11 PHYSICS

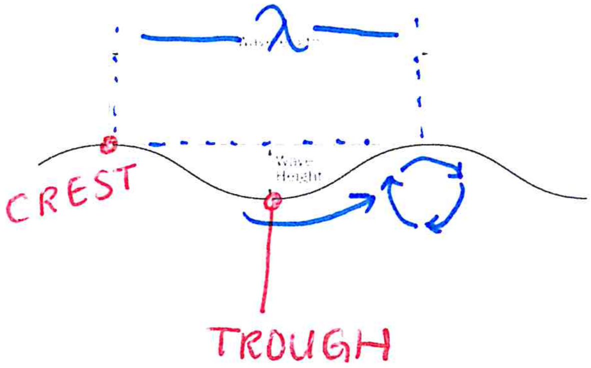
Unit 4: Waves

Booklet 2

May 19th - May 26th

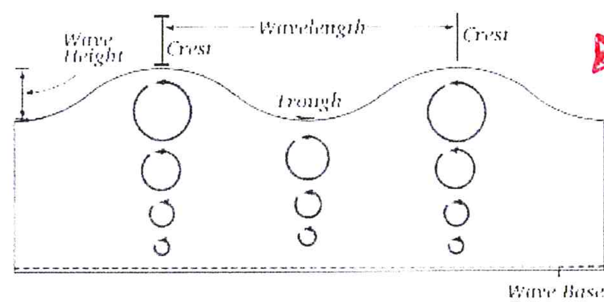
NAME: Answer Key

U4:L3 2D Waves



In the previous booklet, we examined waves moving in one dimension. Waves such as this are found on a string or rope. An example of waves moving in two dimensions is water waves. "2D"

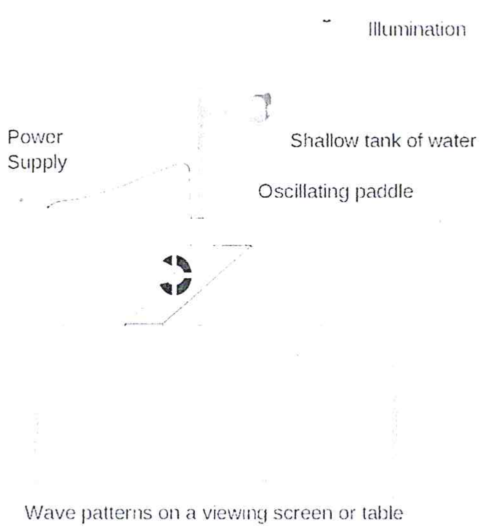
We can consider water waves to be transverse. However, they do move slightly back and forth as well as up and down. **An individual particle, on the surface of a water wave, actually moves in a small oval.**

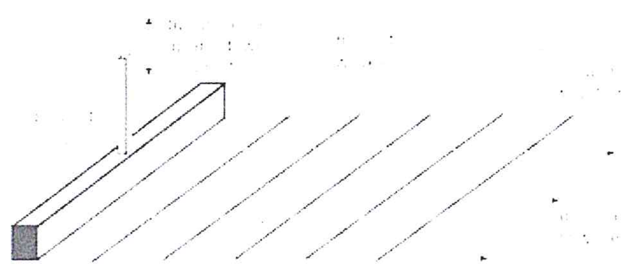


Circular waves can be made on the surface of water by a drop of water from an eyedropper or a finger touching the surface of the water.

☆ **Try it by dripping water into a bowl of water, or dipping your finger into the middle of the bowl of water!**

We can also produce straight waves with ripple tanks. A continuous crest or trough like these waves, is referred to as a **wavefront.**

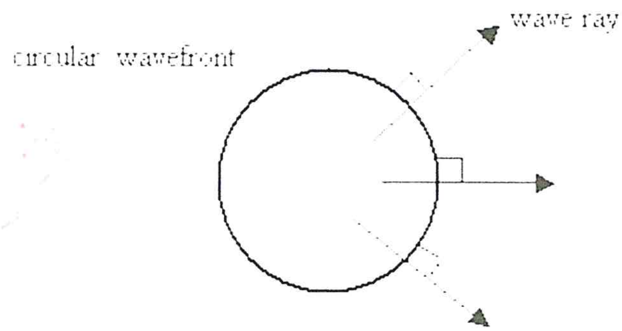




☆ you can youtube "Ripple Tank" to see in action!

