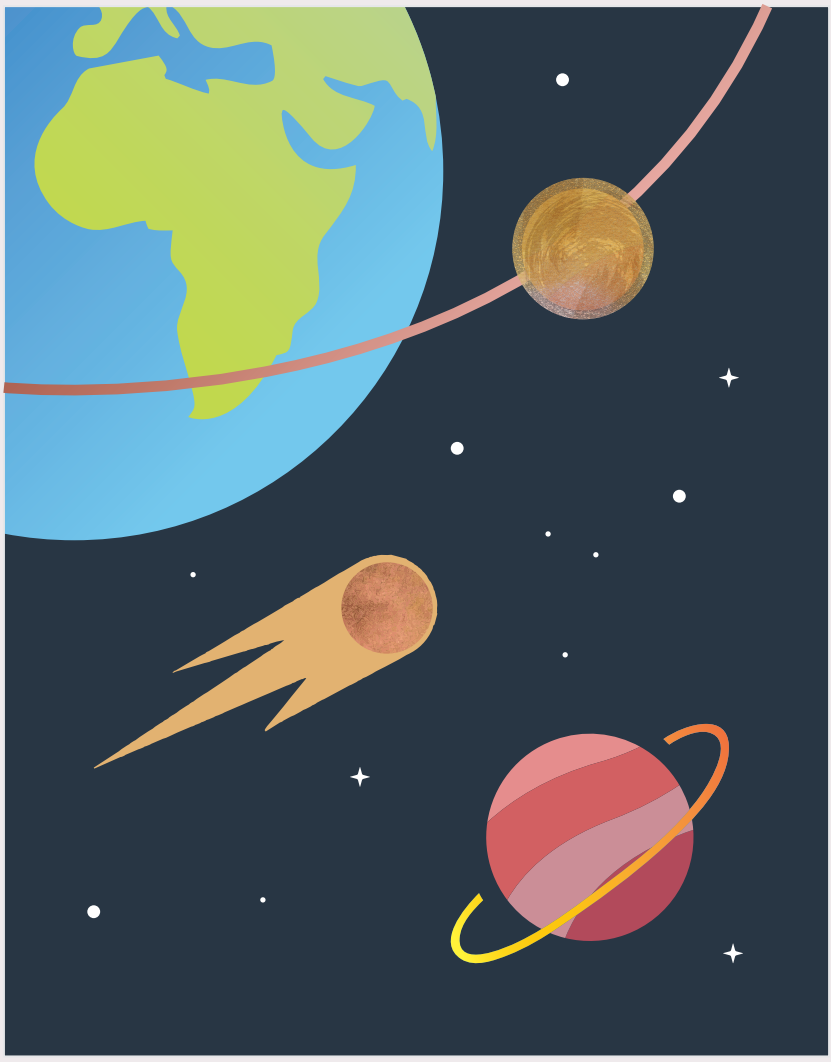
高中自然領域

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(I) 〕



國立彰化師範大學雙語教學研究中心 發行

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★ 第一章 量測 ★
Chapter 1 Measurement

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■ 前言 Introduction

實驗中最重要的是透過各種物理量的量測，來歸納出自然的規律，量測的結果包含數字和單位兩個部分。首先，單位的部分，透過國際單位制所定義的 7 個基本量與單位，可以延伸出其他的導出量與導出單位；而數字位數之取定，則需涵蓋量測工具所能顯示之真值，以及可能誤差。國際標準化組織制定不確定度，以取代原本的誤差概念，並建立量測不確定度的評估與表示規則。不確定度會受儀器、量測者及環境影響，因此本章節帶領同學了解實驗量測數值的正確表達法。

英語在本章中，主要用於讓學生理解不同物理量的名詞。老師可以透過常用語，讓學生更易於認識物理量與其表示法。

1-1 簡介不確定度
Introduction Uncertainty

■ 前言 Introduction

本節學生將學習 A、B 兩類不確定度的概念、計算方法，以應用於量測結果之最佳表示方式，並應注意相似英文名詞間之混淆，以幫助學生理解。

使用英語時，老師要注意避免使用過多統計學上的術語，重點是讓學生了解如何計算不確定度，及正確表示量測結果。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
true value	真值	significant figures	有效位數
error	誤差	estimated value	估計值
uncertainty	不確定度	standard deviation	標準差
average	平均	smallest scale	最小讀數
population standard deviation	母體標準差	instrument accuracy	儀器精確度
sample standard deviation	樣本標準差		

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

❶ ____ equals _____. =____is equal to _____.

例句：Two adds three **equals** five.=Two adds three **is equal to** five.

2 加 3 等於 5。

❷ Round _____ off to _____.

例句：**Round** 357 **off to** 360.

357 四捨五入後，是 360。

❸ Round off the number to the _____place.
=Round off the number to the ____ordinal number ___ decimal place.

例句：**Round off the number to the** tenth **place**.

= **Round off the number to the** first **decimal place**.

將數字四捨五入至小數點第一位。

	0	.	0	0	0	1
round off to the _____ place	ones	decimal point	tenth	hundredths	thousandths	ten-thousandths
round off to the _____ decimal place			first	second	third	fourth

❹ _____ present as _____.

例句：The result should **present as** 0.112 cm.

測量結果應表示成 0.112 公分。

■ 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 the chapter, students are expected to acquire the following concepts:

一、正確表示出量測結果。

Present correct forms of measurements.

二、不確定度的分類及計算。

Classify and evaluate the uncertainty.

三、理解估計值和不確定度的關係。

Grasp the relation between the estimated value and uncertainty.

四、計算一組數據之平均值與標準差。

Calculate the average and the standard deviation of a set of data.

❧ 例題講解 ☙

例題一

說明：正確推算出一組量測數據的平均值與標準差。

Correctly calculate the average and the standard deviation of a set of measurements.

A car service engineer wanted to calibrate the speedometer on a car, so he tested on a nearly straight and undisturbed road. He kept the speedometer at 130 km/h as much as possible while driving. The assistant measured the time it takes for the car to pass through the start and end which are exactly 1.0000±0.0001 km apart by a stopwatch. The stopwatch obtains the following 9 sets of data (in the unit of second): 29.04, 29.02, 29.24, 28.89, 29.33, 29.35, 29.00, 29.25, 29.43. Evaluate the average and standard deviation of the experiment, and show the results in correct forms.

某位汽車維修工程師想要校正車上的時速表，因此在一條幾近筆直且不受干擾的測試道路上，儘可能在行駛過程中讓時速表維持在 130 km/h，而協助者則利用碼表，測量當汽車通過恰相隔 1.0000 ± 0.0001 km 的兩標的物所需要的時間，得到以下 9 組數據（以 s 為單位）：29.04、29.02、29.24、28.89、29.33、29.35、29.00、29.25、29.43，試求出所需時間的平均值與標準差，並以正確形式表示量測結果。

（南一版 111 上選修物理(I)教師手冊 1-1 第 22 頁素養應用題第 1 題）

解題 Solution：

平均值的算法，為所有數據加總，再除以數據總數，計算式如下:

$$平均值 = \frac{29.04 + 29.02 + 29.24 + 28.89 + 29.33 + 29.35 + 29.00 + 29.25 + 29.43}{9}$$

$$= 29.172s$$

(因為測量次數將近 10 次，所以將平均值取至小數點後第三位)

利用所得數據計算標準差為

$$標準差 = \sqrt{\frac{\sum(量測值 - 平均值)^2}{N - 1}} = 0.188s$$

(標準差應配合平均值取至小數點後第三位)

利用所得數據計算 A 類不確定度為

$$u_A = \frac{標準差}{\sqrt{N}} = \frac{0.1883}{\sqrt{9}} = 0.063$$

(不確定度應取至少一位有效數字，通常取二位有效數字，此處取至小數點後第二位)

故，量測結果紀錄為 $29.172 \pm 0.063\ s$ 。

The average is calculated by summing up all the measured values divided by the total number of the data set.

$$\text{Average} = \frac{29.04+29.02+29.24+28.89+29.33+29.35+29.00+29.25+29.43}{9} = 29.172s$$

(because the number of measurements is nearly 10, the average is rounded to the third decimal places)

The standard deviation could be calculated by the set of data.

standard deviation =

$$\sqrt{\frac{\sum(\text{measure value} - \text{average})^2}{N - 1}} = 0.188s$$

(The standard deviation should be rounded to the third decimal places to match the average)

The type A uncertainty could be calculated using the obtained data

$$u_A = \frac{\text{standard deviation}}{\sqrt{N}} = \frac{0.1883}{\sqrt{9}} = 0.063$$

(The uncertainty should be rounded to the third decimal places to match the two significant figures)

Thus, the result should be presented as $29.172 \pm 0.063\ s$.

Teacher: How should the measurement results be correctly presented in this question?

Student: The average plus and minus the standard deviation.

Teacher: Then, how do we calculate the average?

Student: Sum up the nine data points over measurement times.

Teacher: (Writes down the formula of average according to the description of the student.) Yes, and how to calculate the standard deviation?

Student: It could be calculated by the square root of the sum up of the measurements subtracted by the average squared divided by the total number minus one time.

Teacher: (Writes down the formula of standard deviation according to the description of the student.) Correct, then what's the purpose of calculating the standard deviation?

Student: In order to figure out the A type uncertainty.

Teacher: Yes. Could anyone tell me how to calculate the uncertainty?

Student: The square root of the standard deviation has to be divided by the times of the measurements.

Teacher: (Writes down the formula of uncertainty according to the description of the student. $u_A = \frac{\text{standard deviation}}{\sqrt{\text{N}}}$) Great. Could anyone share your calculation?

Student: The average is 29.172 s and the standard deviation is 0.0188 s and the type A uncertainty is 0.063.

Teacher: Correct. How do we show the result?

Student: 29.172 $\pm$ 0.063 s .

Teacher: That's correct.

老師： 請問這一題， 如何正確表示量測結果呢？

學生： 平均值 $\pm$ 不確定度。

老師： 很好，那麼該如何計算平均值呢？

學生： 用量測到的九個數據的和，除以量測次數。

老師： (根據同學敘述，教師寫出平均值之公式) 沒錯，那麼標準差該如何計算呢？

學生： 將所有測值與平均值，取其差值後，取平方後加總，再除以量測值減 1，最後再開根號。

老師： (根據同學敘述，教師寫出標準差之公式)，完全正確，那計算標準差之目的，是為了進一步推算什麼呢？

學生： 要算出 A 類不確定度。

老師：是的，那有沒有同學知道不確定度怎麼算呢？

學生：利用標準差除以量測次數的開根號。

老師：（根據同學敘述，教師寫出不確定度之公式 $u_A = \frac{\text{standard deviation}}{\sqrt{N}}$）。

很棒，那現在請同學開始計算平均值，標準差，以及不確定度的數值，等一下我們請同學分享。

學生：平均值是 29.172 *s*、 標準差是 0.0188 *s*、A 類不確定度是 0.063。

老師：沒錯，那我們該如何表示量測結果呢？

學生：$29.172 \pm 0.063\ s$ 。

老師：沒錯。

例題二

說明：正確表示測量結果。

Describe the measurement results in correct forms.

In an experiment, Xiaoming measured the length of a rectangular box eight times. The data were 12.78 cm, 12.80 cm, 12.75 cm, 12.73 cm, 12.78 cm, 12.81 cm, 12.82 cm, 12.74 cm. Please describe the measurement in the correct form.

小明在某次實驗中針對一個長方形盒子做測量，共測量八次長度，分別為 12.78 cm，12.80 cm，12.75 cm，12.73 cm，12.78 cm，12.81 cm，12.82 cm，12.74 cm，試求不確定度，並以正確形式表示量測結果。

（自翰林版 111 上選修物理(I)教師手冊第 14 頁範例題 1-1）

解題 Solution：

利用所得數據計算平均值為

$$\text{平均值}=\frac{12.78+12.80+12.75+12.73+12.78+12.81+12.82+12.74}{8} = 12.776cm$$

利用所得數據計算標準差為

$$\text{標準差} = \sqrt{\frac{\sum(\text{量測值} - \text{平均值})^2}{N-1}} = 0.033\ \text{cm}$$

(標準差應配合平均值，取至小數點後第三位)

利用所得數據計算 A 類不確定度為

$$u_A = \frac{\text{標準差}}{\sqrt{\text{N}}} = \frac{0.033}{\sqrt{8}} = 0.012$$

(不確定度應取至少一位有效數字，取至小數點後第三位)

故，量測結果紀錄為 12.776 ± 0.012 公分。

The average of the measurement is calculated by the formula below.

$$\text{Average}=\frac{12.78+12.80+12.75+12.73+12.78+12.81+12.82+12.74}{8} = 12.776cm$$

(The standard deviation should be rounded to the third decimal place according to the average)

The standard deviation is calculated by the set of the data as the formula below.

Standard deviation =

$$\sqrt{\frac{\sum(\text{measure value}-\text{average})^2}{\text{N}-1}} = 0.033 \text{ cm}$$

The type A uncertainty could be calculated as:

$$u_A = \frac{\text{standard deviation}}{\sqrt{\text{N}}} = \frac{0.033}{\sqrt{8}} = 0.012$$

(The uncertainty should be rounded to the third decimal place according to the average)

So the measurement result could be record as 12.776 ± 0.012 cm .

Teacher: In this question, what is the correct form to show the measurement results?

Student: The average plus and minus the standard deviation.

Teacher: Then, how do we calculate the average?

Student: Use the eight data points to calculate the average.

Teacher: Then, in order to calculate the uncertainty, what certain value should we know first?

Student: Standard deviation.

Teacher: Correct. How to calculate it? We will have some students write down the standard deviation formula.

Student: Standard deviation $= \sqrt{\frac{\sum(\text{measure value}-\text{average})^2}{\text{N}-1}}$.

Teacher: Great. Does anyone know how to calculate the uncertainty?

Student: The square root of the standard deviation over measurement times ($u_A = \frac{\text{standard deviation}}{\sqrt{\text{N}}}$).

Teacher: Great. Now, please determine the value of the average, standard deviation, and uncertainty. Later we'll have some students share their calculation.

Student: The average is 12.776 cm and the standard deviation is 0.033355 cm and type A uncertainty is 0.012 cm.

Teacher: Correct! But be careful about the significant figures. The number of the digits of the standard deviation and uncertainty should be the same as the average. Thus, after rounding off, the standard deviation should be presented as 0.033cm and the type A uncertainty should remain as 0.012cm.

Teacher: How do we present the results?

Student: 12.776 ± 0.012 cm.

Teacher: That's correct.

老師： 請問這一題，正確形式的量測結果如何表示？

學生： 平均值 ± 不確定度。

老師： 很好，那麼我們該如何計算平均值呢？

學生： 用量測到的八個數據除以量測次數。

老師： 沒錯，接著，為了計算不確定度，應該先計算什麼呢？

學生： 標準差。

老師： 是的，標準差該如何計算呢？請幾位同學上台寫出標準差之公式。

學生： $\text{標準差} = \sqrt{\frac{\Sigma(\text{量測值} - \text{平均值})^2}{\mathrm{N} - 1}}$

老師： 很好，那麼有沒有同學知道不確定度要怎麼算呢？

學生： 利用標準差除以量測次數的根號 $(u_A = \frac{\text{標準差}}{\sqrt{\mathrm{N}}})$。

老師： 很棒，那現在請同學開始計算平均值，標準差，以及不確定度的數值，等一下我們請同學分享。

學生： 平均值是 12.776 公分、標準差是 0.033355 公分、A 類不確定度是 0.012 公分。

老師： 計算結果沒錯，但需注意有效數字的問題，標準差及不確定度，都需與平均值的位數一致。所以，標準差四捨五入後，應表示為 0.033 公分、而 A 類不確定度則維持 0.012 公分。

老師： 那我們該如何表示時間的量測結果呢？

學生： 12.776 ± 0.012 公尺。

老師： 沒錯。

1-2 不確定度的組合
Combination of Uncertainties

■ 前言 Introduction

本節將學習組合不確定度的概念、計算方法以應用於已知相關的物理量上，並應注意相似英文名詞的釐清。

使用英語時，老師要注意學生是否熟知不確定度的概念，再進行組合不確定度，以及物理量加減乘除後的不確定度計算。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
combined uncertainty	組合不確定度	type B uncertainty	B 類不確定度
relative standard uncertainty	相對標準不確定度	plus, sum up	加
the best estimate	最佳估計值	minus	減
physical quantity	物理量	time, multiply	乘
type A uncertainty	A 類不確定度	divide, over	除

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

❶ _____ is calculated by _____

例句：Combined uncertainty could **be calculated by** the square root of sum up of type A uncertainty and type B uncertainty.

組合不確定度，可由 A 型和 B 型不確定度的總和，開根號計算出。

❷ _____ is related to _____

例句：Relative standard uncertainty **is related to** multiplication and division of multiple physical quantities.

相對標準不確定度，和多項物理量之間的乘除運算有關。

❸ _____ has nothing to do with _____.

例句：Relative standard uncertainty **has nothing to do with** the addition and subtraction of various physical quantities.

相對標準不確定度，和各項物理量之間的加減運算無關。

■ 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 the chapter, students are able to acquire the following concepts:

一、量測結果的正確表示。

Present correct forms of measurements.

二、不確定度的分類及其組合。

Classification and combination of the uncertainty.

三、最佳估計值的有效位數和不確定度的關係。

Relation between the significant figures of estimated value and uncertainty.

四、導出量的不確定度評估。

Estimate uncertainty of the derived quantities.

∞ 例題講解 ∞

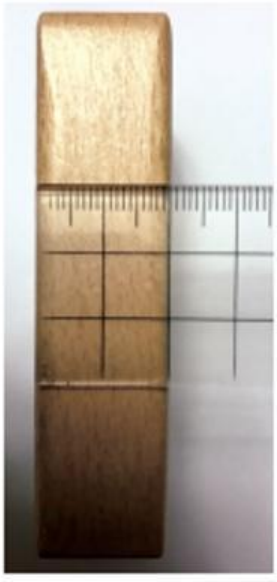
例題一

說明：正確表示出實驗之量測值。

Present the correct forms of measurements in experiments.

Figures 1 to 3 show that A-De uses the ruler, which smallest scale is 1 mm, to measure. Figures 1 to 3 show the measurement of the ruler which least count is 1 mm. The results of the length, width, and height keep showing the same measurements. Please record the length, width, and height of the wood board based on the figures, and include the uncertainty.

圖一到圖三為阿德以最小讀數為 1 mm 的直尺量測一木塊之尺寸，重複多次量測其長、寬、高度，皆顯示相同結果，請根據圖示，正確記錄此木塊的長、寬、高，並包含不準確度。

		
圖一	圖二	圖三

（取自南一版 111 上選修物理(I)教師手冊 1-1 第 12 頁範例 1-1 題）

解題 Solution：

如圖一～圖三所示，直尺最小刻度為 1mm，在量測值均勻分布的前提下，B 類不確定度為 $u_B = \frac{1\text{ mm}}{2\sqrt{3}} = 0.2887\ mm$。

另外，由於多次量測皆顯示相同結果，其標準差為 0，

因此其 A 類不確定度 $u_A = 0$。

綜合上述，組合不確定度表示為

$$u_c = \sqrt{0^2 + (0.2887\ mm)^2} = 0.29\text{ mm}$$

（無條件進位，取到 2 位有效數字）

同時最佳估計值保留至相應的位數，故將木塊的長、寬、高量測結果分別紀錄為：85.00±0.29 mm、41.90±0.29 mm、20.00±0.29 mm。

As the figures 1 to 3 show, the smallest scale of the ruler is the 1mm. If it is the uniform distribution, the type B uncertainty would be

$$u_B = \frac{1\text{ mm}}{2\sqrt{3}} = 0.2887\ mm$$

Furthermore, since the multiple measurements show the same results, its standard deviation is 0. Therefore, The type A uncertainty would be $u_A = 0$

To sum up, the combined uncertainty is

$$u_c = \sqrt{0^2 + (0.2887\ mm)^2} = 0.29\text{ mm}$$

The digits of the best estimate should be the same as the uncertainty, thus, the record of the length, width, and height of the block were recorded as 85.00 ± 0.29mm, 41.90 ± 0.29mm, 20.00±0.29mm respectively.

Teacher: In figures 1 to 3, can you read the value of the ruler measurement?

Student: The length is 85.00 mm, the width is 41.99 mm and the height is 20.00 mm.

Teacher: Good, how do we present the measurements?

Student: The measured value of the ruler and the combined uncertainty.

Teacher: Yes, how do we calculate the combined uncertainty?

Student: The square root of the sum of the type A uncertainty and type B uncertainty.

Teacher: It's great. What's the value of type A uncertainty?

Student: 0.

Teacher: Why?

Student: Because the standard deviation among the measurements is zero.

Teacher: Excellent! Does anyone want to try the value of the type B uncertainty?

Student: Teacher, I don't know how many times I try to calculate, so I can't figure it out.

Teacher: As we just mentioned, if it is a uniform distribution, then we can replace the measurement times with another value, right? We will have some students write down the formula of the type B uncertainty.

Student: $u_B = \frac{instrument\ accuracy}{2\sqrt{3}}$

Teacher: Great. Now please figure out the value of the uncertainty and later we will have some students share the results.

Student: $u_B = \frac{instrument\ accuracy}{2\sqrt{3}} = \frac{1\ \text{mm}}{2\sqrt{3}} = 0.2887\ mm$

Teacher: Well done! However, the number of digits of the uncertainty should have at least one significant figure, but it's usually given with two. So the type B uncertainty should be?

Student: It's 0.29mm.

Teacher: Excellent! Is there anyone who can help calculate the combined uncertainty?

Student: It's 0.29mm.

Teacher: So A-De could use these 85.00±0.29mm, 41.90±0.29mm, 20.00±0.29 mm to present the wood board's width, length, and height.

老師： 在圖一～圖三中，你看到用尺量測出來的數值為何？

學生： 長為 85.00 mm、寬為 41.99 mm，高為 20.00 mm。

老師： 好的，那麼我們該如何表示量測的數值呢？

學生： 尺量出的數值＋組合不確定度。

老師： 沒錯，那組合不確定度該如何計算呢？

學生： $\sqrt{\text{A 類確定度} + \text{B 類不確定度}}$

老師： 很棒，那 A 類不確定度應該是多少呢？

學生： 0。

老師： 為什麼呢？

學生： 因為標準差為 0。

老師： 很棒，那有沒有同學要嘗試看看，B 類不確定度怎麼計算呢？

學生： 老師我不知道量測幾次，所以無法計算。

老師： 我們剛剛有說，如果量測值均勻分布的前提下，是不是可以用其他數值代替呢？請幾位同學上台寫出 B 類不確定度之公式 。

學生： $u_B = \frac{\text{儀器精準度}}{2\sqrt{3}}$

老師： 很棒，那現在請同學開始計算不確定度的數值，等一下我們請同學分享。

學生： $u_B = \frac{\text{儀器精準度}}{2\sqrt{3}} = \frac{1\ \text{mm}}{2\sqrt{3}} = 0.2887\ mm$

老師： 很棒，但不確定度應取至少一位有效數字，通常取二位。所以 B 類不確定度應為何呢？

學生： 0.29 mm。

老師： 很棒，那有沒有同學可以幫忙計算，組合不確定度是多少呢？

學生： 是 0.29 mm。

老師： 很棒，所以阿德量測木塊的長、寬、高就可以由此表示囉。

（教師寫出 85.00±0.29mm、41.90±0.29mm、20.00±0.29mm）

例題二

說明：正確推算不確定度及最佳估計值，並表示測量結果。
Evaluate the uncertainty and the best correctly estimated value, and present the measurements in correct forms.

Student Wang wants to determine the area of the school basketball court by measuring the width and length with a ruler. The measurement shows that the length is 27.96 ± 0.42 m and the width is 13.05 ± 0.16 m. What are the following values regarding the area of the school basketball court?

1. uncertainty.
2. the best estimate.
3. the result of the measurement.

王同學拿捲尺測量學校籃球場的長度和寬度以求得面積，已知其長度的測量結果為 (27.96 ± 0.42) m、寬度的測量結果為 (13.05 ± 0.16) m。
試問此籃球場的面積：

1. 不確定度。
2. 最佳估計值。
3. 測量結果如何表示。

（取自龍騰版 111 上選修物理(I)課本 1-2 第 18 頁 1-2 範例題 1-4）

解題 Solution：

長方形面積是長與寬的乘積，因此需考慮物理量相乘後的不確定度，根據組合不確定度之公式

$$u(A) = |\mathrm{XY}|\sqrt{\frac{u(X)^2}{X^2}+\frac{u(Y)^2}{Y^2}} = \sqrt{Y^2 \times u(X)^2 + X^2 \times u(Y)^2}$$

$$= \sqrt{15.05^2 \times 0.4^2 + 27.96^2 \times 0.16^2} \approx 7.86 = 7.9\, m^2$$

最佳估計值 $\mathrm{A} = \mathrm{XY} = 27.96 \times 15.05 = 420.798 = 420.8\, m^2$

不確定度無條件進位，取二位有效數字。估計值位數取到配合不確定度。

面積是來自長與寬的乘積，所以面積估計值的有效位數，取決於長、寬有效位數中最少的位數。因為長、寬都有 4 個有效數字，所以面積估計值也取 4 位。

最後，估計值之位數，需配合不確定度的最小位數，所以是到小數下一位。

測量結果 $= \mathrm{A} \pm u(A) = 420.8 \pm 7.9$ 平方公尺。

The area of a rectangle is the product of the length and width, so we have to take the uncertainty which is the multiplication of the physical quantity into consideration.

$$u(A) = |\mathrm{XY}| \sqrt{\frac{u(X)^2}{X^2} + \frac{u(Y)^2}{Y^2}} = \sqrt{Y^2 \times u(X)^2 + X^2 \times u(Y)^2}$$

$$= \sqrt{15.05^2 \times 0.4^2 + 27.96^2 \times 0.16^2} \approx 7.86 = 7.9\, m^2$$

The best estimate $\mathrm{A} = \mathrm{XY} = 27.96 \times 15.05 = 420.798 = 420.8\, m^2$

(Keep the same digits of the significant figure as the uncertainty)

The uncertainty is rounded up and given with two significant figures. The number of decimal places in the estimated value should match the uncertainty.

The area is the multiplication of the length and the width, so the significant figures of estimation of the area are determined by the least digits of the length and width among its significant figures. Because there are 4 significant figures of both the length and the width, the digits of the area estimation should be rounded to the same digits: 4 significant figures.

Finally, the estimated value should have the same decimal place as the smallest place in the uncertainty, which means rounding to the next decimal place.

Thus, the measurement result $= \mathrm{A} \pm u(A) = 420.8 \pm 7.9$ m^2

Teacher: About this question, what uncertainty should we take into consideration?

Student: The uncertainty after the multiplication of the physical quantity.

Teacher: Great. How do we calculate the uncertainty?

Student: Based on the width and length that we already knew.

Teacher: Then, what is the formula like?

Student: $u(A) = |\mathrm{XY}| \sqrt{\frac{u(X)^2}{X^2} + \frac{u(Y)^2}{Y^2}} = \sqrt{Y^2 \times u(X)^2 + X^2 \times u(Y)^2}$

Teacher: Good. What are the values of the Y and $u(A)$ here?

Student: Y=15.05，$u(A) = 0.42$.

Teacher: Good. Now please practice calculating and then we will have some students share the results.

Teacher: Could anyone share your calculated result?

Student: About 7.86 m^2.

Teacher: Well done. How should we round the significant figure?

Student: That's 7.9 m^2.

Teacher: That's correct. How do we calculate the best estimate?

Student: Length times width shown in the question.

Teacher: Could anyone share your calculated result?

Student: 420.8 m^2

Teacher: The number is correct and the significant figures are also correct. The digits of the significant after manipulation are according to the least significant figures among all the values.

Teacher: The estimation of length and width have four significant figures. Therefore, the area, which is the product of the length and width, should also have four significant figures.

Teacher: Then, how do we round the uncertainty of the area regarding its significant figures?

Student: Probably 7.9 m^2.

Teacher: Great. Because the minimum number of digits of the area estimation is at the first decimal place, the digits of the uncertainty should be the same.

Teacher: Finally, how to present the results?

Student: 420.8 ± 7.9 m^2.

Teacher: Exactly correct!

