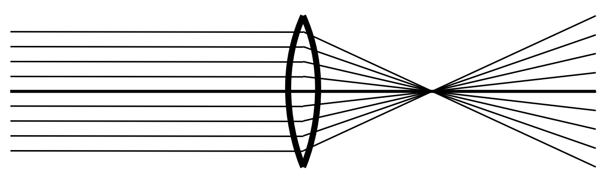
# Thin Lenses

The topics we have covered for spherical mirrors are very similar to how we will treat thin lenses. We will not go into a great deal of detail about lenses in this course. If you're interested, you should take PH303—Optical Physics.

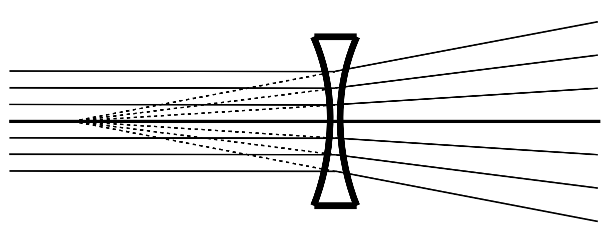
## Converging and Diverging Lenses

Just like mirrors, **converging lenses** bend paraxial light rays toward a focal point, while **diverging lenses** bend paraxial rays away from a focal point:

Converging Lens:



Diverging Lens:



As with the mirrors, the rays to the left of the diverging lens are represented by dotted lines because there are no actual rays there. They are merely extensions of the diverging rays on the right side of the lens back to the focal point.

Lenses can have different shapes, with planer, convex, and concave surfaces. There is, however, an easy way to quickly determine whether a lens is converging or diverging. Converging lenses are fatter in the center than at the edges. Diverging lenses are thinner in the center than at the edges.

An important difference between lenses and mirrors is that light is allowed to travel either direction through a lens. Therefore, each lens has two focal points, at equal distances on either side of the lens. Also note that in the approximation of a *thin lens*, all distances on the principal axis are measured from the center of the lens and we assume all bending takes place at the center of the lens. (Thick lenses are much more complicated.)

Examine the two pictures above, and imagine that the light rays are now coming from the right to the left. For the converging lens, the rays are converging to the focal point on the same side as the incoming rays. They then diverge from this focal point, and are bent into paraxial rays by the lens. Rays converging toward the focal point of the diverging lens that is opposite the incoming ray side also get bent into paraxial rays.

## Ray Tracing

Ray tracing follows very much as it did for mirrors, and the principal rays are described in much the same way. The main difference comes from the fact that there are two focal points. The three principal rays for a thin lens are

- A paraxial ray through the source point will bend toward the focal point on the outgoing side (converging lens) or away from the focal point on the ingoing side (diverging lens).
- A ray through the source point that approaches or passes through the focal point on the incoming side will be bent into a paraxial ray on the outgoing side (converging lens). A ray through the source that approaches the focal point on the outgoing side will be bent into a paraxial ray on the outgoing side.
- A ray through the source point that passes through the center of the lens will proceed unbent.

The characterization of images will proceed as before. Images formed by rays converging to a point on the outgoing side are *real*. Images formed by rays diverging from a point on the incoming side are *virtual*.

## Finding Images Algebraically

The formulas governing the formation of images are the same for lenses as for mirrors: $\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$, and $M \equiv h'/h = -s'/s$. As with mirrors, converging lenses have positive focal length, while diverging lenses have negative focal length.

Again, an image formed on the outgoing side of the lens, a *real* image, has positive image distance $s' > 0$. An image formed on the incoming side of the lens, a *virtual* image, has a negative image distance $s' < 0$.