Optical Instruments

Sections 25.4 - 25.5

Reading Assignment

Read sections 24.1 - 24.3

Homework Assignment 9

Homework for Chapter 25 (**due at the beginning of class on Wednesday, October 27**)
Q: 3, 6, 14
P: 16, 24

Question

A farsighted man has a near point of 100 cm. When wearing his glasses, he can see objects that are 25 cm away. What is the focal length of the lens in his glasses? Assume that the lens is 2.0 cm from his eye.

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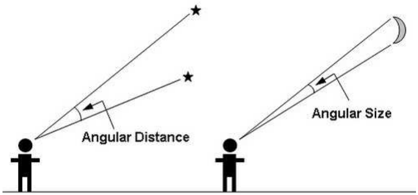
Answer

- To correct farsightedness, the man should place converging lenses (his glasses) in front of his eyes
- With his glasses on, his near point is 25 cm (or 23 cm in front of the lens)
- When an object is placed at this distance, we would like for it to form a virtual image 100 cm from his eye (or 98 cm in front of the lens)
- Using the thin lens equation $1/f = 1/p + 1/q$ where $p = 23$ cm and $q = -98$ cm, and solving for f we find that

$$\begin{aligned} f &= \left(\frac{1}{p} + \frac{1}{q}\right)^{-1} = \left(\frac{1}{23\ \mathrm{cm}} - \frac{1}{98\ \mathrm{cm}}\right)^{-1} \\ &= 30.1\ \mathrm{cm} \end{aligned}$$

Apparent size

- The size of the image formed at the retina depends upon the angle θ subtended by the object at the eye
- As the object moves closer to the eye, θ increases and a larger image is observed
- An average normal human eye, however, cannot focus on an object closer than about 25 cm (the near point)
- Therefore, θ is a maximum when the object is located at the near point



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The simple magnifier

- To further increase the apparent size of an object, a converging lens can be placed in front of the eye
- A **simple magnifier** (or **magnifying glass**) consists of a single converging lens
- If the object is located inside the focal point of the lens, then the lens will form a virtual, upright, enlarged image
- A magnifying glass allows us to place an object closer to our eye (then the near point) so that it subtends a larger angle
- The converging lens then produces a virtual image which must be *at least* 25 cm (the near point) from the eye so that the eye can focus on it

Angular magnification

- We define the **angular magnification** m as the ratio of the angle subtended by an object with a lens in use (θ) to the angle subtended by the object if placed at the near point with no lens in use (θ_0)

$$m = \frac{\theta}{\theta_0}$$

- With a little work (and using the small-angle approximation that $\tan\theta \approx \theta$) we find that

$$m = \frac{N}{p} = N\left(\frac{1}{f} - \frac{1}{q}\right)$$

where N is the near point of the eye (assume that $N = 25\ \mathrm{cm}$)
- Since the image formed in this case is virtual, q is negative
- Therefore, the angular magnification is a maximum when the image is at the near point of the eyes ($q = -25$ cm)

$$m_{\mathrm{max}} = 1 + \frac{25\ \mathrm{cm}}{f}$$

- The angular magnification is a minimum when the image is at infinity ($q = -\infty$) which means that the object is located at the focal point of the lens

$$m_{\mathrm{min}} = \frac{25\ \mathrm{cm}}{f}$$

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Answer

- To obtain maximum magnification, the image should be located at the near point of the eye which, for a normal eye, is 25 cm (so $q = -25.0$ cm)
- Therefore, using the thin-lens equation $1/p + 1/q = 1/f$ and solving for p we find that

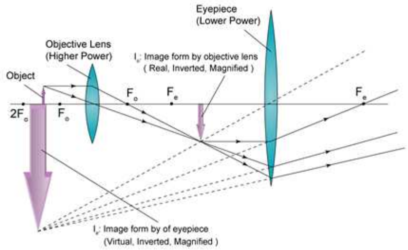
$$\begin{aligned} p &= \left(\frac{1}{f} - \frac{1}{q}\right)^{-1} = \left(\frac{1}{5.00 \text{ cm}} + \frac{1}{25.0 \text{ cm}}\right)^{-1} \\ &= 4.17 \text{ cm} \end{aligned}$$

- The maximum magnification of this simple magnifier is

$$m_{\text{max}} = 1 + \frac{N}{f} = 1 + \frac{25.0 \text{ cm}}{5.00 \text{ cm}} = 6$$

The compound microscope

- A simple magnifier provides only limited assistance in inspecting minute details of an object (with a single lens, an angular magnification of only about 4 or so is possible, without serious aberrations)
- Greater magnification can be achieved by combining two lenses
- A **compound microscope** consists of two lenses:
  - The *objective* has a very short focal length f_o (typically, less than one centimeter)
  - The *eyepiece* has a larger focal length f_e (typically, a few centimeters)
- The two lenses are separated by some distance L that is much greater than either f_e or f_o



Magnification

- The object, which is located just outside of the focal point of the object, produces a real, inverted image (I_1) between at (or very close to) the focal point of the eyepiece
- The eyepiece, which serves as a simple magnifier, produces a virtual, enlarged image (I_2) of I_1
- The lateral M_1 of the first image I_1 is

$$M_1 = -\frac{q_1}{p_1}$$

- However, because $q_1 \approx L$ and $p_1 \approx f_o$, the lateral magnification by the objective is

$$M_o \approx -\frac{L}{f_o}$$

- Assuming that the first image I_1 is located at the focal point of the eyepiece, then angular magnification by the eyepiece is

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

  where N is the near point of the eye
- The overall magnification M of the compound microscope is then

$$M = M_o m_e \approx -\frac{NL}{f_o f_e}$$

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