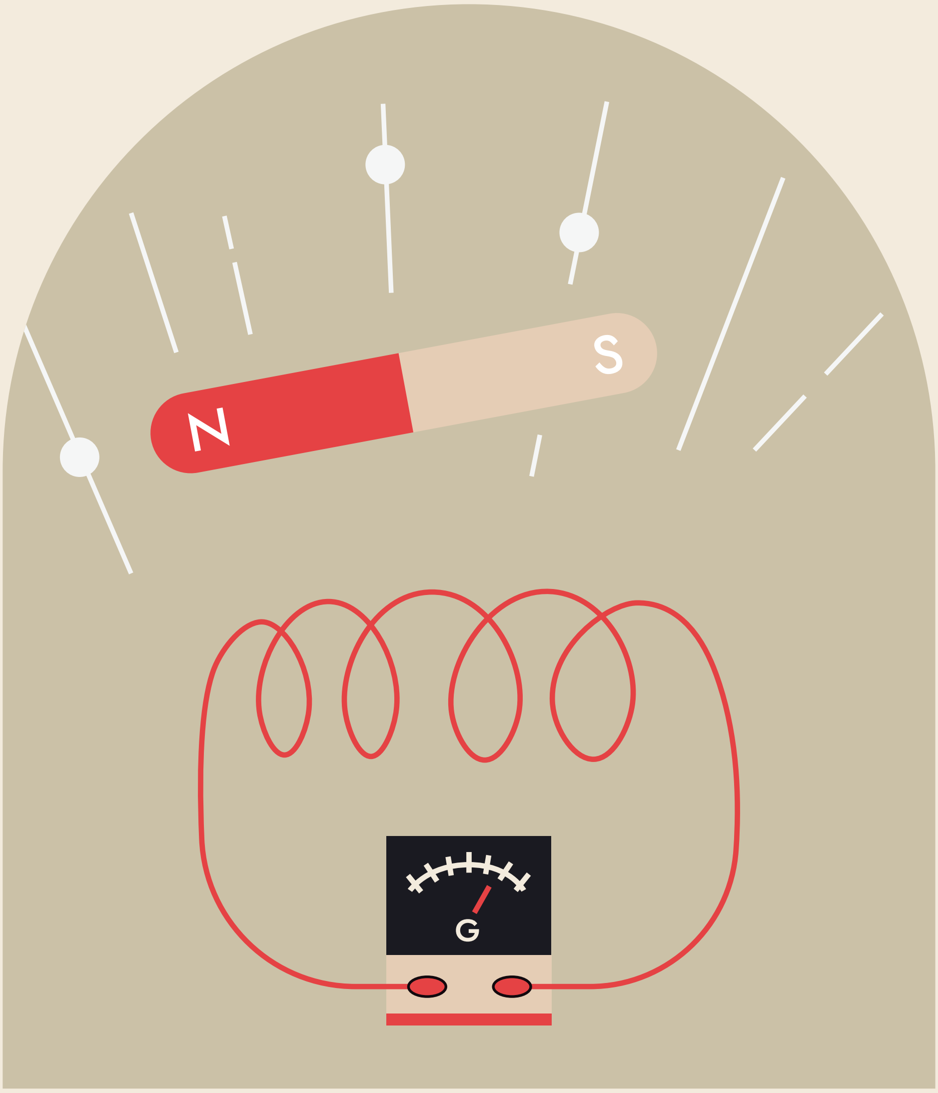
高中自然領域

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(IV)〕



國立彰化師範大學雙語教學研究中心 發行

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★ 主題一 靜電學 ★
Static Electricity

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■ 前言 Introduction

本章先介紹庫侖定律，再引入電場、電位能和電位等術語，以了解靜電學相關定義與概念，及與其在日常生活中的現象與應用。

1-1 庫倫定律
Coulomb Law

■ 前言 Introduction

本節說明電荷分為正電與負電，由庫侖的扭秤實驗討論：同性電荷之間會產生排斥力，異性電之間會相互吸引，這種作用力稱為靜電力。兩個點電荷間的靜電力大小，與兩電荷電量成正比，與兩者之距離平方成反比。若同時有多個點電荷作用在欲分析電荷上的靜電力，則可使用疊加原理來計算。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
electricity	電	Coulomb’s law	庫侖定律
static electricity	靜電學	coulomb, C	庫侖（單位）
electrostatic force	靜電力	repulsive force	排斥力
charge	電荷	attractive force	吸引力
positive/negative charge	正/負電荷	resultant force	合力
electrical neutrality/ electrically neutral	電中性/電中性的	elementary charge	基本電荷
point charge	點電荷	superposition principle	疊加原理

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

❶ __________ have a positive/a negative/net zero charge.

例句：Protons have a positive charge, while electrons have a negative charge. Neutrons **have net zero electric charge**.

質子具有正電荷，而電子具有負電荷。中子則不帶電荷。

❷ __________ attract/repel __________.

例句：Unlike charges **attract** each other, while like charges repel each other.

異性電荷彼此相吸，而同性電荷則相互排斥。

❸ __________ comply with __________.

例句：Electrostatic force is a type of conservative force, and it **complies with** Newton's Third Law.

靜電力為保守力，且滿足牛頓第三運動定律。

❹ the ________ force between __________ and ___________

例句：**The** electrostatic **force between** protons **and** electrons follows Coulomb's Law.

質子與電子之間的靜電力，可滿足庫倫定律。

❺ __________ is inversely proportional to __________.

例句：The magnitude of the electrostatic force **is inversely proportional to** the square of the distance between two point charges.

靜電力量值，與兩個點電荷間的距離平方成反比。

■ 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、認識電荷，了解同性電之間會互相排斥，異性電之間會互相吸引。

Understand the concept of charge and recognize that like charges repel, while unlike charges attract each other.

二、能計算點電荷之間的靜電力。

Can calculate the magnitude of the electrostatic force between point charges.

❧ 例題講解 ☙

例題一

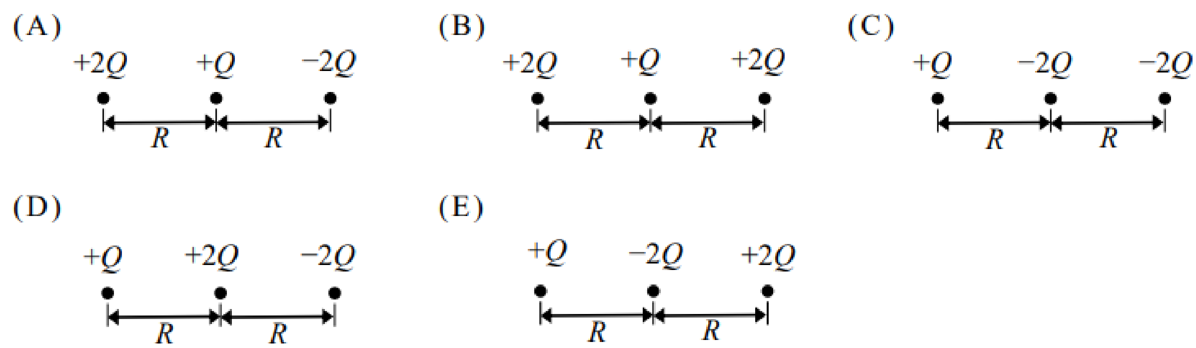
說明：正確使用庫倫定律。

Apply Coulomb's law correctly.

There are three charges in a row. Assuming Q represents the electric charge magnitude (Q > 0), R represents the distance between neighboring point charges, and all charges are fixed in place. Among the following options, which one indicates that the point charge at the left end experiences the greatest magnitude of electrostatic force?

Answer: **B**

三個點電荷排列成一直線，若 Q 為電量（Q＞0），R 為點電荷間的距離，且所有電荷皆固定不動，則下列選項中，位於左端的電荷所受到靜電力的合力量值何者最大？**B**



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Teacher: Does anyone know which physical principle should be adopted for this question? And what does the Law state?

Student: Coulomb's Law. The magnitude of the electric force exerted by two-point charges is proportional to the charges and inversely proportional to the square of the distance between the two charges.

Teacher: Correct! We also know that like charges repel and unlike charges attract to each other.

Teacher: Now, let's start with option (A). The left charge, with a magnitude of +2Q, will be exerted forces by the other two charges. Can anyone explain its force?

Student: It will experience two forces: a repulsive force from the +Q charge to the left, and an attractive force from the -2Q charge to the right.

Teacher: Correct. Which direction will the resultant force on the left charge be?

Student: I don't know! Will it go to the right or the left?

Teacher: We need to first discuss the two forces separately, then sum them up, based on the principle of superposition. The +2Q charge on the left will interact with both charges. The +2Q charge experiences a repulsive force from the +Q charge to the left, with a magnitude of $\frac{k\cdot(2Q)\cdot Q}{R^2}$, denoted as$F_{+Q}(\leftarrow)$. Now, please express the force pulling the +2Q charge to the right from the $-$2Q charge, marked asF_{-2Q}. Don't forget to show the direction!

Student: $F_{-2Q} = \frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\rightarrow)$

Teacher: Good! So, the total force on the +2Q charge is $F = F_{+Q}(\leftarrow) + F_{-2Q}(\rightarrow) = \frac{k\cdot(2Q)\cdot Q}{R^2}(\leftarrow) + \frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\rightarrow) = \frac{kQ^2}{R^2}(\leftarrow)$.

Now, you can use the same method to calculate for options (B), (C), (D), and (E)! I'll give you two minutes, and then I'll invite students to come up and write down their answers.

Student: (B) $F = F_{+Q}(\leftarrow) + F_{+2Q}(\leftarrow) = \frac{k\cdot(2Q)\cdot Q}{R^2}(\leftarrow) + \frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\leftarrow) = \frac{3kQ^2}{R^2}(\leftarrow)$

Student: (C) $F = F_{-2Q}(\rightarrow) + F_{-2Q}(\rightarrow) = \frac{k\cdot Q\cdot(2Q)}{R^2}(\rightarrow) + \frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\rightarrow) = \frac{5kQ^2}{2R^2}(\rightarrow)$

Student: (D) $F = F_{+2Q}(\leftarrow) + F_{-2Q}(\rightarrow) = \frac{k\cdot Q\cdot(2Q)}{R^2}(\leftarrow) + \frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\rightarrow) = \frac{3kQ^2}{2R^2}(\leftarrow)$

Student: (E) $F = F_{-2Q}(\rightarrow) + F_{+2Q}(\leftarrow) = \frac{k\cdot Q\cdot(2Q)}{R^2}(\rightarrow) + \frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\leftarrow) = \frac{3kQ^2}{2R^2}(\leftarrow)$

Teacher: Great, everyone did a great job! Thus, the option with the maximum total force is (B).

Teacher: I would like to note again that Coulomb's Law is only applicable to point charges.

老師： 請問，此題應該利用哪個定律來推導呢？其概念為何？

學生： 庫倫定律，兩電荷之間的靜電力大小，與其電量成正比，與兩者間的距離平方成反比。

老師： 很好，而且同性電荷間會相斥，異性電相吸。

老師： 我們先看(A)選項，左邊帶有+2Q 的電荷會受到其他兩個電荷影響，誰能告訴我，它的受力情形。

學生： 它會受到 2 個力，+Q 電荷會與之產生排斥力向左，-2Q 電荷會與之產生吸引力，故向右。

老師： 左邊電荷所受合力會往哪個方向呢？

學生： 不知道耶！到底會向右還是向左呀？

老師： 我們需要將兩個力分開來討論，然後再加總，這是根據疊加原理。左邊+2Q 的電荷分別會與兩個電荷交互作用，+2Q 電荷會受到+Q 電荷向左排斥，大小為 $\frac{k\cdot(2Q)\cdot Q}{R^2}$，我們記為$F_{+Q}(\leftarrow)$，那請你把+2Q 電荷會受到-2Q 電荷向右吸引的力，F_{-2Q}，表示出來，別忘記標註方向！

學生： $F_{-2Q}=\frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\rightarrow)$。

老師： 很好~

所以+2Q 電荷受到的合力為$F=F_{+Q}(\leftarrow)+F_{-2Q}(\rightarrow)=\frac{k\cdot(2Q)\cdot Q}{R^2}(\leftarrow)+\frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\rightarrow)=\frac{kQ^2}{R^2}(\leftarrow)$。

那其他(B)(C)(D)(E)選項也可以用相同的方法計算喔！

給大家兩分鐘，等等請同學上台寫你的答案。

學生： (B) $F=F_{+Q}(\leftarrow)+F_{+2Q}(\leftarrow)=\frac{k\cdot(2Q)\cdot Q}{R^2}(\leftarrow)+\frac{k\cdot(2Q)\cdot(2Q)}{(2R)^2}(\leftarrow)=\frac{3kQ^2}{R^2}(\leftarrow)$

學生： (C) $F=F_{-2Q}(\rightarrow)+F_{-2Q}(\rightarrow)=\frac{k\cdot Q\cdot(2Q)}{R^2}(\rightarrow)+\frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\rightarrow)=\frac{5kQ^2}{2R^2}(\rightarrow)$

學生： (D) $F=F_{+2Q}(\leftarrow)+F_{-2Q}(\rightarrow)=\frac{k\cdot Q\cdot(2Q)}{R^2}(\leftarrow)+\frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\rightarrow)=\frac{3kQ^2}{2R^2}(\leftarrow)$

學生： (E) $F=F_{-2Q}(\rightarrow)+F_{+2Q}(\leftarrow)=\frac{k\cdot Q\cdot(2Q)}{R^2}(\rightarrow)+\frac{k\cdot Q\cdot(2Q)}{(2R)^2}(\leftarrow)=\frac{3kQ^2}{2R^2}(\leftarrow)$

老師：　大家都做得很好！所以，合力最大的就是(B)選項。

老師：　再補充一點，庫倫定律僅能適用在點電荷喔！

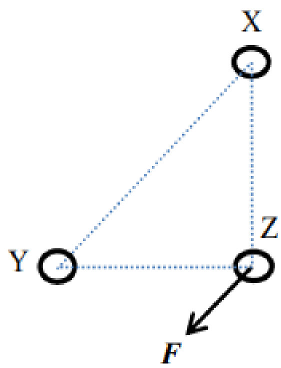
例題二

說明：了解電荷同性相斥，異性相吸。

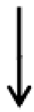
Understand that like charges repel, while unlike charges attract each other.

Three-point charges, X, Y, and Z, are situated at the three vertices of an isosceles right-angled triangle, as shown in Figure 10. The resultant electric force is noted as F that charge Z experiences from X and Y. If the positions of charges X and Y are interchanged while charge Z remains in its original place, which of the following options correctly shows the direction of the resultant Coulomb's force that Z experiences from X and Y? Answer: D

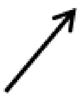
三個點電荷 X、 Y、 Z 位於等腰直角三角形的三個頂點，如圖 所示， Z 所受 X、 Y 的庫侖靜電力之合力為 F。 若 X 與 Y 的位置互換，而 Z 的位置不變，則下列何者為 Z 所受 X、 Y 的庫侖靜電力之合力方向？**D**



(A) 

(B) 

(C) 

(D) 

(E) 

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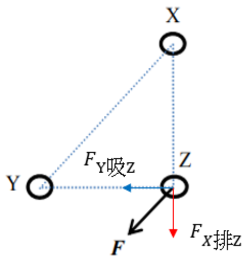
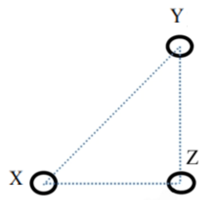
Teacher: OK. From the statement, we know that the resultant Coulomb electrostatic force F experienced by Z from X and Y points towards the lower-left direction. Now, can anyone tell me which two forces combine to give us this resultant force F?

Student: $F_{X對Z}$, the repulsive force between X and Z, and $F_{Y對Z}$, the attractive force between Y and Z.

Teacher: Yes. So the diagram may look like:

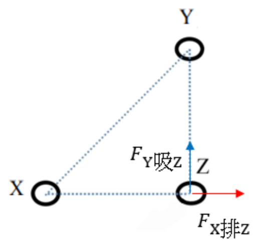


X repels Z, and Y attracts Z. The question asks us to exchange the position of X and Y. Therefore, the diagram will turn out to be:



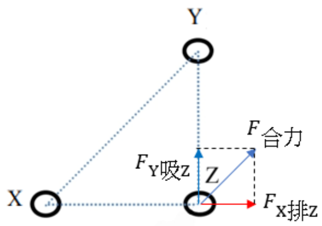
Please depict the forces between Z and X, as well as Z and Y. Keep in mind that X repels Z, while Y attracts Z.

Student:



Teacher: Yes, and what about the resultant force exerted on Z?

Student:

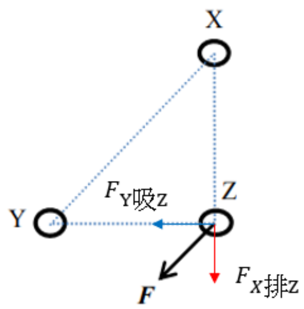


Teacher: Correct, so now we have the answer: D. In addition to using Coulomb's Law, we also adopt the principle of superposition to analyze this question.

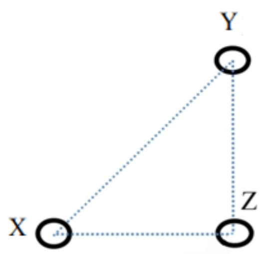
老師： 很好~題目告訴我們：Z 所受 X、Y 的庫侖靜電力之合力，為指向左下方的 F，請問 X、Z，以及 Y、Z 之間的作用力，應分別是吸引力或排斥力呢？

學生： X、Z 的排斥力($F_{X排Z}$)和 Y、Z 的吸引力($F_{Y吸Z}$)。

老師： 是的。所以圖應該長這樣。

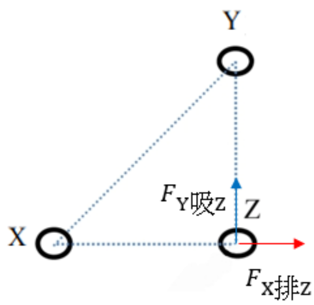


X 與 Z 互相排斥，Y 與 Z 互相吸引。現在題目要我們把 X、Y 互換，像是這樣。



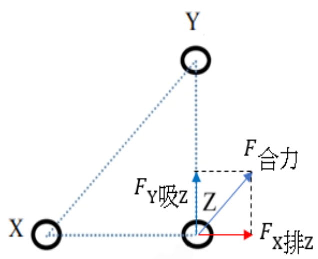
請把 Z 與 X、Y 之間的力標示出來。記得 X 與 Z 互相排斥，Y 與 Z 互相吸引。

學生：



老師： 沒錯。所以 Z 所受的合力方向應如何？

學生：



老師： 很棒，所以正確答案是 D。除了庫倫定律，我們還用了重疊原理來分析此題。

1-2　電場與電力線
Electric Field and Electric Field Line

■ 前言 Introduction

本節介紹帶電體在空間中產生的電場，說明其量值及方向，以及與電力線之間的關係。同時討論點電荷與均勻帶電平板產生的電場，及電場線的分佈，分析電荷在電場中所受到的靜電力與其運動軌跡。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
electric field	電場	electric field line	電力線
charge distribution	電荷分布	tangential direction	切線方向
field source	場源	dense	稠密
testing charge	測試電荷	sparse	稀疏
electric dipole	電偶極	uniformly charged	均勻帶電的
electric dipole moment	電偶極矩	parallel plates	平行板
polarity	極性	unit charge	單位電荷

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

❶ **__________ can be generated by __________.**

例句：Electric field **can be generated by** electric charge.

電場可由電荷產生。

❷ **__________ per unit __________.**

例句：Electric field is defined as the electric force **per unit** charge.

電場定義為每單位電荷所受到的電力。

■ 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、電力線與電場的關係，電力線可顯示電場的量值與方向。

Understand the relationship between the electric field and its field lines. That is: the electric field line represents the magnitude and direction of the electric field.

二、了解點電荷產生的電場。

Understand how the electric field is formed by a point charge.

三、了解帶電平行板間，所形成電場的分布情形。

Understand how the electric field is formed and distributed within charged parallel plates.

例題講解

例題一

說明：了解導體內部的電場。

Understand the electric field within a conductor.

There's a thick metal spherical shell with inner and outer radii R_1 and R_2 respectively. As shown in the diagram, there is a point charge q at the hollow sphere's center. Given the Coulomb constant k, which of the following options represents the magnitude of the electric field at a distance r from the center within the metal shell ($R_1<r<R_2$)?

(A) 0　(B) $\frac{kq}{r^2}$　(C) $\frac{kq}{r}$　(D) $\frac{4kq}{(R_1+R_2)^2}$　(E) $\frac{2kq}{(R_1+R_2)}$

一金屬厚球殼的內、外半徑分別為 R_1 與 R_2，中空球心處靜置一電量為 q 的點電荷，如圖所示。設庫侖常數為 k，則在金屬球殼內距球心為 r 處（$R_1<r<R_2$）的電場量值為下列何者？

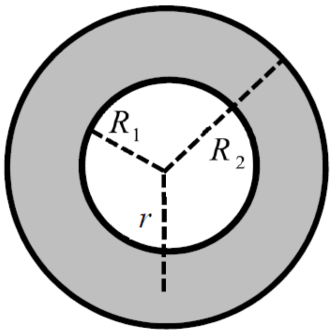
(A) 0

(B) $\frac{kq}{r^2}$

(C) $\frac{kq}{r}$

(D) $\frac{4kq}{(R_1+R_2)^2}$

(E) $\frac{2kq}{(R_1+R_2)}$



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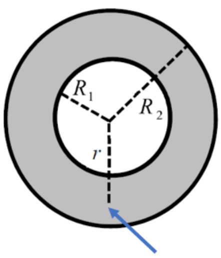
Student: How do we know the electric field at a distance r from the center of the sphere?

Teacher: Please point out the location where the distance from the center of the sphere is r.

Student:



Teacher: Great. So what is the material that is marked by r?

Student: It's metal.

Teacher: Yes! What are the features of metal?

Student: Metal can conduct electricity. It is a conductor.

Teacher: Correct! Conductors can conduct electricity because they contain free electrons. Whenever there is an electric field existing inside a conductor, free electrons will redistribute themselves until the internal electric field becomes zero, achieving force equilibrium.

