Physics in Entertainment and the Arts

Chapter XXI b

Lenses

Simple Lenses

- Refraction also allows us to make light focusing devices other than mirrors
  - lenses

Parallel exit ray
A change of direction

Simple Lenses

- Combining these effects...
  
  Of course this would require some major polishing to work efficiently!

Simple Lenses

- There are two basic lens types
  - converging and diverging

Converging Lenses

- A converging lens is similar in operation to a concave mirror

Converging Lenses

- Example 1: Object beyond F
  - Image is real, inverted, and enlarged

Converging Lenses

- Example 2: Object between F and the lens
  - Image is virtual, upright, and enlarged
  - This is how a magnifying glass or reading glasses work!
Diverging Lenses
- A diverging lens is similar in operation to a convex mirror

The applicable ray diagrams
- Real images form on the opposite side of the lens from the object.
- Virtual images form on the same side of the lens as the object.

Example 1: Object beyond F
- Image is virtual, upright, and reduced.

The Lensmaker's Equation
- Used to design lenses for specific tasks

- \( f \) = focal length
- \( h_o \) = object height
- \( d_o \) = object distance
- \( h_i \) = image height
- \( d_i \) = image distance

Lenses + Mirrors
- Theater spotlights
  - We want an intense collimated (parallel) beam of light

Lens Limitations
- So far we have been ignoring something:
  - Refraction depends upon wavelength.
  - Our simple lenses have different focal points for different light wavelengths!
  - This is called chromatic aberration
  - It can be somewhat fixed by the addition of another lens (or lenses).

Lens Limitations
- Chromatic aberration and its fix
  - The combination lens is called an achromatic lens.
Lens Limitations

- **Spherical aberration** is caused by improper shaping of the lens surface.
- Need a parabolic versus spherical shape.

An improperly ground lens does not focus light to a point.

Spherical aberration can be fixed two ways:
- **Cheap:** Limit incident light to near the optic axis by use of an aperture device.
- **Expensive:** Use precision computer-controlled grinding to get a perfect parabola.

Photography: $f$-number vs Exposure Time

- **Lens aperture** is a measure of how much light we let into a camera.
- It is a numerical measure of the portion of the lens which is uncovered at any time.
- **We define a lens’ $f$-number as**

$$f\text{-number} = \frac{\text{focal length of lens}}{\text{diameter of lens aperture}}$$

Photography:

- Each increase in $f$-number corresponds to a halving of the uncovered lens area.

Photography:

- **So a smaller $f$-number means a larger aperture.**
- and more of the lens is exposed to incoming light.

Typical $f$-numbers for medium priced cameras:

$- f/1.4, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16$  

Photography:

- Each increase in $f$-number approximately correspond to a halving of the uncovered lens area.

Photography:

- A good photographer can determine the correct exposure time to pair with each of the camera’s $f$-numbers.
- or $\text{f-stops}$ as they’re called.

- We can double the light entering a camera in two ways
- Double the exposure time
- Decrease the f-stop to the next smaller.

Photography: Exposure Time Comparisons

- Short Exposure Time:
  - $f/1.4$  
  - Aperture: $/1.4$

- Long Exposure Time:
  - $f/22$
  - Aperture: $/22$

Photography:

- Each method has its drawbacks
- Longer exposure times mean that the object being photographed must remain still longer.
- Any motion will blur the picture.
- Smaller f-stops reduce the photograph’s depth of field.
- Which we will define next.
Photography: Exposure Time Comparisons

Short Exposure Time:
3.1 ms = 0.0031 s
Aperture: f/5.6

Long Exposure Time:
1.3 s
Aperture: f/22

Photography: Depth of Field

- **Depth of field** refers to the range of distances from the camera lens where objects will appear in focus.
- Since light enters the lens from all directions, there is no single focal point for all the light!

Some examples:
- Blurred background
- Sharp foreground

Photography: Depth of Field

- Some examples:
  - Extreme close-up!

Effect of increasing the f-stop:

Photography: Depth of Field

- Some examples:
  - Extreme close-up!