

波動現象 Phenomena of wave motion

波動學第二課

周末班

連續機械行波的能量分佈 Distribution of energies in continuous waves

考慮某一瞬間各質點的能量／單一質點隨時間推移的能量：

- 質點的總機械能 Total mechanical energy of a particle = 動能 KE + 勢能 PE
 - ▶ 總機械能：跟振幅相關。 $(\propto A^2)$
Total mechanical energy: related to amplitude. $(\propto A^2)$
 - ▶ 勢能：跟位移相關。 $(\propto y^2)$
Potential energy: related to displacement of a particle. $(\propto y^2)$
 - ▶ 動能：跟質點的移動速率相關。 $(\propto v^2)$
Kinetic energy: related to speed of a particle. $(\propto v^2)$
- 若沒有能量損耗，總機械能不變。
When there is no energy loss, total mechanical energy remains the same.

連續機械行波的能量分佈 Distribution of energies in continuous waves

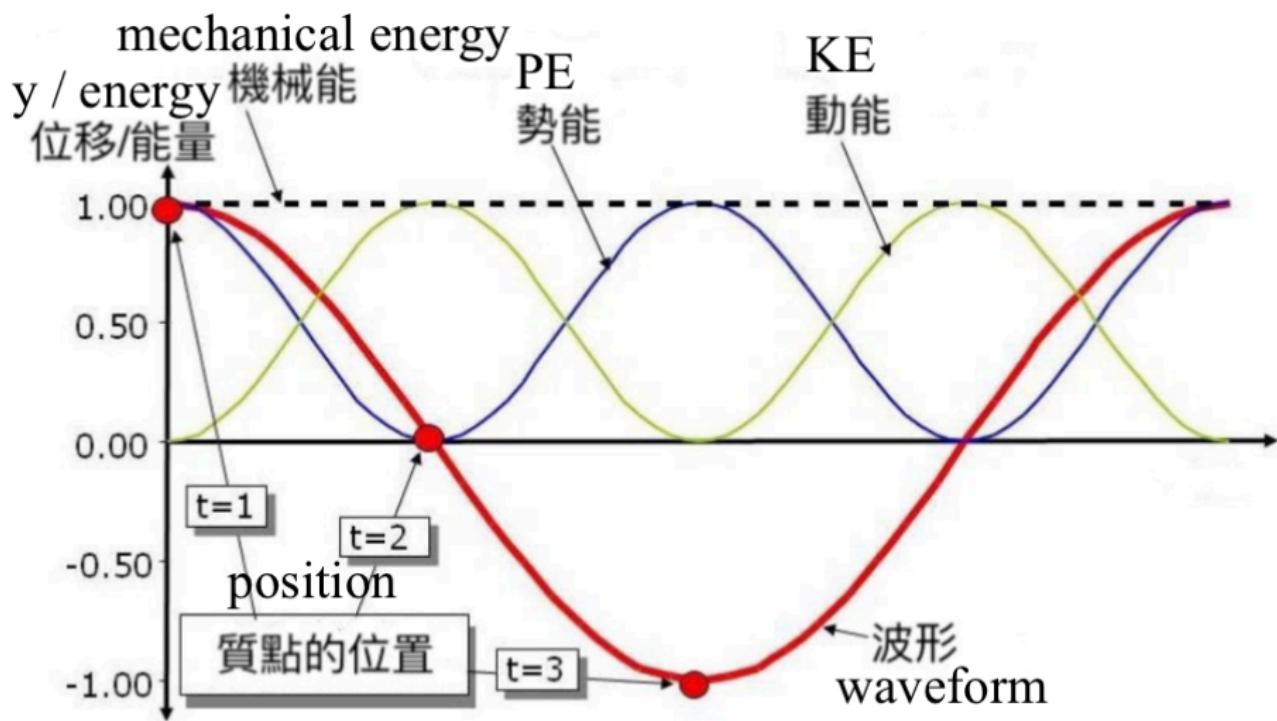
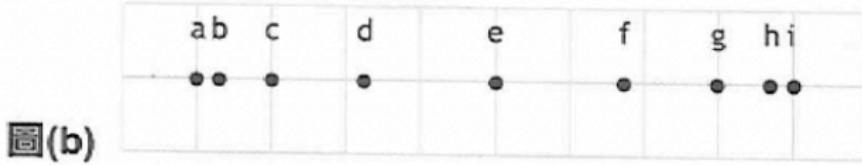
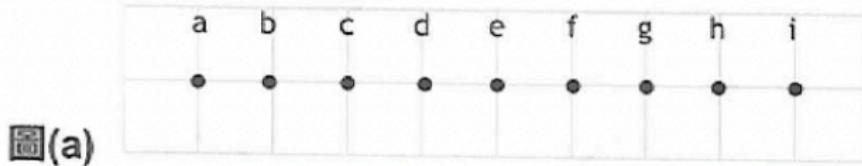
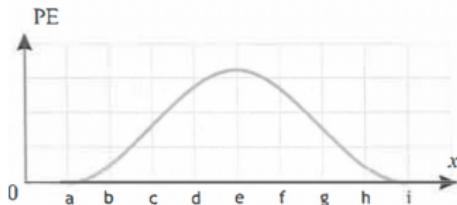


圖 (a) 顯示九個均勻分佈的質點。圖 (b) 顯示一縱波各質點的位置。在此時此刻，下列哪線圖正確地顯示各點的勢能 PE 隨位置 x 的變化？

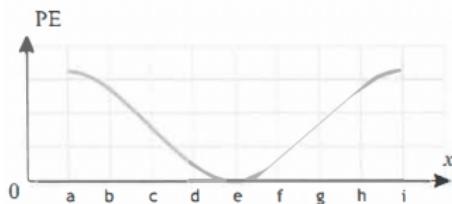
Figure (a) shows nine uniformly distributed particles. Figure (b) displays the positions of the particles in a longitudinal wave. At this moment, which of the following graphs accurately represents the variation of potential energy (PE) with respect to the position (x) of each point?



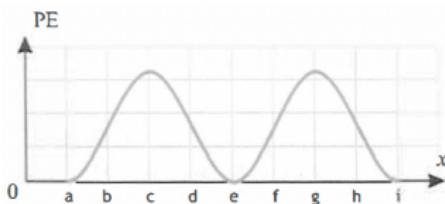
A.



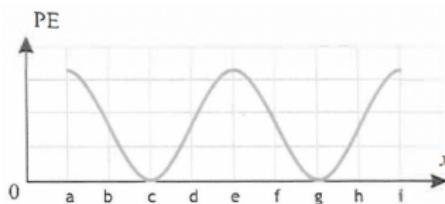
B.



C.



D.



水波槽 ripple tank

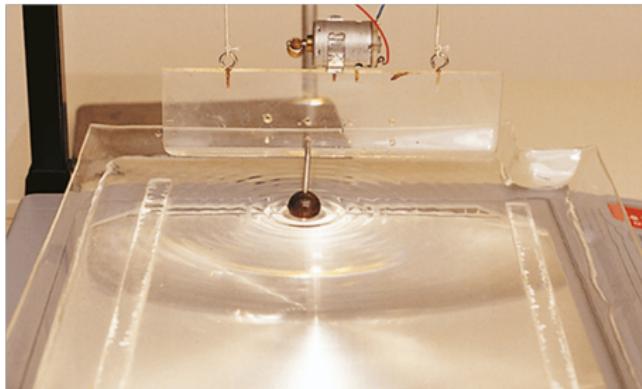


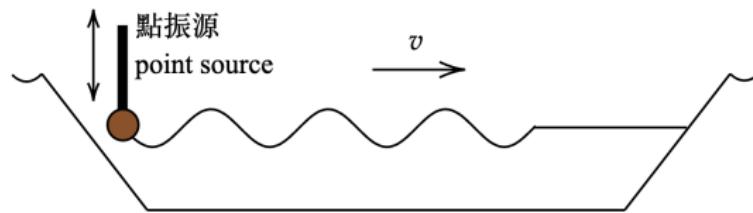
Figure: 水波槽可以用來產生水波 ripple tanks can be used to produce water wave

水波的傳播 Propagation of water wave

- 當點振源移動一次上下一個完整的周期時，會產生一個完整的水波波長。

When point source completes one full oscillation, one wavelength of wave is produced.

- ▶ 點振源的頻率 = 水波的頻率。
frequency of point source = frequency of water wave.
- ▶ 點振源無法控制水波的速率。
point source cannot control speed of water wave.
- ▶ $\because v = f \lambda$ ，頻率越大，波長越短。
 $\because v = f \lambda$, wavelength decreases as frequency increases.



