Physics for Scientists & Engineers 2

Spring Semester 2005

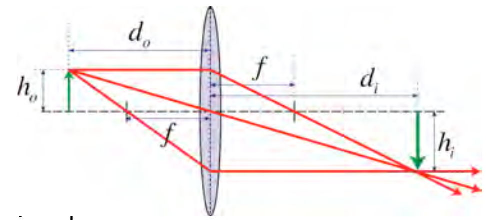
Lecture 39

Review

- The Lens Equation is given by

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

  - f is the focal length
  - d_o is the object distance
  - d_i is the image distance



- The magnification of a lens is given by

$$m=-\frac{d_i}{d_o}=-\frac{h_i}{h_o}$$

  - h_o is the object height
  - h_i is the image height

Review (2)

- We define conventions for distances and heights
  - We define the focal length f of a convex lens to be positive and the focal length of a concave lens to be negative
  - We define the object distance d_o to be positive
  - If the image is on the opposite side of the lens from the object, the image distance d_i is positive and the image is real
  - If the image is on the same side of the lens as the object, the image distance d_i is negative and the image is virtual
  - If the image is upright, then h_i is positive and if the image is inverted, h_i is negative
- The power of a lens is defined to be

$$D=\frac{1\text{ m}}{f}$$

Review (3)

- For a convex lens, we find that for $d_o > f$ we always get a real, inverted image formed on the opposite side of the lens
- For a convex lens and $d_o < f$, we always get a virtual, upright, and enlarged image on the same side of the lens as the object
- The special cases for $d_o > f$ for a convex lens are

Case	Type	Direction	Magnification
$f < d_o < 2f$	Real	Inverted	Enlarged
$d_o = 2f$	Real	Inverted	Same size
$d_o > 2f$	Real	Inverted	Reduced

- For concave lenses, we always get an image that is virtual, upright, and reduced in size

Systems of Lenses

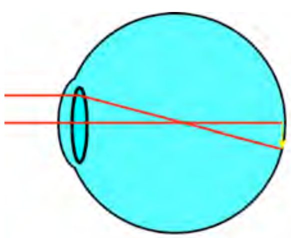
- Now we will look at images formed by systems of lenses rather a single lens
- The concept is to use one lens to image an object
- We use the image of the first lens as the object for the second lens
- Thus we can produce various optical instruments with combinations of lenses
- We start with the human eye and corrections to human vision
- We then proceed to microscopes and telescopes

The Human Eye

- The human can be considered an optical instrument
- The eye is nearly spherical in shape and is about 2.5 cm in diameter
- The front part of the eye is more sharply curved than the rest of the eye and is covered with the cornea
- Behind the cornea is a fluid called the aqueous humor
- Next is the lens composed of a fibrous jelly
- The lens is held in place by ligaments that connect it to the ciliary muscle that allows the lens to change shape and thus change the focus of the lens
- Behind the lens is the vitreous humor
- The index of refraction of the two fluids in the eye are close that of water with a value of 1.44
- The index of refraction of the material making up the lens is 1.34
- Thus most of the refraction occurs at the air/cornea boundary.

The Human Eye (2)

- Refraction at the cornea and lens surfaces produces a real image on the retina of the eye
- The image is converted from light to electrical impulses by rods and cones in the retina
- The impulses are sent to the brain through the optic nerve
- In front of the lens is the iris, which opens and closes to regulate the amount of light that is incident on the retina
- For an object to be seen clearly, the image must be formed at the location of the retina as shown to the right
- The shape of the eye cannot be changed so shaping the lens must control the distance of the image

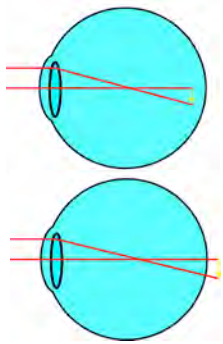


The Human Eye (3)

- For a distance object, relaxing the lens focuses the image
- For close objects, the ciliary muscle increases the curvature of the lens to focus the image on the retina
- This process is called accommodation.
- The extremes over which distinct vision is possible are called the far point and near point
  - The far point of a normal eye is infinity
  - The near point of a normal eye depends on the ability of the eye to focus
- This ability changes with age
- A young child can focus on objects as near as 7 cm
- As a person ages, the near point increases
- Typically, a 50 year-old person has a near point of 40 cm

The Human Eye (4)

- Several common vision defects result from incorrect focal distances
- In the case of myopia (near-sightedness), the image is produced in front of the retina
- In the case of hypermetropia (far-sightedness), the image is produced behind the retina



- Myopia can be corrected using concave (diverging) lenses
- Hypermetropia can be corrected using convex (converging) lenses.

