Light as a Wave

Light has been known to behave as a wave for over 200 years. We know it is transverse and composed of oscillating electric and magnetic fields at 90° to each other. It does not require a medium through which to move, it may move through a vacuum.

Prior to proving light was a wave it was thought light was a RAY or beam of particles, this concept is still useful for determining how optical images are created using mirrors and lenses. A ray is an imaginary beam which travels perpendicular to wave fronts in the direction of wave propagation.

When any wave changes media its speed changes resulting in a bending of its path called REFRACTION. To help understand this, recall the soldier / wheel analogy of refraction. When light rays change media their path stops being a straight line and bends due to speed change. A ratio of the speed of light in a vacuum to that in a particular medium is called the index of refraction and is found as below:

Index of refraction of a medium → $n_{medium} = \frac{c}{v_{medium}}$

Example: the speed of light in water is 2.25×10^8 m/s, what is water's index of refraction?

$n = \frac{c}{v} = \frac{3.00 \cancel{\times 10^8 \text{ m/s}}}{2.25 \cancel{\times 10^8 \text{ m/s}}} = 1.33$ note that n has no units!

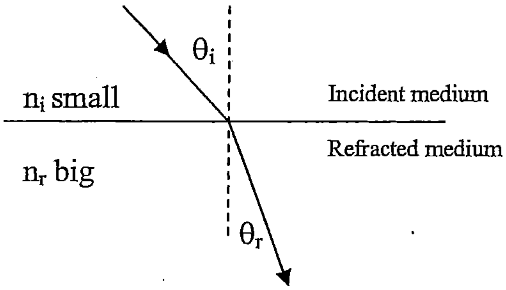
In 1621 Willebrod Snellius spent time determining the relation between indices of refraction and angles of refraction. He discovered that:

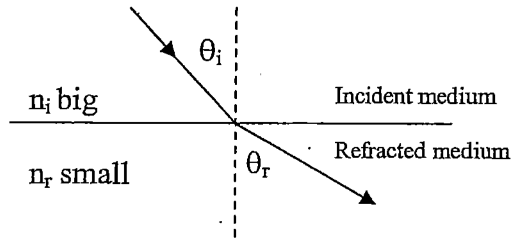
1) ALL ANGLES MUST BE MEASURED FROM A NORMAL LINE (which is 90° to the surface where light changes media)
2) The frequency of a light wave does not change when changing media, only wavelength.
3) The index of refraction of the incident medium multiplied by the sine of the angle of incidence must be equal to the index of refraction of the refracted medium multiplied by the sine of the angle of refraction.

Today this is called SNELL'S LAW and is represented by the equation:

$n_i \sin \theta_i = n_r \sin \theta_r$ or $\frac{n_i}{n_r} = \frac{\sin \theta_r}{\sin \theta_i}$

If a ray of light travels from a medium of lower n to higher n ($n_i < n_r$) the ray will bend toward the normal ($\theta_i > \theta_r$) and of course the reverse is also true.





There is a relationship between index of refractions and wavelength when a light ray changes media. It can be found using the index formula and the fact frequency remains constant.

$$n_{substance} = \frac{c}{v} = \frac{\lambda_{vacuum} f_{vacuum}}{\lambda_{substance} f_{substance}}$$ since f is constant it factors leaving

$$n_{substance} = \frac{\lambda_{vacuum}}{\lambda_{substance}}$$

So the index of refraction of 2 media would be inversely proportioned to wavelengths in those media:

$$\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1}$$

It is possible to create a situation where the refracted angle is 90° to the normal. To do this ni > nr, then θr could equal 90° OR EVEN BE UNDEFINED!

Example: light travels from water into air at an incident angle of 48.7°, what is the angle of refraction?

$n_i \sin \theta_i = n_r \sin \theta_r$

$1.33 \sin 48.7 = 1.0003 \sin \theta_r$

$1.0 \quad = \sin \theta_r$ or $\theta_r = 90°$

When an incident angle produces a refracted angle of 90° the incident angle is called a CRITICAL ANGLE.

At any angle of incidence greater than the critical angle the incident ray is completely REFLECTED back into the incident medium according to the law of reflection ← $\theta_i =$ angle of reflection

1) Describe in detail Young's Double Slit Experiment and how it affected the theory of light propagation.

MIRRORS and LENSES

There are 3 types of mirrors:

1) The plane mirror ← this is a flat geometric plane, like the one in your bathroom
2) The concave mirror ← this is a mirror which curves inward, like a cave
3) The convex mirror ← this is a mirror which curves outward, like a ball

Vocabulary:

Image characteristics: adjectives which describe size, orientation and light rays forming an image

Smaller ← image is smaller than object
Larger ← image is larger than object
Same size ←image is the same size as the object

Real ←image is formed by converging light rays (coming together)
Virtual ←image if formed by diverging light rays (going apart)

Erect ← image is upright
Inverted ← image is upside down

Ray diagram ← a scaled image used to determine information about an image
Principal Axis ← horizontal axis drawn through a curved mirror or lens
Centre of Curvature (C)← central point created if a curved mirror or lens is traced into a full circle
Radius of curvature ← distance from mirror or lens to center of curvature
Focal point (f)← location at which parallel light rays will intersect
Focal length ← distance from mirror / lens to focal point

