Ray tracing

Select LEARNING OBJECTIVES:

- Be able to sketch the three special rays for converging and diverging lenses, as well as concave and convex spherical mirrors.
- Be able to identify if the image produced by single lens/mirror will be upright or upside down, larger or smaller, and real or virtual.
- Be able to find the location of an image from an object created by a thin lens or spherical mirror.

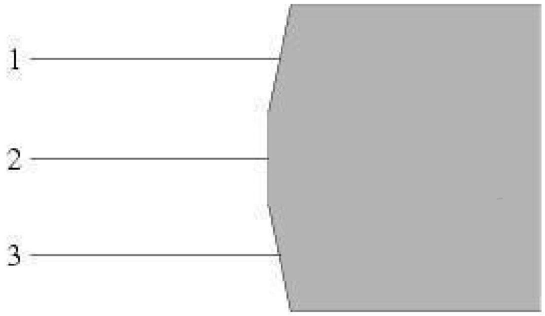
TEXTBOOK CHAPTERS:

Boxsand :: Ray tracing

WARM UP: Use the ray model of light to explain why you see a basketball even though it does not emit light like a light bulb.

With our current understanding of the ray model of light, we can now tackle how optical elements affect light rays. An optical element is any device which alters some property of light as the light interacts with the device. For instance, if a device attenuates the intensity of the light, the device would be considered an optical element. We will focus our attention on optical elements which change the direction of light, specifically thin lenses and spherical mirrors.

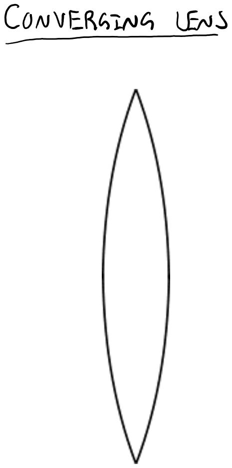
PRACTICE: Three parallel rays of light travel to the faceted piece of glass shown below. Sketch the path of each ray as they travel through the glass.

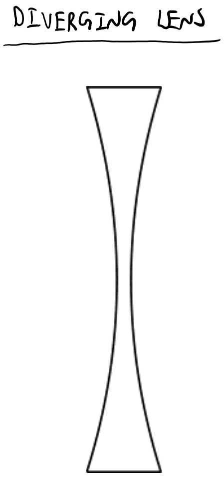


If the frequency of the light is decreased what happens to the point where the rays converge?

1. moves left
2. moves right
3. stays at the same location

Study the image from the practice problem above carefully. Notice how parallel rays enter the piece of glass and emerge bent, eventually crossing paths at a single location. If we knew some geometric features of this glass (e.g. angles, thickness) along with the index of refraction, we could use Snell's law to determine the location where the rays seem to converge. Most lenses you have seen are probably not shaped like the glass from the practice example above. However, they look somewhat similar as shown below.





To mathematically analyze how light is bent by these lenses shown above, you would do the same procedure as the practice problem from above, then apply Snell's law. However, since the boundary between the surrounding medium and the lens is not linear, rather they are curved, the algebra gets very messy. Luckily for us, we can summarize the application of Snell's laws to thin converging and diverging lenses by a set of 3 rules for specific light rays that interact with the lenses as outlined below. Before I list the ray tracing rules for thin lenses, we should first define some new terminology that we will use when analyzing thin lenses.

Terminology

- ***Optical axis*** :: Imaginary line that is perpendicular to the surface of thin lens (or spherical mirror) and intersects the element's center.
- ***Focal point*** :: point at which rays parallel to the optical axis will converge to or appear to diverge from.
- ***Focal length*** ≡ **f** :: distance from optical element to focal point.
- ***Object distance*** ≡ $\mathbf{d_o}$ :: distance from optical element to object.
- ***Image distance*** ≡ $\mathbf{d_I}$ :: distance from optical element to image.
- ***Magnification*** ≡ **m** :: ratio of image height to object height.
- ***Virtual image*** :: image formed by rays that appear to diverge from a location (i.e. the rays do not actually travel through this location).

As promised, the ray tracing rules for thin lenses are below.

Ray tracing for converging thin lens

(1) Ray from object, parallel to optical axis, refracts through far focal point.

(2) Ray from object, through near focal point, refracts parallel to optical axis.

(3) Ray from object, through center of lens, exits undeflected.

Ray tracing for diverging thin lens

(1) Ray from object, parallel to optical axis, refracts as if it came from near focal point.

(2) Ray from object, towards far focal point, refracts parallel to optical axis.

(3) Ray from object, through center of lens, exits undeflected.

*Note that we are constraining ourselves to "thin" lenses, which means that the radius of curvature of the lens is much larger than the thickness of the lens. Can you use rule 3 for converging lenses to help show why this constraint must be satisfied if we are to use these rules?