製造水波 Generating water wave

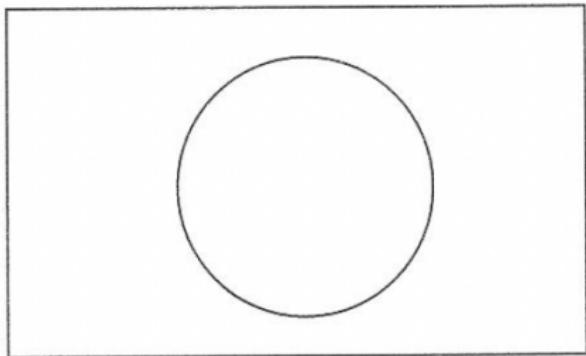


Figure: 脈衝水波 a pulse of water wave

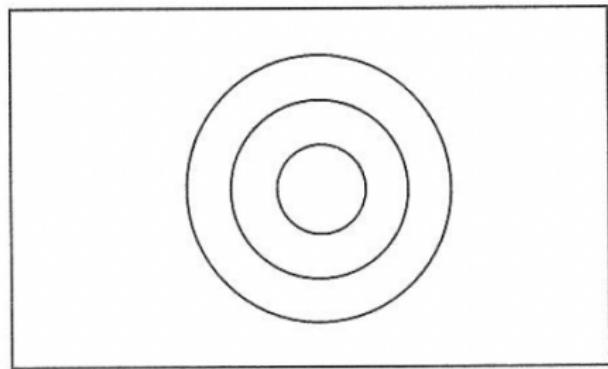
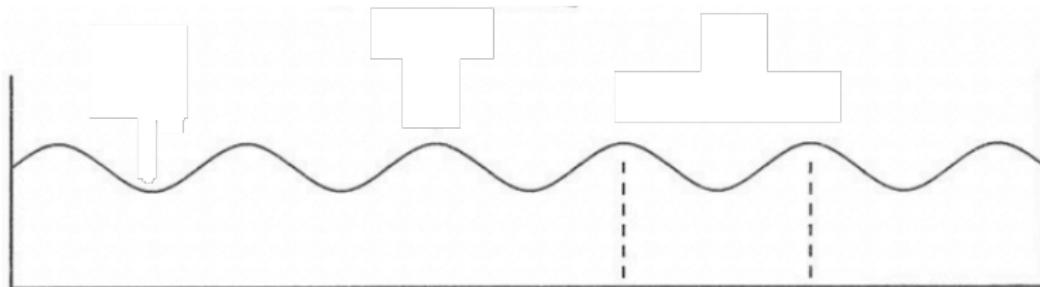
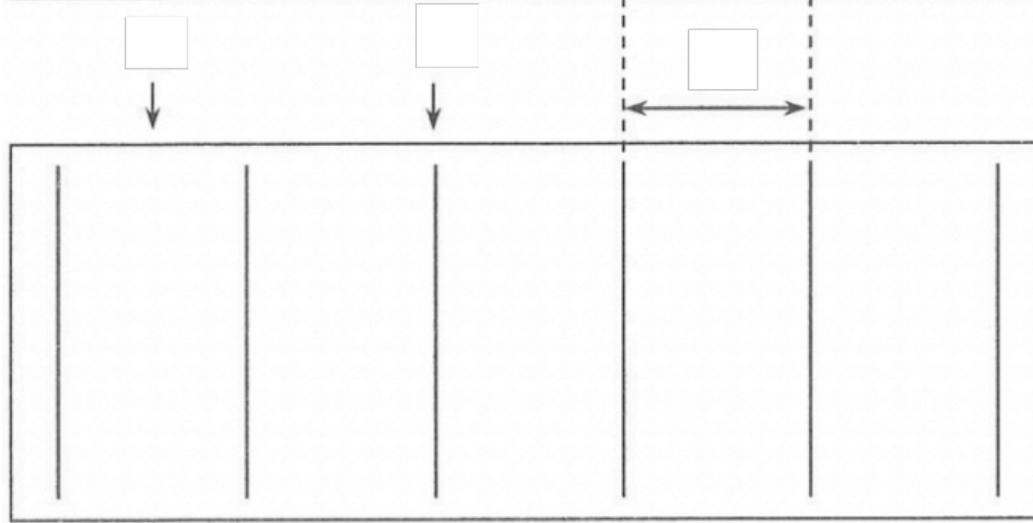


Figure: 連續水波 continuous water wave

以不同角度觀察水波 observe water waves

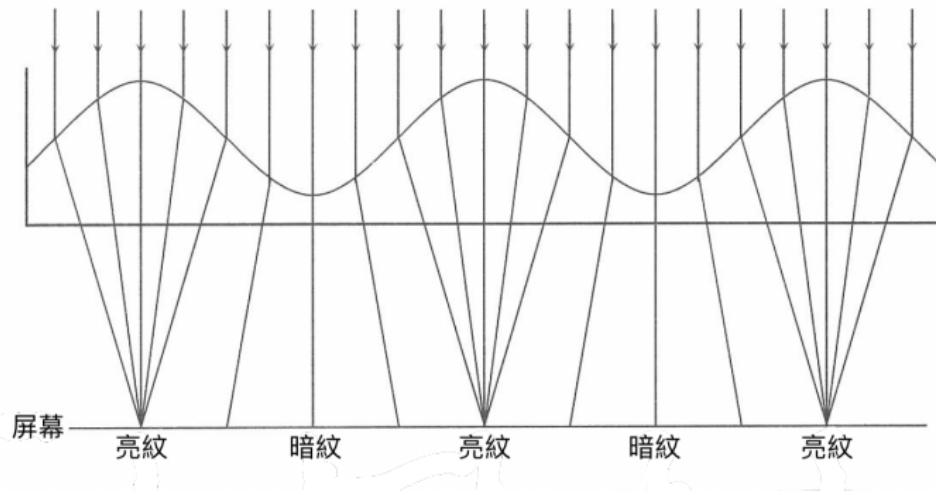


側面圖
side view



俯瞰圖
top view

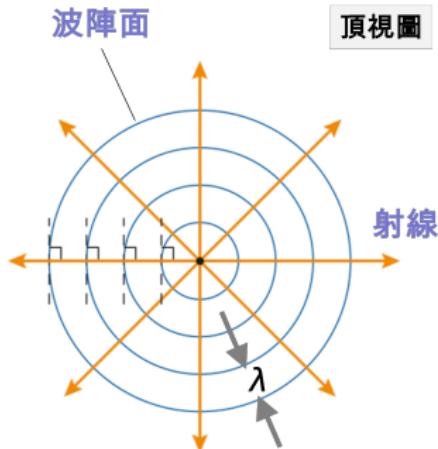
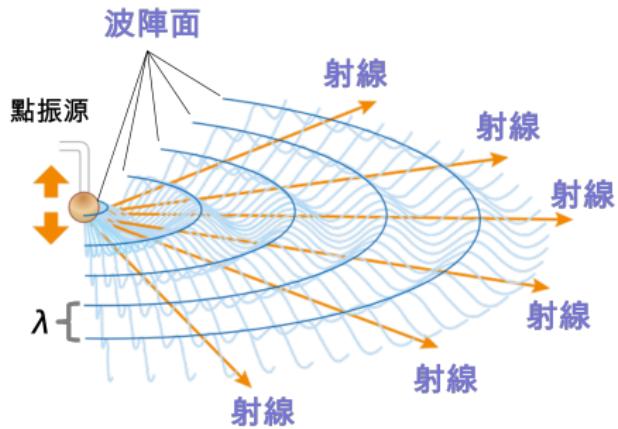
在屏幕上形成的條紋 water wave formed on a screen



- 波峰聚焦光線形成光紋。
Crests converge light rays and form bright fringes.
- 波谷發散光線形成暗紋。
Troughs diverge light rays and form dark fringes.

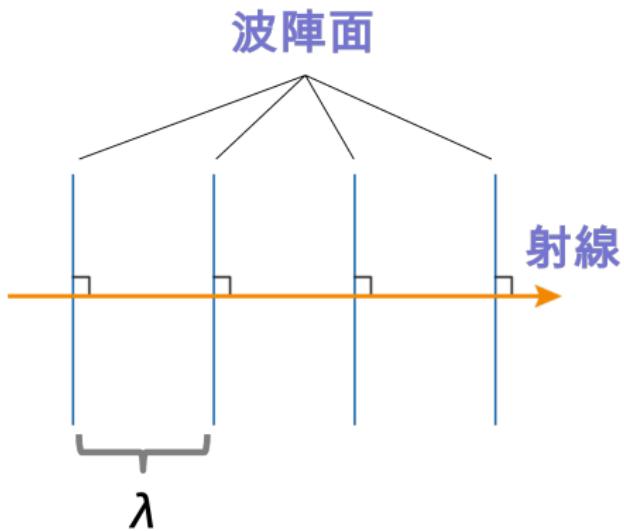
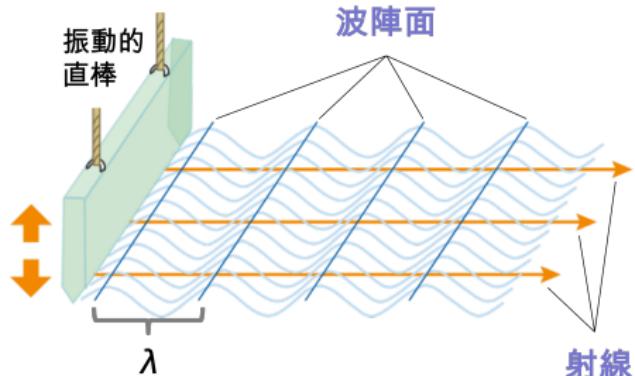
波陣面和射線 Wavefront and rays

- 波峰連接的線稱為波陣面。
Wavefront: line connecting neighboring crests particles particles.
- 射線：表示波的傳播方向的線
Ray: lines showing direction of travel of waves.
- 波陣面必定垂直於射線。
Wavefront must be perpendicular to rays.



波陣面和射線 Wavefront and rays

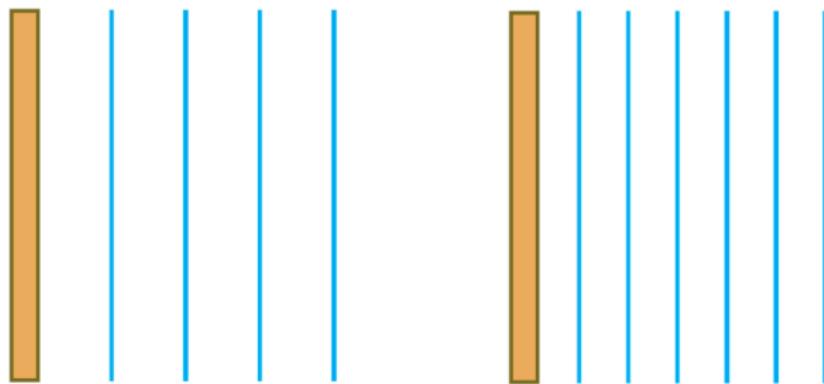
頂視圖



例題 Example

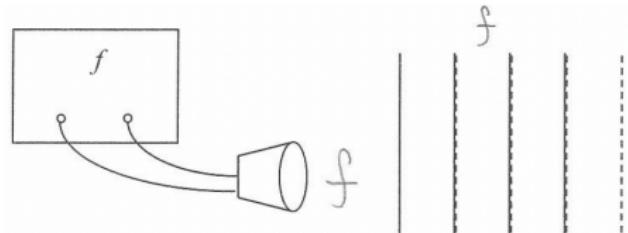
左圖和右圖分別是兩個直線水波 P 和 Q。其中 P 的水比較淺。比較兩波的 λ, v, f 。

The left and right figures respectively depict two straight water waves, labeled as P and Q. Wave P is shallower. Compare λ, v, f of the two waves.



量度水波的頻率 Measuring frequency of water wave

- 在黑暗的環境下，調整頻閃觀察器的頻率直至波形看起來靜止不動。
In dim environment, adjust a stroboscope so that a frozen wave pattern is observed.
- 這時頻閃觀察器的頻率 = 波的頻率。
Frequency of stroboscope = frequency of wave.



