脈衝波分別向左及向右行進，如圖所示。已知繩波的波速為 10m/s，則在 t=0.9 秒時，繩波的形狀為下列何者？ **答案: (D)**





（93 指考物理 4）

Teacher: When it comes to the superposition of two waves, the first step is to plot the height of each wave individually, and then sum up their displacements respectively.

Student: So, we can start by looking at the wave on the left. At 0.9 seconds, both waves travel a distance of $0.9 \cdot 10 = 9$ meters. Therefore, the front end of the left wave, originally at -6 meters, will move to the 3-meter position after traveling 9 meters to the right. Next, the tail end of the left wave, initially at −10 meters, will be at the −1-meter position after moving 9 meters to the right.

Teacher: That's correct. The wave on the right originally had its front end at +6 meters, so it will be at the −3-meter position after moving 9 meters to the left. And its tail end, initially at +10 meters, will be at the +1-meter position after moving 9 meters to the left. So, we first draw the new positions at t=0.9 seconds following the original wave shapes, and then we consider the superposition of the waves. Since a linear superposition remains a straight line, the segments from −1m to 1m are still linear after superposition.

Student: I see, so we can divide it into three regions: −3m to −1m, −1m to 1m, and 1m to 3m, to discuss the appearance after wave superposition.

Teacher: That's right. Let's start with −3m to −1m. In this region, there's only one wave, so it maintains its original shape, with an amplitude of approximately 1.5 meters.

Student: Moving to the -1m to 1m region, because at 0 meters the oscillating displacement of the waves are about 0.6 meters, when superimposed, it adds up to around 1.2 meters.

Teacher: Exactly! In the range from 1m to 3m, there's only one wave, so no need to superimpose; it maintains its original waveform of each wave.

Student: So, the final result after superposition, when connected with a straight line, will resemble as option (D) in the diagram.

老師： 對於兩個波的疊加，第一步我們可以先畫出個別波的震動位移，第二步再進行兩者位移的疊加。

學生： 所以我們可以先看左邊的波。0.9s 兩波各自前進 0.9·10=9m 的距離。所以左邊波前端本來在−6m 位置往右走 9m 就會在 3m 的位置。再來，左邊波尾端本來在−0m 的地方往右走 9m 就會在−1m 的地方。

老師： 沒錯，右邊那個波的波前原本在+6m，往左走 9m，就會在−3m 的地方。而尾端原本在+10m，往左走 9m 就會在+1m 的地方。所以波形先照原本的樣子畫出 t=0.9s 時的新位置，再來看波的疊加。由於直線疊加後一定也是直線，所以−1m~1m 中，兩段直線疊加後仍是直線。

學生： 原來如此，所以我們可以分成，−3m~−1m、−1m~1m、1m~3m 三個區域，討論波疊加後的樣子。

老師： 是的唷，先看−3m~−1m，因為只有一個波所以維持原樣，振幅大概在 1.5m 處。

學生： 再看-1m~1m 區域，因為 0m 處兩個波，位移大概是 0.6m，所以疊加之後是兩個加起來，大概在 1.2m 的高度。

老師： 對的！後面 1m~3m 也只有一個波，所以不用疊加，只維持單一的波形。

學生： 所以最後疊加之後的結果，用直線連接，就會是圖（D）的樣子。

1-5 駐波
Standing Wave

■ 前言 Introduction

說明駐波也是透過波動的疊加原理而推得，以及駐波在生活中的運用。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
antinode	腹點	standing wave	駐波
node	節點		

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

❶ between two _____/between A and B

例句：**The distance between two** adjacent antinodes is half of a wavelength, and so as **the distance between two** adjacent nodes.

相鄰兩腹點之間的距離為波長的一半，也相當於相鄰兩節點間的距離。

❷ twice/two times

例句：The amplitude of standing wave is **twice** of that of its incident wave.

駐波之振幅，為原入射波振幅的 2 倍。

❸ remain _____/continually_____

例句：With respect to standing wave, nodes **remain** stationary; antinodes **continually** oscillate, undergoing simple harmonic motion with maximum amplitude.
對駐波而言，節點維持不動；而腹點則一直振盪，以最大振幅做簡諧運動。

❹ _____, forming _____（分詞構句）=and a fixed end forms

例句：A fixed end remains stationary**, forming** a node in standing wave, while a free end is free to move, forming an antinode of the standing wave.
固定端固定不動，形成駐波的節點，而自由端自由運動，形成駐波的腹點。

❺ the first _____, the second _____, the third _____, and so on/and so forth.

例句：When the oscillation frequency is an integer multiple of the fundamental frequency, they are respectively called **the second** harmonic, **the third** harmonic, and **so on**, or also referred to as **the first** overtone, **second** overtone, **and so forth**.
振動頻率為基頻之整數倍時，依序稱為第二諧音、第三諧音等，或依序稱為第一泛音、第二泛音等。

❻ the + 最高級

例句：In a standing wave, **the lowest** vibration frequency corresponding to **the lowest** pitch.
駐波中最小的振動頻率，對應到最低的音調。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、說明形成駐波的條件與其性質。

To explain the condition of generating standing waves, and its characteristics.

二、說明波腹與波節的定義與性質。

To describe the definition and features of antinode and node.

三、說明基音與泛音，包含形成駐波時，繩長、波長與頻率的關係。

To explain the concepts of fundamental frequency and harmonics, specifically the relationships between the length of the rope, wavelengths, and frequencies in the standing waves.

❧ 例題講解 ☙

例題一

說明：由駐波的波形，推論繩長與波長的關係。

To calculate the relationship between rope length and wavelength in a standing wave.

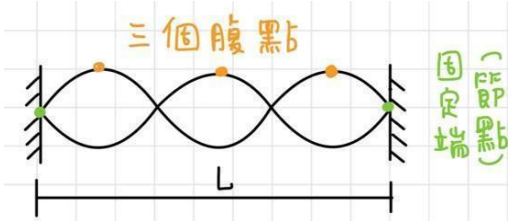
Tighten a uniform thin rope, fix it at two points separated by L. When three antinodes are formed on the rope, what is the wavelength of the standing wave?

(A) $\frac{1}{3}$ L　**(B) $\frac{2}{3}$ L**　(C) L　(D) $\frac{3}{2}$ L　(E) 3L

將一均勻的細繩拉緊，兩端固定於相距為 L 的兩點。當細繩上形成的駐波有三個腹點時，駐波的波長為何？

(A) $\frac{1}{3}$ L　**(B) $\frac{2}{3}$ L**　(C) L

(D) $\frac{3}{2}$ L　(E) 3L



（105 指考物理 2）

Teacher: First, let's draw a diagram of the standing wave according to the problem. The fixed ends on both sides should be nodes, and there should be three wave crests in the middle. The distance between adjacent nodes is half a wavelength, which is the distance of one wave packet.

Student: There are three wave envelopes in the diagram, so the rope length L is three times of a half wavelength.

Teacher: Exactly! We can write the equation $L = \frac{3}{2}\lambda$, and rearranging it gives $\lambda = \frac{2}{3}L$. Therefore, our answer is option (B).

老師：首先我們根據題意，來畫一下此駐波的示意圖，左右兩邊固定，所以是節點，中間要有三個腹點。因為相鄰兩節點間的距離是半個波長，也就是一個波包的距離。

學生：圖中有三個波包，所以繩長 L 相當於半個波長的三倍。

老師：沒錯！可以列出式子 $L = \frac{3}{2}\lambda$，而移項後可以得到 $\lambda = \frac{2}{3}L$，所以我們答案選（B）。

例題二

說明：計算駐波中，繩長與特定頻率的關係。

To calculate the relationship between the rope length and specific frequencies in a standing wave.

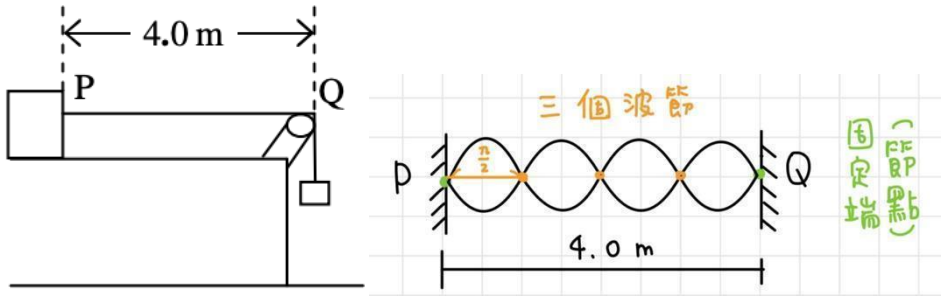
As shown in the diagram, a 5.0m long uniform thin rope with a mass of 0.010kg is attached at one end to the fixed exciter point P on the table. At the other end, it passes through a smooth fixed pulley Q and suspends a weight of 1.0kg. The distance between P and Q is exactly 4.0m. Adjust the vibration frequency of the exciter until three distinct standing wave nodes (excluding the nodes P and Q) are formed between PQ.

If the speed of the rope wave is equal to $\sqrt{\frac{T}{\mu}}$, where T and μ are the tension and linear density of the rope, respectively, what is the vibration frequency of the exciter at that time?

(A) 3 Hz　(B) 10 Hz　**(C) 35 Hz**　(D) 41 Hz　(E) 140 Hz

如圖所示，長 5.0m 的均勻細線，質量為 0.010kg，一端繫於固定在桌上的起振器 P 點，另一端經光滑的定滑輪 Q，懸掛質量為 1.0kg 的重物，PQ 間恰好是 4.0m。調整起振器的振動頻率，直到 PQ 間產生三個清楚的駐波波節（不含 P、Q 兩節點）為止，若繩波的速率等於 $\sqrt{\frac{T}{\mu}}$，其中 T 及 μ 分別為繩之張力及線密度，則當時起振器的振動頻率為若干？

(A) 3 Hz　(B) 10 Hz　**(C) 35 Hz**　(D) 41 Hz　(E) 140 Hz



（98 指考物理 15）

Teacher: There are three wave nodes between the fixed ends, indicating that there are four wave packets, as shown in the above figure. So the rope length of 4m is four times of half the wavelength, or two times of the wavelength.

Student: So, one wavelength is equal to 4m divided by 2, which is 2m.

Teacher: Exactly! Now that we have the wavelength, what formula do we use to find the frequency?

Student: We use the formula of wave speed v=f·λ. If we know the wave speed and divide it by the wavelength, we get the frequency.

Teacher: Excellent! Now, how do we determine the wave speed of the rope?

Student: The question mentions that the rope wave speed is $v = \sqrt{\frac{T}{\mu}}$. Now, the tension in the rope can be determined by the weight of the hanging mass, which is 1.0kg and equals 9.8N. The linear density of the rope is the mass of the rope (0.010kg) divided by the rope length (5m), which is 0.002kg/m. Finally, we substitute these values into $v = \sqrt{\frac{T}{\mu}}$, so the rope wave speed is 70m/s.

Teacher: We're almost there! Now, take the wave speed we just obtained, 70 m/s, and divide it by the wavelength of the standing wave 2m. We get the standing wave frequency of 35 Hz, so the answer is option (C).

老師：兩邊固定端中間有三個節點，表示說有四個波包(如上圖所示)，也就是繩長 4m 等於半波長的四倍，相當於兩個波長。

學生：所以，一個波長就等於 4m 除以 2，也就是 2m。

老師：的確！那有波長之後，要用什麼式子得知頻率？

學生：用波速公式: v=f·λ，只要知道波速，再用波速除以波長就是頻率。

老師：很好唷！那我們如何得知繩波的波速呢？

學生：題目有說繩波波速為$v=\sqrt{\frac{T}{\mu}}$，現在繩張力的大小，等於重物重量大小為 1.0kgw 也就是 9.8N。繩的線密度為繩的質量 0.010kg 除以繩長 5m，也就是 0.002kg/m。最後再帶入$v=\sqrt{\frac{T}{\mu}}$，所以繩波波速為 70m/s。

老師：到最後一步了！把剛剛得到的波速 70 m/s 除以此時駐波波長 2m，就得到駐波頻率為 35 Hz，答案選（C）。

1-6 惠更斯原理
Huygens Principle

■ 前言 Introduction

說明利用惠更斯原理可以推測下一個時刻的波前形狀變化，與波的行進方向。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
Huygens principle	惠更斯原理	point source	點波源
in-phase wave	同相的波	spherical wave	圓形波
plane wave	平面波	wavefront	波前

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

❶ A is perpendicular to B.

例句：Wavefront **is perpendicular to** the direction of wave propagation, so the direction of the wave propagation can be determined by observing the shape of the wavefront.
波前垂直於波的行進方向，因此觀察波前形狀，可以判斷波的行進方向。

❷ generated by _____

例句：The waveform of a spherical wave is concentric circles, usually **generated by** a point source.

圓形波的波形是同心圓，通常由點波源所產生。

❸ If_____, it will _____.

例句：**If** you lightly tap the surface of water with a ruler**, it will** create a plane wave.

若你拿一根尺在水面上輕敲，就可形成平面波。

❹ the + 比較級 …, the + 比較級

例句：**The greater** the difference in water depth, **the greater** the difference in water wave speed, and **the more noticeable** the refraction of the water wave.

水深差距越大，水波速度差距就越大，同時水波的折射也越明顯。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、了解波前的定義。

Understand the definition of wavefront.

二、了解惠更斯原理，並能以此判斷波的傳播方向。

Understand Huygens Principle and be able to determine the direction of wave propagation by using it.

☙ 例題講解 ❧

例題一

說明：了解波前的定義，並知道波的行進方向與波前垂直。

To understand the definition of wavefront, and know that wavefront is perpendicular to the direction of wave propagation

In an experiment in a water wave tank, when water wave enters from shallow water area with depth of 1 cm into deep water area with depth of 2 cm, refraction occurs at the boundary between the shallow and deep water. Assuming that both the water depths and the amplitudes of the water waves are much smaller than the wavelength, so that the square of the wave speed is proportional to the water depth, which of the following statements is correct?

(A) If the angle of incidence is 30 degrees, the angle of refraction is 45 degrees.
(B) If the angle of incidence is 30 degrees, the angle of refraction is 53 degrees.
(C) If the angle of incidence is 45 degrees, the angle of refraction is 60 degrees.
(D) If the angle of incidence is 53 degrees, the angle of refraction is 30 degrees.
(E) If the angle of incidence is 60 degrees, the angle of refraction is 45 degrees.

