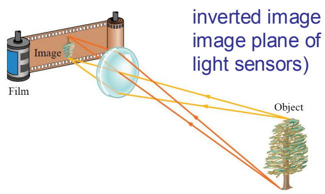
5.2 Optical Instruments

- Optical Instruments
  - –the eye
  - –camera
  - –Magnifiers and microscopes
  - –Telescopes

Optical systems

- For systems of several mirrors and lenses the image formed by one element serves as the object for the next element.

Camera

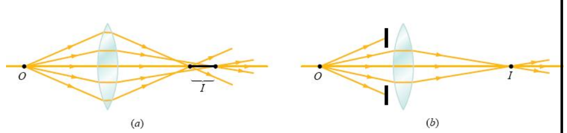


The camera forms a real inverted image of an object at the image plane of the film (digital light sensors)

Limitations of Lens

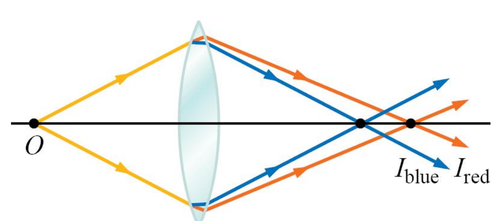
- Spherical aberration
- Chromatic aberration
- F-number

Spherical Aberration



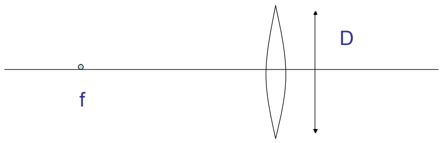
non-paraxial rays   paraxial rays

Chromatic Aberration



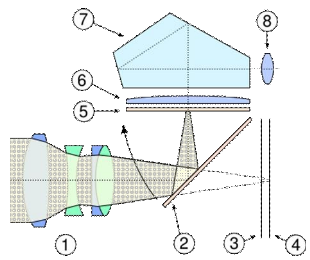
f-number

$$\text{f-number} = \frac{f}{D}$$



"Fast" lenses with low f-numbers (1.2)are difficult to make and expensive because aberrations.

Single lens reflex camera



1 multielement lens
2 mirror
3 shutter
4 film
5 focusing screen
6 lens
7 prism
8 lens

Optical system for a Single lens reflex camera

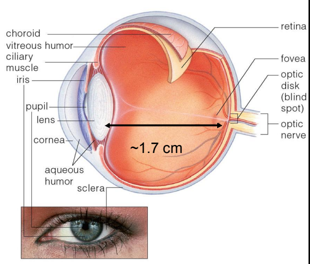
Eye

Cornea, aqueous humor and lens refract light

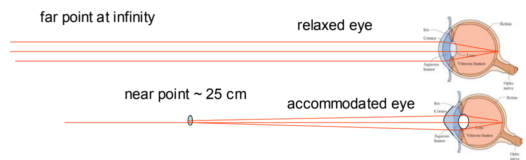
Detection at the retina. Principally at the fovea.

The amount of light entering the eye is regulated by the size of the pupil which is the aperture in the iris.

The eye is focused by changing the flatness of the lens, in a process called accommodation.



Range of Normal Vision



The relaxed eye can focus on an object at infinity (far point)

The accommodated eye can focus on an object at 25 cm (near point)

The near point and the far point can vary in different individuals and can change with age.

Defects in vision

Nearsightedness and farsightedness – due to the mismatch between the focal length of the eye and the distance between lens and retina.

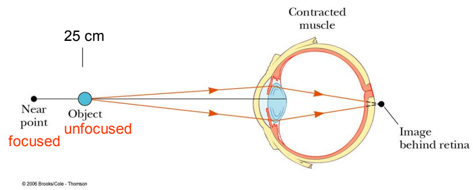
Power of a corrective lens

Prescription eyeglass lenses are specified by the power P

$$P = \frac{1}{f}$$

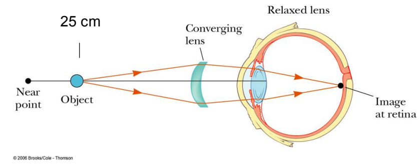
Units of m^{-1} or diopters

Farsightedness
Lack of near vision



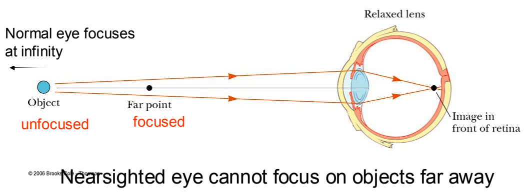
Farsighted eye cannot focus on an object at the near point of a normal eye.
The lens-retina distance is too short and/ or the lens is not convergent enough.

Correcting farsightedness



The light is made to converge more by using a converging lens.

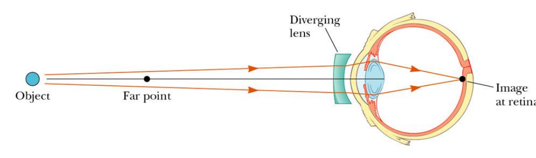
Nearsightedness
lack of far vision



Nearsighted eye cannot focus on objects far away (further than the far point < infinity)

The lens retina distance is too long and/or the lens is too converging.

