SCHOOL OF PHYSICS
UNIVERSITI SAINS MALAYSIA

ZCT191/192 PHYSICS PRACTICAL I/II
1OS3 GEOMETRICAL OPTICS

Lab Manual

OBJECTIVES

1. *To determine the focal length of a converging lens by forming an image on the viewing screen;*
2. *To discover the position of a virtual image formed by a diverging lens;*
3. *To construct and determine the magnifications of a*
   a. *Telescope;*
   b. *Microscope.*

THEORY

Basic Geometrical Optics

A lens is defined to be *thin* if its thickness is small as compared to the other distances involved. For a thin lens,

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}, \tag{1}$$

where f is the *focal length*, o the distance between the object and the lens, and i the distance between the image and the lens. This equation is known as the *thin lens equation*. By measuring o and i, the focal length can be determined. Recall that if the image is on the opposite side of the lens with respect to the object, i will be positive, and the image is *real*; if the image is on the same side instead, i will be negative, and the image is *virtual*.

A virtual image cannot be viewed on a screen, it forms where the backwards extensions of diverging rays cross. You can see a virtual image by looking at it through a lens or mirror. Like all images, a virtual image formed by a lens or mirror can serve as the object of another lens or mirror.

The image formed by a thin lens can be described by its orientation (*upright* or *inverted*) and by its magnification (*enlarged* or *reduced* compared to the original object). *Magnification* (M) is the ratio of image size (s_i) to object size (s_o). It can also be measured using the ratio between the image and object distances as follows:

$$|M| = \frac{s_i}{s_o}, \qquad M = -\frac{i}{o}. \tag{2}$$

Note that if the image is upright, M is positive; if the image is inverted, M is negative.

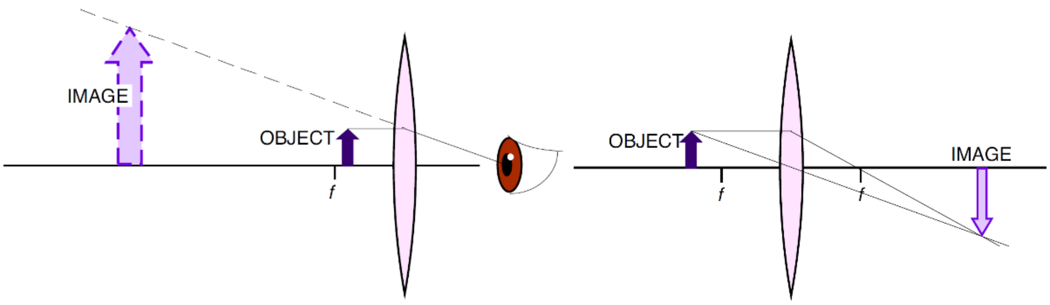

Figure 1: Positions of images when placed closer (left) / further (right) to a convex lens.

In this experiment, two kinds of lenses are used: the *convex lens* (also known as positive / convergent lens) which has a positive focal length, and the *concave lens* (negative / divergent lens) which has a negative focal length. When an object is placed closer to a convex lens than its focal length, the lens works as a magnifier and produces an enlarged virtual image; when an object is placed further from it than its focal length, the lens produces an inverted, real image, and it could be reduced or enlarged, depending how close the object is to the focal point (see **Figure 1**).

When two thin lenses are used, we can analyse the distances by taking the image from one lens as the object for the second. The observer views an image that is "an image of an image". The overall magnification M of a two-lens system is equal to the product of the magnifications of the individual lenses, M_1 and M_2:

$$M = M_1 M_2 = \left(-\frac{i_1}{o_1}\right)\left(-\frac{i_2}{o_2}\right), \tag{3}$$

where (o_1, i_1) and (o_2, i_2) are the object-image distance pairs for each lens system.

Telescopes and Microscopes

The telescope and the microscope are two important optical devices that use two lenses. In each device a primary lens (the *objective*) forms a real image and a secondary lens (the *eyepiece*) is used as a magnifier to make an enlarged virtual image.

