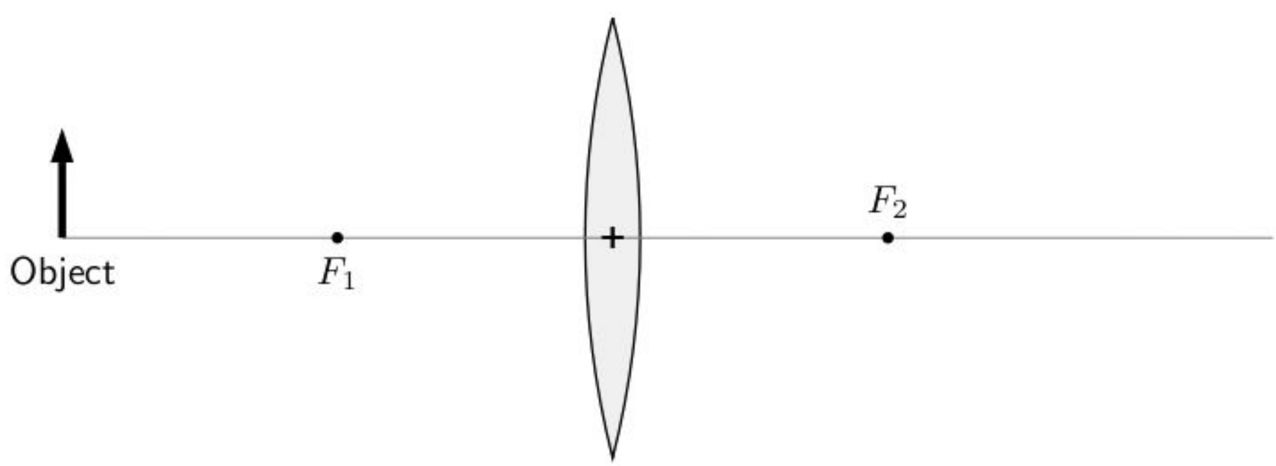
Laboratory 4 Pre-Lab (value: *2 marks*)

Submit to your lab instructor ***by 4pm the day BEFORE*** your scheduled lab period.

1. What does it mean when your *magnification* is *negative*, e.g. M = -3?

2. An object is placed at 2 focal lengths from a converging lens and forms a real, inverted image. How do q and M change when the object is moved to 1.5 focal lengths from the same lens? Explain.

3. Draw the 3 principal rays to locate the image formed by the converging lens below. *Use a ruler & sharp pencil* & *label FULLY*. Calculate the magnification M from your drawing; show ALL work.



Laboratory 4: Thin Lenses

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Explain your answers clearly and concisely. If an equation is to be used in a calculation, *write the equation down* and then insert numbers and solve. Report your final answer to the appropriate significant figures.

The lab write-up is due by the end of the lab. Late labs will not be accepted.

APPARATUS

Arbor Scientific optics set: 2m ruler, tape, illuminated object, lens holder, screen with marked scale, object & image locators, 1 biconvex lens (20 cm); 1m ruler, meter stick optics lens and screen holders, desk lamp.

OBJECTIVE

1. To investigate the image forming properties of converging lenses.

THEORY

Image formation by a thin converging lens

If light from an infinitely distant **object** is incident upon a converging lens, an **image** of that object will be formed at the **focal plane** on the *opposite side* of the lens. The focal plane passes through the **focal point** on the **optic axis** of the lens. If the lens is relatively thin, the distance to the focal point may be measured from the centre of the lens and is called the **focal length** of the lens. Lenses have two focal points, equidistant from the centre of the lens: one in front of the lens and one behind.

If an object is placed *inside* the focal point of a converging lens, the image formed will be on the *same* side of the lens as the object and thus *cannot* be projected onto a screen; such an image is **virtual**. If an object is placed *outside* the focal point, the image formed will be on the *opposite* side of the lens as the object, and can be projected onto a screen; such an image is **real**. Images may be **upright** (same orientation as the object) or **inverted** (upside down relative to object).

If p is the **object distance**, q is the **image distance**, and f is the **focal length** of the lens, then

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \qquad (1)$$

For a converging lens f is *positive*. For a real image q is *positive*; for a virtual image q is *negative*.

Magnification is the ratio of the linear size of the image (h_i) to the linear size of the object (h_o),

$$M = \frac{h_i}{h_o} \tag{2}$$

where h_i is negative if the image is inverted. Magnification may also be found using

$$M = -\frac{q}{p} \tag{3}$$

Ray diagrams

Images may be found by constructing scale ray diagrams (Figure 1) using these 3 principal rays:

- a light ray passing through the centre of a lens is undeviated (ray 1)
- a light ray parallel with the optic axis is refracted through the rear focal point (ray 2)
- a light ray through the front focal point is refracted to be parallel to the optic axis (ray 3)

While two of these rays will establish the image position and character, the third ray should be drawn for confirmation. Vertical & horizontal scales are often *different* for clarity & drawing ease.