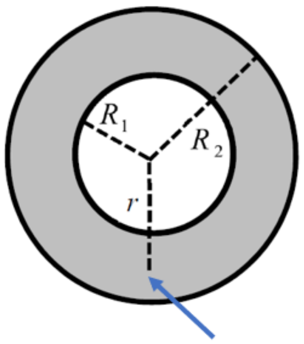
Student: So, there is no electric field inside the conductor!

Teacher: That's right!

學生： 要怎麼知道距離球心為 r 處的電場啊？

老師： 請問距離球心為 r 處在哪裡呢？請同學指出來。

學生：



老師： 很好，那 r 位置的材質是什麼？

學生： 是金屬。

老師： 沒錯！金屬有什麼特性？

學生： 金屬可以導電，是導體。

老師： 很好，導體因為有自由電子，所以可以導電，只要導體內部有電場，自由電子就會重新分佈，直到內部電場為零，才能達到力平衡。

學生： 所以導體內部沒有電場！

老師： 沒錯！

例題二

說明：了解電場、電位與電力線之間的關係。

Understand the relations among electric field, electric potential, and electric field line.

The electric field line for a particular space is illustrated in the diagram. The directions of the electric field are indicated by the arrows. Which of the following is correct?

(A means 甲, B means 乙)

(A) The electric field at Point 甲 [A] is stronger than at Point 乙 [B].

(B) The electric potential at Point 甲[A]is weaker than at Point 乙[B].

(C) If there is no charge at Point 甲[A], then there can be two electric field lines pass through Point 甲[A].

(D) The direction of the electrostatic force experienced by the charged particle at Point 甲[A] is the same as the direction of the electric field at Point 甲[A].

(E) When a charged particle moves along parallel electric field lines near Point 甲, the electric field does not work on the particle.

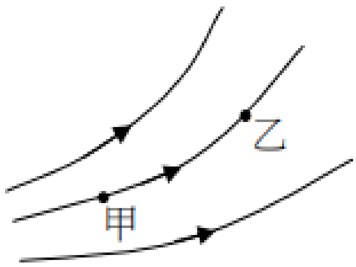
空間中某區域的電力線分布如圖，其電場方向如箭頭所示，下列敘述何者正確？

(A) 甲點的電場較乙點強。

(B) 甲點之電位低於乙點之電位。

(C) 若甲點沒有電荷存在，則可以有兩條電力線通過甲點。

(D) 帶電粒子在甲點所受之靜電力之方向即為甲點電場之方向。



(E) 在甲點附近以平行電力線的方向移動帶電粒子時，電場所施之靜電力不會對該粒子作功 A。

（103 指考物理 4）

Teacher: As shown in the diagram, the electric field lines depict the distribution of the electric field in space, including the magnitude and directions. With the electric field direction going from the bottom left to the top right, please look at option (A).

Student: I know nothing about option (A).

Teacher: Think carefully. What feature of the electric field lines indicates the magnitude of the electric field?

Student: The direction of the arrows?

Teacher: No. Does anyone know what the direction of the arrows on the electric field lines means?

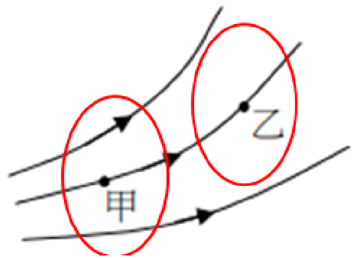
Student: The direction of the electric field?

Teacher: Yes. So what characteristic of the electric field lines indicates the magnitude of the electric field?

Student: I don't know.

Teacher: Look at the diagram.

What is the difference between positions 甲[A] and 乙[B]?



Student: Point 甲[A] has more lines passing through.

Teacher: When more lines pass through the same area, it indicates higher density. What does a denser electric field line mean?

Student: Does it mean a stronger electric field?

Teacher: Yes, that's correct! So, option (A) is correct. What about option (B)?

Student: The electric potential at 甲[A] is higher than at 乙[B].

Teacher: How can you tell?

Student: The arrow points from 甲[A] to 乙[B].

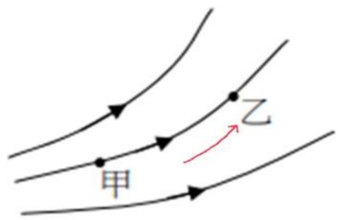
Teacher: Well done! Option (C) is incorrect. Why is that?

Student: Because electric field lines can't intersect.

Teacher: That's right! So, two electric field lines can't pass through 甲[A]. There is a slight mistake in option (D). How can we correct it?

Student: Change "charge" to "positive charge".

Teacher: Good. If a negative charge is in the electric field, the direction of the electrostatic force it experiences will be opposite to the direction of the electric field at point 甲. For option (E), if we move the charge like this



Will the electrostatic force work on this charge?

Student: No, it won't.

Teacher: Really? Work is equal to force multiplied by displacement in the direction of the force. The charge is experiencing a force, right?

Student: It experiences an electrostatic force.

Teacher: And, the charge undergoes displacement, which is parallel to the electric force. Right?

Student: Yes.

Teacher: Then, will the electrostatic force work on the charge?

Student: Yes! I get it!

Teacher: Correct! The electric field will do work on the charge since there is electric force as well as displacement parallel to the force.

老師： 如圖所示，電力線代表空間中的電場分布，包含大小與方向。電場由左下往右上方。請大家看選項(A)。

學生： 我覺得(A)無法判斷耶！

老師： 仔細想想，電力線的什麼性質代表電場的大小？

學生： 箭頭的方向嗎？

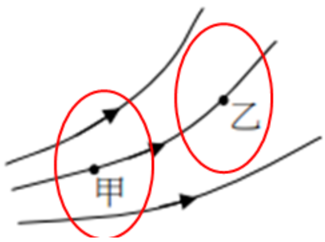
老師： 不是喔！有人知道電力線的箭頭方向表示什麼嗎？

學生： 是電場的方向嗎？

老師： 是的。那電力線的什麼特性代表電場的大小？

學生： 我不知道耶。

老師： 看看這張圖。
甲位置與乙位置有什麼不同？

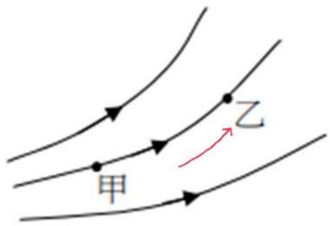


學生： 甲位置通過的線比較多。

老師： 相同面積通過的線越多，表示密度越大。電力線密度越大代表什麼？

學生： 電場越大嗎？

老師： 沒錯！所以(A)選項是正確的。(B)選項呢？
學生： 甲位置的電位比較高，乙位置的電位比較低。
老師： 你是怎麼判斷的呢？
學生： 箭頭方向由甲指向乙。
老師： 很好~(C)選項是不可能的，為什麼呢？
學生： 因為電力線不能相交！
老師： 沒錯！所以不可能有兩條電力線通過甲位置。(D)選項有一點點錯誤，要怎麼改才能變成正確的？
學生： 把「電荷」改成「正電荷」。
老師： 很好，如果是負電荷在電場中，它所受的靜電力方向會與該位置之電場方向相反。(E)選項，我們讓電荷像這樣移動靜電力會對此電荷做功嗎？



學生： 不會吧！
老師： 真的嗎？做功會等於力乘上沿著力方向的位移。電荷有受力對吧？
學生： 有受靜電力作用。
老師： 那電荷有平行於電力方向的位移，對吧？
學生： 是的。
老師： 那靜電力會對電荷做功嗎？
學生： 會！原來是這樣呀！
老師： 是的，電力會作功，因為有電力，也有平行於電力的位移。

1-3　電位能
Electric Potential Energy

■ 前言 Introduction

本小節透過同為保守力的重力來類比靜電力，兩者皆滿足力學能守恆定理。藉由學生所認識的重力位能定義，來建立電位能的概念。同時藉由點電荷受到電力作用，在運動過程造成的動能變化，說明電位能與電力作功之關係，進而探討電力系統的力學問題。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
conservative force	保守力	conservation of mechanical energy	力學能守恆
electric potential energy	電位能	be bounded	被束縛
at infinity	在無窮遠處	binding energy	束縛能

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

❶ __________ the difference between __________.

例句：The work done by electrostatic force on a charge is equal to **the difference between** the initial and final electric potential energies of the charge.

靜電力對電荷所作的功，就等於電荷的初電位能與末電位能之差。

❷ Whether _________ or __________.

例句：**Whether** a positive **or** negative charge is placed freely in an electric field, it will always move from high electric potential energy to the low one.

無論正、負電荷置於電場自由釋放，均會由高電位能，移至低電位能。

■ 問題講解 Explanation of Problems

學習目標

在學習完本單元後，學生應習得以下觀念：

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

一、解電位能的定義。

Understand the definition of electric potential energy.

二、能計算兩個點電荷間，以及多個點電荷系統的電位能。

Can calculate the electric potential energy between two point charges as well as that of multiple point charges.

三、了解靜電力為一種保守力，遵守力學能守恆定理。

Understand that electrostatic force is a conservative force, following the principle of mechanical energy conservation.

꧁ 例題講解 ꧂

例題一

說明： 藉由庫倫靜電力及電位能的概念，分析兩帶電體間的交互作用。

Be familiar with the concepts of Coulomb's electrostatic force and electric potential energy, and analyze the interaction between two charged bodies.

An α particle (Z=2, A=4) with kinetic energy E approaches a stationary gold nucleus (Z = 79, A = 196) from infinity, undergoing a head-on elastic collision. Let r be the distance between the α particle and the gold nucleus during the collision, k be the Coulomb constant, e be the elementary charge, and the electric potential energy is zero when ∞=r. Neglecting gravity, which of the following statements are correct?

(A) During the collision, the α particle experiences a repulsive force of $\frac{158ke^2}{r^2}$ at position *r*.

(B) During the collision, the electric potential energy of the α particle at position r is $\frac{158ke^2}{r^2}$.

(C) After the collision, the α particle moves in the opposite direction to its original incident direction.

(D) The minimum kinetic energy of the α particle during the collision is $\frac{1}{2}E$.

(E) The minimum distance of the α particle during the collision is $\frac{158ke^2}{E}$.

動能為 E 的 α 粒子（Z＝2，A＝4）由無限遠處，向固定不動的金原子核（Z＝79，A＝196）作正面彈性碰撞，設 r 為碰撞過程中， α 粒子與金原子核的距離， k 為庫侖常數，e 為基本電荷的電量，並取 ∞＝r 時的電位能為零，若忽略重力，則下列敘述哪些選項是正確？

(A) α 粒子在碰撞過程中，在 r 處受到 $\frac{158ke^2}{r^2}$ 的排斥力。

(B) α 粒子在碰撞過程中，在 r 處的電位能為 $\frac{158ke^2}{r^2}$。

(C) α 粒子在碰撞後，其運動方向與原入射方向相反。

(D) α 粒子在碰撞過程中的最小動能為 $\frac{1}{2}E$。

(E) α 粒子在碰撞過程中的最小距離為 $\frac{158ke^2}{E}$。

（98 指考 23）

Teacher: According to the given information, how much charge do the α particle and the gold nucleus carry?

Student: The charge of an α particle is +2e, while the gold nucleus carries a charge of +79e.

Teacher: That's correct. So, what type of force during the collision between the α particle and the gold nucleus?

Student: Since both the α particle and the gold nucleus carry positive charges, there will be a repulsive electrostatic force between them.

Teacher: Exactly. Do you remember the formula of electrostatic force?

Student: Yes! The electrostatic force is given by $F_e = \frac{kQq}{R^2}$. Therefore, we can know that option (A) is correct. The α particle experiences a repulsive force of $F_e = \frac{kQq}{R^2} = \frac{158ke^2}{r_{min}}$ at position r during the collision.

Teacher: Great, that is based on Coulomb's Law! So, after the α particle undergoes a head-on elastic collision with the stationary gold nucleus, how does the direction of motion of the α particle change?

Student: It's easy. Since the gold nucleus is stationary and there is a repulsive force between them, the α particle will rebound after the collision. And, its direction of motion will be opposite to the original incident direction. So, option (C) is correct.

Teacher: Excellent. So, for option (B), what should be the electric potential energy of the α particle at position r?

Student: The formula for electric potential energy is $U = \frac{kQq}{r}$, so the electric potential energy of the α particle at position *r* should be $\frac{158ke^2}{r}$.

Teacher: Correct, the formula is based on the hypothesis that zero electric potential energy is when two charged particles are separated at an infinite distance. Since electrostatic force is a conservative force, the conservation of mechanical energy "$E = K + U$" holds. How to determine the minimum kinetic energy of the α particle during the collision? Remember, kinetic energy is related to velocity!

Student: Hmm… kinetic energy is related to velocity, so the minimum kinetic energy of the α particle should occur when its velocity is at its minimum.

Teacher: Correct. So, where does the minimum velocity of the α particle occur during the collision?

Student: The minimum velocity of the α particle occurs when it is closest to the gold nucleus, meaning the velocity is zero at that point. Therefore, the minimum kinetic energy of the α particle is also zero.

Teacher: Great. How can the mechanical energy be expressed?

Student: At this moment, when the α particle is closest to the gold nucleus and the distance between them is r_{min}, the mechanical energy can be expressed as $E = K + U = \frac{158ke^2}{r_{min}}$.

Teacher: Exactly, with the expression for mechanical energy, we know the minimum distance r_{min}.

Student: I got it! By rearranging the equation, we can find that the minimum distance is $r_{min} = \frac{158ke^2}{r_{min}}$.

Teacher: Correct!

老師： 根據題目所述，α 粒子和金原子核分別帶多少電荷呢？

學生： α 粒子帶電量為+2e，而金原子核的帶電量則是+79e。

老師： 沒錯。那麼在 α 粒子和金原子核的碰撞過程中，這兩個帶電體間會產生甚麼交互作用呢？

學生： 由於 α 粒子和金原子核皆帶正電，因此兩者間會產生排斥的靜電力。

老師： 是的。還記得靜電力的公式嗎？

學生： 我知道！靜電力的公式為$F_e = \frac{kQq}{R^2}$，所以可以知道(A)選項，α 粒子在碰撞過程中，在 r 處受到的的排斥力為$F_e = \frac{kQq}{R^2} = \frac{158ke^2}{r_{min}}$，是正確的。

老師： 很棒，這是庫倫定律！那我們也可以知道，在 α 粒子對固定不動的金原子核作正面彈性碰撞後，α 粒子的運動方向會變成怎樣呢？

學生： 很簡單，因為金原子核固定不動，而且兩者間又存在排斥力，所以 α 粒子在碰撞後會反彈，運動方向與原入射方向相反，(C) 選項正確。

老師： 很好。那麼(B)選項，α 粒子在 r 處的電位能應該是多少呢？

學生： 電位能的公式為$U = \frac{kQq}{r}$，因此 α 粒子在 r 處的電位能應為 $\frac{158ke^2}{r}$。

老師： 是的，此公式是假設兩電荷之間相距無限遠時，電位能為零。因靜電力是一種保守力，可遵守力學能守恆 “$E = K + U$”，那要怎麼知道 α 粒子在碰撞過程當中的最小動能呢？記住，動能和速度有關！

學生： 嗯…動能和速度有關，所以 α 粒子速度為最小時的動能，剛好會是他的最小動能。

老師： 沒錯。那麼在碰撞過程中，α 粒子速度的最小值會發生在何處呢？

學生： 當 α 粒子最接近金原子核時，α 粒子的速度會有最小值，也就是零，所以 α 粒子的最小動能也為零。

老師： 很棒。那此時的力學能可以怎麼表示呢？

學生： 此時 α 粒子最接近金原子核，兩者間距離為 r_{min} ，所以力學能可以表示為 $E = K + U = \frac{158ke^2}{r_{min}}$。

老師： 是的，有了力學能，我們就可以知道最小距離 r_{min} 是多少了。

學生： 我會！移項後就可以得到最小距離 $r_{min} = \frac{158ke^2}{r_{min}}$。

老師： 答對了！

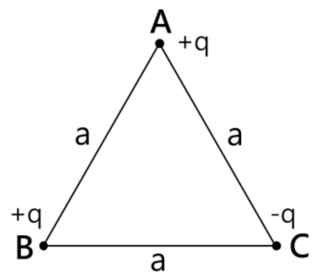
例題二

說明：計算多個點電荷系統，所形成的電位能。

Calculate the electric potential energy formed by a system with multiple point charges.

In an equilateral triangle ABC, there are charges +q, +q, and $-$q at each of the vertices, and the side length of the triangle is a.

Which of the following statements are correct?



(A) The electric potential at point A is zero.

(B) The electric potential energy of the system is $\frac{kq^2}{a}$.

(C) If there is a charge $-$Q at the centroid of the triangle, the electrostatic force experienced by $-$Q is $\frac{6kQq}{a^2}$.

(D) To move this $-$Q charge to infinity, work done is $\frac{\sqrt{3}kQq}{a^2}$.

(E) Following (C), moving $-$Q to infinity does not require work.

正三角形 ABC，各角上分別有+q、+q、−q 之電荷三角形邊長為 a，下列何者正確？

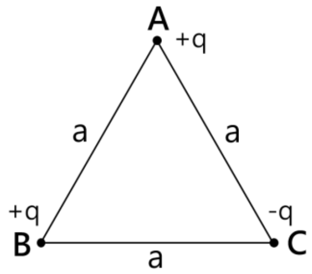
(A) A 點電位為零

(B) 此系統電力位能為 $\frac{kq^2}{a}$。

(C) 若在三角重心處有一電荷−Q 則−Q 所受靜電力為 $\frac{6kQq}{a^2}$。

(D) 若要將此−Q 移至無窮遠處須作功 $\frac{\sqrt{3}kQq}{a^2}$。

(E) 承(C)將−Q 移至無窮遠處不需作功。



（89 高聯）

Student: Teacher, what does option (A) mean by "electric potential"? Is it the same as electric potential energy?

Teacher: We will discuss this in the next section. Electric potential V is defined as the ratio of the system's electric potential U to the test charge's electric charge q, which is $V = \frac{U}{q}$. So, if we know the electric potential energy while charge q is at point A, we can find the position's electric potential.

Student: Okay, let me try. Between A and B, the electric potential energy at A is $U_{AB} = \frac{kq^2}{a}$, so the electric potential is $V_{AB} = \frac{U_{AB}}{q} = \frac{kq}{a}$.

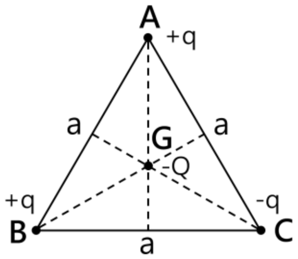
Teacher: Yes. It's not over yet. Don't forget to consider the interaction between A and C!

Student: Between A and C, the electric potential energy at A is $U_{AC} = \frac{-kq^2}{a}$, so the electric potential is $V_{AC} = \frac{U_{AC}}{q} = \frac{-kq}{a}$. Adding these two potentials$V_{AB} + V_{AC} = \frac{kq}{a} + \left(\frac{-kq}{a}\right) = 0$, we can know that the electric potential at point A is zero.

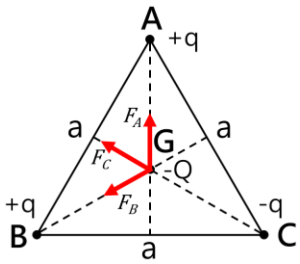
Teacher: Exactly! So, how do we know the total electric potential energy of the system?

Student: It's simple, just add up the electric potential energies between AB, AC, and BC. The total electric potential energy U of the system is $U = U_{AB} + U_{AC} + U_{BC} = \frac{kq^2}{a} + (\frac{-kq^2}{a}) + (\frac{-kq^2}{a}) = \frac{-kq^2}{a}$, so the system's electric potential energy is $\frac{-kq^2}{a}$.

Teacher: Great, this is based on the principle of superposition! Moving on to the next option, if there is a charge $-Q$ at the centroid of this triangle, what is the electrostatic force experienced by $-Q$? From this diagram, we can see that the point charge $-Q$ is at the centroid G. Which charges will influence it? Please draw the direction of the electrostatic forces acting on the charge $-Q$.



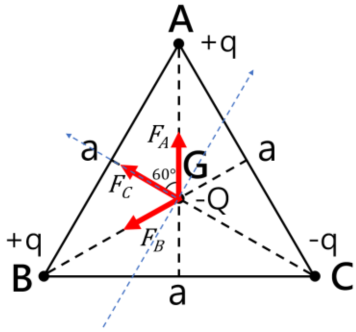
Student: The point charge $-Q$ at the centroid G will experience the influence of charges at points A, B, and C. Between A and G, as well as between B and G, there is an attractive force due to opposite charges; whereas between C and G, there is a repulsive force due to like charges.



Teacher: Yes, so to get the electrostatic force experienced by $-Q$, we need to first know the distances from G to points A, B, and C. Do you remember the characteristics of the distances from the centroid to the vertices?

Student: Yes. The distance from the centroid to a vertex is equal to two-thirds of the median length. For an equilateral triangle, the median length is also the height $h = \frac{\sqrt{3}}{2}a$. Therefore, the distance from the centroid to a vertex is $\frac{\sqrt{3}}{2}a \times \frac{2}{3} = \frac{a}{\sqrt{3}}$. Now, we can know the magnitudes of F_A、F_B、F_C, which are all equal to $\frac{kQq}{(\frac{a}{\sqrt{3}})^2}$.

Teacher: Exactly. So, what should be the resultant force formed by these three electrostatic forces on $-Q$ at point G? We know that the angle between F_C and F_A, between F_B and F_A, as well as between F_C and F_B, is 60 degrees.



Student: We can change the directions of $\overrightarrow{F_A}$ and $\overrightarrow{F_B}$ into the direction of $\overrightarrow{F_C}$.
So, the resultant force of the three electrostatic forces is

$$\overrightarrow{F_A} + \overrightarrow{F_B} + \overrightarrow{F_C} = 2 \times \frac{kQq}{(\frac{a}{\sqrt{3}})^2} \times \cos(60°) + \frac{kQq}{(\frac{a}{\sqrt{3}})^2} = \frac{6kQq}{a^2}.$$

Teacher: Very good! Now, what about options (D) and (E)? How do we know the work required to move −Q to infinity?

Student: Work is the dot product of the force applied and the displacement, but here the displacement is towards infinity. I'm not sure how to calculate that.

