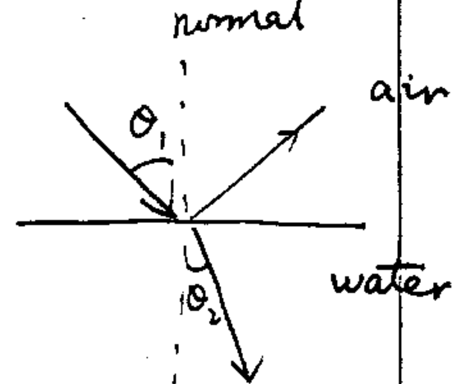
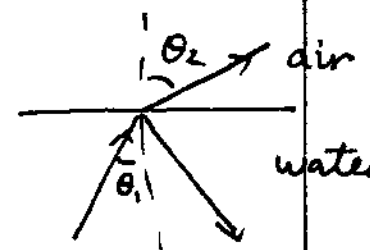
for any media, in which the light velocity is v, we define its refraction index $n = \frac{c}{v}$. For example, H_2O $n = 1.33$

$\Rightarrow v_{water} = 0.75\,c \approx 2.25 \times 10^5$ km/s.

Snell's law: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$

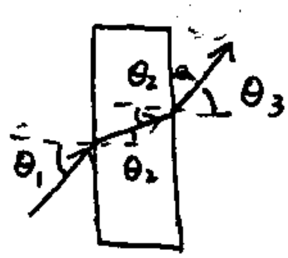


Example: refraction through flat glasses



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_{glass}}{n_{air}}$$

$$\frac{\sin\theta_3}{\sin\theta_2} = \frac{n_{glass}}{n_{air}}$$



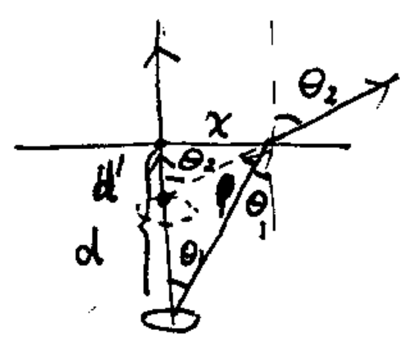
$\Rightarrow \sin\theta_3 = \sin\theta_1 \Rightarrow \theta_1 = \theta_3$ light rays doesn't change direction after passing a flat glass.

Example: apparent depth of a pool

$$\frac{x}{d} = \tan\theta_1$$

$$\frac{x}{d'} = \tan\theta_2$$

$$\Rightarrow \frac{d'}{d} = \frac{\tan\theta_1}{\tan\theta_2} \simeq \frac{\sin\theta_1}{\sin\theta_2} \approx \frac{n_{air}}{n_{o\,water}} = 0.75$$



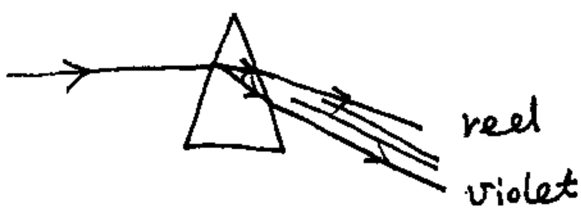
★ dispersion:

Inside media, light with different frequency propagate at different velocity $v(f)$, thus refraction index depends on frequency. $v(\text{purple}) < v(\text{red})$ (water, glass)

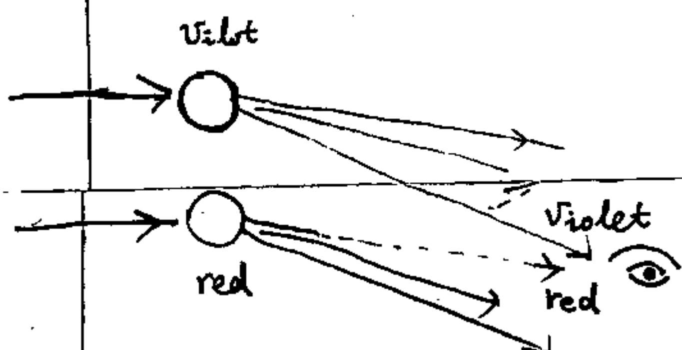
$n_{purple} > n_{red}$.

$\Rightarrow$ The refraction of purple light is stronger than red.