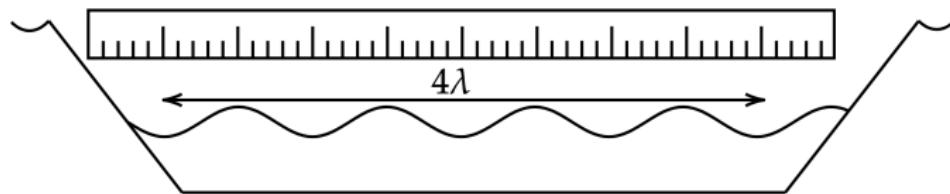
量度水波的波長 Measuring wavelength

- 調整頻閃觀察器的頻率直至波形看起來靜止不動。

In dim environment, adjust a stroboscope so that a frozen wave pattern is observed.

- 使用米尺量度幾個連續水波的波長。

Use a ruler to measure wavelength of water wave.



量度水波的速率 Measuring speed of water wave

- 量度水波槽的兩點距離 d 。
Measure the distance d between two points in ripple tank.
- 使用直振源產生直線波的脈衝。
Use a vibrating straight bar to generate straight waves.
- 使用秒錶量度波傳播 d 的距離所需的時間 t 。
Use a stop watch to measure the time t required for the wave to travel a distance d .
- 水波的速率 speed of water wave $v = \frac{d}{t}$ 。

水波槽 Ripple tank

從牆壁反射的波可能會干擾到觀察的波紋。

Waves that are reflected from the wall may interfere with the observed wave pattern.

- 減少水波在牆內壁反射：
To reduce reflection of wave:

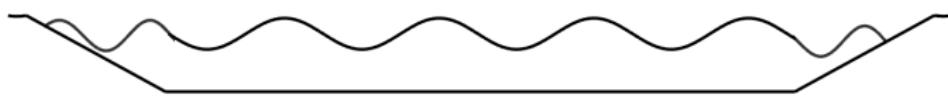


Figure: 四邊傾斜 inclined edges



Figure: 內壁鋪上海綿 spongy lining

例題 Example

增加直振源或點振源的振動頻率，對直線波或圓形波會有甚麼影響？
What is the effect of increasing the frequency of a straight wave or a circular wave?

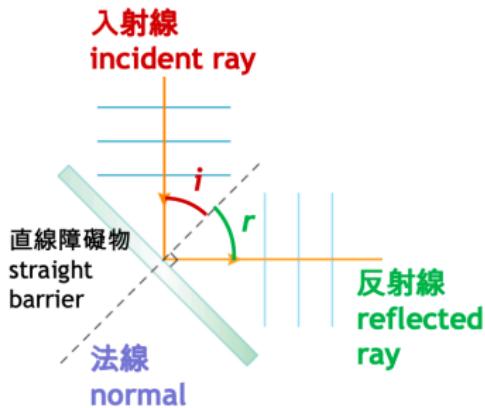
sol. 水深不變，波速也不變。

Water depth is unchanged, wave speed is unchanged.

$$v = f \lambda$$

⇒ 頻率 frequency \uparrow ，波長 wavelength \downarrow 。

波的反射現象 Reflection of waves



- 法線：垂直於反射面的虛構直線
Normal: constructed line perpendicular to reflecting surface
- 入射角 i ：入射線和法線之間的夾角
Angle of incidence i : angle between incident ray and normal
- 反射角 r ：反射線和法線之間的夾角
Angle of reflection r : angle between reflected ray and normal

波的反射現象 Reflection of waves

反射定律 Law of reflection

反射角 angle of reflection r = 入射角 angle of incidence i

- 反射發生在障礙物或邊界。

Reflection occurs at obstacles or boundaries.

- 反射的過程中

After reflection:

- 速率、波長、頻率不變。

speed, wavelength and frequency are unchanged.

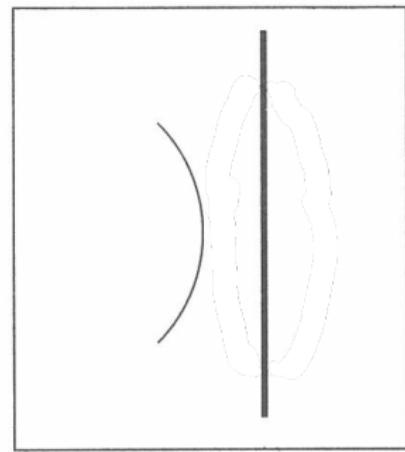
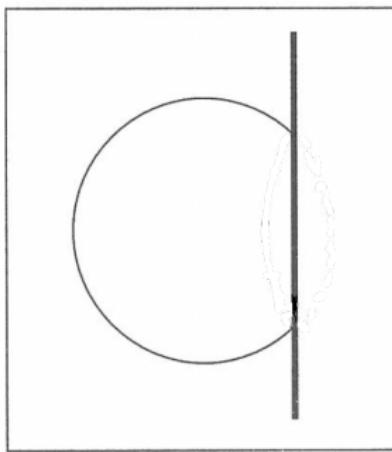
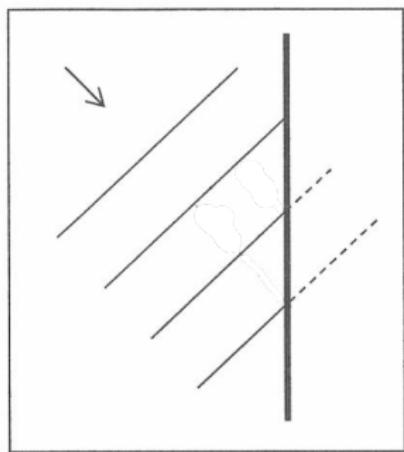
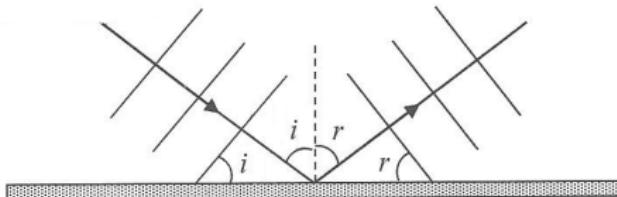
- 波的相位可能改變。

Phase of wave may change.

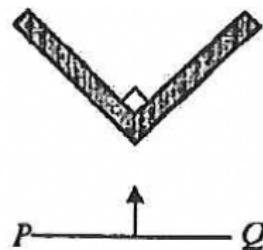
- 波的傳播方向必定改變。

Direction of wave is changed.

波的反射現象 Reflection of waves



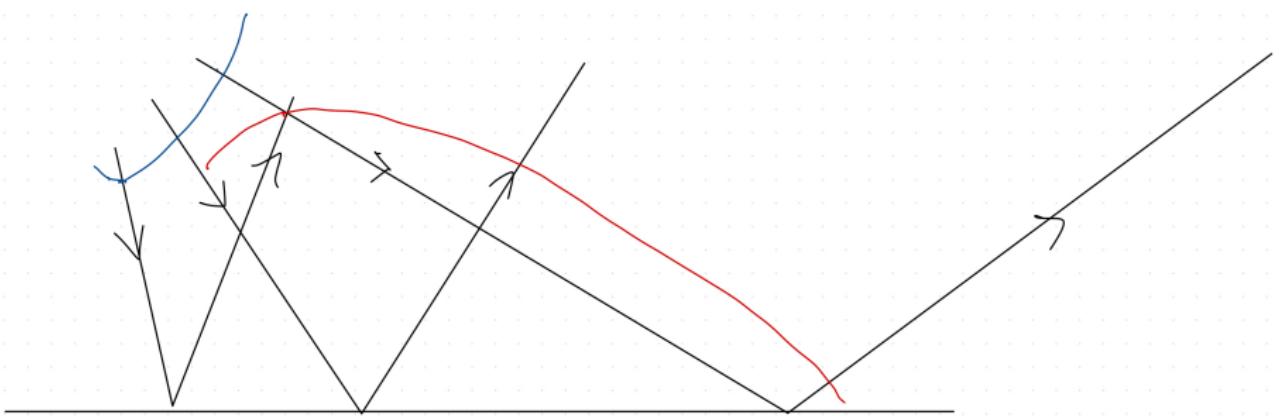
例題 Example



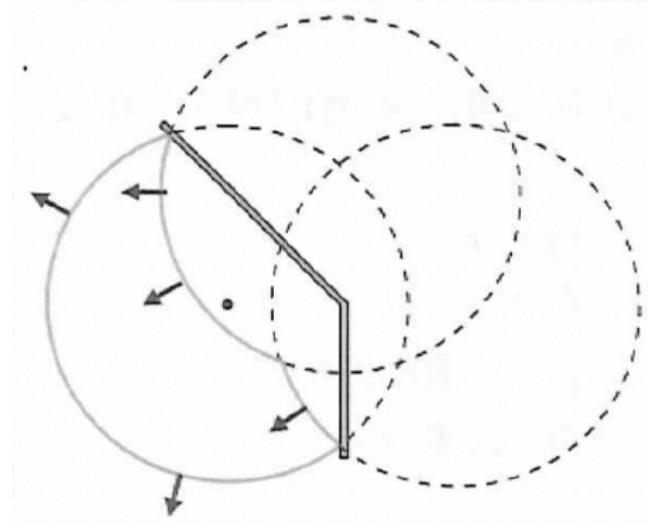
畫出上圖可能的反射脈衝。

Draw possible reflected pulse.

例題 Example



例題 Example



例題 Example

水波槽中有兩個相同的正方形方塊。如圖所示。以下有關反射波的陳述，哪些是正確的？

In the water tank, there are two identical square blocks. Which of the following statements about the reflected waves are correct?

- (1) 部分反射波沿原路折返。

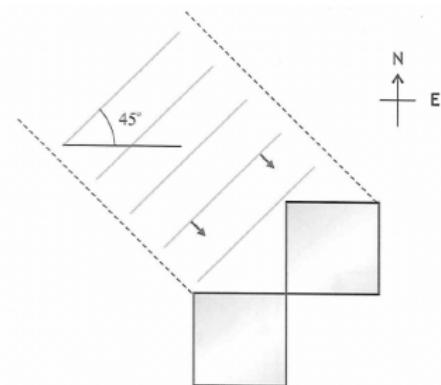
Some reflected wave travel back along the same path.

- (2) 部分反射波將沿正東方向傳播。

Some reflected wave travel eastwards.

