# Refraction

## What is refraction?

Refraction: The phenomenon that occurs at the boundary of two translucent substances. Because light travels at different speeds in different media, it will slightly change direction ("bend") when it goes from one medium to another.

Medium: Substance/material through which light travels.

Index of refraction (n): Factor by which the speed of light is deceased in a given medium, compared to the speed of light in a vacuum.

Note: $n = \frac{c}{v}$ where n: index of refraction of medium

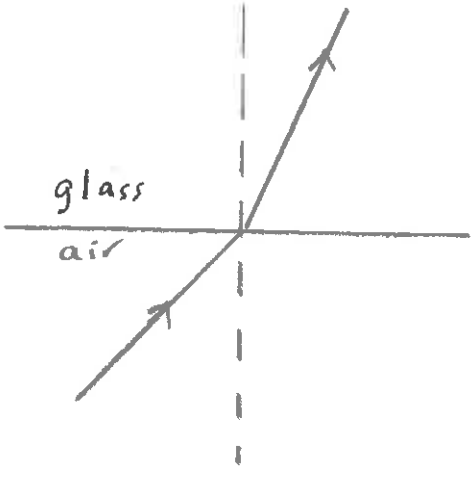
c: speed of light in a vacuum

v: speed of light in medium

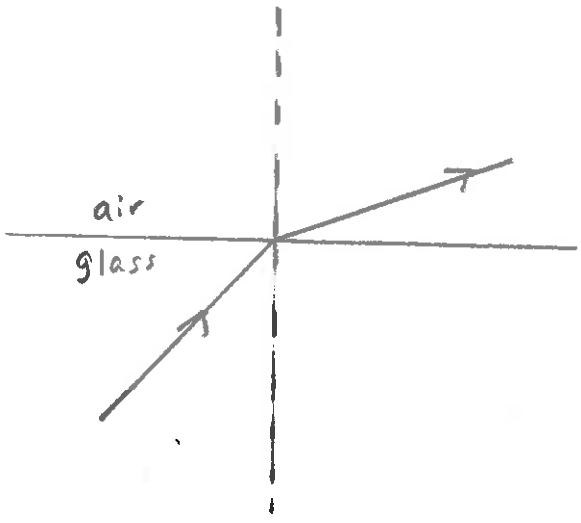
Some indexes of refraction:

| | |
|---|---|
| Vacuum: | 1.00 (exactly) |
| Air: | 1.00029 (essentially 1.00) |
| Crystal: | 2.00 |
| Glass: | 1.50 |
| Water: | 1.33 |
| Ice: | 1.31 |

When light enters a medium that is more optically dense (higher value of n), the ray bends towards the normal.




When light enters a medium that is less optically dense (lower value of n), the ray bends away the normal.



Law of Refraction (Snell's Law)

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

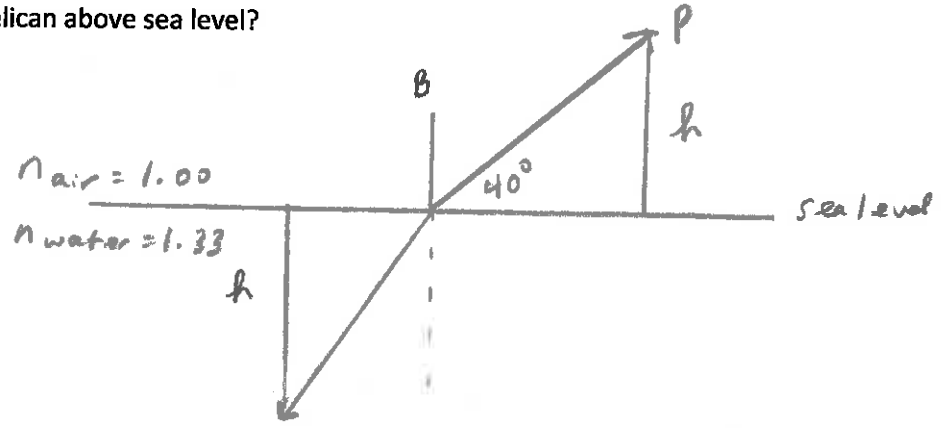
Examples:

1. A light ray travelling through air enters glass (n = 1.50) at an angle of 27°. What is the angle at which the light ray travels through glass?

