Chapter 3: Mirrors and Lenses

- Lenses
  - Refraction
  - Converging rays
  - Diverging rays

- Converging Lens
  - Ray tracing rules
  - Image formation

- Diverging Lens
  - Ray tracing
  - Image formation

- The Lens Equation
  - Calculating image location
  - Calculating magnification
Sources of Paraxial Rays

- The rays coming from a distance source can be considered approximately paraxial when they reach a mirror.

- The rays from a nearby source, such as a candle or bare light bulb, cannot be considered paraxial.

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Mirror Ray Tracing: Limitations

- As noted in the book, these ray tracing rules are an approximation. For this approximation to be accurate, the paraxial rays should be closer to the axis, and the object should be small compared to the mirror radius.
- We’ve drawn these examples in an exaggerated manner, because it is easier to see.
- This is still a very useful technique, though, to determine the approximate location and size of the image.
Clicker Question

Using our ray tracing rules, which is the correct reflected ray for the incoming ray parallel to the axis? The colors are just for clarity and the letter C indicates the center of curvature, not a ray option. **RAY D IS CORRECT**

Spherical Lenses

What if we don’t want to have to look at a reflection to magnify or reduce an image? We can use refractive optics instead (lenses).
A concave surface is called “converging” because parallel rays converge towards one another.

The surface is converging for both air to glass rays and glass to air rays.

Convex Glass Surface

Convex Glass Surface
A concave surface is called “diverging” because parallel rays diverge away from one another.

Again, the surface is diverging for both air to glass rays and glass to air rays.
Lenses

- **Converging lens** "bi-convex" has two convex surfaces
- **Diverging lens** "bi-concave" has two concave surfaces

Compare to Mirrors

- **Convex**
- **Concave**

Note that this is opposite from mirrors, for which a convex surface is diverging and a concave surface is converging. When in doubt, trace some rays!
Converging Lens

- The focal point of a curved mirror was the image point of a distant star.
- It is the same for a lens.
- The focal point of a converging lens is where the incoming rays from a distant star all intersect.
- A distant star is used to guarantee that the incoming rays are parallel.

Note that a lens has a focal point on both sides of the lens, as compared to a mirror that only has one focal point.
Converging Lens

Similarly to a spherical mirror, incoming parallel rays are deflected through the focal point.

Thin Lenses

- Just as the ray tracing for mirrors is approximate and only accurate for certain situations, the ray tracing for lenses is accurate only for what are called “thin lenses”.
- A lens is considered “thin” if the thickness of the lens is much less than the distance from the lens to the focal point.
Thin Lenses: Vocabulary

• The distance from the focal point to the lens is called the “focal length” of the lens.

• To distinguish between converging and diverging lenses, \( f \) is defined as positive for converging lenses and negative for diverging lenses. We’ll come back to this.

Converging Lens: Ray Tracing Rules

• Another simplification that we can make is that we can draw the rays as deflecting from the center line of the lens, rather than drawing deflections at both lens surfaces. Again, this is only a good approximation for thin lenses.
Converging Lens: Ray Tracing Rules

Rule 1:
Similarly to a spherical mirror, incoming parallel rays are deflected through the focal point.

Converging Lens: Ray Tracing Rules

Rule 2:
Rays passing through the center of the lens are undeflected, they continue straight through without being bent. Several rays are shown here as examples.
Clicker Question

The center of a lens is approximately flat, I’ve drawn the normal to the surface for you. Given what we know about refraction, what does this ray REALLY do when it enters the glass?

A. Bend up  
B. Bend down  
C. Go straight through

Converging Lens: Ray Tracing Rules

Rule 3:  
The reverse of Rule 1, rays passing through the focal point are deflected to exit parallel to the axis
The image is real and inverted. In this case, the image is about the same size as the object, but the size of the image will depend on the position of the object relative to the focal point of the lens. Make sure you do the ray tracing to figure out the image position and size!

The image is still real and inverted. We’ve moved the object closer to the lens, and the image is now magnified (larger than the object).
If we move the object very close to the lens (less than the focal length) the rays passing through the lens are diverging; they will never intersect on the far side of the lens.

Is this image
A. Real
B. Virtual

Recall that a virtual image means no light rays reach the image location. This configuration is what occurs when you use a magnifying glass.
Magnifying Glass Applet


Diverging Lens

With a diverging lens, parallel rays are deflected such that when extended backwards, they appear to be coming from the focal point on the other side.
Parallel rays are deflected so they appear to be coming from the focal point in front of the lens.

Just like for converging lenses, rays that pass through the center of the lens continue undeflected (straight) through the lens.
Diverging Lens: Ray Tracing

Rays that, if extended, would pass through the focal point on the other side of the lens, are deflected to be parallel to the axis.

Diverging Lens: Image Formation

The image is virtual, reduced, and right side up.
The Lens Equation

• Ray tracing is useful, but kind of tedious for all these different cases, and accuracy requires very precise drawings.

• We can avoid ray tracing by using the lens equation

• However, this will require some algebra.

Focal Length

• Remember we defined the focal length for a lens

• We also defined the sign of f. The focal length, f, is defined as positive for converging lenses and negative for diverging lenses.
Lens Equation Quantities

- We also need to define some other distances.

Object distance, \( x_o \)

Focal length, \( f \)

Image distance, \( x_i \)

- The object distance is **positive** for an object to the left of the lens. The image distance is **positive** for a (real) image on the right of the lens. These quantities are negative for the reverse situation. Be careful with this.

Lens Equation Quantities

Image distance, \( x_i \)

Focal length, \( f \)

Object distance, \( x_o \)

- The image distance is **negative** for a (virtual) image on the left of the lens.
Clicker Question

• Which quantities are negative in this example?
  A. Image distance
  B. Focal length
  C. Object distance
  D. A and B
  E. A and C