

Workshop Tutorials for Introductory Physics

Solutions to WI6: Reflection and Refraction

A. Review of Basic Ideas:

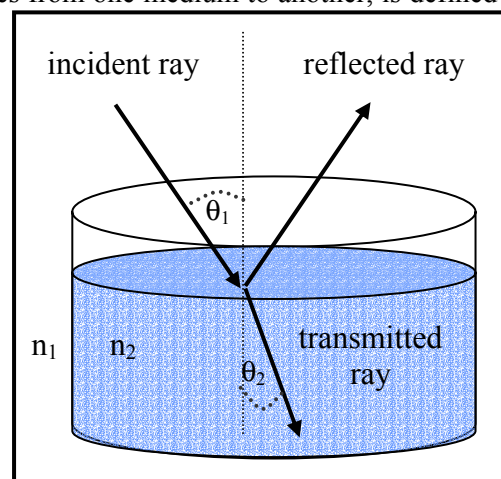
Reflection and Refraction of Light

When you look into the surface of a swimming pool, often you can see both the bottom of the pool and your own **reflection**. When light hits any surface, in this case the surface of the water, there is usually some light reflected, some light absorbed and some which is **transmitted** into the underlying medium. To see your reflection, light reflected from you must have bounced or reflected off the surface. To see the bottom of the pool some light has travelled through the air-water interface to the bottom of the pool where again some light is reflected and the rest absorbed. The **reflected** light then passes back up through the water – air interface and into your eyes.

You may also have noticed that swimming pools always look **shallower** than they really are. To understand why this is we use the laws of reflection and refraction of light and we model light as **rays** travelling in straight lines. Imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle between the perpendicular and the incident ray (the angle of **incidence**) and the angle between the perpendicular and the reflected ray (the angle of reflection) are equal. This is the law of reflection.

The law of refraction, which tells us how light **bends** as it moves from one medium to another, is defined in terms of a quantity known as the refractive index.

The refractive index of a material depends on the **speed** of light in that material. It is the ratio of the speed of light in a vacuum to the speed of light in the medium and so is always greater than 1. Once again imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle of incidence, θ_1 , is the angle between the incident ray and the **perpendicular**. The angle of refraction, θ_2 , is the angle between the perpendicular and the **refracted** ray in the new medium (water in this case). Call the air medium 1, with refractive index n_1 and water medium 2 with refractive index n_2 . The law of refraction states that $n_1 \sin \theta_1 = n_2 \sin \theta_2$. The greater the ratio of n_2 to n_1 , the more the light will bend when it enters medium 2.

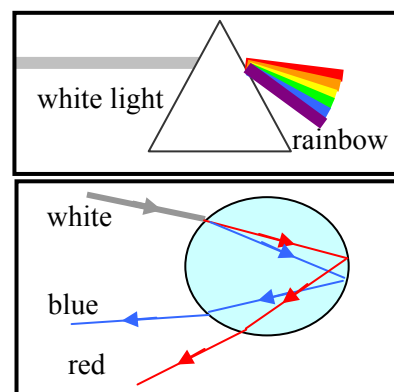


B. Activity Questions:

1. Prism

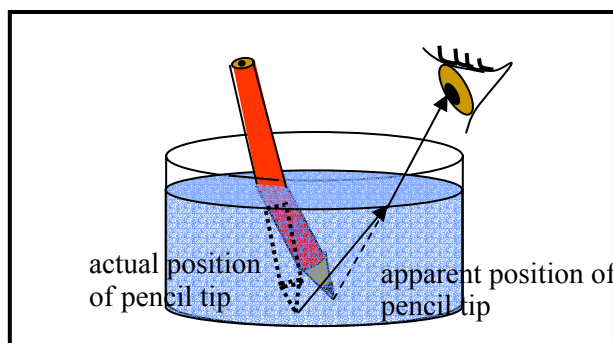
When light moves from air into the prism the light is refracted or bent, and it is bent again as it leaves the prism. The prism has a refractive index which varies for different wavelengths. The refractive index is greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component.