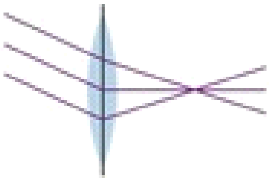
PRACTICE: A light ray can change direction when going from one material into another. This phenomenon is known as

1. reflection.
2. absorption.
3. refraction.
4. scattering.
5. transference.
6. diffraction.
7. diffusion.

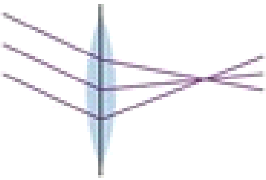
PRACTICE: What is the focal point?

1. The place the rays converge
2. The place the rays appear to converge
3. The location where a screen could be placed to show a focused image
4. The radius of curvature of the lens
5. None of the above

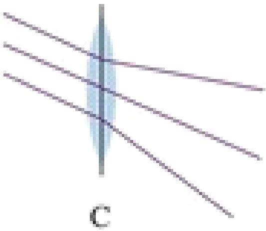
PRACTICE: Which of the following ray diagrams are possible?



A



B



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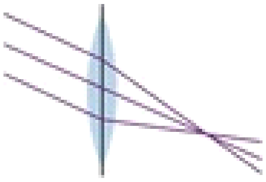


D

PRACTICE: Is the image produced from an object outside the focal length of a converging lens real or virtual?

1. real
2. virtual
3. simultaneously both real and virtual
4. no way of telling
5. Swimming hole

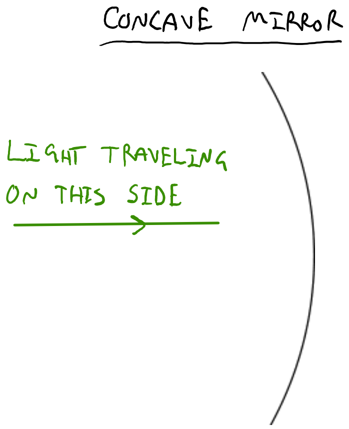
PRACTICE: Is the image produced from an object within the focal length of diverging lens real or virtual?

1. real
2. virtual
3. simultaneously both real and virtual
4. no way of telling

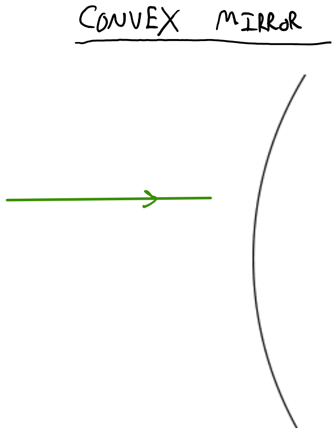
PRACTICE: A lens is used to image an object onto a screen. If the right half of the lens is covered,

1. the left half of the image disappears.
2. the right half of the image disappears.
3. the entire image disappears.
4. the image becomes blurred.
5. the image becomes fainter.

Since mirrors change the direction of light, they are also considered optical elements. Much like the ray tracing rules for thin lenses, there exists a set of ray tracking rules for spherical mirrors. There are two types of spherical mirrors, convex and concave as shown below.



$\boxed{R = 2F}$



The ray tracing rules for spherical mirrors are below.

Ray tracing for concave spherical mirror

(1) Ray from object, parallel to optical axis, reflects through near focal point.

(2) Ray from object, through or from near focal point which depends on if inside or outside focal length, reflects parallel to optical axis.

(3) Ray from object, through or from radius of curvature R, reflects back on itself.