Circular Wave Reflection

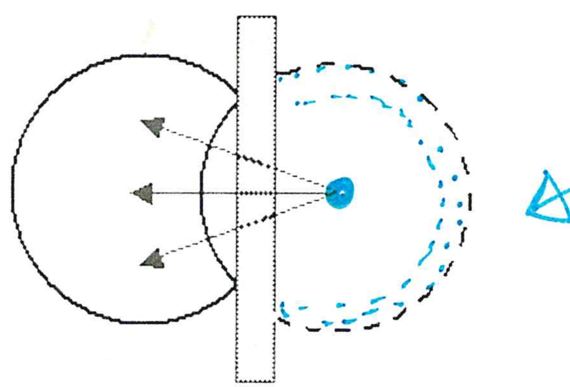
The diagram below shows a circular wavefront.
The wave rays indicate that the circular wavefront moves outward as though it is originating from the centre of the circle. This is the diagram we saw earlier in the lesson.



When the various parts of the wave reflect from a barrier, **the angle of incidence equals the angle of reflection**, although this is more difficult to see.

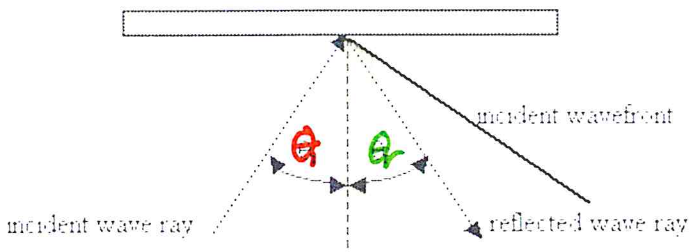
The circular reflected wavefront appears to originate from an imaginary point behind the reflector. This point is the imaginary centre of the reflected wavefront. It is located the same distance behind the barrier as the distance of the centre of the incident wavefront in front of the barrier.
(This is shown by the dotted circle drawn to the right of the barrier)

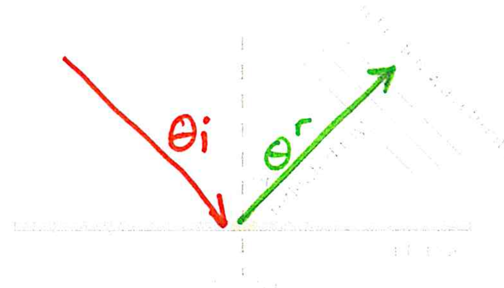
The arrows show the direction of motion of the reflected wavefront.



Wave Reflection Angles

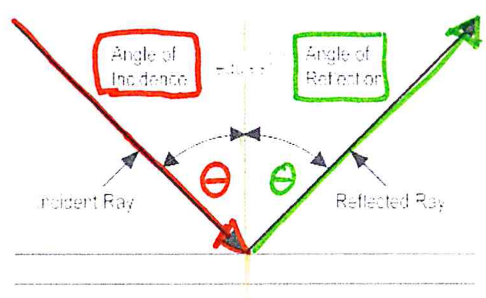
To simplify wave reflection diagrams, we look at the **wave rays**, instead of the wavefronts. When using wave rays instead of wavefronts, the angles of incidence and reflection are measured relative to a **normal**. The normal is the straight line perpendicular to the barrier. It is constructed at the point where the incident wave ray strikes the reflecting material.





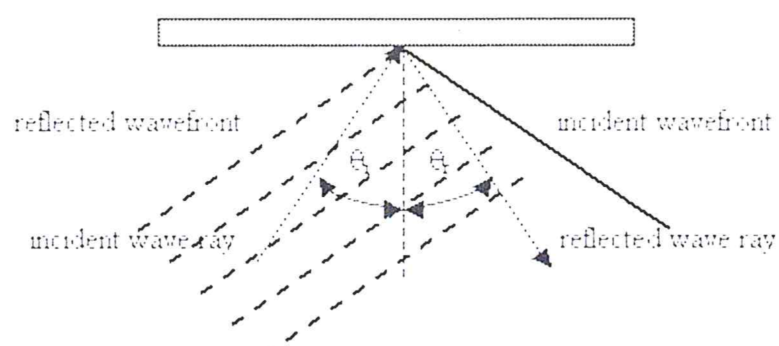
The **angle of incidence**, (θ_i) for the wave ray is defined as the angle between the normal and the incident wave ray.