$*f = \frac{1}{2} C$

Converging mirror ←aka concave mirror
Diverging mirror ← aka convex mirror
Converging lens ←aka convex lens
Diverging lens ←aka concave lens
do ← distance to object
di ← distance to image
Mirror / Lens equation:

$$*\frac{1}{f} = \frac{1}{di} + \frac{1}{do}$$

ho ← height of object
hi ← height of image
M ← magnification, ratio of image size to object size

$$*M = \frac{hi}{ho} = -\frac{di}{do}$$

NOTE that a concave mirror acts like a convex lens and a convex mirror acts like a concave lens

Ray Diagram for a plane mirror:

Any 2 rays can be used to find the image, image exists where rays meet
Since rays DIVERGE trace them back into the mirror, our eyes interpret this as the point the rays left.

Follow the link below to see an example, copy down the rules and the example.

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Ray Diagrams for a concave mirror:

Any 2 rays can be used to find the image, image exists where rays meet.
IF the rays converge you are done, if they diverge (do < f) then you must trace them back into the mirror as done with a plane mirror.

Follow the links below to see ALL examples, copy down the rules and the examples.

NOTE: f is positive for concave mirrors

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YOU HAD BETTER DO THIS, IT TOOK FOREVER TO MAKE THOSE!!

Ray diagrams for the convex mirror:

Any 2 rays can be used to find the image, image exists where rays meet.
SINCE the rays diverge you must trace them back into the mirror as done with a plane mirror.

Follow the link below to see the example, copy down the rules and the examples.
All images will have the same characteristics for a convex mirror no matter where the object is on the principal axis

NOTE: f is negative for convex mirrors.

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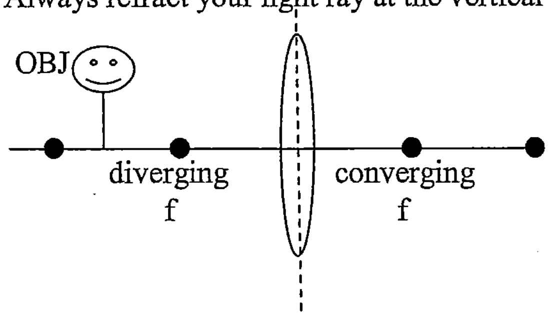
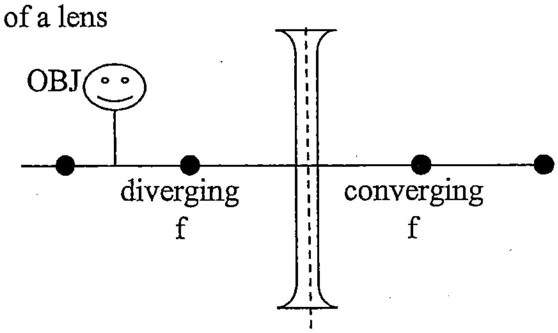
LENSES work oppositely to mirrors. Meaning that where a mirror bounces light off, a lens lets light through. Also a concave mirror produces the same image characteristics as a convex lens and a convex mirror produces the same characteristics as a concave lens.

Lenses have two radii of curvature & therefore two focal lengths (diverging and converging f's). Always refract your light ray at the vertical axis of a lens





Ray diagram rules are at this link, copy them down and follow them:

Convex lens with do > C
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Convex lens with C < do > f
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Convex lens with do = f
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Convex lens with do < f
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Concave lens with any do
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Note: f is positive for the convex lens and negative for the concave lens.

Concave mirrors and convex lenses

Do > C	Real, smaller, inverted image	Hi neg, M neg, $\lvert M\rvert > 1$, Di pos
Do = C	Real, same size, inverted	Hi neg = Ho, M neg $\lvert M\rvert = 1$, Do = Di, Di pos
C > Do > f	Real, larger, inverted	Hi neg, Mag neg, $\lvert M\rvert < 1$, Di pos
Do = f	No image	
Do <f	Virtual, larger, erect	Hi pos, M pos, $\lvert M\rvert > 1$, Di neg

F is positive

Convex mirrors and concave lenses

For any Do	Virtual, smaller, erect	F neg, Di neg, Hi pos, $\lvert M\rvert<1$, M pos,