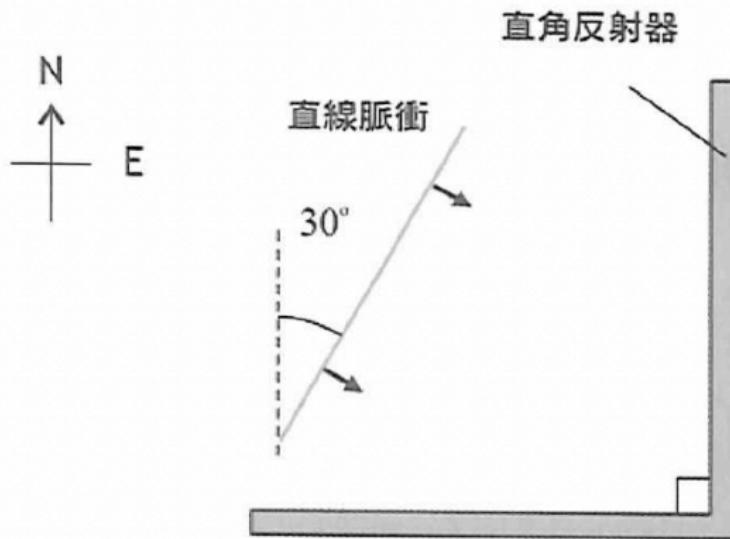
- (3) 這列波將分為三部分，並以不同的方向傳播。

This wave will be divided into three parts and will propagate in different directions.



例題 Example

圖中顯示一個直線脈衝正朝著直角反射器傳播。下列哪些是正確的？
The figure shows a linear pulse propagating towards a right-angle reflector. Which of the following statements are correct?



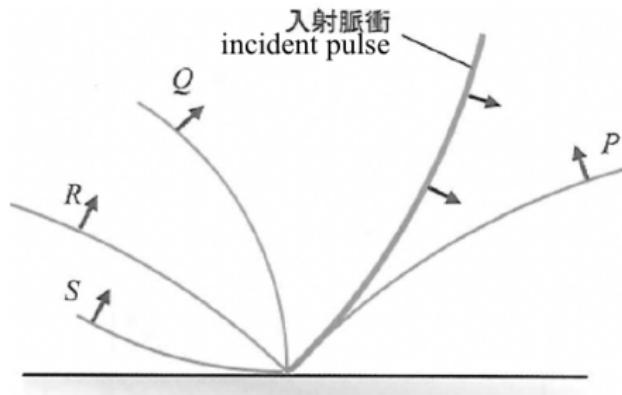
例題 Example

- A. 反射的脈衝將分成兩部分，並以不同的方向離開。
The reflected pulse will be divided into two parts and will leave in different directions.
- B. 這脈衝將受到反射器的兩面無止境重複的反射。
The pulse will undergo endless repeated reflections on both sides of the reflector.
- C. 反射脈衝將沿原來的路徑離開反射器。
The reflected pulse will leave the reflector along its original path.
- D. 在反射過程中，脈衝經過 60° 的旋轉。
During the reflection process, the pulse undergoes a rotation of 60° .

例題 Example

一個圓形脈衝遇上直反射器，並已部分進行反射，哪個字母代表反射的部分？

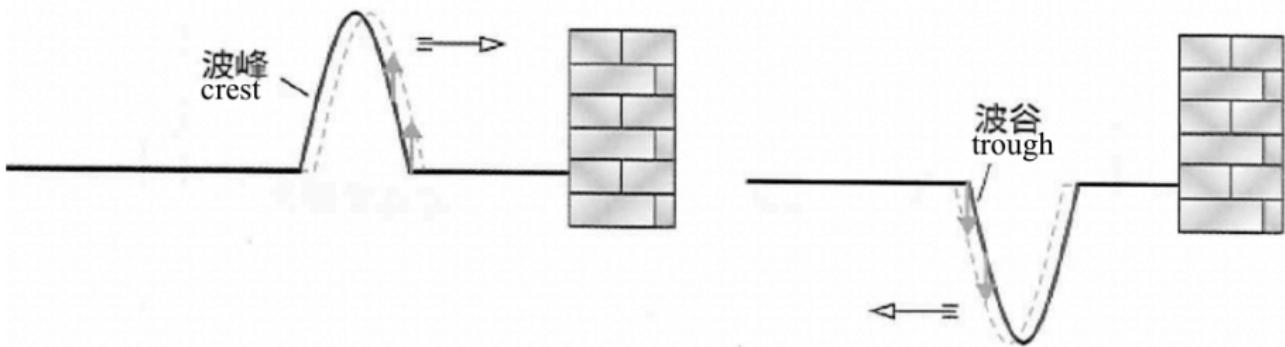
A circular pulse meets a reflector and has partly reflected. Which letter represents the reflected part of the wave?



- A. P
- B. Q
- C. R
- D. S

反射和相位變化 Reflection and phase change

- 在牆壁上（固定端），反射的波涉及 $\pi(180^\circ)$ 相位改變。
At the wall (fixed end), the reflected wave involves a phase change of $\pi(180^\circ)$.



反射和相位變化 Reflection and phase change

- 在自由端，反射的波相位沒有變化。
At free end, the reflected wave does not involve phase change.
- 反射的**水波**在任何情況下都沒有相位變化。
Reflected **water wave** does not have phase change.



反射和相位變化 Reflection and phase change

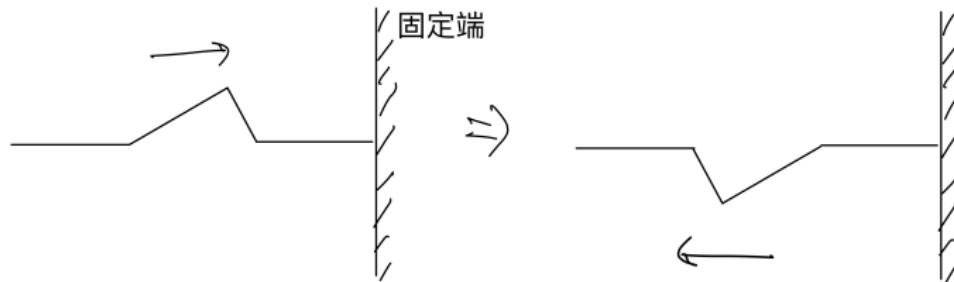


Figure: 反射的波形上下左右倒轉 The reflected wave is inverted in both vertical and horizontal directions.

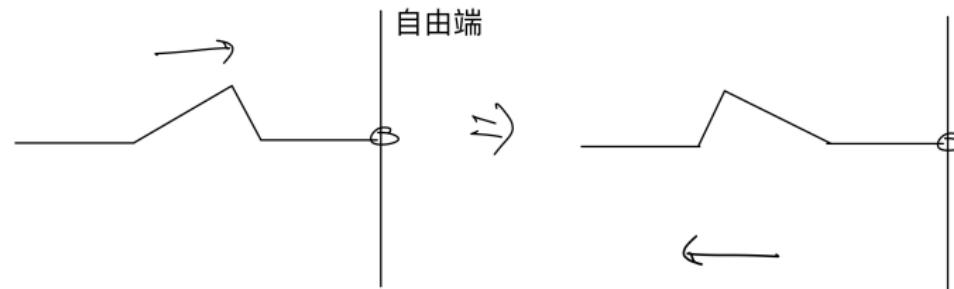


Figure: 反射的波形上下倒轉 The reflected wave is inverted vertically.

折射 Refraction of wave

- 折射是波動在兩種介質之間傳播時改變方向的現象。
Refraction is the phenomenon of the change in direction of a wave as it propagates between two different media.

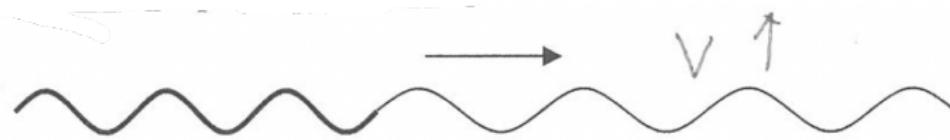


Figure: 左邊是粗繩，右邊是幼繩 Left: thick rope, right: thin rope

折射 Refraction of wave

在折射的發生時，

When refraction occurs,

- 頻率不變。frequency is unchanged.

- 波速改變。wave speed is changed.

- 因為 $v = f\lambda$ ，波長必定改變。

$v = f\lambda$, so wavelength must be changed.

- 如果是傾斜進入邊界，波的方向也會改變。

Direction of the wave would also change except for normal incidence.

- 折射沒有相位改變。

No change in phase.

折射 Refraction of wave

波的傳播方向 

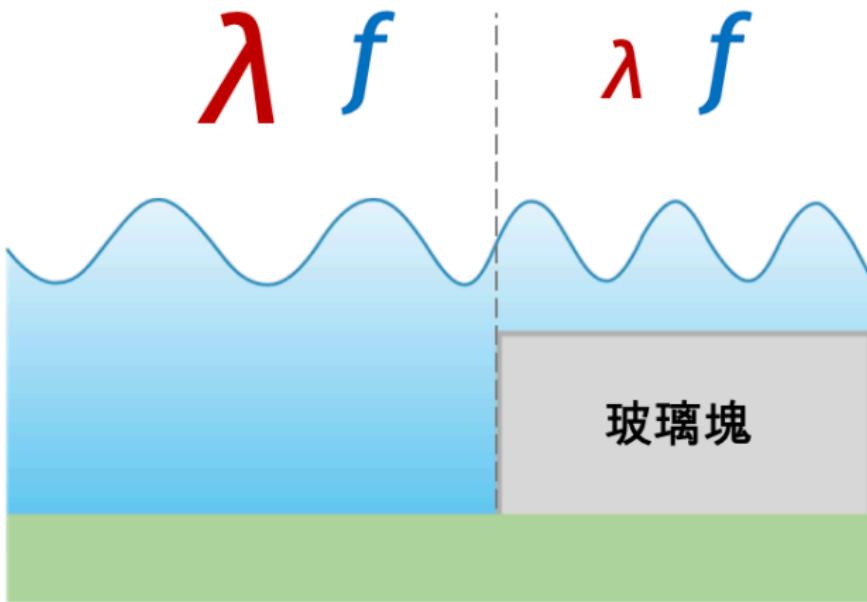


Figure: 深水快，淺水慢， $v \propto \lambda$

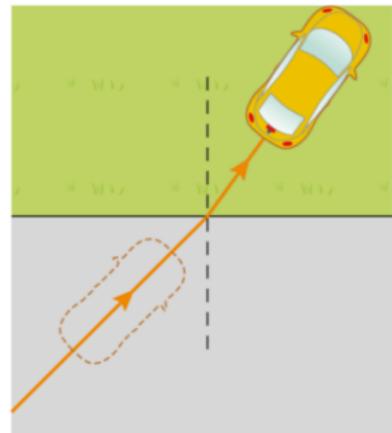
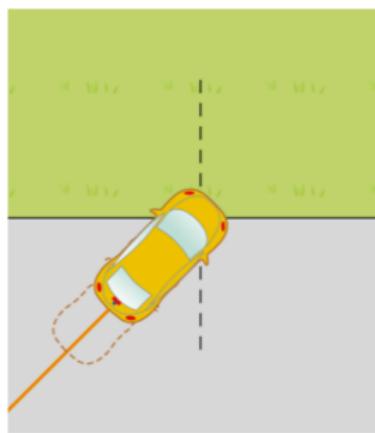
一個非波例子 A non-wave example