Teacher: You are right! The work (W) can not be calculated via W=F·S directly. However, we can use the work-energy theorem, which states that the work done to the system W is equal to the change in the total energy of the system ΔE_t. In this case, the change in kinetic energy is zero, so the change in system energy ΔE_t is equal to the change in potential energy ΔU. We can relate the electric potential and the electric potential energy ($V = \frac{U}{-Q}$) through the equation $\Delta U = (-Q)\Delta V$.

Student: Now that I understand, the change in electric potential ΔV is the electric potential at infinity (V_∞) minus the electric potential of -Q at point G (V_G). The electric potential at infinity is defined as zero, and the electric potential of -Q at point G is

$$V_G = V_{AG} + V_{BG} + V_{CG} = \frac{kq}{(\frac{a}{\sqrt{3}})} + \frac{kq}{(\frac{a}{\sqrt{3}})} + \left(-\frac{kq}{(\frac{a}{\sqrt{3}})}\right) = \frac{\sqrt{3}kq}{a}.$$

Therefore, the change in potential (ΔV) is $V_\infty - V_G = -\frac{\sqrt{3}kq}{a}$.

Teacher: Right. Finally, multiplying the charge −Q by the change in potential (ΔV) gives us the work done (W).

Student: I got it! So, the work done to move −Q to infinity is $W = (-Q)\Delta V = \frac{\sqrt{3}kQq}{a}$.

學生：　老師，(A)選項的電位是什麼意思阿？和電位能一樣嗎？

老師：　我們在下一小節會提到，電位 V 是測試電荷在某一位置時，系統的電位能 U 與測試電荷電量 q 的比值，也就是$V=\frac{U}{q}$，所以我們如果可以算出 q 電荷在 A 點的電位能，就可以求出此位置的電位了。

學生：　好，我試試看。在 A 和 B 之間，A 的電位能為 $U_{AB}=\frac{kq^2}{a}$，所以電位為$V_{AB}=\frac{U_{AB}}{q}=\frac{kq}{a}$。

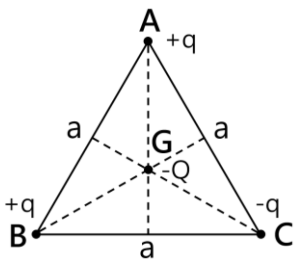
老師：　是的。還沒結束，別忘記加上 A 和 C 之間的作用喔！

學生：　在 A 和 C 之間，A 的電位能為$U_{AC}=\frac{-kq^2}{a}$，所以電位為$V_{AC}=\frac{U_{AC}}{q}=\frac{-kq}{a}$，兩者相加$V_{AB}+V_{AC}=\frac{kq}{a}+\left(\frac{-kq}{a}\right)=0$就可以知道 A 點的電位為零。

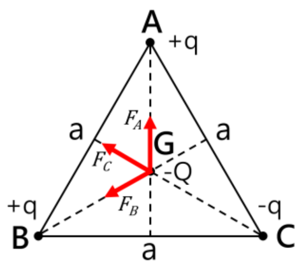
老師：　沒錯！那麼要如何知道系統的總電位能呢？

學生：　很簡單，把 AB 間、AC 間、與 BC 間電位能加起來，就是系統的總電位能 U 了 $U=U_{AB}+U_{AC}+U_{BC}=\frac{kq^2}{a}+(\frac{-kq^2}{a})+(\frac{-kq^2}{a})=\frac{-kq^2}{a}$，所以系統電位能應為$\frac{-kq^2}{a}$。

老師：　很棒，這是應用重疊原理！接著題目問，若此三角形的重心處有一電荷−Q，求−Q 所受的靜電力。從這張圖可以看到，重心 G 處的點電荷-Q，應該會受到哪些電荷的作用呢？請你畫出電荷-Q 會受到的靜電力方向。



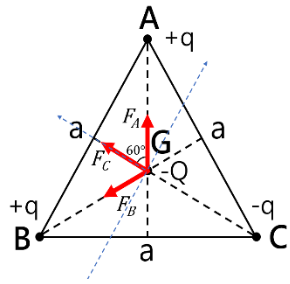
學生：　重心 G 處的點電荷−Q 會分別受到 A、B、C 點的電荷作用。A 和 G，以及 B 和 G 因為是異性電，所以為吸引力；C 和 G 因為是同性電，所以為排斥力。



老師：是的，所以要求出−Q 受的靜電力，必須先知道 G 點分別到 A、B、C 點的距離，還記得重心到頂點的距離有什麼特性嗎？

學生：記得。重心到頂點的距離會等於中線長的$\frac{2}{3}$，正三角形的中線也就是他的高$h = \frac{\sqrt{3}}{2}a$，所以重心到頂點的距離為$\frac{\sqrt{3}}{2}a \times \frac{2}{3} = \frac{a}{\sqrt{3}}$。這樣就可以知道 F_A、F_B、F_C 的量值皆為$\frac{kQq}{(\frac{a}{\sqrt{3}})^2}$。

老師：沒錯。那作用在 G 點上的−Q 的三個靜電力之合力應該多少呢？
已知 F_C 和 F_A、F_B 間夾 60°。



學生：可以把 $\overrightarrow{F_A}$ 和 $\overrightarrow{F_B}$ 轉換到 $\overrightarrow{F_C}$ 的方向，所以三個靜電力的合力為 $\overrightarrow{F_A} + \overrightarrow{F_B} + \overrightarrow{F_C} = 2 \times \frac{kQq}{(\frac{a}{\sqrt{3}})^2} \times \cos(60°) + \frac{kQq}{(\frac{a}{\sqrt{3}})^2} = \frac{6kQq}{a^2}$。

老師：非常好，那麼(D)和(E)選項，要如何知道將−Q 移至無窮遠處需要做多少功呢？

學生：功是作用力和位移的內積，但這邊的位移是無窮遠…我不會算耶。

老師：沒錯，我們無法直接從 W=F·S 算出作功(W)，但我們可以利用功能定理，也就是系統作功 W 會等於系統總能量變化ΔE_t。在這個情況中，動能變化量為零，所以系統總能量變化ΔE_t也就等於位能變化ΔU，而我們可以從前面電位和電位能的關係$V = \frac{U}{-Q}$知道$\Delta U = (-Q)\Delta V$。

學生：那我知道了，電位變化量ΔV就是無窮遠處的電位V_∞減去−Q 在 G 點的電位V_G，無窮遠處的電位定義為零，−Q 在 G 點的電位為$V_G = V_{AG} + V_{BG} + V_{CG} = \frac{kq}{(\frac{a}{\sqrt{3}})} + \frac{kq}{(\frac{a}{\sqrt{3}})} + \left(-\frac{kq}{(\frac{a}{\sqrt{3}})}\right) = \frac{\sqrt{3}kq}{a}$，所以電位變化量$\Delta V = V_\infty - V_G = -\frac{\sqrt{3}kq}{a}$。

老師：沒錯。最後再將電荷−Q 與電位變化量ΔV相乘，就可以得到作功 W 了。

學生：我會了！所以將−Q 移至無窮遠處需作功$W = (-Q)\Delta V = \frac{\sqrt{3}kQq}{a}$。

1-4　電位與電位差
Electric Potential and Potential Difference

■ 前言 Introduction

本節探討測試電荷在電場中所受的靜電力及電位能，並引入電場和電位這兩個僅與場源和位置相關的物理量，同時學習場源分別為點電荷、電荷均勻分布的導體球，及平行帶電金屬板時，所建立的電場與電位間的關係式。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
electric potential	電位	ground	接地
Volt	伏特	equipotential line	等電位線
electric potential difference	電位差	equipotential surface	等位面
voltage	電壓	equipotential volume	等位體
parallel plate	平行板		

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

❶ **__________ be independent of __________.**

例句：Electrostatic force is a conservative force, and the work it does **is independent of** the path taken.

靜電力是保守力，其作功與路徑無關。

❷ **__________ be perpendicular to __________.**

例句：Equipotential lines (surfaces) must **be perpendicular to** the electric force line.

等電位線（面）會與電力線相垂直。

■ 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、了解電位與電位差的定義。

Understand the definition of electric potential and potential difference.

二、能計算帶電平行板間的電位差。

Can calculate the potential difference between parallel charged plates.

三、理解電場與電位差間的關係。

Understand the relationship between electric field and potential difference.

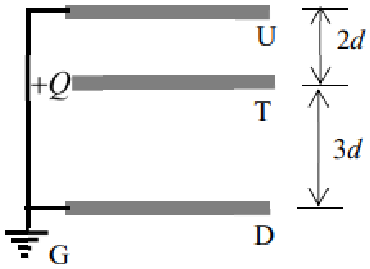
例題講解

例題一

說明：熟悉帶電平行板間的電場、電位差、與電力線分布等特性。

Be familiar with the concepts of the electric field, potential difference, and the distribution of lines of electric force between parallel charged plates.

As shown in the diagram, two identical parallel metal plates, denoted as U and D, considered infinitely large, are spaced at a fixed distance of 5d. They are connected with a copper wire to the ground, which is at a constant potential of 0. Initially, U and D are both uncharged. Now, a metal plate T, identical to U and D, with a charge of +Q and not grounded, is moved parallelly and placed beneath the upper plate at a distance of 2d. Given that the number of electric field lines connecting two plates is directly proportional to the electric field between the plates and also directly proportional to the charge at either the starting or ending point. Besides, the potential difference between D and T is equal to the potential difference between U and T. Which of the following statements are correct in electrostatic equilibrium?



(A) The electric field between D and T is 1.5 times that between U and T.

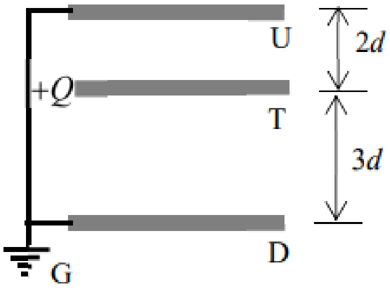
(B) The number of electric field lines that end at plate U is equal to those that end at plate D.

(C) Plate T experiences an upward electrostatic force.

(D) The electrostatic force on plate T is zero.

(E) The charge on plate U is 1.5 times the charge on plate D.

如圖所示，兩片完全相同、可視為無限大的平行金屬薄板 U 與 D，間距固定為 5d，以銅線連接到電位恆為 0 的接地體 G，最初 U 與 D 均不帶電。今將與 U、D 完全相同、帶電量＋Q 且不接地的金屬薄板 T 平行移入，並固定於上板下方 2d 處。已知連接兩板的電力線數目，既與兩板間的電場成正比，也與起點或終點處的電量成正比，且 D、T 間的電位差與 U、T 間的電位差相等，則在靜電平衡時，下列敘述哪些正確？



(A) D、T 間的電場量值為 U、T 間電場量值的 1.5 倍。
(B) 以 U 板與 D 板為終點的電力線數目相等。
(C) T 板受到向上的靜電力。
(D) T 板受到的靜電力為零。
(E) U 板上的電量為 D 板上電量的 1.5 倍。

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Teacher: Originally, both plate U and plate D are uncharged metal plates. What happens when a charged metal plate T with a charge of +Q is introduced?

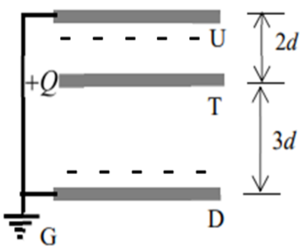
Student: What will happen?

Teacher: Will plate U and plate D still remain uncharged?

Student: It seems not. T metal plate will lead to the U、D metal plates charging by induction, right?

Teacher: Great! That is because U、D metal plates are both grounded, which resulted in charging by induction. Can someone come up and draw out the induced charge distribution?

Student:



Teacher: That's right! Negative charges will flow from the ground through the grounding wire to the U and T metal plates, to keep the U、T plates at zero electric potential. Meanwhile, the middle T metal plate carries a positive charge, while the upper and lower U and D metal plates carry negative charges, which creates an electric field among them. Let's look at option (A). What is the electric field magnitude related to?

Student: It's related to the potential difference between the two metal plates!

Teacher: Exactly. And, is the electric field magnitude related to the distance between two metal plates?

Student: Yes! So, the electric field $E = \frac{V}{d}$.

Teacher: That's right, electric field is proportional to the potential difference and inversely proportional to the distance between the two plates. Please write out the electric fields between U and T (E_{UT}) and D and T (E_{DT}).

Student: The electric field between U and T is $(E_{UT} = \frac{V_{UT}}{2d})$, and the electric field between D and T is $E_{DT} = \frac{V_{DT}}{3d}$.

Teacher: Very good. What's the relationship between E_{UT} and E_{DT}?

Student: The electric potential difference of UT and DT are equal.

Teacher: Exactly, since plate U and plate D are both grounded, the potential of U and D are both zero. So $\frac{E_{DT}}{E_{UT}} = \frac{\frac{V_{DT}}{3d}}{\frac{V_{UT}}{2d}} = \frac{2}{3}$. Option (A) is not correct. Also, we know that the ratio of the electric fields between D and T and U and T is $\frac{2}{3}$. Since electric field lines are related to the electric field, who can tell me the relationship between the two?

Student: The larger the electric field, the denser the electric field lines.

Teacher: Great! The electric field between U and T is stronger. Are the lines of electric force denser or more scattered?

Student: They are denser. So, option (B) is incorrect.

Teacher: Now, let's look at options (C) and (D) together. Both the U metal plate and D metal plate will attract the T metal plate, but which side has a stronger attraction? Is it upward or downward?

Student: The upward attraction is stronger.

Teacher: Yes, how did you know that?

Student: Because the distance between the D and T metal plates is larger, the electrostatic field is weaker. Whereas, the distance between the U and T metal plates is smaller, resulting in a larger electrostatic field. Therefore, the electric force between U and T is stronger than that of D and T.

Teacher: Very good! Option (E) is asking about the charge. The charge is directly proportional to the electric field strength. Could you calculate the ratio between the two?

Student: $\frac{Q_{UT}}{Q_{DT}} = \frac{E_{UT}}{E_{DT}} = \frac{3}{2} = 1.5$

Teacher: That's correct. So, options (C) and (E) are correct.

老師： 原本 U、D 都是不帶電的金屬板，在帶電量為＋Q 的金屬薄板 T 加入後，會發生什麼事呢？

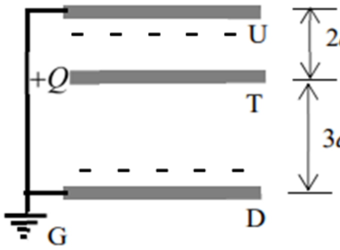
學生： 會發生什麼呀？

老師： U、D 金屬板還會維持原本不帶電的狀態嗎？

學生： 好像不會耶！T 金屬板，應該會造成 U、D 兩金屬板的感應起電吧。

老師： 很好喔！因為 U、D 金屬板都有接地，會因為插入帶電的 T 板而感應起電。同學可以上來畫出感應的電荷分布嗎？

學生：



老師： 沒錯！負電荷會由地板經過接地線到達 U、T 兩金屬板，才能使 U、T 兩板維持零電位（接地）。又因為中間的 T 金屬板帶正電，上下的 U、D 金屬板帶負電，故 UT 及 DT 之間，都能形成電場。我們來看(A)選項，請問電場量值與什麼有關？

學生： 跟兩金屬板的電位差有關！

老師： 是的。那電場量值與兩金屬板的距離有沒有關係呢？

學生： 有！所以電場$E = \frac{V}{d}$。

老師：　沒錯，電場大小與其電位差成正比，與兩板之間距成反比！

請寫出 U、T 間(E_{UT})和 D、T 間(E_{DT})的電場。

學生：　U、T 間電場：($E_{UT}=\frac{V_{UT}}{2d}$，D、T 間電場：$E_{DT}=\frac{V_{DT}}{3d}$)。

老師：　很好，E_{UT}和E_{DT}有什麼關係呢？

學生：　UT 與 DT，兩個電位差一樣。

老師：　沒錯，因為 U 板及 D 板都接地，所以 U、D 的電位都是零。所以$\frac{E_{DT}}{E_{UT}}=\frac{\frac{V_{DT}}{3d}}{\frac{V_{UT}}{2d}}=\frac{2}{3}$。

(A)選項不對。而且我們知道，D、T 間和 U、T 間電場比值是$\frac{2}{3}$，而電力線與電場有關，誰可以告訴我兩者之間的關係？

學生：　電場越大，電力線越密集。

老師：　很好~UT 間的電場比較大，電力線會越疏，還是越密集？

學生：　會越密集。所以(B)選項不正確。

老師：　(C)(D)選項我們一起看，U 金屬板和 D 金屬板都會吸引 T 金屬板，可是哪邊的吸引力更大呢？向上是向下？

學生：　向上的吸引力比較大。

老師：　是的，你怎麼知道的？

學生：　因為 D、T 金屬板之間距離較大，電場較小；而 U、T 金屬板之間距離較小，電場較大，所以 U、T 的靜電力比 D、T 大。

老師：　很好~(E)選想問的是帶電量，帶電量會和電場強度成正比，請同學算出兩者的比值。

學生：　$\frac{Q_{UT}}{Q_{DT}}=\frac{E_{UT}}{E_{DT}}=\frac{3}{2}=1.5$。

老師：　沒錯，所以此題(C)(E)選項正確。

例題二

說明：認識防靜電科技的原理與應用。

Know the principles and application of electrostatic discharge technology.

In many working environments, functional clothing provides essential safety protection. For example, anti-static work clothes with higher conductivity can suppress the accumulation of static charges on the human body and clothing. It can eliminate or reduce the dangers of static discharges. Therefore, it has become a fundamental protective necessity in the petrochemical industry. Which of the following statements about anti-static working clothes is <u>incorrect</u>?

(A) Conductive fibers can be made entirely or partially using conductive materials such as metal or organic substances.

(B) Anti-static fabrics can be produced by uniformly mixing conductive fibers in a certain proportion during the weaving process.

(C) To prevent the accumulation of static charges on clothing, work clothes can be made using conductive fabrics.

(D) The higher the electric resistance per unit length of conductive fibers, the easier it is for charges to flow instead of accumulation.

(E) Anti-static working clothes can use grounding to release charges or neutralize discharges to prevent the accumulation of static charges.

在很多工作環境中，機能衣料提供重要的安全防護，例如：導電性較高的防靜電工作服，可抑制人體及服裝累積靜電荷，以消除或減小靜電放電的危害，因此已成為石油化工業極基本的防護必需品。下列有關防靜電工作服的敘述，何者<u>不正確</u>？

(A) 導電纖維可全部或部分使用金屬或有機物的導電材料製成。

(B) 在紡織時按照一定比例均勻混入導電纖維，可製成防靜電織物。

(C) 為防止服裝累積靜電荷，可利用具有導電性的織物製作工作服。

(D) 導電纖維每單位長度的電阻值愈大，愈容易使電荷流動而不致累積。

(E) 防靜電工作服可利用接地導引電荷或中和放電的方式，防止累積靜電荷。

（108 學測自然 5）

Teacher: From the description in the question, what characteristics should the fabric used in making anti-static work clothing have?

Student: High conductivity, as it helps prevent the accumulation of static charges.

Teacher: Exactly, charges flow more easily in materials with high conductivity, so grounding can more effectively dissipate static charges. Therefore, it can achieve the purpose of preventing static accumulation. Now, look at the options. Do you notice anything incorrect?

Student: Hmm... Options (A), (B), (C), and (E) all seem to be correct, but I'm not sure about option (D).

Teacher: As we discussed earlier, higher conductivity in a material means that charges within the material can flow more easily, resulting in an electrical current. Now, think about it, with the same voltage, what happens to the current as the resistance value increases?

Student: I know! With the same voltage, as the resistance value increases, the current decreases.

Teacher: Yes. The higher the resistance is, the smaller the current resulted. And when the current is smaller, does it mean charges are more likely or less likely to flow?

Student: Oh! With a higher resistance, it means charges are less likely to flow, leading to the accumulation of charges. Therefore, option (D) is incorrect.

Teacher: That's correct!

老師： 從題目的敘述，我們知道製作防靜電工作服的衣料，須具備什麼特性？

學生： 導電性高，因為可以避免靜電荷累積。

老師： 沒錯，電荷在高導電性的材質中較容易流動，透過接地能更容易釋放靜電荷，達到防止靜電累積的效果。那麼看看選項，有發現什麼不對嗎？

學生： 嗯…(A)、(B)、(C)、(E)選項似乎都對，(D)選項不太確定。

老師： 我們前面說過，材料的導電性高，也就代表材料內的電荷越容易流動，而電荷流動也就是電流。想想看，在電壓一樣大的情況下，電阻值越大，電流會怎麼改變呢？

學生： 這我會！在電壓一樣大的情況下，電阻值越大，電流會越小。

老師： 是的。電阻值越大，對應的電流就越小。而電流越小，代表電荷越容易還是越不容易流動呢？

學生： 噢！我知道了，電阻值越大，代表電荷越不容易流動，所以會讓電荷累積，因此(D)選項不正確。

老師： 沒錯！

★ 主題二 電流的磁效應 ★
The Magnetic Effect of Electric Current

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■ 前言 Introduction

說明運動中電荷除了受靜電力也可能受磁力影響。同時，也介紹電流會產生磁場的特性，並分析電流或運動中的電荷，在磁場中所受的磁力，及其應用。

語言作為輔助學科教學使用，希望透過定義、定理，以及相似句構、不同內容的英文句型，學生能夠更容易抓到本章重點。

2-1 電生磁
Electric Currents Create Magnetic Fields

■ 前言 Introduction

本節首先透過磁力及電流，來定義磁場的量值。也討論電與磁的發展史，並說明電流磁效應，可由「安培右手定則」由導線電流的方向來判定所產生的磁場方向，或由「必歐-沙伐定律」計算一小段電流導線，在空間中任一點所產生的磁場量值與方向。英文授課時，教師可搭配 Section 2 的教學句型，說明電流、安培右手定則、電流磁效應等概念的因果關係，幫助學生認識相關的定義及定理。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
average current	平均電流	long straight current-carrying wire	長直載流導線
instantaneous current	瞬時電流	magnetic needle	磁針
magnetic effect of electric current	電流的磁效應	direction of electric current	電流的流向
Ampere's right-hand rule	安培右手定則	Biot-Savart Law	必歐-沙伐定律
magnetic field	磁場	magnitude and direction	量值及方向
magnetic field lines	磁力線	vacuum permeability	真空的磁導率

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

❶ **__________ is opposite to __________.**

例句：In conductors, the direction of electric current in the wire **is opposite to** the flow of free electrons.