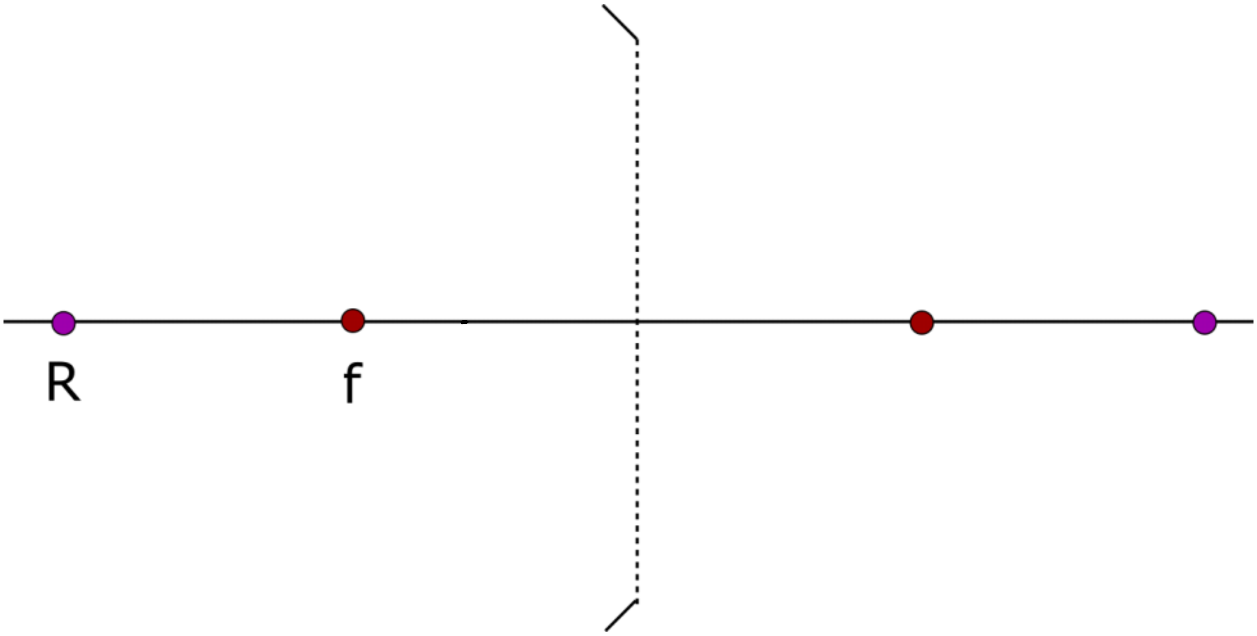
Ray tracing for convex spherical mirror

(1) Ray from object, parallel to optical axis, reflects as if it came from far focal point.

(2) Ray from object, towards far focal point, reflects parallel to optical axis.

(3) Ray from object, towards radius of curvature R, reflects back on itself.

PRACTICE: A gigantic funhouse mirror has a 20 ft radius of curvature and you are standing 6 ft in front of it. Use ray tracing to determine the location and relative size of the image formed. On the diagram below add a vertical arrow to represent the image location



PRACTICE: If a beam of white light falls on a converging lens made of ordinary glass, the red portion of light will be focused

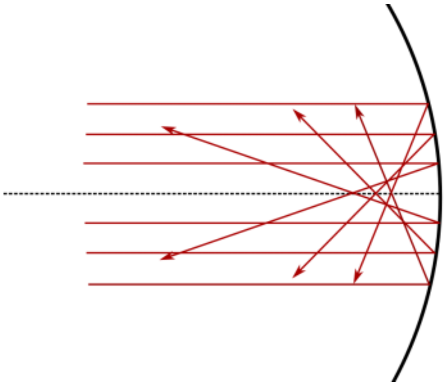
1. Closer to the lens than the blue portion
2. Farther from the lens than the blue
3. At the same point as the blue

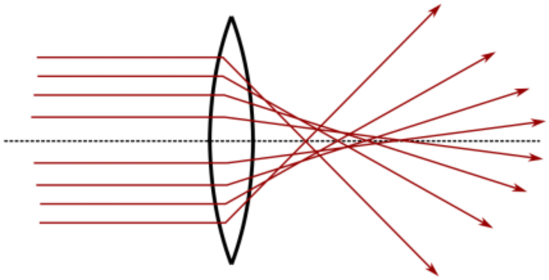
Lens aberrations

Spherical aberration

Light rays from single wavelength light parallel to optical axis do all converge on the focal point due to the spherical shape of the lens/mirror. The geometry of the lens/mirror can be adjusted to minimize the effect; parabolic shapes reduce this type of aberration effect.

Examples: *Spherical mirror* *Spherical lens*

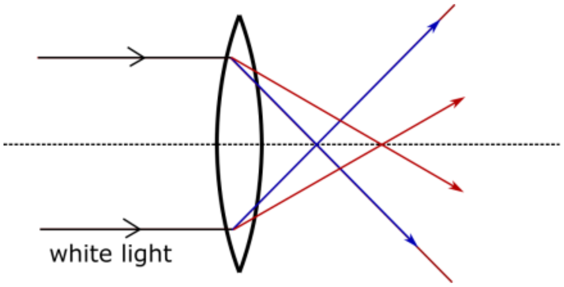


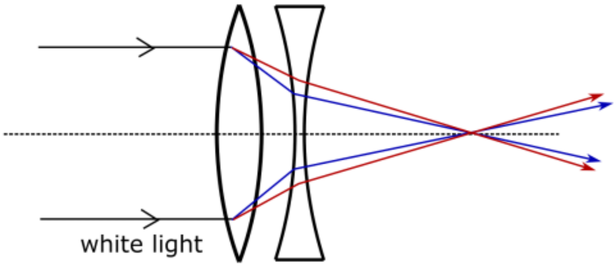


Chromatic aberration

In a given medium, the index of refraction is different for different wavelengths of light. So white light will "split" into its different wavelengths when passing through a lens. Each wavelength will cross a different point on the optical axis if originally parallel to optical axis. Use another lens to minimize effect.

Example: *converging lens* *reduce effect with diverging lens*





QUESTIONS FOR DISCUSSION:

1. If you place a piece of paper at the location of the virtual image of a diverging lens, will the paper burn after a sufficient amount of time?