老師： 請問這一題推算面積時，要考慮什麼不確定度呢？

學生： 物理量乘除後的不確定度。

老師： 很棒，那麼我們該如何計算物理量乘除後的不確定度呢？

學生： 用題目已知的長、寬測量結果。

老師： 那計算 A 類不確定度的公式應如何呢？

學生： $u(A) = |XY|\sqrt{\frac{u(X)^2}{X^2} + \frac{u(Y)^2}{Y^2}} = \sqrt{Y^2 \times u(X)^2 + X^2 \times u(Y)^2}$ 。

老師： 很好，公式中的 Y 及$u(A)$各是多少？

學生： $Y=15.05$ ，$u(A) = 0.42$ 。

老師： 很好，現在讓大家練習計算，等一下請同學分享數值。
老師： 有人可以分享 A 類不確定度的數值嗎？
學生： 大約 7.86 m^2 。
老師： 做得好。我們應該如何取到適當的有效數字？
學生： 大約是 7.9 m^2。
老師： 沒錯，那我們該如何計算最佳估計值呢？
學生： 用題目已知的長乘寬。
老師： 那有沒有同學可以分享你們算出來的數值是多少呢？
學生： 420.8 平方公尺。
老師： 很好，數值正確，有效位數也正確。相乘除後的有效位數，是取所有數值有效為數最少的為準。
老師： 因為長、寬的測量值，有效位數都是 4 位，所以相乘得到的面積，我們也取有效位數 4 位。
老師： 接著，我們該如何取捨面積不準確值(7.86 m^2)的有效數字呢？
學生： 應該是 7.9 m^2。
老師： 很棒，因為面積的估計值為 420.8 m^2，最小位數是小數下一位，所以不準確值也應配合，取到小數下一位
老師： 最後，該如何表示測量結果呢？
學生： 420.8 ± 7.9 平方公尺。
老師： 沒錯！

1-3 物理量的因次
Dimension of a Physical Quantity

■ 前言 Introduction

本節將介紹 SI 制(國際單位制)定義出的 7 個基本單位，並利用基本單位導出其他物理量的單位，我們稱為導出單位。在這裡要特別注意，同一個物理量可能使用不同單位，但不管用什麼單位，他們所代表的物理量仍然相同，也是來自相同基本量推導的結果，也就是每個物理量具有相同的因次。

老師使用英語時，要先注意學生是否認得 SI 制所定義的 7 個基本單位的單字，再進行導出物理量的說明與應用。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
base units	基本單位	acceleration	加速度
derived units	導出單位	angular velocity	角速度
unit	單位	frequency	頻率
displacement	位移	hertz	赫茲
meter	公尺	force	力
kilometer	公里	dimension	因次
mass	質量	dimension analysis	因次分析

time	時間	squared	平方
second	秒	cubed	立方
velocity	速度	brackets	中括號

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

❶ The dimension of _____ is represented as _____.

例句：The dimension of velocity **is represented as** $[L][T]^{-1}$.
速度的因次是以 $[L][T]^{-1}$ 呈現。

❷ The units of _____ could be _____ per _____.

例句：One of the units of velocity **could be** kilometers **per** hour.
速度其中一種單位可表示成 km/hr。

❸ _____ squared

例句：5^2: five **squared**
5^2：5 的平方

❹ _____ cubed

例句：5^3: five **cubed**
5^3：5 的立方

❺ **(cardinal number) to the power of (negative) (cardinal number)**
= (cardinal number) to the (negative) (ordinal number) power
= (cardinal number) to the (negative) (ordinal number)

例句：5^4
= five **to the power** of four
=five **to the** fourth **power**
=five **to the** fourth

■ 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 the chapter, students are able to acquire the following concepts:
一、認識 SI 單位的物理量。
Know the physics quantity of IS units.
二、求出導出物理量的因次。
Evaluate the dimensions of derived physical quantities.

❧ 例題講解 ☙

例題一

說明：根據每個物理量的因次，推導物理量之間的數學關係。
Analyze the dimensions of the physical quantities.

Assume that in a rippled water bank, possible related physical quantities to wave speed would be the gravity "g", the density of water "ρ" and the depth of the water "D". Which of the following statements is true?

(A) v is proportional to gD
(B) v is proportional to ρgD
(C) v is proportional to $\sqrt{gD}$
(D) v is proportional to $g\sqrt{D}$
(E) v is proportional to $\frac{1}{\sqrt{gD}}$

假設在水波槽中，與水波波速可能有關的物理量為重力加速度 g、水的密度 ρ，與水深 D。若僅以上述三個物理量的因次來判斷波速 v，則下列何者正確？

(A) v 正比於 gD

(B) v 正比於 ρgD

(C) v 正比於 $\sqrt{gD}$

(D) v 正比於 $g\sqrt{D}$

(E) v 正比於 $\frac{1}{\sqrt{gD}}$

（取自 110 年物理科指考題 2）

解題 Solution：

先釐清所有物理量的因次，再來檢視波速的可能推導來源

重力加速度 g：單位為 $\frac{m}{s^2}$，因次：$[L][T]^{-2}$

水的密度 ρ：單位為 $\frac{kg}{m^3}$，因次：$[L]^{-3}[M]$

水深 D：單位為 m，因次：$[L]$

波速 v：單位為 $\frac{m}{s}$ ，因次：$[L][T]^{-1}$

令 $([L][T]^{-2})^x([L]^{-3}[M])^y[L]^z = [L][T]^{-1}$

由因次式 L 可得：$x - 3y + Z = 1$

由因次式 M 可得：$y = 0$

由因次式 Z 可得：$-2x = -1$

由上述可知，$x = z = \frac{1}{2}$、$y = 0$

綜合上述可得 v ＝$\sqrt{gD}$

First clarify the dimensions of all physical quantities, and then examine the possible sources of derivation of the wave speed.

Gravity “g”: the unit of it is “meter per second square” ($\frac{m}{s^2}$). Its dimension is $[L][T]^{-2}$

The density of water “ρ”: the unit of it is “kilogram per meter” cubed ($(\frac{kg}{m^3})$.

Its dimension is $[L]^{-3}[M]$

The depth of water "D": the unit of it is "meter" (m). Its dimension is $[L]$

The wave speed "v": the unit of it is "meter per second". Its dimension is $[L][T]^{-1}$

Let $([L][T]^{-2})^{x}([L]^{-3}[M])^{y}[L]^{z} = [L][T]^{-1}$

From the dimension of [L], we can know $x - 3y + Z = 1$

From the dimension of [M], we can know $y = 0$

From the dimension of [Z], we can know $x = z = \frac{1}{2},\ y = 0$

To sum up, we can know, v $= \sqrt{gD}$

Teacher:	In this lesson, we know that all physical quantities can be derived from the basic units. Does any volunteer want to share the three dimensions of the physical quantities in the question?
Student:	The dimension of the gravity would be $[L][T]^{-2}$, the dimension of the ρ would be $[L]^{-3}[M]$ and the dimension of D would be $[L]$.
Teacher:	Great, how about the dimensions of the wave speed?
Student:	$[L][T]^{-1}$
Teacher:	Good. How do we use these three physical quantities to infer the dimensions of the wave speed?
Student:	Setting an unknown.
Teacher:	How?
Student:	Let the x power of the g, times the y power of the density, times the z power of the water depth, be the negative one power of the wave speed.
Teacher:	(According to what student describe, teacher writes down the equation of $([L][T]^{-2})^{x}([L]^{-3}[M])^{y}[L]^{z} = [L][T]^{-1}$) Let's have some students come up to the podium and solve the problem.
Student:	From the dimension of [L], we can know $x - 3y + Z = 1$ From the dimension of [M], we can know $y = 0$ From the dimension of [Z], we can know $x = z = \frac{1}{2},\ y = 0$
Teacher:	That's right. Does anyone know what the power of the three quantities would be equal to the wave speed?
Student:	Both gravity and depth of water are $\frac{1}{2}$ and the for the ρ would be 0.

Teacher: That's correct. So which option should we choose?

Student: probably is (C)

Teacher: Excellent! That's correct.

老師： 從課堂中，我們知道導出物理量需要由基本物理量導出，有沒有同學願意分享題目中三個物理量的因次？

學生： 重力加速度為 $[L][T]^{-2}$、水的密度為 $[L]^{-3}[M]$、水深為 $[L]$

老師： 很好，那波速的因次呢？

學生： $[L][T]^{-1}$。

老師： 很好，接著我們該如何利用上述三個物理量，推出波速呢？

學生： 假設未知數。

老師： 如何假設呢？

學生： 令重力加速度的 x 次方，乘密度的 y 次方，乘水深的 z 次方，是波速的-1次方

老師： （由同學描述寫下數學式：$([L][T]^{-2})^x([L]^{-3}[M])^y[L]^z = [L][T]^{-1}$）
請同學上台練習解出數學式

學生： 由因次式 L 可得：$x - 3y + Z = 1$

由因次式 M 可得：$y = 0$

由因次式 Z 可得：$-2x = -1$

由上述可知，$x = z = \frac{1}{2}$、$y = 0$

老師： 非常棒，所以是重力加速度、水的密度、水深算出來假設多少次方會剛好等於波速呢？

學生： 重力加速度、水深都是 1/2 次方，水的密度是 0 次方。

老師： 沒錯，那我們答案應該選擇哪一個選項呢？

學生： 應該是（C）。

老師： 很棒，答對了。

例題二

說明：物理量的因次分析。
Dimension analysis of physics quantities.

To understand how the sound wave transmits in metal, we can use a simplified one-dimensional model. We can take a metal atom as the small ball of mass “m” and line up to a line with the spacing “D”. And two adjacent small balls are connected by a spring with force constant k. The model mimics the applied force among the atoms. In the assumption of the simplified model, using dimensional analysis to infer which option might be the speed in the metal?

欲了解聲波如何在金屬中傳播，可利用簡化的一維模型：將金屬原子視為質量 m 的小球，以間距 d 排列成一直線，且相鄰兩個小球間以力常數 k 的彈簧連結，藉以模擬原子間的作用力。在此簡化模型的假設下，應用因次分析來判定，下列何者可能為金屬中的聲速？

(A) $d\sqrt{\frac{k}{m}}$　(B) $d\sqrt{mk}$　(C) $\sqrt{\frac{dm}{k}}$　(D) $\frac{dk}{m}$　(E) $\frac{mk}{d}$

（取自 105 物理科指考 3）

解題 Solution：
依題意，對力常數、質量、間距、聲速先進行因次分析：

力常數 $k = \frac{F}{\Delta x} = \frac{ma}{\Delta x}$，因次為 $\frac{[M][L][T]^{-2}}{[L]} = [M][T]^{-2}$

質量 m：因次為$[M]$

間距 d：因次為 $[L]$

聲速 v：因次為$[L][T]^{-1}$

以上四個物理量，共涉及 $[M][L][T]$ 三種因次，可以先選其中 $[L]$ 因次來推理，v 與 d 都含有 $[L]$ 的一次方，所以 d 應與 v 成正比；選項(A)、(B)、(D)有可能。接著，用 $[T]$ 來推理，可得 v 與 $\sqrt{k}$ 正比，選項剩下(A)、(B)可能；最後再用 $[M]$ 因次，得知 v 與 k/m 或 m/k 正比，所以只有(A)正確。

According to the question, we can analyze the dimensions of the elastic constants, mass, density and velocity of sound:

Elastic constants, $k = \frac{F}{\Delta x} = \frac{ma}{\Delta x}$, the dimension of k is $\frac{[M][L][T]^{-2}}{[L]} = [M][T]^{-2}$.

Mass, m, the dimension is $[M]$

Spacing, D, the dimension is $[L]$

Velocity of sound v , the dimension is $[L][T]^{-1}$

Thus, the dimension of the option (A) is

$$d\sqrt{\frac{k}{m}} = [L] \cdot \sqrt{\frac{[M][T]^{-2}}{[M]}} = [L][T]^{-1}$$

So the answer is (A).

The four physical quantities above are involved in three dimensions. We can analyze the dimension of [L] first. The "*v*" and "*d*" have the one power in the dimension $[L]$ so d should be proportional to the v; thus the answer might be (A), (B) and (D). Then, use $[T]$ to reason, we can get v is proportional to $\sqrt{k}$, and (A) and (B) are left; finally, use $[M]$ dimension to know that v is proportional to k/m or m/k, so only (A) is correct.

Teacher: In this lesson, we know that all physical quantities can be derived from the seven basic units. Does any volunteer want to share the three dimensions of the physical quantities like mass, spacing, and sound speed in the question?

Student: The dimension of the mass would be $[M]$, the dimension of density would be [L] and the sound speed would be $[L][T]^{-1}$.

Teacher: Great, then how do we show the dimensions of the elastic constants *k*?

Student: Can it relate to the force?

Teacher: Yes. Does anyone remember what's the relation between the applied force and elastic constant, *k*?

Student: Can we use Hooke's law?

Teacher: That's correct. How do we use the law?

Student: We divide the force by elongation, the force constants.

Teacher: (Writes down the formula F=*kx*) Yes, the force constant (k) represents the amount of force required per unit length of extension of the spring, in N/m

Teacher: Does anyone want to share the dimension of the force constant?

Student: It's $[M][T]^{-2}$.

Teacher: Correct. How do we use these quantities to infer the sound speed?

Student: We have no idea. Teacher.

Teacher: It's okay. We first look at these four physical quantities. They have something in common: They all have the three dimensions of $[M][L][T]$. We can first choose the dimension $[L]$ to infer. What power to the $[L]$ is it in the v and d? Do they have something in common?

Student: One power to the [L]; v should be proportional to the d.

Teacher: Yes, which options might be the answer?

Student: It might be (A) (B) (D).

Teacher: Next, what dimension would you choose to analyze and infer. I will give you minutes to practice. Later we'll have some students share.

Student: We use [T] to infer and v is proportional to the $\sqrt{k}$.

Teacher: Yes, so which options are left?

Student: We still have (A) and (B).

Teacher: Eventually, when we use [M] to infer, what will we get?

Student: V is proportional to either k/m or m/k.

Teacher: So, which option is the correct one?

Student: Option (A).

Teacher: Excellent!

老師： 從課堂中，我們知道導出物理量需要由基本物理量導出，有沒有同學願意分享題目中質量、間距、聲速的因次？

學生： 質量為$[M]$、間距為$[L]$、聲速為$[L][T]^{-1}$。

老師： 很好，那力常數(k)的因次，該如何表示呢？

學生： 和力有關嗎？

老師： 是的，有沒有同學還記得力和力常數的關係？

學生： 可以用虎克定律嗎？

老師： 沒錯，那我們要怎麼用虎克定律呢？

學生： 力除以伸長量是力常數。

老師： (寫出 F=kx 公式)，是的，力常數(k)代表彈簧每伸長單位長度，所需要的力大小，單位是牛頓/公尺。

老師： 那有沒有同學願意分享你們推出來的力常數，因次為何？

學生： 是 $[M][T]^{-2}$。

老師： 沒錯，那接著我們該如何利用這些物理量的判斷聲速呢？

學生： 老師，我不知道。

老師： 沒關係，我們先看到這四個物理量他們都有 $[M][L][T]$ 三種因次，我們可以先選其中 $[L]$ 因次來推理，那 v 與 d 有[L]的幾次方呢？他們有什麼關係呢？

學生： 一次方，v 與 d 應該成正比

老師： 沒錯，所以那些選項幾有可能呢？

學生： 選項(A)、(B)、(D)有可能。

老師： 接著，同學想選擇以什麼來推理呢？請同學練習一下，我們等等請同學分享。

學生： 以 $[T]$ 來推理，可得 v 與$\sqrt{k}$ 正比。

老師： 沒錯，所以選項剩下幾有可能呢？

學生： 選項剩下(A)、(B)可能

老師： 最後，我們用[m]來推理，可以得到什麼呢？

學生： v 與 k/m 或 m/k 正比

老師： 所以只有哪個選項正確呢？

學生： 選項(A)

老師： 太棒了。

★第二章 直線運動★
Chapter 2 Linear Motion

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■ 前言 Introduction

自然界許多物體在空間中的位置，會隨著時間不斷地改變。而物體在空間中的位置隨著時間而變化時，稱為運動。觀察與分析，並描述與推導物體運動的現象，稱為運動學。本章將依序介紹和運動學相關的物理量，透過這些物理量之間的分析與聯結，可以協助我們更有效率地描述及推導，自然界或生活經驗中的運動現象。

英語在本章中，主要用於讓學生認識直線運動，不同物理量的名詞，利用這些名詞能讓學生描述所觀察的運動狀態。

2-1 運動學簡介
Introduction of Kinematics

■ 前言 Introduction

本節學生將學會位移、路徑長、速度、速率、加速度等定義，進而瞭解這些物理量之間的關係，協助描述各種自然或日常現象。

使用英語時，老師應注意各物理量的專有名詞，描述同一種運動狀態，可能會運用到多種不同專有名詞，容易造成學生混淆。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
mechanics	力學	instantaneous velocity	瞬時速度
kinematics	運動學	average speed	平均速率
path length	路徑長	instantaneous speed	瞬時速率
position	位置	acceleration	加速度
displacement	位移	absolute value	絕對值
particle	質點	average acceleration	平均加速度
vector	向量	instantaneous acceleration	瞬時加速度
average velocity	平均速度	be closed to	趨近於

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

❶ _____ at the speed of _____.

例句：A car drives in a straight line **at the speed of** 80 kilometers per hour.
汽車以每小時 80 公里的速率直線行駛。

❷ ____ be opposite to _____.

例句：The direction of the initial velocity **is opposite to** the direction of the subsequent velocity.
初始速度的方向與後續速度的方向相反。。

❸ ____ be the same as _____.

例句：The direction of the initial velocity **is the same as** that of the final velocity.
初始速度的方向和末速相同。

❹ It takes _____ (for sb) to _____.

例句：**It takes 30 minutes for him to** drive for 12 kilometers.
他花了 30 分鐘開車 12 公里。

❺ Sb spend(s) _____ + Ving

例句：**He spends** 30 minutes **driving** for 12 kilometers.
他花了 30 分鐘開車 12 公里。

■ 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 should acquire the following concepts:

一、認識質點的定義。

Know the definition of particles.

二、了解路徑長與位移的差別。

Understand the difference between path length and displacement.

三、分辨速率與速度的不同。

Distinguish the difference between velocity and speed.

四、了解平均加速度與瞬時加速度。

Understand average acceleration and instantaneous acceleration.

五、了解向量的意義。

Understand the meaning of vectors.

六、了解加速度與速度的關係。

Understand the association between acceleration and velocity.

例題講解

例題一

說明：正確分析直線等速率與等加速度運動。

Be able to analyze one dimensional uniform motion and constant acceleration motion.

The improved section of Suhua Highway in the mountainous area has been opened to traffic on the entire line, including some sections in the tunnel, and the maximum speed is officially adjusted to 70 km/h on June 20, 2020. With the current technology, a detection point with automated equipment can be established at every interval in a long tunnel to detect speeding cars at the average speed between the two fixed points. A car drives into a long straight tunnel. The distance between two detections points in a certain section of the tunnel is 4.2 kilometers. The speed of the rear of the car passing through the first detection point is 66 km/h. The speed reaches 74 km/h after 36 seconds of uniform acceleration, followed by 60 seconds of constant speed, and then constant deceleration.

In order that the average speed of the car between the two detection points does not exceed the maximum speed limit of 70 km/h, what is the maximum speed of the car when its tail light pass through the second detection point?

(A) 60 km/hr

(B) 62 km/hr

(C) 64 km/hr

(D) 66 km/hr

(E) 68 km/hr

蘇花公路山區改善路段（簡稱蘇花改）已全線通車，包含隧道內的部分路段，行車最高速限於 2020 年 6 月 20 日正式調整至 70 公里/小時。目前的科技，可以在長隧道內每隔一段區間建置一個具有自動化設備的偵測點，以兩固定點間之平均速率偵測是否超速。有一輛汽車駛入一長直隧道內，隧道內某段區間的兩偵測點間距離為 4.2 公里，該車之車尾通過第一個偵測點時的速率為 66 公里/小時，汽車以等加速運動行駛 36 秒後速率達到 74 公里/小時，接著以等速行駛 60 秒，然後以等減速運動行駛。

為使汽車在兩偵測點之間之平均速率不超過最高速限 70 公里/小時，該車之車尾燈通過第二個偵測點時的最高速率為何？

(A) 60 公里/小時

(B) 62 公里/小時

(C) 64 公里/小時

(D) 66 公里/小時

(E) 68 公里/小時

（取自 109 年物理科指考題第 20 題）

解題 Solution：

汽車以 70 公里/小時等速率行駛 4.2 公里總歷時 $T = \frac{4.2}{70} = \frac{6}{100}$ 小時

第一段等加速行駛距離：$\Delta x_1 = \frac{66+74}{2} \times \frac{1}{100} = \frac{7}{10}$ (公里)

第二段等速行駛距離：$\Delta x_2 = 74 \times \frac{1}{60} = \frac{37}{30}$ (公里)

第三段等減速行駛距離：$\Delta x_3 = 4.2 - \frac{7}{10} - \frac{37}{30} = \frac{34}{15}$ (公里)

由此可知，$\Delta t_3 = \frac{6}{100} - \frac{1}{100} - \frac{1}{60} = \frac{1}{30}$ (小時)

設通過第二個偵測點時的最高速路為 v_3

$$\Delta x_3 = \frac{74 + v_3}{2} \times \frac{1}{30} = \frac{34}{15}$$

故 $v_3 = 62$ (公里/小時)

The car drives for 4.2 kilometers at the speed of 70 km/hr and it takes $T = \frac{4.2}{70} = \frac{6}{100}$ hours

The first constant acceleration driving distance should be $\Delta x_1 = \frac{66+74}{2} \times \frac{1}{100} = \frac{7}{10}$ (kilometer)

The second constant acceleration driving distance should be $\Delta x_2 = 74 \times \frac{1}{60} = \frac{37}{30}$ (kilometer)

The third constant acceleration driving distance should be $\Delta x_3 = 4.2 - \frac{7}{10} - \frac{37}{30} = \frac{34}{15}$ (kilometer)

Then, we can infer that $\Delta t_3 = \frac{6}{100} - \frac{1}{100} - \frac{1}{60} = \frac{1}{30}$ (hour)

Let the highest speed which passes the second detection point be v_3

$\Delta x_3 = \frac{74 + v_3}{2} \times \frac{1}{30} = \frac{34}{15}$

So $v_3 = 62$ (km/hr)

Teacher: Does anyone know how to solve the problem?

Student: No.

Teacher: Let's look at the clue the question provides. Does anyone want to share what you know from the question?

Student: There are three motion processes of the car.

Teacher: Great. What else do you see?

Student: The question also provides the distance between two detection points and the time and speed in each period of road.

Teacher: Good. According to the distance and speed from the two detection points, what can we know?

Student: We can infer the time passing through two detection points.

Teacher: Great. Does anyone want to share the result of how long it takes?

Student: $\frac{6}{100}$ hour.

Teacher: Good job. And then what should we do next?

Student: Because we already know the time required for the first and second motion processes, we can know the time required for the third movement process from the total time.

Teacher: Great. Can anyone show how long it takes in the third motion process?

Student: Is it $\frac{1}{30}$ an hour ?

Teacher: That's correct. And what should we do next?

Student: According to the speed and the distance in each period, we can know the maximum speed in the third movement process.

Teacher: Great. How about calculating it?

Student: Ok.

Teacher: Does anyone finish calculating and can share it with your classmates?

Student: Teacher, my calculation shows that the maximum speed is 62 km/hr.

Teacher: That's correct, which option is the correct answer?

Student: It's (B).

Teacher: Well done!

老師： 有沒有同學想到，這題要怎麼解呢？

學生： 不知道。

老師： 那我們來看看題目給我們的線索，從題目當中知道，汽車一共有幾段不同的運動過程呢？

學生： 總共有三段不同的運動過程。

老師： 很棒，其他同學還有看到甚麼嗎？

學生： 題目有給兩端偵測站的距離，和每一段的時間、速率。

老師： 很棒，從兩端偵測站的距離和兩偵測點的速率，我們可以得到甚麼嗎？

學生： 我們可以得到經過兩端偵測站之間的時間。

老師： 很棒，那有沒有同學願意分享，你們算出來總共歷經多少時間呢？

學生： $\frac{6}{100}$ 小時。

老師： 很棒，那接下來，我們應該怎麼做呢？

學生： 因為題目已經告訴我們第一段和第二段運動過程所需的時間，所以我們可以從總時間知道第三段運動過程所需的時間。

老師： 很棒，那有沒有同學願意分享你們算出來第三段運動過程的時間為何？

學生： 是 $\frac{1}{30}$ 小時嗎？

老師： 沒錯，那接下來，我們還可以怎麼做呢？

學生： 可以由時間和每段運動過程的速率，得知每段運動過程的距離，這樣就可以知道第三段過程所需的最高速率了。

老師： 很棒，那大家要不要嘗試計算看看呢？

學生： 好的。
老師： 有沒有同學已經計算完成，可以和大家分享結果嗎？
學生： 老師，我算出來的最高速率是 62 公里/小時。
老師： 沒錯，所以我們應該選哪個選項呢？
學生： 選(B)。
老師： 沒錯，太棒了！

例題二

說明：能計算平均速度及平均加速度。
Be able to calculate average velocity and average acceleration correctly.

Student Wang throws a yo-yo. The yo-yo was thrown at a speed of 1 meter per second and returned to his hand at the same speed and in the opposite direction after 2 seconds (the position of Wang's hand remained unchanged). The average speed and average acceleration of the yo-yo from leaving Wang's hand to returning to his hand are X m/s and Ym/s^2. Which of the following options can be represented by numbers (X, Y)?

王同學投擲溜溜球(YO-YO 球)。溜溜球以每秒 1 公尺的速率擲出，在 2 秒後以相同速率、相反方向回到他的手中(王同學手的位置未變)。
溜溜球自離開王同學手中到回到他手中的平均速度及平均加速度大小，各為 X m/s 與 Y m/s^2，試問下列哪一選項的數字可表示(X,Y)？

(A) (0,0)
(B) (0,1)
(C) (0.5,1)
(D) (1,0)

（取自 93 年自然科學測題第 11 題）

解題 Solution：

$$\text{平均速度} = \frac{\text{位移}}{\text{時間}}$$

因為位移為 0(回到手中)，所以平均速度為 0。

$$\text{平均加速度} = \frac{\text{速度變化量}}{\text{時間}}$$

由題意可知，一開始和後來的速度方向相反，速度變化為 2m/s，時間 2 秒，因此平均加速度為 1 m/s^2，所以(X,Y) = (0,1)。故選(B)。

Average velocity is equal to displacement divided by time ($\frac{displacement}{\text{time}}$).

Because the displacement is 0, (returned to his hand), the average velocity is 0.

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

From the question, we know that the direction of the velocity is reversed. The change of the velocity is 2 m/s during the 2-second period, so the average acceleration is 1 m/s^2 the (X,Y) = (0,1) the answer is (B).

Teacher: Does anyone know the definition of the average velocity?
Student: Displacement over time.
Teacher: Yes. How much is the displacement in the question?
Student: Is it 0?
Teacher: Right. How come?
Student: It returns back to the hand position.
Teacher: That's right. What's the average velocity in the question?
Student: 0 m/s.
Teacher: Correct. How about the definition of the average acceleration?
Student: Change in velocity over time.
Teacher: That's correct. What are the velocity changes in the question?
Student: Is it 2?
Teacher: Right. How come?
Student: Because the initial velocity is opposite to the latter, the change of the velocity is 2.
Teacher: That's right. So, what is the average acceleration for this question?
Student: 1 m/s^2
Teacher: That's right, since average acceleration= 2(m/s)/2s ＝1m/s. So which option is the answer?
Student: (B).
Teacher: That's correct!

老師： 請問有沒有同學知道平均速度的定義是什麼呢？

學生： 平均速度= $\frac{\text{位移}}{\text{時間}}$。

老師： 沒錯，那麼這題的位移是多少呢？

學生： 是 0 嗎？

老師： 沒錯，為什麼呢？

學生： 是因為回到手上嗎？

老師： 沒錯，那麼這題的平均速度為何呢？

學生： 0 m/s。

老師： 沒錯，那有沒有同學知道，平均加速度的定義是什麼呢？

學生： 平均加速度= $\frac{\text{速度變化量}}{\text{時間}}$。

老師： 沒錯，那麼這題的速度變化量是多少呢？

學生： 是 2m/s 嗎？

老師： 沒錯，為什麼呢？

學生： 因為一開始和後來的速度方向相反，所以速度變化量為 2m/s。

老師： 沒錯，那麼這題的平均加速度為何呢？

學生： 1 m/s^2。

老師： 很棒，平均加速度=2(m/s)/2s = 1m/s^2，所以我們應該選哪個選項呢？

學生： (B)。

老師： 沒錯，太棒了！

2-2 運動關係圖
Kinematics Graphs

■ 前言 Introduction

本節將介紹三種運動關係圖，分別為位置對時間、速度對時間，及加速度對時間的關係圖。透過這些運動關係圖，我們可掌握或推導出更多物體運動的訊息。

使用英語時，老師要先注意幾何圖中有許多幾何名詞，需注意相似名詞間的混淆。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
kinematics graphs	運動關係圖	slope	斜率
position-time graph	位置-時間關係圖(x-t 圖)	area	面積
velocity-time graph	速度-時間關係圖(v-t 圖)	positive value	正值
acceleration-time graph	加速度-時間關係圖(a-t 圖)	time line	時間軸
linear motion	直線運動	secant line	割線
tangent line	切線	curve	曲線

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

❶ _____ be associated with _____.

例句(1)：Slope **is associated with** division.

斜率和除法是有關。

例句(2)：Area **is associated with** multiplication.

面積和乘法有關。

❷ In _____, the __(slope/area)__ represents _____.

例句(1)：**In** a position-time graph**, the slope at a certain point represents** the instantaneous velocity of the moment.

在 x-t 圖中，某一點的斜率，表示此時的瞬時速度。

例句(2)：**In** a velocity-time graph**, the area of the curve represents** the displacement of the process.

在 v-t 圖中，曲線下的面積，表示過程中的位移。

■ 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 should acquire the following concepts:

一、了解位置對時間關係圖。

Be able to understand the position-time graph.

二、了解速度對時間關係圖。

Be able to understand the velocity-time graph.

三、了解速加速度對時間關係圖。

Be able to understand the acceleration-time graph.

例題講解

例題一

說明：掌握加速度-時間關係圖(a-t 圖)的意義。
Comprehend the meaning of an acceleration-time graph (a-t graph).