Example



transmit light



vilot top

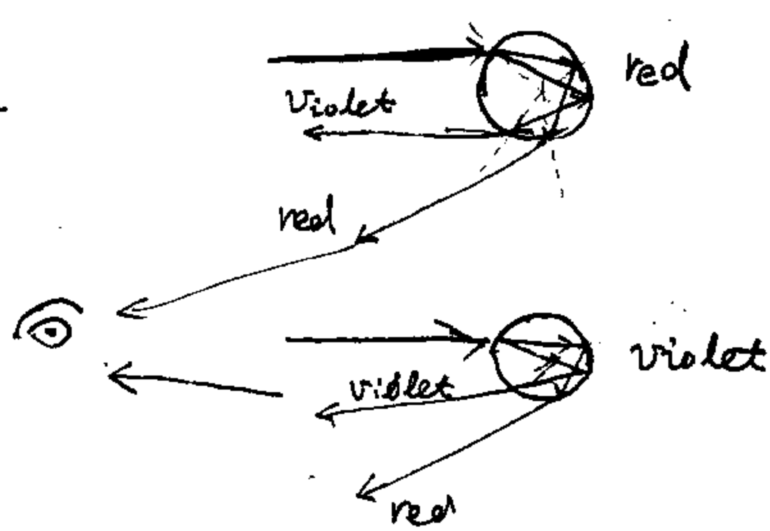
red bottom

but the rain-bow

reflection of sun-light

red – top

Violet – bottow

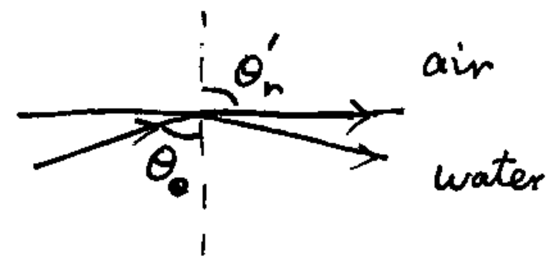


Example: our eyes see different color according to frequency instead of wavelength. For example, when a red light sheds in water, we still see it is red, but its wavelength shrinks to 3/4.

a 650 nm red light $\xrightarrow{\text{water}}$ 489 nm in water

not blue, still red!!

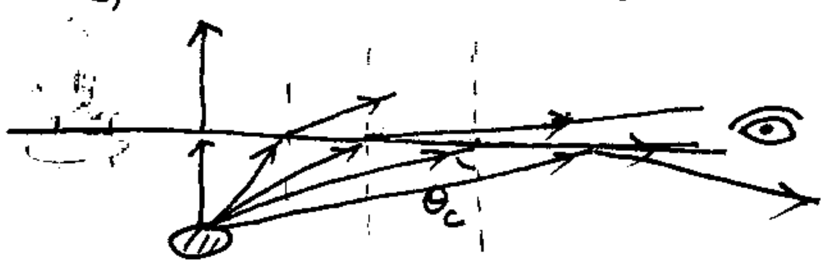
★ total reflection



$$n_{water} \sin\theta = n_{air} \sin\theta'$$

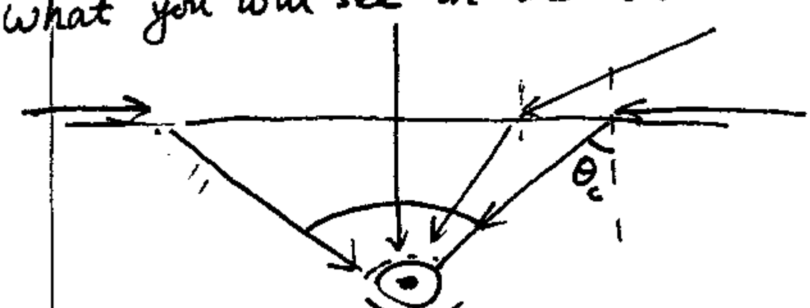
$$\sin\theta_c = \frac{n_{air}}{n_{wat}} \quad \text{if } \theta' = 90°.$$

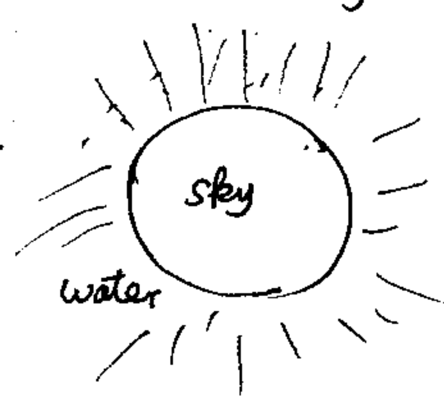
if $\theta > \theta_c$, there will be no refraction light.



you will the object is just close to the surface.