方向的改變：考慮一輛**減速**的汽車

汽車 A 以某角度
進入草坪。

A 的左前輪首先
減速。

A 的行駛方向
偏向法線。



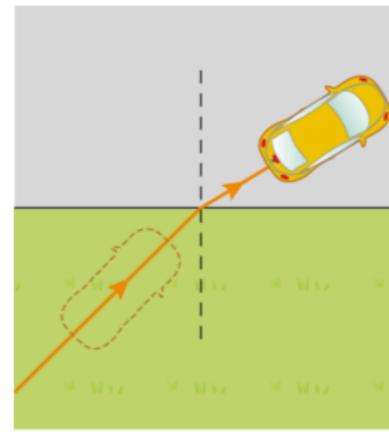
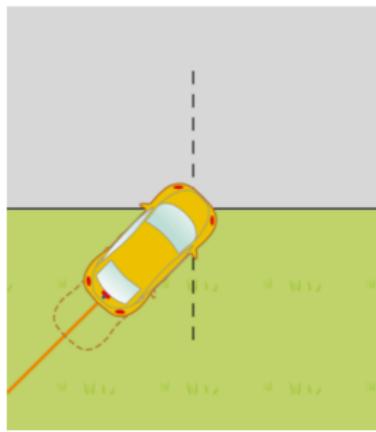
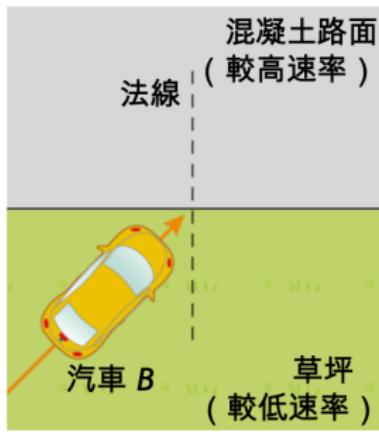
一個非波例子 A non-wave example

考慮一輛**加速**的汽車

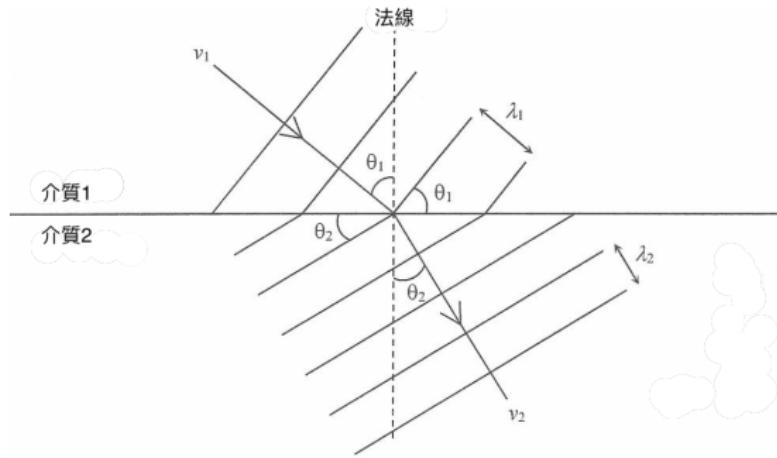
汽車 **B** 以某角度
進入混凝土路面。

B 的左前輪首先
加速。

B 的行駛方向
偏離法線。



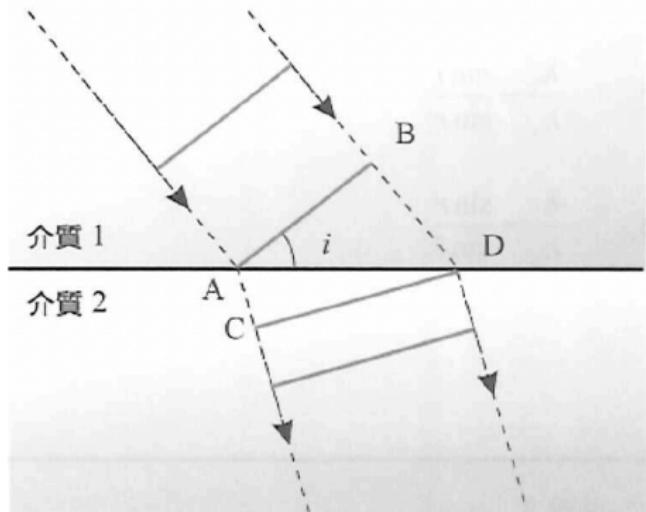
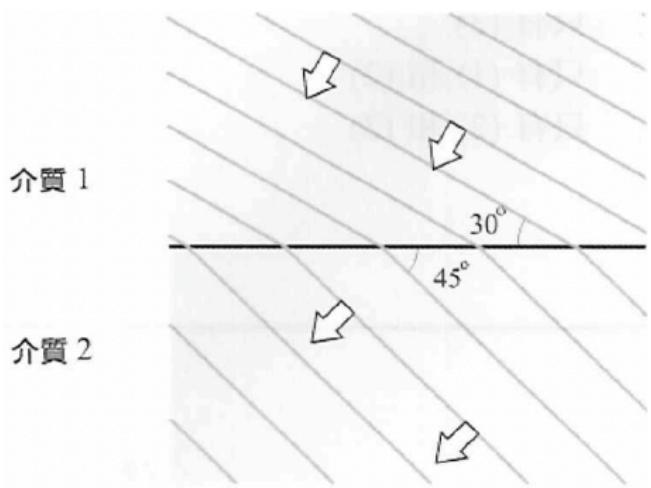
折射波的方向改變 Direction change of refracted wave



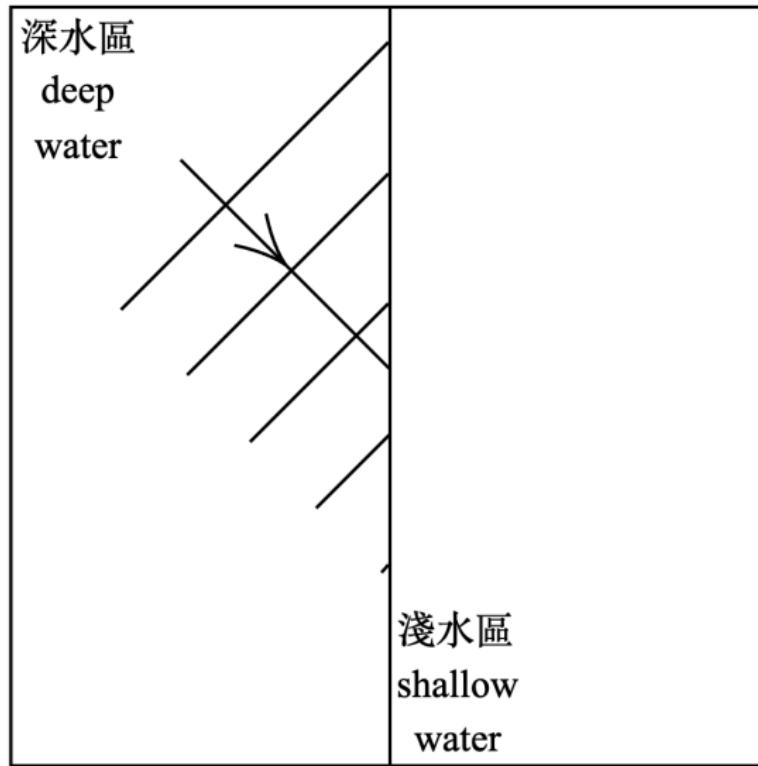
波的折射定律 Refraction law of wave

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

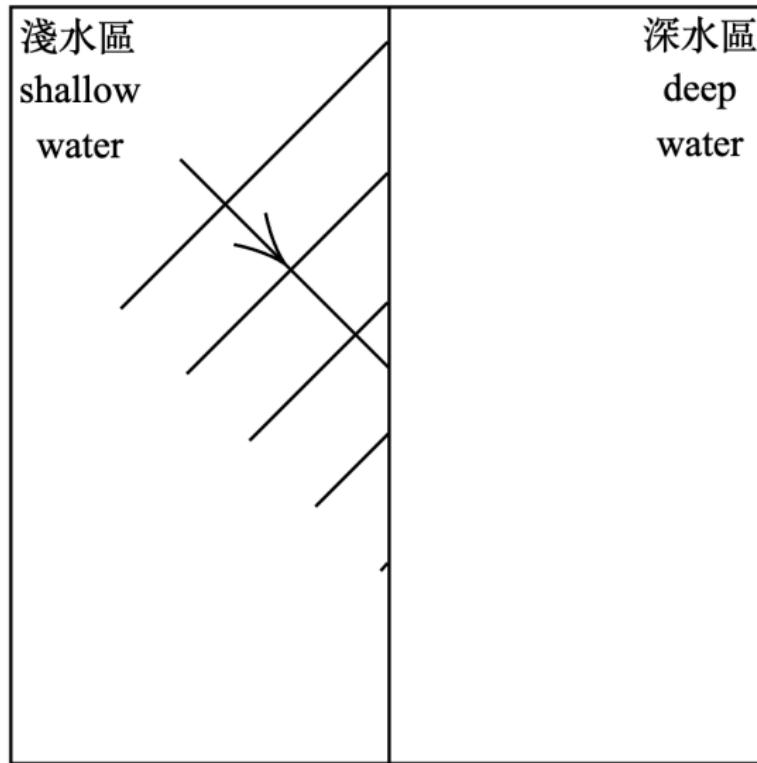
折射波的方向改變 Direction change of refracted wave