The **angle of reflection** (θ_r) for the wave ray is defined as the angle between the normal and the reflected wave ray.



The angle of incidence is equal to the angle of reflection.

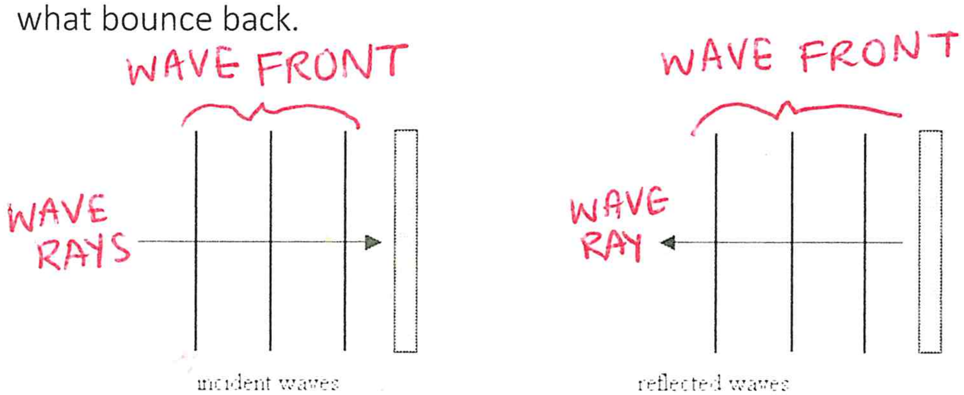
To complete the diagram and show the reflected wavefront, draw a line perpendicular to the reflected wave ray from the point where the ray meets the reflecting surface. Additional reflected wavefronts are shown.

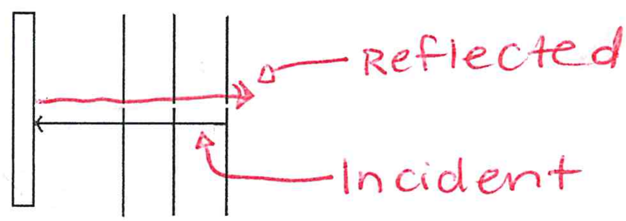


Wave Reflection

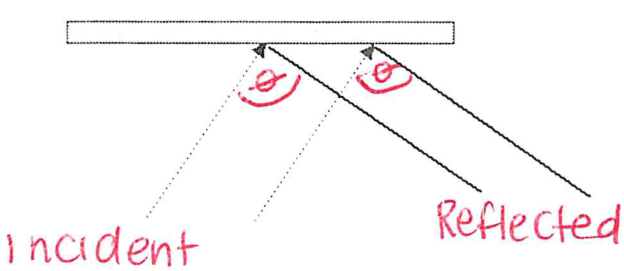
The diagram below shows what happens when a straight wave approaches a **straight barrier**, and then is reflected.

- The wave is reflected back along its original path as shown.
- The arrows are wave rays. They are drawn perpendicular to the wavefronts and show the direction of motion of the fronts.
- "Incident Waves" are the incoming *original* waves, "Reflected Waves" are what bounce back.

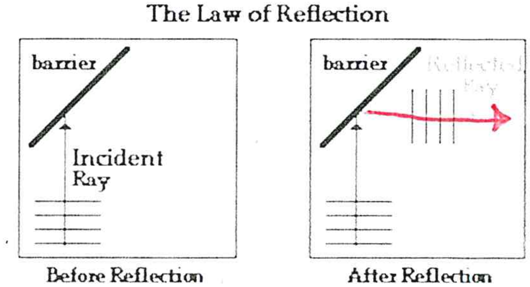




The next situation shows incident waves approaching a barrier **at an angle.** The wave rays are also drawn showing the direction in which the wavefronts are moving.