在一項水波槽實驗中，當水波由深 1 公分的淺水區入射至深 2 公分的深水區時，在淺水區與深水區的交界處發生折射現象。假設水深與水波的振幅都比波長小得多，以致水波的波速平方與水深成正比，則下列敘述何者正確？

(A) 若入射角為30°，則折射角為45°。
(B) 若入射角為30°，則折射角為53°。
(C) 若入射角為45°，則折射角為60°。
(D) 若入射角為53°，則折射角為30°。
(E) 若入射角為60°，則折射角為45°。

（106 指考物理 7）

Teacher: Remember we examined the law of refraction $\frac{\sin\theta_1}{\sin\theta_2}=\frac{v_1}{v_2}$ from the water tank experiment. The question also mentions that the square of the water wave's speed is proportional to the water depth. Thus, we can determine that the ratio of water speeds between the shallow and deep areas is $1:\sqrt{2}$.

Student: Got it, so we can get $\frac{\sin\theta_1}{\sin\theta_2}=\frac{1}{\sqrt{2}}$. We can calculate the ratio of sin of the angles of incidence and refraction in the options. If it is $\frac{1}{\sqrt{2}}$, those would be the possible angles in this water wave tank.

Teacher: Exactly! So in option A, $\frac{\sin\theta_1}{\sin\theta_2}=\frac{1}{\sqrt{2}}$, which is the answer we're looking for.

老師： 還記得我們從水波槽實驗，觀察折射定律 $\frac{\sin\theta_1}{\sin\theta_2}=\frac{v_1}{v_2}$。題目又說水波的波速平方與水深成正比。可以知道淺水區與深水區水速比是 $1:\sqrt{2}$。

學生： 了解，所以可以推出 $\frac{\sin\theta_1}{\sin\theta_2}=\frac{1}{\sqrt{2}}$ ，那我們去計算選項中入射角與折射角的正弦比值，如果是 $\frac{1}{\sqrt{2}}$，就會是這個水波槽可能出現的入射角與折射角。

老師： 沒錯！所以（A）選項中 $\frac{\sin 30^\circ}{\sin 45^\circ}=\frac{1}{\sqrt{2}}$ 就是我們要的答案了。

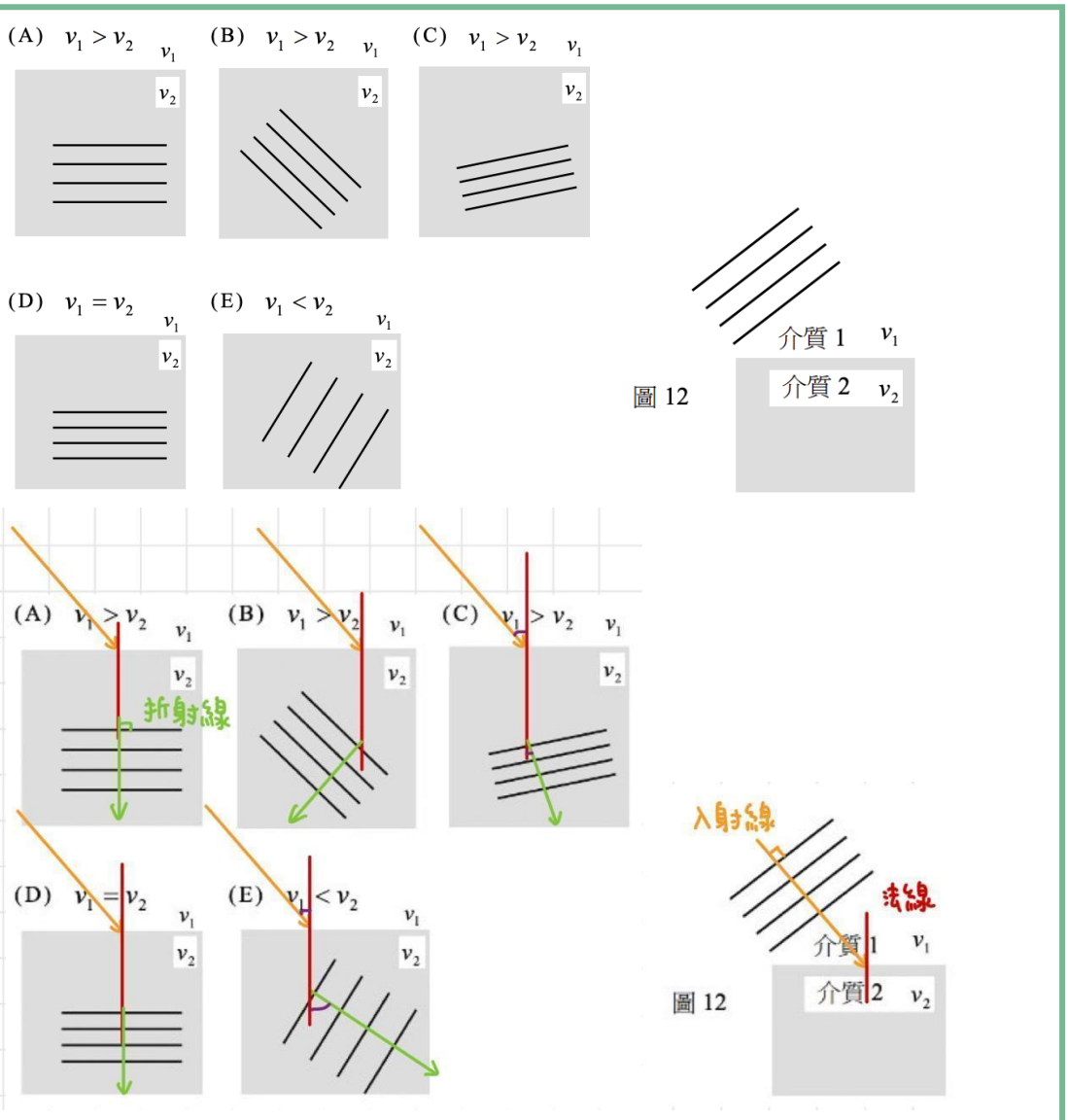
例題二

說明：了解惠更斯原理，並能以此判斷波的傳播方向。

Understand Huygens Principle and be able to use it to determine the direction of wave propagation.

The propagation speeds of the wave in the two media in Figure 12 are denoted as and, respectively. The straight line in the figure represents part of the wavefront of this wave. If the wave propagates from medium 1 through the interface into medium 2, which of the following could be the propagation mode of the wave in medium 2? **Ans: (C) (E)**

圖 12 中波動在兩介質中的傳播速率分別為v_1與v_2。圖中直線代表此波動的部分波前。若波動由介質 1 經過界面傳播進入介質 2，則下列何者可能為該波動在介質 2 的傳播方式？ **答案: (C) (E)**



（95 指考物理 16）

Teacher: Let's start by drawing the path of the wave propagation, which is the line of incidence, in Figure 12.

Student: I know that the line of incidence is perpendicular to the wavefront. And the arrow on the line goes from 1 to 2 because it's going from medium 1 to medium 2.

Teacher: Exactly, so let's draw the incident and normal lines for each option and then determine if the refracted lines make sense.

Student: Okay, and the refracted line is also perpendicular to the wavefront. For options A, B, and D, the incident and refracted lines are not on opposite sides of the normal line, so they don't make sense.

Teacher: Very good! What about option C? Does the refracted line bending toward the normal line make sense?

Student: I know the distance between two wavefronts is the wavelength. Since the wave speed equals the wavelength times the frequency ($v=f \cdot \lambda$), and the frequency doesn't change when the medium changes, a longer wavelength means a higher wave speed. So, option C is going from a faster to a slower medium.

Teacher: That's correct! So, in this case, the refracted angle will be smaller than the incident angle, meaning the refracted line bends toward the normal. Option C is correct.

Student: And for option E, with the larger wavelength, it indicates going from a slower to a faster medium. So, the refracted line will deviate from the normal, as shown in diagram E. Thus, option E is correct as well.

老師： 我們先在圖 12 畫出波動前進的路徑，也就是入射線。

學生： 我知道入射線與波前垂直，且線上箭頭由 1 指向 2，因為是由介質一入射到介質二。

老師： 沒錯，所以我們先畫出每個選項的入射線和法線，再來判斷折射線合不合理。

學生： 好的，而且折射線也是與波前垂直。那（A）、（B）、（D）選項入射線和折射線沒有在法線的兩邊，所以不合理。

老師： 很好唷！那（C）選項，折射線會偏向法線，合理嗎？

學生： 我知道兩波前之間的距離為波長。由於波速等於波長乘以頻率($v=f \cdot \lambda$)，f 且頻率不會因為介質而改變，所以波長越長，波速就越大。所以（C）是由介質是由波速快到慢的。

老師： 沒錯！所以這時候折射角會比入射角小，也就是折射線偏向法線。（C）選項正確。

學生： 那（E）選項由波長較大看出，是由波速慢到快的區域。所以折射線會偏離法線，如同圖（E）所示，所以也是正確的。

1-7 水波的干涉
The Interference of Water Wave

■ 前言 Introduction

說明利用惠更斯原理可以推測下一個時刻的波前形狀變化，與波的行進方向。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
central antinodal line	中央腹線	ray	射線
concave lens	凹透鏡	stroboscope	閃頻器
convex lens	凸透鏡	variable resistor	可變電阻
first nodal line	第一節線	vibration source	振動源
hyperbola	雙曲線	apparent wavelength	視波長
path difference	路程差	water wave tank	水波槽
perpendicular bisector	中垂線		

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

❶ Is equivalent to _____.

例句：Water surface bulge **is equivalent to** a convex lens, which can converge light rays and form bright fringes on the white paper.
水面凸起處相當於凸透鏡，可會聚光線，並在白紙上形成亮紋。

❷ depend on _____

例句：When two waves overlap at a certain position on the water surface, their amplitudes either increase or decrease, **depending on** the phase differences between the two waves.
當兩個波在水面上的某位置疊加時，其振幅可能增加或減少，取決於兩個波的相位差。

❸ are respectively called _____.

例句：Path differences of one wavelength and two wavelengths between two waves **are respectively called** the first and second antinodal lines.
兩個波動，路程差為一波長、二波長者，分別稱為第一腹線、第二腹線。

❹ cause sb to + VR

例句：Each ventral point on the ventral line vibrates up and down over time, **causing** them **to** appear bright or dark on the screen.
腹線上的每個腹點都隨時間上下振動，使它們在屏幕上時而亮，時而暗。

❺ be projected

例句：The reflection phenomenon of water waves in the water tank can **be projected** onto a white paper through the illumination of light.
利用光的照射，將水波槽裡水波的反射現象，投影到地上的白紙上。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、了解波的干涉。

Understand the interference of waves.

二、了解造成腹線與節線的波程差之條件。

Understand the conditions of path difference causing antinodal lines and nodal lines.

三、了解水波槽實驗儀器架設與使用方式，並解釋水波的反射、折射與干涉現象。

Understand the setup and usage of the water wave tank experiment apparatus, and explain the phenomena of water wave reflection, refraction, and interference.

❧ 例題講解 ☙

例題一

說明：解釋水波槽實驗中的折射現象。

Explain the phenomenon of refraction in water wave tank experiment.

Regarding the "Water Wave Tank Experiment" apparatus shown in Figure 1, which of the following statements is correct?

(A) The purpose of the rectangular wooden strip wave generator is to produce circular waves.

(B) The variable resistor is to adjust the current in order to change the intensity of the light.

(C) The distance between adjacent bright fringes displayed on the white paper is exactly equal to the wavelength of the water waves.

(D) The water wave tank needs to be surrounded by sponge strips to prevent a change in the frequency of water waves.

(E) When the troughs of water waves pass through strong light, they act like a concave lens, revealing dark fringes on the white paper.

在圖 1 所示的「水波槽實驗」裝置中，下列關於其分項裝置的敘述，何者正確？

(A) 長方形木條起波器的目的是要產生圓形波。

(B) 可變電阻是用來改變電流，以調整光照的強度。

(C) 白紙上顯示的相鄰兩亮紋間距，恰等於水波的波長。

(D) 水波槽的四周需用海綿條圍住，以避免水波頻率改變。

(E) 水波的波谷在強光通過時，會有類似凹透鏡的效果，在白紙上顯現出暗紋。

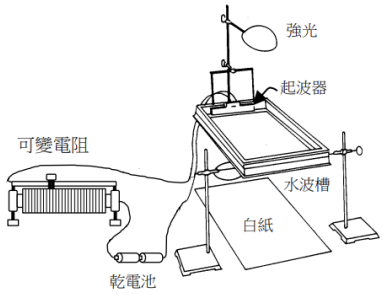


圖 1

（108 指考物理 4）

Teacher: We've introduced the setup and usage of the water wave tank. Let's see which option is correct.

Student: I know the rectangular wooden strip is used to generate straight waves! A is incorrect.

Teacher: We mentioned earlier that the variable resistor is for adjusting the frequency of the wave generator. B is incorrect either.

Student: I remember if the light source is not parallel but a point source, the apparent wavelength shown on the white paper will be magnified.

Teacher: Exactly! It has a multiple relationship with the actual wavelength. So C is incorrect.

Student: The sponges are used in the experiment to prevent the waves from hitting the sides of the water tank, producing unwanted reflected waves. So D is incorrect, either.

Teacher: Then option E is correct. The troughs of water waves act as a concave lens, widening on the sides and narrowing in the middle, causing divergence of light rays. Hence, darker regions appear on the white paper.

老師：我們介紹過水波槽的裝置，和使用的方式。那我們來看一下哪個敘述正確。
學生：老師我知道長方形木條是用來產生直線波的!（A）錯誤。
老師：前面有說過可變電阻的目的，是要調整起波器的頻率。（B）也錯誤。
學生：我記得如果光源不是平行光，而是點光源，那白紙上所顯示的視波長就會被放大。
老師：沒錯唷！會和實際波長有倍數關係。（C）也不能選。
學生：實驗用到海綿，是避免波打到水波槽四周產生的反射波，去干擾要觀察的波。所以（D）也不對。
老師：那E選項正確，水波的波谷如凹透鏡，兩邊寬中間窄，所以會有發散光線的作用，此時白紙上就會呈現較暗的條紋。

例題二

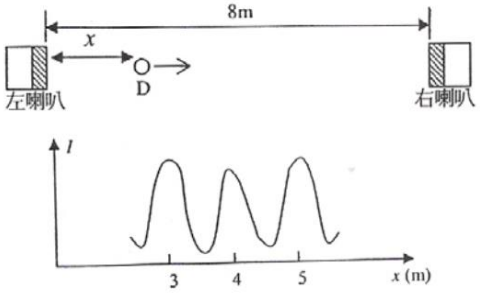
說明：了解波的干涉，及節點和腹點的概念。

Understand the interference of waves and the concepts of node and antinode.