An astronomical refractor telescope is used to view large objects that are at large distances from the lenses. Firstly, the objective lens produces a first real image of a very far away object ($o \to \infty$). So using the thin lens equation, we have

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{i} \approx \frac{1}{i}, \tag{4}$$

where the image forms coincident with the objective's focal point (f_o). The eyepiece is then placed close to that first image, so that the image formed by the objective lens falls within the eyepiece's focal length (f_e) and is thus magnified. The closer the first image is to the eyepiece's focal point, the longer the distance to the final image.

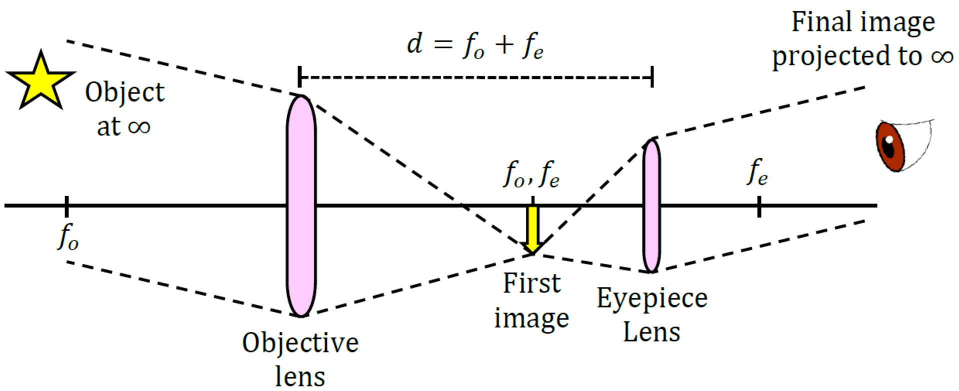

Figure 2: Principles of the refractor telescope. The objective lens forms the first image, then the eyepiece lens greatly magnifies the first image.

Astronomical telescopes are usually built so that the first image forms exactly at the focal point of the eyepiece lens (see **Figure 2**). In this case, the separation between the lenses is exactly $d = f_o + f_e$, which is the length of the telescope tube. The magnification of an astronomical telescope with the object at infinity, and with f_o and f_e both coincident with the first image, is defined as the ratio of the focal length of the objective to that of the eyepiece:

$$M = \frac{f_o}{f_e} = \frac{i_o}{o_e}. \tag{5}$$

Note that this equation is only valid for a telescope with $d = f_o + f_e$.

A *compound microscope* is used to view small objects that are very close to the lenses. A microscope is useful when the magnification required is more than what can be obtained with a single magnifier lens. Firstly, the objective lens produces a first real image of the object, by having the object be just beyond its focal length (see **Figure 3**). The eyepiece will then be placed very close to that first image, so that the first image falls within the eyepiece's focal length and is thus greatly enlarged.

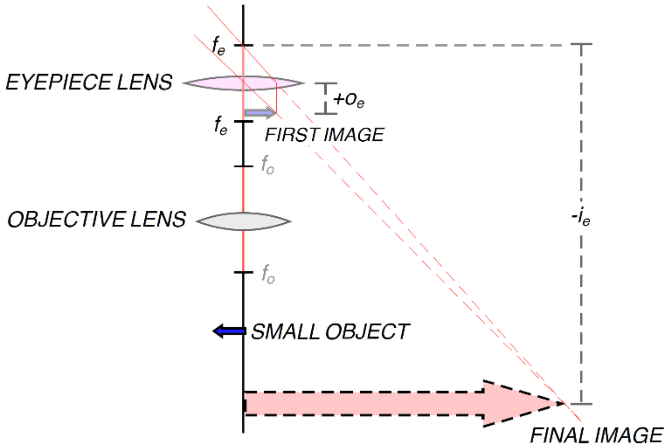

Figure 3: Principles of the microscope. The objective lens forms the first image, this image is real, inverted and reduced. The eyepiece lens forms the final image using the first image as its object, this final image is virtual and greatly enlarged.