The Law of Reflection

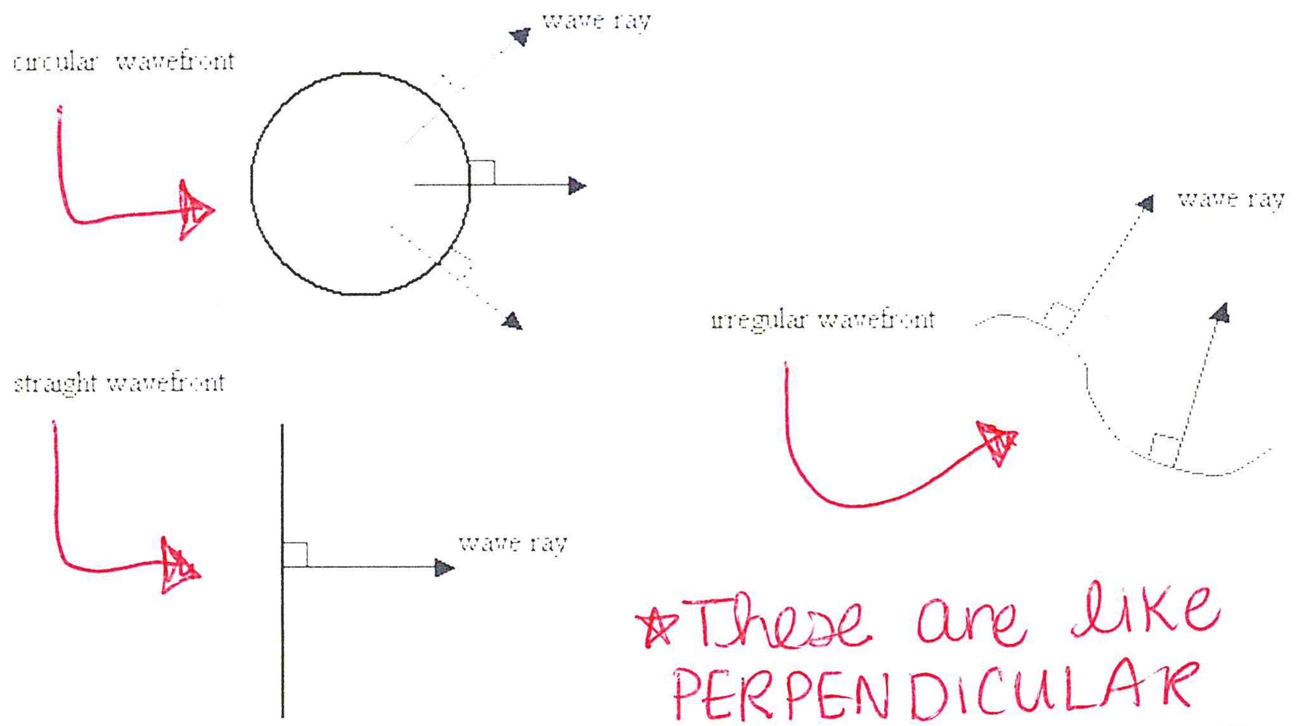


Wave Diagrams

To show the direction of travel of a wavefront, draw an arrow at right angles to the wavefront.

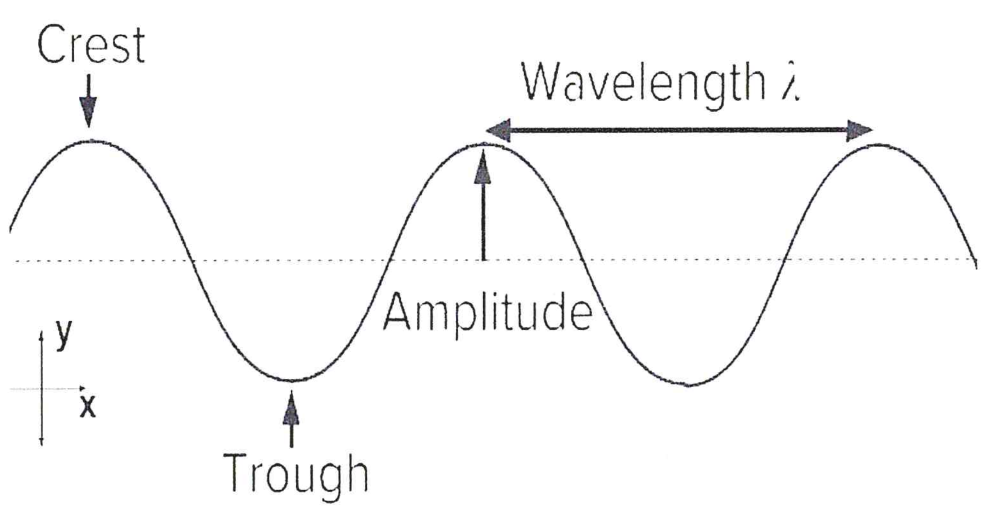
This line is called the **wave ray.**

The diagrams below show the wavefront and the wave ray for a circular wave, a straight wave, and an irregular wave:



★These are like PERPENDICULAR Vector arrows.

