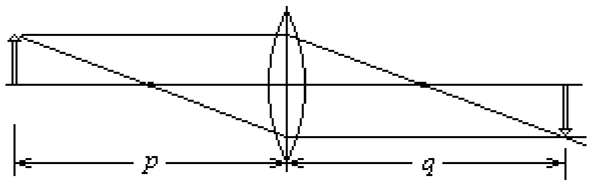
Chapter 27 – problems 3, 5, 7, 8, 9, 11, 15, 17, 22, 23, 25

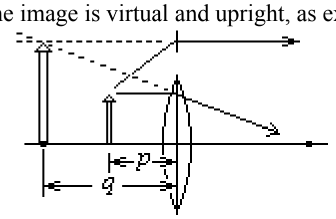
3. and 5. For single-lens problems, such as this one, I will always place the object to the left of the lens. Real images are then to the right of the lens and are inverted. They have positive values of q. Virtual images have negative values of q. They are to the left of the lens and are upright. Notice that this is not the same as for mirrors, where real images are to the left of the mirror and virtual images are to the right of the mirror. The three situations for this problem are sketched below. Notice the general behavior. When the object is far from the lens, the image is real and just outside the right-hand focal point. As the object is brought close to f on the left, the image go to large values of q to the right. When the object is between the lens and f, the image is virtual, upright and to the left of the lens.

   In all of the following cases, f = 40 cm and the object height is 5 cm.

   a. Let f = 40 cm and p = 80 cm. Substitution into the lens equation gives 1/80 + 1/q = 1/40. This has the solution q = 80 cm. The image is real and inverted. The image height is (5)(80)/(80) = 5 cm.

   b. For case b) the object distance is p = 50 cm. This makes the image farther to the right and larger. (The sketch is not shown.) Substitution into the lens equation gives 1/50 + 1/q = 1/40. The solution is q = 200 cm. The image is again real and inverted. The image height is (5)(200)/(50) = 20 cm.
   c. For case c) the object is at 20 cm, which means it is inside the focal length. Therefore, the image is now virtual and can only be seen by looking through the lens. Substitution into the lens equation gives 1/20 + 1/q = 1/40. This has the solution q = -40 cm. The image is virtual and upright, as expected. The image height is (5)(40)/(20) = 10 cm. An accurate diagram is shown below.

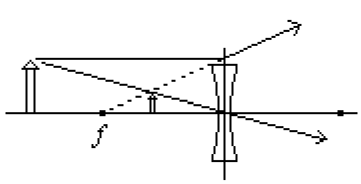
   The solid lines represent the actual sample rays. The dashed lines are backwards extensions showing where the rays seem to originate. Pay attention to the two particular rays shown. Can you see another one that also could have been used?

7. The data tell us that the object is far from the lens. This implies that the image is real and inverted. The image distance of 60 cm is also expected to be very close to the focal length. We substitute into the lens equation, using p = 25 m and q = +0.60 m to get 1/25 + 1/0.60 = 1/f. Solving for f gives f = 0.586 m, or 58.6 cm.

8. Since the image is projected onto a screen, it must be real. The image is also enlarged in each of its dimensions by the factor q/p = 4/0.12 = 33. Therefore, the image has dimensions 83 x 117 cm. Finally, the focal length is found from the lens equation with p = 12/100 m and q = 4.0 m. The result is
   1/4 + 100/12 = 1/f, giving f = 12/103 m = 11.7 cm.

9. A diverging lens will always produce a virtual upright image of a real object. For this problem, f must be a negative number, f = -60 cm. I will only sketch one of the cases and compute the others. Thus, substituting each p into the lens equation produces the following results.
   a. Let p = 200 cm. Then 1/200 + 1/q = -1/60. The result is q = -600/13 = -46.2 cm.
   b. Let p = 100 cm. Then 1/100 + 1/q = -1/60. The result is q = -300/5 = -37.5 cm.
   c. Let p = 30 cm. Then 1/20 + 1/q = =1/60. The result is q = -60/4 = -15.cm.

   Notice that all of the values of image distance lie between the lens and f. This is a general result. Case b) is sketched reasonably accurately below, using 2 of the 3 commonly chosen rays.