水波在界面上的折射 Refraction on boundaries

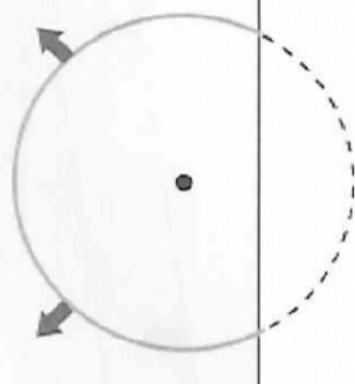


水波在界面上的折射 Refraction on boundaries

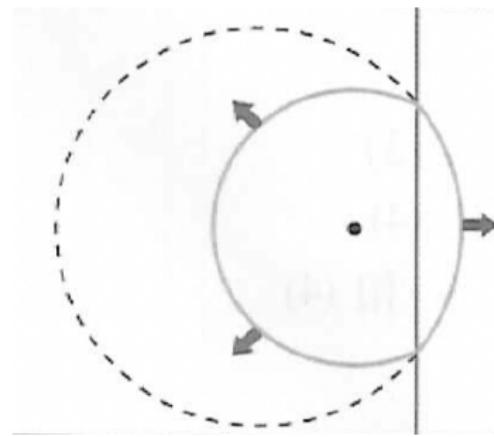


水波在界面上的折射 Refraction on boundaries

深水區域



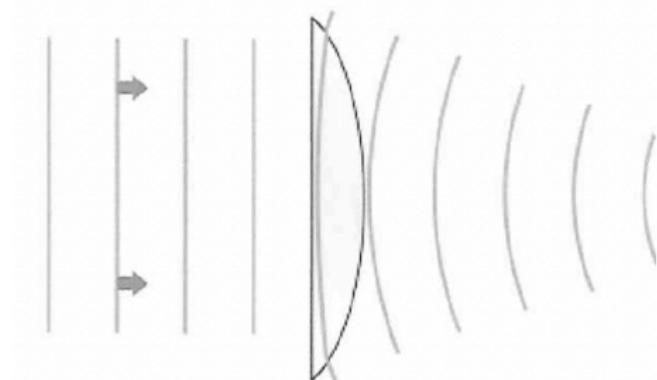
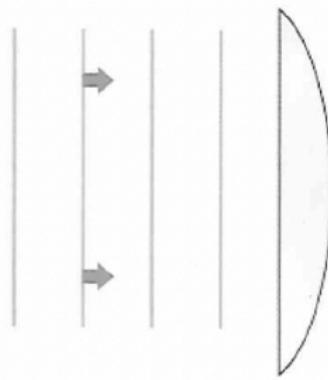
淺水區域



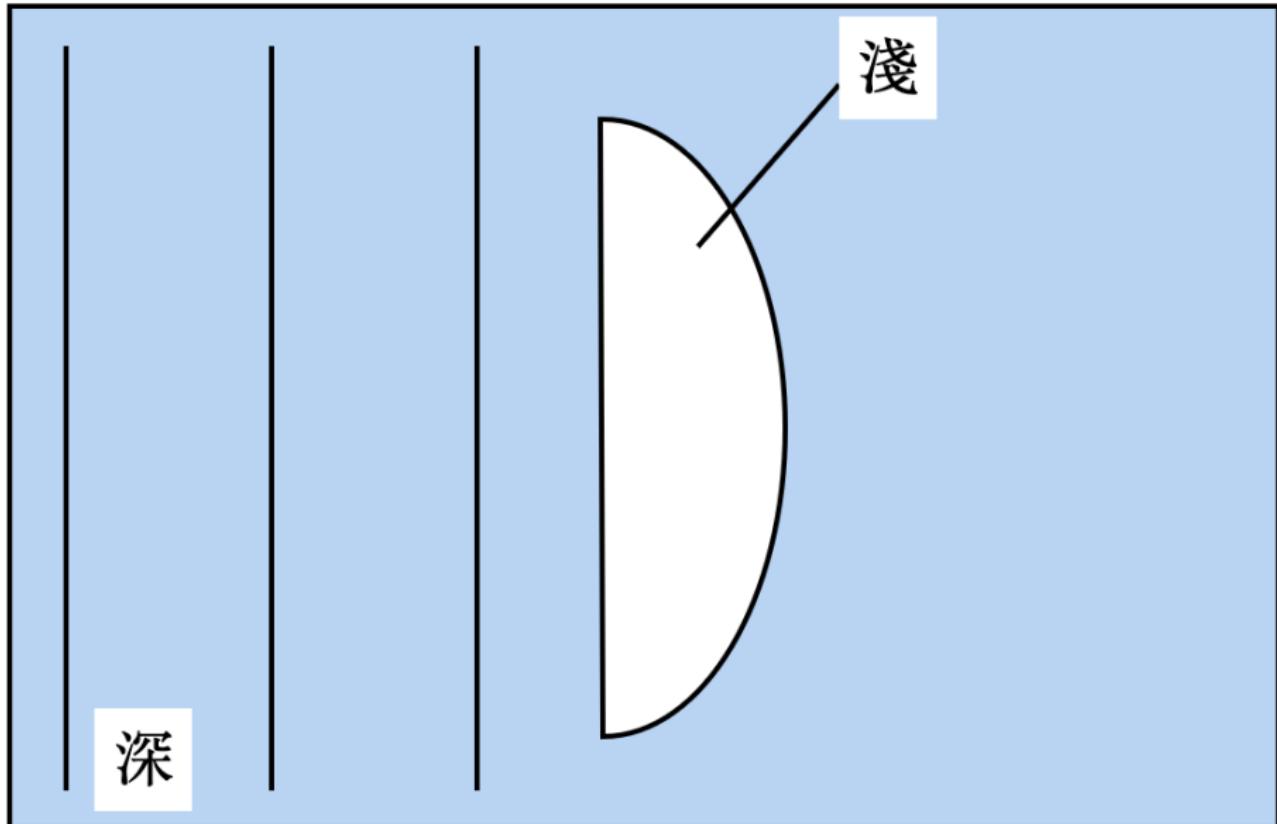
水波在界面上的折射 Refraction on boundaries

水波槽中央是一個平凸形狀的淺水區域：

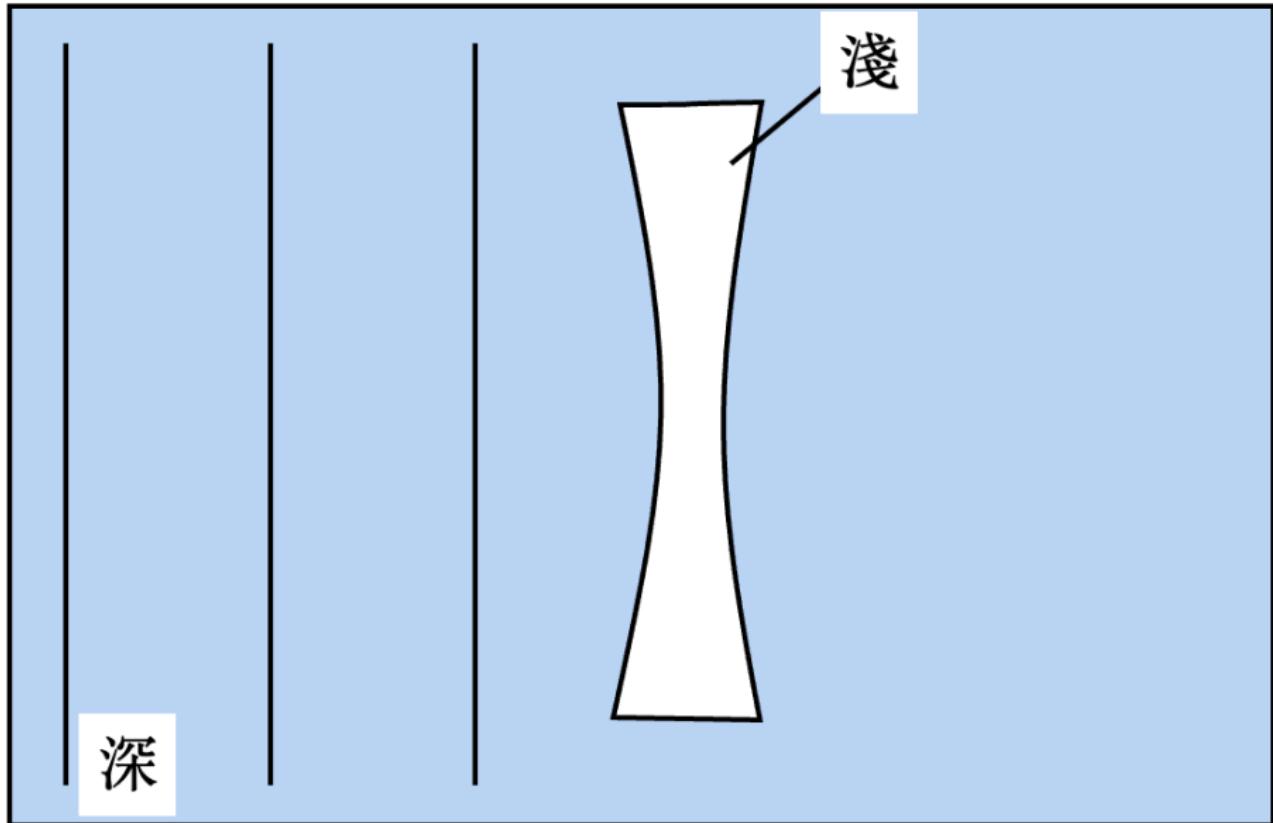
In the middle of the water tank, there is a shallow region with a flat convex shape.



