

Ch 25 Optical Instruments

We have studied principles of geometric optics. Now we are going to apply those principles to construct some useful optical instruments that will help us see better in different ways.

1. Camera

Diagram

Components of a camera:

- **Lens:** **converging** lens with focal length f
 f largely determines the distance between the lens and film
- **Aperture:** “f-stop” = f/D
 f : focal length of lens
 D : diameter of the aperture
“f-stop” determines the amount of light that falls on the film. Larger opening (D) → more light; shorter distance (f) → more light. So the **smaller** the “f-stop”, the **more** light.
- **Shutter:** the **shutter speed** really means the time light is let to fall on film
 $1/60$ means $1/60$ s
- **Exposure:** total amount of light falling on film, product of “shutter speed” and $(\frac{1}{f - stop})^2$.
- **Focusing:** moving the lens (changing the lens-film distance) so that the image is placed exactly at the film. The focal length is not changed.
Lens-film distance can be determined by

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

- **Zooming:** changing the focal length of the lens.

2. Human Eye

2A. Structure

Diagram

A human eye is very similar to a camera. **Retina** acts as the film. But the focusing mechanism is different: the lens-retina distance cannot be changed, so the ciliary muscle changes the focal length of the lens to place the image exactly at the retina.

- To see far away objects, stretch lens to make it thinner (relaxed eye and longer f);
- To see close objects, squeeze the lens to make it thicker (squinted eye and shorter f).

2B. Far Point and Near Point

- **Far Point:** the farthest distance an eye can focus on

For a **normal** eye, far point is at infinity:

$$d_o = \textit{infinity} \rightarrow d_i = f \text{ eye is relaxed}$$

- **Near Point (N):** the closest distance an eye can focus on. For a **normal** eye, $N = 25 \text{ cm}$

2C. Nearsightedness

An eye is **nearsighted** if its **far point** is not at infinity but at some **finite distance**.

To correct nearsightedness, one uses a lens to **place** the image of an **object at infinity** at the **real far point** of the eye (smaller, upright, virtual image) → need a **diverging lens!**

Diagram

$$f = d_i \quad (d_i < 0) \quad \rightarrow \quad f < 0)$$

Important Notes:

d_i and d_o are measured from lens, but far point is measured from the eye
→ need to consider lens-eye distance for glasses, but no extra distance for contact lenses.

2D. Farsightedness

An eye is **farsighted** if its near point is **not at 25 cm** but **at a larger distance**.

To correct farsightedness, one uses a lens to place the image of an **object at 25 cm** at the **real near point of the eye** (larger, upright, virtual image) → need a **converging lens!**

Diagram

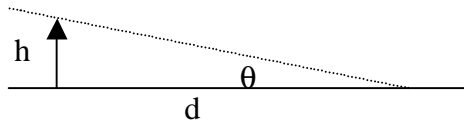
$$d_o = 25\text{cm} - d_{\text{lens-eye}} \quad d_i = N - d_{\text{lens-eye}}$$

Use the lens equation to calculate f .

3. Magnifying Glass

3A. Angular Magnification

- Our perception of the size of an object depends on the distance. Precisely, it is determined by the “**angle subtended**” by the object **relative to the eye**



When d is very large $q = \frac{h}{d}$

- For an **unaided** eye, the closest one can place an object and still see it

clearly is the near point. So the **largest** angle is $q = \frac{h}{N}$

- If an instrument allows one to put the object at a closer distance (put the **image** at distance larger than N so the eye can see), then the angle would be larger (object appears bigger). The **(angular) magnification** is

defined as $M = \frac{q'}{q}$

3B. Relaxed Eye

Diagram

The final image is at infinity, so the object is at the focal point of the converging lens. We have

$$q' = h / f$$

$$M = q' / q = \frac{h / f}{h / N} = N / f$$

3C. Eye Focused at Near Point

Diagram

The image is at near point N (a distance of N in front of the lens), so $d_i = -$

N . Using lens equation we have

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} = \frac{1}{f} + \frac{1}{N}$$

and $M = \mathbf{q}'/\mathbf{q} = \frac{h/d_o}{h/N} = \frac{N}{f} + 1$

4. Telescope

4A. 2-Lens Device

- The lens closest to object is called “**Objective Lens**”.

$$f_o \quad d_o^o \quad d_i^o$$

It has to be a **converging lens**.

- Image** created by the **objective lens** becomes the **object** for the second lens: **Eye Piece**

$$f_e \quad d_o^e \quad d_i^e$$

4B. Keplerian Telescope

Diagram

- A telescope bring a far away object close by, so that the angle subtended is increased
- A Keplerian telescope consists of two **converging** lenses
- Objective lens brings the object close

$$d_o^o = \infty \quad \text{so} \quad d_i^o = f_o \quad \mathbf{q} = h/f_o$$

The **image** is at the **focal point** of the **objective lens**.

- Eye piece** acts as a simple **magnifier**, which magnifies the image for the objective lens. One wants to look with relaxed eye, so the image for the objective lens (object for the eye piece) must be at the focal point of eye piece

$$d_i^e = \infty \quad \text{so} \quad d_o^e = f_e \quad \mathbf{q}' = -h/f_e$$

- The magnification of the telescope is

$$M = \mathbf{q}' / \mathbf{q} = -f_o / f_e$$

The length of the telescope is

$$l = f_o + f_e$$

5. Microscope

- A compound microscope is used to magnify object **at close distance**. It also consists of two **converging lenses**.

Diagram

- The objective lens forms a real inverted image

$$m_o = \frac{d_i^o}{d_o^o} = \frac{l - f_e}{d_o^o}$$

- Eye piece acts as a simple magnifier. The final image is at infinity (looking with relaxed eye), so the image for objective lens is at the focal point of eye piece. And

$$m_e = \frac{N}{f_e}$$

- The total magnification of the microscope is

$$M = m_o m_e = \left(\frac{l - f_e}{d_o^o} \right) \left(\frac{N}{f_e} \right) \approx \frac{Nl}{f_e f_o}$$