導體中，導線內電流方向，與自由電子流動方向相反。

❷ **If you use _______ to represent ______, ______ represent _______.**

例句：**If you use** your right thumb **to represent** the direction of the electric current (I), the other four fingers would **represent** the direction of the resulting magnetic field lines.

若以右手大拇指代表電流 I 的流向，則其餘四指，可代表所產生的磁力線方向。

❸ **__________ is perpendicular to __________.**

例句：The orientation of the magnetic needle around a current-carrying wire **is perpendicular to** the direction of current flow.

載流導線周圍的磁針方指向，會垂直於電流方向。

❹ **In addition to __________, __________.**

例句：**In addition to** the magnetic force between magnets, there is also magnetic force between an electric current and a magnet.

除了磁鐵之間會有磁力，電流與磁鐵之間也會有磁力。

■ 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、了解電流的定義。

Know the definition of electric current.

二、了解電流磁效應，並應用「安培右手定則」，從電流判定磁場方向。

Know the magnetic effect of electric current and apply Ampere's right-hand rule to determine the direction of the magnetic field from the direction of electric current.

三、理解必歐-沙伐定律的意義：根據某段載流導線，透過外積（右手螺旋定則），推導出空間中任一點產生的磁場量值及方向。

Understand the meanings of Biot-Savart Law. Be able to apply it to derive the magnitude and direction of the magnetic field generated by a small segment of current-carrying wire via the cross-product (right-hand rule).

例題講解

例題一

說明：使用必歐-沙伐定律來計算導線周圍各點之磁場。

Calculate the magnetic field at each point around the given current-carrying wire using the Biot-Savart Law.

As depicted in the diagram, when the wire carrying electric current (I) passes through the origin, a short straight segment of the wire with a length ΔL aligns with the *x*-axis. Which of the following descriptions regarding the magnetic field generated by this small straight segment of wire at the six different positions from A to F are accurate? These six points are located on the *xy* plane. Their coordinates are A (5, 0), B (0, 5), C (−5, 0), D (0, −5), E (3, 4), F (6, 8).

(A) The magnetic field strength at point A is greater than at point B.

(B) The magnetic field strength at point B is greater than at point E.

(C) The magnetic field at point C is zero.

(D) The magnetic field at point D is zero.

(E) **The magnetic field strength at point E is four times greater than at point F.**

如圖所示，通有電流 I 的導線經原點時有長度 ΔL 的一小段直導線與 x 軸重合，請問下列有關這小段直線在圖中 A 至 F 等六個不同位置所產生的磁場強度的敘述，哪些是正確的？此六點均位於 xy 平面上，其坐標分別為 A(5，0)，B(0，5)，C(−5，0)，D(0，−5)，E(3，4)，F(6，8)

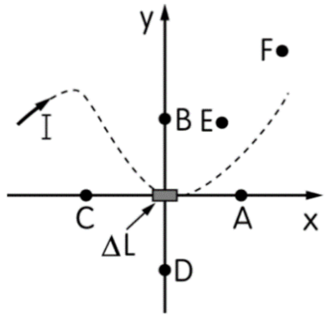
(A) A 的磁場強度大於 B 的磁場。

(B) B 的磁場強度大於 E 的磁場。

(C) C 的磁場為零。

(D) D 的磁場為零。

(E) E 的磁場強度為 F 的 4 倍。



（92 年指考物理 11）

Teacher: To begin, how to determine the magnitude of the magnetic field generated by a small segment of wire at different positions?

Student: We should use the Biot-Savart Law.

Teacher: Yes, Biot-Savart Law explains that the magnetic field is inversely proportional to the square of the distance and directly proportional to the perpendicular component of the electric current. Thus, the resulting magnetic field is proportional to sin θ. Given that sin 0° = 0, we conclude that the magnetic field at point A is 0.

Student: Considering that sin 180° also equals 0, can we deduce that the magnetic field at point C is likewise 0?

Teacher: Exactly, which means the magnetic field at both point A and point C are indeed 0. Thus, option (A) is incorrect while option (C) is accurate.

Student: Now, what about points B and D? These two points are situated perpendicular to the wire’s direction, and their distances from the wire are identical. This implies that their magnetic field is not zero, doesn’t it?

Teacher: Exactly. This means that option (D) is incorrect. Now, let’s turn our attention to points B and E. The distances from both point B and point E to the wire are equal, so our assessment hinges solely on the sine of the included angle. Since the magnetic field at point B is proportional to sin 90°, while at point E it is proportional to sin 53°, and sin 90° > sin 53°, it follows that the magnetic field at point B exceeds that at point E.

Therefore, option (B) is accurate. Moving on, let’s compare points E and F.

Student: Biot-Savart law indicates that the magnetic field is inversely proportional to the square of the distance, and considering that the distance from the wire to point F is twice that from the wire to point E, can we deduce that the magnetic field at point E is four times that at point F?

Teacher: Yes, which confirms that option (E) is accurate.

老師： 首先，該怎麼求出一小段導線電流，在不同位置所產生的磁場大小呢？

學生： 應該使用必歐-沙伐定律。

老師： 是的，必歐-沙伐定律告訴我們磁場大小與距離平方成反比，與垂直於磁場的導線電流分量成正比，也就是與 sin 成正比。因為 $sin\,0° = 0$，所以 A 點磁場強度為零。

學生： 那 $sin\,180°$也是等於零，是不是 C 點磁場也是零？

老師： 沒錯，所以 A 點以及 C 點的磁場都是零。這樣(A)選項就是錯誤的了，並且(C)選項是正確的。

學生： 那 B 點跟 D 點呢？他們兩點跟導線方向是垂直的，而且到導線距離也是相同，它們的磁場都不是零，對吧？

老師： 沒錯，所以(D)選項是錯誤的，我們接下來看 B 點跟 E 點，B 點到導線的距離跟 E 點到導線的距離相同，所以我們只需判斷夾角之正弦值的大小即可，因為 B 點的磁場大小正比於 $sin\,90°$，而 E 點的磁場正比於 $sin\,53°$，$sin\,90° > sin\,53°$，所以 B 點的磁場比 E 點的磁場還大，因此(B)選項是正確的。接下來我們來比較 E 點與 F 點。

學生： 老師，因為必歐-沙伐定律告訴我們，磁場與距離平方成反比，又導線到 F 點的距離是導線到 E 點的距離的兩倍，所以 E 點的磁場是不是 F 點的磁場的四倍？

老師： 沒錯，因此(E)選項是正確的。

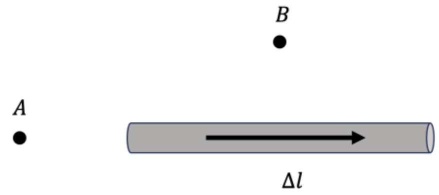
例題二

說明：應用必歐-沙伐定律，分析空間中任一點的磁場大小。

Apply the Biot-Savart Law to qualitatively assess the magnitude of the magnetic field at any given point in space.

As depicted in the diagram, we have a segment of current-carrying wire. What's the order of the magnetic field strengths produced by this wire segment at points A, B, and C?

如圖為一段載流導線，則此段載流導線在 A、B、C 三點所產生的磁場大小順序為何？



Teacher: First of all, according to Biot-Savart Law, the magnitude of the magnetic field is inversely proportional to the square of the distance and directly proportional to the sine of the angle between the wire's direction and the position vector from the wire to the point. Since the angle between the position direction of point A and the wire is 0 degrees, resulting in a sine of 0, the magnetic field at point A is zero.

Student: OK. Now, which point has a stronger magnetic field intensity, B or C?

Teacher: As we discussed with Biot-Savart law, the magnetic field is inversely proportional to the square of the distance. Considering this, which point is situated at a greater distance from the wire?

Student: Point C is positioned farther away from the wire.

Teacher: Exactly, the rule is that the greater the distance, the smaller the magnetic field.

Student: I see. So, if point B has a larger magnetic field than point C, how does point C compare with point A? Both magnetic fields are quite small.

Teacher: To assess that, we need to consider the angle between point C and the wire. Is the angle between point C and the wire 0 degrees?

Student: No, it's not.

Teacher: Right. Since the angle between point C and the wire is not 0 degrees, even if the magnetic field is small, it's still larger than the magnetic field at point A. So, the magnetic field is greater at point B than at point C, and point C has a larger magnetic field than point A.

老師： 首先，必歐-沙伐定律告訴我們，磁場與距離平方成反比，與導線方向以及導線到該點位置向量的夾角之正弦值成正比，因為 A 點位置向量跟導線的夾角是 0 度，而$sin\,0° = 0$，所以 A 點磁場為 0。

學生： 好的，可是 B 點跟 C 點，哪個位置的磁場比較強呢？

老師： 我們剛剛提到過必歐-沙伐定律告訴我們磁場與距離平方成反比，哪個點距離導線較遠呢？

學生： C 點離導線是比較遠的。

老師： 沒錯，距離越遠，磁場大小就會越小。

學生： 哦，所以 B 點的磁場比 C 點還大，那 C 點跟 A 點比較呢？兩個磁場都是很小的耶。

老師： 那我們要看 C 點跟導線的夾角是多大，才可以分析，C 點跟導線的夾角是 0 度嗎？

學生： 不是。

老師： C 點跟導線的夾角不是 0 度，因此即使磁場再小，也是比 A 點的磁場還要大呦。因此答案是 B 點大於 C 點大於 A 點。

2-2 載流導線的磁場
Magnetic Field of a Current-Carrying Wire

■ 前言 Introduction

由「必歐-沙伐定律」以及「安培右手定則」，推導出載流長直導線、圓形線圈，與螺線管在空間所產生的磁場量值與方向。英文授課時，教師需說明載流導線（包含長直導線、圓線圈、螺線管）所生的磁場等概念，透過比較級和代換重要詞語，幫助學生釐清變數之間的因果關係。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
solenoid	螺線管	electromagnet	電磁鐵
circular coil	圓形線圈	soft iron rod	軟鐵棒
clockwise	順時針	uniform magnetic field	均勻磁場
counterclockwise	逆時針		

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

❶ The+比較級…, the+比較級…, and the+比較級….

例句：The magnetic field lines are concentric circles with the wire at the center. **The closer** one gets to the wire, **the stronger** the magnetic field becomes; thus, **the denser** the magnetic field lines are.

磁力線為以導線為圓心的同心圓，愈靠近導線處的磁場量值愈大，所以其磁力線也愈稠密。

❷ ______ is directly proportional to ______ and inversely proportional to ______.

例句：The resulting magnetic field **is directly proportional to** the electric current (I) in the long wire **and inversely proportional to** the distance (d) perpendicular to the wire.

長直導線所產生的磁場，與其電流 I 成正比，與到導線的垂直距離 d 成反比。

❸ __________ are similar to __________.

例句：The magnetic field lines of a circular current-carrying wire **are similar to** those of a circular magnet.

圓形載流導線的磁力線，與圓形磁鐵的磁力線相似。

❹ __________ be visualized as consisting of __________.

例句：When electric current flows through a solenoid, the resulting magnetic field can **be visualized as consisting of** numerous loops of current-carrying circular coils placed abreast.

電流通過螺線管，所產生的磁場可看成是由很多匝、並排的載流圓形線圈組合而成。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、了解載流導線（例：長直導線、圓線圈、螺線管）如何由「必歐-沙伐定律」與「安培右手定則」推導出，其所產生的磁場量值與方向。

Understand how the magnitude and direction of the magnetic field produced by a current-carrying wire (e.g., a long straight wire, a circular coil, a solenoid) are determined by using Biot-Savart Law and Ampere's right-hand rule.

二、計算載流長直導線與載流圓形線圈中心軸上，所產生的磁場。

Calculate the magnetic field along the central axis resulting from a long straight current-carrying wire or a current-carrying circular coil.

三、計算載流螺線管電流，所產生的均勻磁場大小與方向。

Calculate the magnitude and direction of the uniform magnetic field produced by a current-carrying solenoid.

❧ 例題講解 ☙

例題一

說明：應用長直載流導線，所產生的磁場公式，來反推特定磁場所在的位置。

Apply the formula for the magnetic field strength of a current-carrying long wire to derive the distance corresponding to a specific magnetic field.

In the early days, the United States utilized Edison's DC power supply system with a voltage of 110V. It is known that the electric current in the transmission cable of this system is 100A. In the power supply area, the Earth's magnetic field measures 5.0×10^{-5}T, and the vacuum permeability is $\mu_0 = 4\pi \times 10^{-7}$ (T·m/A). At what vertical distance from a long straight cable in this power supply system will the magnetic field generated by the electric current be equal to the magnitude of Earth's magnetic field?

(A) 50 m (B) 35 m (C) 10 m (D) 2.5 m **(E) 0.40 m**

美國早期使用愛迪生創設的直流供電系統，電壓為 110V。已知此系統之傳輸電纜線的電流為 100A，供電區域的地球磁場量值為 5.0×10^{-5}T，而真空磁導率 $\mu_0 = 4\pi \times 10^{-7}$ (T·m/A)。試問距此供電系統中一段長直的電纜線多少垂直距離處，其電流所產生的磁場與地球磁場的量值相等？

(A) 50 m (B) 35 m (C) 10 m (D) 2.5 m **(E) 0.40 m**

（106 指考物理單選 11）

Teacher: Do you know the magnetic field strength at a vertical distance (r) from a long straight wire?

Student: Yes! This can be calculated using the formula for magnetic field magnitude: $B = \frac{\mu_0 I}{2\pi r}$.

Teacher: Exactly, the magnetic field's strength is denoted as B, the vacuum permeability is a constant represented by μ_0, the electric current is marked as I, and the vertical distance from the wire is indicated as r.

Student: According to the given information in the question, the magnetic field is equivalent to the Earth's magnetic field, signifying a value of 5.0×10^{-5}T. The vacuum permeability, μ_0, is established at $4\pi \times 10^{-7}$(T·m/A). The current is determined as 100A. Thus, the vertical distance can be calculated as $r = 0.4m$.

Teacher: Exactly! Therefore, the answer is option (E).

Student: Teacher, it appears we didn't take into account the provided voltage of 110V in the question.

Teacher: You're absolutely right. The given voltage isn't required for calculating the magnetic field, since the magnetic field depends on the electric current instead of voltage.

老師： 大家知道距離長直導線垂直距離為 r 的磁場大小嗎？

學生： 知道！可以用磁場大小 $B = \frac{\mu_0 I}{2\pi r}$ 來計算。

老師： 沒錯，其中磁場大小是B，真空磁導率 μ_0 是個常數，電流是 I，垂直導線的距離為 r。

學生： 題目告訴我們磁場大小與地球的磁場量值相等，代表磁場大小是5.0×10^{-5}T，真空磁導率 $\mu_0 = 4\pi \times 10^{-7}$ (T·m/A)，電流是 100A，由此可計算出垂直距離為 $r = 0.4m$。

老師： 沒錯！所以答案是(E)選項。

學生： 老師，我們好像都沒有用到題目給的電壓大小是 110V？

老師： 是的，我們不需用到電壓大小，因為磁場只與電流有關。

例題二

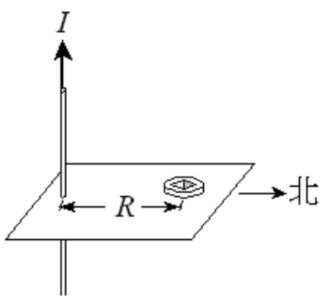
說明：應用長直載流導線之磁場公式，分析任一位置的磁場大小。

Apply the formula of the magnetic field strength of a current-carrying long wire to determine the magnetic field magnitude in space.

As depicted in the diagram, there is a thin straight wire perpendicular to a horizontal table.

A small magnetic needle is placed on the table at a distance (R) of 10 cm from the wire. When there is no electric current in the wire, the magnetic needle remains horizontal with its N pole pointing north. However, when a direct current (I) flows through the wire, the angle between the N pole of the magnetic needle and the north becomes θ. Now, if the distance (R) is altered to 20 cm while maintaining the angle between the N pole of the magnetic needle and the north as θ, what adjustment must be made to the magnitude of the electric current flowing through the wire?

(A) 4I　(B) 2I　(C) I　**(D) 2I**　(E) 4I



如圖所示，一條細長的直導線與水平桌面垂直，桌面上平放的小磁針沿桌面到導線的距離 R=10 公分。設導線未通電流時，小磁針保持水平且其 N 極指向北方；而當導線上的直流電流為 I 時，小磁針 N 極與北方的夾角為θ。當 R 改為 20 公分時，若欲使小磁針 N 極與北方的夾角仍為θ，則導線的電流大小必須調整成下列何者？

(A) 4I　(B) 2I　(C)I　**(D)2I**　(E)4I。

（100 指考物理單選 19）

Teacher: Why did the magnetic needle initially align itself northward?

Student: It's due to the Earth's magnetic field which always points towards the north. Consequently, in the absence of any current, the small magnetic needle aligns itself with the northward direction.

Teacher: Exactly, but what's the reason behind the magnetic needle deviating by an angle θ when a direct current (I) flows through the wire?

Student: This happens because the Earth's magnetic field naturally points northward. However, the electric current in the wire generates a magnetic field that is oriented westward at the location of the small magnetic needle. Thus, the resultant magnetic field becomes the direction of north by west. Consequently, the small magnetic needle becomes skewed towards the northwest at an angle θ.

Teacher: Great! Based on Ampere's Right Hand Rule, we find the resulting magnetic field is to the west. Then, to maintain the angle θ unchanged when relocating the small magnetic needle, the magnetic field at the new position must also remain constant. Do you know how the distance between an electric current and a vertical long straight wire influences the magnetic field?

Student: Yes, I've learned that the magnetic field's magnitude at a distance (r) from a long straight wire is given by $B = \frac{\mu_0 I}{2\pi r}$.

Teacher: Exactly! The magnetic field strength (B) of the long straight wire is inversely proportional to $\frac{I}{r}$ the distance r. Given that the question mentions a change in r from 10 cm to 20 cm, effectively doubling the distance (r), how many times should the electric current (I) be increased to ensure that the magnetic field's magnitude at the small magnetic needle remains unchanged?

Student: In this case, the electric current (I) must be doubled!

Teacher: Excellent! Therefore, the answer to this question is option (D).

老師： 磁針一開始指向北邊的原因是什麼呢？

學生： 是因為地面上的地球磁場方向向北，所以還沒通電流時，小磁針會指向北邊。

老師： 沒錯，但是為何導線通過直流電流為 I 時，磁針會偏轉 θ 呢？

學生： 因為地球磁場向北，但是通過導線的電流在小磁針處造成了向西的磁場，因此小磁針所在之處的磁場總和，就會是北偏西，夾角 θ。

老師： 很棒呦！我們是透過「安培右手定則」來判斷，電流產生的磁場向西。那麼為了讓θ不變，所以在移動小磁針後，小磁針所在的新位置的磁場大小應該也要不變才對，那大家知道電流跟垂直長直導線的距離會怎麼影響磁場大小嗎？

學生： 知道，之前學過距離長直導線 r 處的磁場大小是$B = \frac{\mu_0 I}{2\pi r}$。

老師： 沒錯，所以長直導線磁場 B 正比於 $\frac{I}{r}$，題目告訴我們當 r 由 10 公分改成 20 公分，也就是 r 變成兩倍，那電流 I 要變成多少倍才能讓在小磁針處的磁場大小保持不變呢？

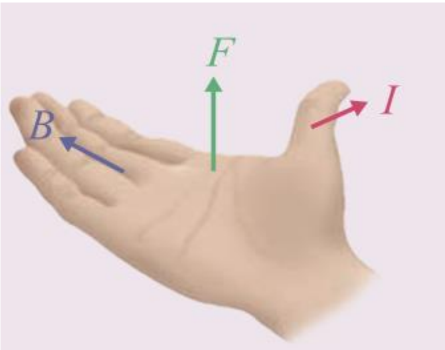
學生： 那電流 I 也要變成兩倍才可以！

老師： 很棒！所以這題的答案是(D)選項。

2-3 載流導線在磁場中所受的磁力
Magnetic Force due to a Current-Carrying Wire in applied magnetic field

■ 前言 Introduction

本節透過「右手開掌定則」，來推導載流導線於磁場中所受的磁力，並認識其應用，例如：算出兩載流平行導線間的作用力，與電動機原理。英文授課時，教師可以搭配一些英文句型，解釋載流導線在磁場中的受力情形，及造成磁力所需的條件。此外，亦可透過代換重要詞語的方式說明平行載流導線間的作用力，幫助學生理解相關的概念。



■ 詞彙 Vocabulary

單字	中譯	單字	中譯
magnetic force	磁力	irregularly shaped conductor	不規則形狀導線
direction of electric current	電流流向	closed electric circuit	封閉電流迴路
external uniform magnetic field	外加均勻磁場	torque	力矩

number of turns in the coil	線圈纏繞的匝數	area enclosed by the coil	線圈所圍之面積
brush	電刷	electric motor	電動機（馬達）
Right-Hand Rule	右手開掌定則		

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

❶ __________ is dependent on __________.

例句：The magnetic force of an electric wire **is dependent on** the current and the external magnetic field, as well as the angle between them.

磁力與電流、外加磁場、及兩者之夾角有關。

❷ __________ is parallel to __________

例句：If the electric current **is parallel to** the magnetic field, the magnetic force exerted on the current-carrying wire is zero.

若電流流向與磁場方向平行時，則載流導線所受的磁力為零。

❸ When pointing __________ in the direction of __________.

例句：**When pointing** the thumb in the direction of the current and extending the four fingers **in the direction of** the external magnetic field, the direction in which the palm is pushed outward indicates the direction of the magnetic force on the long straight wire carrying current.

大拇指指向電流流向，四指指向外加磁場方向後，則掌心向外推的方向，就是載流長直導線在磁場中所受磁力方向。

❹ **When the currents in two parallel current-carrying wires flow in __(the same direction/opposite directions)__, the wires would __(attract each other/ experience a repulsive force)__.**

例句(1)：**When the currents in two parallel wires flow in** the same direction**, the wires would** attract each other.

若兩平行載流導線電流同向，則兩導線會互相吸引。

例句(2)：**When the currents in two parallel current-carrying wires flow in** opposite directions**, the wires would** experience a repulsive force.

若兩平行載流導線電流反向，則兩導線會互相排斥。

■ 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、了解載流導線在磁場中所受的力，例如：不規則導線於均勻磁場中所受的力。

Understand the forces acting on a current-carrying wire due to an external magnetic field, such as the force on an irregular wire in a uniform magnetic field.