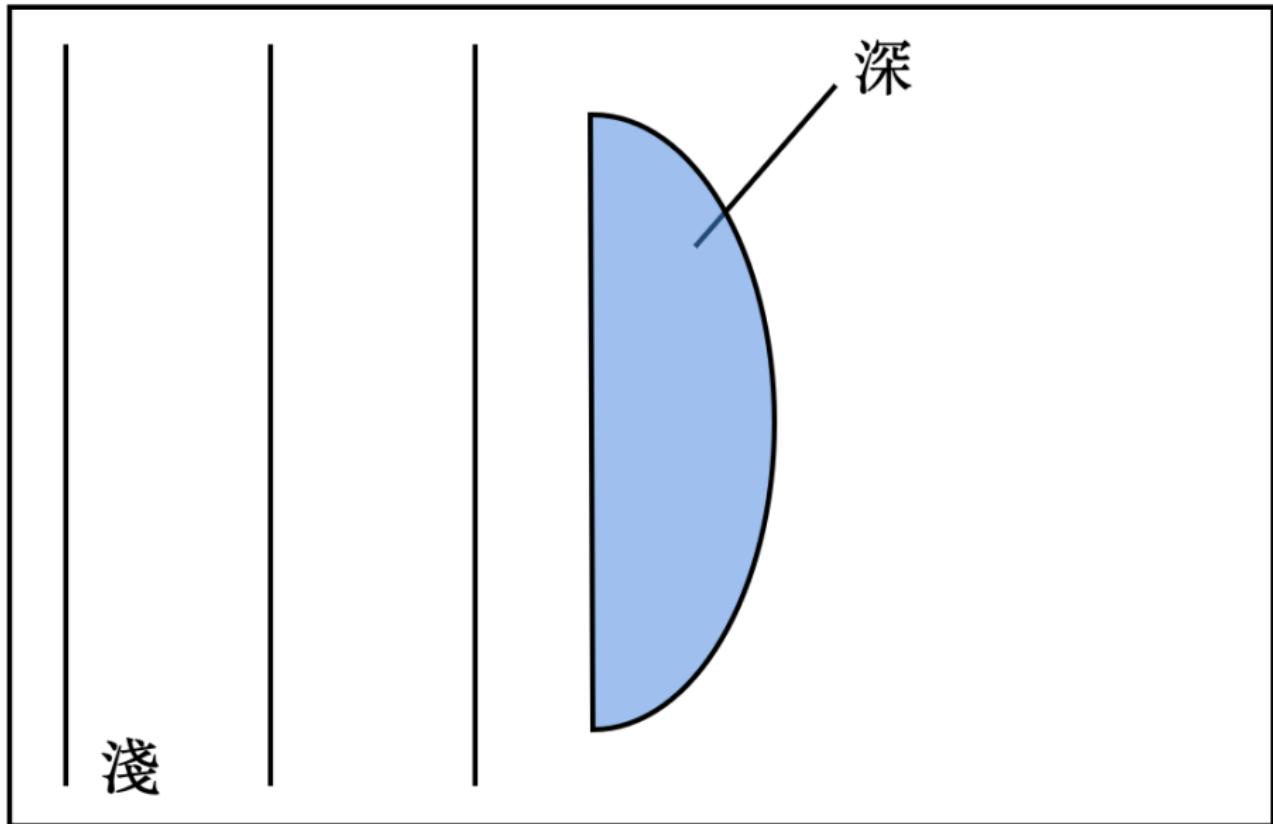
例題 Example



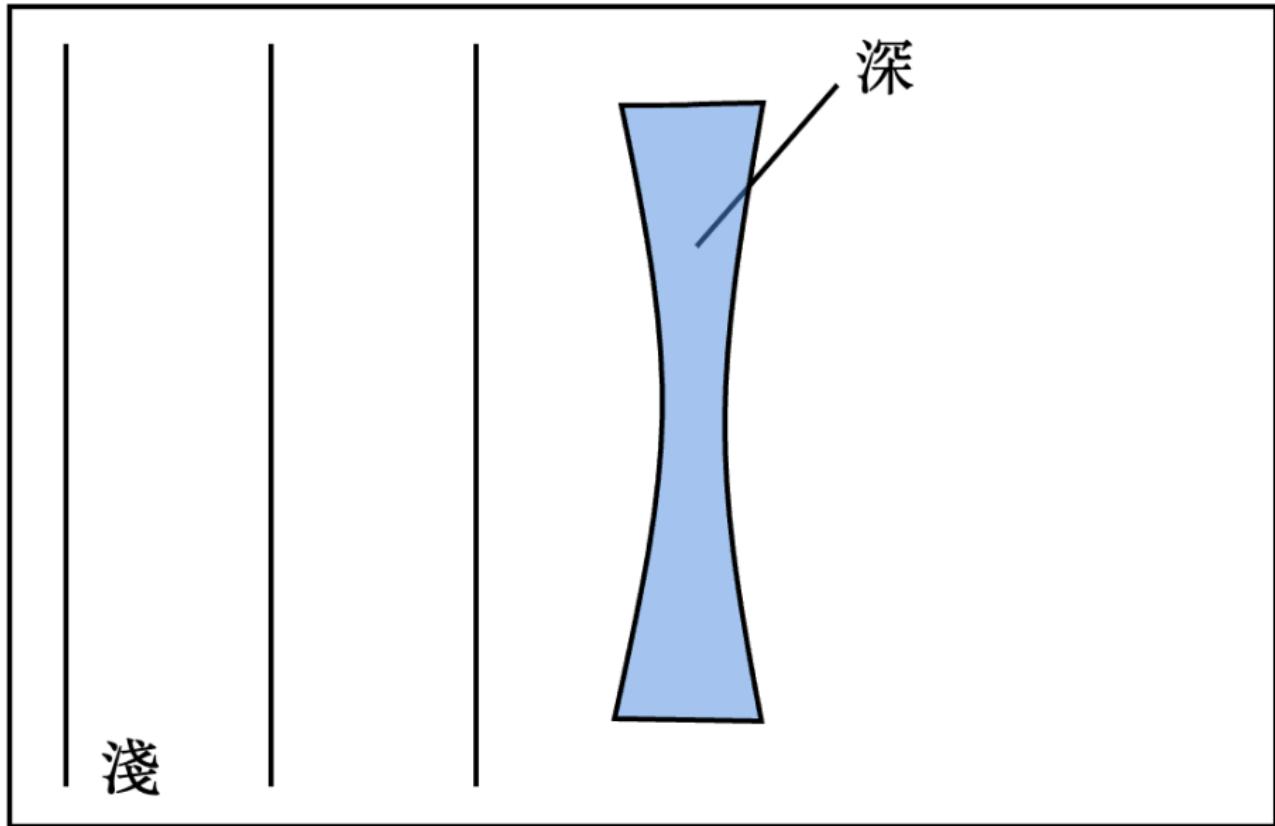
例題 Example



例題 Example



例題 Example



水波在界面上的折射 Refraction on boundaries

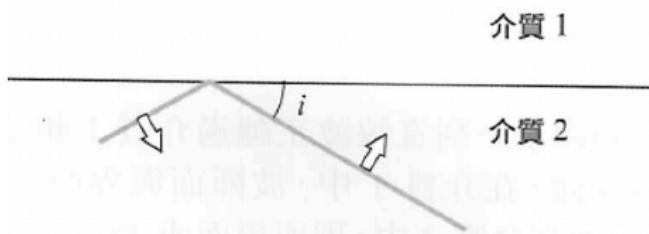
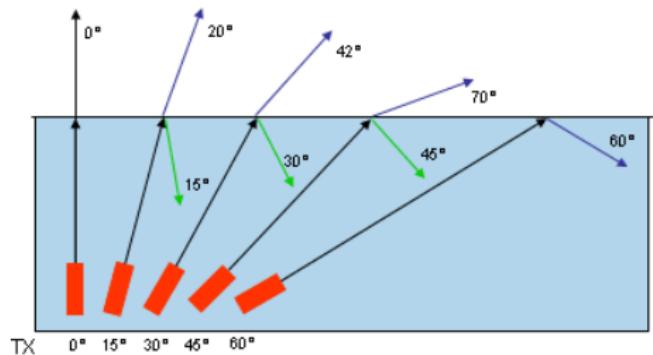
...不同於反射，折射時波陣面不會出現「斷折」的情況。

Unlike reflection, the wavefront cannot possibly ‘break’ during refraction.



全內反射 Total internal reflection

從低速介質到高速介質，若入射角持續增加，最終會發生全內反射。
When the angle of incidence continues to increase from a low-speed medium to a high-speed medium, eventually total internal reflection will occur.



當繩子遇上繩子（不考）

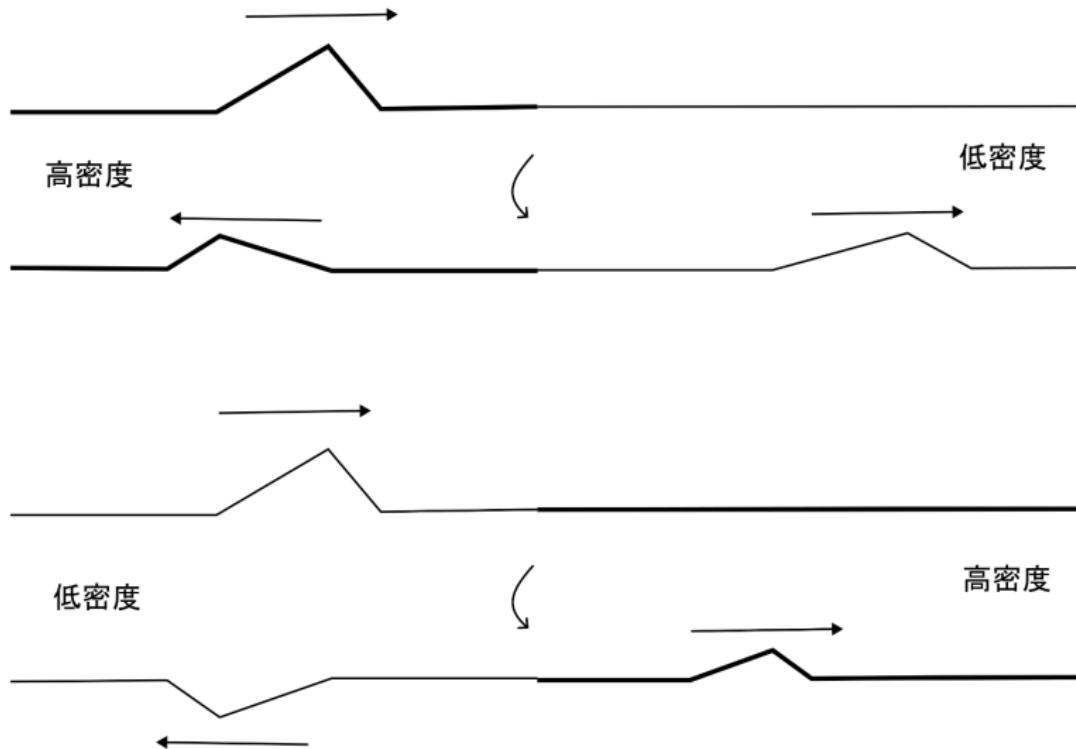
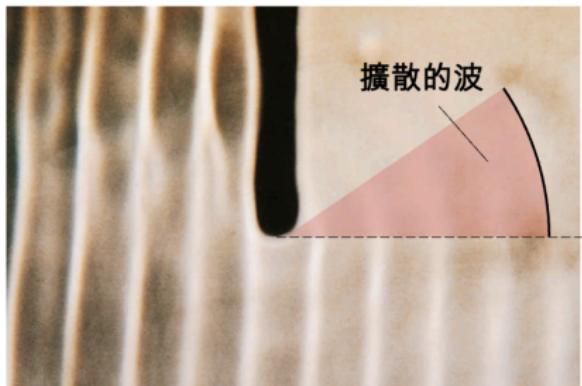
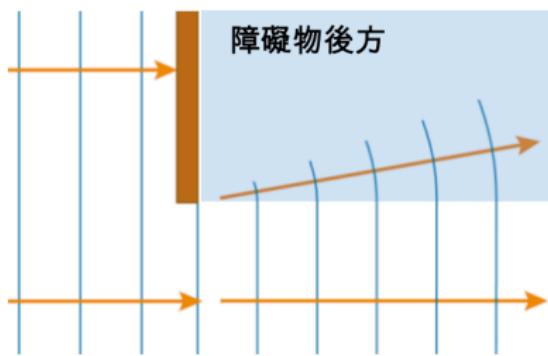