Two speakers facing each other are separated 8 meters apart. Both speakers simultaneously emit sound waves with the same phase and frequency, as shown in Figure (a). A detector D detects the intensity I of the sound between the two speakers, as illustrated in Figure (b). If x is the distance from the detector to the left speaker, which of the following option mostly close to the wavelength of the sound?

(A) $\frac{1}{4}$ m　(B) $\frac{1}{2}$ m　(C) 1 m　**(D) 2 m**　(E) 4 m

兩個互相面對的喇叭相距 8 公尺。兩喇叭同時放出同相位、同頻率的聲波。如圖（a）所示。一偵測器 D 於兩喇叭之間偵測到聲音的強度 I 如圖（b）。若 x 為偵測器與左喇叭的距離，則此聲波之波長最接近下列何者？



(A) $\frac{1}{4}$ m　(B) $\frac{1}{2}$ m　(C) 1 m
(D) 2 m　(E) 4 m

（99 指考物理 15）

Teacher: Our task is to determine the wavelength, from diagram (b). The places where the sound intensity is the highest at 3m, 4m, and 5m, which are thus the positions of antinodes.

Student: So, relatively speaking, the places where the sound intensity is weakest are nodes.

Teacher: Exactly. What is the relation between the distance of two adjacent antinodes and wavelength?

Student: The distance of two adjacent antinodes is half of a wavelength.

Teacher: Very good! Therefore, half a wavelength is 1m. That means the wavelength is 2m. The answer is option (D).

老師： 我們要找出聲波的波長，從（b）圖看出，聲音強度最大的地方分別在 3m、4m、5m 的地方，所以這些是腹點位置。

學生： 那相對來說，聲音強度最弱的地方，就是節點。

老師： 沒錯，那相鄰兩腹點的距離，與波長的關係為何呢？

學生： 相鄰腹點之距離，是半個波長。

老師： 很好唷！所以半波長是 1m。那波長就會是 2m。答案選（D）。

★第二章 聲波★
Sound Waves

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■ 前言 Introduction

本章探討聲波，包含聲音是如何傳遞的，及影響音速的因素。也探討樂器發聲的原理，涉及聲音的共振現象，並討論影響樂器音調和音色的原因。

2-1 聲波的傳播
Propagation of Sound Waves

■ 前言 Introduction

聲波需要透過介質才能傳遞，包含氣體、液體及固體三種形式的介質。聲波是以縱波的形式傳遞，因此，介質的振動方向與波的傳遞方向相互平行。同時，音速則因介質的不同而改變。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
sound wave	聲波	sine wave	正弦波
medium	介質	equilibrium point	平衡點
transverse wave	橫波	propagation	傳播
longitudinal waves	縱波	pulse wave	脈衝波
rarefaction waves	疏密波	vibration	振動
periodic wave	週期波	simple harmonic motion	簡諧運動

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

❶ _____ are mechanical waves that must have a medium to propagate.

例句：Sound waves **are mechanical waves that must have a medium to propagate.**
聲波屬於力學波，必須要有介質才能傳播。

❷ _____ is/are related to _____.

例句：The speed of sound wave in air **is related to** humidity and temperature of air.
聲波在空氣中傳播的速率，與空氣的溼度和氣溫皆有關係。

❸ Without _____, we would not be able to _____.

例句：**Without** medium**, we would not be able to** hear sound.
如果沒有介質存在，我們將無法聽見聲音。

■ 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：
At the end of learning the chapter, students are able to acquire the following concept:
一、理解聲波的波形以及波速的計算公式。
Understand the waveform of sound waves and the formulas to calculate wave speed.

∞ 例題講解 ∞

例題一

說明：利用回音的現象，計算兩物體之間的距離。

Determine the distances between two objects through the phenomenon of echo.

The rescue team planned to use a rope launcher to connect ropes between the two sides of the valley. One of the team members clapped his hands continuously to measure the distance to the other side of the cliff. He claps faster and faster, and when he claps 20 times in 6 seconds, the clapping rhythm is synchronized with the echo. Knowing that the speed of sound in the air is 340 m/s, what is the shortest distance between the team member and the cliff on the other side of the river valley?

(A) 340　(B) 120　(C) 100　**(D) 50**　(E) 20

救難隊欲發射拋繩器，以繩索連接河谷兩岸。一名隊員連續拍手，估對岸峭壁距離。他愈拍愈快，當 6 秒拍手 20 次時，拍手節奏與回音同步。已知空氣中聲速為 340 公尺 /秒，則該隊員與河谷對岸峭壁的最短距離約為多少公尺？

(A) 340　(B) 120　(C) 100　**(D) 50**　(E) 20

（99 年學測 22）

Teacher: This question needs to use the echo to determine the distance between the cliffs. What do you think?

Student: [distance=speed of sound × time of propagation]. Although the speed of sound is given, the question does not tell us how long it takes for one-way sound propagation.

Teacher: Right. The question doesn't show how long it takes for one-way of the sound propagation, but we can get the result from other hints of the statements. This is the key point of the question.

Student: Can we get the hints from "when he claps 20 times in 6 seconds, the clapping rhythm is synchronized with the echo"? But I still didn't get it.

Teacher: Correct. First, let's look at the statement "the clapping rhythm is synchronized with the echo", and what makes this happen?

Student: The clapping sound and the echo exist at the same time, which means that the clapping sound overlaps with the echo sound?

Teacher: Bingo. Because the clapping sound and the echo overlapped, so it sounds as one single voice to us, which comes from the overlap of clapping sound and the echo.

Student: So how do we use this to determine how long it takes for one-way sound propagation?

Teacher: Because the clapping sound overlaps with the echo, we can imagine that the person who clapped his hands "clapped again immediately when he heard the echo". The question said that he clapped his hands 20 times in 6 seconds, which means that the time between each clapping is 6/20=0.3 (seconds).

Student: I see. It means that the time for the sound to go back and forth between the two banks is 0.3 (seconds), thus the time for the sound to propagate one way is 0.3/2=0.15 (seconds). So the distance between the team members to the cliffs is 340m/s · 0.15sec = 51 (m), which is about 50 meters.

Teacher: Right. Very good.

老師： 此題需利用回音現象，推導出對岸峭壁的距離，大家有什麼看法嗎？

學生： [距離=聲速×傳遞時間]，雖然題目有告訴我們聲速，但卻沒告訴我們單程聲音傳遞了多久的時間。

老師： 沒錯，題目沒有告訴我們單程聲音傳遞的時間，但我們卻能從題目的某處，推出單程聲音傳遞了多久時間，而這也是這個題目想要考的重點。

學生： 是從「當 6 秒拍手 20 次時，拍手節奏與回音同步。」這句話找嗎？但我還是無法理解這是什麼意思。

老師： 是的，首先我們先看「拍手節奏與回音同步」這句話，什麼樣的情形會讓你覺得拍手的節奏與回音同步呢？

學生： 聽到拍手聲和回音出現的時機一直相同，也就是拍手聲剛好與回音聲重疊的意思嗎？

老師： 答對了，由於拍手聲和回音重疊了，所以我們的耳朵會聽起來像是只有一個聲音，而這個聲音是由拍手聲和回音重疊所造成的。

學生： 那我們又要如何利用這點，去推算單程聲音傳遞了多久時間呢？

老師： 由於拍手聲和回音重疊，所以我們可以想像成那個拍手的人是「聽到回音的時候立即再拍一下」，而題目又說 6 秒拍手了 20 次，代表每次拍手的時間間隔是 $\frac{6}{20} = 0.3(秒)$。

學生：我懂了，這就代表聲音來回兩岸的時間是$0.3(秒)$，而單程聲音傳遞的時間就是 $\frac{0.3}{2} = 0.15(秒)$，因此答案就是 $340m/s \times 0.15sec = 51(m)$，所以大約就是 50 公尺。

老師：沒錯，就是這樣。

例題二

說明：學習如何理解波形圖的意義。

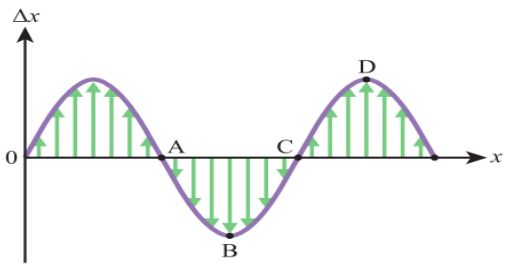
Learn how to interpret the meanings of a waveform.

A sound wave moves to the right on the x-axis in the air, and the relationship between the vibration displacement Δx of each particle and the position x is shown in the figure.

Answer the following questions:

1. Among points A, B, C and D, which one is the midpoint of compression? And which one is the midpoint of rarefaction?
2. Among points A, B, C and D, which one is the most tense?
3. Which type of wave is this? Transverse or longitudinal waves?

某聲波在空氣中的 x 軸上向右前進，各質點的振動位移 Δx 對位置 x 的關係如圖所示，試問：



1. A、B、C、D 哪一點為疏部中點？哪一點為密部中點？**C 為疏部中點；A 為密部中點**
2. A、B、C、D 哪一點的壓力最大？**A**
3. 此波為橫波？還是縱波？**縱波**

（龍騰版 110 下課本 （選修物理 III） 第二章 第 63 頁 範例 2-1）

Teacher: The first question asks us to identify the middle positions of the compression and rarefaction regions. What is the tip?

Student: The direction of particle displacement on the left and right sides of each point. Since the direction of wave movement is to the right, for the midpoint of the rarefaction region, the direction of particle displacement on the left side of the middle point moves to the left, and that of the right side moves to the right. As for the compression region, the particle on the left side of the midpoint moves to the right, and that of the right particle moves to the left.

Teacher: That's right, if the vibration displacement Δx in this figure is positive, it means the displacement is to the right, and if it is negative, it means the displacement is to the left. Therefore, we can see from the figure that C is the midpoint of the rarefaction, and A is the midpoint of the compression.

Student: The following question asks about the position with the most tense, then it must be the midpoint of compression, right?

Teacher: That’s right, because the pressure of the gas is proportional to the density, so the pressure at the midpoint of the compression region. Now, let’s look at the third question. Is this wave a transverse wave or a longitudinal wave?

Student: It is a longitudinal wave, because the vibration displacement of particles is Δx (on the vertical axis of the graph), and the wave speed is towards the x axis (on the horizontal axis of the graph). The displacement of the particle is thus parallel to the direction of the wave propagation.

Teacher: Good. That’s correct.

老師： 第一題要我們分別找出疏部及密部的中點，請問大家訣竅是什麼呢？

學生： 看每一點左右兩方的質點位移方向，由於波移動的方向是向右，所以疏部中點左方質點位移方向往左，右方質點位移方向向右，而密部中點左方質點位移方向向右，右方質點的位移方向向左。

老師： 沒錯，而此題的振動位移 Δx 如果是正的話代表位移向右，如果是負的話代表位移向左，因此由圖我們可以看出 C 為疏部中點，而 A 為密部中點。

學生： 接著第二題問我們哪一點的壓力最大，應該就是密部中點 A 對吧？

老師： 沒錯，由於氣體壓力與密度成正比，所以密部中點的壓力最大。接下來，看第三題，此波是橫波還是縱波呢？

學生： 縱波，因為質點的振動位移為 Δx (縱軸座標)，而波傳播方向為 x(橫軸座標)，故兩者移動方向互相平行。

老師： 沒錯，答對了。

2-2 空氣柱的駐波
Standing Waves in a Column of Air

■ 前言 Introduction

長笛、單簧管等管樂器，是利用其管內的空氣柱形成駐波，而演奏出悅耳的音樂。本節延續第一章所提到之駐波觀念，探討開管樂器和閉管樂器形成駐波的條件，並帶出基音、諧音與泛音的定義，介紹樂音與噪音的區別。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
standing wave	駐波	overtone	泛音
node	節點	harmonic	諧音
antinode	腹點	music timbre	樂音
air column	空氣柱	noise	噪音
pitch	音調	timbre	音色
fundamental frequency	基音		

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

❶ _____ can be divided into two types: _____ and _____ according to _____.

例句：Wind instruments **can be divided into two types:** closed-wind instruments **and** open-wind instruments **according to** their resonance conditions.

管樂器依照其共振的條件，大致可分為閉管樂器與開管樂器兩類。

❷ We can adjust the _____ by adjusting the _____.

例句：**We can adjust the** pitch **by adjusting the** length of the air column.

我們可藉由調節空氣柱的長度，來改變音調的高低。

❸ _____ is/are not _____, but _____.

例句：The sound emitted by a common sounding body **is not** single frequency**, but** a combination of waves with multiple frequencies.

一般的發聲體發出的聲音，並不只有單一頻率，而是有多種頻率的波之組合。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、學習如何計算空氣柱內駐波之相關參數，並了解音色背後的物理意義。

Learn how to calculate the parameters of standing waves in air columns and understand the physical principles underlying timbre.

☙ 例題講解 ❧

例題一

說明：知道如何由管樂器的駐波，推算泛音的波長及頻率。
Understand of the concept of standing waves regarding wind instruments and be able to calculate the overtone's wavelength and frequency.

Ah Xiang blows air into a glass tube with a length of 17.0cm and openings at both ends. Based on the sounds made by the glass tube when the temperature is 15.0°C, please answer the following questions:

(1) What is the wavelength of the second overtone? $\frac{34}{3}(cm)$

(2) If one end is pressed with a finger to make it closed, and air is blown into the tube from the other end, what is the frequency of the second overtone of the sound it produces? **2500(Hz)**

阿祥往一根長度為 17.0cm、兩端開口的玻璃管內吹氣，在 15.0°C 時，玻璃管所發出之聲音中，請問：

(1) 第二泛音之波長為何？$\frac{34}{3}(cm)$

(2) 若用手指頭按住一端，使其呈現封閉狀態，從另一端對管內吹氣，其所發出的聲音之第二泛音的頻率為何？ **2500(Hz)**

（翰林版 110 下教學備課用書 (選修物理 III) 第二章 第 59 頁 範例 2-2）

Teacher: First of all, we need to know the type of air column in this exercise. What is the type of this air column?

Student: It is an open-wind air column. Because the statements show it "open at both endings".