二、了解平行載流導線間的作用力。

Understand the forces that arise between parallel current-carrying wires.

三、了解電動機，即馬達的運作原理。

Understand the operational principles of electric motors.

ꕤ 例題講解 ꕤ

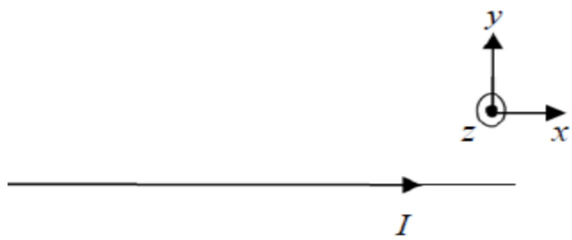
例題一

說明：根據「右手開掌定則」，掌握導線所受的磁力與電流、及外加磁場，三者方向的關係。

Determine the relation among the directions of an external magnetic field, electric current, and magnetic force by using the right-hand rule.

To confirm the occurrence of magnetic force acting on a long straight wire carrying current I in an external magnetic field, if the wire is parallel to the +*x*-axis, with the current along the +*x*-axis, as illustrated in the figure where the *x*- and *y*-axes lie on the paper. If the force exerted by a uniform magnetic field causes the wire to levitate, indicating that the magnetic force is directed along the +*z*-axis (perpendicular to the paper), what is the direction of the uniform magnetic field?

(A) +*y*-axis direction
(B) −*y*-axis direction
(C) +*z*-axis direction
(D) −*z*-axis direction
(E) −*x*-axis direction



為了驗證通有電流 I 的長直導線，在磁場中所受磁力，將一條平行於 *x* 軸的導線通以沿 +*x* 軸方向的電流，如圖所示，其中 *x*、*y* 軸在紙面上。若一均勻磁場對導線的作用力可使導線懸浮空中，即磁力指向+*z* 軸方向(垂直穿出紙面)，則此均勻磁場的方向為何？

(A) +*y* 軸方向　(B) −*y* 軸方向　(C) +*z* 軸方向
(D) −*z* 軸方向　(E) −*x* 軸方向

（106 指考物理單選 15）

Student: Teacher, how do we find the direction of the magnetic force on a long straight wire?

Teacher: We can apply the Right-Hand Rule for assessment. Simply open your right hand, with the thumb representing the current direction and the four fingers indicating the external magnetic field direction. The direction pointed by the palm reveals the orientation of the magnetic force exerted by the long straight wire in the external magnetic field.

Student: So, if the force is in the +z-axis direction, does that mean that we should align our palm with the +z-axis direction?

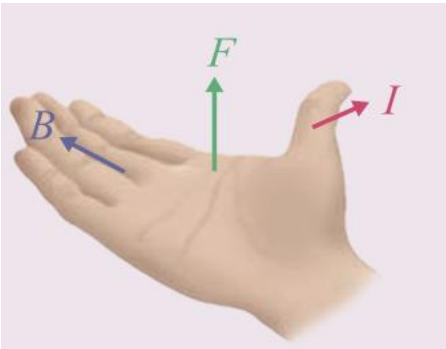
Teacher: Exactly! Considering the question and the picture, the current is directed towards the +x-axis. At this point, in what direction are the four fingers pointing?

Student: The four fingers will point in the +y-axis direction!

Teacher: Excellent! So, the magnetic field direction is like the +y-axis, and the correct answer is option (A).

學生： 老師，要怎麼判斷長直導線磁場受力的方向呢？

老師： 我們可以用右手開掌定則來判別，將右手打開，大拇指代表電流方向，四指代表外加磁場方向，則掌心指向的方向就是長直導線在外加磁場中所受到的磁力方向。



學生： 所以題目告訴我們載流導線受力向+z 軸方向，就是把掌心對向+z 軸方向嗎？

老師： 沒錯，而根據題目敘述與圖，電流方向是向+x 軸方向，這時候四指指向什麼方向呢？

學生： 四指會指向+y 軸方向！

老師： 很棒呦！因此磁場方向就是向 +y 軸方向，答案是(A)選項。

例題二

說明： 推導載流導線所受磁力方向，進而分析合力。

Analyze the resultant force by determining the direction of the magnetic force on a current-carrying wire.

Two fixed, long, insulated straight wires are arranged perpendicularly to each other, with wire 甲 positioned on top and wire 乙 on the bottom. They are in close proximity but not in contact, both parallel to the horizontal plane (i.e., the paper surface), as depicted in the figure. If both wires carry an identical current I in the direction indicated by the arrow, which of the following statements accurately describes the electromagnetic force acting on wire 乙?

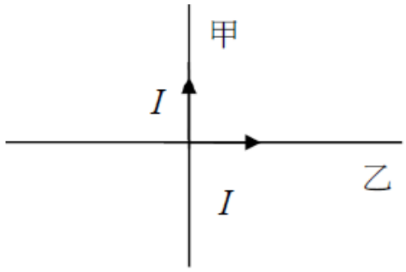
(A) Experiencing an upward net force

(B) Experiencing a downward net force

(C) Experiencing a counterclockwise torque

(D) Experiencing a clockwise torque

(E) The net force and torque exerted are both zero.



兩根位置固定的絕緣長直導線互相垂直，導線甲在上，導線乙在下，兩者緊臨但並不接觸且均與水平面（即紙面）平行，相對位置如圖所示。若兩根導線都帶有相同的電流 I，方向如箭頭所示，則下列關於導線乙所受電磁力的敘述，何者正確？

(A) 受一向上之淨力。

(B) 受一向下之淨力。

(C) 受一逆時鐘方向之力矩。

(D) 受一順時鐘方向之力矩。

(E) 所受之淨力及力矩皆為零。

（105 指考物理單選 13）

Teacher: First of all, the force on a current-carrying wire is influenced by the magnetic field it receives, and this magnetic field must come from another wire. So, we need to figure out the direction of the magnetic field on wire B caused by wire A first.

Student: How do we determine the direction of the magnetic field from wire A?

Teacher: We can use our right hands. The thumb shows the direction of the current, and the way your fingers naturally curl represents the direction of the magnetic field.

Student: So, for wire A, the magnetic field in the right half goes into the paper, and in the left half, it comes out of the paper?

Teacher: Exactly! Now, after knowing the direction of the magnetic field on wire B, we can use the Right-Hand Rule to figure out the magnetic force exerted on it.

Student: How do the fingers on the right hand represent?

Teacher: Open your right hand. In this position, the thumb indicates the current direction, and the four fingers denote the external magnetic field direction. The palm's orientation signifies the direction of the magnetic force experienced by the long straight wire due to the external magnetic field.

Student: So, in the diagram of the question, the current in the right half of wire B flows to the right, and the magnetic field direction is in the paper. Applying the Right Hand Rule, we can know that the force is upward.

Teacher: Excellent! And in the left half, where the current is to the right and the magnetic field is out of the paper, the force is downward based on the Right Hand Rule.

Student: Does wire B experience a counterclockwise torque then?

Teacher: Exactly! So, the answer is option (C). Great job!

老師： 首先，導線所受的力可以由導線所接收到的磁場，及導線本身的電流來求得，但是此磁場，一定是由另一條導線提供的，所以我們需要先分析導線甲在導線乙所造成的磁場方向。

學生： 老師，該怎麼判斷導線甲所造成的磁場方向呢？

老師： 我們可以用右手來判斷，右手大拇指代表電流的方向，四指自然捲曲的方向就是磁場的方向。

學生： 所以導線甲在右半部造成的磁場方向是射入紙內方向，左半部則是射出紙張的方向嗎？

老師： 沒錯！知道導線乙上的磁場方向之後，我們可以使用右手開掌定則來判斷導線乙所受的磁力方向。

學生： 這次右手各指代表什麼呢？

老師： 將右手打開，此時大拇指代表電流方向，四指代表外加磁場方向，則掌心指向的方向就是長直導線在外加磁場中所受到的磁力方向。

學生： 所以題目的圖片中，乙導線右半部電流方向是向右，磁場方向是射入紙內方向，用右手開掌定則可以知道，受力是向上向。

老師： 很棒呦！左半部則是電流方向向右，磁場方向是射出紙張方向，用右手開掌定則可以知道受力是向下方向。

學生： 所以導線乙受到的是逆時鐘方向的力矩嗎？

老師： 沒錯，所以答案是(C)選項。

2-4 帶電質點在磁場中的運動
Motion of a Charged Particle in Magnetic Field

■ 前言 Introduction

探討運動中的帶電質點，在磁場中所受磁力，進而分析其運動軌跡與應用。在授課中，教師可說明帶電質點在磁場中所受磁力情形與其應用，幫助學生認識相關理論、重點。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
The Lorentz Force	勞倫茲力	cyclotron radius	迴轉半徑
charged particle	帶電粒子	cyclotron period	迴轉週期
trajectory	運動路徑	spiral path	螺旋線
pitch	螺旋間距	velocity selector	速度選擇器
mass spectrometer	質譜儀	cyclotron	迴旋加速器

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

❶ Under identical conditions of ___________, ___________.

例句：**Under identical conditions of** charge, speed, and entry into a magnetic field, positive charges and negative charges experience equal magnetic forces in opposite directions.

在相同的帶電量、速度、及磁場下，正、負電荷所受的磁力量值相等，方向相反。

❷ ___________ be supplied by ___________.

例句：The centripetal force required for the constant velocity circular motion of charged particles can be **supplied by** the magnetic force.

磁力可提供帶電質點，作等速圓周運動所需的向心力。

❸ ___________ is independent of ___________.

例句：The rotational period of a charged particle in a uniform magnetic field **is independent of** the particle's speed.

一帶電質點在均勻磁場中的迴轉週期，與質點速率無關。

❹ ___________ is transformed into ___________.

例句：When charged particles are accelerated by electric potential difference, the electric potential energy **is transformed into** kinetic energy.

當帶電粒子經由電位差加速後，其電位能會轉換為動能。

■ 問題講解 Explanation of Problems

學習目標

在學習完本單元後，學生應習得以下觀念：

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

一、了解帶電質點在磁場中的受力大小與方向。

Understand the magnitude and direction of the force applied to a charged particle in a magnetic field.

二、分析帶電質點在均勻磁場中的運動軌跡。

Analyze the trajectory of charged particles navigating a uniform magnetic field.

三、認識帶電質點所受磁力的應用，例如：速度選擇器與質譜儀。

Know the applications of magnetic force exerted on charged particles, such as velocity selectors and mass spectrometers.

例題講解

例題一

說明：應用「右手開掌定則」，來判斷運動的帶電粒子在磁場中，所受磁力方向。

Use the Right-Hand Rule to determine the direction of the magnetic force acting on charged particles.

As depicted in the diagram, when neglecting gravity, a particle is horizontally launched toward a vertical, long, straight wire carrying steady current. The particle trajectory is deflected by the magnetic field generated by the wire, as indicated by the dotted arrow. Which of the following inferences is accurate?

(A) If the particle is an α particle, the current in the wire flows from top to bottom.

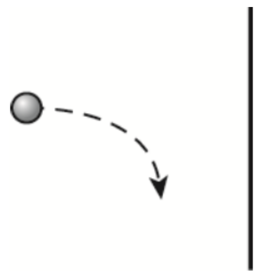
(B) If the particle is a β particle, the current in the wire flows from top to bottom.

(C) If the particle is a γ particle, the current in the wire flows from top to bottom.

(D) If the particle is an electron, the current in the wire flows from bottom to top.

(E) If the particle is a photon, the current in the wire flows from bottom to top.

如圖所示，在重力可忽略的環境中，某一粒子水平射向一條通有穩定電流的鉛垂長直導線，該粒子會因導線電流所產生的磁場而偏折，其路徑如虛線箭頭所示。下列推論何者正確？



(A) 若該粒子為 α 粒子，則導線中的電流方向為由上往下。
(B) 若該粒子為 β 粒子，則導線中的電流方向為由上往下。
(C) 若該粒子為 γ 粒子，則導線中的電流方向為由上往下。
(D) 若該粒子為電子，則導線中的電流方向為由下往上。
(E) 若該粒子為光子，則導線中的電流方向為由下往上。

（104 指考物理單選 13）

Teacher: Do you still recall what α particles, β particles, and γ particles are?

Student: Yes. α particles are helium nuclei, β particles are electrons, and γ particles are high-energy electromagnetic waves.

Teacher: Exactly. Therefore, α particles are positively charged, and β particles are negatively charged. Both will be exerted by magnetic force due to the existence of magnetic fields. The magnetic force is always perpendicular to the velocity of the particle, thus which can only alter their direction of movement. On the other hand, γ particles are a type of photons carrying nil charges, therefore, no magnetic force is exerted on γ particles in the magnetic field.

Student: Got it. So, if the current direction is from top to bottom, in the left half, the magnetic field points to the finger. If the particle moves downward, it means it is forced downward. Does that imply the particle is negatively charged?

Teacher: Exactly. According to $B = q\vec{v} \times \vec{B}$, we can determine the ±sign of the charge q, from the cross product between v and B, and the given direction of the magnetic force. If the particle were positively charged, the force would be upward. Therefore, with a downward current, it must be a β particle. Hence, option (B) is correct, while options (A) and (C) are incorrect.

Student: Student: OK. Conversely, if the current direction is from bottom to top, it should be positively charged.

Teacher: Excellent! So, options (D) and (E) are both incorrect because electrons are negatively charged, and photons are not affected by magnetic fields.

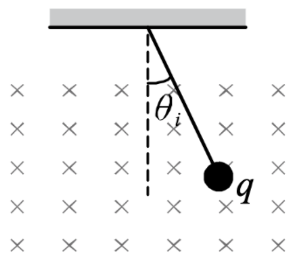
老師： 首先，大家還記得 α 粒子、β 粒子以及 γ 粒子是什麼嗎？
學生： 知道。以前學過 α 粒子是氦原子核，β 粒子是電子，γ 粒子是高能量的電磁波。
老師： 沒錯，所以 α 粒子帶正電，β 粒子帶負電，兩者都會受到磁場作用，而產生磁力。磁力會垂直於運動速度，所以只能改變運動速度的方向。而 γ 粒子屬於光子，不帶電，所以沒有磁力產生。
學生： 原來是這樣，所以如果電流方向由上向下，在左半部的磁場方向是進射入紙內，且粒子移動方向向下，若它所受磁力向下，那這樣粒子本身是帶負電，對嗎？
老師： 沒錯，根據$\vec{B} = q\vec{v} \times \vec{B}$，透過外積，及磁力的方向，就可推出 q 的正負。如果粒子帶正電，那粒子的受力方向就會是向上。因此如果電流方向向下，必定是 β 粒子。所以(B)選項是正確的，而(A)選項與(C)選項都是錯誤的。
學生： 好的，那相反的，如果電流方向由下向上，就應該是帶正電的囉？
老師： 很棒！所以(D)選項跟(E)選項都是錯誤的，因為電子帶負電，而光子不會受到磁場的影響。

例題二

說明：應用力圖分析，來分析均勻磁場中單擺的受力。

Use force analysis to determine the forces acting on a simple pendulum within a uniform magnetic field.

As depicted in the diagram, a small ball with mass m and positive charge q hangs from a string fixed at one end. The length of the string is l. The system is positioned in a uniform magnetic field, with the magnetic field direction B perpendicular to the paper. Initially, the stationary ball makes an angle θ_i with the vertical line. Upon release, the charged ball swings to the left, reaching a maximum swing angle of θ_f on its left side. Assuming negligible friction and air resistance, and with gravity acceleration g and the ball's speed at the lowest point as v, which of the following relationships or statements regarding the force and motion state of the ball are correct?



(A) $\theta_i < \theta_f$

(B) The magnetic force does not work on the ball during the swinging process.

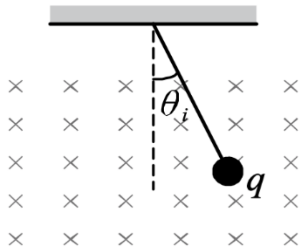
(C) Gravity consistently does positive work on the ball throughout the swinging process.

(D) When the ball passes the lowest point for the first time, the tension in the rope is

$$\boldsymbol{T = mg + qvB + \frac{mv^2}{l}}$$

(E) Both gravity and the magnetic force experienced by the ball during its movement are constant values.

如圖所示，一質量為 m、帶正電荷 q 的小球以一端固定的細繩懸掛著，繩長為l，系統置於均勻的磁場中，磁場 B 的方向垂直穿入紙面。開始時靜止的小球擺角與鉛直線夾 θ_i，釋放後帶電小球向左擺動，設其左側最大擺角與鉛直線夾 θ_f。若摩擦力與空氣阻力均可忽略，重力加速度為 g 而小球在最低點的速率為 v，則下列關於小球受力與運動狀態的關係式或敘述，哪些正確？



(A) $\theta_i < \theta_f$

(B) 在擺動過程中，磁力不對小球作功。

(C) 在擺動過程中，重力對小球永遠作正功。

(D) 小球在第一次通過最低點時，繩子的張力 $\boldsymbol{T = mg + qvB + \frac{mv^2}{l}}$。

(E) 小球在運動過程中所受的重力及磁力均為定值。

（102 指考物理多選 23）

Teacher: Let's start by analyzing the magnetic force on the ball as it swings left. We can use the formula $\vec{B} = q\vec{v} \times \vec{B}$ by adopting the cross product of v and B to determine the magnetic force at each moment. Due to the cross-product, the direction of the magnetic force on the ball is always perpendicular to the direction of its motion.

Student: Got it. Because the magnetic force is perpendicular to the ball's velocity, it doesn't do any work during the process. The question mentions ignoring friction and resistance, according to energy conservation, θ_i and θ_f should be the same.

Teacher: Exactly, which means option (A) is incorrect, and option (B) is correct.

Student: Does gravity always do positive work on the particle?

Teacher: Not necessarily. We need to consider different scenarios. When the ball is swinging downward, its vertical displacement is downward, aligning with the gravitational force, so gravity does positive work.

Student: I see. But when the ball swings upward from the bottom, the vertical displacement is upward, opposing gravity, so gravity does negative work.

Teacher: Excellent! Hence, option (C) is incorrect. Now, onto option (D). What forces act on the ball at its lowest point, and in which direction?

Student: The magnetic force exerted on the ball can be determined by $\vec{B} = q\vec{v} \times \vec{B}$, where q is positive, v is to the left, and B is into paper, so the magnetic force should be downward. Besides, the ball experiences gravity downward and the rope tension upward.

Teacher: Great! The resultant force provides the required centripetal force to swing. At the lowest point, the centripetal force is upward. So, using $T - mg - qvB = m\frac{v^2}{l}$, we get $T = m\frac{v^2}{l} + mg + qvB$ after rearranging the terms. Therefore, option (D) is correct. Now, let's move on to option (E).

Student: Teacher, the magnitude of the magnetic force on the ball depends on its speed, but when it swings to the highest point, it has no speed. So, which moment is not affected by magnetic force, right?

Teacher: Excellent! Therefore, the magnetic force isn't constant during the swing, making option (E) incorrect. In conclusion, the correct answers are (B) and (D).

老師： 首先，我們可以先分析小球在向左擺動時所受的磁力，在小球運動的過程中，每一個瞬間所受的磁力方向，都可以透過 $\vec{B} = q\vec{v} \times \vec{B}$，以右手進行外積來分析。每瞬間小球所受的磁力，都跟運動方向垂直。

學生： 原來是這樣子，那因為磁力方向都是跟小球運動方向垂直，就代表磁力不作功，題目又說忽略摩擦力與阻力，因此能量應該是守恆的，這樣θ_i以及θ_f應該是相同的。

老師： 沒錯，所以(A)選項是錯誤的，而(B)選項是正確的。

學生： 那重力一定是作正功嗎？

老師： 不一定喲，我們要分析一下，當小球向下擺動時，其垂直方向的位移向下，與重力方向相同，因此重力是作正功。

學生： 我知道了，但是當小球從最低點往上擺動時，小球位移的垂直位移是向上，與重力反向，因此重力是作負功。

老師： 很棒呦！所以(C)選項是錯誤的，接下來看(D)選項。小球在最低點時，所受到的力有哪些呢？方向又向哪呢？

學生： 小球所受磁力，需根據$\vec{B} = q\vec{v} \times \vec{B}$，其中 q 為正，v 向左，B 射入紙面，所以此時磁力向下。而重力也向下，繩子張力則向上。

老師： 沒錯，這三個力的合力，提供了小球擺動時的向心力(向上)，所以我們可以寫出 $T - mg - qvB = m\frac{v^2}{l}$，移項過後可以得到 $T = m\frac{v^2}{l} + mg + qvB$，所以(D)選項是正確的呦。接下來看(E)選項。

學生： 老師，小球受的磁力大小跟小球的運動速度有關，可是小球擺到最高點就沒有速度了，此時就沒有受到磁力的作用了，對吧？

老師： 很棒！因此小球擺動的過程中磁力並不是定值，(E)選項是錯誤的，本題答案選(B)選項以及(D)選項。

★ 主題三 電磁感應 ★
Electromagnetic Induction

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■ 前言 Introduction

本章以法拉第電磁感應定律與冷次定律為基礎，講述磁場變化與應電流間的關係，並討論電磁感應於生活中的應用，如發電機與變壓器。最後介紹電磁理論的發展，認識電磁波於日常的應用。

3-1 電磁感應與應電流
Electromagnetic Induction and Induced Current

■ 前言 Introduction

本節說明法拉第電磁感應實驗與電磁感應的基本原理，當通過封閉線圈的磁力線數改變，如：磁場改變、磁場與線圈之夾角變化時，會產生應電流。若磁力線數變化率越大，則應電流越大。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
magnetic field	磁場	induced current	應電流
current	電流	electromagnetic induction	電磁感應
coil	線圈	magnetic rod	磁棒
iron core	鐵芯	approach	靠近
galvanometer	檢流計	magnetic field lines	磁力線
deflection	偏轉		

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

❶ __________ do/does not necessarily require__________.

例句：The generation of induced current **does not necessarily require** actual relative motion between the magnetic rod and the coil; it only requires a change in the magnetic field lines inside the coil.

應電流的產生，不一定需要磁棒與線圈真正地相對運動，僅需線圈內磁力線數發生變化。

❷ The change in __________.