Reminder of parts of a wave:



Parabolic Wave Reflection

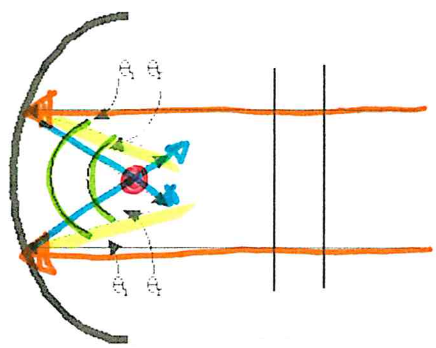
Parabola is a CURVED shape!

When straight waves reflect from a parabolic reflector, they also obey the laws of reflection. The waves reflect to the focal point of the reflector, just a light waves reflect from a parabolic mirror to a focal point.

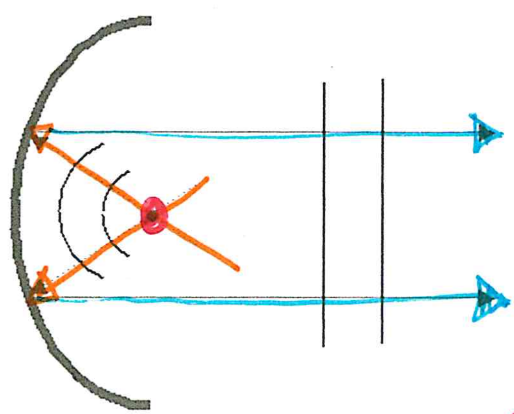
The **focal point** is the point in front of the parabolic reflector where the wave rays converge.

- Two incident wave rays are shown perpendicular to the wavefront pointing towards the parabolic reflector.
- A normal is drawn at the point where the wave ray strikes the reflecting surface.
- The reflecting wave rays are drawn moving away from the reflector and so that the angle of reflection is equal to the angle of incidence.
- Two reflected wavefronts are shown moving towards the focal point.

● is FOCAL point



If circular waves are generated at the focal point, they will be reflected away from the parabolic surface as straight waves.
The diagram below shows two circular waves moving away from the focal point towards the parabolic reflector. After they have reflected they move away from the reflector as straight waves. This situation is the direct opposite to the one above.



★same color coordination as above

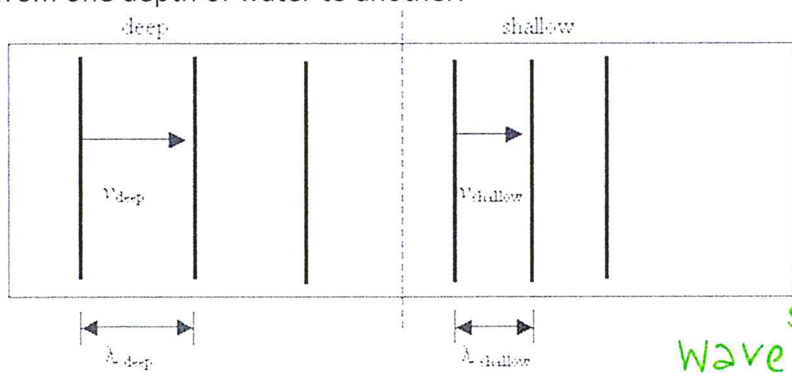
● = incident waves

● = reflected waves

U4:L4 Shallow and Deep Waves

Water waves of a certain definite frequency can be created in a ripple tank. In such a ripple tank, there can be two different depths of water.

The diagram below shows waves moving from deep water to shallow water. As the waves move into the shallow water, the frequency of the waves does not change. When the waves were created by a wave generator, the waves had a set frequency. This frequency does not change as the waves move from one depth of water to another.



Remember: This is the symbol for wavelength ("lambda")

In the deep water, the speed of the waves is $v_{deep} = f_{deep}\lambda_{deep}$.

