

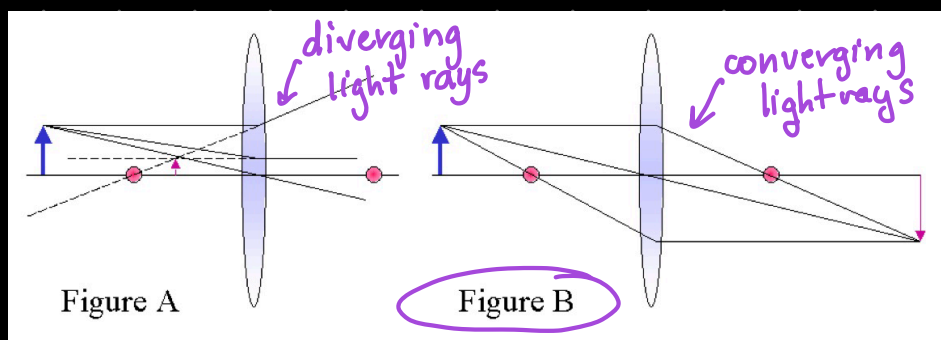
An object 5 cm high is located 75 cm from a converging lens ( $X_1 = 75$  cm) of focal length  $f_1 = 50$  cm. A second converging lens of focal length  $f_2$  is located 200 cm from the first lens ( $X_2 = 200$  cm). An image of the object is to be formed on a screen 200 cm from the second lens ( $X_3 = 200$  cm).

The question we want to answer is:

**What must be the focal length  $f_2$  of the second lens so that the final image clearly appears on the screen?**

Before we answer this question, let's take a closer look at the situation and answer preliminary questions.

The two lenses are converging lenses. First we need to determine the correct ray diagram for a converging lens.



The ray diagram in Figure B is correct for a converging lens. The light rays that pass through the lens converge to form a real image.

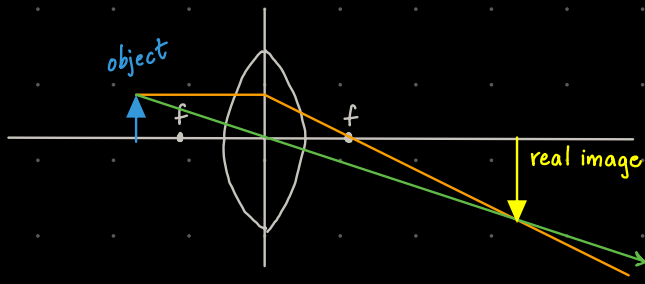
1. What does it mean for an image to be classified as 'real'?

→ a real image is produced when real light rays pass

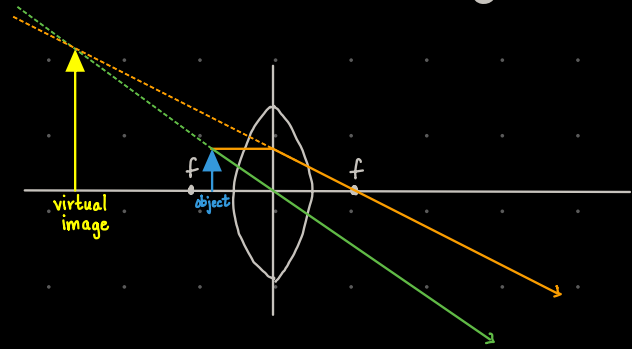
through a lens and converge. The real image forms at that point where the rays converge.

2. If an object is positioned outside of the focal length of a converging lens, what type of image will be formed?

Let's look at two ray diagrams for converging lenses:

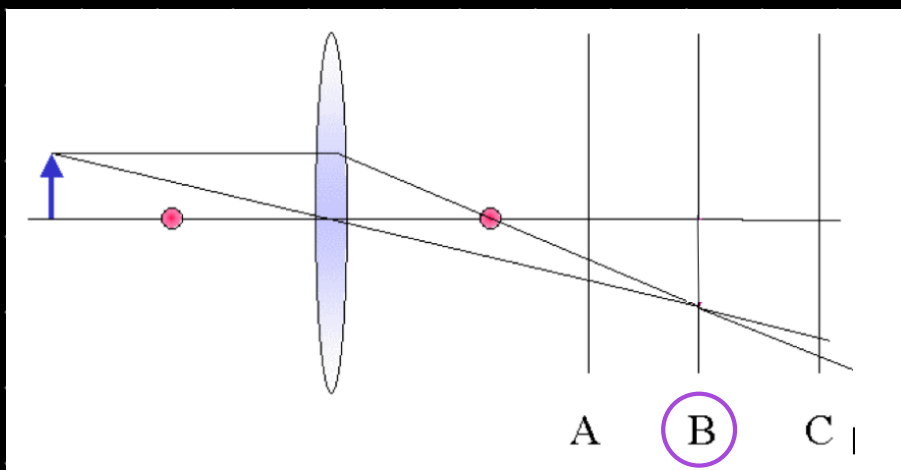


For a converging lens, when  $d_o > f$ , the image produced is always a real image.