例句：**The change in** magnetic field lines through a closed coil would result in induced current.

封閉線圈中的磁力線數變化，會產生應電流。

❸ The more/-er __________, the more/-er __________.

例句：**The faster** the number of magnetic field lines through the coil changes with time, **the greater** the induced current will be.

線圈中磁力線的數目隨時間變化得愈快，則應電流愈大。

■ 問題講解 Explanation of Problems

學習目標

在學習完本單元後，學生應習得以下觀念：

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

一、認識法拉第電磁感應定律。

Understand Faraday’s Law of electromagnetic induction.

二、理解磁場變化率與感應電流間的關係。

Understand the relationship between the change rate of the magnetic field and the induced currents.

ꕥ 例題講解 ꕥ

例題一

說明：熟悉法拉第電磁感應定律中造成應電流的因素。

Be familiar with the factors resulting in induced currents in Faraday's Law of electromagnetic induction.

During a demonstration experiment on "electromagnetic induction," a student first connects a small coil with an iron core to a direct current power supply to form a circuit in order to generate a magnetic field. Then, they use a larger coil connected only to an ammeter, wrapped around the outside of the small coil, to detect induced current. Which of the following operations is impossible to produce induced current?

(A) Shifting the small coil inside and outside of the large coil.
(B) Adjusting the voltage of the power supply abruptly.
(C) Alternating the positive and negative ends of the power supply connecting to the small coil.
(D) Connecting a switch within the circuit of the small coil and alternately opening and closing it.
(E) Connecting a switch within the circuit of the large coil and alternately opening and closing it.

某生做「電磁感應」的示範實驗時，先將具有鐵心的小線圈串接直流電源供應器，形成迴路以產生磁場，再利用一個只串接檢流計的大線圈，套在小線圈外圍檢測應電流。下列哪一項操作方式，不可能產生應電流？

(A) 將小線圈在大線圈內外來回抽送。
(B) 將電源供應器的電壓忽大忽小的調節。
(C) 將電源供應器的正負端交換連接小線圈的兩端。
(D) 在小線圈的迴路中串接開關並交替斷開與接通的動作。
(E) 在大線圈的迴路中串接開關並交替斷開與接通的動作。

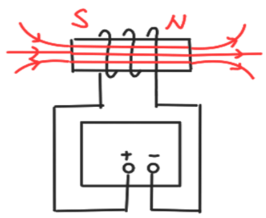
（108 學測自然 6）

Teacher: According to Faraday's law of electromagnetic induction, how does a large coil generate induced current?

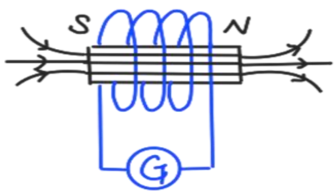
Student: There needs to be a change in the magnetic field inside the large coil.

Teacher: True, in a thorough way, there should be a change of magnetic field lines! Connect the small coil to a DC power supply, and it can become an electromagnet. Let's have a student draw the magnetic field lines.

Student:



Teacher:



Based on the diagram, for Option (A), can shifting the small coil inside and outside of the large coil alter the magnetic field inside the large coil?

Student: Yes!

Teacher: That's correct. And what about Option (B)?

Student: It also works.

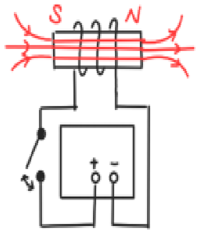
Teacher: Why can adjusting the voltage of the power supply produce a changing magnetic field?

Student: It's so strange. Changing the electric current can change the magnitude of the magnetic field. So, why is it related to voltage? Could it be that voltage can affect the quantity of electricity?

Teacher: You got the key point. Changing voltage can change the current in the small coil, and consequently, the generated magnetic field also changes. For option (C), what happens if we alternate the positive and negative ends of the power supply connected to the small coil?

Student: The direction of the current will change, and thus result in the alternation of the magnetic field directions.

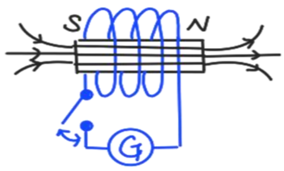
Teacher: Yes. Option (D): Connect a switch in series with the loop of the small coil and alternate between opening and closing it. Like this:



When the circuit is connected, current flows through; otherwise, there is no current through the coil. Do you think this can change the magnetic field?

Student: Yes. Initially, when there's current flowing through the small coil, it generates a magnetic field. Without current flowing, there's no magnetic field. Repeatedly operating the switch can create a changing magnetic field.

Teacher: Very good. Option (E): Connect a switch to the large coil and alternate between on and off. Like this:



Will this change the magnetic field inside the large coil?

Student: No, it won't. Therefore, the condition in option (E) won't induce any current.

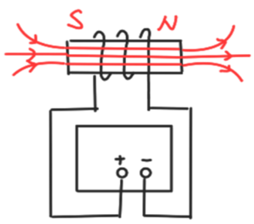
Teacher: Excellent, since there is no electric power in the large coil, no reaction occurs if we turn the switch on and off.

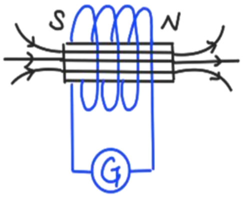
老師： 根據法拉第電磁感應定律，大線圈要如何產生感應電流呢？

學生： 大線圈內需要有磁場變化。

老師： 很好，嚴格來講，是需要有磁力線數的變化。小線圈串接直流電源供應器，可以成為一個電磁鐵，請同學來畫出磁力線。

學生：



老師：


依據同學畫的圖，

(A)選項：將小線圈在大線圈內外來回抽送，可以在大線圈內產生變化的磁場嗎？

學生：可以！

老師：沒錯，那(B)選項呢？

學生：也可以。

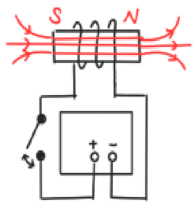
老師：為什麼調整電源供應器的電壓，可以產生變化的磁場？

學生：好奇怪喔！電流大小改變，才能改變磁場的大小，為什麼會跟電壓有關呢？會不會是電壓可以影響電量大小呢？

老師：你說得很好，改變電壓即改變小線圈電流，產生的磁場也會跟著改變。
(C)選項：將電源供應器的正負端交換連接小線圈的兩端，會如何呢？

學生：電流方向會改變，磁場方向改變。

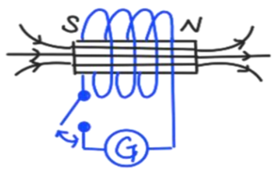
老師：嗯嗯，(D)選項：在小線圈的迴路中串接開關，並交替斷開與接通的動作，像是這樣。



把電路接通，電流就會通過，反之，線圈就沒有電流通過。
你們覺得這可以使磁場改變嗎？

學生：可以！原本有電流流經小線圈，會產生磁場，沒有電流通過就無法產生磁場，反覆操作可以產生變動的磁場。

老師：很好~(E)選項：在大線圈的迴路中接上開關，並交替開與關，像是這樣。
會造成大線圈內磁場的變動嗎？



學生：不會，所以(E)選項不會產生感應電流。

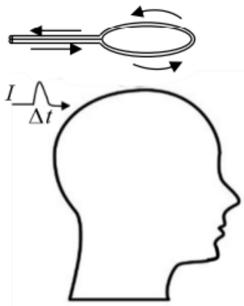
老師：太好了，因為大線圈上沒有電源，所以切換大線圈的開關不會有任何現象發生！

例題二

說明：熟悉電磁感應定律，並判別電流磁效應與電磁感應的差異。

Be familiar with the Law of electromagnetic induction, and differentiate between the magnetic effect of current (Ampere's Law) and electromagnetic induction.

Several students investigated the impact of magnetic fields on brain neural tissue and clinical medical applications. According to information on a website, they knew that metal coils are capable of carrying high currents. The coils are placed a few centimeters above the head and subjected to a pulsed current of approximately one kilo-ampere, lasting for a few milliseconds, as illustrated in the diagram (where the pulse current is represented by I and the pulse duration by Δt).



The current passing through the coil generates an instantaneous high-intensity pulse magnetic field and currents in specific brain regions, stimulating the cranial nerve. Which of the following discussions by the students is more reasonable?

(A) Student A: Pulsed current I flowing through the coil will generate a high-intensity magnetic field. This is because of electromagnetic induction.

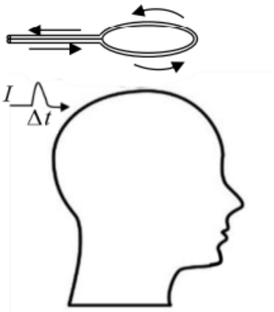
(B) Student B: The pulsed magnetic field generated by the pulsed current I in the coil will result in an induced electric field in the surrounding space. This is because of the magnetic effect of the current (Ampere's Law).

(C) Student C: If the pulsed current becomes a steady direct current, it can continuously stimulate the cranial nerve.

(D) Student D: The magnetic field in certain brain parts stays the same after the pulsed current passes through the coil for a certain period.

(E) Student E: If the maximum intensity of the pulsed current remains the same but the duration of the pulsed current Δt is shortened, the induced electric field and current in the brain will increase.

學生為探討磁場對腦部神經組織的影響及臨床醫學應用，查閱網頁資訊得知：「利用可耐高電流的金屬線圈，放置頭部上方約數公分處，並施以線圈約千安培、歷時約幾毫秒的脈衝電流，如圖所示（脈衝電流以 I 表示，脈衝電流時間以 Δt 表示）。
電流流經線圈產生瞬間的高強度脈衝磁場，磁場穿過頭顱對腦部特定區域產生應電場及應電流，而對腦神經產生電刺激作用。」以下學生討論的內容，何者較合理？



(A) 甲生：脈衝電流 I 流經線圈會產生高強度的磁場，是電磁感應所造成。

(B) 乙生：脈衝電流 I 在線圈產生的脈衝磁場，會在線圈周圍空間產生應電場，是電流磁效應所造成。

(C) 丙生：若將脈衝電流改為穩定的直流電流，可持續對腦神經產生電刺激作用。

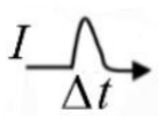
(D) 丁生：脈衝電流通過線圈後的一段時間，通過腦部特定區域的磁通量仍維持固定。

(E) 戊生：若脈衝電流最大強度不變，但縮短脈衝電流時間 Δt ，則在腦部產生的應電場及應電流會增強。

（109 指考物理 6）

Student: Teacher, what is pulse current?

Teacher: Look in the top left corner of the picture,



the current was initially zero, but within a short period of time (Δt), there's a sudden appearance of a high peak of current, we call it a pulse current.

Student: Got it!

Teacher: The question states: "Passing current through a coil generates an instantaneous high-intensity pulse magnetic field." What principle is this?

Student: It’s the magnetic effect of current.

Teacher: Very good, the effect is also known as “Ampere’s Law”, that is the effect of electricity produces magnetism. Now the question says: “The magnetic field passing through the skull generates a corresponding electric field and electric current in specific areas of the brain.” What principle is this?

Student: Is it still the magnetic effect of electric current?

Teacher: The magnetic effect of current states that when electric current flows through a conductor, it generates a magnetic field around the conductor. But for the magnetic field to induce electric field and electric current, what conditions are required?"

Student: I don’t know.

Teacher: Only changing the magnetic field over time can induce electric current! What do we call this phenomenon?

Student: Oh! Electromagnetic induction.

Teacher: That’s right, the effect of magnetism induces electricity. Let’s take a look at options (A) and (B) first.

Student: I see. So neither option (A) nor option (B) is correct.

Teacher: Exactly! Who can tell how to correct option (A)?

Student: “Pulse electric current (I) flowing through a coil will generate magnetic field” is due to the magnetic effect of current (Ampere’s Law), not electromagnetic induction.

Teacher: Very good. And what about option (B)?

Student: “The pulse magnetic field generated by pulse current I in the coil will then create an induced electric field in the surrounding space” is electromagnetic induction, not the magnetic effect of electric current (Ampere’s Law).

Teacher: Excellent! Now, as option (C) suggests, if we replace pulse current with steady direct current, can it still induce electric field and current in the brain?

Student: I think it can!

Teacher: Direct current produces a steady magnetic field. Can a steady, unchanging magnetic field induce electric current through electromagnetic induction?

Student: Ah! No!

Teacher: That’s right. A steady magnetic field cannot induce an electric field around the coil, thus it cannot have any effect on brain nerves. Do you think option (D) is correct?

Student: No, because pulse electric current only has current for that one instant.

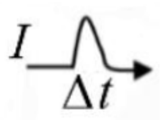
Teacher: Very good. After the pulse current passes through, it won't generate a magnetic field anymore, so the magnetic flux through the specific area of the brain becomes zero. Option (E) states: "Changing the pulse current time Δt will enhance the induced electric field and electric current." Is this correct? Why?

Student: Yes, it's correct. The faster the magnetic field changes over time, the larger the induced electric current occurs.

Teacher: Excellent!

學生： 老師，脈衝電流是什麼呀？

老師： 看到圖片的左上角，



電流值原本為 0，在短時間內(Δt)突然出現高起的電流峰值，就稱為脈衝電流。

學生： 懂了！

老師： 題目說：「電流流經線圈產生瞬間的高強度脈衝磁場」這是什麼原理呢？

學生： 電流磁效應。

老師： 很好，電流磁效應就是電生磁的現象，也稱為安培定律。題目又說：「磁場穿過頭顱對腦部特定區域產生應電場及應電流」這是什麼原理呢？

學生： 一樣是電流磁效應嗎？

老師： 電流磁效應是電流流經導線，會在導線周圍產生磁場。磁場要產生應電場及應電流，需要什麼條件呢？

學生： 不知道耶！

老師： 隨時間變動的磁場，才可以產生應電流喔！此現象稱為什麼呢？

學生： 喔喔！電磁感應。

老師： 是的，這是磁生電的效應。你們可以先看看(A)、(B)選項。

學生： 原來如此。所以(A)、(B)選項都不對。

老師： 沒錯！誰來說說看(A)選項應該怎麼修正呢？

學生： 「脈衝電流I流經線圈會產生磁場」是電流磁效應，不是電磁感應。

老師： 很好，(B)選項呢？

學生： 「脈衝電流I在線圈產生的脈衝磁場，會在線圈周圍空間產生應電場」是電磁感應，不是電流磁效應。

老師： 太棒了！如果像(C)選項所說，把脈衝電流改成穩定的直流電，依然可以產生應電場及應電流，刺激腦部嗎？

學生： 可以吧！

老師：　直流電會產生穩定的磁場，穩定不變的磁場可以經由電磁感應，形成感應電流嗎？

學生：　啊！不行！

老師：　是的。穩定的磁場無法在線圈周圍產生應電場，故無法對腦神經產生電的作用。你們覺得(D)選項是正確的嗎？

學生：　不對，因為脈衝電流只有那一瞬間有電流。

老師：　很好~脈衝電流通過之後，就不會再產生磁場了，所以通過腦部特定區域的磁通量為零。

(E)選項說：改變脈衝電流時間 Δt，應電場及應電流會增強。請問是正確的嗎？為什麼呢？

學生：　是正確的。磁場隨時間變化得愈快，則應電流愈大。

老師：　很棒！

3-2 冷次定律 Lenz's Law

■ 前言 Introduction

本節說明冷次定律的意義，即線圈中產生的應電流所感應出的磁場，會與磁力線變化的方向相反。並介紹如何透過冷次定律和安培右手定則，來判別應電流流向，最後解釋冷次定律符合能量守恆原理。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
counterclockwise	逆時針方向	Lenz's law	冷次定律
clockwise	順時針方向	oppose	抵抗
magnet	磁鐵	conservation of energy	能量守恆
induced electromotive force	應電動勢		

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

❶ Adhering to ______________, ______________.

例句：**Adhering to** the principle of conservation of energy, the directions of a magnetic field generated by induced current always opposed the change in the magnetic field lines.

為了遵守能量守恆原則，感應電流所產生的磁場方向，總是與磁力線數的改變方向相反。

❷ __________ be transferred from ______________.

例句：In experiments regarding Lenz's Law, the generated electrical energy may **be transferred from** the reduced kinetic energy of the magnetic rod.

在冷次定律實驗中，產生的電能可能來自磁棒所減少的動能。

■ 問題講解 Explanation of Problems

☙ 學習目標 ❧

在學習完本單元後，學生應習得以下觀念：

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

一、了解冷次定律的機制。

Understand the mechanism of Lenz's law.

二、能透過冷次定律及安培右手定則，正確判斷感應電流的流向。

Can accurately distinguish the direction of the induced current based on Lenz's law and Ampere's right-hand rule.

三、理解冷次定律為能量守恆的必然結果。

Understand Lenz's law as a necessary consequence of energy conservation.

꧁ 例題講解 ꧂

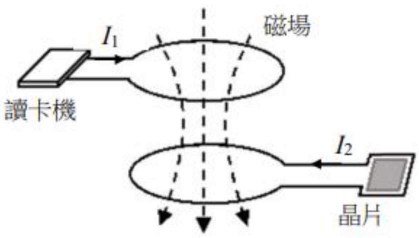
例題一

說明：理解冷次定律與電磁感應定律，分析產生應電流的條件及方向。

Understand Lenz's Law and the Law of Electromagnetic Induction, and analyze the conditions and directions for inducing current.

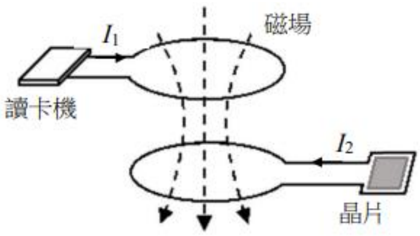
Commonly used chip cards contain built-in coils, as shown in the bottom half of the figure. The left arrow indicates the direction of the induced current flow $I_2 > 0$. The top half of the figure represents the reader coil, with the right arrow indicating the direction of the current flow $I_1 > 0$ during operation. When $I_1 > 0$, the magnetic field generated by the coil is illustrated by the dashed lines. When the chip card coil is close to the reader coil, the magnetic field generated by the current I_1 will cause changes in the induced current I_2, letting the chip transmit information. When both coils are stationary and $I_2 = 0$, how should the current I_1 in the card reader coil generate an induced current $I_2 > 0$ as shown in the diagram? (Select 2 options)

(A) $I_1 > 0$ and remains constant.
(B) $I_1 > 0$ and increases gradually.
(C) $I_1 < 0$ and increases gradually.
(D) $I_1 \leq 0$ and remains constant.
(E) $I_1 < 0$ and decreases gradually.



常用的晶片卡中有內建線圈，如示意圖的下半部所示，向左箭號代表應電流 $I_2 > 0$ 的流向。圖的上半部為讀卡機線圈，向右箭號代表電流 $I_1 > 0$ 時的流向。當 $I_1 > 0$ 時線圈產生的磁場，如虛線所示。晶片卡線圈貼近讀卡機線圈時，電流 I_1 產生的磁場會造成應電流 I_2 的變動，驅動晶片發出訊息。當兩線圈均為靜止且 $I_2 = 0$ 時，欲使晶片卡線圈產生圖示 $I_2 > 0$ 流向的應電流，則讀卡機線圈的電流 I_1 應如何？（應選 2 項）

(A) $I_1 > 0$ 且維持定值。
(B) $I_1 > 0$ 且漸增。
(C) $I_1 < 0$ 且漸增。
(D) $I_1 \leq 0$ 且維持定值。
(E) $I_1 < 0$ 且漸減。



（111 學測自然 6）

Teacher: The current I_1 in the card reader coil can generate a magnetic field. How can the magnetic field let the coil on the chip form a current?

Student: The magnetic field needs to change over time.

Teacher: Excellent! This phenomenon is called “electromagnetic induction”. Among these options, which ones can cause the magnetic field to change over time?

Student: Options (B), (C), and (E).

Teacher: Great. So, can we choose all of these three options?

Student: Yes.

Teacher: Let’s think again. Take a look at the direction of the current I_2. What kind of magnetic field will this current produce?

Student: The current I_2 will produce an upward magnetic field.

Teacher: Very good, the determination of magnetic field from electric current is based on Ampere’s Right Hand Rule. Now, from Lenz’s law, the magnetic field generated by the induced current opposes the direction of the changing magnetic field. How will the magnetic field change?

Student: The magnetic field will gradually increase downward.

Teacher: That’s right. Option (C) indicates $I_1 < 0$, meaning that the current is counterclockwise when viewed from above. It will generate an upward magnetic field.

Student: Oh! Then, to oppose the increasing upward magnetic field, the coil on the chip will produce a downward magnetic field. So the induced current $I_2 < 0$.

Teacher: Excellent! In sum, to answer this problem, we need to combine the concepts of Lenz’s Law (magnetism produces electricity) and Ampere’s Law (electricity produces magnetism).