A car with mass of 1000 kg stops at the intersection and waits for the traffic light. After the light turns green, the car does linear motion in driving straightly toward the direction of +x. The relationship between the acceleration (a) and the position (x) of the first 300m is shown in the figure below. In which segment is the car moving in uniform motion?

(A) 0< *x* <100m

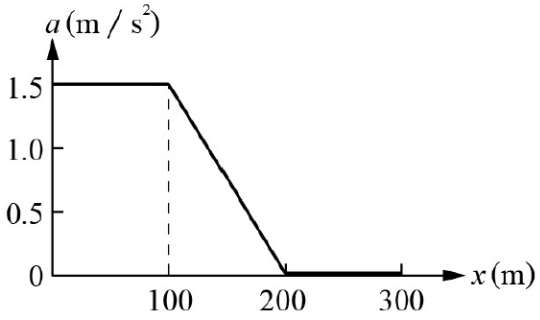
(B) 100m< *x* <200m

(C) 200m<x<300m

(D) 0< *x* <200m

(E) 0< *x* <100m and 200m< *x* <300m

一質量為 1000kg 的汽車，在十字路口(x=0)停下等待，當紅燈轉綠燈後，開始在筆直水平到路上沿 +*x* 方向作直線運動，前 300m 的加速度 a 與位置 *x* 知關係如下圖所示，汽車在下列哪一路段作等速度運動？



(A) 0< *x* <100m

(B) 100m< *x* <200m

(C) 200m<x<300m

(D) 0< *x* <200m

(E) 0< *x* <100m 及 200m< *x* <300m

（取自 108 年物理科指考題第 19 題）

解題 Solution：

由加速度對位移的關係圖得知，在 200m 至 300m 之間的加速度 a=0，因為圖中顯示，此段的加速度維持在零，所以 a=0，故此段作等速度運動。

From the graph, during 200m-300m the acceleration is maintaining in 0, so in the segment, the car is moving with constant velocity motion.

Teacher: Does anyone want to share what "uniform motion" means?
Student: The velocity would be the same.
Teacher: Could you give more explanation? What's the relationship with the acceleration-time graph?
Student: In uniform motion, the acceleration would be 0.
Teacher: That's correct. Which segment represents the car driving with constant velocity motion?
Student: It might be (C).
Teacher: Great! That's correct.

老師： 有沒有同學願意分享，什麼是等速度運動呢？
學生： 速度一直相等。
老師： 同學可以再多說一點嗎？那和"加速度-時間"關係圖，有什麼關係呢？
學生： 等速度運動表示加速度為 0。
老師： 沒錯，那大家覺得哪一段的選項代表汽車作等速度運動呢？
學生： 應該是（C）。
老師： 很棒，答對了。

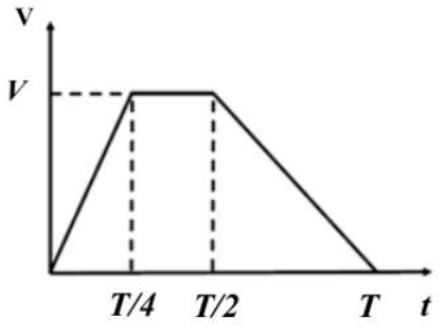
例題二

說明：能計算或分析加速或減速運動的平均速度。

Be able to calculate or analyze the average speed of acceleration and deceleration motion.

A train starts to move straight along the trail from a standstill. The following graph shows the relationship of its velocity and time.

Let the time taken be T and the velocity during $\frac{T}{4} \le t \le \frac{T}{2}$ be V. Which option is the average velocity of the train in the whole way?



一列火車自靜止開始沿著直線軌道前進，其速度 v 與時間 t 的關係如下圖所示。若全程耗時為 T，在$\frac{T}{4} \le t \le \frac{T}{2}$ 時段的速度 v=V，則列車在全程的平均速度為下列何者？

(A) $\frac{V}{3}$　(B) $\frac{V}{2}$　**(C) $\frac{5V}{8}$**　(D) $\frac{3V}{4}$　(E) $\frac{4V}{5}$

（取自 105 年物理科指考題第 4 題）

解題 Solution：

平均速度$= \frac{位移}{時間}$

可由 v-t 圖下的面積求出位移 S

$s = \frac{\left[\left(\frac{T}{2}-\frac{T}{4}\right)+T\right]\times V}{2} = \frac{5}{8}VT$，所以平均速度為 $\frac{\frac{5}{8}VT}{T} = \frac{5}{8}V$ 。

Average velocity $= \frac{displacement}{time\ taken}$

From the area of the v-t graph we can know the displacement (S)

$$s = \frac{\left[\left(\frac{T}{2}-\frac{T}{4}\right)+T\right]\times V}{2} = \frac{5}{8}VT$$

So, the average velocity is $\frac{\frac{5}{8}VT}{T} = \frac{5}{8}V$.

Teacher: Does anyone know the definition of the average velocity?

Student: Change in velocity over the time taken.

Teacher: Correct. Then, how do we calculate the displacement?

Student: The area under the v-t graph is the displacement.

Teacher: Does anyone want to share how long the displacement is?

Student: $\frac{5}{8}VT$.

Teacher: That's correct. So what's the average velocity?

Student: $\frac{5}{8}V$.

Teacher: That's correct. Average velocity $= \frac{\frac{5}{8}VT}{T} = \frac{5}{8}V$.

So, which option should we choose?

Student: (C)

Teacher: That's right! Awesome!

老師： 請問有沒有同學知道平均速度的定義是什麼呢？

學生： 平均速度= $\frac{位移}{時間}$。

老師： 沒錯，那麼我們該如何計算位移呢？

學生： 利用 v-t 圖形下的面積就是位移

老師： 那有沒有同學願意分享位移大小是多少呢？

學生： 位移= $\frac{5}{8}VT$ 。

老師： 很棒，所以我們的平均速度是多少呢？

學生： 平均速度= $\frac{5}{8}V$。

老師： 沒錯，平均速度= $\frac{位移}{時間} = \frac{\frac{5}{8}VT}{T} = \frac{5}{8}V$。所以我們應該選哪個選項呢？

學生： (C)

老師： 沒錯，太棒了！

2-3 等加速運動
Uniform/Constant Acceleration Motion

■ 前言 Introduction

本節將介紹等加速運動的概念及公式，並且應用於自由落體與鉛直上拋運動中，以強化學生對直線等加速運動的理解。

使用英語時，老師要注意等加速運動中有許多物理量，避免學生對不同運動狀態的名詞混淆。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
uniform/constant acceleration motion	等加速運動	vertical projectile motion	鉛直上拋運動
initial moment	初始時刻	opposite	相反
rectangle	矩形	same	相同
trapezoid	梯形	climax	最高點
gravitational acceleration	重力加速度	symmetry	對稱性
free falling	自由落體運動	proportional	成正比
height	高度	inversely proportional	成反比
fall	落下	magnitude	大小

air resistance	空氣阻力	direction	方向
gravity	地球引力		

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

❶ _____ be proportional to _____ when _____ is constant.

例句：According to Newton's Second Law, acceleration **is proportional to** the force exerted **when** the mass **is constant.**

根據牛頓第二定律，當質量固定，加速度會和所受外力成正比。

❷ _____ be inversely proportional to _____ when _____ is constant.

例句：The acceleration **is inversely proportional to** the mass **when** the applied force **is constant.**

當受力固定時，加速度和質量會成反比。

❸ S + get(s)/ become(s) + __(Adj.)__.

例句(1)：When the direction of the gravitational acceleration is opposite to that of velocity, the velocity **would get** slower.

當重力加速度的方向與速度的方向相反時，速度會變慢。

例句(2)：When the direction of gravitational acceleration is the same as that of velocity, the velocity **would become** faster.

當重力加速度的方向與速度的方向相同時，速度會變快。

■ 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 concepts:

一、了解等加速運動的概念與特性。

Understand the concepts and features of constant acceleration motion.

二、了解自由落體運動的特性。

Understand the features of free falling.

三、能分析鉛直上拋運動的特性。

Be able to analyze the features of vertical projectile motion.

四、能夠運用直線等加速運動公式之計算。

Be able to utilize the formulas of linear uniform accelerated motion.

五、能將直線等加速運動公式，應用於自由落體與鉛直上拋運動。

Be able to manipulate the formulas of linear uniform accelerated motion to free falling and vertical projectile motion.

例題講解

例題一

說明：能運用等加速運動公式於自由落體的實例計算。
Be able to manipulate the formulas of uniform acceleration motion to examples of free fall.

When animals jump they bend and straighten their legs to accelerate their jump. The following table shows the vertical height of kangaroos and fleas when they jump. If air resistance is ignored, how many times faster are the kangaroos jumping off the ground than fleas?

	the vertical height of jumping (meter)
kangaroos	2.5
fleas	0.1

動物跳躍時，會將腿部彎曲然後伸直加速跳起。下表是袋鼠與跳蚤跳躍時的垂直高度。若不計空氣阻力，則袋鼠躍起離地的瞬時速率約是跳蚤的多少倍？

	跳躍的垂直高度 (公尺)
袋鼠	2.5
跳蚤	0.1

(A) 1000
(B) 25
(C) 5
(D) 1

（取自 95 年自然科學測題第 29 題）

解題 Solution：
由題目條件可知躍起至最高點的末速為 0，且因不計空氣阻力，所以加速度為重力加速度(g)，作等加速運動。因為題目已知，跟待求出之物理量，皆不含時間(t)，故從三個等加速運動公式選擇公式 $V^2 = {V_0}^2 + 2a\Delta x$，可知 $V_0 \propto \sqrt{\Delta x}$ 因此 $\frac{V_{袋鼠}}{V_{跳蚤}} = \frac{\sqrt{2.5}}{\sqrt{0.1}} = 5$，故選(C)。

From the question, the final velocity of jumping to the highest point is 0. Because air resistance is not considered, the acceleration is the acceleration of gravity (g). Thus, it is a constant acceleration motion. Knowing from the question and the physical quantities, we need to choose the formula that does not include the time(t) from the three formulas of constant accelerated motion.

So we choose $V^2 = {V_0}^2 + 2a\Delta x$.

And we know $V_0 \propto \sqrt{\Delta x}$ (Δx is the displacement and in this question, it refers to the height).

Thus, $\frac{V_{kangaroo}}{V_{\text{flea}}} = \frac{\sqrt{2.5}}{\sqrt{0.1}} = 5$. The answer is (C).

Teacher:	Does anyone know what kind the motion is?
Student:	Uniform accelerated motion and free falling.
Teacher:	Yes, and from the question, when jumping to the highest point what's the direction of the velocity? Should it be upward, downward or 0?
Student:	The final velocity of jumping to the highest point is 0.
Teacher:	Yes. According to the uniformly accelerated motion formula, which formula can we apply?
Student:	$V^2 = {V_0}^2 + 2a\Delta x$.
Teacher:	Yes, knowing from the question and the physical quantities we choose the formula does not include the time(t).
Teacher:	So what's the relation between the height and the speed?
Student:	Velocity is proportional to the root of height.
Teacher:	Yes, Δx is the displacement and in this question, it refers to the height. Do any students know how many times the result is?
Student:	5 times.
Teacher:	Great. Because the height ratio of the two animals is 2.5/0.1= 25 times, and the velocity is inversely proportional to the root of the height. $V^2 = 2a\Delta x$ ($V^2 = 2a\Delta x$, $V \propto \sqrt{\Delta x}$)，the ratio of the velocity is $\sqrt{25}$ =5 times.
Teacher:	Which option is the answer?
Student:	(C).
Teacher:	Yes. Good job!

老師： 請問有沒有同學知道這題作什麼運動呢？

學生： 等加速運動、自由落體運動。

老師： 沒錯，那從題目中，躍起到最大高度時，速度應該向上、向下、或是零呢？

學生： 躍起最大高度時，速率為 0。

老師： 沒錯，那我們應該選擇等加速運動的哪一條公式呢？

學生： $V^2 = {V_0}^2 + 2a\Delta x$。

老師： 很好，因為，題目已知跟待求出之物理量，皆不含時間(t)，所以我們選擇沒有包含 t 的運動公式。

老師： 根據公式，速率和高度有什麼關係嗎？

學生： 速率和高度的平方根成正比。

老師： 沒錯，公式中的 Δx 是位移，在此題就是高度。那有沒有同學想嘗試算看看結果是幾倍呢？

學生： 是 5 倍嗎？

老師： 很棒，因為兩種動物的高度比是 2.5/0.1=25 倍，速度與高度平方根成正比（$V^2 = 2a\Delta x$、$V \propto \sqrt{\Delta x}$），所以速度比是 $\sqrt{25}=$ 5 倍。

老師： 所以我們應該選哪個選項呢？

學生： (C)。

老師： 沒錯，太棒了！

例題二

說明：能分析鉛直上拋運動之速度與加速度大小及方向。

Determine the magnitudes and directions of velocity and acceleration regarding vertical projectile motion.

A stone is thrown vertically upwards and moves with free fall motion. If we ignored the air resistance, which of the following statements are true? (You should choose two options.)

(A) **When the stone is thrown up and falling down, the magnitude of the acceleration is the** same and so are the directions.

(B) When the stone is thrown up and falling down the magnitude of the acceleration is the same but the directions are opposite.

(C) When the stone is thrown up to the highest point the velocity and acceleration are 0.

(D) When the stone is thrown up to the highest point the velocity and acceleration are not 0.

(E) When the stone is thrown up to the highest point the velocity is 0 but acceleration is not.

一石塊垂直上拋後自由落下，如果不計空氣阻力，則下列敘述何者正確(應選二項)？

(A) 石塊往上飛行時和向下掉落時的加速度都是一樣大小，且方向相同。

(B) 石塊往上飛行時和向下掉落時的加速度都是一樣大小，但方向相反。

(C) 石塊往上飛行到最高點時，其速度和加速度皆為零。

(D) 石塊往上飛行到最高點時，其速度和加速度皆不為零。

(E) 石塊往上飛行到最高點時，其速度為零但加速度不為零。

（取自 85 年自然科學測題第 56 題）

解題 Solution：

鉛直上拋運動為一種等加速度運動，加速度維持 g 向下，當質點抵達最高點時為瞬間靜止，所以速度為 0。

因此，(A)(B)選項中，石塊向上飛行和向下掉落時的加速度均為 g，且方向向下；(C)(D)(E)選項中，當石塊飛行到最高點時，速度為 0，加速度為 g，且方向向下。

故選(A)(E)。

Vertical projectile motion is a type of constant acceleration motion with acceleration of gravitational acceleration (“g”) downwards. Also, the velocity is 0 when the particle reaches the highest point.

Thus, in (A) and (B) when the stone is thrown up and falling down, the acceleration is the gravitational acceleration (g) and the direction is downward. In (C), (D), (E), when the stone is thrown upwards to the highest point the velocity is 0 but acceleration is not.
The answers are (A), (E).

Teacher: Does anyone know the characteristics of vertical projectile motion?
Student: The acceleration of gravity (g) and the velocity is 0 when the particle reaches the highest point.
Teacher: Yes. What is the direction of gravitational acceleration?
Student: Downward.
Teacher: Correct. Does the downward acceleration from gravity exist in the entire motion?
Student: Yes.
Teacher: That's correct. Then when reaching the highest point, are the velocity and acceleration both 0?
Student: No, only the velocity is zero. The acceleration is still $g=9.8m/s^2$ with direction downwards.
Teacher: Great. Which options should we choose?
Student: (A) and (E).
Teacher: Correct. Well done.

老師： 請問有沒有同學知道鉛直上拋運動的特性呢？
學生： 加速度 g、當質點抵達最高點速度為 0。
老師： 沒錯，那加速度 g 的方向應朝向哪裡呢？
學生： 向下。
老師： 沒錯，那是整個運動過程的加速度都是 g，且方向向下嗎？
學生： 是的。
老師： 沒錯，那麼在最高點的時候，速度為 0，加速度也為 0 嗎？
學生： 不是喔，只有速度為 0，加速度應該是 g=9.8m/s2 向下。
老師： 很棒，所以我們應該選哪個選項呢？
學生： (A)(E)。
老師： 沒錯，太棒了！

2-4 相對運動
Relative Motion

■ 前言 Introduction

在前面描述物體運動時，我們皆選擇相對於地面靜止的坐標系觀察。而當選擇的坐標系不同時，其位置、速度與加速度，可能會隨之改變。因此，本章節將介紹相對位置、相對速度與相對加速度的概念，以了解運動的相對性。

使用英語時，老師要注意描述相對運動中的名詞與句子，避免過於繞口，而造成學生的混淆。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
coordinate system	坐標系	object	物體
deviation	差值	origin	原點
relative position	相對位置	ground	地面
relative velocity	相對速度	the observed object	被觀察者
relative acceleration	相對加速度	vector	向量
observer	觀察者		

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

❶ _____ with respect to _____ is ____.

例句：The velocity of object A **with respect to** B **is** 2 m/s towards B.

物體 A 相對於 B 的速度是 2 公尺/秒 朝向 B。

❷ For ___, B is at the velocity of _____ towards _(the east / west/ north/ south/ right/ left) .

例句：**For** A, **B is at the velocity of** 90 km/hr **towards** the east.

對 A 來說，B 以 90 公里/小時的速度向東。

❸ ____ appear(s)/ seem(s) to _____.

例句：The ball **appears to** move 10 m/s towards the right with respect to the ground.

相對於靜止地面，這顆球是以 10 m/s 的速度向右移動。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、了解運動的相對性觀點。

Understand the concepts of relative motion.

二、能了解、描述與應用相對位置、相對速度與相對加速度。

Understand, describe and apply relative position, relative velocity, and relative acceleration.

三、能選擇適當的坐標系，有效運用於解題中。

Choose proper coordination and solve physics problems effectively.

例題講解

例題一

說明：能對相對位移進行推理分析 。

Be able to analyze the relative displacement.

Assume that there are two particles start to move toward the north and the east from the origin at uniform accelerated motion with the acceleration of 1 m/s^2. After 2 seconds, how far is the distance between the two particles?

(A)$\sqrt{2}$m

(B) 2m

(C) $2\sqrt{2}$m

(D) 3m

(E) 4m

設有二質點分別以 1 米/秒 ^{2}之等加速度自原點，向正北及正東開始運動。2 秒後二質點之距離為？

(A) $\sqrt{2}$ 米

(B) 2 米

(C) $2\sqrt{2}$米

(D) 3 米

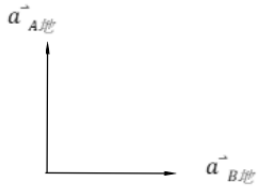
(E) 4 米

（取自 104 學年國立台東高中第一學期物理科期中考第 15 題）

解題 Solution：

設兩物體為 A 與 B

由題目可知相對初速度為 0、$\vec{a}_{A地} = 1m/s^2$(正向北方)、$\vec{a}_{B地} = 1m/s^2$(正向東方)



本題將求兩者之相對位移 S_{AB}。$S_{AB} = \frac{1}{2}\, a_{AB} t^2$

兩者之間的相對加速度 $\vec{a}_{AB} = \vec{a}_{A地} - \vec{a}_{B地} = \vec{a}_{A地} + \vec{a}_{地B}$

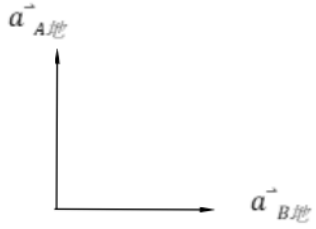
經由向量的運算可知 $a_{AB} = \sqrt{2}\, m/s^2$

因此 $S_{AB} = \frac{1}{2}\, a_{AB} t^2 = \frac{1}{2} \cdot \sqrt{2} \cdot 2^2 = 2\sqrt{2}$ (m)，故選(C)。

Let the two objects be A and B.

From the question description, the relative initial velocity is 0 and

$\vec{a}_{A \text{ to the Earth}} = 1m/s^2$ (toward the north) and $\vec{a}_{B \text{ to the Earth}} = 1m/s^2$ (toward the east)



The question aims to require the relative displacement with respect to each other S_{AB}

$$S_{AB} = \frac{1}{2}\, a_{AB} t^2$$

The relative velocity with respect to each other

$$\vec{a}_{AB} = \vec{a}_{A\ to\ the\ Earth} - \vec{a}_{B\ to\ the\ Earth} = \vec{a}_{A\ to\ the\ Earth} + \vec{a}_{The\ earh\ to\ B}$$

From the operation of the vector, we can know $a_{AB} = \sqrt{2}\, m/s^2$

Thus $S_{AB} = \frac{1}{2}\, a_{AB} t^2 = \frac{1}{2} \cdot \sqrt{2} \cdot 2^2 = 2\sqrt{2}$ (m)

The answer is (C).

Teacher: Does anyone know what we need to know from the question?

Student: Distance.

Teacher: Yes. Is it the relative distance to the ground or something else?

Student: The relative distance between the two particles.

Teacher: Yes. How do we calculate it?

Student: We have no idea.

Teacher: From the clues, the question provides, what kind of motion does it perform?

Student: Uniformly accelerated motion.

Teacher: Great. Is there any uniformly accelerated motion formula related to the distance and time we can apply to this question?

Student: $S = V_0 t + \frac{1}{2} a t^2$.

Teacher: Good. How do we deal with the two particles by using the formula?

Student: $S_{AB} = V_{0_{AB}}t + \frac{1}{2}\,a_{AB}t^2$.

Teacher: Great. Does anyone want to share what the relative initial velocity and relative acceleration should be?

Student: The relative initial velocity should be 0 and the relative acceleration should be $\sqrt{2}$

Teacher: That's correct. How does the relative acceleration $\sqrt{2}$ come out?

Student: The relative acceleration between the two particles is

$$\vec{a}_{AB} = \vec{a}_{A\ to\ the\ Earth} - \vec{a}_{B\ to\ the\ Earth} = \vec{a}_{A\ to\ the\ Earth} + \vec{a}_{The\ earh\ to\ B}$$

then, use the operation of the vector.

Teacher: Excellent. Since the two particles move orthogonally to each other. The relative displacement between the two is the hypotenuse of the tracks of the two particles.

Teacher: So, what option should we choose?

Student: (C).

Teacher: Correct. Good job.

老師： 請問有沒有同學知道，這題要我們求的是什麼呢？

學生： 距離。

老師： 沒錯，那是相對於地面的距離嗎？還是其他呢？

學生： 是兩質點的相對距離。

老師： 沒錯，那我們該如何算相對距離呢？

學生： 不知道。

老師： 我們可以先從題目給我們的線索，看看這兩質點是做什麼運動呢？

學生： 等加速運動。

老師： 很棒，那有沒有同學記得等加速有什麼和距離、時間相關的公式，可以使用呢？

學生： $S = V_0t + \frac{1}{2}at^2$。

老師： 很棒，那我們該如何把兩質點相對情形放進去公式內表示呢？

學生： $S_{AB} = V_{0_{AB}}t + \frac{1}{2}\,a_{AB}t^2$。

老師： 非常棒，那有沒有同學願意分享相對初速和相對加速度應為何呢？

學生： 相對初速為 0，相對加速度為 $\sqrt{2}$。

老師： 沒錯，那你是怎麼計算出相對加速度是 $\sqrt{2}$ 呢？

學生： 兩者之間的相對加速度 $\vec{a}_{AB} = \vec{a}_{A地} - \vec{a}_{B地} = \vec{a}_{A地} + \vec{a}_{地B}$，接著利用向量的運算。

老師： 非常棒，因為兩質點的方向互相垂直，所以兩質點距離，相當於它們所走路徑的斜邊。

老師： 所以我們應該選哪個選項呢？

學生： (C)。

老師： 沒錯，太棒了！

例題二

說明：能正確推算出相對速度。

Be able to analyze relative velocity correctly.

A car moving forward horizontally, at the same time, there is no wind but is raining heavily. If the velocity of the rain is 30 m/s then, the velocity of rain measured on the car would be?

(A) 30m/s

(B) 40m/s

(C) 50m/s

(D) 60m/s

(E) 70m/s

汽車以 40 公尺/秒之速度水平前進，此時無風而下大雨，若雨速為 30 公尺/秒，則在車上所測得之雨速為？

(A) 30 公尺/秒

(B) 40 公尺/秒

(C) 50 公尺/秒

(D) 60 公尺/秒

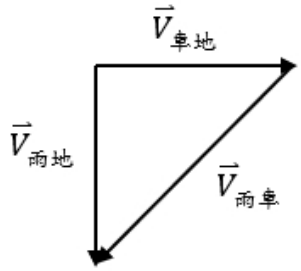
(E) 70 公尺/秒

（取自 60 年夜大）

解題 Solution：

由題目可知 $\vec{V}_{雨地} = 30m/s$(向下方)、$V_{車地} = 40m/s$(向右方)。

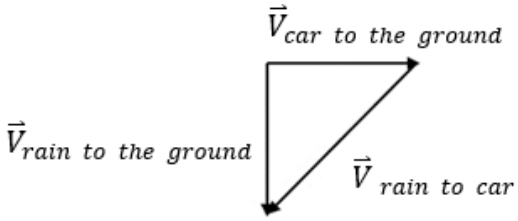
本題將求兩者之相對速度 $V_{雨車}$



相對速度 $\vec{V}_{雨車} = \vec{V}_{雨地} - \vec{V}_{車地} = \vec{V}_{雨地} + \vec{V}_{地車}$。

經由向量的運算可知 $V_{雨車} = 50$ 公尺／秒，故選(C)。

According to the question, we can know the $\vec{V}_{\text{rain to place}} = 30m/s$ (downward) and $\vec{V}_{car\ to\ the\ ground} = 40m/s$(rightward)



Relative velocity

$\vec{V}_{rain\ to\ car} = \vec{V}_{rain\ to\ the\ ground} - \vec{V}_{car\ to\ the\ ground} = \vec{V}_{rain\ to\ the\ ground} + \vec{V}_{The\ ground\ to\ car}$

By the operation of the vector, the $V_{rain\ to\ car} = 50$ *m/s*. The answer is (C).

Teacher: Does anyone know what the question wants us to find out?

Student: The velocity of the rain with respect to the car.

Teacher: Yes. What's the relation to the velocity of the rain with respect to the car?

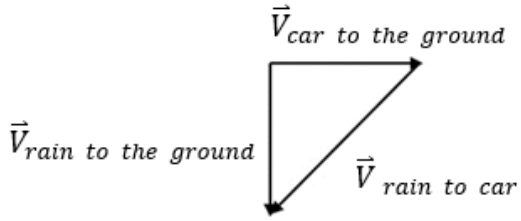
Student: The velocity of the rain with respect to the ground and the velocity of the car with respect to the ground.

Teacher: Yes, and how do we present the equation?

Student: $\vec{V}_{rain\ to\ car} = \vec{V}_{rain\ to\ the\ ground} - \vec{V}_{car\ to\ the\ ground}$

$= \vec{V}_{rain\ to\ the\ ground} + \vec{V}_{The\ ground\ to\ car}$

Teacher: Very good. Let's draw the direction of these vectors.



Teacher: Correct. Does anyone want to share how we calculate the relative velocity of rain to the car?

Student: By the operation of the vectors.

Teacher: Great. Does anyone want to share the result of the relative velocity of rain to the car?

Student: It's 50 m/s.

Teacher: Bravo. So $V_{rain\ to\ car} = \sqrt{30^2 + 40^2} = 50$ m/s .

Teacher: Which option is the answer?

Student: (C).

Teacher: Correct. Well done!

老師： 請問這題要我們求什麼？

學生： 雨相對於車的速度。

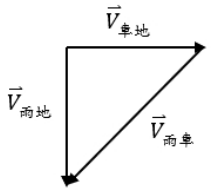
老師： 沒錯，雨相對車的速度會跟什麼有關呢？

學生： 雨相對於地面的速度，和車相對於地面的速度。

老師： 沒錯，那我們該如何以數學式表示呢？

學生： $\vec{V}_{雨車} = \vec{V}_{雨地} - \vec{V}_{車地} = \vec{V}_{雨地} + \vec{V}_{地車}$。

老師： 沒錯，讓我們一起畫出這些向量的方向。



老師： 那有沒有同學願意分享，我們該如何計算 $\vec{V}_{雨車}$ 呢？

學生： 透過向量的運算。

老師： 很棒，那有沒有同學願意分享，你們算出來雨相對於車的速度為何呢？

學生： 是 50 公尺/秒。

老師： 非常棒，所以 $V_{雨車} = \sqrt{30^2 + 40^2} = 50$ 公尺/秒。

老師： 所以我們應該選哪個選項呢？

學生： (C)

老師： 沒錯，太棒了！

★第三章 平面運動★
Chapter 3 Plane Motion

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國立彰化師範大學英語系　巫冠誼

■ 前言 Introduction

日常生活中物體的運動軌跡，可能是直線，或沿著平面上曲線進行，甚至是立體的三維軌跡。當物體軌跡非直線時，如：沿著平面進行曲線軌跡運動時，屬於平面運動。此時，因為運動軌跡的方向改變，我們需要透過向量來討論其運動現象。本章中，我們將先介紹向量的基本規則，平面運動通常需要分解成兩個彼此互相垂直的直線運動，並應用前一章所學有關直線運動的概念，來探討平面運動的問題。

英語在本章中，除了需要引用前一章的物理用語，還須加上向量相關之語詞，來描述本章的平面運動現象。老師可以透過日常用語，讓學生更易於理解其運動情形與表示法。

3-1 平面向量
Plane Vector

■ 前言 Introduction

本節學生將學習向量的平移、向量的加法與減法、純量與向量的相乘、向量的分解，與坐標表示法等，以便描述平面運動的物理現象。

使用英語時，老師需介紹各物理量的單字，且注意相似運動現象，可能運用到的不同名詞避免混淆。另外，學生容易將平行/水平，還有鉛直/垂直相混淆。所以需要特別提醒。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
vector	向量	trigonometric functions	三角函數
scalar	純量	diagonal	對角線
parallelogram	平行四邊形	rectangular coordinates	直角坐標
triangle	三角形	Pythagorean theorem / Pythagoras' theorem	畢氏定理
addition	加法	magnitude	量值(大小)
subtraction	減法	direction	方向
translation	平移	parallel	平行
arrow	箭頭	perpendicular	垂直

reversion	反向	vertical	鉛直
angle	角度	horizontal	水平

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

❶ The __horizontal/vertical__ components of vector A is _____.