In the shallow water, the speed of the waves is $v_{shallow} = f_{shallow}\lambda_{shallow}$.

The two frequencies are identical. Therefore we can say that:

$$\frac{v_{deep}}{v_{shallow}} = \frac{\lambda_{deep}}{\lambda_{shallow}} \quad \text{OR} \quad \frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2}$$

When the waves move from deep water to shallow water, their speed decreases. At the same time, the wavelength of the waves must also decrease.

Example:

A water wave may have a wavelength of 2.0 cm in the deep section of a tank and 1.5 cm in the shallow section. If the speed of the water wave in the shallow section is 12 cm/s, then what is the speed in the deep section?

$$\boxed{v_{deep} = \frac{v_{shallow}\lambda_{deep}}{\lambda_{shallow}}} = \frac{(12cm/s)(2.0cm)}{1.5cm} = 16\ cm/s$$

$$\cancel{V_s} \times \frac{V_d}{\cancel{V_s}} = \frac{\lambda_d \times V_s}{\lambda_s}$$

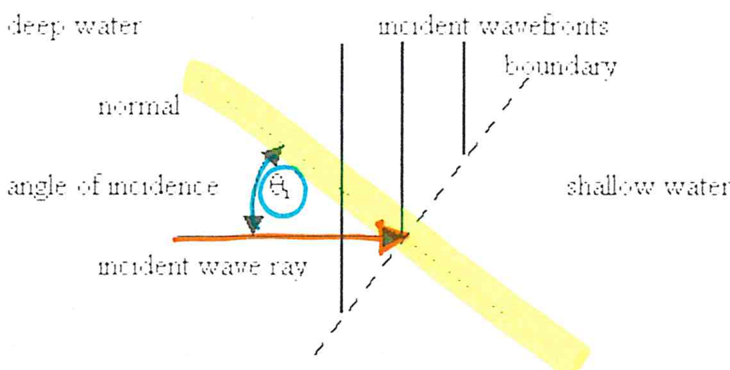
Refraction

When a wave travels from one depth of water to another in such a way that it meets the boundary between the two depths straight on, there is no change in direction.

But when the wave meets the boundary at an angle, the direction of travel does change. This change in direction of a wave as it passes from one depth to another is called **refraction**.

The diagram below shows water waves in deep water about to enter shallow water at an angle.

- One incident wave ray is drawn showing the waves moving towards the boundary.
- A normal is drawn perpendicular to the boundary at the point where the wave ray meets the boundary.
- The angle of incidence is shown between the normal and the incident wave ray.



When a wave travels at an angle into a medium in which its speed is less, the refracted wave ray is bent (refracted) towards the normal.

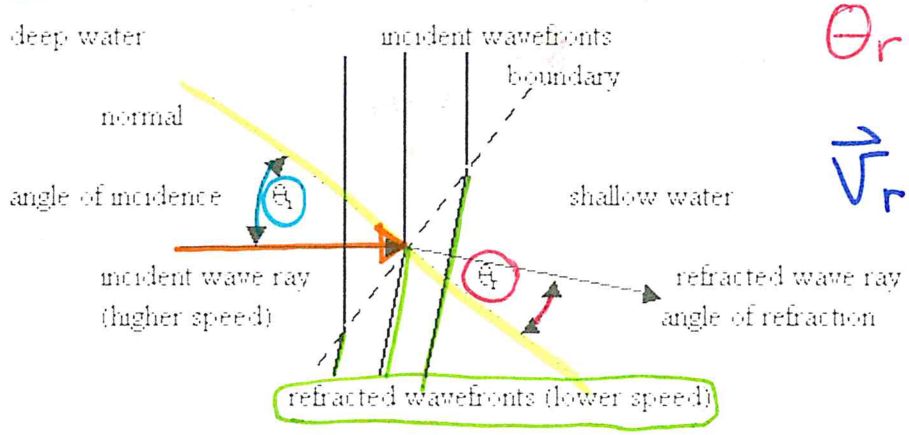
The diagram below shows what happens when the wavefronts move into the shallow water.

- The refracted wavefronts are drawn perpendicular to the refracted wave ray.
- Note that the distance between the refracted wavefronts (wavelength) is less that the distance between the incident wavefronts.
- The speed of the refracted wavefronts is therefore less than the speed of the incident wavefronts.