老師： 讀卡機線圈中的電流 I_1，可產生磁場，請問磁場要如何使晶片上的線圈形成電流？

學生： 磁場須隨時間變動。

老師： 很好~這個現象稱為「電磁感應」。這些選項中，哪些可以使磁場隨時間變動呢？

學生： (B)、(C)、(E)選項都可以！

老師： 很好~所以這三個選項都可以選嗎？

學生： 是的！

老師： 再想想！看看電流 I_2 方向，此電流會產生怎樣的磁場呢？

學生： 電流 I_2 方向會產生向上的磁場。

老師： 很好，從電流判斷磁場，是根據安培右手定則。接著，依照冷次定律，應電流所產生的磁場，會抵抗原本的磁場變化方向，所以磁場應該如何變動呢？

學生： 磁場應該要向下漸增。

老師： 沒錯，(C)選項 $I_1 < 0$，代表由上往下看電流是逆時針流，會產生向上的磁場喔。

學生： 哦！然後晶片上的線圈為了抵抗向上漸增的磁場，會產生向下的磁場，所以感應電流$I_2 < 0$。

老師： 很好，所以，此題我們需同時結合冷次定律（磁生電），以及安培定律（電生磁），才能完成。

例題二

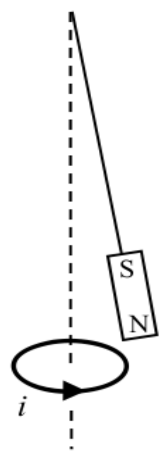
說明： 透過冷次定律與電磁感應，判斷應電流方向。

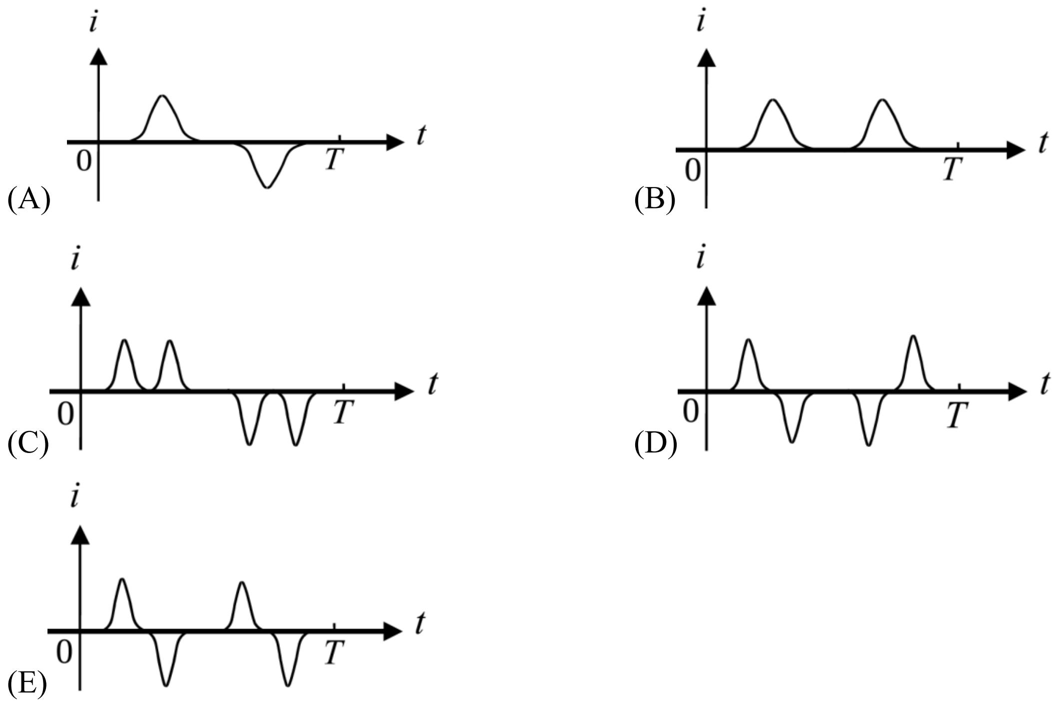
Determine the direction of induced current through Lenz's Law and electromagnetic induction.

A long magnetic rod hangs from a cotton thread to form a pendulum. As Diagram 3 shows, below the pendulum, there's a circular wire with current flowing in the direction of the arrow. At time t=0, the pendulum is released from its position and swings back and forth.

If the pendulum's motion is considered periodic with period T, which graph best represents the relationship between the current *i* in the wire and time t during one complete cycle of the pendulum's motion? **E**

一細長磁鐵棒繫於棉線下端形成單擺，並於此擺的正下方放置一環形導線，如圖 3 所示，箭頭所示方向表示導線上電流的正方向。當時間 t = 0 時，單擺由下圖的位置自靜止釋放而來回擺動，若此單擺的擺動可視為週期運動，其週期為 T，下列何者最可能表示該導線上的電流 i 與時間 t 在單擺擺動一週期內的關係圖？ **E**





（103 指考物理 9）

Teacher: Let’s think about it. When the magnetic bar is at the endpoint versus the midpoint, will there be more magnetic lines passing through the coil?

Student: Hmm... When the magnetic bar is at the midpoint, there will be more magnetic lines passing through the coil compared to when it’s at the endpoint.

Teacher: That’s right. Therefore, as the magnetic bar swings from the right endpoint to the midpoint, the number of magnetic lines of the coil will increase. According to Lenz’s law, how will the direction of the induced current in the coil?

Student: The coil experiences an increasing downward magnetic field, so the direction of the magnetic field produced by the induced current should be upward. Then, based on Ampere’s right-hand rule, we know that as the magnetic bar swings from the right endpoint swings to the midpoint, the direction of the induced current is counterclockwise.

Teacher: Great. As shown in Diagram 3, we define counterclockwise current as positive. Similarly, when the magnetic bar swings from the midpoint to the left endpoint, how will the magnetic field received by the coil and the direction of the induced current change?

Student: I know! As the magnetic bar swings from the midpoint to the left endpoint, the downward magnetic field that the coil receives decreases. To compensate for the decreasing downward magnetic field, the direction of the induced current changes to a clockwise, or negative direction.

Teacher: Very good. But, we haven't come to an end. We're only halfway through the cycle. Next, when the magnetic bar swings from the left endpoint to the midpoint, how will the direction of the induced current change?

Student: Just like at the beginning, the induced current opposes the increasing downward magnetic field, producing an upward magnetic field, so the current direction is positive.

Teacher: Yes. Finally, what will be the direction of the induced current as the magnetic bar swings from the midpoint to the right endpoint?

Student: The direction of the induced current will become negative, so the answer is option (E).

Teacher: Exactly!

老師： 想想看，當磁棒在端點還是中點時，通過線圈的磁力線會較多呢？

學生： 嗯…磁棒在中點的時候，通過線圈的磁力線會比在端點來得多。

老師： 沒錯。因此當磁棒從右端點擺動到中點時，線圈收到的磁力線數目會越來越多，那麼根據冷次定律，線圈中的感應電流流向會是如何呢？

學生： 線圈受到向下的磁場增加，所以感應電流所產生的磁場方向應向上，透過安培右手定則，可知磁棒從右端點擺動到中點時，感應電流應為逆時針。

老師： 很棒。如圖 3 所示，我們令逆時針的電流為正，那麼同理，當磁棒從中點擺動到左端點時，線圈受到的磁場和感應電流流向會如何改變呢？

學生： 我知道！當磁棒從中點擺動到左端點時，線圈所受向下的磁場變小了，為了補償向下磁場，感應電流的流向會變為順時針，也就是負方向。

老師： 非常好。不過還沒結束，現在才進行到週期的一半，接下來當磁棒從左端點擺動到中點時，感應電流的方向又會如何改變呢？

學生： 和一開始一樣，感應電流為抵抗向下增加的磁場，而產生方向向上的磁場，電流流向為正。

老師： 是的。最後，當磁棒從中點擺動到右端點時的感應電流流向呢？

學生： 感應電流的流向會變為負，所以答案是選項(E)。

老師： 沒錯！

3-3 法拉第電磁感應定律
Faraday's Law of Electromagnetic Induction

■ 前言 Introduction

本節講解磁通量與電動勢的定義和關係：磁通量為磁場與線圈面積向量的內積，而法拉第電磁感應定律說明，線圈內磁通量隨時間的變化率等於線圈上的感應電動勢。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
magnetic flux	磁通量	induced emf	應電動勢
normal	法線向量	electromotive force, emf	電動勢
area vector	面積向量	electromagnetic induction	電磁感應
Weber	韋伯	series	串聯
Tesla	特斯拉	Faraday's Law	法拉第定律

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

❶ __________ the product of __________.

例句：The magnetic flux is defined as **the product of** the magnetic field and the projected area in the direction of the magnetic field.

磁通量定義為，磁場與面積在磁場方向投影值的乘積。

❷ __________ connected in series __________.

例句：When the total number of turns of the coil is N, the total emf is equivalent to N times of single turn coil **connected in series**, which is N times that of each single turn.

當線圈總匝數為 N 時，相當於 N 個單圈線圈的串聯，則總電動勢變為單圈之 N 倍。

❸ __________ can induce __________.

例句：Changing magnetic field **can induce** current in a nearby coil.

變化的磁場可以在附近的線圈中感應出電流。

■ 問題講解 Explanation of Problems

學習目標

在學習完本單元後，學生應習得以下觀念：

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

一、了解法拉第電磁感應定律。

Understand Faraday’s Law of electromagnetic induction.

二、理解磁通量及應電動勢的定義。

Understand the definition of magnetic flux and induced emf.

例題講解

例題一

說明：熟悉冷次定律與應電動勢的應用。

Be familiar with Lenz's Law and the applications of induced emf.

As shown in the diagram below, the magnetic field is perpendicular to the paper, increasing the magnetic flux through the square loop ABCD steadily at a rate of 1.0 $T\cdot m^2/s$. The resistances of segments AB and CD are respectively 0.6 kΩ and 0.4 kΩ. Voltmeters V_1 and V_2 are connected with their positive terminals at points A and D, and their negative terminals at points B and C. The measured voltage values are V_1 and V_2. Assuming the magnetic field generated by the current I in the loop and the current passing through the voltmeters can be ignored, which of the following equations might be correct?

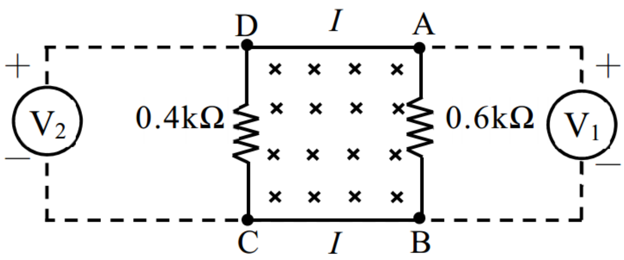
(A) I = 1 mA

(B) I = 1 μA

(C) $V_1 = V_2 = 0.6$ V

(D) $V_1 = -0.6$ V, $V_2 = 0.4$ V

(E) $V_1 = 0.6$ V, $V_2 = 0.4$ V



如下圖所示，磁場垂直指入紙面，使通過正方形迴路 ABCD 的磁通量，穩定地以 1.0 $T\cdot m^2/s$ 的時間變化率增加，AB 段與 CD 段的電阻分別為 0.6 kΩ 與 0.4 kΩ。將伏特計 V_1 與 V_2 的正極（＋）分別接到 A、D 點，負極（－）分別接到 B、C 點，測得的電壓值分別為 V_1 與 V_2。假設迴路上應電流 I 產生的磁場與通過伏特計的電流均可忽略，則下列選項中哪些關係式可能是正確的？

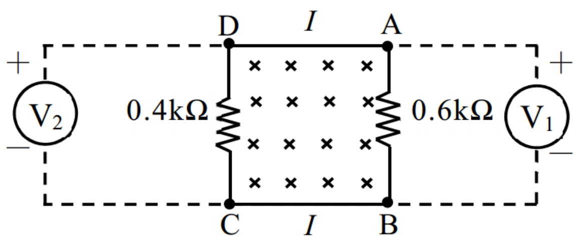
(A) I = 1 mA

(B) I = 1 μA

(C) $V_1 = V_2 = 0.6$ V

(D) $V_1 = -0.6$ V, $V_2 = 0.4$ V

(E) $V_1 = 0.6$ V, $V_2 = 0.4$ V



（111 分科物理 14）

Teacher: As the magnetic field pointing into the paper continuously increases, what should be the direction of the induced current in the coil?

Student: To oppose the increasing magnetic field pointing into the paper, the magnetic field generated by the induced current in the coil should be pointing outwards of the paper. According to Ampere's Right-Hand Rule, the direction of the induced current in the coil should be counterclockwise.

Teacher: Very good. We already know that the potential at the entry point of the resistor is higher than that at the exit point. So, what can we infer about the positive and negative relationship between V_1 and V_2?

Student: It should be $V_1 < 0$ and $V_2 > 0$.

Teacher: That's right. Before determining the magnitude of the induced current, we need to know the magnitude of the induced electromotive force generated by the magnetic field. Which physical principle should we adopt?

Student: The induced electromotive force generated by the magnetic field is equal to

$\varepsilon = \left|-\frac{\Delta\phi}{\Delta t}\right| = 1.0V$.

Teacher: That's right, this is based on Faraday's Law. After calculating the induced electromotive force, we can use Ohm's Law to determine the magnitude of the induced current in the coil.

Student: It's easy. The induced current in the coil is $I = \frac{\varepsilon}{\mathrm{R}} = \frac{1}{0.4+0.6} = 1.0\ mA$.

Teacher: Correct! With the current and resistance values, we can calculate the values of V_1 and V_2.

Student: I got it! $V_1 = -1 \times 0.6 = -0.6\ \ V$, and $V_2 = 1 \times 0.4 = 0.4\ \ V$.

Therefore, options (A) and (D) are correct.

Teacher: Correct!

老師：　請問，射入紙面的磁場持續增加，那麼線圈中的感應電流方向應如何呢？

學生：　為了抵抗增加的射入磁場，線圈中感應電流所產生的磁場，應為射出紙面。根據安培右手定則，線圈中的感應電流應為逆時針。

老師：　很好。已經知道流入電阻端的電位高於流出電阻那端，所以可以得知 V_1 和 V_2 的正負關係應該為如何？

學生：　應該為$V_1 < 0$，且$V_2 > 0$。

老師： 沒錯。而在求出感應電流值之前，我們要先知道磁場產生的感應電動勢是多少。感應電動勢如何算出？

學生： 磁場產生的感應電動勢為$\varepsilon = \left|-\frac{\Delta\phi}{\Delta t}\right| = 1.0V$。

老師： 是的，這是依據法拉第定律而得。算出感應電動勢後，再透過歐姆定律，就可以算出線圈中的感應電流值了。

學生： 很簡單，線圈中的感應電流為$I = \frac{\varepsilon}{R} = \frac{1}{0.4+0.6} = 1.0\ mA$。

老師： 沒錯。有了電流和電阻值，我們就可以算出V_1和V_2分別的值了。

學生： 我會！

$V_1 = -1 \times 0.6 = -0.6\ \ V$，且$V_2 = 1 \times 0.4 = 0.4\ \ V$，因此(A)和(D)選項正確。

老師： 答對了！

例題二

說明：正確分析法拉第電磁感應定律的物理變因。

Analyze the physical variables when adopting Faraday's Law of electromagnetic induction.

An electromagnetic flowmeter can measure the flow rate of a conducting fluid (volume passing through per unit of time). It is commonly used for measuring blood flow in vessels.
Shown in the diagram below, it comprises a coil producing a magnetic field and two electrodes for measuring electromotive force. It can be installed externally to measure fluid flow in pipelines. Let V represent the flow rate, B represents the magnetic field generated by the electromagnetic coil, and D represents the diameter of the pipe. If the directions of magnetic field B, flow rate V, and electrode connections for measuring induced electromotive force are mutually perpendicular, then the induced electromotive force measured will be proportional to which equation?

電磁流量計可以量測導電流體的流量（單位時間流過的流體體積），常用來量測血液在血管中的流速。如下圖所示，它是由一個產生磁場的線圈，及用以量測電動勢的兩個電極所構成，可架設於管路外來量測液體流量。以 V 代表流速，B 代表電磁線圈產生的磁場，D 代表管路內徑，若磁場 B 的方向、流速 V 的方向與量測感應電動勢兩極連線的方向三者相互垂直，則量測到的感應電動勢會和下列何式成正比？

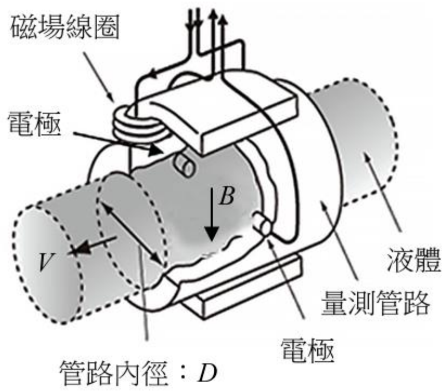
(A) $\frac{BD}{V}$

(B) $\frac{1}{VBD}$

(C) $\frac{V}{BD}$

(D) $\frac{VB}{D}$

(E) VBD



（107 指考物理 12）

Teacher: We've mentioned that induced electromotive force equals the rate of change of magnetic flux Φ with respect to time t within the coil. Do you remember how to express the formula for induced emf?

Student: Yes, it's $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$.

Teacher: Excellent. Since we have learned that magnetic flux $\phi = \underset{B}{\rightarrow} \cdot \underset{A}{\rightarrow}$.

, how can we rewrite the formula for induced emf?

Student: It can be written as $\varepsilon = -N\frac{\Delta(\underset{B}{\rightarrow}\cdot\underset{A}{\rightarrow})}{\Delta t}$.

Teacher: That's correct. Since the question asks which factors are directly proportional to induced emf, we can approach it from the perspective of units. If we let the unit of magnetic field be T, length be m, and time be s, what can we infer about the unit of induced emf?

Student: Um… It should be $\frac{T\cdot m^2}{s}$.

Teacher: Exactly. The magnetic field is written in the numerator. So, which options can we eliminate?

Student: Options (B) and (C) have magnetic field in the denominator, so we can eliminate (B) and (C).

Teacher: Great. Let's consider option (A) next. How can we express its unit?

Student: The unit of velocity V is $\frac{m}{s}$, so the unit of option (A) is $\frac{T\cdot m}{\frac{m}{s}} = T \cdot s$. Therefore, option (A) doesn't fit.

Teacher: That's correct. What about options (D) and (E)?

Student: The unit of option (D) is $\frac{m/s\cdot T}{m} = \frac{T}{s}$, and the unit of option (E) is $m/s \cdot m \cdot T = \frac{T\cdot m^2}{s}$. Therefore, option (E) is correct.

Teacher: That's right.

老師： 我們說過，應電動勢等於現圈內磁通量 Φ 隨時間 t 的變化率，還有印象應電動勢的公式要怎麼表示嗎？

學生： 知道，是 $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$。

老師： 很好。我們已經學過磁通量 $\phi = \underset{B}{\rightarrow} \cdot \underset{A}{\rightarrow}$，所以可以怎麼改寫應電動勢的公式呢？

學生： 可以寫成 $\varepsilon = -N\frac{\Delta(\underset{B}{\rightarrow}\cdot\underset{A}{\rightarrow})}{\Delta t}$。

老師： 是的。由於題目是問感應電動勢和哪些因素成正比，所以我們可以從因次的角度解題。如果令磁場單位為 T、長度單位為 m、時間單位為 s，那我們可以推測應電動勢的單位會是？

學生： 嗯…應該是 $\frac{T\cdot m^2}{s}$。

老師： 沒錯，所以可以知道磁場在分子，這樣我們可以先排除掉哪些選項呢？

學生： (B)跟(C)的磁場項在分母，所以可以先排除掉(B)跟(C)。

老師： 很棒，再來先看(A)選項，他的單位可以怎麼表示呢？

學生： 流速 V 的單位是$\frac{m}{s}$，所以(A)選項 $\frac{BD}{V}$ 的單位是$\frac{T\cdot m}{m/s} = T \cdot s$，因此(A)選項不符合。

老師： 是的。那麼(D)和(E)選項呢？

學生： (D)選項 $\frac{VB}{D}$ 的單位為 $\frac{m/s \cdot T}{m} = \frac{T}{s}$，(E)選項 VBD 的單位為 $m/s \cdot m \cdot T = \frac{T \cdot m^2}{s}$，所以(E)選項正確。

老師： 沒錯。

3-4 電磁感應的應用
Applications of Electromagnetic Induction

■ 前言 Introduction

本節說明交流電與發電機的結構及運作機制，以及解釋變壓器的特性與應用，如發電廠電力運輸的方式。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
electric generator	發電機	slip ring	集電環
alternating current	交流電	power plant	發電廠
mechanical energy	力學能	transformer	變壓器
electrical energy	電能	primary coil	主線圈
alternating current generator	交流發電機	secondary coil	副線圈

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

❶ __________ once every __________.

例句：In an AC generator, the direction of the current in the coil changes **once every** half rotation.

交流發電機中的線圈每轉動半圈，電流流向就會改變一次。

❷ Thus, __________.

例句：DC power cannot cause a change in the magnetic field. **Thus,** the transformer cannot work if we adopt a DC power supply.

直流電源無法造成磁場的改變。因此，如果我們輸入直流電源，變壓器就無法運作。

❸ In order to __________.

例句：**In order to** reduce heat loss, electric power transmission is carried out at low current and high voltage.

為減少熱損耗，電能會透過低電流和高電壓進行傳輸。

■ 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、了解交流電的生成機制。

Understand the mechanism of producing alternating current.

二、認識發電機的構造與運作原理。

Understand the structure and the working principles of electric generators.

三、理解變壓器的工作原理與特性。

Understand the working principles and features of transformers.

例題講解

例題一

說明：熟悉電磁感應與變壓器原理。

Be familiar with the principles of electromagnetic induction and transformers.

As shown in the diagram, there is an ideal transformer with a primary coil and a secondary coil with a turn ratio of 2:1. The primary coil is connected to a track with zero resistance, and a metal rod PQ can slide along the track to form a loop. Where the loop is located, there is a uniform magnetic field of 0.50 T perpendicular to the paper. The metal rod PQ has a length of 20 cm and a resistance of 0.40 Ω. The secondary coil is connected to a 10 Ω resistor, and other resistances can be ignored. If the metal rod slides along the track at a constant velocity of 2.0 m/s due to an external force, which statements below are correct?

(A) The direction of the induced current in the primary coil loop is counterclockwise.

(B) The induced current in the primary coil is 0.50 A.

(C) The induced electromotive force in the secondary coil is 1.0 V.

(D) The induced current in the secondary coil is 0.10 A.

(E) The electrical power consumed by the secondary coil is 0.

如下圖所示，有一主線圈與副線圈匝數比為 2：1 的理想變壓器，主線圈外接一組電阻為零的軌道，而金屬棒 PQ 可在軌道上滑行形成迴路，迴路所在區域有 0.50 T 垂直進入紙面之均勻磁場，金屬棒 PQ 的長度為 20 cm、電阻為 0.40 Ω，副線圈外接 10 Ω 的電阻，其餘的電阻均可忽略。若金屬棒因受外力而在軌道上以速率 v = 2.0 m/s 等速度滑行時，則下列敘述哪些正確？

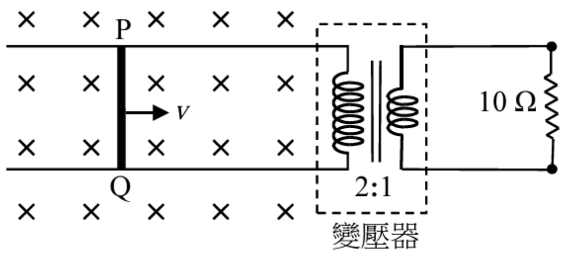
(A) 主線圈迴路的應電流方向為逆時鐘。

(B) 主線圈中的應電流 I = 0.50 A。

(C) 副線圈中的應電動勢為 1.0 V。

(D) 副線圈中的應電流 I = 0.10 A。

(E) 副線圈消耗的電功率 P = 0。



（104 指考物理 23）

Teacher: How can we know the direction of the current in the primary coil loop?