This is how rainbows are produced, the raindrops act as prisms, but the light doesn't just pass through the drops, it is reflected off the back surface of the drop and comes out the front separated into different wavelengths.



2. Bent pencil

The light from the pencil is refracted when it passes from the water into air, bending away from the normal as it moves from high to low refractive index. The light coming from the pencil tip appears to be coming from the apparent pencil tip as shown opposite.

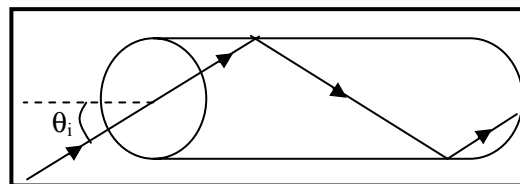


3. Losing your marbles

The refractive index of the marbles and the liquid is the same, so light passing through the beaker will not be bent as it moves from water to marble to water again. If the marbles are transparent, they will be invisible in the liquid.

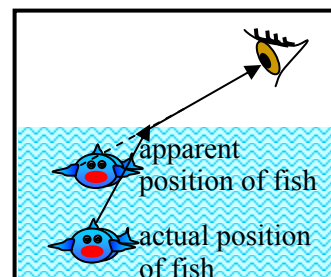
4. Total internal reflection

The light ray that enters the cable is totally internally reflected provided the incident angle, θ_i , is greater than the critical angle. Light is trapped inside the cable and almost none gets out the sides.



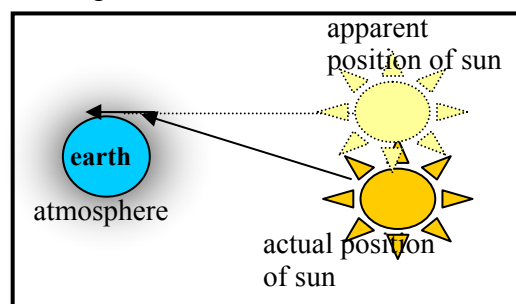
C. Qualitative Questions:

1. Light travelling from one medium into another is bent or refracted. When the medium it is entering has a higher refractive index than the one it is leaving, it is bent away from the normal to the surface. Water has a higher refractive index than air, so this is what happens when light reflects off a fish, passes through the water's surface and into your eye. The apparent position of the fish is closer than its actual position, and the ratio of the apparent depth to the actual depth is equal to the ratio of the refractive indices; $d_{\text{apparent}} / d_{\text{actual}} = n_{\text{air}} / n_{\text{water}}$.



2. The Earth is surrounded by the atmosphere, which extends a few hundred kilometres into space. When a ray of light enters the atmosphere it is refracted, or bent, by the atmosphere.

When light travels from a medium with lower refractive index to one with higher refractive index the light is bent towards the normal to the surface of the new medium. See diagram opposite. When the sun is below the physical horizon, it may still be visible because the light it emits is refracted, so its apparent position is above the horizon.



D. Quantitative Question:

It is a calm clear day and the surface of the water is perfectly smooth. Refractive index of water is 1.33.

a. The critical angle for the air water interface can be found using Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$. The critical angle is when total internal reflection occurs, ie the fish would only see a reflection from the surface of the water, and not anything outside the water. This occurs when $\theta_1 = 90^\circ$, so:

$n_1 \sin \theta_1 = n_2 \sin \theta_2$, or $1 \times \sin(90^\circ) = 1.33 \times \sin \theta_2$, which gives $\sin \theta_2 = 1/1.33$, and $\theta_2 = 49^\circ$. Any rays with incident angle greater than 49° never make it to the fish.

b. See diagram. Light coming from the bird and the fisherman is diffracted, or bent, making them appear higher up and further away than they actually are. Some fish, such as angler fish, allow for this effect. Angler fish can accurately spit a stream of water at an insect a few feet above the water, allowing for diffraction.

