Converging and Diverging Surfaces

- If the surface is **convex**, it is a **converging surface** in the sense that the parallel rays bend toward each other after passing through the interface.
- If the surface is **concave**, it is a **diverging surface**.
Snell’s Law at work

\[ \sin \theta_1 = \frac{1}{n_{\text{glass}}} \sin \theta_i \]

Converging Lens

Combining two converging surfaces, one gets converging (focusing) lens:

• The parallel rays converge at the second focal point \( F' \).
• The first focal point is at the front. All rays originated at this point become parallel to the axis after the lens.

Diverging Lens

To an eye on the right-hand side, these diverging rays appear to be coming from the point \( F' \): the second focal point.
Lenses

- **Thin Lenses:**
  - If the thickness of the lens is much less than the distance from the lens to each focal point.
  - The distances from the lens to F and F' are the same (focal length f of the lens).
  - f is taken as **positive** for converging lenses and **negative** for diverging lenses.
  - All rays passing through the center of the lens do not refract (bend).

Three Rays Again

- A ray parallel to the axis is refracted through F'.
- A ray through the center of the lens continues un-deviated.
- A ray that (extended when necessary) passes through F is deflected parallel to the axis.

*Any of the two rays are sufficient to locate the image point.*
Real Image from a Lens

Java Applet

- Very similar to the images of a concave mirror.

Properties of the image

- If the object is outside the focal point
  - It is real: the light rays do go through where the image is.
  - It is inverted.
  - If the object is outside of 2f, the image is smaller; At 2f, it has the same size; Inside 2f and up to f, it has a larger size.
- Inside the focal point
  Virtual, vertical, and always bigger.

Clicker Question

If I block the right half of the lens (looking back toward the source),
Clicker Question

If I block the right half of the lens (looking back toward the source),

1) The image will be brighter.
2) The image will be dimmer.
3) The right side of the image will be missing.
4) The left side of the image will be missing.
5) The image will be the same.

Usage of a converging lens

- Camera
- Eye
- Magnifying glass
- Telescope
- Microscope
- Eyeglasses
- ...

Parallel Rays

- If parallel rays fall on the lens, then the image can be determined by a ray going through the center of the lens and a second ray going through the first focal point of the lens.
- The image is always on the focal plane.

Divergent Lens

http://www.phys.hawaii.edu/~teb/optics/java/dlens/
Features of the image

• It is a virtual image: the light rays do not go through the image.
• The image is always smaller than the object.
• The image is erect.

The Lens Formula

\[
\frac{1}{s_{\text{image}}} = \frac{1}{s_{\text{obj}}} - \frac{1}{f}
\]

Converging lens \( f > 0 \); Diverging lens \( f < 0 \)
\( s_{\text{obj}} > 0 \); if \( s_{\text{image}} > 0 \), real image; \( s_{\text{image}} < 0 \), virtual

Power of a lens

• The focal length determines the image of the object formed by a lens.
• The power of the lens is defined as \( 1/f \). It describes the extent that the lens bends the light rays. When \( f \) is in meters, the power is in diopters.
  – \( f = 50 \text{cm}, \ P = 2 \text{D} \)
  – For a diverging lens, both \( f \) and \( P \) are negative.

Example - prescription: \(-2.5 \text{D} = -40 \text{cm} \) (diverging lens)

Aberrations

- Chromatic aberration
- Spherical aberration
- Pincushion distortion
Compound Lens

- In many optical instruments, **several lenses** are used to get the desired images.
- Rules for the ray tracing
  - Using the ray tracing to find the image from the first lens.
  - From this, find three rays needed for ray tracing through the second lens.
  - Ignore the first lens and apply the ray tracing rules to the second lens.

- If the thin lenses are so close that they touch each other, they form a combination that behaves just like another thin lens.
- The power of the combined thin lens is equal to the sum of the powers for the separate lenses.

\[
\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}
\]

or

\[
D = D_1 + D_2
\]

Fresnel Lens