EQUIPMENT

Equipment Components

1. Optics Bench (120 cm)
2. Viewing Screen
3. Geometric Lens Set
    a. Convex Lens 1 (+10 cm)
    b. Convex Lens 2 (+20 cm)
    c. Concave Lens (−15 cm)
4. Adjustable Lens Holders × 2
5. Light Source and AC Adapter
6. Paper Grid and Rubber Band

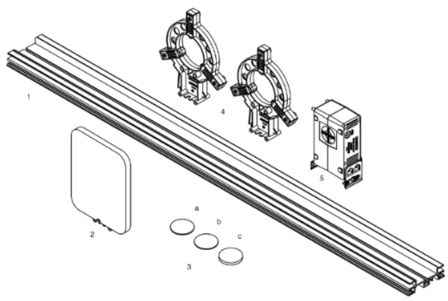

Figure 4: List of equipment.

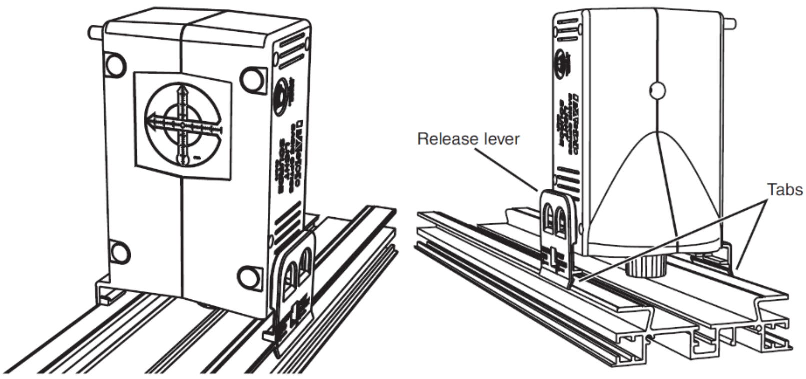

Figure 5: The front (crossed-arrow) and back (point source) of the light source.

The optics components (e.g. the view screen and adjustable lens holders) can be snapped onto the wide central channel of the *optics bench*. Place the base of the component on the bench and push down firmly to snap it in place. To move it, squeeze the tab on the base and slide the component along the bench. The included *light source* (**Figure 5**) functions as a bright point source and an illuminated crossed-arrow object.

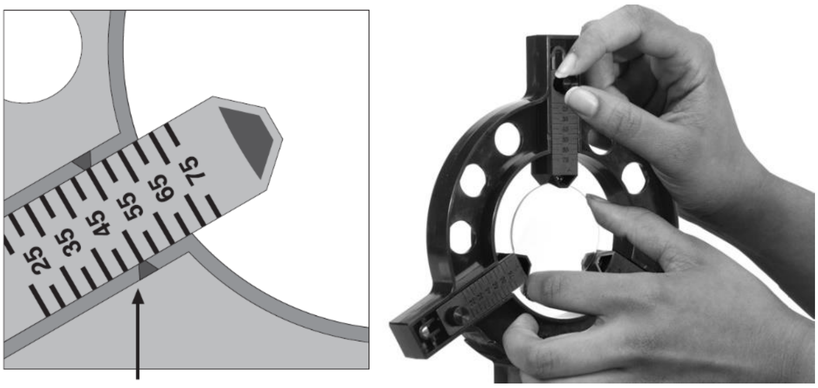

Figure 6: The adjustable lens holders. Align the marks (left) corresponding to the diameter (50 mm) of the lens. After positioning the lower arms, place the lens in the ring and secure it with the top arm (right).