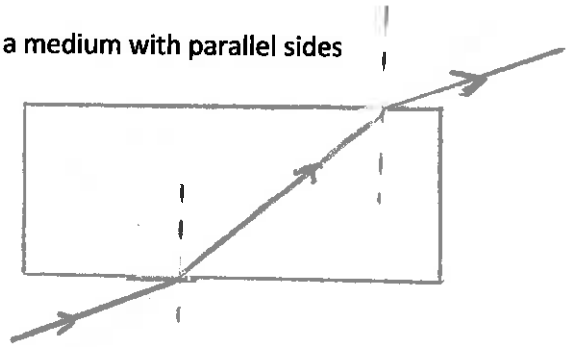
2. A light ray traveling through air at an angle of 29° enters an unidentified substance where it then travels at an angle of 25°. What is the index of refraction of the unidentified substance?

3. Since the refractive index of water is 1.33, what is the speed of light in water?

4. A pelican is flying above sea level in search of its next snack. It sees a fish at an angle of 40° to the horizontal, as shown below. The fish is located 1.0 m away, horizontally, from the buoy. The height of the pelican above the water is equal to the depth of the fish. What is the height of the pelican above sea level?



Light through a medium with parallel sides



Critical Angle and Total Internal Reflection

Critical Angle ($\theta_c$): Maximum angle for which refraction will occur

Minimum angle for which total internal reflection will occur

Is an incident angle

Depends on both media involved

Only happens when light goes from a medium with higher index of refraction to one with a lower index of refraction

Ex:

When the incident ray hits the surface at an angle greater than the critical angle, all the light is reflected. When this occurs in a closed medium, this is called total internal reflection.

How to find the critical angle

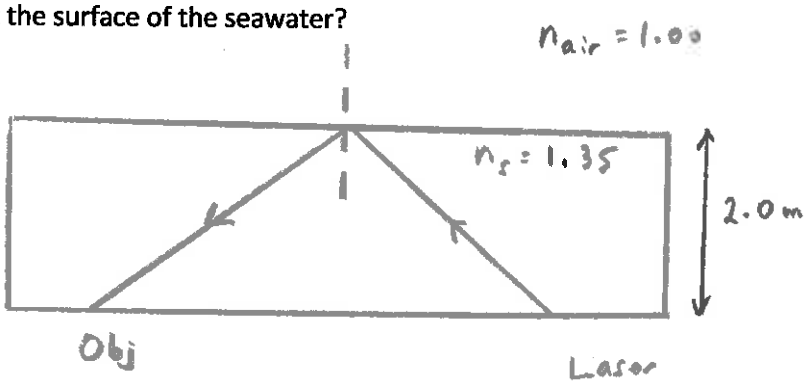
- When the angle of refraction is 90 °

Examples:

1. A light ray inside a glass block (n= 1.50) hits the surface as if it were to enter in air. For what angle of incidence will total internal reflection occur?

2. An adjustable laser is attached to the bottom of a reservoir containing seawater (n = 1.35). The laser is adjusted so that the reflected light illuminates an object (the fish) placed on the bottom of the reservoir.

What minimum distance must there be between the laser source light and the object so that the ray of light does not exit the surface of the seawater?



Lenses

Lenses are made of transparent materials that have an index of refraction greater than the index of refraction of air (usually plastic or glass)

Because light enters and leaves the lens at an angle, it changes direction. By changing the shape of the lens, we can control exactly how the light will be deviated.