例句：**The** horizontal **components of vector A is** $\vec{A}\perp$.

$\vec{A}$ 的垂直分量被表示為$\vec{A}\perp$。

❷ _____ could be decomposed into _____.

例句：The velocity of a block on an inclined plane **could be decomposed into** horizontal and vertical components.

木塊在斜坡上的速度，可以被分解為水平與垂直分量。

❸ The absolute value of _____ is _____.

例句：**The absolute value of** vector A **is** equal to the root of the A_x squared plus A_y squared.

向量 A 的絕對值等於根號A_x平方加A_y平方。$|\vec{A}| = \sqrt{{A_x}^2 + {A_y}^2}$

❹ The component(s) of _____ onto _____ are _____ (and) _____.

例句：**The components of** $\vec{A}$ **onto** Coordinate axis **are** $\overrightarrow{A_x}$ *and* $\overrightarrow{A_y}$.

$\vec{A}$ 在 x, y 坐標軸上的分量，分別表示為 $\overrightarrow{A_x}$ 和 $\overrightarrow{A_y}$。

■ 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、了解向量的表示法。

Understand how to present vectors.

二、向量的加法與減法。

Addition and subtraction of vectors.

三、了解向量的分解與坐標表示法。

Understand vector decomposition and coordinate notation.

四、純量與向量之間的相乘。

The multiplication between scalars and vectors.

❧ 例題講解 ☙

例題一

說明：正確進行分量形式的向量加法。

Addition of vectors in terms of component forms.

There are two vectors on the plane which are $\vec{A} = 6\hat{\imath} + 5\hat{\jmath}$ and $\vec{B} = 2\hat{\imath} + 1\hat{\jmath}$.
Try to answer the magnitude of resultant vector of $\vec{A} + \vec{B}$.

(A) 2　　(B) 6　　(C) 8

(D) 10　　(E) 14

平面上有兩個向量，其中$\vec{A} = 6\hat{\imath} + 5\hat{\jmath}$、 $\vec{B} = 2\hat{\imath} + 1\hat{\jmath}$，試回答向量 $\vec{A} + \vec{B}$ 的量值為多少？

(A) 2　　(B) 6　　(C) 8

(D) 10　　(E) 14

（取自龍騰版 111 年選修物體 I 第三章第 86 頁 3-1 習題 1）

解題 Solution：

此題需先分別將 i, j 分量加總，之後再透過畢氏定理，計算總和向量的斜邊，即為兩向量和之量值大小。

$\vec{A}+\vec{B}=(6\hat{\imath}+5\hat{\jmath})+(2\hat{\imath}+1\hat{\jmath})=8\hat{\imath}+6\hat{\jmath}$

$|\vec{A}+\vec{B}|=\sqrt{8^2+6^2}=10$

故選(D)。

Firstly, we need to calculate the addition of components i and j, then by using the Pythagorean theorem, calculate the bevel edge, which is the magnitude of two vectors.

$\vec{A}+\vec{B}=(6\hat{\imath}+5\hat{\jmath})+(2\hat{\imath}+1\hat{\jmath})=8\hat{\imath}+6\hat{\jmath}$

$|\vec{A}+\vec{B}|=\sqrt{8^2+6^2}=10$

The answer is (D).

Teacher: For this question, we need to calculate the addition of components i and j, then by using the Pythagorean theorem to calculate the bevel edge, which is the magnitude of two component vectors.

Teacher: Write down the two equations, $\vec{A}=A_x\hat{\imath}+A_y\hat{\jmath}$ and $|\vec{A}|=\sqrt{{A_x}^2+{A_y}^2}$, on the blackboard and let students practice for a while and ask them to share the calculation.

Student: $\vec{A}+\vec{B}=(6\hat{\imath}+5\hat{\jmath})+(2\hat{\imath}+1\hat{\jmath})=8\hat{\imath}+6\hat{\jmath}$

$|\vec{A}+\vec{B}|=\sqrt{8^2+6^2}=10$

Teacher: That's correct, which option is the correct answer?

Student: It's (D).

老師： 此題我們需先將兩個向量的 i, j 分量分別加總，之後再透過畢氏定理，計算總和向量的斜邊，即為兩向量和之量值大小。

老師： 將 $\vec{A}=A_x\hat{\imath}+A_y\hat{\jmath}$、$|\vec{A}|=\sqrt{{A_x}^2+{A_y}^2}$ 二式寫於黑板上，並請學生練習，等一下請學生上台分享計算過程。

學生： $\vec{A}+\vec{B}=(6\hat{\imath}+5\hat{\jmath})+(2\hat{\imath}+1\hat{\jmath})=8\hat{\imath}+6\hat{\jmath}$

$|\vec{A}+\vec{B}|=\sqrt{8^2+6^2}=10$

老師： 沒錯，所以我們應該選哪個選項呢？
學生： 選(D)。
老師： 沒錯，太棒了！

例題二

說明：進行分量形式向量的加法，及其絕對值之算法。

Adding the component vectors and calculating the magnitude of the sum vector.

Given the vectors $\vec{A}=(A_x, A_y)=(2, 3)$ and $\vec{B}=(B_x, B_y)=(3, -2)$, determine the following:

(1) What are $\vec{A}+\vec{B}$, $|\vec{A}+\vec{B}|$?

(2) What are $\vec{A}+3\vec{B}$, $|\vec{A}+3\vec{B}|$?

(3) What are $-3\vec{A}+\vec{B}$, $|-3\vec{A}+\vec{B}|$?

若 $\vec{A}=(A_x, A_y)=(2, 3)$，$\vec{B}=(B_x, B_y)=(3, -2)$，則：

(1) $\vec{A}+\vec{B}$ 與 $|\vec{A}+\vec{B}|$ 各為何？

(2) $\vec{A}+3\vec{B}$ 與 $|\vec{A}+3\vec{B}|$ 各為何？

(3) $-3\vec{A}+\vec{B}$ 與 $|-3\vec{A}+\vec{B}|$ 各為何？

（取自翰林版 111 上選修物理 I 習作第七回例題 5）

解題 Solution：

兩個向量相加的結果，可以只推得其向量和之大小，稱為量值；也可以推得分量形式的合向量，包含：大小及方向。計算過程如下：

When adding two vectors, we can calculate the magnitude of the sum vector, or the addition of the two vectors in a component form including the magnitude and direction, as the calculation below.

(1) $\vec{A}+\vec{B}=(2, 3)+(3, -2)=(5, 1)$，$|\vec{A}+\vec{B}|=\sqrt{5^2+1^2}=\sqrt{26}$

(2) $\vec{A}+3\vec{B}=(2, 3)+3\times(3, -2)=(2, 3)+(9, -6)=(11, -3)$

$$|\vec{A}+3\vec{B}|=\sqrt{11^2+(-3)^2}=\sqrt{130}$$

(3) $-3\vec{A}+\vec{B}=-3\times(2,3)+(3,-2)=(-6,-9)+(3,-2)=(-3,-11)$

$|-3\vec{A}+\vec{B}|=\sqrt{(-3)^2+(-11)^2}=\sqrt{130}$

Teacher: Write down the two equations, $\vec{A}=A_x\hat{i}+A_y\hat{j}$ and $|\vec{A}|=\sqrt{{A_x}^2+{A_y}^2}$, on the blackboard and let students practice for a while and ask them to share the calculation.

Student: (1) $\vec{A}+\vec{B}=(2,3)+(3,-2)=(5,1)$，$|\vec{A}+\vec{B}|=\sqrt{5^2+1^2}=\sqrt{26}$

(2) $\vec{A}+3\vec{B}=(2,3)+3\times(3,-2)=(2,3)+(9,-6)=(11,-3)$

$|\vec{A}+3\vec{B}|=\sqrt{11^2+(-3)^2}=\sqrt{130}$

(3) $-3\vec{A}+\vec{B}=-3\times(2,3)+(3,-2)=(-6,-9)+(3,-2)$
$=(-3,-11)$

$|-3\vec{A}+\vec{B}|=\sqrt{(-3)^2+(-11)^2}=\sqrt{130}$

Teacher: That's correct!

老師：將$\vec{A}=A_x\hat{i}+A_y\hat{j}$、$|\vec{A}|=\sqrt{{A_x}^2+{A_y}^2}$ 二式寫於黑板上，並請學生練習，等一下請學生上台分享計算過程。

學生：(1) $\vec{A}+\vec{B}=(2,3)+(3,-2)=(5,1)$，$|\vec{A}+\vec{B}|=\sqrt{5^2+1^2}=\sqrt{26}$

(2) $\vec{A}+3\vec{B}=(2,3)+3\times(3,-2)=(2,3)+(9,-6)=(11,-3)$

$|\vec{A}+3\vec{B}|=\sqrt{11^2+(-3)^2}=\sqrt{130}$

(3) $-3\vec{A}+\vec{B}=-3\times(2,3)+(3,-2)=(-6,-9)+(3,-2)$
$=(-3,-11)$

$|-3\vec{A}+\vec{B}|=\sqrt{(-3)^2+(-11)^2}=\sqrt{130}$

老師：沒錯，太棒了！

3-2 平面運動的描述
Description of Plan Motion

■ 前言 Introduction

本節將介紹位置與位移、速度與加速度，從之前的直線運動，延伸到平面運動的描述。老師要注意向量符號不可省略，且分解向量時，需用到三角函數等數學工具，透過正確的數學計算，才能解釋物理上的運動現象。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
position	位置	average acceleration	平均加速度
displacement	位移	instantaneous acceleration	瞬時加速度
average velocity	平均速度	drawing diagrams	作圖
instantaneous velocity	瞬時速度	be closed to	趨近於

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

❶ The acceleration of a free fall object is _____.

例句：**The acceleration of a free fall object is** 9.8 m/s^2.

一個自由落體的加速度量值為 9.8 m/s^2 。

❷ **In two-dimensional motion, the _____ can be presented as _____ on the rectangular coordinate.**

例句(1)：**In two-dimensional motion, the** position **can be presented as** (r_x, r_y) **on the rectangular coordinate.**

在二維運動中，位置的直角坐標可以表示為(r_x, r_y)。

例句(2)：**In two-dimensional motion, the** velocity **can be presented as** (V_x, V_y) **on the rectangular coordinate.**

在二維運動中，速度的直角坐標可以表示為(V_x, V_y)。

例句(3)：**In two-dimensional motion, the** acceleration **can be presented as** (a_x, a_y) **on the rectangular coordinate.**

在二維運動中，加速度的直角坐標可以表示為(a_x, a_y)。

■ 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、能夠描述平面運動的位置與位移。

Describe the position and displacement of two dimensional motion.

二、能夠描述平面運動的速度與加速度。

Be able to describe the velocity and acceleration of two dimensional motion.

例題講解

例題一

說明：能透過分量形式之速度與加速度，計算某瞬間的速度量值。

Calculate the magnitude of the velocity at a certain moment by the velocity and the acceleration in the component form.

On a plane, an object is moving in uniformly accelerated motion. Its initial velocity is $\vec{V_0} = -5\hat{\imath} + 2\hat{\jmath}$ and the acceleration is $\vec{a} = +5\hat{\jmath}$ (presented in SI unit). At the end of the 2 second, what is the velocity m/s?

平面上某物體作等加速運動，其初速 $\vec{V_0} = -5\hat{\imath} + 2\hat{\jmath}$、加速度 $\vec{a} = +5\hat{\jmath}$ (單位皆為 SI 制)，則 2s 末物體的速度量值為多少 m/s?

(A) 6

(B) 8

(C) 12

(D) 13

(E) 15

（取自龍騰版 111 年選修物體 I 第 88 頁 3-2 進階題 3）

解題 Solution：

由等加速度公式 $V = V_0 + at$ 可得 $\vec{V} = (-5\hat{\imath} + 2\hat{\jmath}) + (+5\hat{\jmath}) \times 2 = -5\hat{\imath} + 12\hat{\jmath}$

$|\vec{V}| = \sqrt{(-5)^2 + (12)^2} = 13$，故選(D)

From the formula $V = V_0 + at$, we can know $\vec{V} = (-5\hat{\imath} + 2\hat{\jmath}) + (+5\hat{\jmath}) \times 2 = -5\hat{\imath} + 12\hat{\jmath}$

$|\vec{V}| = \sqrt{(-5)^2 + (12)^2} = 13$. So the answer should be (D).

Teacher: What is the kind of motion in the question?

Student: Uniformly accelerated motion.

Teacher: (Remind students of the three formulas of uniformly accelerated motion, and let students practice for a while, and ask them to share their calculations.)

Student: From the formula $V = V_0 + at$, we can know

$$\vec{V} = (-5\hat{\imath} + 2\hat{\jmath}) + (+5\hat{\jmath}) \times 2 = -5\hat{\imath} + 12\hat{\jmath}$$

$$|\vec{V}| = \sqrt{(-5)^2 + (12)^2} = 13$$

Teacher: Yes, so which option should we choose?

Student: (D).

Teacher: Great! That's correct.

老師： 請問本題作甚麼運動？

學生： 等加速度運動。

老師： (提示等加速運動有三大公式，並請學生練習，等一下請學生上台分享計算過程。)

學生： 由等加速度公式 $V = V_0 + at$ 可得

$$\vec{\mathrm{V}} = (\text{-}5\hat{\imath} + 2\hat{\jmath}) + (+5\hat{\jmath}) \times 2 = \text{-}5\hat{\imath} + 12\hat{\jmath}$$

$$|\vec{\mathrm{V}}| = \sqrt{(\text{-}5)^2 + (12)^2} = 13$$

老師： 沒錯，所以我們應該選哪個選項呢？

學生： (D)。

老師： 沒錯，太棒了！

例題二

說明：根據分量形式的初速、末速、及時間，計算平均加速度。

Calculate the average acceleration by the initial and final velocity and time in the form of the components.

The initial of an object is $\overrightarrow{V_1} = 4.0\hat{\imath} - 3.0\hat{\jmath}$, after 5 seconds the velocity becomes $\overrightarrow{V_2} = 2.0\hat{\imath} + 5.0\hat{\jmath}$. All the units are m/s.

(1) What is the average acceleration $a_{a\vec{v}}$ of the particle? Present it as the unit of the vector.

(2) What is the magnitude of the average acceleration?

某質點的初速度為$\overrightarrow{V_1} = 4.0\hat{\imath} - 3.0\hat{\jmath}$，5s 後變成$\overrightarrow{V_2} = 2.0\hat{\imath} + 5.0\hat{\jmath}$，單位都是 m/s。

(1)某質點的平均加速度 $a_{a\vec{v}}$ 為何？請以單位向量表示。

(2)平均加速度 $a_{a\vec{v}}$ 的量值多大？

（取自南一版 111 上選修物理 I 習題）

解題 Solution：

我們需先計算初速與末速之差，得到這 5 秒內的速度變化 $(\Delta\vec{v})$，再依據速度變化求出平均加速度$(\vec{a} = \frac{\Delta v}{\Delta t})$。另外，因題目已知為分量形式，所以運算 $\vec{a} = \frac{\Delta v}{\Delta t}$ 時，需將 i, j 分量分別計算。

$$\overrightarrow{a_{av}} = \frac{\triangle\vec{v}}{\triangle t} = \frac{\overrightarrow{V_2} - \overrightarrow{V_1}}{\triangle t} = \frac{(2.0\hat{\imath}+5.0\hat{\jmath}) - (4.0\hat{\imath}-3.0\hat{\jmath})}{5} = -0.4\hat{\imath} - 1.6\hat{\jmath}$$

$$|a_{a\vec{v}}| = \sqrt{(-0.4)^2 + (1.6)^2} = 0.4\sqrt{17} m/s^2$$

We need to calculate the subtraction between initial and final velocities to get the change in velocity $(\Delta\vec{v})$. According to the changes in velocity, we can get the average acceleration.

In addition, since the title is known to be in component form, when calculating $\vec{a} = \frac{\Delta v}{\Delta t}$, the i and j components need to be calculated separately.

$$\overrightarrow{a_{av}} = \frac{\triangle\vec{v}}{\triangle t} = \frac{\overrightarrow{V_2} - \overrightarrow{V_1}}{\triangle t} = \frac{(2.0\hat{\imath}+5.0\hat{\jmath}) - (4.0\hat{\imath}-3.0\hat{\jmath})}{5} = -0.4\hat{\imath} - 1.6\hat{\jmath}$$

$$|a_{a\vec{v}}| = \sqrt{(-0.4)^2 + (1.6)^2} = 0.4\sqrt{17} m/s^2$$

Teacher: What is the formula of average acceleration?

Student: Change in velocity over time taken.

Teacher: (Write down the formula according to the description of the students $\overrightarrow{a_{av}} = \frac{\triangle \vec{v}}{\triangle t}$.)

So We need to calculate the subtraction between initial and final velocities to get the change in velocity ($\Delta\vec{v}$). According to the changes in velocity, we can get the average acceleration within the five seconds. Based on this we can determine the average acceleration by $\overrightarrow{a_{av}} = \frac{\triangle \vec{v}}{\triangle t}$.

Teacher: In addition, since the title is known to be in component form, when calculating $\vec{a} = \frac{\Delta v}{\Delta t}$, the i and j components need to be calculated separately, and let students practice for a while, and ask them to share their calculations.)

Student: $\overrightarrow{a_{av}} = \frac{\triangle \vec{v}}{\triangle t} = \frac{\overrightarrow{V_2} - \overrightarrow{V_1}}{\triangle t} = \frac{(2.0\hat{\imath}+5.0\hat{\jmath})-(4.0\hat{\imath}-3.0\hat{\jmath})}{5} = -0.4\hat{\imath} - 1.6\hat{\jmath}$

$|a_{a\vec{v}}| = \sqrt{(-0.4)^2 + (1.6)^2} = 0.4\sqrt{17} m/s^2$

Teacher: Great! That's correct.

老師： 請問平均加速度的公式為何呢？

學生： 速度變化除以時間。

老師： (依學生描述寫下公式 $\overrightarrow{a_{av}} = \frac{\triangle \vec{v}}{\triangle t}$)，所以，我們須先計算初速與末速之差，並請學生練習，得到這 5 秒內的速度變化($\Delta\vec{v}$)，再依據速度變化求出平均加速度($\vec{a} = \frac{\Delta v}{\Delta t}$)。

老師： 另外，因題目已知為分量形式，所以運算 $\vec{a} = \frac{\Delta v}{\Delta t}$ 時，需將 i, j 分量分別計算。請大家練習一下，等一下請學生上台分享計算過程。

學生： $\overrightarrow{a_{av}} = \frac{\triangle \vec{v}}{\triangle t} = \frac{\overrightarrow{V_2} - \overrightarrow{V_1}}{\triangle t} = \frac{(2.0\hat{\imath} + 5.0\hat{\jmath}) - (4.0\hat{\imath} - 3.0\hat{\jmath})}{5} = -0.4\hat{\imath} - 1.6\hat{\jmath}$

$|a_{a\vec{v}}| = \sqrt{(-0.4)^2 + (1.6)^2} = 0.4\sqrt{17} m/s^2$

老師： 沒錯，太棒了！

3-3 水平拋射
Horizontal Projectile

■ 前言 Introduction

本節與下一節將介紹拋體運動，由於運動在相垂直的方向具有獨立性，因此可將拋體運動，分解為水平方向的等速運動，及鉛直方向的等加速運動之組合。本節中，我們將探討水平拋射的運動。老師要注意分解物理量、訂定坐標軸，需用到許多數學概念與計算，但進行複雜的計算之前，需先理解物理的概念意義。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
independence of motion	運動獨立性	horizontal displacement/range	水平位移/射程
projectile motion	拋體運動	vertical displacement	鉛直位移
parabola	拋物線	initial horizontal velocity	水平初速度
horizontal projectile	水平拋射	landing time	飛行時間
trajectory equation	軌跡方程式		

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

❶ In projectile motion, the _____ is _____.

例句：**In projectile motion, the** horizontal motion is uniform.
平拋運動過程，水平方向是作等速度運動。

❷ Using simultaneous equations, we can get _____.

例句：**Using simultaneous equations, we can get** the trajectory equation.
兩式聯立可得軌跡方程式。

❸ _____ has nothing to do with _____.

例句：The landing time is related to the height only and **has nothing to do with** the horizontal initial velocity.
飛行時間僅與高度有關，與水平方向之初速度無關。

❹ _____ is/are independent of _____.

例句：The horizontal and vertical components of two-dimensional motion **are independent of** each other.
水平方向和鉛直方向的運動，彼此互相獨立。

■ 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、了解水平拋射運動中，忽略空氣阻力影響，水平方向作等速運動。

Understand that in horizontal projectile motion when ignoring air resistance, particles would move uniformly in the horizontal direction.

二、了解水平拋射運動中，忽略空氣阻力影響，鉛直方向作自由落體運動。

Understand that in horizontal projectile motion when ignoring air resistance, particles would move free falling in the vertical direction.

三、能描述水平拋射運動中的鉛直及水平方向的運動現象。

Be able to describe the motion of the horizontal and the vertical components in projectile motion.

❧ 例題講解 ☙

例題一

說明：比較自由落體與平拋運動之相關性。

Compare the relationship between horizontal projectile motion and vertical free fall motion.

Iron ball A and ball B are released from the same height and at the same time. Iron ball A with 100 grams falls horizontally and iron ball B with 200 grams does the free falling. Two fall on the same ground, as the picture shows. Ignoring the air resistance, which statement is correct?

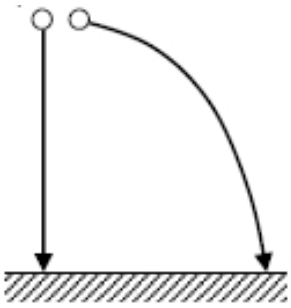
(A) Ball A had a longer path and touched the ground more slowly.

(B) Ball A had a higher speed and touched the ground faster.

(C) Ball B had more gravity so it touched the ground first.

(D) Two balls had the same acceleration so they touched the ground at the same time.

甲乙兩鐵球同時由相同高度釋出，甲球 100 克以水平射出，乙球 200 克垂直自由下墜，兩球均落到同一水平地面，如右圖所示，若不計空氣阻力，下列敘述何者正確？



(A) 甲球經過的路徑較長，比較慢著地。
(B) 甲球運動的速率較快，比較先著地。
(C) 乙球比甲求受的重力大，故以求先著地。
(D) 兩球都以相同的加速度下墜，故同時著地。

（取自 83 年自然科學測題 35）

解題 Solution：

先將平拋運動過程，分解為水平方向及鉛質方向之運動，且兩個方向互相獨立。其中，鉛直方向作自由落體運動，所以落地時間僅與其高度有關，與水平之初速無關。所以平拋運動的落地時間與鉛直之自由落體，兩者之落地時間相等。

故選 (D)。

Firstly, we can classify the projectile motions into horizontal and vertical motions and each is independent. The vertical motion is in free falling so the landing time is only related to the height and has nothing to do with initial horizontal velocity. Thus the landing times of the projectile motion and the vertical free falling are the same.

Teacher:	Does anyone know what kind of motion the horizontal and vertical motions do in projectile motion?
Student:	Horizontal motion does the uniform motion and the vertical motion does the free falling.
Teacher:	That's right. How do we get the landing time in the horizontal projectile motion?
Student:	From the vertical motion.
Teacher:	Yes, Do the landing times of balls A and B touch the ground at the same time?
Student:	Yes.
Teacher:	How come?
Student:	Since both landing times are calculated by the free falling.

Teacher: Does anyone want to share the formula of the landing time?

Student: $T = \sqrt{\frac{2h}{g}}$.

(Write down the formula according to the students' description.)

Teacher: Great. Since the equation of motion is $h = \frac{1}{2}gt^2$, we obtain $t = \sqrt{\frac{2h}{g}}$

Teacher: So is the landing time of free falling related to the mass?

Student: No.

Teacher: Right. Do balls A and B touch the ground at the same time?

Student: Yes.

Teacher: Great. Which option is the answer?

Student: (D).

Teacher: Yes. Good job!

老師： 請問同學平拋運動的水平方向與鉛直方向，各別作什麼運動？

學生： 水平方向作等速度運動；鉛直方向作自由落體運動。

老師： 沒錯，那我們該如何得到平拋運動的飛行時間呢？

學生： 直接由鉛直方向自由落體運動可得知。

老師： 沒錯，所以，甲和乙的飛行時間會相同嗎？

學生： 會

老師： 為甚麼呢？

學生： 因為兩者都是以自由落體來計算飛行時間。

老師： 很好，那有沒有同學願意分享自由落體飛行時間的公式呢？

學生： $T = \sqrt{\frac{2h}{g}}$.

老師： 很棒，因為運動公式: $h = \frac{1}{2}gt^2$，所以得到$t = \sqrt{\frac{2h}{g}}$

老師： 從公式中，我們可看出，自由落體的飛行時間和質量有關嗎？

學生： 無關

老師： 沒錯，那麼甲和乙的飛行時間會相同嗎？

學生： 會。

老師： 很棒，所以我們應該選哪個選項呢？

學生： (D)

老師： 沒錯，太棒了！

例題二

說明：對水平拋射運動進行正確之分析與推算。

Analyze and calculate horizontal projectile motion correctly.

Stones A and B have the same mass and are thrown horizontally from the same height and reach on a plain ground. Knowing that the initial velocity of stone A is two times higher than that of B and ignoring the air resistance, which of the following statements is incorrect?

(A) The trajectory of A is longer.

(B) When reaching the ground, stone A has more energy.

(C) When reaching the ground, both have the same acceleration.

(D) Both have the same landing time in the air.

(E) When reaching the ground, the vertical velocity of A is larger.

甲、乙兩質量相同的小石子，自同一高度以水平方向的初速拋出，落在平坦的地面上，已知甲的初速為乙的 2 倍，若不計空氣阻力，則下列敘述何者錯誤？

(A) 甲的射程較大。

(B) 落地時，甲的動能較大。

(C) 落地時，兩者的加速度相等。

(D) 兩者在空中的飛行時間相等。

(E) 落地時，甲速度的鉛直分量較大。

（取自 91 年指考 1）

解題 Solution：

水平拋射運動，在鉛直方向是作自由落體運動，水平方向則作等速度運動。

因甲、乙石子自相同高度水平拋出，所以飛行時間 T 相等，故(D)對。

(A)水平射程 $R = V_0 \times T$。

由題目可知甲的初速為乙的 2 倍，所以甲的水平射程為乙的 2 倍，故(A)對。

(B)因飛行時間相同，所以甲、乙之鉛直方向速度相同，但水平方向速度不同，根據向量的合成，甲的速度大於乙的速度，而動能和速度呈正相關，因此甲的動能大於乙的動能，故(B)對。

(C)兩者均為重量加速度 g，故(C)對。

(E)因飛行時間相等，所以甲速度的鉛直分量和乙速度的鉛直分量相等，故(E)錯。故選(E)。

In the horizontal projectile motion, the vertical motion does free fallings and the horizontal motion does the uniform motion. Since the two stones are thrown out horizontally from the same height, the flight time is the same.
Thus (D) is correct.
(A) The horizontal trajectory is $R = V_0 \times T$.
From the question we can know the initial velocity of A is two times faster than B so the projectile trajectory is two times longer than B. Thus, A is correct.

(B) Because they reached the ground at the same time, the vertical motions of A and B are the same but the horizontal motions of A and B are different. According to vector summation, the velocity A is higher than that of B, and the kinetic energy is positively associated to the velocity, so, the kinetic energy of A is larger than that of B.
Thus (B) is correct.

(C) Both have the same gravitational acceleration, g, thus (C) is correct.

(E) Because they reached the ground at the same time, the vertical components of the velocities of A and B are the same, thus (E) is not correct. So the answer is (E).

Teacher: Does anyone know what kinds of motion the horizontal and vertical motions do in projectile motion?
Student: Horizontal motion does the uniform motion and the vertical motion does the free falling.
Teacher: Yes, then is the time in free fall related to the height and the mass?
Student: It is related to height but has nothing to do with mass.
Teacher: Great. Both stones fall from the same height. Are their landing times the same or not? and why?
Student: They are the same because they fall from the same height.
Teacher: Good. Everyone practices the question and later we will have someone share the answer. (Waiting for a while.) Is everyone done? Are there any of you who need time?
Student: We are done.
Teacher: Good. Let's start with option (A). Does anyone want to share the thinking process? I will go first. The option (D). We just mentioned that both of their flight times are the same so (D) is correct.

Student: (A) the horizontal trajectory is $R = V_0 \times T$. From the question we can know the initial velocity of A is two times faster than B, so the projectile trajectory is two times longer than B. Thus, A is correct.