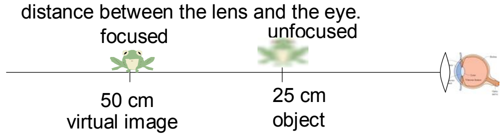
Correcting nearsightedness



Nearsighted vision can be corrected by using a diverging lens (making the light less convergent).

Example

A farsighted person has a near point of 50 cm. What power lens will correct this to normal vision. (ignore the distance between the lens and the eye.



Use a lens that can take an object at 25 cm and form a virtual image at a distance of 50 cm.

$$f=\frac{\ell\ell'}{\ell+\ell'}=\frac{(25)(-50)}{25-50}=+50cm=0.50m$$

P= 1/0.5m =2.0 diopters

A converging lens

Example

A nearsighted person has a far point of 25 cm. What power lens will correct this to normal vision. (ignore the distance between the lens and the eye.

Use a lens that can take an object at infinity and form a virtual image at 25 cm.

$$\frac{1}{\ell}+\frac{1}{\ell'}=\frac{1}{f} \qquad \frac{1}{\infty}+\frac{1}{-25}=\frac{1}{f}$$

A diverging lens

f=-25 cm=-0.25m

P= $\frac{1}{-0.25}=-4.0$diopters

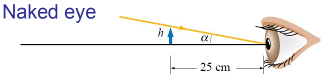
Magnifiers

How do we image small objects?

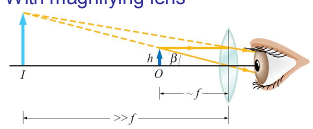
- We can image a small object by bringing it close to our eye.
- But we cannot bring it closer than the near point. (we can't focus on it).
- Alternatively we can produce a larger image of the object at the near point (or farther away) that can be focused on by the eye.

Angular magnification

Naked eye



With magnifying lens



Angle subtended by the object (small angle approx. radians)

$$\alpha = \frac{h}{25cm}$$

$$\beta = \frac{h}{f}$$

$$m = \frac{\beta}{\alpha} = \frac{25cm}{f}$$

If f is smaller than 25 cm the image will be magnified. You can bring the object close to the eye.

Question

What a magnifying glass with a focal length of 10 cm is used. What is the magnification?

Compound Microscope

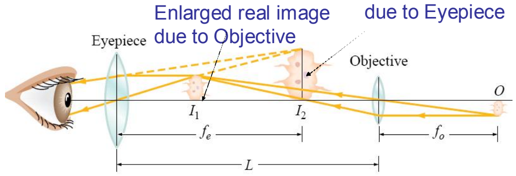
A compound microscope magnifies the image of small objects using 2 lenses.

- Objective lens forms an enlarged real image
- Eyepiece lens forms an enlarged virtual image that is visualized by the eye. (as with the magnifying glass)

Compound Microscope (not to scale)

Enlarged real image due to Objective

Enlarged virtual image due to Eyepiece



objective magnification $m_o \sim -\frac{(L - f_e)}{f_o} \sim -\frac{L}{f_o}$ for $L >> f_o$

eyepiece magnification $m_e = \frac{25cm}{f_e}$ magnifier

Total magnification $m = -\frac{L}{f_o}\left(\frac{25cm}{f_e}\right)$

Question

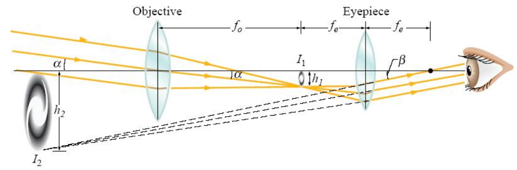
Find the magnification of a compound microscope with focal lengths for the objective and eyepiece of 6.1 mm and 1.7 mm respectively and the lenses are 8.3 cm apart?

Refracting telescope

A refracting telescope collects light from distant objects and form an image with a large angular magnification using 2 lenses

- Objective lens forms a real image of the far away object near the focal length
- Eyepiece views the image like a magnifier.

Refracting telescope



α is the angle subtended by light $\alpha$from the far away object. $\alpha = \frac{h_1}{f_o}$

β is the angle subtended by the light through the eyepiece $\beta = \frac{h_1}{f_e}$

angular magnification $m = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$

Telescope

The Hubble space telescope has an objective mirror with a focal length of 57.8 m viewed with optics equivalent to an eyepiece with a focal length of 7.2×10^{-3}m What is the angular magnification?

$$m = \frac{f_o}{f_e} = \frac{57.8}{7.2 \times 10^{-3}} = 8.0 \times 10^3$$

Hubble Telescope Image of M100 Spiral Galaxy (NASA)

Limits to magnification

- For refracting optics there are problems of chromatic and spherical aberration.
- Problems in precision in constructing the refracting and reflecting surfaces.
- Diffraction – A basic problems having to do with the wave nature of light (discussed next)