Adjustable Lens Holders

The three 'fingers' of the *adjustable lens holders* (**Figure 6**) hold the lenses in place, they can hold lenses from 25 mm to 75 mm in diameter. To setup the lens holders,

1. Loosen the thumbscrews on the two lower arms. Line up the appropriate diameter marks on the arms with the triangular marks on the ring. Tighten the thumbscrews to lock the arms.
2. Loosen the thumbscrew on the top arm and slide it up.
3. Rest the edge of the lens on the lower two arms and slide the top arm down. Tighten the thumbscrew on the top arm to secure the lens.

The lens set consists of three lenses, each **50 mm** in diameter. Two of the lens are double convex each with focal lengths of +20 cm and +10 cm, respectively. The third lens is a diverging double concave lens with a focal length of −15 cm.

PROCEDURE

Part A: Focal Length and Magnification of a Thin Lens

In this part, you will determine the focal length by measuring several pairs of object and image distances and plotting $1/i$ versus $1/o$.

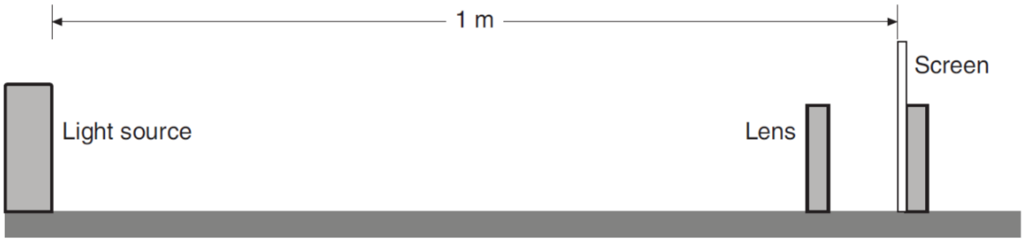

Figure 7: Experimental setup for Part A.

Measurement

1. Place the light source and the screen at the **0 cm** and **100 cm** marks on the optics bench, respectively, with the light source's crossed-arrow object facing toward the screen. Place the **+10 cm lens** between them (see **Figure 7**).
2. Starting with the lens close to the screen, slide the lens away from the screen to a position where a clear image of the crossed-arrow object is formed on the screen.
3. Record this **position of the lens**, the size of the crossed-arrow (**object size**, s_o) and the size of the projected image of the crossed-arrow on the screen (**image size**, s_i) in **Table 1**.
4. Without moving the screen or the light source, move the lens to a second position where the image is in focus. Record this second **position of the lens**, and the corresponding **object** and **image sizes** in **Table 1**. Note that you will not see the entire crossed-arrow pattern on the screen, so in this situation, measure the image and object sizes as the distance between **two index marks** on the pattern (see **Figure 8** for example).
5. Repeat steps 2 to 4 by changing the position of the screen to **90 cm**, **80 cm**, **70 cm**, **60 cm**, and **50 cm**, respectively. For each screen position, find two lens positions where clear images are formed. For these you do not need to measure the image and object sizes.

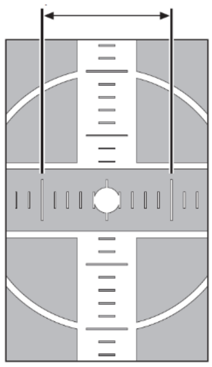

Figure 8: Index marks on the crossed-arrow pattern of the light source.

Analysis

1. For each lens position, calculate the distance between the lens and the light source (object distance, o) and the distance between the lens and the screen (image distance, i).
2. For each object and image distance, calculate $1/o$ and $1/i$.
3. Plot $1/i$ versus $1/o$ and find the linear best-fit line. Record the values of the x- and y-intercepts.
4. For each intercept, calculate a value of f, then, find the percentage difference between these two values.
5. Average these two values of f and record this final value.

6. For the first two rows in **Table 1**, use the image and object distances to calculate the magnification M_d at each position of the lens.
7. For the same two rows, use the image and object sizes to calculate the absolute value of the magnification $|M_\mathrm{s}|$.
8. Average the values of $|M|$ obtained from the two methods and record their final values.
9. Calculate the percentage difference between the absolute values $|M|$ found using the two methods.