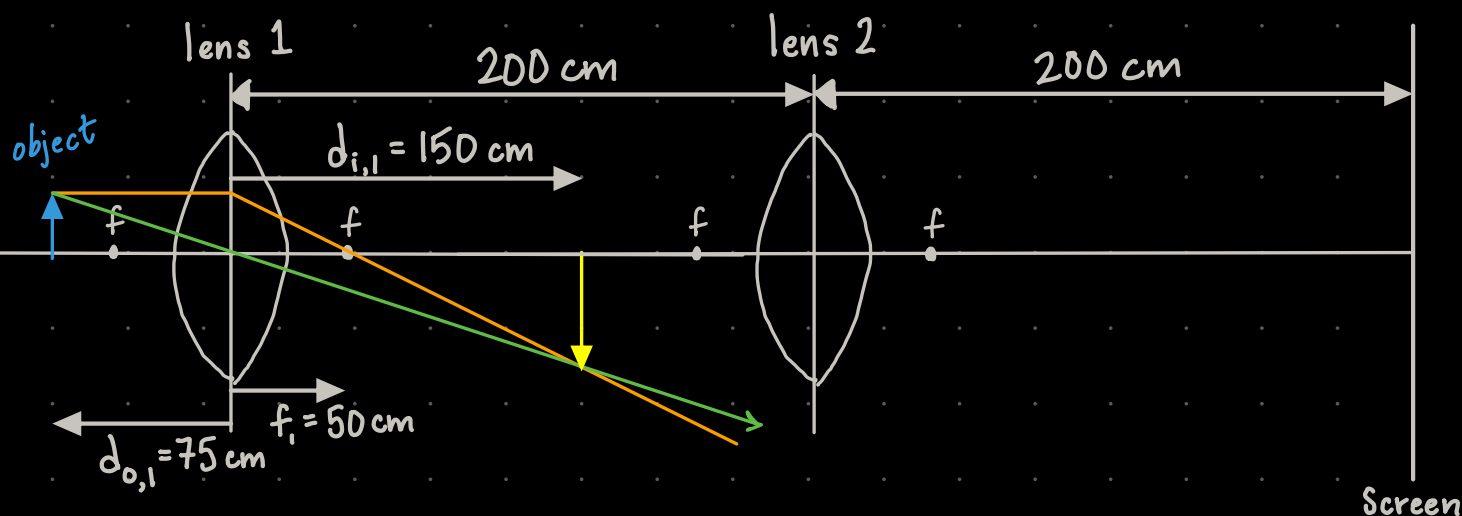
For a converging lens, when  $d_o < f$ , the image produced is always a virtual image. This is also known as a simple magnifier.

3. For which screen position(s) (A, B, or C) will the image produced be a clear, crisp arrow?



A clear, crisp image will form at the point where real light rays converge and intersect. This is at position B. If you place the screen at position A or C, you would see an image but it would be blurry.

Now we are ready to draw a ray diagram for the two-lens system.



Lens 1 produces a real image on the right side of lens 1. This first image will become the object for lens 2. Before drawing the ray diagram for lens 2, let's calculate the first image distance using the lens equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{50} - \frac{1}{75} = 0.0067 \text{ cm}^{-1}$$
$$d_i = 150 \text{ cm}$$

Now we know this first image forms 150 cm from lens 1 and therefore this first image is located 50 cm from lens 2 - we were told that the lenses are 200 cm apart.

Since this first image is going to be the object for lens 2, we can say that  $d_{o,2} = 50 \text{ cm}$ . We are also told that the final image is formed on a screen that is 200 cm from lens 2. So, now we can also say  $d_{i,2} = 200 \text{ cm}$ . With these  $d_o$  and  $d_i$  values for lens 2, we can calculate the focal length of lens 2.

$$\frac{1}{f_2} = \frac{1}{d_{o,2}} + \frac{1}{d_{i,2}} = \frac{1}{50} + \frac{1}{200} = 0.025 \text{ cm}^{-1} \rightarrow \boxed{f_2 = 40 \text{ cm}}$$

Since  $d_{o,2} > f_2$ , lens 2 will produce a real image on the screen.

