Weds/Thurs: PRELABs

Fri: HW by 5pm

Supp Ex 99, 100, 102, 103, 104, 105

Ch 18 Q 5

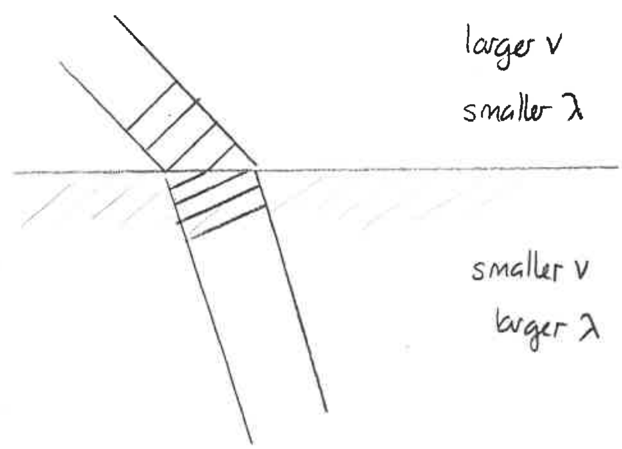
Ch 18 Prob 68

Refraction

When light passes from one medium into another it can change direction. This is called refraction. Refraction is a consequence of the fact that light travels with different speeds in different materials.

Demo: PhET Bending light

* show waves



In these situations the frequency of the wave in the two media is the same. Then $v = \lambda f$ implies that

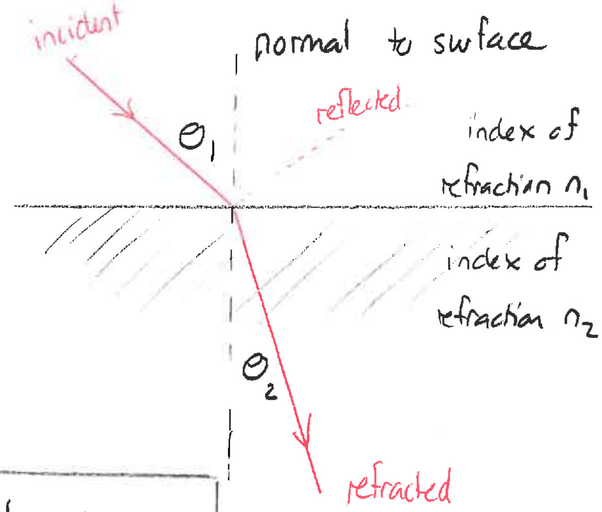
$$\lambda = v/f$$

changes. A useful quantity that will appear in the subsequent analysis is the index of refraction of the medium

$$\boxed{n = c/v}$$

where c = speed of light in a vacuum and v = speed of light in the medium.

In practical terms we can describe the change of direction in terms of light rays although the eventual rule can be derived from the wave picture



This eventually produces <u>Snell's law</u>

Let θ_1 be the angle between the normal and the incident ray. Let θ_2 be the angle between the normal and the refracted ray. Then

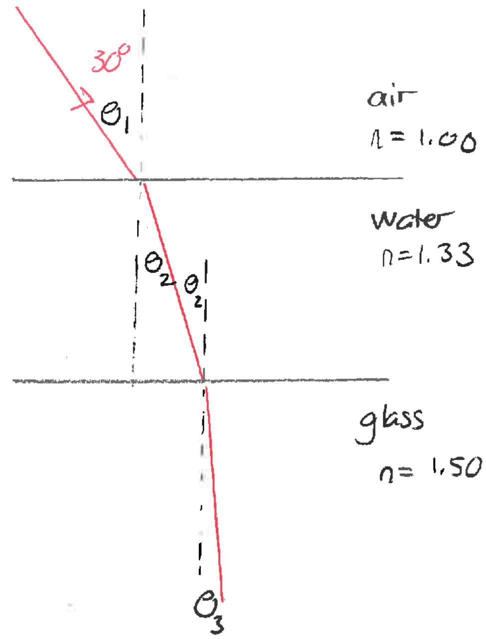
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 and n_2 are the indices of refraction for the two media.

Example: Consider three materials as illustrated. A light ray is incident from air into water. Determine

a) angle at which it travels in water

b) " " " " " " glass



Answer:

a) "1" is air and "2" is water

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

$$\Rightarrow 1.00 \sin 30° = 1.33 \sin\theta_2 \Rightarrow \sin\theta_2 = \frac{1.00 \sin 30°}{1.33}$$

$$= 0.376$$

$$\Rightarrow \theta_2 = \sin^{-1}(0.376) \Rightarrow \theta_2 = 22°$$

b) Let "2" water and "3" be glass. We notice that by parallel lines the angle of incidence on the glass is the same as θ_2

$$n_2 \sin\theta_2 = n_3 \sin\theta_3 \Rightarrow 1.33 \sin 22° = 1.50 \sin\theta_3$$

$$\Rightarrow \sin\theta_3 = \frac{1.33 \sin 22°}{1.50} \approx 0.33$$

$$\Rightarrow \theta_3 = \sin^{-1}(0.33) \Rightarrow \theta_3 = 19°$$

We can establish some general rules regarding the way in which the light bends and the relative indices of refraction.

Quiz 1 90% - 100%

Snell's law gives:

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

So we see that if $n_2 > n_1$ then $\sin\theta_2 < \sin\theta_1$ and thus $\theta_2 < \theta_1$

This gives:

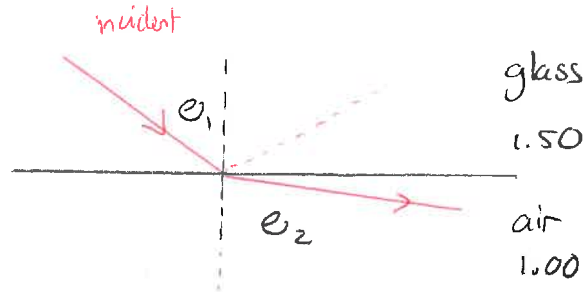
If light passes from a medium with a lower index of refraction into one with a higher index of refraction then it bends towards the normal. If .... from higher .... into lower.. bends away from the normal.

Quiz 2 80% → 100%

Total internal reflection

Now consider light passing from a material with larger index of refraction into one with smaller index of refraction. Then

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



$\Rightarrow \quad \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \quad > \sin\theta_1$

So $\theta_2 > \theta_1$ and the light bends away from the normal

Demo: PhET Bending light

- glass $\to$ air

As θ_1 increases, so does θ_2 and there will be a point at which $\theta_2 = 90°$. If θ_1 is increased any further then no light is refracted and it is all reflected within the incident material. This is called total internal reflection

Demo: PhET Bending light

- show TIR

The angle of incidence at which this first occurs is called the critical angle θ_c. Then we can show

> If $n_1 > n_2$ then whenever $\theta_1 > \theta_c$ the light will all be reflected internally. The critical angle is
>
> $$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Proof: TIR occurs when $\theta_2 = 90°$ $\Rightarrow$ $n_1 \sin\theta_c = n_2 \sin 90°$

$\Rightarrow \quad \sin\theta_c = n_2/n_1 \quad \Rightarrow \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ ∎

Quiz 3 30%-0

Quiz 4

Note that whenever the light is not refracted and total internal reflection occurs, the law of reflection describes the direction of the reflected light.

Image production by refraction

Refraction explains why underwater images appear in unusual locations

Light rays that travel from the object through the water bend as they pass into the air.