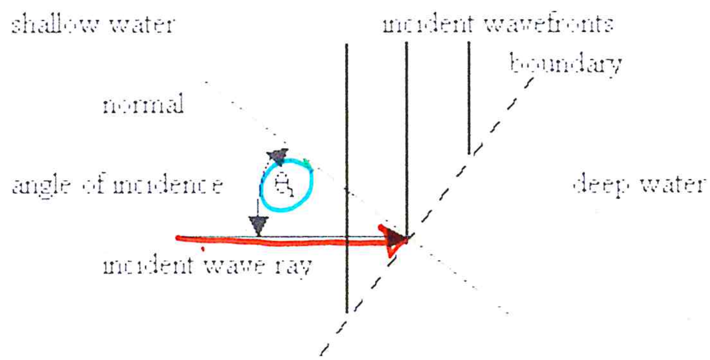
$\theta_r < \theta_i$

so...

$\vec{v}_r < \vec{v}_i$



The diagram below shows wavefronts about to move from **shallow water to deep water.**



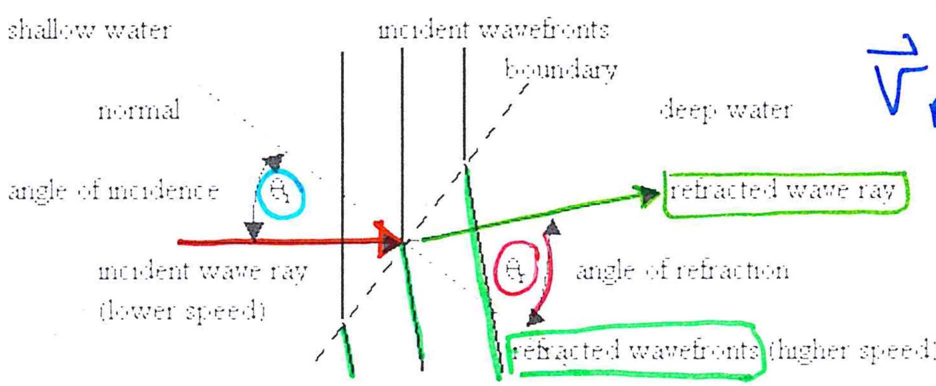
In this case, the incident waves are moving into deep water where the speed is more.

- The refracted wave ray is then bent away from the normal.
- The diagram also shows the refracted wavefronts perpendicular to the refracted wave rays.
- In this case, the wavelength of the refracted waves is greater than the incident waves, and therefore the speed of the refracted waves is also greater.

$\theta_r > \theta_i$

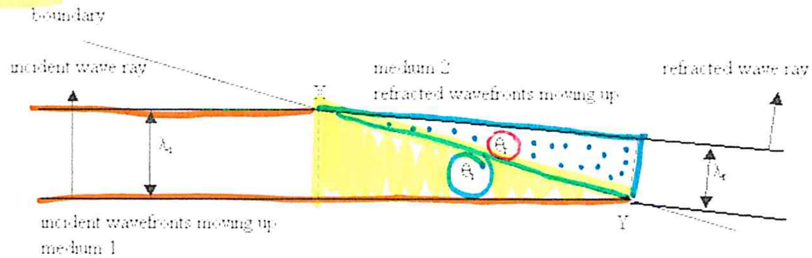
so...

$\vec{v}_r > \vec{v}_i$



Snell's Law

Snell's Law for water waves allows us to calculate the angles, speeds and wavelengths associated with refraction. The diagram below will help us to understand how the law is derived.



We can use trigonometry to analyze two wavefronts refracted at the boundary.

First look at medium 1 where two incident wavefronts are shown approaching a boundary. To simplify the calculations, it is convenient to use the angle of incidence and the angle of refraction between the wavefronts and the boundary.