Teacher: That's right. We can recall the concepts introduced previously. The two open ends of the air column are at the positions of the antinodes, thus the length of the column (L) is equal to an integer times of half wavelength: L=n(λ_n/2), therefore, $\lambda_n = \frac{2L}{n}$。

Student: I see, since the tube length 17 cm, and the question is about the second overtone, so n=1+2=3, it can be calculated that $\lambda_3 = \frac{2\times17}{3} = \frac{34}{3}(cm)$.

Teacher: Good. Then let's look at the second question. The second question is about frequency, can we use the wavelength from the first question to calculate?

Student: No, because in the second exercise, the air column becomes a closed-wind one for one end is held down by the finger, the two questions are under different conditions. So we cannot use the wavelength from the first exercise to calculate the second one.

Teacher: Nice! Since it is a closed-wind air column, we can recall the concepts introduced previously. The closed-end of the column is at the position of the nodes and the open-end is at antinodes. Therefore, the length of the closed-wind air column (L) is an odd multiple of a quarter of the wavelength: $L=(2n+1)(\lambda_n/4)$.
Thus, $f_n = v/\lambda = (2n+1)(v/4L) f_n = v/\lambda = (2n+1)(v/4L)$. Now, what is the *v* and *n* in this exercise?

Student: *v* is the speed of sound in air, and the formula is: v=331+0.6T. T is the temperature in Celsius. According to the temperature given from the exercise, v=331+0.6×15=340(m/s), and since it is a closed-wind air column, *n* of the second overtone is 2.

Teacher: That's right, if you put these values into the formula, you can get: $f_2 = \frac{5\times340}{4\times0.17} = 2500(Hz)$. Pay attention to the unit of speed here is (m/s), so the unit of tube length must be converted into meters before being calculated.

Student: Get it!

老師： 首先我們要先知道此題空氣柱的類型，請問此題的空氣柱是什麼類型的呢？

學生： 此題是開管空氣柱，因為題目有寫是「兩端開口」的玻璃管。

老師： 沒錯，既然是開管空氣柱，利用我之前在課堂上介紹的概念：在兩開口端，皆為反節點(也就是波腹)。因此，[管長=半個波長的整數倍]：$L = n(\frac{\lambda_n}{2})$，推得$\lambda_n = \frac{2L}{n}$。

學生： 我了解了，已知管長 L 是 17 公分，而題目問的是第二泛音所以 n=1+2=3，可以算出 $\lambda_3 = \frac{2\times17}{3} = \frac{34}{3}(cm)$。

老師： 是的，接著讓我們繼續看第二題，第二題題目是問頻率，但我們能用第一題所得到的波長去解嗎？

學生：不能，第二題由於手指頭按住了其中一端，所以變成閉管空氣柱了，因此兩題的駐波條件不同，不能用第一題得到的波長去解第二題。

老師：說得好，既然是閉管空氣柱，我們可以用之前介紹的觀念：閉口處為節點，而開口處為反節點，因此[管長=1/4 波長的奇數倍]: L=(2n+1)(λ_n/4)，推導出 $f_n = v/\lambda = (2n+1)(v/4L)$。同學們，請問這裡的 v 和 n 分別要代多少呢？

學生：v 是聲速，空氣中的音速公式為：v=331+0.6T，T 是攝氏溫度。根據題目給的溫度，v=331+0.6×15=340(m/s)，而由於是閉管空氣柱，故第二泛音的 n=2。

老師：沒錯，將這些值代入公式中，可得：$f_2 = \frac{5}{4}f_1 = \frac{5\times340}{4\times0.17} = 2500(Hz)$，提醒各位由於這裡的速度的單位是(m/s)，所以管長的單位要先化成公尺，再代喔。

學生：知道了，謝謝老師。

例題二

說明：了解音色及音調的物理意義，並理解管長與聲音波長之關係。

Understand the physical meaning of timbre and pitch and grasp the relationship between column length and the wavelength of the sound wave.

When carrying out a frequency-intensity experiment on the sound produced by a fixed-length air column with the speed of sound 340 m/s, the results are shown in Figure 8. Which of the following statements are correct?

(A) The pitch of the sound produced by this air column is completely determined by the sound with a frequency of 1 kHz.

(B) The fundamental sound produced by this column of air has a wavelength of 34 cm.

(C) The air column is open at one end and closed at the other.

(D) The length of this air column is 17 cm.

(E) If the air temperature gets lower, the frequency of the air column's sound will also be reduced.

當聲速為 340 m/s 時，對一長度固定之空氣柱發出的聲音，進行頻率對強度的量測實驗，其結果如圖 8 所示，則下列敘述哪些正確？

(A) 此空氣柱所發聲音的音色，完全由頻率 1 kHz 的聲音決定。

(B) 此空氣柱發出基頻聲音的波長為 34 cm。

(C) 此空氣柱為一端開口一端閉口 。

(D) 此空氣柱的長度為 17 cm 。

(E) 若空氣溫度降低，則空氣柱發聲的頻率亦會降低。

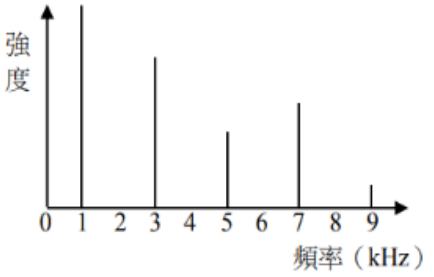


圖 8

（104 年指考 22）

Teacher: There are five options in this exercise. Let's check one by one. First, option A. It says that the pitch of the sound produced by the air column is completely determined by the sound with frequency of 1 kHz. Is this correct?

Student: No, the lowest frequency of 1kHz is the fundamental pitch, which determines the pitch of the sound. But the timbre is determined by the combinations of the fundamental frequency and other overtones, rather than relying on the fundamental frequency only.

Teacher: True, so option A is wrong, and then look at option B. It says that the wavelength of the fundamental frequency sound is 34cm. Since we know that the fundamental frequency is 1kHz, we can determine the wavelength.

Student: $\lambda = \frac{v}{f} = \frac{340}{1000} = 0.34(m) = 34(cm)$ Option B is correct.

Teacher: Good. Now, let's see option C, it says that this air column is open at one end and closed at the other, which is a closed-wind air column. Then how can we tell if it is an open-wind or closed-wind air column?

Student: We know from the frequency formula that we had deduced before, $f_n = \frac{nv}{2L}$ (n=1,2,3,…). If it is an open-wind air column, the first three frequency ratios should be 1:2:3 by order. If it is a closed- wind air column, the formula would be $f_n = \frac{nv}{4L}$ (n=1,3,5,…), and the first three frequency ratios should be 1:3:5 by order.
So as the figure shows, it is a closed-wind air column.

Teacher: Very good, then option D says that the length of the air column is 17cm. We already know that this is a closed-wind air column. Let's use the formula of the frequency of the closed-wind air column to calculate the length of the air column.

Student: From the formula $f_n = \frac{nv}{4L}$, we can know $L = \frac{nv}{4f_n}$.

If we use the fundamental frequency f_1 to calculate, the result would be $L = \frac{340}{4\times1000} = 0.085(m) = 8.5(cm)$, so option D is incorrect.

Teacher: Finally, let's see option E. It says that if the air temperature gets lower, the frequency of the sound produced by the air column will also decrease. To check whether this statement is correct, we need to find out the relationship between the air temperature and the frequency of the sound produced by the air column. Now, let's try.

Student: When the wavelength stays the same, from $v = f \times \lambda$, we know that $v \propto f$, and $v = 331 + 0.6T$. It shows that the lower the temperature T is, the slower the speed of sound v is. So when the air temperature T drops, the sound frequency of the air column will also drop.

Teacher: Right. Since the length of the column is fixed, the wavelength keeps constant.

So option E is correct, The T in formula $v = 331 + 0.6T$ is at the unit of Celcius. Thus, the answers are BCE.

老師： 這題有五個選項，讓我們一個個依序討論，首先看 A 選項，選項說空氣柱所發聲音的音色，完全由頻率 1 kHz 的聲音決定，對嗎？

學生： 不對，1kHz 是最低的頻率，稱為基音，會決定音調的高低。但音色並非僅由基音決定，而是基音和其它泛音組合所決定。

老師： 沒錯，所以 A 選項是錯的，接著看 B 選項，選項說基音的波長為 34cm。既然你們已經知道基頻是 1kHz，可以算出相對應的波長是多少呢？

學生： 由 $\lambda = \frac{v}{f} = \frac{340}{1000} = 0.34(m) = 34(cm)$，故 B 選項是對的。

老師： 是的，再來讓我們看 C 選項，選項說此空氣柱為一端開口一端閉口，也就說是閉管空氣柱，那我們要怎麼判斷是開管還是閉管空氣柱呢？

學生： 可以由頻率的比來判斷，老師之前推導過，開管空氣柱的頻率公式為：$f_n = \frac{nv}{2L}$ (n=1,2,3,…)，因此如果是開管空氣柱的話，前三個頻率比由小到大應為 1：2：3。而如果是閉管空氣柱的話，頻率公式為：$f_n = \frac{nv}{4L}$(n=1,3,5,…)，前三個頻率比由小到大應為 1：3：5，故依照題目所給的圖來看，是閉管空氣柱沒錯。

老師： 很好，接著是 D 選項，選項說此空氣柱的長度是 17cm，我們已經知道這是個閉管空氣柱了，讓我們利用閉管空氣柱頻率的公式去推空氣柱的長度吧。

學生： 好的，由$f_n = \frac{nv}{4L}$，可知$L = \frac{nv}{4f_n}$，如果我們以基頻f_1去計算的話，可得 $L = \frac{340}{4\times1000} = 0.085(m) = 8.5(cm)$，故 D 選項是錯的。

老師： 那最後我們來看 E 選項，若空氣溫度降低，則空氣柱發聲的頻率亦會降低，要判斷空氣溫度和空氣柱發聲頻率的關係式，請大家現在試著想想。

學生： 沒問題，由$v = f \times \lambda$，在波長不變的情況下，得 $v \propto f$，又$v = 331 + 0.6T$，可知溫度 T 越小聲速vv越慢，故當空氣溫度 T 下降時，空氣柱發聲的頻率也會下降。

老師： 答對了，公式$v = 331 + 0.6T$中的 T 單位是攝氏。因為管長固定，所以波長不變。因此 E 選項是正確的，故此題答案為 B C E。

2-3 共振與共鳴
Resonance

■ 前言 Introduction

本章節介紹共振（共鳴）的現象，延續上一章節的觀點，樂器在發出不同音階的聲音時會伴隨著不同頻率的駐波，而這些能在振動體內形成駐波的特定頻率，被稱為該物體的自然頻率或固有頻率。一般情況下，物體受到外界的波動影響時，物體並不會有太劇烈的振動，不過當外界的波頻率和物體本身的自然頻率相同時，波動的能量不會被物體消耗，因而可以逐漸累積，產生明顯的振動現象，稱為「共振」。由於共振時所產生的聲音音量會被放大，因此共振也被常稱為「共鳴」。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
natural frequency	自然頻率	goblet	高腳杯
resonance	共振、共鳴	instrument	樂器
resonance box	共鳴箱	stringed instrument	弦樂器
amplitude	振幅	wind instrument	管樂器
tuning fork	音叉		

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

❶ When _____ is equal to _____, it may cause _____ due to_____.

例句：**When** the sound frequency **is equal to** the natural frequency of the goblet, **it may cause** the glass to break **due to** resonance.
當聲音頻率等於高腳杯的自然頻率時，可能使玻璃杯因共振而破裂。

❷ There are many examples of _____ occurring in _____, both good and bad.

例句：**There are many examples of** resonance phenomena **occurring in** daily life**, both good and bad.**
共振現象發生在日常生活中的例子甚多，有好也有壞。

❸ When _____, if the frequency of the _____ matches the vibration frequency of the _____, the amplitude will become larger and larger.

例句：**When** swinging on a swing**, if the frequency of** the applied force **matches the vibration frequency of the** swing**, the amplitude will become larger and larger.**
盪鞦韆時，如果施力的頻率與鞦韆的振動頻率吻合，則振幅就會愈來愈大。

■ 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：

At the end of learning the chapter, students are able to acquire the following concepts:

一、學習共鳴的物理意義，並與前一小節，空氣柱內形成駐波的條件相整合。

Learn the physical meaning of resonance and combine it with the conditions of standing waves in air column introduced in the previous section.

❧ 例題講解 ☙

例題一

說明：利用共鳴的現象，來判斷空氣柱的種類。

Determine the type of air column and its characteristics through resonance phenomena.

There is a protruding pipe on the wall. Xiao Ming wants to use resonance to estimate the length of this section of pipe. He placed a sound frequency generator at the open end of the pipe to make the sound wave into the pipe, and gradually increased the frequency from 600 (Hz) to 1500 (Hz), then he found that the water pipe would resonate only with 800 (Hz) and 1200 (Hz). What is the length of the pipe? (The speed of sound is 344 m/s)

Ans: 43(cm)

工地牆上有一凸出水管，小明想用共鳴的方法來測量此段水管的長度。他將聲頻產生器放在水管口使聲波傳入管內，從頻率 600(Hz)開始逐漸增加到 1500(Hz)期間，發現該水管只有在 800(Hz)及 1200(Hz)時會產生共鳴，則該水管的長度為何？(聲速為 344 m/s)

Ans: 43(cm)

（翰林版 110 下教學備課用書 （選修物理 III）第二章 第 62 頁 範例 2-3）

Teacher: Class, the exercise asks for what is the length of the water pipe, does it make you think of any formula?

Student: There are relevant formulas about standing waves of the air column in 2-2, and it includes the length of column (L).

Teacher: Good. Besides, the statements tell us the frequency, so it seems that we have to use the formulas to determine the length of the pipe. Now, if we want to find the length of the column (L), what are the factors we have to figure out first?

Student: From the formula $f_n = \frac{nv}{4L}$, we need f_n、v and n to get L. Also, we need to check if it is an open-wind or close-wind column?

Teacher: Right. Because we have f_n and v for the statements, the things left are n and the type of air column. So let's start with its type. From the statements, we can see that it has resonance with 800(Hz) and 1200(Hz), what does that mean?

Student: These two frequencies are able to generate standing waves in the water pipe.

Teacher: Yes, and because the tested frequency gradually increases from 600 (Hz) to 1500 (Hz), so 800 (Hz) and 1200 (Hz) are two adjacent frequencies that can generate standing waves respectively. According to the ratio of 800:1200=2:3, the two are the second harmonic and the third harmonic of an open-wind air column respectively. Then, how to get the length of the pipe?

