

5.1 Simple Optical Systems

Lens Combinations

Cameras

The Eye

Combinations of lenses

- When two lenses are used in combination, the image of the first lens is the object for the second lens.
- The total magnification is the product of the magnifications of the first and second lens.

Find the image formed by two lenses in combination

Image formed by lens 1

$$q_1 = \frac{p_1 f_1}{p_1 - f_1} = \frac{(30)(10)}{30 - 10} = 15 \text{ cm}$$

from lens 1

Image formed by lens 2

$$p_2 = 20 - q_1 = 20 - 15 = 5 \text{ cm}$$

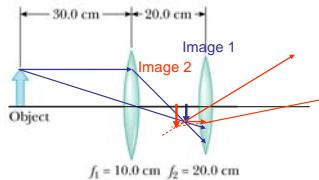
$$q_2 = \frac{p_2 f_2}{p_2 - f_2} = \frac{(5)(20)}{5 - 20} = -6.7 \text{ cm}$$

from lens 2

Magnification

$$M = M_1 M_2 = \left(\frac{-q_1}{p_1} \right) \left(\frac{q_2}{p_2} \right) = \left(\frac{-15}{30} \right) \left(\frac{-6.7}{5} \right) = -0.67$$

Inverted
Reduced



Lens Power

The power of a lens is defined as

$$\mathcal{P} = \frac{1}{f} \quad \text{Units of diopter.}$$

where f is the focal length of the lens in meter.

A lens with a focal length of -20 cm has a power of -5.0 diopters.

Powers are often used by optometrists to describe eye glass lenses

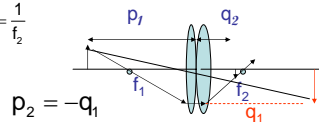
For two lenses in contact the total power is the sum of powers of the individual lenses

$$\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_1} \quad \frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_2}$$

$$-\frac{1}{q_1} + \frac{1}{q_2} = \frac{1}{f_2}$$

Eliminate q_1

$$\frac{1}{p_1} + \frac{1}{q_2} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f}$$



The image of the first lens is the object for the second lens. Virtual object has a negative sign.

Simple optical systems

Lens

Light detection system

Focusing mechanism

Light intensity adjustment

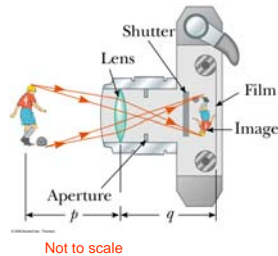
Camera

Lens refracts light

Film (or light detector) near focal point of the lens

Focusing by movement of the lens detector distance.

Aperture changes the light intensity level of the image.



Camera lens

Good camera lenses are a combination of several lenses to correct for spherical and chromatic aberration.

May have either a fixed focal length or variable focal length (zoom lens).

The "speed" of the lens is determined by the f-number = focal length/ diameter

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

The lower the f-number the higher the intensity of light at the film (detector)



Zoom Lens
Variable focal length

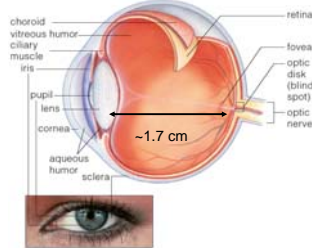
Eye

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.



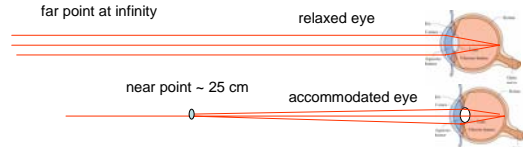
Range of vision

far point at infinity

relaxed eye

near point ~ 25 cm

accommodated eye



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

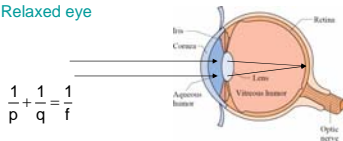
The accommodated eye can focus on an object at 25 cm (near point)

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

Question

For the normal eye what is the focal length of the relaxed eye. What is the focal length of the accommodated eye focusing on an object at the near point?

Relaxed eye



$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

When $p = \infty$

$$q = f = 1.70 \text{ cm}$$

Question

For the normal eye what is the focal length of the relaxed eye. What is the focal length of the accommodated eye focusing on an object at the near point?

Accommodated eye

near point

25 cm

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

When $p = 25 \text{ cm}$

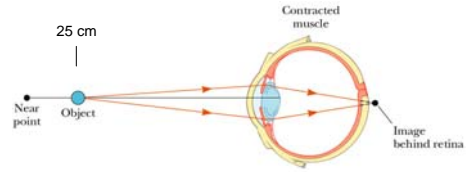
$$f = \frac{pq}{p+q} = \frac{(25)(1.7)}{25+1.7} = 1.6 \text{ cm}$$

f does not have to change very much

Defects in vision

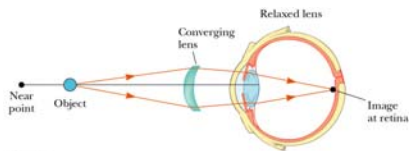
Nearsightedness and farsightedness – due to the mismatch between the focal length of the eye and the distance between lens and retina.

Farsightedness Lack of near vision



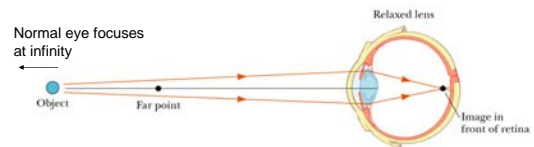
Farsighted eye cannot focus on an object at the nearpoint of a normal eye.
The lens-retina distance is too short and/ or the lens is not convergent enough.

Correcting farsightedness



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

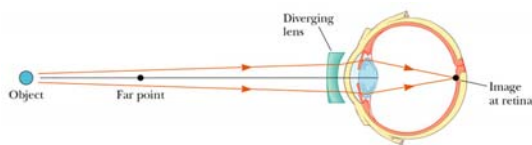
Nearsightedness lack of far vision



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.

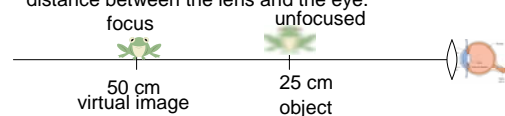
Correcting nearsightedness



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.



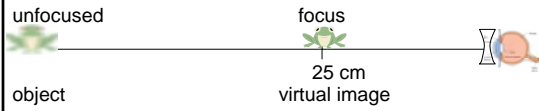
Use a lens that can take an object at 25 cm and form a virtual image at a distance of 50 cm.

$$f = \frac{pq}{p+q} = \frac{(25)(-50)}{25-50} = +50\text{cm} = 0.50\text{m} \quad \mathcal{P} = 1/0.5\text{m} = 2.0 \text{ diopters}$$

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.

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad \frac{1}{\infty} + \frac{1}{-25} = \frac{1}{f} \quad \text{A diverging lens}$$

$$f = -25 \text{ cm} = -0.25 \text{ m} \quad \mathcal{P} = \frac{1}{-0.25} = -4.0 \text{ diopters}$$