Student: Hmm… I'm not sure.

Teacher: Let's start by looking at the change in the magnetic field. When the metal rod moves to the right, how does the magnetic flux through the loop area change?

Student: When the metal rod moves to the right, the loop area decreases, causing the magnetic field lines entering the page to decrease.

Teacher: Correct. Do you remember Faraday's law? When the magnetic field lines entering the page decreases, what kind of induced current will be produced?

Student: An induced current will be generated to compensate for the decreasing magnetic field lines entering the page. So, according to the right-hand rule, the direction of the induced current in the loop should be clockwise.

Teacher: Yes. So, what should be the magnitude of the induced current in the primary coil? Let's first calculate the induced electromotive force in the primary coil.

Student: The induced electromotive force in the primary coil is equal to $\varepsilon = lvB = 0.2 \times 2 \times 0.5 = 0.2V$. Therefore, the induced current in the primary coil is $I = \frac{\varepsilon}{R} = \frac{0.2}{0.4} = 0.5\ A$.

Teacher: Great. Now, what would be the induced electromotive force in the secondary coil?

Student: The turn ratio of the transformer's primary coil to its secondary coil is 2:1, so the ratio of the induced electromotive force between the primary and secondary coils is also 2:1. Therefore, the induced electromotive force in the secondary coil is 0.1 V.

Teacher: No, that's incorrect. Let's think back. Is the power source connected to the transformer's direct current or alternating current?

Student: It's an alternating current.

Teacher: That's right. Now, take a closer look. Is the current in the primary coil direct current or alternating current?

Student: Oh! It's direct current, so this transformer won't function, right?

Teacher: Yes. So, what would be the induced electromotive force, induced current, and electrical power in the secondary coil?

Student: They would all be zero.

Teacher: Correct!

老師： 要怎麼知道主線圈迴路中的應電流方向呢？

學生： 嗯…我不知道耶。

老師： 我們可以先從磁場的變動開始看，當金屬棒向右移動時，迴圈面積上的磁通量會如何改變呢？

學生： 當金屬棒向右移動時，迴圈面積變小，所以射入紙面的磁力線數減少。

老師： 沒錯。還記得冷次定律嗎？當射入紙面的磁力線數變少時，會產生怎麼樣的應電流呢？

學生： 會產生補償射入紙面磁力線，根據右手定則，則迴路中的應電流方向應該會是順時針。

老師： 是的。那麼主線圈中的應電流值為多少呢？可以先算出主線圈中的應電動勢。

學生： 主線圈中的應電動勢 $\varepsilon = lvB = 0.2 \times 2 \times 0.5 = 0.2 \ \ V$，所以主線圈的應電流值為 $I = \frac{\varepsilon}{R} = \frac{0.2}{0.4} = 0.5 \ \ A$。

老師： 很棒。那麼副線圈中的應電動勢會是多少呢？

學生： 變壓器的主線圈與副線圈匝數比為 2：1，所以主副線圈的應電動勢比為 2：1，因此副線圈的應電動勢為 0.1 V。

老師： 不對喔。回想一下，變壓器所接的電源是直流還是交流呢？

學生： 是交流電。

老師： 沒錯。那仔細看看，主線圈中的電流是直流還是交流呢？

學生： 哦！是直流電，所以這個變壓器不能作用，對嗎？

老師： 是的。所以副線圈的應電動勢、應電流和電功率應該會是多少呢？

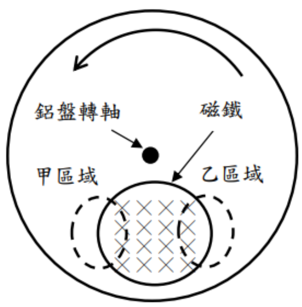
學生： 都會是 0。
老師： 答對了！

例題二

說明：能正確應用法拉第電磁感應定律於生活科技。

Can correctly apply Faraday's Law of electromagnetic induction to daily life technology.

High-speed trains commonly employ magnetic braking systems. The working principle of a magnetic brake can be summarized as follows: By bringing the N pole of a magnet close to a circular aluminum disk rotating counterclockwise, magnetic force lines vertically point into the aluminum disk (represented by ╳), causing it to decelerate, as shown in the diagram. In the diagram, the area labeled "甲" on the left aluminum disk (dashed line area) moves toward the magnet, while the area labeled "乙" on the right aluminum disk (dashed line area) moves away from the magnet. Which of the following statements about the aluminum disk magnetic brake are correct? A means 甲, B means 乙.



(A) The induced current in the region "A" of the aluminum disk will produce an induced magnetic field penetrating out of the plane of the paper.

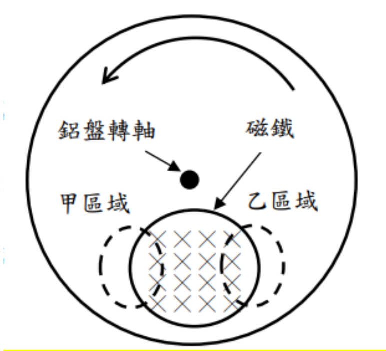
(B) The induced current in the region "B" of the aluminum disk will produce an induced magnetic field penetrating out of the plane of the paper.

(C) The interaction between the magnetic field and the induced current will generate a net torque that slows down the rotation of the aluminum disk.

(D) The heat generated by the induced current in the aluminum disk is the primary reason for slowing down the disk.

(E) If the solid aluminum disk is replaced with a disk filled with small cavities, the magnetic brake effect on the cavity-filled disk will be the same as on the solid disk.

高速鐵路列車通常使用磁剎車系統。磁剎車工作原理可簡述如下：將磁鐵的 N 極靠近一塊正在以逆時鐘方向旋轉的圓形鋁盤，使磁力線垂直射入（以╳表示）鋁盤內，鋁盤隨即減速，如圖所示。圖中磁鐵左方鋁盤的甲區域（虛線區域）朝磁鐵方向運動，磁鐵右方鋁盤的乙區域（虛線區域）朝離開磁鐵方向運動。下列有關鋁盤磁剎車的敘述哪些正確？



(A) 鋁盤甲區域的應電流會產生穿出紙面的應磁場。

(B) 鋁盤乙區域的應電流會產生穿出紙面的應磁場。

(C) 磁場與應電流之間的作用力，會產生將鋁盤減速旋轉的淨力矩。

(D) 應電流在鋁盤產生的熱能，是將鋁盤減速的最主要原因。

(E) 若將實心鋁盤換成布滿小空洞的鋁盤，則磁鐵對空洞鋁盤所產生的減速效果與實心鋁盤相同。

（109 指考物理 24）

Teacher: If the aluminum disk rotates counterclockwise, how would the perceived magnetic field change for regions A and B?

Student: For region A, there's an increase in the magnetic field entering the aluminum disk. For region B, there's a decrease in the magnetic field entering the aluminum disk.

Teacher: Yes, so according to Lenz's law, what direction of the magnetic field would be generated by the induced currents in regions A and B?

Student: The induced current in region 甲 would produce a magnetic field opposing the increased magnetic field entering the aluminum disk. The induced current in region B would produce a magnetic field entering the aluminum disk to compensate for the decreased magnetic field.

Teacher: Correct. Now, for options (C) and (D), think about whether the reason for the aluminum disk slowing down is the interaction of the magnetic field and induced current or the thermal energy generated by the induced current.

Student: It should be the interaction of the magnetic field and induced current, right?

Teacher: Yes. The aluminum disk slows down due to the resistive magnetic force, which force appears due to the existence of the induced electric current of the aluminum disk and the external magnetic field (F_B=ILB). The interaction of the magnetic field and induced current creates a net torque that slows down the aluminum disk's rotation. Now, if we replace the solid aluminum disk with one filled with small holes, would the slowing-down effect change?

Student: Hmm… I'm not sure.

Teacher: Only the metallic parts would generate induced currents, and the aluminum disk filled with small holes has a smaller metallic surface area.

Student: Oh, I see. So, the aluminum disk filled with small holes would generate smaller induced currents, leading to a weaker slowing-down effect.

Teacher: Exactly.

老師： 鋁盤逆時針轉動，對於甲和乙區域而言，感受到的磁場會如何改變呢？

學生： 對甲區域來說，感受到入鋁盤的磁場增加；對乙區域而言，感受到入鋁盤的磁場減小。

老師： 是的，那麼根據冷次定律，甲和乙區域產生的應電流會產生什麼方向的磁場呢？

學生： 甲區域的應電流會產生射出鋁盤的磁場，以抵抗所增加的射入磁場；乙區域的應電流會產生射入磁場，以補償減少的射入磁場。

老師： 沒錯。再來(C)和(D)選項，想想看造成鋁盤減速的原因是磁場和應電流的作用，還是應電流產生的熱能呢？

學生： 應該是磁場和應電流的作用，對嗎？

老師： 是的，鋁盤減速是因受到磁力所造成的阻力，而此一磁力來自鋁盤上的應電流與外加磁場間的作用所導致 (F_B=ILB)。磁場和應電流的作用，會產生將鋁盤減速旋轉的淨力矩。那若是將實心鋁盤換成佈滿小洞的鋁盤，減速效果會改變嗎？

學生： 嗯…我不知道耶。

老師： 金屬的部分才會產生應電流，而佈滿小洞的鋁盤的金屬面積較小。

學生： 哦～我知道了，所以佈滿小洞的鋁盤產生的應電流較小，所以減速效果較差。

老師： 沒錯。

3-5 電磁波 Electromagnetic Waves

■ 前言 Introduction

本節介紹電磁波的特性與波譜，講解電磁波如何振盪及傳播，最後說明偏振的現象特徵。

■ 詞彙 Vocabulary

單字	中譯	單字	中譯
virtual current	虛擬電流	linearly polarized wave	線偏振波
induced electric field	應電場	transverse wave	橫波
induced magnetic field	感應磁場	non-polarized light	非偏振光
electromagnetic wave	電磁波	polarizer	偏振片
electromagnetic spectrum	電磁波譜		

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

❶ __________ **over time** _____________.

例句：A magnetic field that changes **over time** can generate an electric field.

隨時間變化的磁場可產生電場。

❷ **Besides** ___________, ______________.

例句：**Besides** plane waves, electromagnetic waves can also be spherical waves or cylindrical waves.

除了平面波，電磁波也可以是球面波或圓柱形波。

❸ __________ **be perpendicular to** _______________.

例句：If the direction of polarization of linearly polarized light **is perpendicular to** the transmission axis of the polarizer, then it will be unable to pass through this polarizer.

如果線偏振光的偏振方向與偏振片的透射軸垂直，則線偏振光無法透過此偏振片。

■ 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、了解電磁波的形成與性質。

Understand the formation and the features of electromagnetic waves.

二、能理解並判讀電磁波譜。

Understand and identify the electromagnetic spectrum.

三、認識電磁波的偏振。

Understand the polarization of electromagnetic waves.

꧁ 例題講解 ꧂

例題一

說明：熟悉電磁波譜並正確從耳溫槍量測，歸納溫度與波長之關係 。

Be familiar with the electromagnetic spectrum and correctly reason the relation between temperature and wavelength from the measurement of ear thermometers.

Our eardrums emit electromagnetic waves due to thermal radiation, and an ear thermometer detects the highest intensity wave with a wavelength of λ_m to determine body temperature. When the ear temperature is 308.1 K, the measured wavelength is 9404.5 nanometers, and when the ear temperature is 310.1 K, the measured wavelength is 9343.9 nanometers. Which statements are correct?

(A) The electromagnetic waves detected by the ear thermometer from the eardrum mainly fall within the infrared range.

(B) The ear thermometer determines temperature based on the relationship between wavelength λ_m and absolute temperature.

(C) If the temperature is higher, the frequency of the electromagnetic waves corresponding to λ_m will be lower.

(D) If the ear thermometer measures a wavelength λ_m of 9300 nanometers, the corresponding ear temperature is 300 K.

(E) If the ear thermometer measures a wavelength λ_m of 9353 nanometers, the individual being measured does not have a fever above 38°C.

耳膜因熱輻射會發出電磁波，耳溫槍可偵測其中強度最高、波長為 λ_m 的波，並利用波長 λ_m 與耳溫間的關聯來判定體溫。已知耳溫 308.1 K 時，測得的波長 λ_m 為 9404.5 奈米，而耳溫 310.1 K 時測得的波長為 9343.9 奈米，則下列敘述哪些正確？

(A) 耳溫槍所測得來自耳膜之電磁波主要在紅外光範圍。

(B) 耳溫槍是利用波長 λ_m 與絕對溫度成正比的關係來判定溫度。

(C) 若溫度越高，則對應於 λ_m 的電磁波頻率將越低。

(D) 若耳溫槍測得的波長 λ_m 為 9300 奈米，則對應的耳溫為 300K。

(E) 若耳溫槍測得的波長 λ_m 為 9353 奈米，則被測者未達 38°C 的發燒溫度。

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Teacher: According to the electromagnetic spectrum, what range of light does the temperature gun measure fall into?

Student: The wavelength range of infrared light is approximately between 760 nm and 10^6 nm, so the electromagnetic waves measured by the temperature gun mainly fall within the range of infrared light.

Teacher: That's right. So, based on the statements of the problem, what relationship can we summarize between the temperature and the thermal radiation wavelength?

Student: Hmm... When the temperature is lower, the measured wavelength is longer. When the temperature is higher, the measured wavelength is shorter. So temperature and wavelength are inversely proportional.

Teacher: Exactly, so we can also infer that, as temperature increases, how will the frequency change? Let's think about the relationship between wavelength and frequency first.

Student: Wavelength and frequency are also inversely proportional, so as the temperature increases, the wavelength becomes shorter, and the frequency becomes higher.

Teacher: Great, since the speed of the electromagnetic wave of the thermal radiation is always the speed of light, the wavelength is inversely proportional to the frequency. Next, let's try to determine if the scenarios described in options (D) and (E) are correct.

Student: It's easy! For option (D), the wavelength of 9300 nanometers is less than the wavelength of 9343.9 nanometers measured at a temperature of 310.1 K, so the temperature corresponding to a wavelength of 9300 nanometers will be higher than 310.1 K.

Teacher: That's correct. Now for option (E), do you remember how to convert Celsius temperature to Kelvin temperature?

Student: Yes. If the ear temperature is 38°C, which is 273 + 38 = 311 K, then its corresponding wavelength will be less than the wavelength at 310.1 K, which is 9343.9 nanometers. So, we can tell that the wavelength of 9353 nanometers in option (E) corresponds to a temperature lower than 38°C.

Teacher: Correct! The wavelength of an object's radiation is inversely proportional to its temperature, and the temperature needs to be Kelvin scale. This relation is called Wien's Displacement Law.

老師： 根據電磁波譜，可以知道耳溫槍測得的電磁波是介於甚麼光的範圍？

學生： 紅外光的波長範圍約在 760 nm 到 10^6 nm 之間，所以耳溫槍測得的電磁波主要在紅外光的範圍。

老師： 沒錯，那麼根據題目所述，我們可以歸納出溫度和熱輻射的波長之間，有甚麼關係？

學生： 嗯…當溫度較低時，測到的波長較長；溫度較高時，測到的波長較短。所以溫度和波長呈反比。

老師： 是的，所以我們也可以推得，當溫度越高，頻率會如何改變呢？可以先想想波長和頻率的關係。

學生： 波長和頻率也是反比關係，所以當溫度越高，波長越短，頻率會變得更高。

老師： 很棒，因為輻射的電磁波波速固定為光速，所以頻率會與波長成反比。接著來試試看根據題目給的條件，推測 (D)和 (E)選項對不對？

學生： 很簡單！(D)選項中，波長 9300 奈米，小於耳溫為 310.1 K 時測得的波長 9343.9 奈米，因此波長 9300 奈米對應的溫度會高於 310.1K。

老師： 沒錯。那麼(E)選項，還記得攝氏溫標如何轉換成凱氏溫標嗎？

學生： 記得。如果耳溫達 38°C，也就是 273+38=311 K，則其對應的波長會小於耳溫為 310.1 K 時的波長 9343.9 奈米，所以可以知道(E)選項的波長 9353 奈米所對應的溫度未達 38°C。

老師： 答對了，溫度會與其輻射的波長成反比，其中的溫度需使用絕對溫標，而此一關係稱為維恩位移定律。

例題二

說明：理解電磁波的形成與特性。

Understand the formation and characteristics of electromagnetic waves.

Which of the following statements about electromagnetic waves is correct?

(A) Electromagnetic waves are longitudinal waves.

(B) Visible light is an electromagnetic wave that propagates at the same speed in a vacuum and a medium.

(C) Electromagnetic waves, like mechanical waves, exhibit phenomena such as reflection, refraction, interference, and diffraction.

(D) Electromagnetic waves with the same intensity but with higher frequencies propagate faster in a vacuum.

(E) Whenever there are both electric and magnetic fields, they would interact with each other and produce electromagnetic waves.

下列關於電磁波的敘述，何者正確？

(A) 電磁波為縱波。

(B) 可見光是電磁波，在真空中與介質中均以相同速率傳播。

(C) 電磁波與力學波一樣都有反射、折射、干涉與繞射現象。

(D) 相同強度的電磁波頻率越高，在真空中傳播的速率越快。

(E) 只要電場和磁場同時存在，便會產生交互作用而形成電磁波。

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Teacher: Look at option (E) first. As we mentioned earlier, what are the requirements for forming electromagnetic waves?

Student: There must be changing electric or magnetic fields over time, interacting with each other, to form electromagnetic waves.

Teacher: That’s right. So even if electric and magnetic fields exist simultaneously, if neither of them doesn’t change over time, electromagnetic waves won't be generated.

Student: I understand now, so option (E) is incorrect.

Teacher: Very good. Let’s move on to option (A). Do you still remember the difference between transverse and longitudinal waves?

Student: It's easy. In a transverse wave, the medium vibrates perpendicular to the direction of wave propagation, while in a longitudinal wave, the medium vibrates parallel to the direction of wave propagation.

Teacher: Excellent. Now, think about the direction of variation and propagation of electromagnetic waves. Are electromagnetic waves transverse or longitudinal waves?

Student: I know! The propagation direction of electromagnetic waves is perpendicular to the direction of variation of electric and magnetic fields, so electromagnetic waves are transverse waves.

Teacher: That's right. So for option (C), do electromagnetic waves, like mechanical waves, exhibit phenomena such as reflection, refraction, interference, and diffraction?

Student: Yes. Electromagnetic waves also have these characteristics, so option (C) is correct.

Teacher: Great. As we've discussed, electromagnetic waves include microwaves, infrared, visible light, ultraviolet, and so on, so is option (B) correct?

Student: No, though visible light is an electromagnetic wave, its propagation speed differs in a vacuum and a medium. The propagation speed in a vacuum is faster than in a medium.

Teacher: Very good. So, does the frequency of electromagnetic waves affect their propagation speed in a vacuum?

Student: No, the propagation speed of electromagnetic waves for any frequency in a vacuum remains the same, which is $3 \times 10^8\ m/s$, so option (D) is incorrect.

Teacher: Exactly!

老師： 先看到(E)選項，我們說過，電磁波形成的要件是甚麼？

學生： 要有隨時間變動的電場或磁場，兩者交互作用，才能形成電磁波。

老師： 沒錯，所以即便電場和磁場同時存在，但不會隨時間改變的話，就不會產生電磁波。

學生： 我懂了，所以(E)選項錯誤。

老師： 很好。接著看到(A)選項，還記得橫波和縱波的差異嗎？

學生： 很簡單。橫波的介質振動方向和波前進的方向垂直，縱波的介質振動方向則和波前進的方向平行。

老師： 很棒，那麼回想一下電磁波的變動方向和傳遞方向，請問電磁波是橫波還是縱波？

學生： 我知道，電磁波的傳遞方向和電場及磁場的變動方向垂直，所以電磁波是橫波。

老師： 是的，那麼(C)選項，電磁波與力學波一樣都有反射、折射、干涉與繞射現象，對嗎？

學生： 沒錯，電磁波也有反射、折射、干涉和繞射的特性，(C)選項正確。

老師： 很棒。而我們說過，電磁波包含了微波、紅外線、可見光、紫外線等，那麼(B)選項正確嗎？

學生： 不對，雖然可見光是電磁波，但可見光在真空和介質中的傳播速率不一樣，在真空中的傳播速率比在介質中快。

老師： 很好。那麼電磁波的頻率會影響它在真空中的傳播速率嗎？

學生： 不會，任何頻率的電磁波在真空中的傳播速率都一樣，為$3 \times 10^8\ m/s$，所以(D)選項不對。

老師： 沒錯！

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(IV)]

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

[Elective Physics (IV)]

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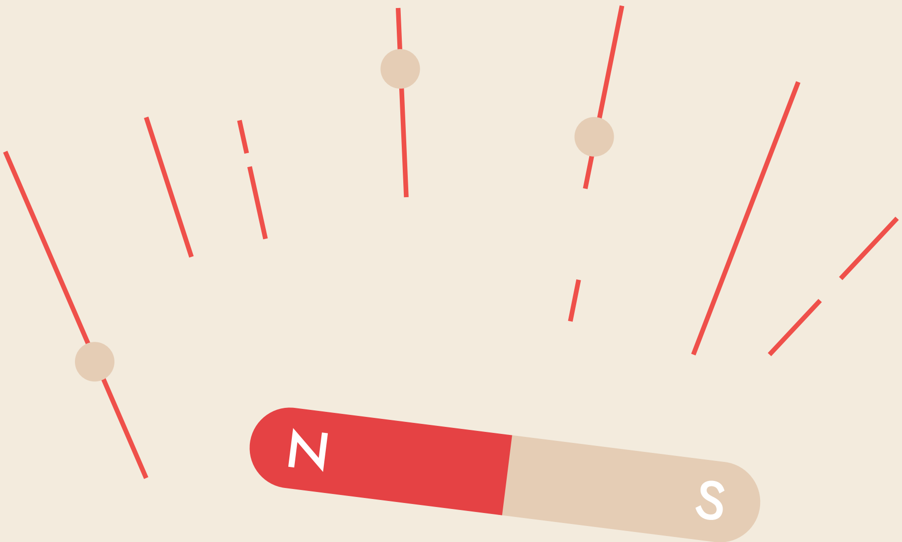

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