Student: Plug in 800(HZ) to calculate:

$f_2 = \frac{2\times344}{2L} = 800$, so $L = \frac{688}{2\times800} = 0.43(m) = 43(cm)$

Teacher: Well done.

老師： 同學們，題目問水管的長度是多少，有讓你們聯想到了什麼公式嗎？

學生： 2-2 節裡面關於空氣柱駐波的相關公式，就有管長 L 在裡面。

老師： 觀察力不錯喔，而且題目有給我們頻率，所以初步來看很有可能利用空氣柱駐波頻率，來算水管的長度。那我想問，之前我們在算空氣柱相關問題時，如果要算管長 L，我們需要掌握哪些條件呢？

學生： 由閉管空氣柱頻率 $f_n = \frac{nv}{4L}$ 來看，要算 L 的話需要頻率 f_n、聲速 v 以及 n 值，當然也要確定是開管還是閉管空氣柱。

老師： 沒錯，此題由於頻率和聲速已經給你了，只剩下 n 值和空氣柱類型還未知，我們先從空氣柱類型開始著手，題目中有提到在 800(Hz)及 1200(Hz) 時會產生共鳴，這時什麼意思呢？

學生： 這兩個頻率能夠在水管內產生駐波。

老師：是的，而且由於測試頻率是從 600(Hz)開始逐漸增加到 1500(Hz)，所以 800(Hz)及 1200(Hz)分別是相鄰的兩個能夠產生駐波的頻率，由兩者的比為 800:1200=2:3 來看，兩者分別為開管空氣柱的第二諧音和第三諧音，那接下來要怎麼求出水管的長度呢？

學生：取 800(Hz)帶入開管空氣柱的頻率去計算：

$f_2 = \frac{2\times344}{2L} = 800$，所以 $L = \frac{688}{2\times800} = 0.43(m) = 43(cm)$

老師：做得好！

例題二

說明：瞭解共鳴管形成駐波的條件，與可能存在的頻率。

Determine the conditions of forming standing waves in the wind column and the possibly existing frequencies.

Put a speaker at one end of a 50 cm metal tube with openings at both ends. The sound gradually increases from 1000 (Hz) to 2000 (Hz). If the speed of sound in air is 340 (m/s), how many times can it resonate? **Ans:3 times.**

將一揚聲器置於兩端開口、長度為 50(cm)金屬管之一端，發出的聲音從 1000(Hz)開始逐漸增加至 2000(Hz)，若空氣中聲速為 340(m/s)，則能產生共鳴的次數為何？

Ans:3(次)

（翰林版 110 下教學備課用書 （選修物理 III） 第二章 第 65 頁 第 12 題）

Teacher: The statements show that the pipe opens at both sides, so it is an open-windpipe. What's the condition of forming standing waves of open-wind air column frequency?

Student: Both ends are antinodes in open-wind pipe when forming standing wave.

Teacher: Great! Then, what is the formula of the open-wind air column frequency (f) as function of wave speed ( ) and the length of the pipe (L)?

Student: $f_n = \frac{nv}{2L}$

Teacher: Right. Then the exercise asks for the times of resonance in the range of 1000(Hz) ~ 2000(Hz), what does that mean?

Student: The number of times that f_n falls in this range.

Teacher: Right. It means the times that n is a positive integer in this range, so we can respectively put 1000(Hz) and 2000(Hz) into $f_n = \frac{nv}{2L}$ to get the possible value of n in this range. Let's try.

Student: Okay, so from $f_n = \frac{nv}{2L}$, we can get $n = \frac{2f_nL}{v}$.

By using 1000(Hz) and 2000(Hz), we can get $n \fallingdotseq 2.94$ and $n \fallingdotseq 5.88$ respectively, so n is in the range of 2.94 to 5.88.

Teacher: Also, n has to be a positive integer, so n may be 3, 4 or 5, which means the possible number of resonances is 3.

Student: Get it!

老師： 此題告訴我們金屬管是兩端開口，所以是一個開管空氣柱，大家能告訴我開管空氣柱形成駐波的條件嗎？

學生： 在兩端開口的管子形成駐波時，兩端皆會是反節點。

老師： 很好，因此管子形成駐波的頻率(f)，與波速( )及管長(L)的公式應為何？

學生： 是 $f_n = \frac{nv}{2L}$。

老師： 沒錯，因為兩端開口處，皆是反節點(波腹)。那接著題目問在頻率範圍為1000(Hz)～2000(Hz)之間能夠產生共鳴的次數，是什麼意思呢？

學生： f_n落在此範圍內的個數。

老師： 是的，換句話說就是 n 在此區間是正整數的次數，所以我們可以分別將左邊界的值 1000(Hz)及右邊界的值 2000(Hz)帶入$f_n = \frac{nv}{2L}$去找出 n 在此區間可能有多少個值，同學們試試看吧。

學生： 好的，所以由$f_n = \frac{nv}{2L}$，可得$n = \frac{2f_nL}{v}$，最小值帶入，得到 $n \fallingdotseq 2.94$，最大頻率帶入，得到 $n \fallingdotseq 5.88$，故 n 介於 2.94～5.88 之間

老師： 但 n 必須為正整數，所以 n 可能為 3、4、5，故能產生共鳴的次數共有 3 次。

學生： 知道了，謝謝老師。

★ 主題三 光的折射及其應用 ★
Refraction of Light and Its Applications

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■ 前言 Introduction

本章探討幾何光學，利用幾何的方法，推導光的折射、反射以及其在薄透鏡中的成像，幫助學生們理解光線在不同介質中的傳遞路徑。

3-1 光的折射與司乃耳定律
Refraction of light and Snell's law

■ 前言 Introduction

本小節介紹光線反射與折射現象，及其遵守的相關定律，光的折射會遵守司乃耳定律，反射則滿足反射定律。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
normal line	法線	optically thinner medium	光疏介質
incident angle	入射角	optically denser medium	光密介質
reflection angle	反射角	apparent depth	視深
diffusion	漫射	real depth	實深
refraction	折射	medium	介質
index of refraction	折射率		

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

❶ We can _____ because of _____.

例句：**We can** see objects from any angle **because of** the diffusion of light.
我們從任意角度都可看見物體，是光線漫射所造成的結果。

❷ When light passes from _____ into _____, the refracted lines _____ the normal line.

例句：**When light passes from** glass **into** air, **the refracted line**s would deviate away from **the normal line.**
當光由玻璃進入空氣時，折射線則會偏離法線。

❸ In addition to being dependent on the _____, the _____ also changes with the _____.

例句：**In addition to being dependent on the** medium, **the** refractive index **also changes with** the frequency of light.
除了與介質有關外，折射率還隨光的頻率而變化。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

理解光在不同介質中如何折射，及光速的變化。

Understand how light refracts in different media and how the light speed changes.

❧ 例題講解 ☙

例題一

說明：應用司乃耳定律推算介質的折射率，及介質中的光速。

Apply Snell's Law to derive the refractive index as well as light speed of the medium.

As shown in the figure, light from the air strikes a liquid medium at an incident angle of 53°, causing partial refraction and partial reflection at the interface. It is known that the angle between the refraction line and the reflection line is 90°, then:

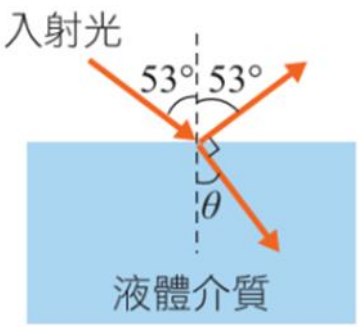
(1) What is the refractive index of this liquid medium? **4/3**

(2) What is the speed of light in this liquid medium? **2.25×10^8 (m/s)**

如圖所示，光自空氣中以 53° 的入射角射向某液體介質，在界面處產生部分折射和部分反射，已知折射線和反射線的夾角為 90°，則：

(1) 此液體介質的折射率為多少？ **4/3**

(2) 光在此液體介質中的速率為多少？ **2.25×10^8 (m/s)**



（龍騰版 110 下課本 (選修物理 III) 第三章 第 95 頁 範例 3-2）

Teacher: Students, the first question asked about the refractive index. When it comes to the refractive index, which formula do you think of?

Student: Snell's law, $n_1 sin\theta_1 = n_2 sin\theta_2$

Teacher: Great, Snell's Law tells us the relationship between the refractive index n and the refraction angle (\). Please give it a try.

Student: Okay, first, assume that the refractive index of air is n_1, and n_1 is known to be 1. Then from the figure, we can see that the incident angle θ_1 is 53° and the refraction angle θ_2 is 37°. The value we require is the refractive index n_2 of the liquid.

Teacher: That's right, then let us put the value into Snell's law: $1 \times sin53° = n_2 \times sin37°$, we can get $n_2 = 4/3$, and then let us look at the second question, which asks about the speed of light in this liquid medium. Anyone have any ideas?

Student: According to the relation of refractive index and the corresponding medium's speed of light: $n = c/v$, we can get $v = c/n$. If c is replaced by the speed of light and n is replaced by n_2, we can find the speed of light of the liquid medium v.

Teacher: That's right, so $v = \frac{3\times10^8}{\frac{4}{3}} = 2.25 \times 10^8(m/s)$.

老師： 同學們，第一小題問到了折射率，說到折射率你們會想到哪一個公式呢?

學生： 司乃耳定律，$n_1 sin\theta_1 = n_2 sin\theta_2$。

老師： 很棒，司乃耳定律告訴我們，介質折射率(n)與折射角(\)的關係。請大家試試看吧。

學生： 好的，首先假設空氣的折射率為n_1，而n_1已知為 1，接著由圖可知入射角θ_1為53°並且折射角θ_2為 37°，我們要求的值為液體的折射率n_2。

老師： 沒錯，接著讓我們把數值帶入司乃耳定律中：$1 \times sin53° = n_2 \times sin37°$，可得到$n_2 = 4/3$，接著讓我們看第二小題，題目問光在此液體介質中的速率為多少?有人有什麼想法嗎?

學生： 根據折射率的定義：$n = c/v$，可得$v = c/n$，把這裡的c用光速代，n用n_2代，就可以得到光在液體介質中的速率v了。

老師： 沒錯，因此$v = \frac{3\times10^8}{\frac{4}{3}} = 2.25 \times 10^8(m/s)$。

例題二

說明：學習色散現象，也就是光的頻率，會些微影響其在介質中的折射率。

Learn the phenomenon of dispersion, that is the frequency of light slightly affects its refractive index in media.

As shown in the picture, after sunlight passes through a prism, visible light appears on the screen. Between A and B, then:

(1) Which color is light A?

(2) Which color of light, A or B, travels faster in the prism?

Answer: (1) red; (2) A

如圖所示，太陽光經過三稜鏡後，在屏幕上有可見光出現在 A、B 之間，則：

(1) A 為何種光？

(2) A 與 B 何種色光在三稜鏡的速度較快？

答：(1)紅；(2)A

（龍騰版 110 下習作 (選修物理 III) 第三章 第 24 頁 第 9 題）

Teacher: The question mentions that visible light appears between A and B on the screen after the sunlight passes through the prism. First, we need to know what colors of light A and B are respectively. Does anyone know?

Student: A is red light and B is purple light.

Teacher: Correct answer, but why?

Student: In the same medium, the refractive index of violet light is the largest when their incident angles are the same, the refractive angle of the violet light will be the largest and that of the red light will be the smallest.

Teacher: Yes, that's right. Let's look at the second question. It is known that A is red light and B is violet light. Which color light travels faster in the prism?

Student: According to the definition of refractive index: n=c/v, the larger the refractive index n is, the smaller the light speed v will be. So red light will propagate faster.

Teacher: Yes, that’s correct.

Teacher: The question states that after passing through a triangular prism, sunlight forms visible light between points A and B on the screen. First, we need to determine what colors of light A and B represent. Does anyone know?

Student: A is red light and B is purple light.

老師： 題目說到太陽光經過三稜鏡之後在屏幕上 A、B 之間出現了可見光，首先我們要知道 A、B 分別是什麼顏色的光，同學們有人知道嗎？

學生： A 是紅光，B 是紫光。

老師： 答對了，但為什麼呢？

學生： 在相同介質中，紫光的折射率最大而紅光的折射率最小，因此若以相同角度入射時，紫光的偏折角度會最大，而紅光偏折角度最小。

老師： 沒錯，說的好，接著我們來看第二小題，已知 A 是紅光，B 是紫光，所以哪一種色光在三稜鏡中傳播的速率較快呢?

學生： 根據折射率與光速的關係：$n = c/v$，可得$v = c/n$，可知折射率n越大，則光速v會越小，所以紅光傳播的比較快。

老師： 沒錯，正確答案。

老師： 題目說到太陽光經過三稜鏡之後在屏幕上 A、B 之間出現了可見光，首先我們要知道 A、B 分別是什麼顏色的光，同學們有人知道嗎？

學生： A 是紅光，B 是紫光。

3-2 光的全反射
Total Internal Reflection of Light

■ 前言 Introduction

根據司乃耳定律，當入射角變大時，折射角也會隨之變大，而當光從密介質進入疏介質時，折射角會大於入射角，因此當入射角超過某角度時，可能發生光線無法折射，而只能全部反射，稱為「全反射」現象。此節從司乃耳定律出發，介紹「全反射」的推導，及其相關的應用。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
total internal reflection	全反射	binoculars	雙筒望遠鏡
critical angle	臨界角	optical fiber	光纖
refraction angle	折射角	telescope	望遠鏡
endoscope	內視鏡		

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

❶ When the _____ is greater than the _____, _____ occurs.

例句：**When the** incident angle **is greater than** its critical angle, the phenomenon of total reflection **occurs.**

當入射角大於其臨界角時，會發生全反射現象。

❷ _____ use the characteristics of _____ to _____.

例句：Endoscopes **use the** total reflection **characteristics of** optical fibers **to** capture images of organs or tissues in the body.

內視鏡藉由光纖的全反射特性，可以拍攝體內器官或組織的影像。

❸ The center of the _____ is composed of _____, and the outside is covered with _____.

例句：**The center of the** optical fiber **is composed of** a material with a high refractive index, **and the outside is covered with** a material with a low refractive index.

光纖的中心由折射率高的材料所組成，其外側以折射率低的材料包覆。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

根據上一節所學的司乃耳定律，了解光全反射的發生條件。

Learn the conditions for total reflection of light based on Snell's Law learned in the previous section.

❧ 例題講解 ☙

例題一

說明：學習如何透過司乃耳定律，判斷兩介面之間發生全反射的條件。

Learn how to adopt Snell's law to determine the conditions of occurring total reflection between two interfaces.

