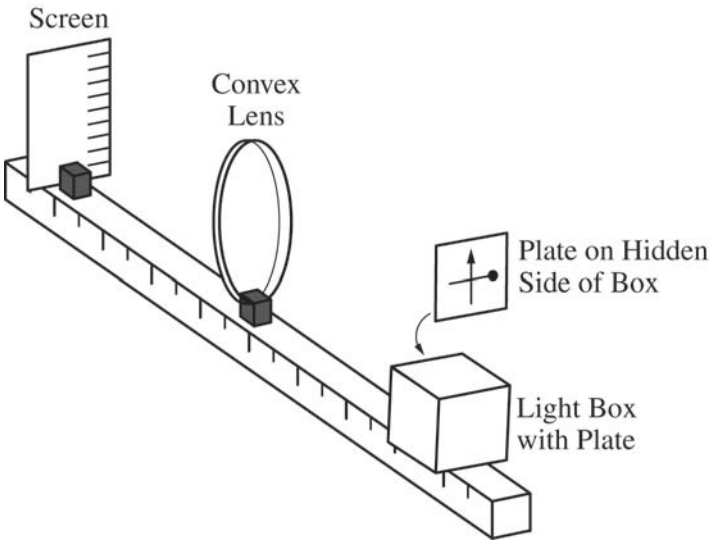
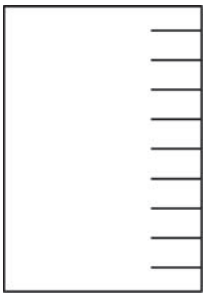


3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.



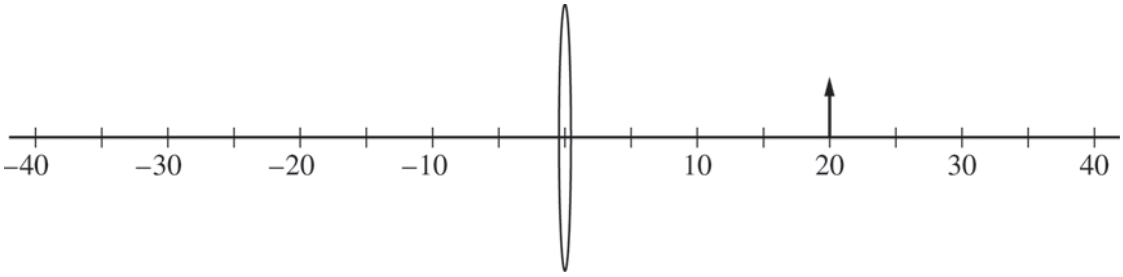
(b)

i. Calculate the focal length of the lens.

ii. Calculate the magnitude of the magnification of the image.

(c)

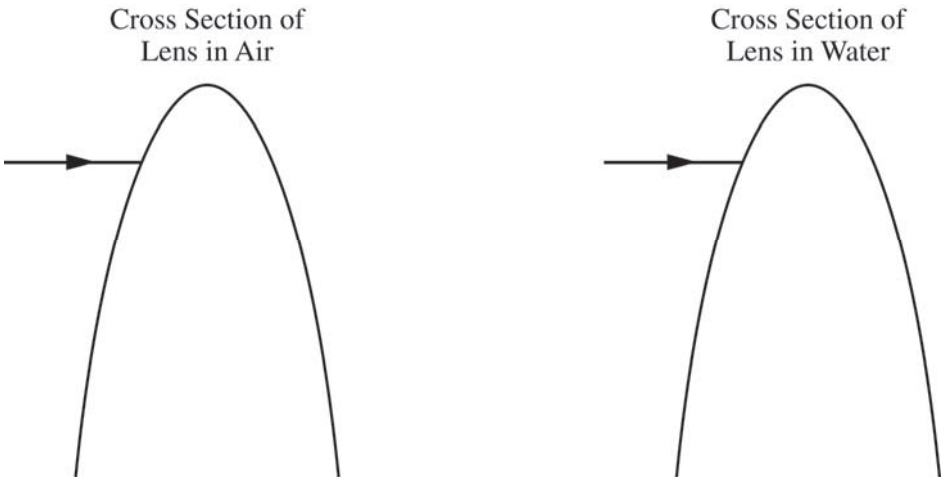
i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

(d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.



ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

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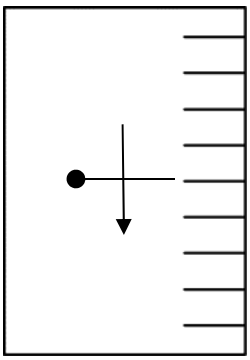
Question 3

12 points total **Distribution of points**

(a) 2 points



For the arrow drawn upside down relative to the object — 1 point
For bar/circle drawn left-to-right reversed relative to the object or consistent with an (incorrect) upright arrow — 1 point

(b)

i. 1 point

For correctly showing a calculation of the focal length and a correct answer with units — 1 point

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{20\text{ cm}} + \frac{1}{30\text{ cm}}$$

$$f = 12\text{ cm}$$

ii. 1 point

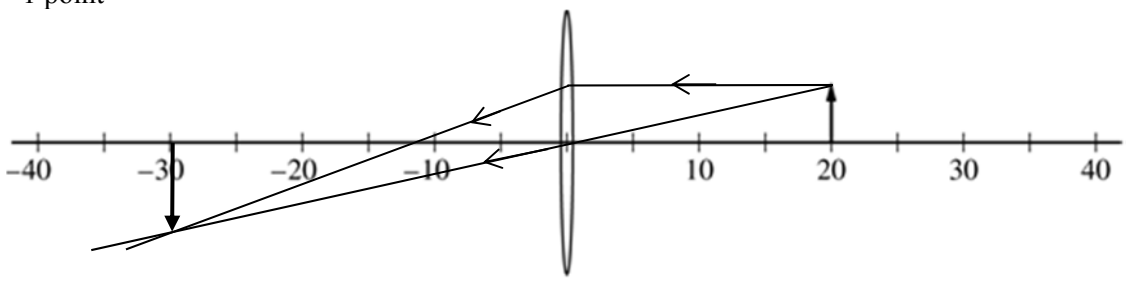
For correctly showing a calculation of the magnitude of the magnification (with or without sign) and a correct answer — 1 point

$$M = d_i/d_o = 30\text{ cm}/20\text{ cm}$$

$$M = 1.5$$

(c)

i. 1 point



For two reasonably correctly drawn rays consistent with the calculated focal length, and inclusion of an inverted image — 1 point

Question 3 (continued)

Distribution of points

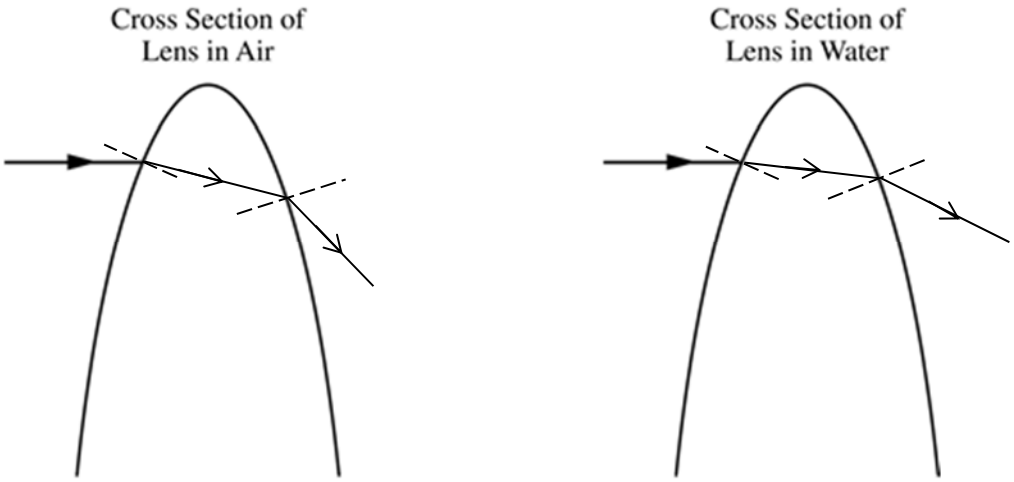
(c) (continued)

ii. 2 points

For a correct explanation of how the rays drawn relate to the focal length — 1 point
For a correct explanation of how the image relates to the magnification — 1 point
Example: The horizontal ray from the object bends to cross the axis at 12 cm from the middle of the lens, which is the focal length. The image arrow is about 1.5 times the height of the object, which is the magnification.

(d)

i. 2 points



For showing the downward refraction of the rays at each surface of the lens in air (i.e., toward the normal entering the lens and away from the normal leaving the lens) — 1 point
For the rays refracted by the lens in water at greater angles to the normal than the corresponding angles for the lens in air — i.e., less bending (can be earned even if first point was not, scoring is relative to whatever is drawn for the lens in air) — 1 point

ii. 3 points

For describing a greater focal length when the lens is in water or a comparison consistent with part (d)(i) — 1 point
For describing a larger image distance and image size or a comparison consistent with part (d)(i) — 1 point
For describing how the rays drawn in (d)(i) support the descriptions — 1 point
Example: The rays do not bend as much as they pass from water to glass as when they pass from air to glass (and vice versa). This means parallel rays coming into the lens will converge at a farther distance, so the focal length is longer. Rays from an object also will converge farther from the lens, so the new image is farther and larger.