(B) Because they reached the ground at the same time, the vertical motions of A and B are the same but not the horizontal motions of A and B are not. According to vector summation, the velocity of A is higher than that of B and the kinetic energy is positively associated to the velocity, so, the kinetic energy of A is larger than that of B.

Thus (B) is correct.

(C) Both have the same gravitational acceleration, g, thus (C) is correct.

(E) Because they reached the ground at the same time, the vertical components of the velocities of A and B are the same, thus (E) is not correct.

Teacher: Great. Which options should we choose?

Student: (E).

Teacher: Correct. Well done.

老師： 請問同學，平拋運動的水平方向與鉛直方向，各作甚麼運動？

學生： 水平方向作等速度運動；鉛直方向作自由落體運動。

老師： 沒錯，那自由落體的時間和高度、質量有關嗎？

學生： 和高度有關，和質量無關。

老師： 很好，那麼甲、乙兩石子自相同高度落下，他們的飛行時間會相同還是不同呢？為甚麼呢？

學生： 會相同，因為從相同高度落下。

老師： 很棒，那請大家練習看看這題，我們等一下請同學分享自己的答案。（過一會兒）大家都練習完了嗎？還有同學需要時間嗎？

學生： 練習完了。

老師： 很好，那我們從(A)選項開始，有沒有同學自願分享自己的思考過程呢？老師先來，(D)剛剛有說過甲乙的飛行時間相同，所以(D)對。

學生：(A)水平射程 $R = V_0 \times T$。
因為甲的初速為乙的兩倍，所以甲的水平射程為乙的兩倍，故(A)對。
(B)因飛行時間相同，所以甲、乙之鉛直方向速度相同，但水平方向速度不同，根據向量的合成，甲的速度大於乙的速度，而動能和速度呈正相關，因此甲的動能大於乙的動能，故(B)對。
(C)兩者均為重量加速度 g，故(C)對。
(E)因飛行時間相等，所以甲速度的鉛直分量和乙速度的鉛直分量相等，故(E)錯。
老師：很棒，所以我們應該選哪個選項呢？
學生：(E)。
老師：沒錯，太棒了！

3-4 斜向拋射
Oblique Projectile

■ 前言 Introduction

本節將繼續介紹拋體運動中的斜向拋射運動，由於運動狀態在互相垂直的分量上，會出現獨立性。因此，可將斜向拋體運動，分解為水平方向的等速運動，以及鉛直方向的等加速運動。在本節中，學生需學會斜向拋射運動的物理概念、描述方式，及相關計算。使用英語時，老師要注意分解物理量、定坐標軸，需用到許多數學推算的用語。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
elevation angle	仰角	oblique projectile	斜向拋射
vertical component	鉛直分量	vertical projectile	鉛直上拋
horizontal component	水平分量		

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

❶ When _____ is constant, and _____, the _____ would be different as well.

例句：**When** the magnitude of initial velocity **is constant**, **and** the elevation angle is different, **the** trajectory **would be different as well.**

當初速度的固定時，當斜拋角度不同時，物體的運動軌跡也隨之不同。

❷ In _____ motion, the __ does __ motion.

例句：**In** oblique projectile **motion, the** horizontal motion **does** uniform **motion.**

斜向拋射運動的水平方向作等速直線運動。

❸ _____ opens ___ upward/downward.

例句：The parabola **opens upward.**

拋物線的開口向上

■ 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、了解斜向拋射運動中，忽略空氣阻力影響，水平方向作等速運動。

Understand that in oblique projectile motion when ignoring air resistance, particles would do uniform motion in the horizontal direction.

二、了解斜向拋射運動中，忽略空氣阻力影響，鉛直方向作鉛直上拋運動。

Understand that in oblique projectile motion when ignoring air resistance, particles would do vertical projectile motion in the vertical direction.

三、能透過各種物理量描述斜向拋射中的鉛直及水平方向運動。

Be able to describe the physical quantities of the vertical and the horizontal directions regarding oblique projectile motion.

∞ 例題講解 ∞

例題一

說明：對斜向拋射運動進行正確之分析與計算。

Analyze and calculate the motion of oblique projectiles correctly.

When a baseball reaches above the home base, at a height of 1.0 m, the hitter hits the ball in the opposite direction at an elevation angle of $\cos\theta = \frac{3}{5}$ and a speed of 126 km/h. After being hit 5.0 s later, it just flies over the home run wall. What is the height above the ground when the ball flies over the home run wall? (Assuming the ground of the baseball field is level, take the acceleration of gravity $g = 10\text{m/s}^2$)

(A) 4 (B) 8 (C) 10 (D) 12 **(E) 16**

棒球抵達本壘板上方時，在離地 1.0 m 的高度，被打擊者以與水平面夾角為 θ ($\cos\theta = \frac{3}{5}$) 的仰角、量值為 126 km/h 的速度反向擊出，該球在被擊出後 5.0 s 恰好飛越全壘打牆的上空，是問球飛越全壘打牆瞬間，離地高度為多少 m？(假設棒球場地面為水平，取重力加速度 $g = 10\text{m/s}^2$)

(A) 4

(B) 8

(C) 10

(D) 12

(E) 16

（取自 110 年指考物理 4）

解題 Solution：

本題屬於斜向拋射運動，需分解成水平（做等速直線運動），及鉛直（做等加速度運動）兩個分量。因為題目僅要算出最後高度，所以只計算鉛直運動即可。$V_{0_y} = V_0$

球被擊出的初速 $V_0 = 126\,km/h = 35\,m/s$ 。

分解為鉛直方向的初速度 $V_{0_y} = V_0$，$\sin\theta = 35 \times \frac{4}{5} = 28\,m/s\,(\uparrow)$ 。

設棒球打擊後，經過 5s 的鉛直位移為 h，由等加速運動公式可得

$h = V_{0_y}t - \frac{1}{2}gt^2 = 28 \times 5 - \frac{1}{2} \times 5 - \frac{1}{2} \times 10 \times 5^2 = 15(m)$ 。

其中的加速度 g，方向向下，所以需用 (-10) 帶入。因此，飛越全壘打牆瞬間，離地高度 H = 15 + 1 = 16(m)。故選(E)。

The motion in the question is in oblique projectile motion so we have to classify it into horizontal component (which is in uniform linear motion) and vertical component (which is in uniform accelerated motion). Because the question requires only the final height, we can only calculate the vertical motion.

The initial velocity when the ball is hit is $V_0 = 126\,km/h = 35\,m/s$.

So the initial velocity vertical motion $V_{0_y} = V_0,\ \sin\theta = 35 \times \frac{4}{5} = 28\,m/s\,(\uparrow)$.

Assumed that the displacement from the hitting moment after 5 seconds is h. From the formulas of uniformly accelerated motion, we can know

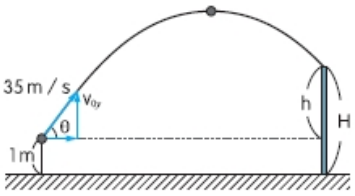
$$h = V_{0_y}t - \frac{1}{2}gt^2 = 28 \times 5 - \frac{1}{2} \times 5 - \frac{1}{2} \times 10 \times 5^2 = 15(m)$$

Knowing that the acceleration is g and be downward, put (-10) into the operation

Thus when the ball was flying over the home run wall the height from the ground is 15+1=16 (m).

So the answer is (E).

Teacher: As the following figure shows, (draw the picture of the trajectory the baseball flies and ask students what kind of motion it is.)



Student: Oblique projectile.

Teacher: What kind of the motion do the horizontal and vertical motion do in oblique projectile motion?

Student: Horizontal motion does the uniform motion and the vertical motion does the free falling.

Teacher: Yes, and how do we determine the H (answer could be seen in the figure)?

Student: H is h+1.

Teacher: That's right. How do we determine the H? Please practice it and later we will have students share their calculations.

Student: The motion of the vertical component in the oblique projectile motion is uniformly accelerated motion. So, from the kinematics formulas we can know that

$$h = V_{0_y}t - \frac{1}{2}gt^2 = (V_0 \sin\theta)t - \frac{1}{2}gt^2 = 28 \times 5 - \frac{1}{2} \times 10 \times 5^2 = 15(m).$$

Teacher: Great. So what is the H from the ground?

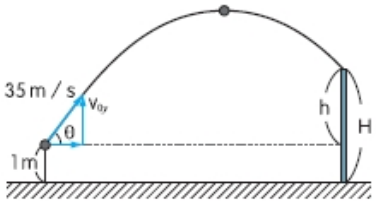
Student: 16m.

Teacher: Excellent. Which option is the answer?

Student: (E).

Teacher: Correct. Good job.

老師： 如下圖所示，畫出棒球飛越過程的路徑圖，並詢問學生本題棒球作何種拋體運動？



學生： 斜向拋射。

老師： 沒錯，那麼斜向拋射的鉛直與水平方向各作何種運動呢？

學生： 水平方向作等速運動；鉛直方向作鉛直上拋運動。

老師： 沒錯，那我們該如何算出 H 呢？（提示：由圖可看出）

學生： H 是 h+1。

老師： 沒錯，那我們該如何算出 h 呢？請大家練習計算，等一下請同學上台分享計算過程。

學生： 斜向拋射之鉛直方向，是做等加速運動，由運動公式可得

$$h = V_{0_y}t - \frac{1}{2}gt^2 = (V_0 \sin\theta)t - \frac{1}{2}gt^2 = 28 \times 5 - \frac{1}{2} \times 10 \times 5^2 = 15(m)$$

老師： 很棒，所以離地高度 H 是多少呢？

學生： 16 m

老師： 非常棒，所以我們應該選哪個選項呢？

學生： (E)

老師： 沒錯，太棒了！

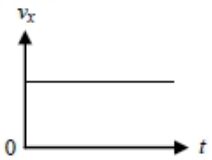
例題二

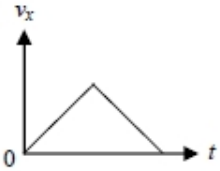
說明：能閱讀理解斜向拋射運動的關係圖。

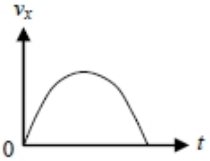
Be able to comprehend the diagrams regarding oblique projectile motion.

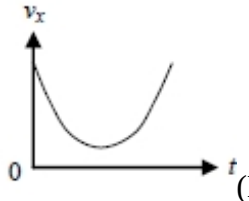
In a baseball game, the hitter hits a home run by swinging the bat diagonally upward. Ignore the air resistance, so the horizontal motion of the baseball is not affected by any external force when flying. Which of the following graphs can represent the relationship between the horizontal speed *Vx* of the baseball with respect to its flight time t before landing?

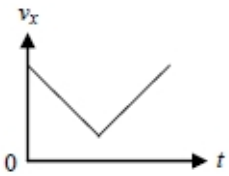
棒球比賽中，打擊者用力向斜上方揮棒，擊出高飛全壘打。若不考慮空氣阻力，因此棒球在空中飛行時水平方向不受外力作用，則下列圖形何者可以代表棒球的水平方向速度 *Vx* 與其落地前飛行時間 *t* 的關係？

(A) 

(B) 

(C) 

(D) 

(E) 

（取自 101 年學測 66）

解題 Solution：

斜向拋射過程，只受到重力向下，所以水平方向不受任何外力作用，因而能維持等速度運動，所以任何時刻之水平速度皆不變。故選(A)。

In an oblique projectile, the only force reacted on the object is gravitational force downwards. Therefore, the horizontal motion is not influenced by any force, and thus it does constant velocity motion. So, at any time, the horizontal velocity remains the same.
So the answer is (A).

Teacher: What kind of motion is in the question?
Student: Oblique projectile.
Teacher: Yes, according to the question, what does it mean that horizontal direction is not influenced by the force?
Student: Horizontal acceleration is 0.
Teacher: Yes, so, what kind of motion is horizontal motion?
Student: Uniform motion.
Teacher: Yes, so at any time, what would the velocity be?
Student: Remain the same.
Teacher: What would the v-t graph be like if the horizontal velocity is the same?
Student: It would be a horizontal line.
Teacher: Bravo. Which option is the answer?
Student: (A).
Teacher: Correct. Well done!

老師： 請問這題的棒球，作哪種運動呢？
學生： 斜向拋射運動。
老師： 沒錯，根據題目，他說水平方向不受外力，這句話代表什麼意思呢？
學生： 水平加速度為 0。
老師： 沒錯，所以水平方向會作哪種運動呢？
學生： 等速度運動。
老師： 很好，所以在任何時刻的水平速度會如何呢？
學生： 保持不變。
老師： 水平速度保持不變在 v-t 圖中，應該是甚麼形狀呢？
學生： 水平線。
老師： 非常棒，所以我們應該選哪個選項呢？
學生： (A)。
老師： 沒錯，太棒了！

★第四章 牛頓運動定律★
Chapter 4 Newton’ s Law of Motion

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國立彰化師範大學英語系　巫冠誼

■ 前言 Introduction

在前面幾章中，我們了解如何描述物體的運動狀態，而造成物體運動變化的基本原因是“力的作用”。因此本章將帶領我們思考「力」，是如何影響物體的運動狀態變化，以及力的種類，與分析技巧。我們將透過「牛頓三大運動定律」，來探討物體的運動變化，並熟悉日常生活常見的運動現象。

英語在本章中，主要用於讓學生了解概念。老師在課程中可以多運用生活例子、從生活化的語言開始，讓學生練習描述理論與概念，及其應用。

4-1 力的合成與分解
Composition and Decomposition of Force

■ 前言 Introduction

前一章曾學習過，當多個力同時作用於物體上，該物體所受的合力，可由三角形法，和平行四邊形法來推導。而分析力學問題時，常需要將力加以分解為兩個互相垂直的分力，可能是鉛質與水平，或是切線與法線分力。本節學生將理解力的合成與力的分解之目的，及其推導技巧。

使用英語時，老師應注意講解避免用語過於繞舌，使學生因複雜名詞，而不理解其中的觀念。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
analysis	分析（名詞）	horizontal	水平的
analyze	分析（動詞）	perpendicular	垂直的
resultant force	合力	vertical	鉛直的
force component	分力	inclined plane	斜面
tangential component	切線分力	vertical surface	垂直面
normal component	法線分力	parallelogram rule	平行四邊形法
free-body diagram	力圖分析	triangle rule	三角形法
parallel	平行的	translation	平移

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

❶ _____ could be decomposed into _____.

例句：$\vec{A}$ **could be decomposed into** tangential and normal components.

$\vec{A}$ 可以被分解為切線分量與法線分量。

❷ Combine _____ and _____ to form _____.

例句：**Combine** force A **and** force B **to form** the resultant force C.

$\vec{A}$ 和 $\vec{B}$ 可以被合成為 $\vec{C}$ 。

❸ _____ is parallel/perpendicular to _____.

例句：The force *A* **is parallel to** the force *B*.

$\vec{A}$ 和 $\vec{B}$ 互相平行。

❹ _____ parallel/perpendicular to _____

例句：The component force of A **parallel to** the inclined plane is 10N.

A 平行於斜面方向的分力是 10N。

■ 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 the chapter, students are able to acquire the following concepts:

一、利用三角形法或平行四邊形法推導力的合成。

The force could be composed by the parallelogram rule or the triangle rule.

二、分析力圖時，每個力，可以分解為水平分量和鉛直分量。

When analyzing force diagrams, each force could be decomposed to the horizontal and vertical components.

三、遇到斜面問題時，可將力分解成平行斜面的分力和垂直斜面的分力。

For problems associated with inclined planes, each force could be decomposed to the components of parallel and perpendicular to the inclined plane.

❧ 例題講解 ☙

例題一

說明：正確應用力的合成。

Apply composition of force correctly.

The magnitude of two common point forces is certain. If the angle between them increases from 0° to 90°, which of the statements is correct about the magnitude of the two resultant forces?

(A) decrease first and then increase

(B) gradually increase

(C) be no changes

(D) gradually decrease

(E) increase first and then decrease

兩個大小為一定的共點力，如其間的夾角由 0°增至 90°時，則其合力的大小：

(A)先減小後增加　(B)逐增加　(C)不改變

(D)逐次減小　(E)先增加後減小

（62 年日大）

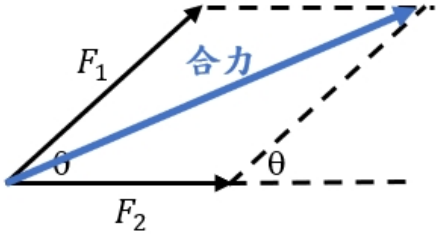
解題 Solution：

如右圖所示，令二共點力其間夾角為 θ，由餘弦定理可得:

合力 $=\sqrt{{F_1}^2+{F_2}^2+2F_1F_2cos}$

若 θ 由 0°增至 90°時，cos 由 1 漸減至 0

所以合力亦漸減，故選(D)。



:

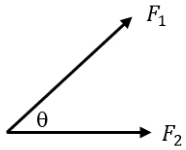
Assumed that the angle between the two common points is θ. From the Law of cosine, we can acquire that the resultant force is equal to $\sqrt{{F_1}^2+{F_2}^2+2F_1F_2cos}$

If θ increases from 0° to 90°, cos gradually decreases from 1 to 0.

Therefore, the combined force is also gradually decreasing.

So choose (D).

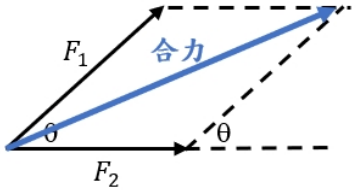
Teacher: (As the following figure shows, draw it on the blackboard.) As the question indicates, how do we draw the free-body diagram?



Student: Using the parallelogram rule or the triangle rule.

Teacher: Good. Let's practice and have students draw it.

Student:



Teacher: Great. How about the magnitude of the resultant force? (Explain the concept of translation according to the figure drawn by students.)

Student: Using the law of cosine.

Teacher: Good job. And we have some students share their calculations.

Student: Resultant force $=\sqrt{{F_1}^2+{F_2}^2+2F_1F_2cos}$.

Teacher: Excellent. When the θ is from the 0° to 90°, how would the $\cos\theta$ change?

Student: It would decrease from 1 to zero.

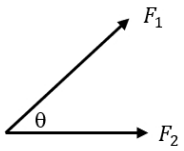
Teacher: Great. So how does the magnitude of resultant force change?

Student: It gradually decreases.

Teacher: Bravo, so which option should we choose?

Student: (D).

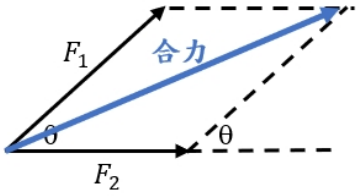
老師：(如下圖，畫示意圖於黑板上) 依題目所述，我們該如何畫出合力呢？



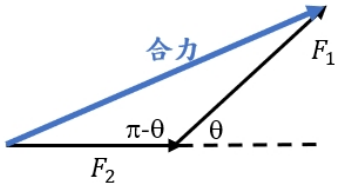
學生：利用平行四邊形法或三角形法。

老師：很好，那請大家練習一下，我們等一下請同學上台畫畫看。

學生：



老師：很好，那我們該如何求合力的大小呢？(利用學生的圖講解力的平移概念，再另畫下圖)。



學生：利用餘弦定理。

老師：很棒，請同學上台分享計算過程。

學生：合力$=\sqrt{{F_1}^2+{F_2}^2+2F_1F_2cos}$ 。

老師：很好，依題目所述，θ 由 0°增至 90°時，$\cos\theta$ 會如何呢？

學生：會由 1 逐漸減至 0。

老師：很棒，所以合力的大小會如何呢？

學生：會漸減。

老師：沒錯，那我們應該選擇哪個選項呢？

學生：(D)。

例題二

說明：正確應用力圖分析。

Apply force diagram analysis correctly.

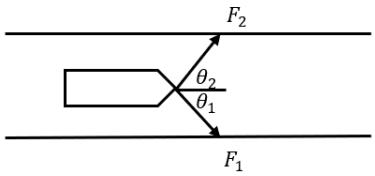
Two people pull a boat with ropes along the canal. If the boat is to move along the central line of the river, the magnitude and the directions of the two forces are F_1, F_2, θ_1, θ_2 as shown in the figure below, then the relationship of these four variables should be:

(A) $\boldsymbol{F_1 sin\theta_1 = F_2 sin\theta_2}$

(B) $F_1 tan\theta_1 = F_2 tan\theta_2$

(C) $F_1 cot\theta_1 = F_2 cot\theta_2$

(D) $F_1 sec\theta_1 = F_2 sec\theta_2$



兩人沿著運河以繩攬拉動一船。如欲使船沿河中央線前進，兩人所施之力及其方向各為 F_1、F_2、θ_1、θ_2 如下圖，則此四變數的關係為：

(A) $\boldsymbol{F_1 sin\theta_1 = F_2 sin\theta_2}$

(B) $F_1 tan\theta_1 = F_2 tan\theta_2$

(C) $F_1 cot\theta_1 = F_2 cot\theta_2$

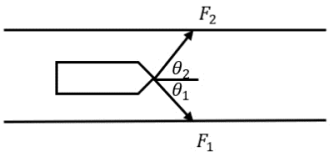
(D) $F_1 sec\theta_1 = F_2 sec\theta_2$

（取自 69 夜大）

解題 Solution：

根據題目敘述條件，沿河中央線前行，表示兩力之總和，必沿著河岸方向，亦即兩力垂直於河岸分量之和為 0，即 $F_1 sin\theta_1 + F_2 sin\theta_2 = 0$

所以 $F_1 sin\theta_1 = F_2 sin\theta_2$，故選(A)。



According to the condition of the question, moving along the central line of the river represents that the sum of the perpendicular component corresponding to the river bank is 0.

That is $F_1 sin\theta_1 + F_2 sin\theta_2 = 0$.

Therefore, $F_1 sin\theta_1 = F_2 sin\theta_2$. So we should choose (A).

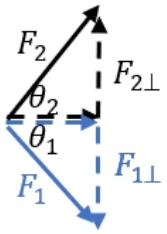
Teacher: Based on the figure on the right hand side, please infer in which direction the components of $F_1$and F_2 would cancel each other?

Student: The components of up and down.

Teacher: Great. Since the boat is moving toward the right, the resultant force vertical to the direction of the velocity is 0.

Teacher: Now everyone should practice decomposing the two force, F_1 and F_2 then we will have students share their analysis.

Student:



Teacher: Great, according to the question, in order to make the boat move along the central lobe of the river, what is the perpendicular component of the resultant force s?

Student: It would be 0.

Teacher: Correct. What's the equation of that? We will have students share their calculations.

Student: $F_1 sin\theta_1 + F_2 sin\theta_2 = 0$

Teacher: Great, so which option should we choose?

Student: (A).

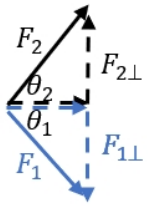
老師： 根據右圖，請大家先判斷，F_1 及 F_2 在甚麼方向的分力會抵消？

學生： 上下方向

老師： 很好，因為船是往右前進，所以垂直於速度方向的合力應等於零。

老師： 現在，請大家先練習將 F_1、F_2 兩力作力的分解，等一下請同學上臺分享。

學生：



老師： 很好，依題目所言，要使船沿河中央線前進，兩力的鉛直分量合力應該如何呢？

學生： 等於 0。

老師： 沒錯，那如何用數學式表示呢？請同學上台分享計算過程。

學生： $F_1\sin\theta_1 + F_2\sin\theta_2 = 0$

老師： 沒錯，那我們應該選擇哪個選項呢？

學生： (A)。

4-2 慣性與牛頓第一定律
Inertia and Newton’s First Law of Motion

■ 前言 Introduction

本節中將會利用生活中常見的例子，使學生理解慣性的意義，除此之外，教師也會帶學生認識伽利略斜面實驗，與牛頓第一運動定律-慣性定律的由來及概念。

本節老師將以英文生活常例，引導學生了解慣性與牛頓第一運動定律，老師要注意使用貼近學生生活化的語言，著重概念上的理解。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
inertia	慣性	in motion	動作
remain	維持	constant velocity	等速度
state of motion	運動狀態	center of mass	質心
stop/standstill/at rest	靜止	body/object	物體

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

❶ _____ remains _____.

例句：When exerted by zero resultant force, a body at rest **remains** at rest or remains in motion at uniform motion in a straight line.

當物體所受合力為零，則靜者恆靜，動者恆作等速直線運動。

❷ _____ stand still/keep still/hold still/be at rest.

例句：The center of mass of a body is moving at the same velocity or **standing still/keeping still/holding still/at rest.**

物體的質心維持等速度運動，或維持靜止。

❸ The force on _____ is _____.

例句：**The** resultant **force on** the body **is** zero.

物體受力為零。

❹ _____ be affected by _____.

例句：When an object **is** not **affected by** the external force, it remains at rest or in motion at constant velocity.

物體不受外力作用，就可維持靜止或等速運動。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、了解慣性的定義。

Understand the definition of inertia.

二、了解牛頓第一運動定律-慣性定律。

Understand Newton’s First Law of Motion.

例題講解

例題一

說明：正確應用與分析慣性定律。

Apply and analyze inertia correctly.

Student Zheng stood in a moving car, and when the brakes were applied to the car, her body would lean forward. According to the picture on the right, which of the following is the main reason for Student Zheng to lean forward?

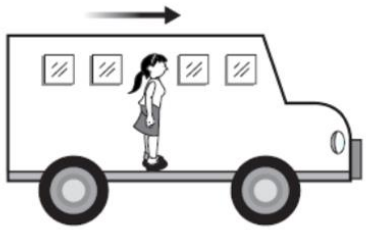
(A) The car gives a forward force to Student Zheng.

(B) The air in the car gives a forward force to Student Zheng.

(C) The ground on the car gives a backward force to Student Zheng.

(D) When the bus brakes were applied, the direction of the body weight shifted.

曾同學站在行駛中的車內，當煞車時，他的身體會向前傾。依據右圖，下列哪一項是造成曾同學身體向前傾的主要理由？



(A)車輛給曾同學一向前的力。

(B)車內空氣給曾同學一向前的力。

(C)車內地板給曾同學一向後的摩擦力。

(D)車載煞車時，改變了曾同學重力的方向。

(取自 93 年學測 12)

解題 Solution：

因為慣性的關係，曾同學想要保持原來的運動狀態（向前移動），此時曾同學和地板之間有相對運動的傾向，因此產生一向後的摩擦力來阻止其向前的相對運動，但上半身仍依慣性前傾，故選(C)。

Because of the inertia, Student Zheng would tend to remain in her original motion state. In this moment, there's a tendency of the relative motion between Student Zheng and the ground, thus, a backward friction is generated to prevent the relative motion moving forward. However, the upper body still leans forward due to the inertia. So we choose (C).

Teacher: Have you ever experienced the sudden brakes applied to the car when you are in your parent's moving car? Did your upper body lean forward at that moment?
Student: Yes.
Teacher: Why do our bodies act like this?
Student: Due to the inertia.
Teacher: Great. What's inertia?
Student: Remain in original motion states.
Teacher: Correct, every object has a tendency to remain in the original motion state. It is called inertia. And what's the original motion state of Student Zheng?
Student: Forward.
Teacher: Good. So when brakes are suddenly applied to the car, what's the tendency of motion she would be?
Student: Forward.
Teacher: Good. Is there a relative motion between the ground and Student Zheng?
Student: Yes.
Teacher: What will happen if we want to prevent the relative motion to the ground?
Student: A backward friction is generated to prevent the relative motion moving forward.
Teacher: Good. The upper body still leans forward due to the inertia, then which option should we choose?
Student: (C).
Teacher: Well done.

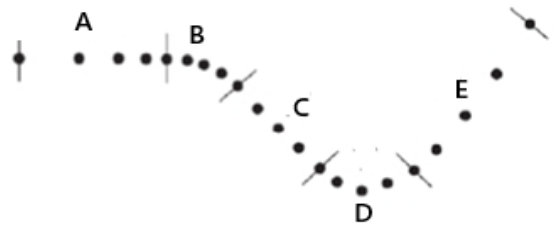
老師：同學們被爸爸媽媽載的時後有遇過突然煞車的經驗嗎？這時候是不是身體都會向前傾呢？
學生：是的。
老師：那大家覺得為什麼我們的身體會向前傾呢？
學生：因為慣性嗎。
老師：很好，那什麼是慣性呢？

學生： 維持原本的運動狀態。
老師： 沒錯，每個物體都有一種「維持原有運動狀態」傾向，稱為慣性。那麼曾同學原本的運動狀態是如何呢？
學生： 往前。
老師： 很好，所以當車子突然煞車時，他會想要如何呢？
學生： 向前。
老師： 很好，所以他和地板是不是會有一個向前的相對運動傾向呢？
學生： 是的。
老師： 所以這時候為了想要阻止曾同學和地板的相對運動，會發生什麼事呢？
學生： 會有向後的摩擦力阻止向前的相對運動。
老師： 很好，因此曾同學的上半身依舊會向前傾。所以我們應該選什麼選項呢？
學生： (C)
老師： 很棒。

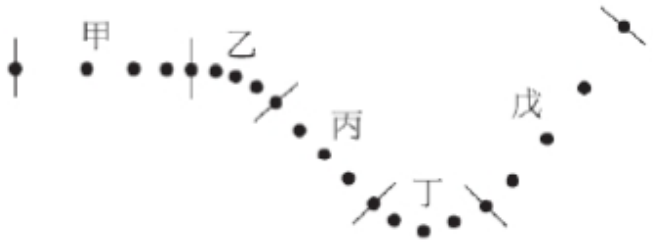
例題二

說明：正確應用與分析牛頓第一運動定律。
Apply and analyze Newton's First Law of Motion correctly.