There are different media placed in a large transparent container, and the refractive index of each layer of media. As shown in the figure, assuming that each layer is parallel, then:

If light is incident from the air end, at which interface will total reflection occur?

(A) Air, oil

(B) Oil, water

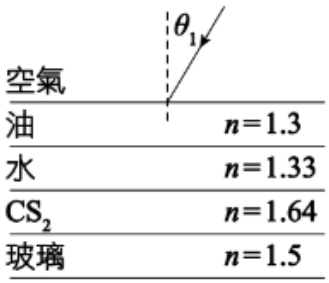
(C) Water, CS_2

(D) CS_2, glass

(E) None of them are possible

有不同的介質放入一個大型的透明容器中，每層介質的折射率如圖所示，假設每層間均為平行，則：

若光線由空氣端射入，則哪一介面可能會發生全反射？



(A) 空氣、油

(B) 油、水

(C) 水、CS_2

(D) CS_2、玻璃

(E) 均不可能

（龍騰版 110 下習作 (選修物理 III) 第三章 第 26 頁 第 5 題）

Teacher: This question is asking you which interface may be subject to total reflection. Do you have any ideas?

Student: The textbook says that total reflection is possible only when light is emitted from an optically dense medium to an optically thin medium, so the answer should be (D).

Teacher: Is this really the case? Let's try to verify it using Snell's law. First, assume that the refraction angle of light in oil is θ_2. Since each interface is parallel to each other, the incident angle of light in oil is also θ_2, then would you all infer this?

Student: Yes, in this case, the refraction angle and incident angle of light in the third to fifth layers are θ_3 、θ_4 and θ_5 respectively.

Teacher: That's right, let's assume that the refractive index of each substance from top to bottom is n_1、n_2、n_3、n_4 and n_5 respectively. According to Snell's law, what kind of equation can we make?

Student: $n_1 sin\theta_1 = n_2 sin\theta_2 = n_3 sin\theta_3 = n_4 sin\theta_4 = n_5 sin\theta_5$

Teacher: Yes, then when we substitute the refractive index, it becomes $n_1 sin\theta_1 = n_2 sin\theta_2 = n_3 sin\theta_3 = n_4 sin\theta_4 = n_5 sin\theta_5$. Did you find anything in this way?

Student: No, can you give more hints?

Teacher: Did you notice that I equalized all five values? This means that the light is refracted at each interface, but what we want is which interface will have total reflection, and how to do it?

Student: Try replacing the refraction angle of each interface with 90°. If it is reasonable, it means total reflection may occur.

Teacher: The answer is correct, let us start from θ_2: $1 sin\theta_1 = 1.3$. We can find that $sin\theta_1 = 1.3$ is obviously impossible. Therefore, light will be refracted at the interface between air and oil. At the same time, $n_1 sin\theta_1 = n_2 sin\theta_2$. Please continue to follow this method. Give it a try later.

Student: Okay, in the end, I found that no matter which value of θ is substituted for 1, it is unreasonable, so we get $n_1 sin\theta_1 = n_2 sin\theta_2 = n_3 sin\theta_3 = n_4 sin\theta_4 = n_5 sin\theta_5$. The light is refracted at each interface. So the answer should be (E).

Teacher: Yes, (E) is the correct answer. The condition of light emitted from dense medium to thin medium is essential for total reflection, but even under this condition, total reflection may not always occur.

老師： 這題在問大家哪一個介面可能會發生全反射，大家有什麼想法嗎？

學生： 課本上說，只有當光由光密介質射向光疏介質時全反射才有可能發生，所以答案應該是(D)。

老師： 真的是這樣嗎？我們來試試用司乃耳定律驗證看看，首先假設光線在油中的折射角為θ_2，由於每個介面均為互相平行，所以光線在油中的入射角也為θ_2，那這樣各位會以此類推嗎？

學生： 會，這樣的話光線在第三層到第五層中的折射角和入射角分別為θ_3、θ_4以及θ_5。

老師： 沒錯，接下來假設由上而下每一種物質的折射率分別為n_1、n_2、n_3、n_4以及n_5，根據司乃耳定律，我們可以列出什麼樣的等式呢？

學生： $n_1 sin\theta_1 = n_2 sin\theta_2 = n_3 sin\theta_3 = n_4 sin\theta_4 = n_5 sin\theta_5$。

老師： 是的，接著我們在把折射率代進去，就變成了$1 sin\theta_1 = 1.3 sin\theta_2 = 1.33 sin\theta_3 = 1.64 sin\theta_4 = 1.5 sin\theta_5$，這樣大家有發現什麼嗎?

學生： 沒有欸，可以請老師多提示一些嗎？

老師： 各位有發現我把五個值都劃上等號嗎？這代表光線在每個介面都發生折射了，但我們要的是哪一個介面會發生全反射，要怎麼做呢？

學生： 把每個介面的折射角都代入 90°試試看，如果合理的話代表可能會發生全反射。

老師： 答對了，讓我們從θ_2開始：$1 sin\theta_1 = 1.3$，可以發現$sin\theta_1 = 1.3$明顯不可能，因此在空氣和油的介面光是會發生折射的，同時$n_1 sin\theta_1 = n_2 sin\theta_2$，依照這個做法請大家繼續往後做試試看。

學生： 好的，做到最後發現不管哪一個θ的值代 1，都是不合理的，所以得出$n_1 sin\theta_1 = n_2 sin\theta_2 = n_3 sin\theta_3 = n_4 sin\theta_4 = n_5 sin\theta_5$，光線在每個介面都可以折射了，所以答案應該是(E)。

老師： 沒錯，(E)才是正確答案。光由光密介質射向光疏介質，是發生全反射的必要條件，但此條件下，不一定就會全反射。

例題二

說明：測試學生們是否理解全反射發生的條件，及光波在介質中的變因。

Test students' understanding of the conditions under which total reflection occurs and the associated variables of light waves in the medium.

When a light ray is incident from medium A into medium B and can produce total reflection, which of the following physical quantities are in A? Must be less than B?

(A) Density

(B) Refractive index

(C) Speed of light

(D) Frequency of light

(E) Wavelength of light.

一光線由介質 A 射入介質 B 而能產生全反射時，下列哪些物理量，在 A 中必小於 B？

(A) 密度

(B) 折射率

(C) 光速

(D) 光的頻率

(E) 光的波長。

（104 年指考 22）

Teacher: This question is to test whether you understand the conditions for total reflection and the associated variables of light waves in a medium. What are the basic conditions for total reflection to occur?

Student: Light is incident from an optically denser medium to an optically thinner medium.

Teacher: That's right, so in this question the optically dense medium is A and the optically thin medium is B. So how are the optically dense medium and optically thin medium defined?

Student: The refractive index of optically dense media is larger than that of the thin media.

Teacher: Yes, how does the refractive index affect the speed of light in different media?

Student: Light travels slower in media with a high refractive index.

Teacher: Very good, then we can also determine the wavelength of light in different media. Since the frequency of light in different media remains unchanged, and the light speed in media v= f · λ, the wavelength λ of light becomes shorter with a large refractive index.

Student: Teacher, I know, so the answer is CE.

老師： 這題是在測試大家全反射發生的條件，及光波在介質中的相關變因。請問全反射發生的條件是什麼？

學生： 光要從光密介質射入光疏介質。

老師： 沒錯，那麼光密介質和光疏介質是怎麼定義的呢？

學生： 光密介質的折射率比較大，光疏介質的折射率比較小。

老師： 是的，那折射率的大小如何影響光速呢？

學生： 光在折射率大的介質中速度比較慢。

老師： 很好，接著我們也可判斷光在不同介質的波長變化。因為頻率不因介質而改變，且光速$v = f \cdot \lambda$，可知光在折射率大的介質中，波長λ比較短。

學生： 老師我知道了，所以答案是 CE。

3-3 光的色散與彩虹成因
Dispersion of Light and Causes of Rainbows

■ 前言 Introduction

彩虹是令人驚豔的自然現象，而其背後的成因是由於光的色散。本節將說明光的色散，其背後的原理，以及如何產生彩虹。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
chromatic dispersion	色散	primary rainbow	虹
rainbow	彩虹	secondary rainbow	霓
(Triangular) prism	三稜鏡	deflection angle	偏向角
spectrum	光譜	vertex angle	頂角
visible light	可見光		

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

❶ In the same _____, different ____ of _____ have different _____.

例句：**In the same** medium, **different** colors **of** light **have slightly different** speeds.
相同介質中，不同顏色的光，速率有些微不同。

❷ The _____ we see is the dispersion phenomenon formed by _____.

例句：**The** rainbow **we see is the dispersion phenomenon formed by** sunlight being refracted, reflected and re-refracted by water droplets.
我們所看到的彩虹，是太陽光經過水珠的折射、反射，及再折射後，因色散而形成的現象。

❸ the greater _____, the greater _____.

例句：According to Snell's Law, **the greater** the refractive index is of the prism, **the greater** the deflection angle becomes.
根據司乃耳定律，三稜鏡的折射率愈大，則偏向角愈大。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

理解光的色散概念以及彩虹的成因。

Understand the principles of light dispersion and the causes of rainbows.

❧ 例題講解 ☙

例題一

說明：學習形成光的色散之條件。

Learn the condition of forming light dispersion.

The following combinations of light sources and optical components can be used to conduct optical experiments. Which ones are more suitable for observing light dispersion phenomenon? (should select 2 items)

(A) Monochromatic laser and a convex lens

(B) Sun and a Prism

(C) Green laser pen and a concave lens

(D) An incandescent lamp and a transparent glass marble

(E) A red light-emitting diode (LED) lamp and a transparent glass

下列的光源及光學元件組合可以用來進行光學實驗，哪些較適合觀察光的色散現象？（應選 2 項）

(A) 單色光雷射及一個凸透鏡　　**(B) 太陽及一個三稜鏡**

(C) 綠光雷射筆及一個凹透鏡　　**(D) 白熾電燈及一顆透明的玻璃彈珠**

(E) 紅色發光二極體（LED）燈及一塊透明的玻璃

（101 年學測 42）

Teacher: This question asks us what combination can be used to observe the dispersion of light. So what conditions must we have to conduct this experiment?

Student: The incident light source must be polychromatic light, and the medium through which the light passes must be changed.

Teacher: True, but all the options in this question have different media than air, so just check if their light source is a polychromatic light source.

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

老師：這題問我們什麼組合可以用來觀察光的色散，那請問大家要進行這項實驗必須具備什麼樣的條件呢？

學生：入射光源必須要為多色光，且光需經過不同介質才行。

老師：沒錯，但本題中所有選項都有與空氣不同的介質，所以只要檢查它們的光源是否為多色光源就好。

老師：所以答案應該是(B)(D)。

例題二

說明：探討不同色光在三菱鏡的色散，所產生的折射角差異。

Deriving the difference of refraction angles between different colors of light considering dispersion of prism.

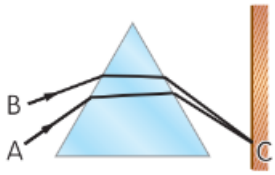
As shown in the diagram on the right, A and B are two monochromatic lights. After being refracted by the prism, lights A and B both converge at point C. It is known that one of the lights is blue. Which of the following are correct? (Multiple choice)

(A) A is blue light, B is yellow light.

(B) A is yellow light, B is blue light.

(C) A is blue light, B is red light.

(D) A is red light, B is blue light.



如右圖，A、B 為兩道單色光，經三稜鏡折射後，A、B 兩道光會合在 C 點，已知其中一道光為藍光，則下列哪些正確？（多選）

(A) A 為藍光，B 為黃光。　(B) A 為黃光，B 為藍光。

(C) A 為藍光，B 為紅光。　(D) A 為紅光，B 為藍光。

（翰林版 110 下教學備課用書 (選修物理 III) 第三章 教學補充資料 3-18）

Teacher: In this diagram, there are two beams of light both traveling towards point C after passing through the prism. The question is to determine the colors of the two beams. First, what is the difference between the two rays of light?

Student: The deflection angle of A is relatively larger than that of B.

Teacher: Yes, since the light with greater deflection angle means the light with higher refractive index, Also, according to the concept of dispersion, the smaller the wavelength, the higher the refractive index. Thus, the wavelength of light beam A should be smaller than that of B.

Student: Okay, so the answer should be (A)(C).

老師： 此圖中有兩束光線經過三稜鏡後匯聚在 C 點，題目問兩道光的組合那些可能是正確的，首先請問同學們，這兩道光之間有什麼差異呢？

學生： A 的偏向角比較 B 大。

老師： 沒錯，因為偏折角越大，代表折射率越大；而根據色散，波長越小，折射率會越大，所以偏折角越大，波長越小，因此，A 的波長應比 B 小。

學生： 好的，所以答案應該是(A)(C)。

3-4 薄透鏡成像與應用
Imaging and Applications of thin lens

■ 前言 Introduction

本小節從探討各種常見透鏡的成像規則與結果，並介紹生活中透鏡應用的實例。藉由學習透鏡成像，也可更加熟悉前幾節的原理概念。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
thin lens	薄透鏡	focal length	焦距
convex lens	凸透鏡	real image	實像
concave lens	凹透鏡	virtual image	虛像
converging lens	會聚透鏡	magnifier	放大鏡
diverging lens	發散透鏡		

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

❶ _____ can be classified into _____ types according to _____.

例句：Convex lenses **can be classified into** three **types according to** their shapes: biconvex lenses, meniscus lenses, and plano-convex lenses.
凸透鏡依形狀可分類為三種：雙凸透鏡、凹凸透鏡、平凸透鏡。

❷ _____ are commonly used _____ to _____.

例句：Cameras **are commonly used** optical instruments **to** record images.
照相機是常用的光學儀器，來記錄景物的影像。

❸ _____ are very _____ that allow us to _____.

例句：Our eyes **are** very precise optical instruments **that allows us to** see the world clearly.
我們的眼睛是非常精密的光學儀器，讓我們清楚看見世界。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

熟悉各個透鏡的成像原理與公式，以及生活上的應用。

Become familiar with the imaging principles and formulas of lenses and their applications in real life.

❧ 例題講解 ☙

例題一

說明：學習運用透鏡的成像公式來解題。

Learn to apply imaging formulas for lenses to solve problems.

When the object is 40 cm away from the lens, a real image with a magnification of 1/2 can be produced on the screen. If the lens is moved to the object a distance d, it is found that real images of different sizes are produced on the screen, then:

(1) What is the shifting distance d in cm?