The sine of the angle of incidence can be expressed as $\boxed{sin\theta_i = \frac{\lambda_i}{XY}}$

looking @ 90° Triangles made with the boundary (yellow) and blue

The sine of the angle of refraction can be expressed as $\boxed{sin\theta_r = \frac{\lambda_r}{XY}}$

The ratio of the sines can be expressed as

$$\boxed{\frac{sin\theta_i}{\sin\theta_r} = \frac{\lambda_i}{\lambda_r} = {}_i n_r}$$

This ratio is a constant. **This is Snell's Law for water waves.**

The constant is referred to as the **index of refraction** for the wave moving from medium 1 to medium 2 and is given the symbol ${}_1 n_2$.

medium 1 = n_1 } index of refraction
medium 2 = n_2 }

We learned earlier that the velocity and wavelength of an incident and reflected wave are proportional $\boxed{\frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}}$. (1st page of U4L4)

Therefore we can also state that:

$$\boxed{\frac{sin\theta_i}{\sin\theta_r} = \frac{\lambda_i}{\lambda_r} = \frac{v_i}{v_r} = {}_i n_r}$$

SNELL'S LAW

ALSO: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

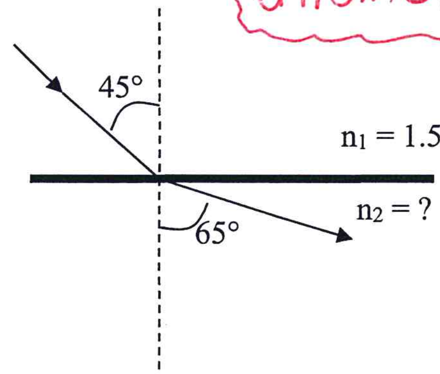
Name: answers.

n = index of refraction

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

Snell's Law Practice Worksheet

1) For the drawing to the right, find n_2.



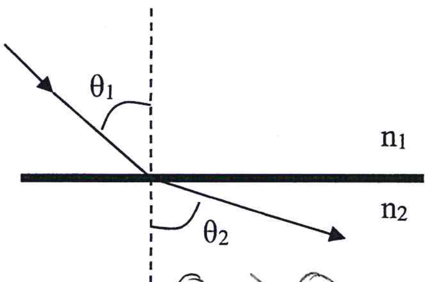
$$\frac{\sin 45^\circ}{\sin 65^\circ} = \frac{n_2}{1.5}$$

$$n_2 = \frac{1.5(\sin 45^\circ)}{\sin 65^\circ}$$

$$\boxed{n_2 \approx 1.2}$$

2) For the drawings below, state whether n_1 is bigger than n_2, n_2 is bigger than n_1, or n_1 is equal to n_2.

a)



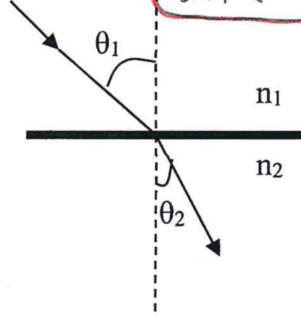
$\theta_2 > \theta_1$

so... $n_2 < n_1$

b)

$\theta_1 > \theta_2$

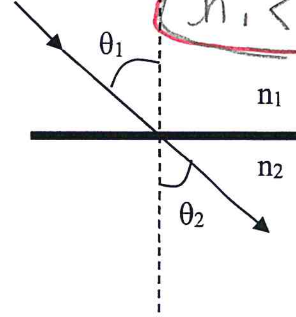
$n_1 < n_2$



c)

$\theta_1 > \theta_2$

$n_1 < n_2$



Indexes of Refraction	
Air or vacuum: 1.00	**Barium glass: 1.60**
Water: 1.33	**Flint glass: 1.70**
CR39: 1.498	**Polycarbonate: 1.586**
Crown Glass: 1.523	**Diamond: 2.45**

1. A ray of light traveling from air into crown glass strikes the surface at an angle of 30 degrees. What will the angle of refraction be?

$$\frac{\sin\theta_R}{\sin 30^\circ} = \frac{1.00}{1.523}$$

$$\sin\theta = \frac{\sin 30^\circ (1)}{1.523} = 0.328$$

$$\sin^{-1}(0.328) = \theta = 19^\circ$$

2. Light traveling through air encounters a second medium which slows the light to 2.7×10^8 m/s. What is the index of the second medium?

speed of light = 2.998×10^8 m/s

$$\frac{n_1}{n_2} = \frac{\vec{v}_2}{v_1}$$

$$\frac{1}{n_2} = \frac{2.7 \times 10^8 \text{ m/s}}{2.998 \times 10^8 \text{ m/s}}$$

$$\frac{1}{n_2} = 0.9$$

$$n_2 = \frac{1}{0.9}$$

$$\boxed{n_2 = 1.\overline{11}}$$