A ball moves on a horizontal plane. The figure shows the positions of the ball every 0.02 second. The processes are labeled as segment A、B、C、D and E.
In which segment the resultant force on the ball is 0?
(A)A　(B)B　**(C)C**　(D)D　(E)E



一小球在水平面上移動，每隔 0.02 秒小球的位置如圖所示，每一段過程分別以甲、乙、丙、丁和戊標示，試問在哪一段，小球所受的合力為零？



(A)甲　(B)乙　**(C)丙**　(D)丁　(E)戊

（取自 94 年學測 32）

解題 Solution：

由牛頓第一運動定律：不受外力作用(合力為零)時，靜者恆靜，動者恆作等速度運動。而等速度運動，是指物體運動之速度大小及方向都不改變，故選(C)。

According to Newton's First Law of Motion, when a body is not affected by external force (or the resultant force is 0) it would remain at rest or moving at constant velocity.

In uniform motion, both of the magnitude and direction of the velocity do not change, so we choose (C).

Teacher:	Does anyone want to share what we know from Newton's First Law of Motion?
Student:	When a body is not affected by external force (or the resultant force is 0) it would remain at rest or moving at constant velocity.
Teacher:	Great. In the question, the ball is in motion in the beginning so when the resultant force is 0, what state of motion is the ball in?
Student:	Keep moving at the same velocity or called "uniform motion".
Teacher:	Good job. Constant velocity motion not only shows equal displacement within the same time duration, but also keeps moving along the same direction.
Teacher:	Therefore, what are the characteristics of uniform motion?
Student:	The magnitude and the direction of the velocity do not change.
Teacher:	Correct, under that case, within the same time duration how would be the distance between the two neighboring points?
Student:	Their distances would be the same.
Teacher:	Great. Constant velocity motion means not only maintaining a fixed distance but also keeping the same direction.

Teacher: So, which segment among A, B, A, B, C, D, and E fits this situation?
Student: segment C.
Teacher: Great, then which option should we choose?
Student: (C)

老師： 有沒有同學願意分享，牛頓第一運動定律告訴我們什麼呢？
學生： 當物體不受外力作用(或合力為零)時，靜者恆靜，動者恆作等速度運動。
老師： 很棒，本題中這個小球一開始就有在運動，所以當合力為零時，小球應該會作甚麼運動呢？
學生： 維持本來的速度運動。
老師： 很棒。等速運動不僅在相同時間內具有相等的位移，還會沿著相同的方向持續運動。
老師： 那等速度運動有甚麼特徵呢？
學生： 物體運動之速度大小及方向都不改變。
老師： 那如果物體速度大小不變的情形下，相同時間內，兩點之間的距離會如何呢？
學生： 會相同。
老師： 很好，不但距離維持固定，而且方向也不變，才是等速度運動。
老師： 所以甲、乙、甲、乙、丙、丁和戊五段中哪一個符合這樣的情形呢？
學生： 丙。
老師： 沒錯，那我們應該選擇哪個選項呢？
學生： (丙)。

4-3 牛頓第二運動定律
Newton’s Second Law of Motion

■ 前言 Introduction

本節將介紹牛頓第二運動定律，及其適用條件-觀察者在慣性坐標系，接著透過地球與月球的例子，介紹質量與重量之差異，並探討視重的意義。最後，透過實例，介紹力圖分析的推導機制與步驟，讓學生逐漸熟悉牛頓第二運動定律在真實生活中的應用。

本節涉及許多與力相關的單字，如：彈力、摩擦力、正向力，教師在提及不同種類的力時，須確保學生認識這些英文單字，才能理解其中的觀念，並應用於解題。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
internal force	內力	friction	摩擦力
external force	外力	weight	重量
system	系統	mass	質量
cancel	抵銷	shape	形狀
in pair	成對	scale	磅秤
interaction	交互作用	apparent weight	視重
spring force	彈力	Inertial frame of reference	慣性坐標系
tension	張力	observer	觀察者

deformation	形變	coefficient	係數
rigid body	剛體	kinetic friction	動摩擦
normal force	正向力	static friction	靜摩擦

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

❶ _____ be directly proportional to _____.

例句：When mass is constant, the acceleration of the body **is directly proportional to** the resultant force.

當質量固定時，物體之加速度和其所受合力成正比。

❷ ____ be inversely proportional to _____.

例句：When the resultant force is constant, the acceleration of the body **is inversely proportional to** the mass.

當合力固定時，物體之加速度與物體質量成反比。

❸ _____ comes in pairs _____.

例句：Force must **come in pairs.**

“力”必成對存在。

❹ _____ point to/directed toward _____.

例句：The direction of gravitational force always **points to** the center of the Earth.

=The direction of gravitational force **is directed toward** the center of the Earth.

重力的方向，恆指向地心。

❺ _____ be opposite to _____

例句：The direction of the spring force **is opposite to** the direction of the deformation.
彈力的方向與形變量方向相反。

❻ _____ cancel _____ out.

例句：The internal forces of a system appear in pairs and can **cancel** each other **out**.
系統的內力，會成對出現，且互相抵消。

■ 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 the chapter, students are able to acquire the following concepts:

一、了解牛頓第二運動定律之核心概念。

Understand the core concepts of Newton's second law of motion.

二、認識力的 SI 單位為牛頓(N)。

Know the SI unit of force is Newton (N).

三、區分質量與重量之不同。

Distinguish the difference between mass and weight.

四、了解視重的定義及意義。

Understand the definition and meaning of apparent weight.

五、熟悉力圖分析的步驟，以解答力學問題。

Become familiar with the steps of force diagram analysis to solve problems of mechanics.

例題講解

例題一

說明：正確應用與分析牛頓第二運動定律。
Apply and analyze Newton's Second Law of Motion correctly.

A sedan with a mass of 2000kg moved forward at a constant speed on the level ground, and then the driver slammed on the brakes to quickly stop the rotation of the wheels. When the wheels didn't rotate, the car decelerated and glided to a standstill.
If the kinetic friction coefficient between the ground and the tires is 0.4, and the acceleration due to gravity is g =10m/s^2, what is the magnitude of the acceleration during decelerating gliding?

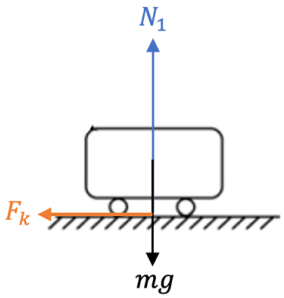
質量為 2000kg 的轎車，原本在水平地面上以等速前進，接著駕駛急踩剎車，使車輪迅速停止轉動，在車輪不轉的的情況下，轎車即減速滑行至靜止。若地面與輪胎間的動摩擦係數為 0.4，且取重力加速度 g =10m/s^2，則減速滑行時的加速度量值為多少？

(A) 0 m/s^2
(B) 0.4 m/s^2
(C) 4 m/s^2
(D) 80 m/s^2
(E) 800 m/s^2

(100 年物理科指考 5)

解題 Solution：

由牛頓第二定律 $F=ma$ ，需先透過轎車所受的外力來源畫出力圖。
接著，因為轎車在鉛直方向維持靜止，所以 $mg-N=0$ 。
而在水平方向。則可得 $F_k=\mu_k N=\mu_k mg=ma$ 。
將 m 相消可得
$a=\mu_k g=0.4\times 10=4\ (m/s^2)$，故選(C) 。



According to Newton's First Law of Motion, $F=ma$, we can know that $F_k=\mu_k N=\mu_k mg=ma$.
Then, the sedan in vertical direction remains still, so $mg-N=0$.

And in horizontal direction, we can know $F_k = \mu_k N = \mu_k mg = ma$.
Cancel m on both sides of the equation, and we can acquire the following equation $a = \mu_k g = 0.4 \times 10 = 4\ (m/s^2)$. So choose (C).

Teacher: According to Newton's Second Law of Motion, *F=ma*, we define the sedan as the system. As we already knew the mass of the car, the question needs to acquire acceleration. Does anyone know what external force is on the system?
Student: Gravity, normal force and kinetic friction.
Teacher: (Drawing a free-body diagram according to the student's response.) So what is the resultant force on the system?
Student: The kinetic friction.
Teacher: That's correct. From the motion state of the sedan, what's the vertical direction in the free body diagram?
Student: It would be 0.
Teacher: Great. According to *F=ma* the sedan in vertical direction remains still so the resultant force is 0. We know that $mg - N = 0$.
Teacher: I will leave 3 minutes for you to practice, later we will have students share their equations.
Student: $F_k = \mu_k N = \mu_k mg = ma$.
Teacher: Great. What about the acceleration?
Student: $a = \mu_k g = 0.4 \times 10 = 4\ (m/s^2)$.
Teacher: Correct. So which option should we choose?
Student: (C).

老師： 根據牛頓第二運動定律(*F=ma*)，選定轎車為系統，我們已知轎車質量，題目想要求出加速度，有沒有同學知道物體所受外力，有哪些呢？
學生： 重力、正向力、動摩擦力。
老師： （順著學生之回答，在黑板畫出力圖）所以物體所受的合力為何呢？
學生： 動摩擦力。
老師： 沒錯，我們從轎車的運動狀態，可以掌握力圖的鉛直方向，應如何？
學生： 鉛直的合力=0 。
老師： 很好，根據 *F=ma*，轎車在鉛直方向維持靜止，所以，合力=0，得到 $N = mg$
老師： 接著，給大家 3 分鐘的練習時間，我們等一下請同學上台分享自己的列式。

學生： $F_k = \mu_k N = \mu_k mg = ma$。
老師： 很好，所以我們可以知道加速度為何呢？
學生： $a = \mu_k g = 0.4 \times 10 = 4\ (m/s^2)$。
老師： 沒錯，那我們應該選擇哪個選項呢？
學生： (C) 。

例題二

說明：正確應用與分析牛頓第二運動定律。

Apply and analyze Newton's Second Law of Motion correctly.

A person walks on the level ground, pulling up and pushing down obliquely as the luggage moves forward at constant velocity. If the angle between the pushing and pulling is θ, as the figure shows at the right side. Knowing that the kinetic friction coefficient between the luggage and the ground is 0.30, and $\sin\theta = 0.60$, $\cos\theta = 0.80$, how many times is the pulling force to the pushing force?

(A) 0.40
(B) 0.63
(C) 0.81
(D) 1.60

一人在水平地面上，分別以斜向上拉及斜向下推等兩種方式使行李箱等速度往前移動，若拉力及推力與水平面的夾角皆為 θ，如右圖所示。已知行李箱與地面的動摩擦係數為 0.30，且 $\sin\theta = 0.60$、$\cos\theta = 0.80$，則拉力大小為推力大小的幾倍？

(A) 0.40
(B) 0.63
(C) 0.81
(D) 1.60

(97 年物理科指考 4)

解題 Solution：

將斜向上的拉力作力分解

鉛直方向：$N_1 = mg - F_1 \sin\theta$，水平方向：$F_1 \cos\theta = \mu N_1$

可得 $F_1 = \frac{mg\mu}{\cos\theta + \mu \sin\theta}$

將斜下方的推力，作向量分解

鉛直方向：$N_2 = mg + F_2 \sin\theta$，水平方向：$F_2 \cos\theta = \mu N_2$

可得 $F_2 = \frac{mg\mu}{\cos\theta - \mu \sin\theta}$，所以 $\frac{F_1}{F_2} = \frac{\cos\theta - \mu \sin\theta}{\cos\theta + \mu \sin\theta} = 0.63$，故選(B)。

Decomposing the obliquely pulling up force into vertical direction: $N_1 = mg - F_1 \sin\theta$, and horizontal direction: $F_1 \cos\theta = \mu N_1$

According to these two equations, we can get $F_1 = \frac{mg\mu}{\cos\theta + \mu \sin\theta}$

Decomposing the obliquely pushing force into vertical direction: $N_2 = mg + F_2 \sin\sin\theta$, and horizontal direction: $F_2 \cos\theta = \mu N_2$

According to these two equations, we can get $F_2 = \frac{mg\mu}{\cos\theta - \mu \sin\theta}$

Therefore, $\frac{F_1}{F_2} = \frac{\cos\theta - \mu \sin\theta}{\cos\theta + \mu \sin\theta} = 0.63$

So choose (B).

Teacher: Do you remember what we should do after identifying a system in addressing the mechanics question?

Student: We have to select an appropriate coordinate.

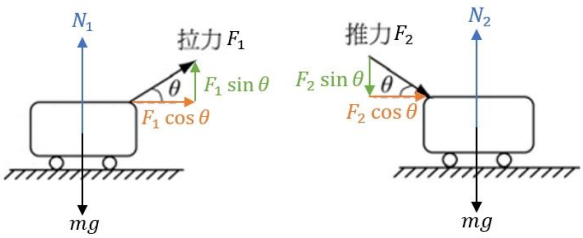
Teacher: Correct, in this question, what direction can we choose as the coordinate axis?

Student: We can choose the vertical and horizontal directions (X and Y axes).

Teacher: That's right. Because direction Y remains stationary and direction X remains in constant velocity. The two components achieve force equilibrium so the components' addition is 0.

Teacher: Good. You will have 3 minutes to practice drawing the free-body diagram of the pushing and pulling force on the horizontal and vertical coordinate system. Later we will have students share.

Student:



Teacher: Great. After drawing the free-body diagram, what should we do next?

Student: We should write down the equations of vertical and horizontal directions.

Teacher: Good. You will have 3 minutes to practice working out the equation of the vertical and horizontal directions. Later we will have students share their solutions.

Student: (1) Pulling

Vertical direction: $N_1 = mg - F_1 \sin\theta$

Horizontal direction: $F_1 \cos\theta = \mu N_1$

We can get

$$F_1 = \frac{mg\mu}{\cos\theta + \mu \sin\theta}$$

(2) Pushing

Vertical direction: $N_2 = mg + F_2 \sin\theta$

Horizontal direction: $F_2 \cos\theta = \mu N_2$

We can get

$$F_2 = \frac{mg\mu}{\cos\theta - \mu \sin\theta}$$

Teacher: Great. The question needs to determine how many times the pulling force is to the pushing force. Does anyone want to share the calculation?

Student: $\frac{F_1}{F_2} = \frac{\cos\theta - \mu \sin\theta}{\cos\theta + \mu \sin\theta} = 0.63$

Teacher: Great, so which option should we choose?

Student: (B).

老師：　還記得我們之前在說明力學問題時，處理步驟時有說過，選定系統後，接著要做甚麼呢？

學生：　選定適當的坐標軸。

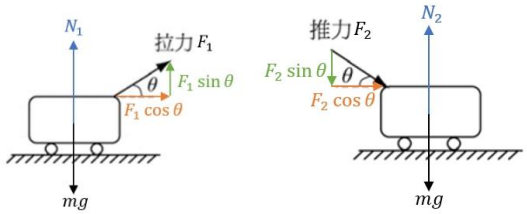
老師：　沒錯，那這題當中，我們可以選甚麼方向為坐標軸呢？

學生：　我們可以選水平方向(X 軸)與鉛直方向(Y 軸)。

老師：　沒錯，因為 Y 方向維持靜止，而 X 方向維持等速度，兩個分量都達“力平衡”，所以 X、Y 分量之和皆為零。

老師：　現在請大家花 3 分鐘的時間，以水平方向與鉛直方向坐標軸，畫出推力與拉力的分解力圖，我們等一下請同學上台分享。

學生：



老師：　很好，畫完力圖以後，我們要進行甚麼步驟呢？

學生：　列水平方向與鉛直方向的方程式。

老師：　很棒，一樣請大家花 3 分鐘的時間，分別列出拉力與推力的水平方向與鉛直方向方程式，我們等一下請同學上台分享。

學生：　(1)拉力

鉛直方向：$N_1 = mg - F_1 \sin\theta$，水平方向：$F_1 \cos\theta = \mu N_1$

可得 $F_1 = \frac{mg\mu}{\cos\theta + \mu \sin\theta}$

(2)推力

鉛直方向：$N_2 = mg + F_2 \sin\theta$，水平方向：$F_2 \cos\theta = \mu N_2$

可得 $F_2 = \frac{mg\mu}{\cos\theta - \mu \sin\theta}$

老師：　非常棒，題目想要我們求拉力是推力的幾倍，有沒有同學願意上台分享我們該如何計算呢？

學生：　$\frac{F_1}{F_2} = \frac{\cos\theta - \mu \sin\theta}{\cos\theta + \mu \sin\theta} = 0.63$

老師：　沒錯，那我們應該選擇哪個選項呢？

學生：　(B)

4-4 牛頓第三運動定律
Newton’s Third Law of Motion

■ 前言 Introduction

本章將介紹牛頓第三運動定律及其在生活之應用，教師應注意常見之迷思概念，如：作用力與反作用力為因果關係，誤以為反作用力會比作用力還慢出現。力很抽象，也經常非肉眼（或身體）所能辨識，因此在介紹作用力與反作用力時，教師可以多用生活例子，讓學生體認力的定義與效果，也使學生較容易理解。最後，也需整合牛頓三大定律的概念，應用於解題中。

本節老師將以英文生活常例，引導學生了解牛頓第三運動定律的概念，老師要盡量使用貼近學生生活化的語言，著重概念上的釐清。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
action	作用力	reaction	反作用力

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

❶ ____ at the same time.

例句：Action and reaction happen and disappear **at the same time.**

作用力與反作用力必同時產生、同時消失。

❷ _____ act on/ exert on _____.

例句：Action and reaction **act on/exert on** different bodies.

作用力與反作用力，會作用在不同物體上。

■ 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 the chapter, students are able to acquire the following concepts:

一、了解牛頓第三運動定律意涵。

Understand the concept of Newton's third law of motion.

二、了解作用力與反作用力之關係。

Understand the relation of action and reaction forces.

例題講解

例題一

說明：正確應用與分析牛頓第三運動定律。

Apply and analyze Newton's Third Law of Motion correctly.

A metal ball is hung from the ceiling by a thin rope whose mass could be negligible. As shown in the figure below, the forces related to this system are as follows: W_1 is the gravitational force on the metal ball, W_2 is the gravitational force of the metal ball on the earth, and T_1 is the force that the hanging rope exerts on the metal ball, T_2 is the force that suspension wire to the ceiling, and T_3 is the force that a metal ball exerts to the rope. Which of the following statements is correct? (Choose 3)

(A) T_1 and T_2 are the action and reaction.

(B) W_1 and W_2 are the action and reaction.

(C) T_1 and T_3 are the action and reaction.

(D) T_1 and W_1 are the action and reaction.

(E) *The magnitude of* T_1, T_2, T_3, W_1, W_2 are the same.

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

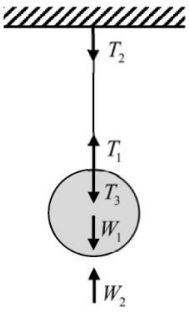
(A) T_1 與 T_2 互為作用力與反作用力。

(B) W_1 與 W_2 互為作用力與反作用力。

(C) T_1 與 T_3 互為作用力與反作用力。

(D) T_1 與 W_1 互為作用力與反作用力。

(E) T_1、T_2、T_3、W_1、W_2的量值均相等。



(103 年自然科學測 66)

解題 Solution：

W_1 與 W_2、T_1 與 T_3互為兩組作用力與反作用力，因此 $W_1 = W_2$ 、$T_1 = T_3$。

接著選金屬球為系統，根據 $\Sigma\vec{F} = m\vec{a}$（牛頓第二定律），分析其受力及加速度(a=0)，可得 $W_1 - T_1 = 0$。

最後，因為 T_1 與T_2 為同一條細線上的張力，所以兩者大小相等，即 $T_1 = T_2$

因此，$\boldsymbol{T_1 = T_2 = T_3 = W_1 = W_2}$，選(B)、(C)、(E)。

W_1 and W_2 , T_1 and T_3 are action and reaction in pairs，so $W_1 = W_2$, $T_1 = T_3$.

Then we select the metal ball as the system.

According to $\Sigma\vec{F} = m\vec{a}$ (Newton's Second Law), we can analyze the force diagram of the metal ball and obtain that $W_1 - T_1 = 0$.

Last, because T_1 and T_2 are the tension on the same rope, the magnitude of these two forces are equal, that is $T_1 = T_2$.

Therefore, $\boldsymbol{T_1 = T_2 = T_3 = W_1 = W_2}$**.** So the answers are (B), (C), (E).

Teacher:	Does anyone want to share what action and reaction you observe in this question?
Student:	W_1 and W_2 , T_1 and T_3 .
Teacher:	Yes, so in the (A), (B), (C), (D) four options, which options are correct?
Student:	(B) and (C).
Teacher:	Great. How about (E)? Does anyone know what option (E) means?
Student:	We have no idea.
Teacher:	OK. According to Newton's Third Law of Motion, what is the magnitude between action and reaction?
Student:	It would be the same.
Teacher:	Good. So what's the relationship between W_1 and W_2 and that between T_1 and T_3?
Student:	$W_1 = W_2$, $T_1 = T_3$.
Teacher:	Yes, we select the metal ball as the system of interest, and which forces are outside the system and which forces are inside the system?
Student:	W_1, T_1 .
Teacher:	That's right! Since the metal ball remains stationary, its acceleration is a = 0. According to $\Sigma\vec{F} = m\vec{a}$ (Newton's Second Law), what is the relationship between these two forces?
Student:	W_1 equals T_1.

Teacher: Good. Now we already know that $T_1 = T_3 = W_1 = W_2$ then how about force T_2? When we ignore the mass of the rope, in the same string, how is the tension in the system?

Student: The tensions would be the same.

Teacher: Yes, what can we know from this sentence?

Student: $T_1 = T_2$.

Teacher: Great. Including the relationship of the tension, what equation can we get?

Student: $T_1 = T_2 = T_3 = W_1 = W_2$.

Teacher: Good job. What is the magnitude of these five forces?

Student: They are the same.

Teacher: Yes, which options should we choose?

Student: (B), (C), (E).

老師： 有沒有同學願意分享這題當中你們認為有哪些作用力與反作用力呢？

學生： W_1 與 W_2 、T_1 與 T_3。

老師： 很好，所以(A)、(B)、(C)、(D)四個選項中，我們可以知道哪些選項是正確的呢？

學生： (B)、(C) 。

老師： 很棒，那麼(E)選項呢？有沒有同學有想法？

學生： 不知道。

老師： 根據牛頓第三運動定律，作用力與反作用彼此大小如何？

學生： 相等。

老師： 很棒，所以 W_1 與 W_2、 T_1 與 T_3 他們的關係為何？

學生： $W_1 = W_2$ 、$T_1 = T_3$。

老師： 沒錯，那接著我們選金屬球為系統，哪些是系統所受的外力呢？

學生： W_1、T_1 。

老師： 沒錯，因為金屬球維持靜止，也就是加速度 a=0，根據 $\Sigma\vec{F} = m\vec{a}$ (牛頓第二定律)，所以這兩個力的關係為何？

學生： $W_1 = T_1$ 。

老師： 很好，所以我們現在已知的關係有$T_1 = T_3 = W_1 = W_2$，那還少了一個 T_2 的力，我們知道在忽略繩子重量的時候，同一條繩子，張力會如何？

學生： 張力會相等。

老師： 沒錯，所以我們可以由這句話得到甚麼呢？

學生： $T_1 = T_2$ 。
老師： 很好，所以再把這個關係加上去，我們會得到甚麼關係式呢？
學生： $T_1 = T_2 = T_3 = W_1 = W_2$ 。
老師： 很好，所以這五個力大小如何呢？
學生： 皆相等。
老師： 沒錯，那我們應該選擇哪個選項呢？
學生： (B)、(C)、(E)。

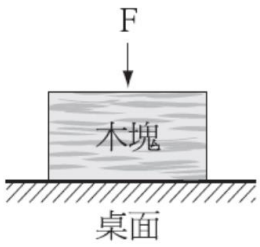
例題二

說明：正確應用與分析牛頓第三運動定律。

Apply and analyze Newton's Third Law of Motion correctly.

As shown in the figure below, one exerts force F to the wooden block on the table. Assume W is the gravitational force exerting on the wooden block and N is the force that the table exerts to the wooden block.

(A) F and W are action and reaction.
(B) F and N are action and reaction.
(C) W and N are action and reaction.
(D) F, W and N are action and reaction.
(E) All of F, W and N are not action and reaction.



如下圖所示，有人施力 F 於一放置在桌面上的木塊。設 W 代表木塊所受之地球引力，N 代表桌面作用於木塊之力，下列敘述何者正確？

(A) F 和 W 互為作用力與反作用力。
(B) F 和 N 互為作用力與反作用力。
(C) W 和 N 互為作用力與反作用力。
(D) F、W 和 N 三者同時互為作用力與反作用力。
(E) F、W 和 N 三者中沒有任何作用力與反作用力的關係。

(85 年自然科學測 43)

解題 Solution：

人施力於木塊之力 F 的反作用力，為木塊施於人之力；木塊受地球引力 W 的反作用力，為地球受木塊的引力；桌面作用於木塊之力 N 的反作用力，為木塊作用於桌面之力。所以三者並無作用力與反作用力的關係。F、W、N 皆是木塊所受的外力，受力對象為同一物體，所以，三力的任何兩者，皆不可能成為作用力與反作用力之關係。

故選(E)。

The reaction of the force that one exerts on the wooden block is the force of the wooden block exerts on the person.

The reaction of the gravitational force on the wooden block is the force exerts on the Earth.

The reaction of the force that the table exerts on the wooden block is the force that the wooden block exerts on the table. F, W, N are all forces exerted on the block, which are forces on the same object. Therefore, the three forces are not possible to be any pair of action and reaction forces. So the answer is (E).

Teacher:	From the options, we can know which forces are the action and reaction. I will leave you 3 minutes to practice finding the reaction of the three forces (F, W, N).
Student:	OK.
Teacher:	Time's up. First is the force that one exerts on the wooden block, does anyone want to share what the reaction is?
Student:	The force that wooden block exerts on the person.
Teacher:	Yes. How about the gravitational force exerting on the wooden block? What is its reaction?
Student:	The force that wooden block exerts on the Earth.
Teacher:	Correct. How about the force of the table acting on the wooden block. What is its reaction?
Student:	The force of the wooden block acting on the table.
Teacher:	Great. Do those forces relate to the action-reaction?
Student:	No.
Teacher:	Great. Since F, W, N are all forces exerted on the block, which are forces on the same object. Therefore, the three forces are not possible to be any pair of action and reaction forces.
Teacher:	Which option should we choose?
Student:	(E).

老師： 從選項來看，我們可以知道題目想問我們，哪些力互為作用力與反作用力？給同學 3 分鐘的時間練習看看題目所敘述的三個力(F、W、N)他們的反作用力是甚麼？

學生： 好的。

老師： 時間到，我們首先來看人施力於木塊之力(F)，有沒有同學願意分享他的反作用力是甚麼呢？

學生： 木塊施於人之力。

老師： 沒錯，那木塊受地球引力(W)，他的反作用力是甚麼呢？

學生： 地球受木塊的引力。

老師： 沒錯，那桌面作用於木塊之力(N)，他的反作用力是甚麼呢？

學生： 木塊作用於桌面之力。

老師： 很好，所以這三個力之中，有互為作用力與反作用力的關係嗎？

學生： 沒有。

老師： 沒錯，因為 F、W、N 皆是木塊所受的外力，受力對象為同一物體，所以，三力的任何兩者，皆不可能成為作用力與反作用力之關係。

老師： 那我們應該選擇哪個選項呢？

學生： (E)。

★第五章 週期運動★

Chapter 5 Periodic Motion

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■ 前言 Introduction

本章旨在介紹牛頓運動定律的應用，包括:等速圓周運動及簡諧運動。在教學時，建議從生活例子出發，再與物理概念做連結，以激發學生學習動機。引用牛頓定律解題時，也需緊密結合運動學的定義及公式。

在英文方面，學生能透過學習理解不同字首和字尾的意義更有效地學習如何表示方向，也能加以利用被動態表達彈簧被拉伸及壓縮的情況，老師需向學生解釋主動和被動的差別，如此才能讓學生對於文法更得心應手。

5-1 等速圓周運動
Uniform Circular Motion

■ 前言 Introduction

在日常生活中，處處可見圓周運動，如：遊樂場中的摩天輪、雲霄飛車、輻射飛椅等等皆是，物體繞著圓形軌跡運動，即稱之為圓周運動。當物體以固定的速率做圓周運動，稱為等速圓周運動，如：之前在物理課程中提及，地球繞日運行的軌道，其長短軸幾乎相等，可以視為等速圓周運動。上述的例子，不但做等速圓周運動，也呈現出週期性運動的現象。

英文方面，提醒學生 counter-有反/反抗/相反的意思，而字根-ular 有與...相似的意思，所以老師提醒學生 angle/angular 和 circle/circular 的變化和意思。句子中如有涉及到介係詞的用法，可以從意思上理解，減輕背誦的負擔。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
angular displacement	角位移	radian	弧度/徑
angular velocity	角速度	arc length	弧長
period	週期	counterclockwise	逆時針
frequency	頻率	clockwise	順時針
centripetal acceleration	向心加速度	centripetal force	向心力
uniform circular motion	等速圓周運動		

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

❶ _____ point to _____.