(2) How many centimeters is the distance between the object and the screen?

(3) What is the focal length of this lens in cm?

Ans: (1) 20 (2) 60 (3) 40/3

物體距透鏡 40 cm 時，可產生放大率為 1/2 的實像於屏幕上，若將透鏡向物移一段距離 d 後，發現又在屏幕上產生不同大小的實像，則：

(1) 距離 d 為多少 cm?

(2) 物體與屏幕之距離為多少 cm?

(3) 此透鏡之焦距為多少 cm?

答：(1) 20 (2) 60 (3) 40/3

（翰林版 110 下教學備課用書 (選修物理 III) 第三章 教學補充資料 3-26 演練 3）

Teacher: First, let's look at the first question. It says that after moving the lens a certain distance, we find that real images of different sizes are produced on the screen. How could this happen?

Student: This is because the second possibility is found in the imaging formula: $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$, and in this possibility the object distance p becomes smaller.

Teacher: Yes, since the magnification of the first imaging is 1/2, according to the formula of "magnification = distance of object/distance of image", the object distance of the first time is 40cm, thus the image distance should be q=20cm. Then, from the imaging formula, the object distance becomes 20cm and the image distance is 40cm, so the lens needs to move 20cm toward the object.

Student: Okay, then the second question asks about the distance between the object and the screen, which refers to the object distance plus the image distance, right?

Teacher: Yes, so the answer is 40+20=60cm. Next, look at the third question, how to calculate the focal length of this lens?

Student: Using the imaging formula: $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$, $\frac{1}{20}+\frac{1}{40}=\frac{1}{f}$, we can get f=40/3cm.

Teacher: Great! Thus, this problem needs to combine the two formulas regarding magnification and imaging.

老師： 首先我們來看第一題，它說將透鏡移動一段距離之後又發現屏幕上產生不同大小的實像，這是怎麼回事呢？

學生： 這是由於在成像公式：$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$中找到了第二種可能，而在此種可能是物距 p 變小了。

老師： 沒錯，接著由於第一次成像的放大率為 1/2，而第一次的物距為 40cm，根據 "放大率=像距/物距"，可知第一次的像距 q=20cm。再由成像公式，可得第二次的物距為 20cm，像距為 40cm，因此透鏡需向物體移動 20cm。

學生： 好的，那第二題問物體與屏幕間的距離，就是指物距加上像距，對吧？

老師： 是的，因此答案是 40+20=60cm。接著看第三題，此透鏡的焦距要怎麼算呢？

學生： 利用成像公式：$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$，$\frac{1}{20}+\frac{1}{40}=\frac{1}{f}$，可得$f=40/3$cm。

老師： 很棒！所以此題需整合成像公式，及放大率公式。

例題二

說明：利用透鏡成像公式解題。

Learn to apply the lens imaging formula to solve problems.

The camera device of a smartphone mainly consists of two parts: the lens and the photosensitive element located on the imaging plane. In order to enable objects of different distances to be imaged on the photosensitive element, the distance between the lens and the photosensitive element needs to be varied between 4.0 mm and 4.5 mm by the automatic control mechanism of the mobile phone. It is known that a photographic device can image an object at infinite distance through a lens onto a photosensitive element. If the lens can be regarded as a single thin lens and the focal length of the lens is fixed, which of the following statements is correct?

(A) The lens is a concave lens

(B) The focal length of the lens is approximately 4.0mm

(C) The image of the object in front of the lens on the photosensitive element is an upright real image

(D) Objects in front of the lens can be clearly focused as long as the object distance is greater than 36 mm

(E) When the object distance is 4.0 m, the distance between the lens and the photosensitive element is 4.5 mm

智慧型手機的照相裝置主要包括兩部分：鏡頭透鏡和位於成像平面的感光元件。為了使遠近不同的物體均能成像於感光元件上，透鏡和感光元件之間的距離，需靠手機的自動控制機件，使其在 4.0 mm 到 4.5 mm 之間變動。已知照相裝置可以將無窮遠處的物體透過透鏡成像於感光元件上，若鏡頭透鏡可視為單一薄透鏡，且透鏡的焦距固定，則下列敘述哪些正確？

(A) 鏡頭透鏡為凹透鏡

(B) 鏡頭透鏡的焦距約為 4.0mm

(C) 鏡頭前的物體在感光元件上所成的像為正立實像

(D) 鏡頭前的物體，只要其物距大於 36 mm，都可以清楚對焦

(E) 當物距為 4.0 m 時，透鏡和感光元件之間的距離為 4.5 mm

（109 年指考 23）

Teacher: Let's look at option (A) first. Do you think it is right? Why?

Student: That's wrong, because the camera needs to form a real image on the sensor in order to show the image, so it should be a convex lens.

Teacher: Good, what about option (B)?

Student: Correct. Because the problem mentions that objects at infinity can be imaged on the photosensitive element, and according to the imaging rules of convex lenses, objects at infinity should be imaged at the focus on the other side.

Teacher: Yes, according to the question, the distance between the lens and the photosensitive element varies between 4.0mm and 4.5mm, so option (B) is correct, but what about option (C)?

Student: Wrong, real image should be inverted.

Teacher: That's right, but what about option (D)?

Student: Correct, if using the imaging formula: $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$, $\frac{1}{36}+\frac{1}{q}=\frac{1}{4}$, it can be obtained that q=4.5cm. The image is just right on the photosensitive element so when the object distance is greater than 36mm, the image can be clearly seen.

Teacher: Great, what about option (E)?

Student: Incorrect, given that f=4 mm, substitute the given conditions into the imaging formula: $\frac{1}{4}+\frac{1}{4.5}\neq\frac{1}{4}$.

老師： 我們首先看(A)選項，大家覺得是對的嗎？為什麼？

學生： 是錯的，因為相機需在感光元件上成實像，才能顯影，所以應該是凸透鏡才對。

老師： 說的好，那麼(B)選項呢？

學生： (B)是對的，因為題目有說可將無窮遠的物體成像在感光元件上，而無窮遠的物體，根據凸透鏡的成像規則，應成像在另一側的焦點上。

老師： 沒錯，依據題意，透鏡和感光元件之間的距離在 4.0mm 到 4.5mm 之間變動，所以(B)選項是對的，那麼(C)選項呢？

學生： 錯的，實像應該是倒立的。

老師： 說的對，那麼(D)選項呢？

學生： 正確，如果利用成像公式：$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$，$\frac{1}{36}+\frac{1}{q}=\frac{1}{4}$，可得$q = 4.5\text{cm}$。剛剛好可以成像在感光元件上，因此物距只要大於 36mm 都可以清楚對焦。

老師： 很棒喔，那麼(E)選項呢？

學生： 錯的，已知$f = 4\ mm$，將題目條件代入成像公式：$\frac{1}{4}+\frac{1}{4.5}\neq\frac{1}{4}$。

★ 主題四 光的干涉與繞射 ★
Diffraction and Interference of Light

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■ 前言 Introduction

先說明光的演變史，微粒說與波動說的起源與不同處，接下來從水波現象引入波動說，並解釋光通過雙狹縫產生干涉圖樣現象與定量推導，再解釋光通過單狹縫所產生的繞射現象，並給予定量計算。

4-1 光的干涉
Interference of Light

■ 前言 Introduction

先介紹光的微粒說與波動說，包含楊氏所提的疊加原理，接著，以雙狹縫干涉現象來佐證光的波動模型，引入同調光源與光程差概念，由光程差推導出亮紋、暗紋的公式。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
interference	干涉	optical path difference	光程差
diffraction	繞射	phase difference	相位差
corpuscle	微粒	bright fringe	亮紋
optics	光學	dark fringe	暗紋
double slit	雙狹縫	wavelength	波長
parallel	平行	constructive interference	建設性干涉
coherent light	同調光源	destructive interference	破壞性干涉

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

❶ When _____, _____ is/are observed.

例句：**When** optical path differences between two beams are integer multiples of the wavelength, bright fringes **are observed** on the screen.
當兩束光之光程差為波長整數倍時，屏幕上會觀察到亮紋。

❷ _____ represent _____.

例句：Dark fringes **represent** the results of two beams superimposed into destructive interference.
暗紋代表兩束光疊加後，形成破壞性干涉的結果。

■ 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：
At the end of learning the chapter, students are able to acquire the following concept:
說明相位差可決定干涉的亮紋和暗紋。
Explain that phase difference determines the bright and dark fringes of interference.

例題講解

例題一

說明：定性的應用雙狹縫干涉公式。

Qualitative application of the formulas of double-slits interference.

In the "Young's double slit interference experiment", parallel light of wavelength λ is incident perpendicular to a slit, as shown in the figure. The distance from the plane of the slit to the light screen S is denoted as D, the distance between the two slits is d, and D >> d >> λ. Let the distance between the centers of adjacent bright fringes on the screen be denoted as (Δy)l, and the distance between the centers of adjacent dark fringes be denoted as (Δy)d. Which of the following statements are correct?

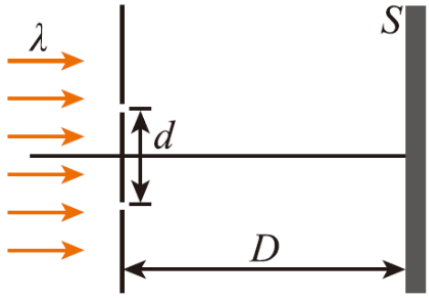
(A) When D and d are kept constant, and λ increases, then (Δy)l increases.

(B) When D and d are kept constant, and λ increases, then (Δy)d decreases.

(C) When λ and D are kept constant, and d increases, then (Δy)d increases.

(D) When λ and D are kept constant, and d increases, then (Δy)l decreases.

(E) When λ and d are kept constant, and D increases, then both (Δy)l and (Δy)d decrease.



在「楊氏雙狹縫干涉實驗」中，波長為 λ 的平行光垂直於狹縫入射，如圖所示。設狹縫所在平面至光屏 S 的間距為 D，兩個狹縫的間距為 d，且 D>>d>>\lambda。令光屏上相鄰兩亮紋中央的間距以符號(Δy)l 表示，相鄰兩暗紋中央的間距以符號(Δy)d 表示，則下列敘述中哪些正確？

(A) 當 D 與 d 維持不變， λ 變大時，則(Δy)l 變大。

(B) 當 D 與 d 維持不變， λ 變大時，則(Δy)d 變小。

(C) 當 λ 與 D 維持不變，d 變大時，則(Δy)d 變大。

(D) 當 λ 與 D 維持不變，d 變大時，則(Δy)l 變小。

(E) 當 λ 與 d 維持不變，D 變大時，則(Δy)l 及(Δy)d 均變小。

（指考物理 93 補考多選 12）

Teacher: In the double slits interference experiment, what are the widths of bright fringes and dark fringes?

Student: In the double-slits interference experiment, the width of the light fringe and the width of the dark fringe should be the same, both $\Delta y = \frac{D\lambda}{d}$ Just like the picture below.

Teacher: That's right! Here, D represents the distance from the double slits to the screen, d represents the spacing between the two slits, λ is the wavelength of the incident parallel light, and Δy is the width between two bright fringes, which is also the width between two dark fringes. So, when D and d remain unchanged, what is the relationship between Δy and λ ?

Student: Δy and λ are directly proportional.

Teacher: That's right, based on $\Delta y = \frac{D\lambda}{d}$, Δy is proportional to the wavelength λ, where D is the distance from the slits to the light screen; d is the distance between the two slits. And λ is the wavelength of the incident parallel light; Δy is the width between the two bright fringes as well as the width between the two dark fringes. What is the relationship between Δy and λ when D and d are constant?

Student: Δy and λ are directly proportional.

Teacher: That's right, so option (D) is correct in stating that when λ and D are held constant and d grows, then $(\Delta y)_l$ grows smaller, and option (C) is wrong. What is the relationship between Δy and D when λ and d are constant?

Student: Δy and d are inversely proportional.

Teacher: Yes, so option (E) is incorrect because $(\Delta y)_l$ and $(\Delta y)_d$ should increase when D increases.

老師：　在雙狹縫干涉實驗裡面，亮紋寬度和暗紋寬度分別是多少呢？

學生：　雙狹縫干涉實驗裡亮紋寬度和暗紋寬度應該是一樣的，都是$\Delta y = \frac{D\lambda}{d}$，就像這張圖。

老師：　沒錯，其中 D 代表的是雙狹縫到光屏的距離，d 代表的是兩個狹縫的間距，λ 是入射平行光的波長，Δy是兩亮紋間寬度也是兩暗紋間寬度。那麼當 D 與 d 不變的時候，Δy和 λ 的關係是什麼呢？

學生：　Δy和 λ 是成正比的。

老師：　沒錯，根據$\Delta y = \frac{D\lambda}{d}$，$\Delta y$和 λ 成正比，因此(A)選項所敘述的當 D 與 d 維持不變，λ 變大時，則 $(\Delta y)_l$ 變大是正確的，而(B)選項是錯誤的。那麼當 D 與 λ 不變的時候，Δy和 d 的關係是什麼呢？

學生：　Δy和 d 是成反比的。

老師：　沒錯，所以(D)選項所敘述的當 λ 與 D 維持不變，d 變大時，則 $(\Delta y)_l$ 變小是正確的，而(C)選項是錯誤的。接下來當 λ 與 d 不變的時候，Δy和 D 的關係是什麼呢？

學生：　Δy和 D 是成正比的。

老師：　是的，所以(E)選項是錯誤的，因為當 D 變大時，$(\Delta y)_l$和$(\Delta y)_d$應該是變大的。

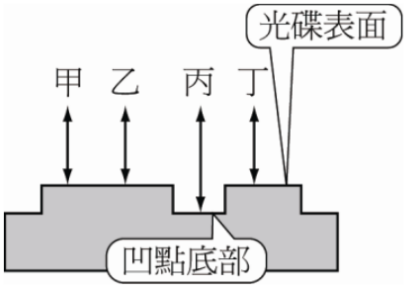
例題二

說明：理解兩光束形成破壞性干涉的條件。

Understand the conditions for destructive interference between two light beams.

The surface of the CD-ROM records the message in dimples, and its magnified side view is shown in the schematic diagram. In the figure, the light rays 甲 and 乙 in the laser beam of the reading signal are reflected by the surface of the optical disc, superimposed and become constructive interference. If the two light rays C and D can be superimposed into destructive interference, how many times the depth of the bottom of the pit can be the wavelength of the laser beam?