Example: Corrective Lenses (1)

- *Question:*
- What is the power of the corrective lens for a myopic (near-sighted) person whose uncorrected far point is 15 cm?
- *Answer:*
- The corrective lens must form a virtual, upright image 15 cm in front of the lens of an object located at infinity as shown below

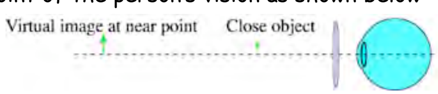
- Thus the object distance will be ∞ and the image distance will be –15 cm

$$\frac{1}{\infty}+\frac{1}{-0.15\text{ m}}=\frac{1}{f}=-6.7\text{ diopters}$$

- The required lens is a diverging lens with a power of –6.67 diopters (a focal length of -0.15 m)

Example: Corrective Lenses (2)

- *Question:*
- A hypermetropic (far-sighted) person whose uncorrected near point is 75 cm wishes to read a newspaper at a distance of 25 cm. What is the power of the corrective lens needed for this person?
- *Answer:*
- The corrective lens must produce a virtual, upright image of the newspaper at the near point of the person's vision as shown below



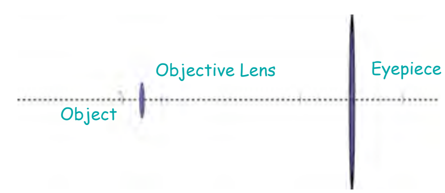
- The object and image are on the same side so the image distance is negative
- Thus the object distance is 25 cm and image distance is -75 cm

$$\frac{1}{0.25\text{ m}}+\frac{1}{-0.75\text{ m}}=\frac{1}{f}=+2.7\text{ D}$$

- The required lens is a converging lens with a power of +2.7 diopters (focal length of +0.38 m)

The Microscope

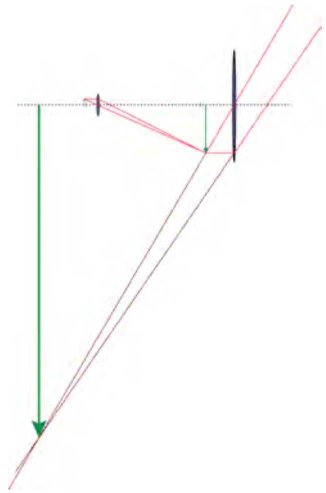
- Microscopes exist in many forms
- The simplest microscope is a system of two lenses
- In our example the microscope is constructed of two thin lenses



- The first lens is a converging lens of short focal length, f_o, called the objective lens
- The second lens is another converging lens of greater focal length, f_e, called the eyepiece
- The object to be magnified is placed just outside the focal length of the objective lens

Microscope (2)

- This objective lens forms a real, inverted, and enlarged image of the object some distance from the objective lens
- This image then becomes the object for the eyepiece lens
- This intermediate image is placed just inside the focal length of the eyepiece
- The eyepiece lens then produces a virtual, upright, and enlarged image of the intermediate image
- The resulting magnification of the microscope is just the product of the magnifications from each lens



Microscope (3)

- The magnification of the microscope is given by

$$m = -\frac{0.25L}{f_o f_e}$$

- where L is the distance between the two lenses and 0.25 results from the assumption that the final image is produced at a comfortable distance of 0.25 m
- Note that real microscopes have complicated, compound lenses designed to overcome problems such as spherical aberration and chromatic aberration, but the principle of the magnification provided by microscopes is given by this analysis

Example: Microscope

- Assume that we have a microscope with an objective lens and an eyepiece separated by 30 cm. The focal length of the objective lens is 20 mm and the focal length of the eyepiece is 20 mm.
- What is the magnification of the microscope?

$$|m| = \frac{0.25L}{f_o f_e} = \frac{0.25 \cdot 0.30\text{ m}}{(0.020\text{ m})(0.020\text{ m})} = 188$$