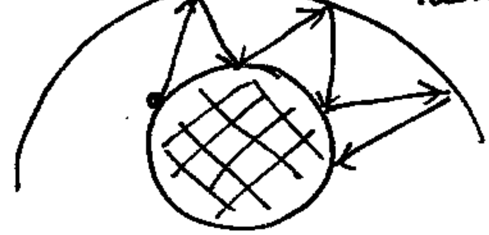
what you will see in the water



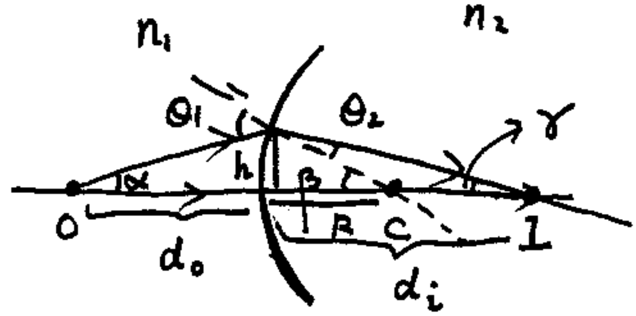


Fiber

Shortwave radio



• refraction at a spherical surface



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

small angle

$\Rightarrow \quad n_1\theta_1 \approx n_2\theta_2$

$\theta_1 = \alpha + \beta, \quad \theta_2 = \beta - \gamma$

$\Rightarrow \quad n_1(\alpha+\beta) \approx n_2(\beta - \gamma)$

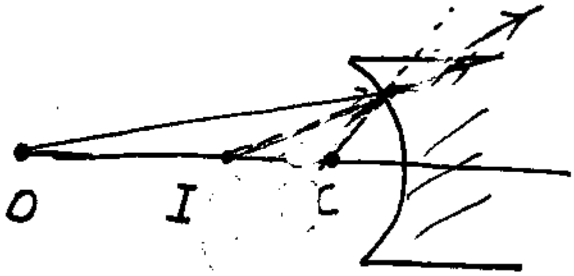
$\alpha = \frac{h}{d_o} \quad \beta = \frac{h}{R}, \quad \gamma = \frac{h}{d_i}$

$$\Rightarrow \boxed{\frac{n_1}{d_o} + \frac{n_2}{d_i} = \frac{n_2 - n_1}{R}}$$

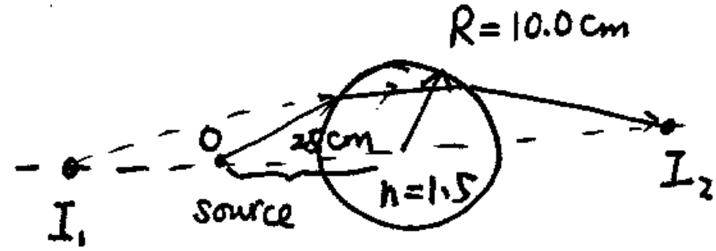
$d_i < 0$ if I is on the side of object

$R < 0$ is concave to the object

also apply to concave case by taking $R < 0$ and $d_i < 0$.



a spherical "lens"



The first step: $R = 10.0\,cm$, $d_0 = 25.0\,cm$ $-R$ / $n = 1.5$

$$\frac{1}{15} + \frac{1.5}{d_{I_1}} = \frac{0.5}{10} \Rightarrow \frac{1.5}{d_{I_1}} = \frac{1}{20} - \frac{1}{15} = \frac{-1}{60}$$

$$d_{I_1} = -90\,cm$$

The first image will behave as the object of the second spheric refraction. d_o' and d_i are with respect to the back of the sphere

$$d_o' = 90 + 20 = 110\,cm, \quad R = -10\,cm, \quad n_2 = 1, \quad n_1 = 1.5$$

$$\frac{1.5}{d_o'} + \frac{1}{d_i} = \frac{-0.5}{-10} \Rightarrow \frac{1}{d_i} = +\frac{1}{20} - \frac{1.5}{110}$$

$$= \frac{4}{110}$$

$$\Rightarrow d_i = \frac{110}{4}\,cm = 27.5\,cm$$

$\Rightarrow$ The image is at 27.5cm from the back of the sphere.