光碟表面以凹點記錄訊息，其放大側視的示意圖如圖所示。圖中讀取訊號的雷射光束中之甲與乙兩光線在經過光碟表面反射之後，疊加成為建設性干涉。如果丙與丁兩光線可疊加成為破壞性干涉，則凹點底部的深度可為雷射光束波長的多少倍？

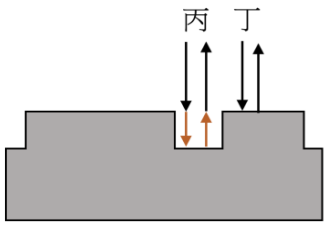


(A)2 (B)$\frac{3}{2}$ (C)1 (D) $\frac{1}{2}$ **(E)** $\frac{1}{4}$ 。

（指考物理 99 單選 2）

Student: Teacher, how do we know the optical path difference between beam C and beam D for this question?

Teacher: Assuming the light is projected vertically into the disc. Thus, the optical path difference between beam C and beam D can be obtained from the depth of the optical disk groove. Since beam C enters the optical disk groove and then rebounds out of the groove, beam C travels twice the depth of the optical disk groove than beam D, as shown in the diagram below

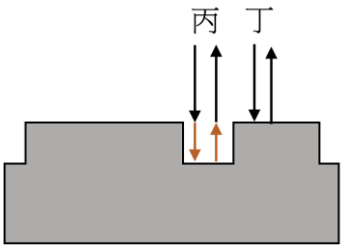


Student: So that's how it works! Is the condition for destructive interference that the difference in wavelength between the two beams is a multiple of 1/2 times the wavelength?

Teacher: That's right! When twice the depth of the disc groove is odd multiples of half the wavelength, the beams form destructive interference. In contrast, constructive interference occurs when twice the depth is even multiple of half the wavelength. So the depth of the disc groove should be odd multiples of 1/4 times the wavelength, the answer is (E) option.

學生： 老師，這題要怎麼知道丙光束跟丁光束的波程差呢？

老師： 假設光源以鉛直方向射入光碟片，因此丙光束跟丁光束的光程差，可由光碟凹槽的深度來得到。因為丙光束進入了光碟凹槽再反彈出光碟凹槽，所以丙光束比丁光束，多走了兩倍光碟凹槽的深度，如這張圖。



學生： 原來是那樣！那形成破壞性干涉的條件，是不是兩束光的波程差相差 $\frac{1}{2}$ 倍波長的倍數呢？

老師： 沒錯！所以當凹槽深度的 2 倍，是半個波長的奇數倍時，就會造成破壞性干涉，半個波長的偶數倍時會形成建設性干涉。因此光碟凹槽的深度應是 $\frac{1}{4}$ 倍波長的奇數倍，答案就是(E)選項。

4-2 光的繞射
Diffraction of Light

■ 前言 Introduction

先講解菲涅耳以波動模型，解釋光的繞射現象，再定量分析繞射圖中，亮紋與暗紋的位置，可推得中央亮帶寬度，及其他亮帶與暗紋的寬度。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
diffraction	繞射	central bright band	中央亮帶
width of the slit	狹縫寬度	incident vertically	垂直入射
wavelength	波長		

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

❶ **_____ is proportional to _____.**

例句：The width of the bright fringe **is proportional to** the wavelength of the beam.
亮紋寬度與光束的波長成正比

❷ **If _____, ____ will _____.**

例句：**If** the width of the slit becomes wider, the width of the bright fringe **will** become narrower.
若狹縫寬度變寬，則亮紋寬度會變窄。

■ 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：

At the end of learning the chapter, students are able to acquire the following concept:

說明兩道光之間的相位差，可決定繞射的亮紋和暗紋的位置。

Explain that the phase difference between two light beams determines the positions of the bright and dark fringes of diffraction.

❧ 例題講解 ☙

例題一

說明：理解形成繞射條紋的條件。

Understanding the conditions of forming diffraction fringes.

The figure shows a schematic diagram of a single-slit diffraction experimental setup, where the width of the slit is d. Now, parallel light of wavelength λ is incident perpendicularly on the single-slit, and the angle between the Q point at the edge of the screen and the vertical line in the slit is θ_m. Which of the following choices would be a possible cause if the dark pattern formed by diffraction the light is not observed on the screen?

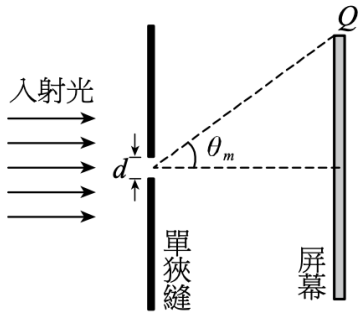
(A) $\boldsymbol{d >> \lambda}$

(B) $\boldsymbol{d\sin\theta_m < \lambda}$

(C) Incident light is too bright.

(D) Incident light is not homogeneous.

(E) The incident light is monochromatic.



如圖為單狹縫繞射實驗裝置示意圖，其中狹縫寬度為 d。今以波長為 λ 的平行光，垂直入射單狹縫，屏幕邊緣 Q 點與狹縫中垂線的夾角為 θ_m。若在屏幕上未觀察到繞射形成的暗紋，下列哪些選項是可能的原因？

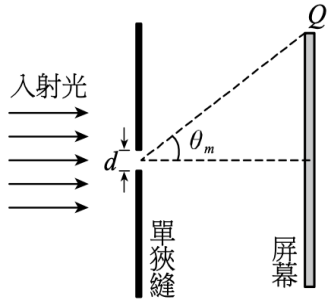
(A) $\boldsymbol{d >> \lambda}$

(B) $\boldsymbol{d\sin\theta_m < \lambda}$

(C) 入射光太亮

(D) 入射光不具有同調性

(E) 入射光為單色光



（102 年物理指考題 22）

Teacher: If no dark fringes formed by diffraction are observed on the screen, what might be the reason?

Student: I think there is probably no diffraction at all.

Teacher: Yes, it means that the diffraction is not obvious enough or there is no diffraction at all. Previously, we discussed that if diffraction is to be formed, what should be the relationship between the slit width and the wavelength?

Student: There should not be too much difference between them.

Teacher: That's right, if the difference between the two is too large, the diffraction will be not obvious, so option (A) is correct. And, let's talk about option (B). $d\sin\theta_m$ is the maximum wave path difference, but what is the condition for single slit diffraction to form dark fringes?

Student: The condition for forming dark fringes is that the optical path difference is an integer multiple of the wavelength.

Teacher: That's right, if the optical path difference is less than one time of the wavelength, then even the first dark fringe can't be seen, so option (B) is also correct. What about option (C)?

Student: I know! Dark fringes showing up or not has nothing to do with the brightness of the incident light, so option (C) is incorrect.

Teacher: That's right! So let's move on to option (D). What will we see on the screen if the incident light is not homogeneous?

Student: Both bright and dark fringes cannot exist. As mentioned in the previous lesson, it is necessary to have a homogeneous light source in order to create stable phase differences in order to form the diffraction pattern.

Teacher: Great! So option (D) is also correct, what about option (E)?

Student: Diffraction pattern can only be seen by using monochromatic light, so option (E) is wrong.

Teacher: Excellent! So the answers are (A), (B) & (D) options.

老師： 如果在屏幕上沒有觀察到繞射形成的暗紋，有可能是什麼原因呢？

學生： 我覺得可能是根本沒有形成繞射。

老師： 是的，代表繞射不明顯或是根本沒形成繞射，在之前的課程中我們提到要形成繞射的話，狹縫寬度跟波長的關係是什麼？

學生： 狹縫寬度跟波長大小，應該不能差距太多。

老師： 沒錯，若兩者相差太多，那繞射就會很不明顯，因此(A)選項是正確的。接下來看選項(B)，$dsin\theta_m$ 就是最大的波程差，而單狹縫繞射形成暗紋的條件是什麼呢？

學生： 形成暗紋的條件是光程差是波長的整數倍。

老師： 沒錯，如果今天光程差不到波長的一倍，那麼連第一暗紋都看不到，因此(B)選項也是正確的。那(C)選項呢？

學生： 我知道！暗紋出現與否，跟入射光亮度無關，所以(C)選項是錯誤的。

老師： 沒錯！那我們接下來看(D)選項，若入射光不具有同調性，屏幕上會看到什麼情況呢？

學生： 我們會觀察不到亮紋和暗紋！之前的課程有提到要有同調光源才能形成穩定的繞射圖樣。

老師： 沒錯！所以(D)選項也是正確的，那(E)選項呢？

學生： 用單色光才能出現繞射圖樣，所以(E)選項錯誤。

老師： 很棒！所以答案是(A)、(B)與(D)選項。

例題二

說明：單狹縫繞射與雙狹縫干涉公式的應用。

Applying the formulas for single-slit diffraction and double-slits interference.

A student wants to measure the distance between two slits of a double-slits by using a single-slit with a slit width of 3.20×10^{-3}centimeters and laser light of unknown wavelength. First, a laser light source is used as a vertical incidence for the single-slit diffraction experiment, the distance from the single slit to the screen is 150.00 centimeters, and the width of the central bright fringe on the screen is measured to be 5.93 centimeters.

Now, the single-slit is replaced by a double slit, and the rest of the equipment and the distance are not changed, then the double-slits interference experiment is conducted, and the distance between the two neighboring dark fringes on the screen is measured to be 0.60 centimeters. According to the above data, what is the distance between the two slits of a double-slits?

(A) 0.16 mm　(B) 0.32 mm　(C) 0.63 mm

(D) 1.26 mm　(E) 2.52 mm.

某生欲以一狹縫寬度為3.20×10^{-3}公分的單狹縫，及未知波長的雷射光，來測量一雙狹縫的兩狹縫間距。先以雷射光為光源垂直入射作單狹縫繞射實驗，單狹縫至屏幕的距離為 150.00 公分，經測得屏幕上中央亮帶的寬度為 5.93 公分。現將單狹縫換成雙狹縫，其餘器材與距離均未改變下，再作雙狹縫干涉實驗，在屏幕上測得相鄰兩暗紋間的距離為 0.60 公分。依據以上數據，雙狹縫的兩狹縫間距為若干？

(A) 0.16 毫米　(B) 0.32 毫米　(C) 0.63 毫米

(D) 1.26 毫米　(E) 2.52 毫米。

（指考物理 95 單選 5）

Teacher: We know the width of the single slit central bright fringe is 5.93 cm from the title. Do you still remember how to calculate the width of the single slit central bright fringe?

Student: The width of the central bright fringe of a single slit is double of those of other bright fringes. Thus, the width of the central bright fringe is $2\Delta y = 2\frac{r\lambda}{b}$, where Δy represents the width of other bright fringes except the central bright band, r represents the distance from the slit to the screen, and λ is the wavelength of the beam, b represents the slit width of the single slit.

Teacher: That's right! Since the edges of the central bright fringe are formed by the dark fringes of n=±1, its width is double of those of other bright fringes. So we know $5.93 = 2\frac{r\lambda}{b}$. The question tells us that the width between the two dark fringes of the double slit is 0.60 centimeters, can you calculate the width between the two dark stripes of the double slit?

Student: The width between the two dark stripes of the double slit is $\Delta y' = \frac{r\lambda}{d}$, where $\Delta y'$represents the width of the dark line, r represents the distance from the slit to the screen, λ represents the wavelength of the light beam, and d represents the width of the double slit.

Teacher: That's right, so we know $0.6 = \frac{r\lambda}{d}$. Now we divide the two equations, $\frac{5.93}{0.60} = \frac{2d}{b}$, and the question tells us that the width of a single slit, b is 3.20×10^{-3} centimeters. Therefore, the width between the double-slits d is 1.58×10^{-2} centimeters, which is about 0.16 millimeters, so the answer is (A).

老師： 題目告訴我們單狹縫中央亮紋的寬度是 5.93 公分，大家還記得單狹縫中央亮紋的寬度，怎麼計算出來嗎？

學生： 單狹縫中央亮紋的寬度是其他亮紋的兩倍，所以中央亮紋的寬度為：$2\Delta y = 2\frac{r\lambda}{b}$。其中$\Delta y$代表其他亮紋寬度，$r$代表的是狹縫到屏幕的距離，$\lambda$代表光束的波長，$b$代表單狹縫的狹縫寬度。

老師： 沒錯，因為中央亮紋兩側的邊界是 n=±1 的暗紋，因此中央亮紋的寬度是其他亮紋的兩倍。所以我們可以寫出$5.93 = 2\frac{r\lambda}{b}$，那題目告訴我們雙狹縫兩暗紋間的寬度是 0.60 公分，大家還記得雙狹縫兩暗紋間的寬度怎麼計算出來嗎？

學生： 雙狹縫兩暗紋間的寬度是$\Delta y' = \frac{r\lambda}{d}$，其中$\Delta y'$代表暗紋寬度，$r$代表的是狹縫到屏幕的距離，$\lambda$代表光束的波長，d 代表雙狹縫之間的寬度。

老師： 沒錯，所以我們可以寫出$0.6 = \frac{r\lambda}{d}$。現在我們將剛剛的兩條式子相除，可以得到$\frac{5.93}{0.60} = \frac{2d}{b}$，題目告訴我們單狹縫的狹縫寬度 b 是$3.20 \times 10^{-3}$公分，代入後就可以得到雙狹縫之間的寬度 d 大約等於1.58×10^{-2}公分，就是大約等於 0.16 毫米，所以答案是(A)選項。

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/	

自然領域雙語教學資源手冊：物理科英語授課用語

[高中選修(III)]

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

[Elective Physics (III)]

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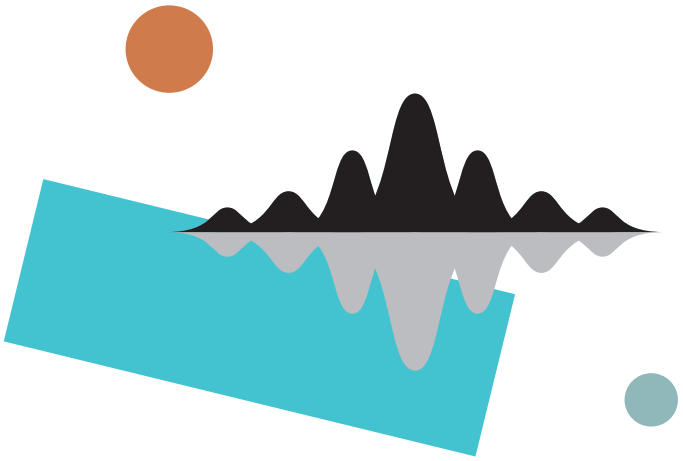

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