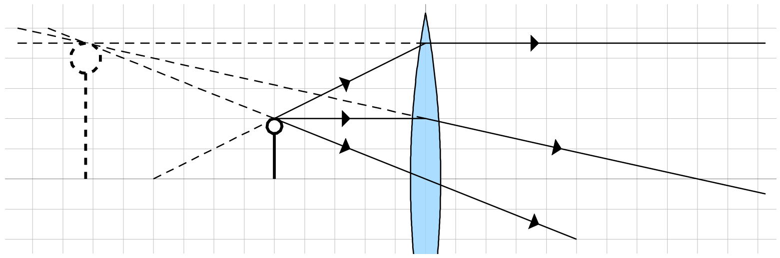
34.78. a. It is converging, because the ray bends toward the optic axis.

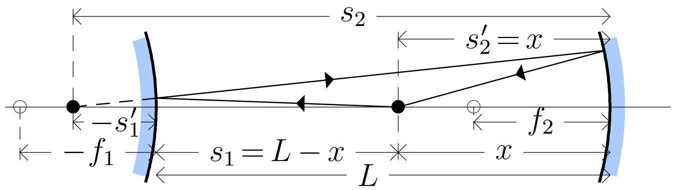
b. The ray exits parallel to the axis, so it must have come from the direction of the focal point. On the diagram, the focal point is 9 squares from the center of the lens, so the focal length is 18 cm.

c.



d. From the diagram, the object distance is 5 squares or $s = 10$ cm. Using Eq. 34.16, $\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$, the image distance is $s' = \left(\frac{1}{f} - \frac{1}{s}\right)^{-1} = \left(\frac{1}{18\,\text{cm}} - \frac{1}{10\,\text{cm}}\right)^{-1} = (-0.0444\ \text{cm}^{-1})^{-1} = -22.5$ cm. This means the image is virtual, on the same side of the lens as the object, and 22.5 cm from the lens, which agrees with the diagram.

34.93 a.



The focal length of each mirror is half its radius of curvature, $\frac{0.360\,\mathrm{m}}{2} = 0.180\,\mathrm{m} = f$. Since the first mirror (the one on the left) is convex, its focal length is $f_1 = -f$, and $f_2 = +f$. From the diagram, $s_1 = L - x$, and from Eq. 34.6,

$$\frac{1}{s_1'} = \frac{1}{f_1} - \frac{1}{s_1} = -\left(\frac{1}{f} + \frac{1}{L-x}\right).$$

From the diagram we see that s_1' is negative if the image is left of the mirror and positive if it is right of the mirror. Therefore the distance to the next mirror is $s_2 = L - s_1'$, and

$$\frac{1}{s_2'} = \frac{1}{f_2} - \frac{1}{s_2} = \frac{1}{f} - \frac{1}{L - s_1'} = \frac{1}{x}.$$

$$\frac{1}{x} = \frac{1}{f} - \frac{1/s_1'}{L/s_1' - 1} = \frac{1}{f} - \frac{\frac{1}{f} + \frac{1}{L-x}}{\frac{L}{f} + \frac{L}{L-x} + 1} = \frac{1}{f} - \frac{L - x + f}{L\,(L-x) + L\,f + f\,(L-x)}$$

$$\frac{L - x + f}{L\,(L-x) + L\,f + f\,(L-x)} = \frac{1}{f} - \frac{1}{x} \qquad \{\times [L^2 + 2\,L\,f - (L+f)\,x]\}$$

$$L - x + f = \left(\frac{1}{f} - \frac{1}{x}\right)[L^2 + 2\,L\,f - (L+f)\,x] \qquad \{\times x\}$$

$$(L+f)\,x - x^2 = \left(\frac{x}{f} - 1\right)[L^2 + 2\,L\,f - (L+f)\,x]$$

$$\left(\frac{L+f}{f} - 1\right)x^2 + \left(L + f - \frac{L^2 + 2\,L\,f}{f} - (L+f)\right)x + L^2 + 2\,L\,f = 0$$

$$\frac{L}{f}\,x^2 - L\left(\frac{L}{f} + 2\right)x + L\,(L + 2\,f) = 0$$

$$x^2 - (L + 2\,f)\,x + f\,(L + 2\,f) = 0$$

$$
\begin{aligned}
x &= \frac{1}{2}\left[L+2\,f \pm \sqrt{(L+2\,f)^2-4\,f\,(L+2\,f)}\,\right]\\
&= \frac{1}{2}\left[L+2\,f \pm \sqrt{(L-2\,f)\,(L+2\,f)}\,\right]\\
&= \frac{L}{2}+f \pm \frac{1}{2}\sqrt{L^2-4\,f^2}\\
&= \frac{0.600\,\mathrm{m}}{2}+0.180\,\mathrm{m} \pm \frac{1}{2}\sqrt{(0.600\,\mathrm{m})^2-4\,(0.180\,\mathrm{m})^2}\\
&= 0.480\,\mathrm{m} \pm \frac{1}{2}\sqrt{0.2304\,\mathrm{m}^2} = 0.480\,\mathrm{m} \pm 0.240\,\mathrm{m}\\
&= 0.240\,\mathrm{m}\ \mathrm{or}\ 0.720\,\mathrm{m},
\end{aligned}
$$

but $x < L$ so $x = 0.240\,\mathrm{m}$ only.

b. By reversing the arrows in the diagram, we can see that the answer should be the same (although the intermediate image is now on the right of the right mirror). $f_1 = +f$, $f_2 = -f$, $s_1 = x$, so

$$\frac{1}{s_1'} = \frac{1}{f} - \frac{1}{x}.$$

$s_2 = L - s_1'$, $s_2' = L - x$, so

$$\frac{1}{s_2'} = -\frac{1}{f} - \frac{1}{L-s_1'} = -\frac{1}{f} - \frac{\frac{1}{f}-\frac{1}{x}}{\frac{L}{f}-\frac{L}{x}-1} = -\frac{1}{f} - \frac{x-f}{L\,x-L\,f-f\,x} = \frac{1}{L-x}.$$

$$-\frac{1}{f} - \frac{1}{L-x} = \frac{x-f}{L\,x-L\,f-f\,x} \qquad \{\times f\,(L-x)\,[(L-f)\,x-L\,f]\}$$

$$[-(L-x)-f]\,[(L-f)\,x-L\,f] = f\,(L-x)\,(x-f)$$

$$(L-f+f)\,x^2 + [-(L+f)\,(L-f)-L\,f-f\,(L+f)]\,x + L\,f\,(L+f) + L\,f^2 = 0$$

$$L\,x^2 + (-L^2-2\,L\,f)\,x + L\,f\,(L+2\,f) = 0$$

$$x^2 - (L+2\,f)\,x + f\,(L+2\,f) = 0,$$

which is the same equation as above.