F is negative

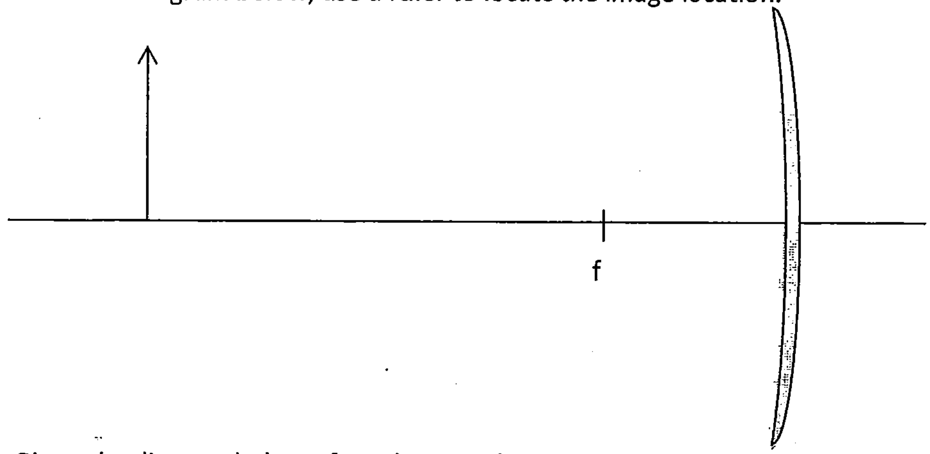
Do always positive, Ho always positive

Real/Virtual Images

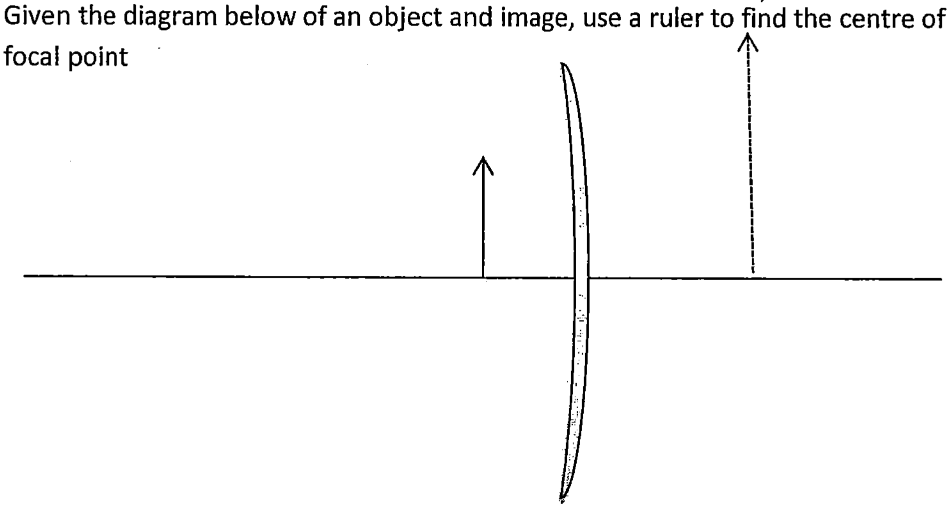
Real	Do positive F positive Di positive Image inverted Rays converge	 Hi negative Magnification negative
Virtual	Do positive F positive or negative Di negative Image erect Rays Diverge	 Depends on type of lens / mirror Hi positive Magnification positive

Mirrors and Lenses Extra Practice

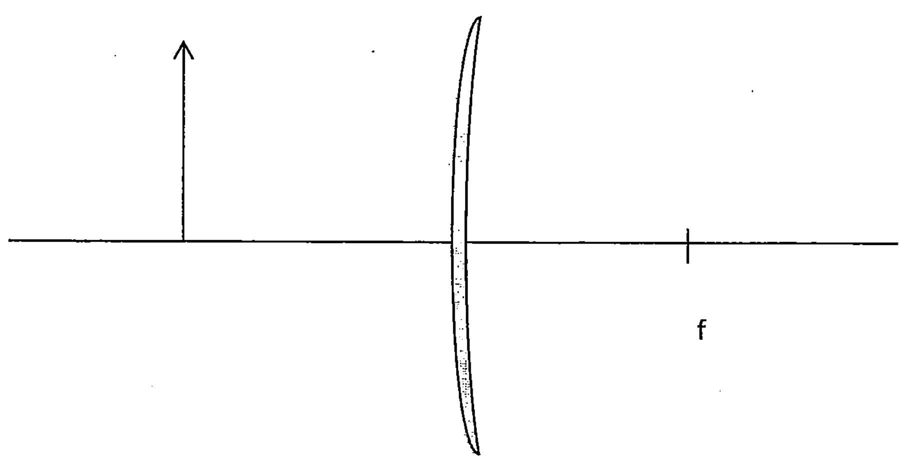
1) Given the diagram below, use a ruler to locate the image location.



2) Given the diagram below of an object and image, use a ruler to find the centre of curvature and focal point



3) Given the diagram below locate the image using a ruler.



4) A glowing object 3.0 cm high is placed 30 cm in front of a converging mirror (concave mirror), of focal length 2.0 cm. determine the location of the image, its height, and characteristics.

5) A converging mirror (concave mirror) has focal length 20 cm, locate the image if the object is at 10 cm and state the image characteristics.

6) A diverging mirror (convex mirror) has focal length 20 cm, an object is 10 cm from the mirror, state the image characteristics and calculate its location.

7) An object 8.0 cm high is placed 80 cm in front of a converging lens (convex lens) of focal length 25 cm, locate the image and find its height.

8) A converging lens (convex lens) is used to make images the same size as the object. If the items to be copied are 30 cm from the lens, what is the focal length?