例句：The direction of the centripetal acceleration always **points to** the center of the circle.

向心加速度方向，恆指向圓周軌道的圓心。

❷ _____ rotate around _____.

例句：The rope **rotates around** the center of the circular path.

繩子繞著圓周軌道的中心旋轉。

❸ _____ between _____.

例句：The angle **between** the rope and the vertical line is θ.

繩子和鉛直線的夾角是 θ。

■ 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 expected to acquire the following concepts:

一、了解等速圓周運動的意義。

Understand the meaning of the uniform circular motion.

二、了解角速度定義與表示法。

Understand the definition and the presentation of the angular velocity.

三、角速度與速度之間的換算。

Convertion between angular velocity and linear velocity.

四、了解向心加速度定義與表示法。

Understand the definition and representation of centripetal acceleration

五、了解向心力之定義與公式。

Understand the definition and the equation of centripetal force.

六、推導角速度與週期的關係。

Derive the relation between angular velocity and the period of rotation.

例題講解

例題一

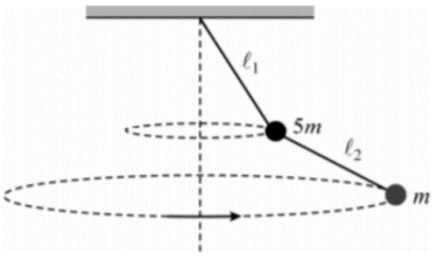
說明：分析圓周運動物體之受力。

Analyze the acting forces in uniform circular motion.

As shown in the figure below, two thin ropes with fixed lengths l_1 and l_2 and negligible mass are tied to particles of mass 5m and m respectively, and the two particles rotate around the same vertical line in horizontal uniform circular motion with the same angular frequency. It is known that the acceleration of gravity is g, the tensions of the two ropes are T_1 and T_2 respectively, and the sin values of the angles between the two ropes and the vertical line are $\frac{1}{\sqrt{5}}$ and $\frac{2}{\sqrt{5}}$

How many times is the tension T_2 to mg?

(A) $\sqrt{3}$
(B) 2
(C) $\sqrt{5}$
(D) $\sqrt{7}$
(E) $3\sqrt{5}$



如下圖所示，兩條長度固定為 l_1、l_2 且質量可忽略不計的細繩，分別繫著質量為 5m 和 m 的質點，兩質點以相同的角頻率繞同一鉛直線水平等速圓周運動。已知重力加速度為 g，兩繩的張力分別為 T_1 及 T_2，兩繩與鉛直線夾角的正弦值分別是 $\frac{1}{\sqrt{5}}$ 及 $\frac{2}{\sqrt{5}}$，請問張力 T_2 為 mg 的多少倍？

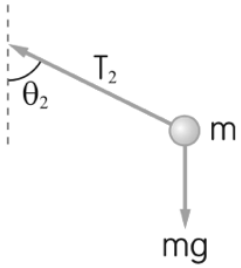
(A) $\sqrt{3}$　(B) 2　**(C) $\sqrt{5}$**　(D) $\sqrt{7}$　(E) $3\sqrt{5}$

（取自 107 年指考物理科 19）

解題 Solution：

如下圖所示，對 m 而言，其做水平等速圓周運動，故鉛直方向合力為 0。

如下圖所示，對 m 而言，其做水平等速圓周運動，故鉛直方向合力為 0。



$$T_2 = cos\theta_2 = mg \rightarrow \frac{T_2}{mg} = \frac{1}{cos\theta_2} = \sqrt{5}$$

故選(C)

As shown in the figure, for m, it is in uniform circular motion in the horizontal plane, so the vertical component of the summation force is zero. So choose (C).

Teacher: First, we have to analyze the acting force toward the question. Does anyone know which system we should choose for the system of interest?

Student: The m.

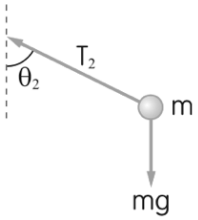
Teacher: Great. Because there is a component of T_2 that achieves force equilibrium. Does anyone know which direction the component is in?

Student: The vertical component.

Teacher: Well done. Since the movement of the vertical direction remains still, what's the resultant force of the vertical component?

Student: It should be 0.

Teacher: Great, I will leave you some time to draw a free body diagram with m as the system of interest and decompose it into horizontal and vertical components. Later, we will have students go up and write it down.



Teacher: Great, I will leave you some time to practice determining the equation of the acting force in the vertical component. Later, we will have students go up and write it down.

Student: $T_2 = cos\theta_2 = mg$

Teacher: Great. The question ask how many times the T_2 is to mg. After transposing the equation we can know it's $\frac{1}{cos\theta_2}$ times.

(Write down the equation $\frac{T_2}{mg} = \frac{1}{\cos\theta_2}$ on the blackboard.)

So, what's the value of $\frac{T_2}{mg}$?

Student: $\sqrt{5}$.

Teacher: Very good, so which option should we choose?

Student: (C).

Teacher: Good job.

老師： 首先，我們須先對此題進行力的分析，因為題目是問下方的繩子張力：T_2，有沒有同學知道我們應該選擇什麼作為系統呢？

學生： 選擇 m。

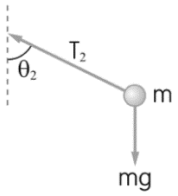
老師： 很好，因為T_2有一個方向的分量，呈現力平衡，同學認為是哪個方向呢？

學生： 鉛直方向。

老師： 很好，因為鉛直方向維持靜止，所以鉛直的合力應為何？

學生： 合力為 0。

老師： 是的，現在給大家一些時間，請練習以 m 為系統的力圖分析，並分解為水平與鉛直兩個分量，我們等一下請同學上台畫畫看。



老師： 很棒，再給大家一些時間，請大家練習把此物體在鉛直方向受力的方程式寫出來，我們等一下請同學上台寫寫看。

學生： $T_2 = cos\theta_2 = mg$。

老師： 很好，而題目欲求 T_2 是 mg 的多少倍，將式子移項可知是 $\frac{1}{cos\theta_2}$ 倍。

（將算式$\frac{T_2}{mg} = \frac{1}{\cos\theta_2}$寫於黑板上）所以$T_2$對 mg 的比值是多少？

學生： $\sqrt{5}$。

老師： 非常棒，所以我們要選哪個選項?

學生： (C)。

老師： 很棒！

例題二

說明：能夠分析物體在斜面做圓周運動之受力。

Analyze the forces exerting on an object moving with uniform circular motion on an inclined plane.

A car with mass m moving with uniform circular motion of radius R on the inclined runway with angle θ corresponding to the horizontal plane. The following figure shows when looking directly at the car. Assuming that the magnitude of the acceleration of gravity is g, which of the following statements is correct?

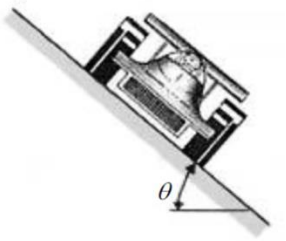
(A) If $\theta = 0$, the car can not move with constant circular motion without friction.

(B) Only when the friction against the gliding force along the inclined plane $mgsin\theta$ exists, it could do circular motion.

(C) It can do the circular motion without the friction, and the normal force of the inclined plane to the car is $mgcos\theta$.

(D) **The car can do circular motion without friction, and the velocity is** v $= \sqrt{gRtan\theta}$

(E) The friction points downward along the inclined plane can increase the centripetal force of the circular motion.



質量為 m 的汽車與水平夾角為 θ 的斜面跑道作為 R 的圓周運動，其面對車頭直視時的示意圖如下圖所示。設重力加速度的量值為 g，下列敘述哪些正確？

(A) 若夾角 $\theta = 0$，無摩擦力則無法做圓周運動。

(B) 需摩擦力克服沿斜面的下滑力$mgsin\theta$才可作圓周運動。

(C) 無摩擦力也可做圓周運動，此時斜面跑道對車的正向力為 $mgcos\theta$ 。

(D) 無摩擦力也可作圓周運動，此時速率$v = \sqrt{gRtan\theta}$ 。

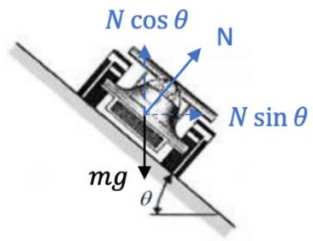
(E) 沿斜面向下的摩擦力，可增加作圓周運動的向心力

（取自 110 年指考物理科 22）

解析 Solution：

1. 若夾角為 0 則為水平跑道，欲做圓周運動，需有靜摩擦力提供所需的向心力，故(A)正確。

2. (C)(D)無摩擦力也可作圓周運動，此時汽車所需的向心力，則完全由正向力的分量提供。汽車在斜面跑道之受力分析如下圖。



鉛直方向：合力為 0

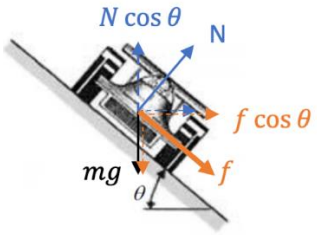
$$N\cos\theta = mg \rightarrow N = \frac{mg}{cos\theta}$$

水平方向：正向力的水平分力，提供圓周運動所需的向心力

$$Nsin\theta = F_c = \frac{mv^2}{R} \rightarrow v = \sqrt{gRtan\theta}$$

故(B)(C)錯誤，(D)正確。

(E)右上圖中若加上沿斜面向下的摩擦力，則可增加水平方向的分力，即增加圓周運動的向心力，如下圖所示。

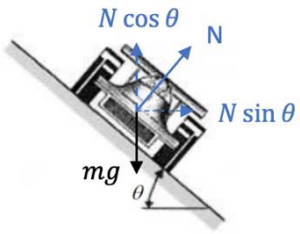


$Nsin\theta + f\cos\theta = F_c' > F_c$

故(E)正確。

The angle $\theta = 0$ means the runway is horizontal. A car moving with circular motion needs static friction in order to provide the required centripetal force, so (A) is correct.

As for (B), (C), (D), it could move with circular motion without the existence of friction. The required centripetal force can only be provided by the component of normal force. The free-body diagram and force analysis of the car is shown below.



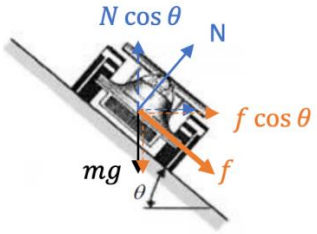
In vertical direction: the resultant force is 0

$$N\cos\theta = mg \rightarrow N = \frac{mg}{cos\theta}$$

In horizontal direction: the component of the normal force is centripetal force.

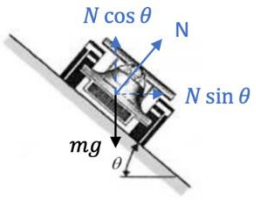
$$Nsin\theta = F_c = \frac{mv^2}{R} \rightarrow v = \sqrt{gRtan\theta}$$

Thus, (B) and (C) are incorrect, and (D) is correct.



In the figure, the friction pointing downward along the inclined plane increases, the horizontal component also increases, and the required centripetal force in circular motion also increases. So we should choose (A), (D), (E).

Teacher:	According to the conditions mentioned in the question, we can consider the options. First, option (A). If the angle is 0, then would the inclined plane exist?
Student:	No, it would be the horizontal plane.
Teacher:	Great, then if it does the circular motion on the plane road, should we need forces to make it work?
Student:	Yes.
Teacher:	Good. So if a car moves with circular motion, it needs horizontal external force to provide the centripetal force it needs. Thus, except for the friction, there are no other sources of horizontal force, it could not move circularly.
Teacher:	Next, for (B), (C), (D), we need to analyze the acting force on the car. I will leave you some time to analyze it, later we will have students go up and draw it.

Student: 

Teacher: Great. Next, I will leave you some time, everyone should practice determining the equations of vertical and horizontal components.

Student: Vertical direction: $N\cos\theta = mg$

Horizontal direction: $N\sin\theta$

Teacher: Excellent. What force makes the car do horizontally uniform circular motion?

Student: $Nsin\theta$

Teacher: Great. Then we take a look at (B). There is nothing between the value of the centripetal force,$Nsin\theta$, in circular motion and the oblique gliding force.
Look at (C), according to the free-body diagram, what's the normal force that the inclined plane does to the car?

Student: N.

Teacher: Good. So (C) is incorrect. Then, let's take a look at (D). Do you remember there is a formula of the centripetal force in circular motion related to the velocity v.

Student: $F_c = \frac{mv^2}{R}$.

Teacher: Great, now everyone determines the velocity, v with the analysis of horizontal components and the circular motion. Later we will have students go up and try.

Student: $Nsin\theta = F_c = \frac{mv^2}{R} \rightarrow v = \sqrt{gRtan\theta}$.

Teacher: Good! So (D) is correct. Finally, we take a look at (E). If the obliquely gliding force increases then what would the equation of horizontal component be?

Student: $N\sin\theta + f\cos\theta$

Teacher: The equation of centripetal force would be like that. Does the original centripetal force increase?

Student: Yes.

Teacher: Good. So (E) is correct as well. Which options should we choose?

Student: (A), (D), (E).

Teacher: Good job.

老師：依題目所述的條件，我們來看看選項。首先，(A)選項：如果夾角為 0 的話，那還會有斜面嗎？

學生：不會，是水平的路面。

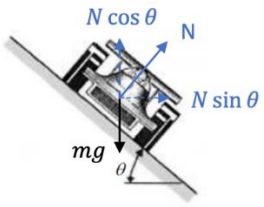
老師：很好，那如果水平的道路上，要做圓周運動是不是需要有力讓他作用呢？

學生：是的。

老師：很好，所以如果水平的道路上，要做圓周運動，需要有水平的外力，提供所需的向心力。所以，除了摩擦以外，沒有其他外力來源，因此無法作圓周運動。

老師：接著來看選項(B)(C)(D)，我們須先對汽車進行力的分析，給大家一些時間，請大家練習一下力的分析，我們等一下請同學上台畫畫看。

學生：



老師：很棒，那再給大家一些時間，請大家練習將鉛直方向，與水平方向受力的方程式寫下來。

學生：鉛直方向：$N\cos\theta = mg$

水平方向：$N\sin\theta$

老師：很好，那是什麼力，提供這台汽車進行水平方向的等速圓周運動呢？

學生：$Nsin\theta$

老師：很棒，那我們來看選項(B)，提供圓周運動向心力的量值為 $N\sin\theta$ ，與斜面下滑力無關。接著來看選項(C)，根據力圖，我們知道斜面提供給汽車的正向力為何呢？

學生：N

老師：很好，所以選項(C)不正確，再來看選項(D)，還記得圓周運動的向心力有一個公式和速度 v 有關嗎？是哪一個公式呢？

學生：$F_c = \frac{mv^2}{R}$

老師：很棒，現在請大家練習一下利用水平方向的力圖分析，和圓周運動的公式結合將速度 v 計算出來，等一下我們請同學上台試試看

學生：$Nsin\theta = F_c = \frac{mv^2}{R} \rightarrow v = \sqrt{gRtan\theta}$

老師：很好，所以選項(D)正確。最後我們來看選項(E)，如果增加斜面向下的摩擦力，那們水平方向的受力方程式應該如何呢？

學生： $N\sin\theta + f\cos\theta$

老師： 也就是說向心力的來源，變成上面那個式子，是否有因為摩擦 (*f*) 的存在而增加呢？

學生： 有。

老師： 很好，所以選項(E)也正確，那這題我們要選哪幾個選項呢？

學生： (A)(D)(E)

老師： 很棒。

5-2 簡諧運動
Simple Harmonic Motion

■ 前言 Introduction

對原本維持靜止於穩定平衡點的物體施力，使其偏離後放手，可觀察到物體以固定頻率來回作週期性運動。當所受外力滿足虎克定律時，此種週期性運動現象，符合數學上的簡諧函數，因此稱為簡諧運動。本節將介紹簡諧運動的定義與特性、再探討彈簧、單擺等簡諧運動的實例，並利用等速圓週運動在特定軸上之投影，協助理解簡諧運動的相關物理量。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
equilibrium point	平衡點	oscillation	振盪(名詞)
Hooke's law	虎克定律	oscillate	振盪(動詞)
spring constant	彈性常數	amplitude	振福
reference circle	參考圓	momentum	動量
project	投影	simple harmonic motion	簡諧運動
end	端點	The principle of conservation of mechanical energy	力學能守恆定理

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

❶ _____ be stretched out _____.

例句：When a spring **is stretched out**, the displacement is more than 0.

當彈簧被拉長時，位移會大於零。

❷ _____ be compressed.

例句：When a spring **is compressed**, the displacement is less than 0.

當彈簧被壓縮時，位移會小於零。

❸ _____ be conserved = _____ remain(s) constant.

例句：When there are only conservative forces exerted to a system, the mechanical energy of the system **is conserved**.

=When there are only conservative forces exerted to a system, the mechanical energy **remains constant**.

當運動過程只受保守力作用時，力學能會守恆。

❹ _____ back and forth _____.

例句：A particle oscillates **back and forth** between two points.

質點會在兩點間來回振盪。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、了解簡諧運動定義與特性。

Understand the definition and the characteristics of simple harmonic motion.

二、認識簡諧運動的相關物理量。

Know the related physical quantities of the simple harmonic motion.

❧ 例題講解 ☙

例題一

說明：能透過假想的等速圓周運動，在某特定軸之投影，來分析簡諧運動過程，速率與位移的關係。

Analyze the relation between speed and displacement of objects with simple harmonic motion, by means of the projection of a specific axis of an imaginary constant circular motion.

An object moves in simple harmonic motion on the smooth plane. When its displacement arrives at the half of the amplitude, the speed is v. Then, what is the speed when the object passes the equilibrium point where the displacement is 0?

一物體在光滑水平面上作簡諧運動，當其位移為振幅一半時，速率為 v，則此物體通過位移為零之平衡點時的速率為下列何者？

(A) $2v$

(B) $\frac{2\sqrt{3}}{3}v$

(C) v

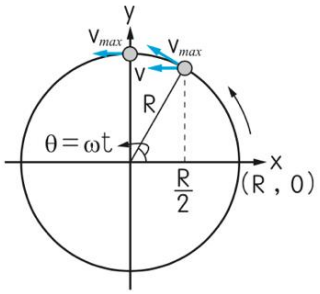
(D) $\frac{\sqrt{3}}{2}v$

(E) $\frac{1}{2}v$

(取自 107 年指考物理科 16)

解題 Solution：

如下圖所示，分析物體在平面上做簡諧運動過程的位移、速率，可視為物體做等速圓周運動，在 *x* 軸上的投影，來進行分析：



$$x = \frac{R}{2} = Rcos\omega t \rightarrow cos\omega t = \frac{1}{2}$$

$$v = |-v_{max} sin\omega t| = v_{max} \times \frac{\sqrt{3}}{2}$$

$$\therefore v_{max} = \frac{2\sqrt{3}}{3} v$$

故選(B)

As shown in the figure below, analyze the displacement and velocity of an object in the process of simple harmonic motion on the plane. It can be regarded as the projection of the object on the x-axis for constant-velocity circular motion for analysis:

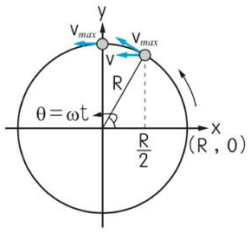
$$x = \frac{R}{2} = Rcos\omega t \rightarrow cos\omega t = \frac{1}{2}$$

$$v = |-v_{max} sin\omega t| = v_{max} \times \frac{\sqrt{3}}{2}$$

$$\therefore v_{max} = \frac{2\sqrt{3}}{3} v$$

So choose (B).

Teacher: (According to the question, draw a diagram on blackboard.)



Teacher: According to the question, it requires the speed of equilibrium point. Does anyone want to share the formula of the displacement and speed in simple harmonic motion?

Student: $x = Rcos\omega t$ 、$v = |-v_{max} sin\omega t|$

Teacher: Good. How do we figure out the answer by using the formulas? I will leave you some time and later I will have students go up and share.

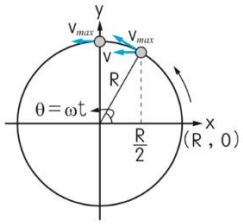
Student: $x = \frac{R}{2} = Rcos\omega t \rightarrow cos\omega t = \frac{1}{2}$

$v = |-v_{max} sin\omega t| = v_{max} \times \frac{\sqrt{3}}{2}$

$\therefore v_{max} = \frac{2\sqrt{3}}{3} v$

Teacher: Great. So the (B) option is correct.

老師：（依題目所述，將下圖畫於黑板上）



老師：依題目所言，欲求出平衡點的速率，有沒有人願意分享簡諧運動位移和速率的公式為何呢？

學生：$x = R\cos\omega t$ 、$v = |-v_{max}\sin\omega t|$

老師：很好，利用這些公式，想想看我們該如何得到答案呢？給大家一些時間練習，我們等一下請同學上台分享。

學生：$x = \frac{R}{2} = Rcos\omega t \rightarrow cos\omega t = \frac{1}{2}$

$v = |-v_{max} sin\omega t| = v_{max} \times \frac{\sqrt{3}}{2}$

$\therefore v_{max} = \frac{2\sqrt{3}}{3} v$

老師：棒，所以我們該選(B)選項。

例題二

說明：能透過彈簧之震盪之週期公式，推出簡諧運動之相關運動物理量。

Determining the associated kinematics quantities of simple harmonic motion by means of the formula of period regarding a spring system.

A spring with force constant of 1.00N/m, one end is fixed on the wall, and the other end is connected to a mass particle with a mass of 1.00kg, and the particle performs one-dimensional simple harmonic motion on a smooth horizontal plane, with x representing that the particle deviates from the equilibrium point (the original spring length).

When $x > 0$, it means the spring is stretched and when $x < 0$, it means the spring is compressed. At time t = 0s, the velocity of the particle toward the direction of spring extension is not 0, and the displacement is $x =$ 0.02m. If mechanical energy is conserved during motion, then at time t = πs, which of the following statements about particle motion is correct?

(A) Moves toward the compression direction of the spring, and x =0.02m.

(B) Moves toward the compression direction of the spring, and $x = -0.02$m.

(C) The particle moves back to the equilibrium point, and starts to be compressed.

(D) The particle moves back to the equilibrium point, and starts to be stretched out.

(E) The momentum of the particle is the same as that of t = 0s.

一力常數為 1.00N/m 的彈簧，一端固定在牆上，另一端連結質量為 1.00kg 的質點，且質點在光滑水平面上作一維簡諧運動，以 x 代表質點偏離平衡點（彈簧自然長度）的位移，$x > 0$ 表示彈簧被拉長，$x < 0$ 表示彈簧被壓縮。在時間 t = 0s 時，質點朝彈簧伸長的方向運動速率不為零，且位移 $x =$ 0.02m。若運動過程中力學能守恆，則時間 t = πs 時，下列有關質點運動的敘述何者正確？

(A) 朝彈簧壓縮的方向運動，且 x =0.02m。

(B) 朝彈簧壓縮的方向運動，且 $x = -0.02$m。

(C) 質點回到平衡點，且開始被壓縮。

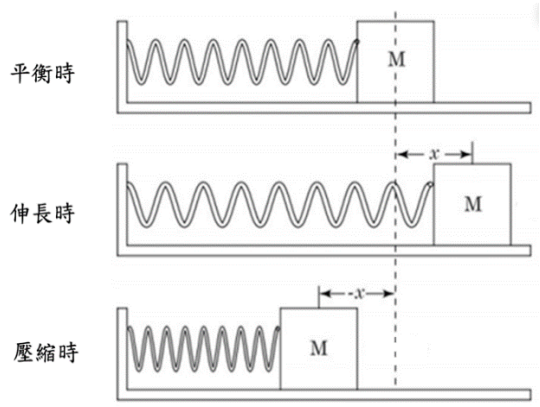
(D) 質點回到平衡點，且開始被拉長。

(E) 質點動量和時間 t = 0s 時的動量一樣。

(取自 109 年指考物理補考 5)

解題 Solution：

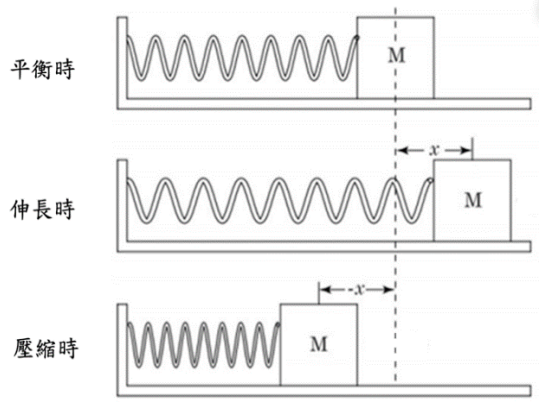
依題目所述，該物體的運動狀況應如下圖所示。



由題目所知，可得質點做簡諧運動的週期為 $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1.00}{1.00}} = 2\pi\ s$。

在 t = 0s 時，質點朝彈簧伸長方向運動速率不為 0，且位移 $x =$ 0.02m，代表此時質點在平衡點與右端點之間且向右移動。當時間 t = πs 時，質點經過 0.5 個週期，位在平衡點與左端點之間，且向左移動，故選(A)。

As the question describes, the motion of the object should be like the figure below.



From the question, the period of the particle in simple harmonic motion is

$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1.00}{1.00}} = 2\pi\ s.$

At t = 0s, the particle moves toward the compression of the spring at which the speed is not 0, and the displacement is 0.02m. It means that the particle is between the equilibrium point and the right end and moves toward the right. At t = πs, the particle experiences 0.5 periods and is located between the equilibrium point, which moves toward the left. So choose (A).

Teacher: As the question states, does anyone know how many periods it experiences when t=π(s)?

Student: No.

Teacher: Is there any periodic formula related to mass and spring constant?

Student: $T = 2\pi\sqrt{\frac{m}{k}}$

Teacher: Great. I will leave you some time to calculate the period of the particle in harmonic motion, and later, I will have students go up and share.

Student: $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1.00}{1.00}} = 2\pi$ s.

Teacher: Good, so how many periods does it experience at t=π(s)?

Student: Half period.

Teacher: Yes, assume that in the beginning, the particle moves from the equilibrium point. After the half period, where should the particle be?

Student: The equilibrium point.

Teacher: Great. Then the question states that it starts on the x=0.02m. Between which end and the equilibrium point should the particle move?

Student: The right end.

Teacher: Correct. After half period, between which end and the equilibrium point should the particle move?

Student: The left end.

Teacher: Excellent. Since it is between the equilibrium point and the left end, which movement should the particle be in?

Student: Compressing the spring.

Teacher: Good, which option should we choose?

Student: (A).

Teacher: Excellent.

老師： 依題目所述，有沒有同學知道 π 是多少週期呢？

學生： 不知道。

老師： 我們是不是有一個質量、彈簧常數有關的週期公式呢？

學生： $T = 2\pi\sqrt{\frac{m}{k}}$

老師：　很棒，現在給大家一些時間，請大家嘗試計算看看此質點做簡諧運動的週期，等一下請同學上台分享。

學生：　$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1.00}{1.00}} = 2\pi$。

老師：　很好，所以 π 是多少週期呢？

學生：　半個週期。

老師：　假設一開始質點在平衡點後出發，經過半個週期後，質點應該會在哪個位置呢？

學生：　平衡點。

老師：　很棒，那現在題目說一開始是在 x=0.02m，那質點是在平衡點和哪個端點之間運動呢？

學生：　右端點。

老師：　沒錯，那它經過半個週期後，應該會在平衡點和哪個端點間呢？

學生：　左端點。

老師：　非常棒，既然在平衡點與左端點之間，那此質點是在壓縮彈簧還是伸長彈簧呢？

學生：　壓縮彈簧。

老師：　很好，那麼我們應該選擇哪一個選項呢？

學生：　(A)。

老師：　非常好。

★第六章 萬有引力★
Chapter 6 Universal Gravitation

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■ 前言 Introduction

本節旨在解釋「萬有引力定律」，以及「克卜勒三大行星運動定律」的概念，也介紹這些定律之應用，如:人造衛星的運行，在推導過程，經常需整合上述多項定律。

在英文方面，主要介紹如何用英文表達正比和反比，其中提供兩個主要句型供參考，一為形容詞用法，二為複詞片語用法，講解時老師可透過字義讓學生更容易理解反比的英文；在表倍數的句型，學生容易將介係詞搞混，因此在講解過程中，需要特別強調。

6-1 萬有引力定律
Law of Universal Gravitation

■ 前言 Introduction

本章節將介紹萬有引力定律:牛頓提出所有具有質量的物體之間，都會互相吸引，故稱為萬有引力。本章節將介紹萬有引力定律之公式，並解釋其概念。

在英文敘述時，老師可以使用 that/those，代替前述重複的名詞或片語。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
law of universal gravitation	萬有引力定律	universal gravitational constant	重力常數
gravitational force	重力	centers of mass	質心
particle	質點		

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

❶ _____ (directly) proportional to _____.

例句：The universal gravitation is **proportional to** the masses of the two objects.

萬有引力的量值，正比於兩物體質量的乘積。

❷ _____ inversely proportional to _____.

例句：The universal gravitation is **inversely proportional to** the square of the distance between the two objects.

萬有引力的量值，和兩物體間的距離平方成反比。

❸ _____ be along _____.

例句：The directions of the gravitational forces **are along** the line joining the centers of the two bodies and opposite each other.