15. Since the image is 2 meters long, and the object is 0.50 m long, it follows that q = 4p. From the lens equation

$$\frac{1}{p}+\frac{1}{4p}=\frac{1}{80}\Rightarrow\frac{4p}{5}=80\Rightarrow p=100$$
cm, and the image distance is q = 400 cm.

17. The image that is to be formed by a diverging lens having a focal length of 60 cm is virtual and upright (of course). Since the image is to be 1/3 as large as the object, the image distance must be 1/3 as large as the object distance. Now, you must remember that this is a virtual image, so that q must be negative. You must also remember that the lens is a diverging lens, which means its focal length is negative. Letting f = -60 cm and $q = -p/3$, we have
    $1/p - 3/p = -1/60$. The result is $-2/p = -1/60$, or p = 120 cm.
    The image distance is $q = -p/3$ = -40 cm.

22. As discussed at length in class, the magnification for optical instruments is different from the simple relation $-q/p$. The proper definition is
    M = (angular size of image using the instrument)/(angular size of object using naked eye)
    Application of this concept to a "simple magnifier" is not simple because the magnification depends on how the lens is used as well as how the object is held when it is viewed with the naked eye. The way we will use the concept for a simple magnifier is as follows:
    1. The lens is held next to the eye as you look through the lens.
    2. When viewing the object without the lens, the object is assumed to 25 cm from your eye.
    3. The object is positioned to produce the image where the viewer chooses.
    4. The magnification under these conditions is M = (25 cm)/ p.

    If you set up different assumptions, such as holding the lens away from the eye, the equation for M is different.
    Now we are ready to work the problem. Remember that the image distance is negative. Thus, using the lens equation,
    $-(1/20) + 1/p = 1/8.0$, which leads to p = 5.7 cm.
    The magnification is M = 25/5.7 = 4.4. If instead, you use the approximate formula, M = 25/8 = 3.1.

23. You need to follow the logic using a drawing. First sketch the two lenses 40 cm apart. Each one has a focal length of 20 cm, so that the focal points between the lenses are located at a common spot. The first task is to locate the position of the image produced by the 1st lens. The object is located 80 cm to the left of lens 1, so that
    $$\frac{1}{80}+\frac{1}{q_1}=\frac{1}{20}\Rightarrow q_1=\frac{80}{3}$$
    cm.
    The image from lens 1 is then used as the object for lens 2. Since this image is 80/3 cm to the right of lens 1, it must be 40 – 80/3 or 40/3 cm to the left of lens 2. We now use this image as the object for lens 2. We let p_2 = 40/3 in the lens equation for lens 2 to get
    $$\frac{3}{40}+\frac{1}{q_2}=\frac{1}{20}\Rightarrow q_2=-40$$
    cm.
    This final image is a virtual image located right at the location of lens1. The size of this final image is computed by using q/p successively. Since the first image is inverted, the final image is also inverted (remember that virtual images have the same orientation as the "object" they are looking at}.
    $q_1/p_1 = (80/3)/80 = 1/3$, and $q_2/p_2 = 40/(40/3) = 3$.

    Therefore, the final image is the same size as the original object.

25. Since the moon is far away, the image of the moon is real, inverted, and located essentially at the focal point of the mirror. Thus, the image distance is q = 5.0 m. Recall that the ratio of object distance to image distance is the same as the ratio of object size to image size.
    $p/q = h_o/h_i \rightarrow (3.8 \times 10^8 \text{ m}) / (5.0 \text{ m}) = (3.5 \times 10^6 \text{ m})/h_i$. The answer is h_i = 0.046 m, or 4.6 cm.

26. In class I showed that the angular magnification of a telescope is the ratio of the focal length of the objective to the focal length of the eyepiece. This is true whether the telescope is a reflecting telescope of a refracting telescope. For example, in problem 25 above, if an eyepiece having a focal length of 5 cm is used, the angular magnification is (500 cm)/(5 cm) = 100. In other words, the moon seen through the telescope is 100 times as large as the moon seen with the naked eye.