Some uses of lenses:

- Eyeglasses
- Microscope
- Telescope
- Overhead projector

Types of lenses

| Diverging Lenses Concave | Converging Lenses Convex |
|---|---|
| Biconcave | Biconvex |
| Planoconcave | Planoconcave |
| Diverging meniscus<br>(negative meniscus) | Converging meniscus<br>**(positive meniscus)** |

Note: when light travels through a lens, it changes direction TWICE: once when it enters the lens and once when it leaves the lens.

Parts of a lens

Principal axis: same as for reflection

Optical center (O):

Primary Focus (F)

Secondary Focus (F')


Drawing the principal rays going through a lens

3 principal rays

Through the optical center: The refracted ray comes out undeviated

Parallel to the principal axis: Converging (convex) lens

The ray is refracted through the focal point

Diverging (concave) lens

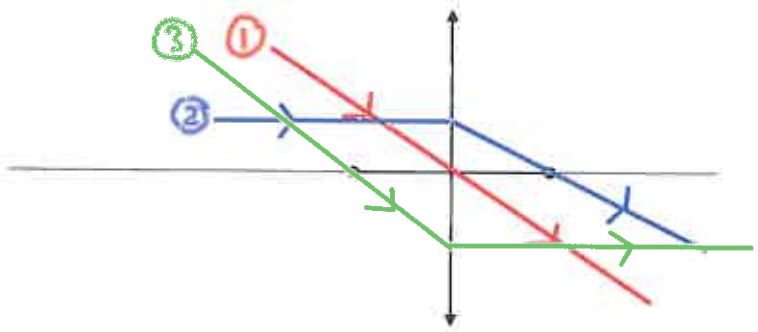
The ray is refracted "as if" it came from the focal point

Through the focus: The ray is refracted parallel to the principal axis (converging lens)

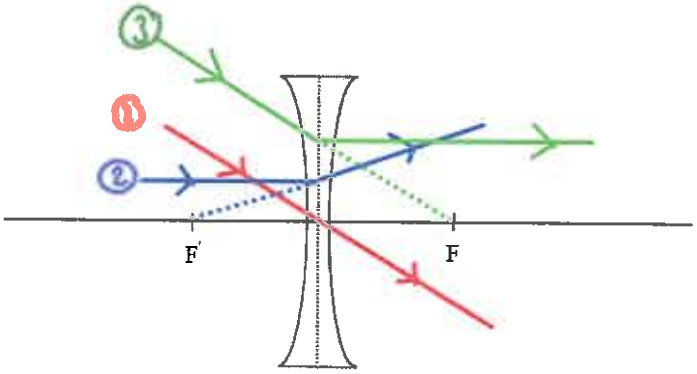
Or "as if" from

As if TO focus on the other side: the ray is refracted parallel to the principal axis (diverging lens)

**Convex (converging lens)**




**Concave (diverging lens)**



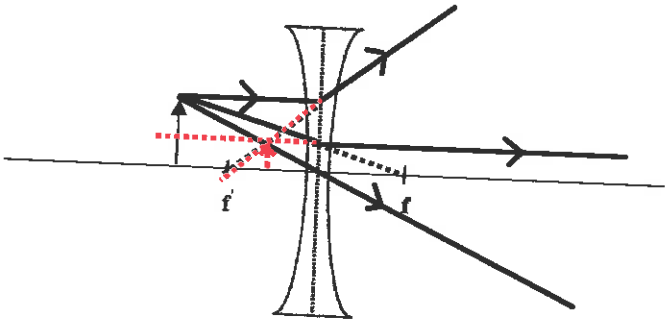
Images formed by Lenses

Images formed by DIVERGING lenses (concave)

Always:

- Virtual
- Upright
- Smaller than the image
- Located between F and O

Example:

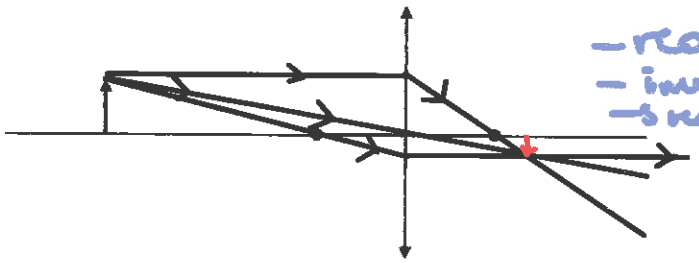



Images formed by CONVERGING lenses (convex)

| Object ↓ / Image → | Real or Virtual? | Upright or Inverted? | Smaller or bigger than object? | Image Location? |
|---|---|---|---|---|
| Far beyond 2F | Real | Inverted | Smaller | At F |
| Beyond 2F | Real | Inverted | Smaller | Between 2 and 2F |
| At 2F | Real | Inverted | Same Size | At 2F |
| Between 2F and F | Real | Inverted | Larger | Beyond 2F |
| At F | NO IMAGE FORMED | | | |
| Between F and O | Virtual | Upright | Larger | Same side of lens as object |

Example:

1.

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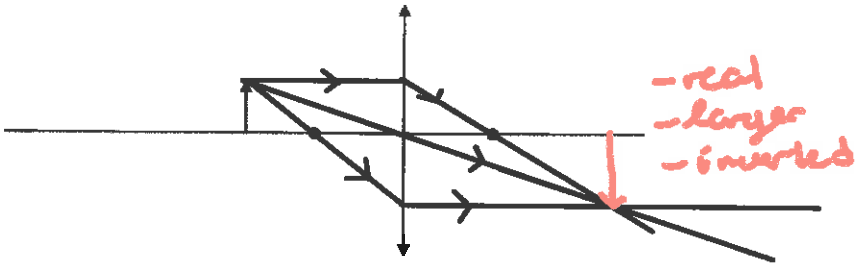


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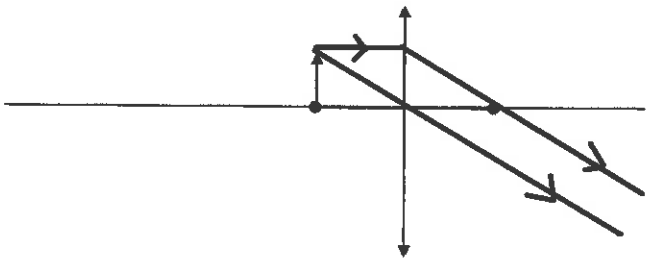


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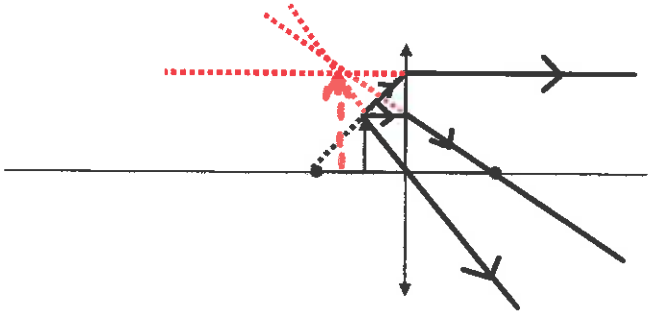

Locating images using formulas (lenses)

Just as for mirrors, for lenses we have:

M $h_o$ $h_i$ $d_o$ $d_i$

The meaning of positive and negative signs is the same for mirrors

f: focal length of the lens (distance between focal point and vertex)

note: if f is positive, the lens is converging (convex)

if f is negative, the lens is diverging (concave)

Distances are always measured from the optical center of the lens

Examples:

1. A rabbit 0.10 m in height is located 1.5 m from a converging lens with a focal length of 0.50 m. What is the height of the rabbit's image?

2. A manufacturer of slide projectors wants to produce images 1.5 m in height on a screen that is placed 5.0 m from the lens of the projector. If the height of the slides is 30 mm, calculate the focal length of the lens.

3. An object and a screen are fixed at a distance of 80 cm apart. A convex lens forms an image of the object on the screen. Find the focal length of the lens.