兩物體間的萬有引力方向，必沿著兩點質心之連線方向。

❹ There is/are _____ between/in _____.

例句：There **is** universal gravitation **between** any two particles.

任意兩質點間，都有萬有引力的作用。

❺ that(單數) /those(複數) 作為代詞的用法

例句：When considering the magnitude of force, the gravitational force (weight) that the Earth exerts on an apple is equal to the gravitational force (weight) that the apple exerts on the Earth.

考慮力的量值時，地球對蘋果的萬有引力（重力），等於蘋果對地球的萬有引力（重力）。

*此時的 that 是代替前述的 the gravitational force。

■ 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、了解萬有引力的意涵。

Understand the meaning of universal gravitation.

二、了解萬有引力定律的概念及公式。

Understand the concept and the formula of universal gravitation.

❧ 例題講解 ☙

例題一

說明：分析與計算地表物體所受之重力。

Analyze and calculate the weight of the objects on the surface of the Earth.

When a ripe apple falls from up to the ground, according to Newton's law of universal gravitation, which of the following statements is true?

(A) The Earth exerts attraction force on the apple but the apple doesn't to the Earth.

(B) The apple exerts attraction force to the Earth but the Earth doesn't to the apple.

(C) Considering the magnitude of the force, the gravitational force of the apple to the Earth is greater than that of the Earth on the apple.

(D) Considering the magnitude of the force, the gravitational force of the apple to the Earth is less than that of the Earth to the apple.

(E) Considering the magnitude of the force only, the gravitational force of the apple to the Earth is equal to that of the Earth to the apple.

當成熟的蘋果由樹上落下時，根據牛頓的萬有引力定律，下列哪一敘述是正確的？

(A) 地球對蘋果有吸引力，但是蘋果對地球沒有吸引力。

(B) 蘋果對地球有吸引力，但是地球對蘋果沒有吸引力。

(C) 僅考慮力的量值時，地球對蘋果的吸引力大於對地球的吸引力。

(D) 僅考慮力的量值時，地球對蘋果的吸引力小於對地球的吸引力。

(E) 僅考慮力的量值時，地球對蘋果的吸引力等於其對地球的吸引力。

（取自 88 年學測自然科 40）

解題 Solution：

萬有引力滿足牛頓第三運動定律，所以，地球對蘋果的吸引力的大小，等於蘋果對地球的吸引力，且兩力方向相反，因為它們是作用力與反作用力。

故選（E）。

Universal gravitation meets Newton's third law of motion. Thus, the magnitude of the gravitational force of the apple on the Earth is equal to that of the Earth to the apple. And their directions are opposite, since the pair of forces are action and reaction forces.

Thus, choose (E).

Teacher: It is said that Newton discovered the law of universal gravitation when he sat under the apple tree and an apple fell. When we talk about the mass of an object, we mean the force that is attracted by the Earth. Does the force that the Earth attracts the apple have the reaction force according to Newton's third law of motion?

Student: Yes, the magnitudes of the action and reaction are the same, and the directions of those are opposite.

Teacher: Great. What's the reaction force that the apple attracted to the Earth?

Student: The force that the apple attracts to the Earth.

Teacher: Well done. So which option should we choose?

Student: (E).

Teacher: Good job.

老師： 據說牛頓當時在蘋果樹下乘涼，發現蘋果會往地下掉，因而發現了「萬有引力定律」。我們說一個物體的重量，是由於它受到地球吸引的力，那麼蘋果被地球吸引的力，是否也會遵循牛頓第三運動定律，有一個反作用力呢？

學生： 是的，因為作用力與反作用力大小相等，方向相反。

老師： 很好，那麼蘋果被地球吸引的力，它的反作用力為何呢？

學生： 蘋果吸引地球的力。

老師： 很棒，所以我們應該選哪一個選項呢？

學生： (E)。

老師： 非常棒。

例題二

說明：從萬有引力定律，推導重力(F_g)、引力常數(G)，及重力加速度(g)之關係。

Analyze the relations among the gravitational force (F_g), gravitational constant (G), and gravitational acceleration (g) from the Universal Gravitational Law.

Universal gravitation between two particles is directly proportional to the product of the masses and inversely proportional to the square of the distance. Xiao-Chun wants to calculate the mass of the Earth by universal gravitational constant G, the gravitation on the Earth g, and the radius of the Earth R. Which of the following calculations he writes is correct?

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

(A) $\boldsymbol{M = \frac{gR^2}{G}}$

(B) $M = \frac{GR^2}{g}$

(C) $M = \frac{Gg}{R^2}$

(D) $M = \frac{R^2}{gG}$

(E) $M = gGR^2$

（改編自 100 年指考 68）

解析：

結合萬有引力定律，和牛頓第二運動定律，可推得地球質量

$$F = \frac{GMm}{R^2} = mg \rightarrow g = \frac{GM}{R^2} \rightarrow M = \frac{gR^2}{G}$$

故選(A)。

Combining the law of universal gravitation and Newton's second law of motion, we can know.

$$F = \frac{GMm}{R^2} = mg \rightarrow g = \frac{GM}{R^2} \rightarrow M = \frac{gR^2}{G}$$

Teacher: Does anyone want to share the formula of universal gravitation?

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

Teacher: Good. What's the relation between universal gravitation and gravitational acceleration?

Student: We don't have any ideas.

Teacher: OK. Simply put, what's the relation between force and acceleration?

Student: They are in proportion to each other.

Teacher: Great. The resultant force exerted on an object is proportional to the object's acceleration. Which law do you use to infer this equation?

Student: Newton's second law of motion.

Teacher: Yes. What is the formula of this law?

Student: $\Sigma F = ma$

Teacher: Great. How do we use this formula with something we already knew? I will leave you some time to think about it and later I will have students share.

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

Teacher: Great. How can I know the M from this equation?

Student: Delete the "small m" and then, translocate the unknown "big M".

$$\frac{GMm}{R^2} = mg \rightarrow g = \frac{GM}{R^2} \rightarrow M = \frac{gR^2}{G}$$

Teacher: Well done. So which option should we choose?

Student: (A).

Teacher: Good job.

老師： 有沒有同學願意分享，「萬有引力定律」公式？

學生： $F = \frac{GMm}{R^2}$

老師： 很好，那萬有引力和重力加速度，有什麼關係呢？

學生： 不知道。

老師： 我們簡化來說，力和加速度會有什麼關係呢？

學生： 力和加速度成正比。

老師： 很棒，物體所受之合力與加速度成正比。那這是從哪一個定律出來的呢？

學生： 牛頓第二運動定律。

老師： 很好，那這個定律的公式是什麼呢？

學生： $\Sigma F = ma$

老師： 很好，所以我們要怎麼把我們知道的東西帶進去呢？給同學一些時間思考一下，我們等一下請同學分享。

學生： $F = \frac{GMm}{R^2} = mg$

老師： 很棒，那我怎麼求出 M 呢？

學生： 將“小 m”消掉，再進行移項，提出未知“大 M”。

$$\frac{GMm}{R^2} = mg \rightarrow g = \frac{GM}{R^2} \rightarrow M = \frac{gR^2}{G}$$

老師： 非常好，所以我們應該選哪個選項呢？

學生： (A)

老師： 非常棒。

6-2 地球表面的重力
Gravitational Force on the Surface of the Earth

■ 前言 Introduction

由於地球並非完美的球形，所以我們以球心之平均距離，得出地表的重力加速度值，當作世界各地重力加速度的平均值。此外，重力不需透過物體之間的接觸也能互相作用，屬於超距力。而地球對於地球上物體的重力，是物體具有重量的來源。重力的作用，可以用「場」來描述，稱為「重力場」。本節將介紹重力加速度與重力場之公式，及其概念。在英文方面，引導學生用英文表達倍數的說法，老師須提醒學生，其中 half 和 twice 表示只適用第一種句型。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
sphere	球形	the surface of the Earth	地表
uneven	非均勻的	radius	半徑
gravitational acceleration	重力加速度	gravitational field	重力場
the center of the Earth	地心	strength	強度

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

❶ _____ is due to _____.

例句：The weight of the object on the surface of the Earth **is due to** the gravity that the Earth acts on the object.
地面上物體的重量，來自地球對物體所施的重力。

❷ _____ be seen as _____.

例句：The gravitational force near the surface of the Earth could **be seen as** a constant since the radius of the Earth is comparably huge compared with the heights of objects.
地表附近的重力加速度，可視為定值，因為相對於物體所處的高度，地球半徑相當大。

❸ _____ be inversely proportional to _____.

例句：The gravitational field strength outside the Earth **is inversely proportional to** the square of the distance of the center of the Earth to the specific position.
地球外部某一點的重力場，與其離地心之距離平方成反比。

❹ _____ and _____ are in proportion
=_____ proportional to _____

例句：The universal gravitation is proportional to the product of the masses of the two objects.
=The universal gravitation **and** the product of the masses of the two objects **are in proportion**.
萬有引力的量值，和兩物體的質量乘積成正比。

❺ _____ act/exerts on _____

例句：Weight is the force the Earth **exerts on** an object.

重量是地球對物體所施的力。

❻ 倍數的說法即表示法

1. S + Be V. + as+__ half/…times /twice, triple ___+ as _____

2. S + Be V. + _____ times + comparative adj.+ than _____

例句：**The gravitational force of an object on the Earth is** six **times** greater **than** that of the moon.

物體在地球表面所受的引力，是月球的 6 倍。

■ 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、表示地表物體所受的重力。

Present the weight of the object on the Earth.

二、了解地表附近的重力加速度之概念與公式推導。

Understand the concept of gravitational acceleration and infer the formula.

三、了解重力場強度的概念與公式。

Understand the concept of gravitational field strength and the formula.

∞ 例題講解 ∞

例題一

說明：了解行星球運轉時，萬有引力與、距離、及加速度之關係。

Understand the relations among gravitational force, distance, and acceleration regarding planetary motion.

If a planet moves along an elliptical orbit around the star S, which of the following statements about the magnitude of the acceleration of the planet at the point shown in the right figure is correct?

(A) All positions have the same magnitude of acceleration.

(B) At point A the magnitude of acceleration is the greatest.

(C) At points B and F the magnitudes of acceleration are the greatest.

(D) At point C and E the magnitudes of acceleration are the greatest.

(E) At point D the magnitude of acceleration is the greatest.

若有一行星繞著恆星 S 作橢圓軌道運動，則下列有關行星在右圖所示各點的加速度量值的敘述，何者正確？

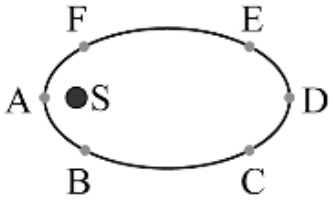
(A) 所有點都一樣大。

(B) 點 A 處最大。

(C) 點 B 與點 F 最大。

(D) 點 C 與點 E 最大。

(E) 點 D 最大。



(98 年指考物理科 1)

解題 Solution：

由牛頓第二運動定律可知，加速度與其合力成正比。

因為萬有引力值與兩物體間之距離平方成反比，所以點 A 所受之萬有引力最大。

由上述可知，點 A 之加速度最大，因為 A 點距離太陽(S)最近。

故選(A)。

According to Newton's Second Law of motion, the acceleration of an object is proportional to the resultant force.

The magnitude of the universal gravitation is inversely proportional to the square of the distance between two objects. The planet at point A exerted the greatest gravitational force, since point A has the shortest distance to the Sun (S).

Teacher: Does anyone know what the magnitude of the acceleration is dependent on?
Student: The resultant force.
Teacher: Correct. From Newton's 2nd law of motion, the resultant force is proportional to acceleration. What are the forces that act on the planet at each point?
Student: Gravitational force.
Teacher: Great. Only the gravitational force exerted by the Sun on the planet.
Teacher: How do we know which point is under the greatest force?
Student: By using the law of universal gravitation.
Teacher: Good. Does anyone want to tell us what the law of universal gravitation is?
Student: It is directly proportional to the product of the masses and inversely proportional to the square of the distance.
Teacher: Good. Is the product of the masses the same?
Student: Yes.
Teacher: Good, and why?
Student: Since it is the product of masses of the same planet and the sun.
Teacher: Great. How about the distance, are they different from each other?
Student: Yes.
Teacher: If we want to know the point under the greatest gravitational force, which point should we choose, the point closest to the S or farthest to the S?
Student: The closest one.
Teacher: Bravo. Therefore, we have to choose the point with the least distance to the S, which one is it?
Student: Point A.
Teacher: Well done, which option should we choose?
Student: (B).
Teacher: Correct.

老師： 有沒有同學知道加速度量值，與什麼有關呢？
學生： 合力。
老師： 沒錯，由牛頓第二運動定律，我們知道加速度與合力成正比，那麼行星在各點所受的力是那些？
學生： 萬有引力。

老師： 很好，行星只受到來自太陽吸引的萬有引力，沒有其他外力來源了。
老師： 那我們該如何知道，那一個點的萬有引力最大呢？
學生： 利用萬有引力定律。
老師： 很好，那有沒有同學願意分享萬有引力定律在說什麼呢？
學生： 物體所受的萬有引力和距離平方成反比，和兩物體質量乘積成正比。
老師： 很好，那各點的質量乘積有不同嗎？
學生： 沒有
老師： 很好，為什麼呢？
學生： 因為都是同一個行星和太陽的質量乘積。
老師： 很棒，那各點的距離有不同嗎？
學生： 有。
老師： 那如果我們要求的點為萬有引力越大者，我們該選擇和 S 的距離比較近的還是比較遠的呢？
學生： 比較近的。
老師： 很棒，也就是和 S 的距離要比較小的，哪一個點和 S 的距離比較小呢？
學生： A 點
老師： 很棒，所以我們要選哪一個選項呢？
學生： (B)
老師： 非常棒。

例題二

說明：透過萬有引力定律，推算出重力加速度

Calculate the gravitational acceleration by means of the Law of universal gravitational.

Assume that the mass of a certain planet is five times greater than the Earth and the radius is half of that of the Earth. And they have the same density. How many times is the gravitational acceleration on the planet's surface to that of the Earth's surface?

(A) $\frac{5}{4}$ time　(B) $\frac{5}{2}$ time　(C) 5 time　(D)10 time　**(E) 20 time**

設某星球之質量為地球之 5 倍，其半徑為地球之一半，且密度均勻，則在此星球表面的重力加速度，為地球表面重力加速度之

(A) $\frac{5}{4}$ 倍　(B) $\frac{5}{2}$ 倍　(C) 5 倍　(D) 10 倍　**(E) 20 倍**

(62 年日大 1)

解題 Solution：

由地表的重力加速度 $g = \frac{GM}{r^2}$，可知

$$\frac{g_{星球}}{g_{地球}} = \frac{\frac{GM_{星球}}{r_{星球}^2}}{\frac{GM_{地球}}{r_{地球}^2}} = \left(\frac{r_{地球}}{r_{星球}}\right)^2 \frac{M_{星球}}{M_{地球}} = 2^2 \times 5 = 20$$

故選(E)。

Form the gravitational acceleration on the Earth's surface $g = \frac{GM}{r^2}$, we know that

$$\frac{g\ \text{planet}}{g\ \text{Earth}} = \frac{\frac{GM\ \text{planet}}{r\ \text{planet}^2}}{\frac{GM\ \text{Earth}}{r\ \text{Earth}^2}} = \left(\frac{r\text{Earth}}{r\ \text{planet}}\right)^2 \frac{M\ \text{planet}}{M\ \text{Earth}} = 2^2 \times 5 = 20$$

So choose (E).

Teacher: Does anyone know the relation between gravitational acceleration on the Earth's surface and the gravitational constant?

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

Teacher: Good. Now please take some time to calculate how many times gravitational acceleration is on the planet's surface than on the Earth's surface. Later we will have some students share the answer.

Student: $\frac{g\ \text{planet}}{g\ \text{Earth}} = \frac{\frac{GM\ \text{planet}}{r\ \text{planet}^2}}{\frac{GM\ \text{Earth}}{r\ \text{Earth}^2}} = \left(\frac{r\text{Earth}}{\text{r planet}}\right)^2 \frac{M\ \text{planet}}{M\ \text{Earth}} = 2^2 \times 5 = 20$

Teacher: Well done, which option should we choose?

Student: (E).

Teacher: Excellent.

老師： 有沒有同學願意分享，地表重力加速度，與萬有引力常數的關係為何？

學生： $g = \frac{GM}{r^2}$。

老師： 很好，請大家依題目所述，利用一些時間算算星球表面的重力加速度，是地球表面重力加速度的幾倍，我們等一下請同學上台分享。

學生： $\frac{g\ \text{星球}}{g\ \text{地球}} = \frac{\frac{GM\ \text{星球}}{r\ \text{星球}^2}}{\frac{GM\ \text{地球}}{r\ \text{地球}^2}} = \left(\frac{r\text{地球}}{\text{r 星球}}\right)^2 \frac{M\ \text{星球}}{M\ \text{地球}} = 2^2 \times 5 = 20$

老師： 很棒，所以我們該選哪個選項呢？

學生： (E)

老師： 非常棒。

6-3 行星與人造衛星
Planet and Artificial Satellite

■ 前言 Introduction

本節由萬有引力定律，來解釋天體的運行， 並解釋克卜勒行星運動定律背後的原因。此外，我們也介紹人造衛星及同步衛星的特徵，利用克卜勒行星運動定律，和牛頓萬有引力定律的結合，推導出軌道半徑、週期、運行速率等之關係。

在英文方面，學生容易混淆公轉和自轉的英文，老師需解釋公轉和自轉的差別，進而解釋英文的用法。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
Kepler's Laws of Planetary Motion	克卜勒行星運動定律	Kepler's second law/ the law of equal area	克卜勒第二定律/等面積定律
circular orbit	圓形軌道	semi-major axis	半長軸
radius	半徑	ellipse	橢圓
period	週期	geostationary/geosynchronous satellite	同步衛星
sidereal period	恆星週期	height	高度
velocity	速率	projectile motion	拋體運動
revolve/orbit	公轉	radian	弧度

spin/ rotate	自轉	constant	定值
focus	焦點		

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

❶ **the square of _____** 次方
the cube of _____ 立方

例句：For different planets, **the square of** their orbital period around their star is proportional to **the cube of** their orbital radius.
不同的行星，其所繞恆星週期平方，和其軌道半徑之立方，成正比。

❷ **_____ sweep out/cover _____.**

例句：The same planet revolving the sun **sweeps out /covers** the same area within the same period of time.
同一行星對太陽公轉，在相等時間內，所掃過的面積相等。

❸ **_____ be the same as _____.**

例句：The period of any geostationary satellite **is the same as** that of rotation of the Earth.
同步衛星的軌道週期，與地球自轉週期相同。

❹ **_____ be parallel to _____.**

例句：The axis of the orbit of a geostationary satellite **is parallel to** the axis of rotation of the Earth.
同步衛星的繞行軸，與地球自轉軸平行。

❺ _____ be close to _____.

例句：When the velocity of the projectile motion is increasing, the curvature of the path would bend flatter to **be close to** the shape of the Earth.

當平拋速度增加，物體軌跡的弧度，會變得平緩，越來越接近地球表面的弧度。

❻ _____ be less than _____.

例句：When the heights of the objects' motion **are** far **less than** the radius of the Earth, the gravitational field could be regarded as a constant.

當物體運動的高度遠小於地球半徑時，可以將重力場視為定值。

The three Kepler's Law of Planetary Motion (English Version)

(1) All planets move about the Sun in elliptical orbits with the Sun as one of the focus.

(2) A planet covers the same area of space within the same time duration.

(3) The squares of the sidereal periods (of revolution) of the planets are directly proportional to the cubes of their mean distances from the Sun.

克卜勒三大行星運動定律

(1) 行星繞太陽運行的軌道為橢圓，且太陽位在橢圓的焦點之一。

(2) 太陽與行星的連線，在相同的時間掃過相同的面積。

(3) 行星公轉之週期平方，與其軌道半長軸的立方成正比。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、行星繞太陽運行時，受到太陽的重力作用，由此可推導克卜勒行星運動三大定律。

When planets orbit the sun, they are affected by the gravity of the sun, from which Kepler's three laws of planetary motion can be inferred.

二、衛星繞著行星做圓周運動時，重力提供所需之向心力。

When planets orbit the sun, the centripetal force is provided by gravity.

三、推導出繞行星公轉的衛星，其公轉的速率和週期的關係。

Derive the speeds and the periods of satellites that orbit their planets.

❧ 例題講解 ☙

例題一

說明：了解同步衛星的運作概念。

Understand how geosynchronous satellites work.

Intercontinental communication satellite orbits the equator of the Earth and its period is the same as the rotation of the Earth. This is a so-called geostationary satellite. This kind of satellite seems to be suspended in the sky and stands still when we watch from the ground. Which of the following statements about the satellite is correct?

(A) Its position is too high to be affected by Earth's gravity, so it can remain stationary in the sky.

(B) The gravitational force it experiences from the Sun is exactly equal to the gravitational force the Earth exerts on it.

(C) The gravitational force it experiences from the Moon is exactly equal to the gravitational force the Earth exerts on it.

(D) The gravitational force it experiences from Earth is exactly equal to the centripetal force required for it to move in uniform circular motion around the Earth.

洲際通訊衛星繞地球赤道運轉，其週期與地球自轉相同，此種衛星稱為同步衛星。相對地，由地面看此衛星好像是懸在高空中靜止不動。下列有關同步衛星的敘述，何者正確？

(A) 它的位置太高，不受地心引力的作用，所以它能懸在高空中靜止不動。

(B) 它所受的太陽引力恰等於地球對它的引力。

(C) 它所受的月亮引力恰等於地球對它的引力。

(D) 它所受的地心引力，恰等於它繞地球作等速率圓周運動所需的向心力。

（87 年自然科學測 49）

解題 Solution：

同步衛星的軌道為圓周，且維持等速圓周運動，因此，衛星只受到地球之萬有引力，所以此力恰好提供其繞行地球所需的向心力。

故選(D)

Because a geostationary satellite is affected by the gravity of the Earth only, the centripetal force it needs to orbit the earth is the gravity of the Earth.

Teacher: What planet does the geostationary satellite orbit?
Student: The Earth.
Teacher: What would the satellite orbit be like?
Student: It should be a circular orbit.
Teacher: Yes, what is the force acting on the geostationary satellite?
Student: The gravity of the Earth.
Teacher: Good. What force can provide the centripetal force it needs?
Student: The gravity of the Earth.
Teacher: Great. Which option should we choose?
Student: (D).
Teacher: Well done.

老師： 同步衛星繞行哪顆行星？
學生： 地球。
老師： 很好，那麼同步衛星的軌道，應該如何呢?
學生： 圓周軌道。
老師： 是的，那同步衛星受那些力作用呢？
學生： 地球之引力。

老師： 很好，所以同步衛星運動所需要的向心力，是由什麼力提供呢？
學生： 地球之引力。
老師： 很棒，所以我們該選哪個選項呢？
學生： (D) 。
老師： 非常棒。

例題二

說明：整合萬有引力定律，及克卜勒第三行星定律，在人造衛星之應用。

Integrate the gravitational law and Kepler's Laws of Planetary Motion on artificial satellites.

The period that a geostationary satellite orbits the Earth is the same as the period of the Earth's rotation. If a new satellite with the same mass as a geostationary satellite is deployed so that it takes about 3 hours to orbit the Earth once, and the orbits of the two satellites are both circular, then how many times is the new satellite affected by the gravitational force than the new satellite?

(A) 16　(B) 8　(C) 1　(D) $\frac{1}{8}$　(E) $\frac{1}{16}$

同步衛星繞地球運行的週期和地球自轉的週期相同。若部署一顆與同步衛星質量相同的新衛星，使其繞行地球一次的時間約為 3 小時，且兩顆衛星的軌道均為圓形，則該新衛星所受的重力量值約是同步衛星的多少倍？

(A) 16　(B) 8　(C) 1　(D) $\frac{1}{8}$　(E) $\frac{1}{16}$

(108 自然科學測 51)

解題 Solution：

本題已知，為兩顆人造衛星的週期關係，欲求出兩者之重力比。需整合克卜勒行星第三運動定律，得到週期與軌道半徑之關係($T^2 \propto R^3$)，再透過「萬有引力定律」，由距離推出所受重力。

新衛星與同步衛星軌道半徑比值：$\left(\frac{R_1}{R_2}\right)^3 = \left(\frac{3}{24}\right)^2 \Rightarrow \frac{R_1}{R_2} = \frac{1}{4}$

另外，重力與軌道半徑平方成反比，所以新衛星所受的重力量值與同步衛星所受的比值為 $\left(\frac{4}{1}\right)^2 = 16$，故選(A)。

Knowing the periodic relation between the two artificial satellites, we want to determine the gravity ratio between the two. Integrating the Kepler's third law of planetary motion, we can know the $T^2 \propto R^3$

The ratio of the orbiting radius between the new satellite and the original one is

$\left(\frac{R_1}{R_2}\right)^3 = \left(\frac{3}{24}\right)^2 \Rightarrow \frac{R_1}{R_2} = \frac{1}{4}$

Moreover, from the law of the gravitational gravity, the gravity and the square of the radius of the orbit are in inverse proportion, so the ratio of the gravitational value of the new satellite to that of the original one is $\left(\frac{4}{1}\right)^2 = 16$.

Teacher: According to the question, what are the known and unknown things?

Student: The known thing is period and the unknown is gravity.

Teacher: According to the question, which one of Kepler's laws of planetary motion is about the period?

Student: The third one.

Teacher: Great. What is it about?

Student: The square of the period is proportional to the cube of the radius.

Teacher: Correct. We know the period of the new satellite is once three hours and how about the geostationary satellite?

Student: We don't know.

Teacher: Do you remember what the geostationary satellite orbits around? And what planet has the same period?

Student: The Earth, so is it 24 hours?

Teacher: Correct. Then I will leave you some time to calculate the ratio between the new satellite and the geostationary satellite, and we will have some of you share the result.

Student: $\left(\frac{R_1}{R_2}\right)^3 = \left(\frac{3}{24}\right)^2 \Rightarrow \frac{R_1}{R_2} = \frac{1}{4}$

Teacher: Great. What should we do if we want to know how many times the magnitude of the new satellite is than that of the geostationary satellite? How should we calculate?

Student: Using universal gravity.

Teacher: Yes, which two physical quantities can be described by the law of universal gravity?

Student: The gravity is inversely proportional to the square of the distance.

Teacher: Great. Then I will leave you some time as usual to calculate and we will have students share the result as well.

Student: The ratio of the gravitational value of the new satellite to that of the original one is $\left(\frac{4}{1}\right)^2 = 16$.

Teacher: Bravo. Which option should we choose?
Student: (A).
Teacher: Well done.

老師： 依題目所述，已知跟未知分別是甚麼？
學生： 已知是週期，未知是所受重力
老師： 克卜勒行星運動定律中，哪一個定律和週期有關呢？
學生： 克卜勒第三運動定律。
老師： 很好，那他在說什麼呢？
學生： 週期平方和半徑立方成正比。
老師： 沒錯。我們已知新衛星的週期是 3 小時，那麼同步衛星的週期是多少呢？
學生： 不知道。
老師： 還記得同步衛星和是繞著誰轉嗎？它的週期和誰相同呢？
學生： 地球，所以是 24 小時嗎？
老師： 沒錯，那現在給大家一些時間嘗試算算看新衛星和同步衛星的半徑比為何，我們等一下請同學上台分享。
學生： $\left(\frac{R_1}{R_2}\right)^3 = \left(\frac{3}{24}\right)^2 \Rightarrow \frac{R_1}{R_2} = \frac{1}{4}$
老師： 很好，現在我們想從兩顆衛星半徑的關係，推出它們所受的重力比，應該引用哪一項原理呢？
學生： 利用萬有引力定律。
老師： 是的，萬有引力定律描述哪兩項物理量之間的關係呢？
學生： 重力量值和距離的平方成反比。
老師： 很棒，那我們一樣給大家一些時間算算看，我們等一下請同學上台分享。
學生： 衛星所受的重力量值與同步衛星所受的比值為 $\left(\frac{4}{1}\right)^2 = 16.$
老師： 很棒，所以我們該選哪個選項呢？
學生： (A)
老師： 非常棒。

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(I)]

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

[Elective Physics(I)]

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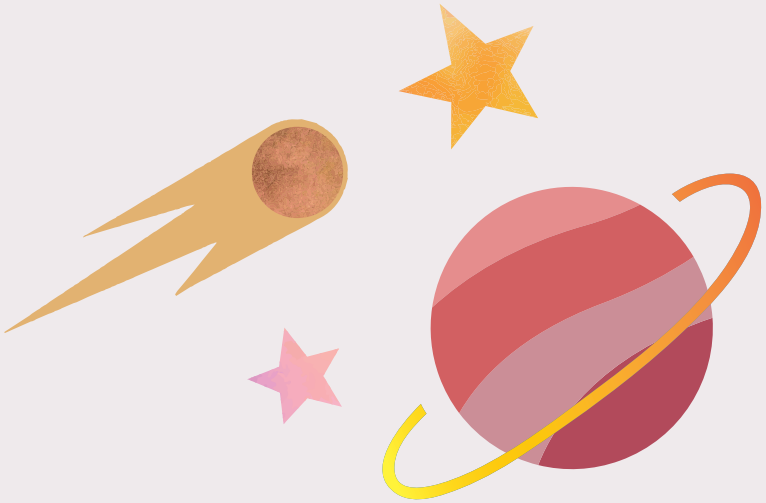

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