46 Refractive Index & Snell's Law ♡

Data:

$$\text{refractive index of glass} = 1.50$$
$$\text{refractive index of water} = 1.34$$
$$\text{refractive index of diamond} = 2.42$$
$$\text{refractive index of cubic zirconia} = 2.16$$
$$\text{refractive index of air} = 1.00$$
$$\text{speed of light in a vacuum} = 3.00 \times 10^8 \text{ m/s}$$

Refraction describes the change of direction of light on entering or leaving a material when it crosses the boundary.

Refraction is caused by the difference in the speed of light in the materials. To compare the speed of light in different materials, we compare their refractive indices.

$$\text{refractive index} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in a material}} \qquad n = \frac{c}{v}$$

Air has a refractive index of 1.00, so the speed of light in air is very similar to the speed of light in a vacuum.

The larger the refractive index, the slower light travels.

Example 1 – Calculate the speed of light in diamond.

$$n = \frac{c}{v} \quad \text{so} \quad v = \frac{c}{n} = \frac{3 \times 10^8}{2.42} = 1.24 \times 10^8 \text{ m/s}$$

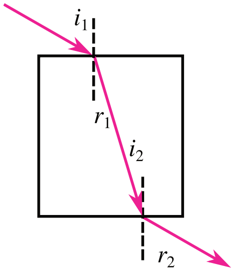
46.1 Calculate the speed of light in the following materials.

(a) What is the speed of light in glass.

(b) What is the speed of light in water.

46.2 The speed of light in hydrogen disulphide is 1.59×10^8 m/s. Calculate the refractive index of hydrogen disulphide.

Snell's Law enables us to calculate the angles when light refracts.



For light entering a material from air

$$\sin(r_1) = \frac{\sin(i_1)}{n} \quad \text{so} \quad r_1 = \sin^{-1}\left(\frac{\sin(i_1)}{n}\right)$$

For light leaving a material to pass into air

$$n \times \sin(i_2) = \sin(r_2) \quad \text{so} \quad r_2 = \sin^{-1}(n \times \sin(i_2))$$

These formulae are explained on P141.

Example 2 – Light enters glass with an incident angle of $25°$. Calculate the angle of refraction.

$$r = \sin^{-1}\left(\frac{\sin(i)}{n}\right) = \sin^{-1}\left(\frac{\sin(25°)}{1.50}\right) = \sin^{-1}(0.28) = 16°$$

46.3 Calculate r for light entering glass from air if:

(a) $i = 20°$;

(b) $i = 30°$;

(c) $i = 40°$.

46.4 Calculate r for light leaving glass into air if:

(a) $i = 20°$;

(b) $i = 30°$;

(c) $i = 40°$.

46.5 Light is incident on a boundary between water and air.

(a) Calculate r for light entering water if $i = 60°$.

(b) Calculate r for light leaving water if $i = 35°$.

46.6 In an experiment shining light through air into transparent wafflecheese, $i = 60°$ and $r = 16°$.

(a) Calculate the refractive index (n) for wafflecheese.

(b) Calculate the speed of light in wafflecheese.

46.7 A ray of light makes an angle of incidence of $40°$ with the normal between air and a liquid. The angle of refraction in the liquid is $28°$. Calculate the value of the refractive index of the liquid.

46.8 The index of refraction of a kind of glass for a certain wavelength of red light is 1.51. It is 1.55 for violet. A ray of white light is incident on a prism made of the glass at $30°$ to the normal. Calculate the angle between the red and violet rays in the glass.

46.9 A ray of monochromatic light, travelling through air, makes an angle of $30°$ with the surface of a rectangular block of a certain type of transparent plastic. It makes an angle of $53°$ with the surface inside the plastic. What is the value of the plastic's refractive index?

46.10 *[Harder]* A block of glass is sitting on the bottom of a tank full of water. Light enters the glass from the water with an incident angle $i = 40°$. What will the angle of refraction (r) in the glass be? *[Hint: if you like, you can pretend that there is a very small air gap between the glass and the water.]*

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When light passes from one material (with refractive index n_1) to a second material (refractive index n_2), then the general formula is

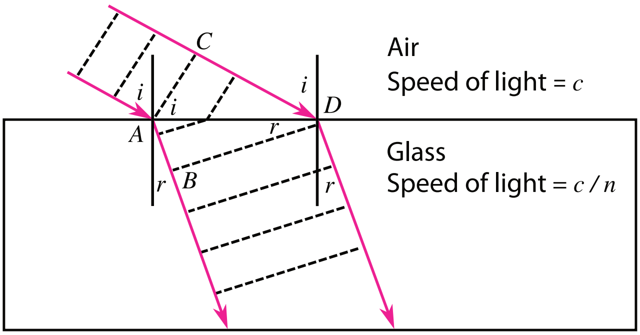
$$n_2 \sin(r) = n_1 \sin(i)$$

Notice that if the first material is air, $n_1 = 1$, then $n_2 \sin(r) = \sin(i)$.

If the second material is air, $n_2 = 1$, then $\sin(r) = n_1 \sin(i)$.

These agree with our earlier formulae, as well as the answer for Q46.10.

Reasoning behind Snell's Law



The wavefronts meet the rays at right angles.
In the time (t) that lights travels from C to D, light also travels from A to B.

$$t = \frac{AB}{(c/n)} = \frac{CD}{c}$$

So $CD = n \times AB$ and $CD/AB = n$.

$$\begin{array}{llllll} \angle CAD = i & \text{and} & CD & = AD\sin(\angle CAD) & \text{so} & CD = AD\sin(i) \\ \angle ADB = r & \text{and} & AB & = AD\sin(\angle ADB) & \text{so} & AB = AD\sin(r) \end{array}$$

Dividing these equations gives $\frac{CD}{AB} = \frac{\sin(i)}{\sin(r)}$ but $\frac{CD}{AB} = n$.

Therefore $n = \frac{\sin(i)}{\sin(r)}$, so $\sin(r) = \frac{\sin(i)}{n}$.

This is Snell's Law.