Figure: 波進入波密/波疏介質時，出現部分反射，部分折射的現象

衍射（繞射）Diffraction

- 當行波經過狹縫或阻礙物邊緣時，會發生衍射，擴散至狹縫或阻礙物後方的區域。

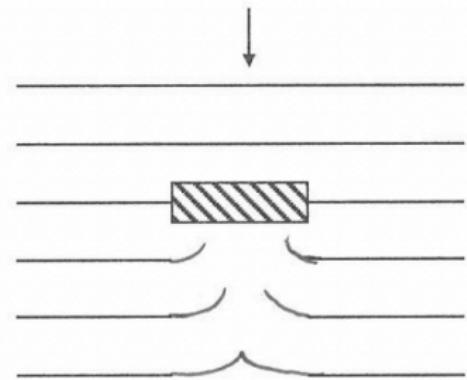
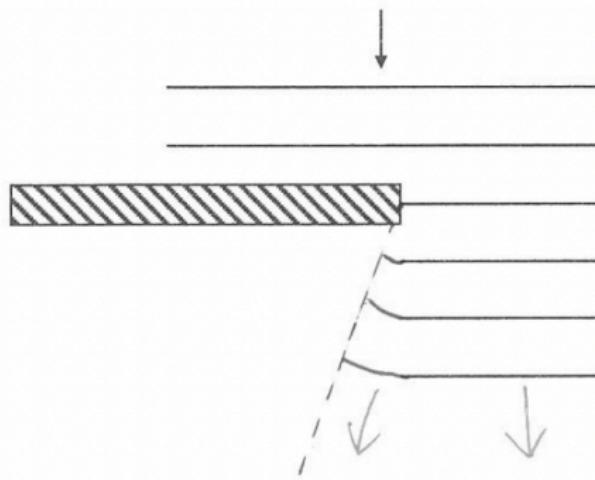
When a wave passes through a narrow gap or encounters the edge of an obstacle, diffraction occurs, spreading into the region behind the gap or obstacle.



衍射（繞射）Diffraction

- 衍射過程中 For diffraction:
 - ▶ 速率、頻率和波長都不會改變。
speed, frequency and wavelength do not change.
 - ▶ 只會改變波在障礙物邊緣的傳播方向。
only the direction of wave propagation at the edges of obstacles will change.
- 衍射是波獨有的現象。可以用這現象來判斷一個事物是不是波。
Diffraction is unique to waves, and it can be a reason to show that something is wave-like.

衍射 Diffraction



例題 Example

例題 Example

影響衍射程度的因素 Factors affecting extent of diffraction

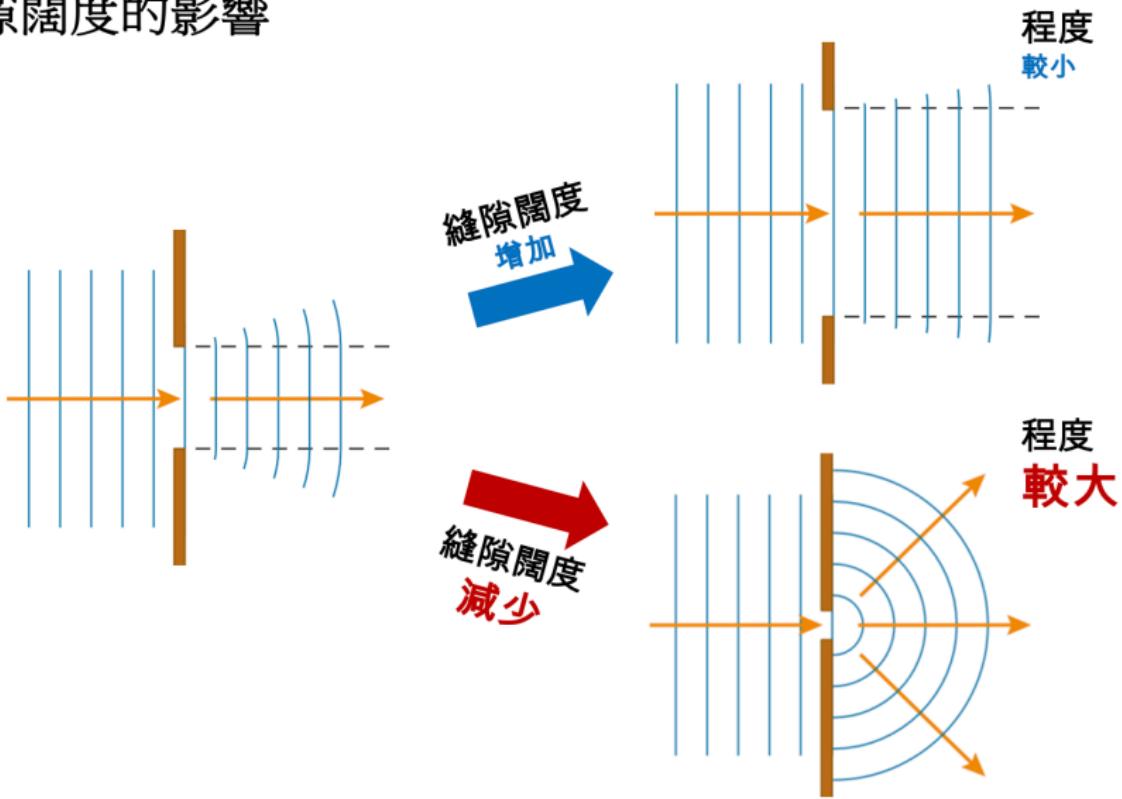
- 衍射的程度是根據 $\frac{\lambda}{a}$ 影響。

$$\text{The extent of diffraction} \sim \frac{\lambda}{a}$$

- ▶ 波長 $\uparrow \Rightarrow$ 衍射程度 \uparrow
- ▶ 狹縫寬度 $\uparrow \Rightarrow$ 衍射程度 \downarrow
- 阻礙物的大小不影響衍射的程度，除非障礙物極小至能讓波直接穿過。
- 圓形波： $\lambda \approx a$
- 振幅減半： $\lambda \approx 2a$

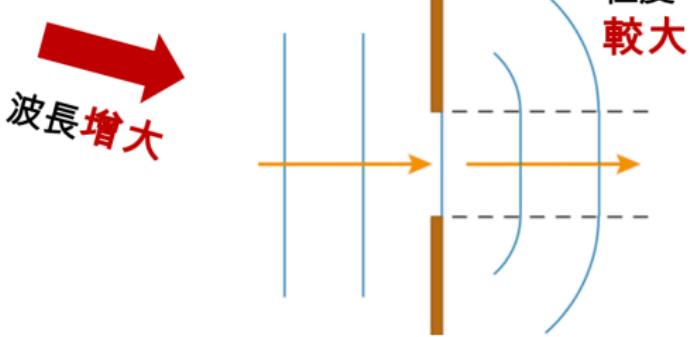
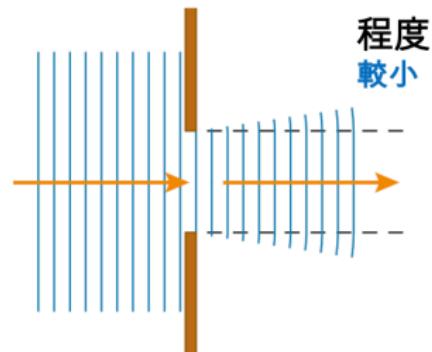
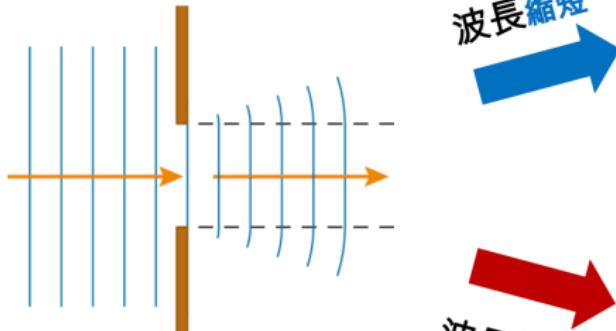
不同縫隙寬度的衍射 Diffraction for different gap width

縫隙闊度的影響



不同波長的衍射 Diffraction for different wavelengths

波長的影響



例題

水波槽中，一道屏障中央有一個縫隙。以下哪些改變可增加平面水波穿過該縫隙時的繞射程度？

In the water tank, there is a gap in the center of a barrier. Which of the following changes can increase the degree of diffraction when a plane water wave passes through the gap?

- (1) 增加振動頻率。
Increase frequency of oscillation.
- (2) 減少水深。
Decrease depth of water.
- (3) 減少縫隙的寬度。
Increase width of the gap.