(a)

(b)

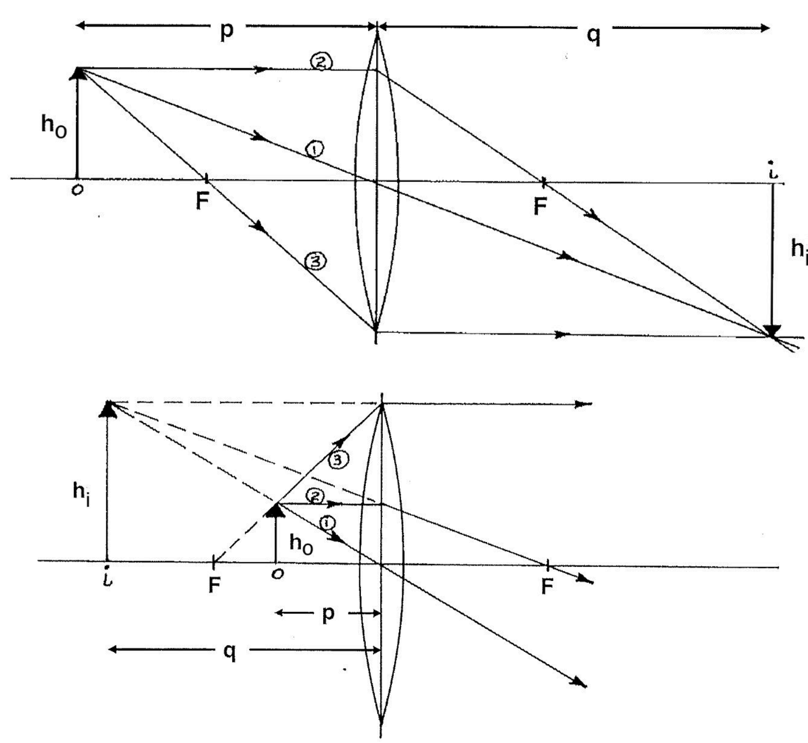


Figure 1: (a) ray diagram for a real image (b) ray diagram for a virtual image

NAME:

DATE: PARTNER:

Laboratory 4: Thin Lenses

Part A: Focal length of a converging lens

1. [***3 marks***] Mount the lens & screen on the metre stick and *carefully* focus the image of a distant object (>10 m) on the screen. **Record the *positions* of the lens & screen below (*in cm*).**

lens position = ______________ *screen position* = ______________

Calculate the value for the image distance q (*in cm*) from your data above:

image distance: $q =$ $=$ ________________

Calculate the focal length f **of the lens** (*in cm*) using Equation 1 (focusing on a distant outdoor object allows us to assume that the object distance $p \approx \infty$). Show all work/steps *fully.*

**** Check your value of f with your lab instructor before continuing with the lab. ****

Part B: Image formation by a converging lens for various object distances

1. Tape the 2m ruler securely to the lab bench *with the '0' end on the left.* Mount the lens in its holder & position it at the ruler's midpoint, *i.e. the right face of the holder at 100.0 cm.* Using f from Part A, position the (lit) 'face' of the object at a *distance* of $2^1/_2$ focal lengths *left* of the lens position. Place the *viewing screen* anywhere to the *right* of the lens, calibrated grid towards the lens.

Locate the *image position* (the position of 'best' focus of the object on the screen) *by moving the viewing screen toward/away from the lens while keeping it up against the ruler* and reading the position of the *righthand side* of the screen. **DO NOT MOVE the object OR the lens and be careful NOT TO BUMP THE RULER! Record** the ***positions*** *(in cm) of the object, lens & image* and the *type of image formed (real/virtual)* **in Table 1.**

Measure the length (*in cm*) of the vertical portion of the object's lit 'F' (h_o), i.e. center-to-center distance between the furthest apart LEDs. Use the calibrated (*cm*) markings on the viewing screen to **measure** the corresponding length of the image (h_i) & note its orientation. **Record in Table 2.**

2. Position the object at a distance of 2 focal lengths from the lens and **repeat Step 1**.

3. Position the object at a distance of $1^1/_2$ focal lengths from the lens and **repeat Step 1**.

Step	Object position (cm)	Lens position (cm)	Image position (cm)	Object distance p (cm)	Image distance q (cm)	Image type ($\Re$ or $\mathcal{V}$)	calculated focal length f_{calc} (cm)	% diff
1								
2								
3								
4								

Table 1: Part B values for object distance, image distance and image nature [***3 marks***].

Step	h_o (cm)	h_i (cm)	image orientation	M (h_i/h_o)	M $(-q/p)$	% diff
1						
2						
3						
4	n/a	n/a		n/a	n/a	n/a

Table 2: Part B values for image size, orientation and magnfication [***3 marks***].

4. [***3 marks***] Position the object at $^1/_2$ focal length from the lens. **Describe what occurs if you try to form an image on the screen as you did in previous steps**.

Remove the viewing screen. Turn off the object & replace it with the 'object marker' (*'D'*) positioned so its right face is at the *same position* as the object was at AND the coloured arrows face towards the lens. Squat down near the right end of the 2m ruler (e.g. 200.0 cm) and look *towards* the lens to see the *image* of the object marker IN the lens. *Make sure* you are viewing from low enough that the top of the actual object marker *IS NOT* visible above the top of the lens. **Qualitatively, where does the image of the object marker *appear* to be formed? What characteristics does the image have? What *type* of image is it?**

Using your value of f from Part A, the *object distance* p ($= {}^1/_2\, f$) and Equation 1, **calculate the expected *image distance* q for this scenario. What does the sign of q mean? Does the value of q agree with your qualitative estimate of the image location? Discuss briefly**.

Verify the calculated image position experimentally using the method of *parallax*. Position the (taller) 'image locater' roughly 40 cm *further from the lens* than the (shorter) 'object marker'. The image locater marks the position where we think the *image* of the object marker is being formed. **Look *through the lens* at the image of the object marker and *over the lens* at the top of the image locater *at the same time***, positioning your eye so that the lines marked on the centers of the coloured portions appear to be aligned (see Figure 2). Now, move your head from side-to-side *horizontally*. The image locater and the image of the object marker will seem to move *horizontally* relative to each other and the center lines will NOT remain aligned; this is because the image locater and the image of the object marker are NOT located at the same position in space. This differential motion is called ***parallax***. **Move the image locater a few cm CLOSER to the lens**, moving your head side-to-side as before after each adjustment, until there is *no relative motion between the image locater and the image of the object marker - i.e. they 'stay aligned'*. The image locater is then physically at the same position in space as the image of the object marker *and the resulting image distance should be similar to what you calculated previously (above)*. **Note the positions of the various optical elements and record the values in Table 1 & Table 2. ** NOTE: the image size *CANNOT* be measured in this case ****.

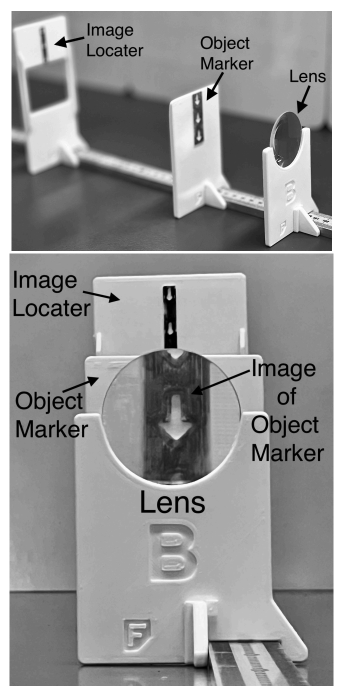


Figure 2: Image location.

5. [***3 marks***] **Calculate the focal length** f_{calc} **for Steps 1-4** using Equation 1 & the corresponding p & q values from Table 1. **Compare EACH** f_{calc} **with** f **from Part A using *percent difference* & comment** on the agreement of your f_{calc} values.

Show a *full* sample calculation with all work for Step 1. Record all results in Table 1.

6. [***4 marks***] **Calculate the magnification** M **for Steps 1-3** using BOTH Equation 2 & 3. Watch your signs! (*An inverted image means* $M < 0$*, so when using* $M = h_i/h_o$ *you must ADD a negative sign as appropriate.*) **Compare the two calculated values of** M **for EACH step using *percent difference* & comment** on the agreement of your magnifications.

Show a *full* sample calculation of all work for Step 1. Record all results in Table 2.

7. [***6 marks***] Using your value of f *from part A*, **draw *two* (2) *separate, FULL PAGE ray diagrams* and *graphically DETERMINE the image distance* q *that RESULTS from drawing ALL 3 principal rays*.** Use a sharp pencil, a ruler, the provided graph paper, and TAKE YOUR TIME - you will only get good results if you measure/draw carefully. **Label each diagram FULLY** (see the samples provided in the Theory section), clearly indicating the horizontal scale used. *A video on the lab website offers useful tips on drawing & labelling ray diagrams.*

In the 1st diagram place the object at $2^1/_2\, f$ from the lens; draw all 3 rays & LOCATE q.

In the 2nd diagram, place the object at $^1/_2\, f$ from the lens; draw all 3 rays & LOCATE q.

8. [***3 marks***] **Record the value of q found from each ray diagram**:

image distance when object located at $2^1/_2\, f$: $q =$ ______________

image distance when object located at $^1/_2\, f$: $q =$ ______________

Compare EACH value of q from the ray diagrams to its corresponding value from Part B using *percent difference*; for $2^1/_2\, f$ use the *measured* value of q from Table 1; for $^1/_2\, f$ use the *calculated* value of q at the end of step 4. **Show all work & comment on the agreements.**

What are some *specific* major source(s) of error when drawing ray diagrams?