Table 1: Measurements for Part A.

<table>
<tr><th>Screen position (cm)</th><th>Lens position (cm)</th><th>s_o (mm)</th><th>s_i (mm)</th></tr>
<tr><td rowspan="2">100 cm</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">90 cm</td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">80 cm</td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">70 cm</td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">60 cm</td><td></td></tr>
<tr><td></td></tr>
<tr><td rowspan="2">50 cm</td><td></td></tr>
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</table>

Part B: Virtual Images

In this part, you will set up a diverging lens to form a virtual image. You will then use another lens to form a real image of the virtual image. In this way you can identify the location of the virtual image.

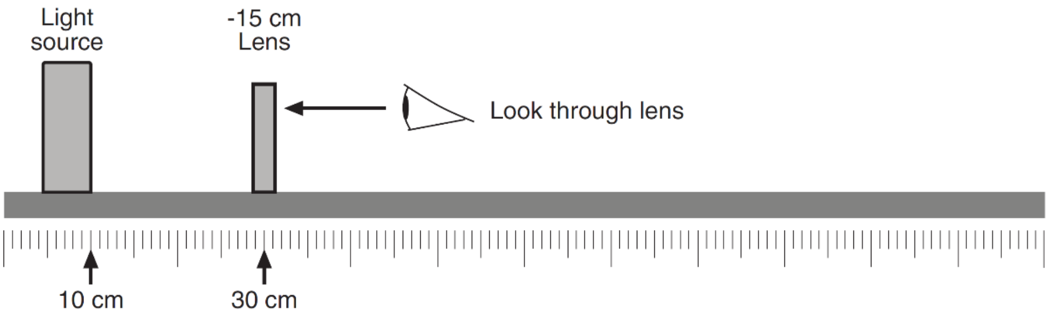

Figure 9: Experiment setup for steps 1-3 of Part B.

Measurement

1. Place the **−15 cm lens** on the bench at the **30 cm** mark.
2. Place the **light source** at the **10 cm** mark with the crossed-arrow object toward the lens.
3. Look through the lens toward the light source (see **Figure 9**), and record in **Table 2** if the image is (a) upright / inverted; (b) enlarged / reduced; and (c) closer / further than the object to the lens.

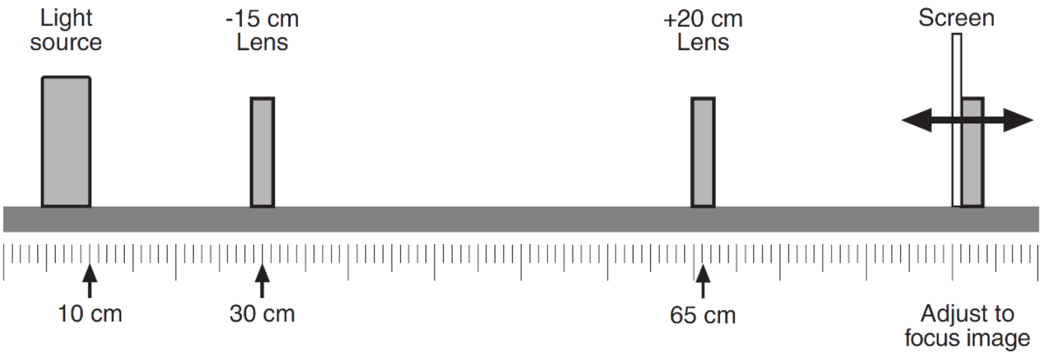

Figure 10: Experiment setup for steps 4-5 of Part B.

4. Place the **+20 cm lens** on the bench at the **65 cm** mark (see **Figure 10**).
5. Place the viewing screen behind the positive lens. Slide the screen to a position where a clear image is formed on it and record its position.

The real image that you see on the screen is formed by the positive lens with the virtual image (formed by the negative lens) acting as the object. The location of the virtual image can be discovered by replacing it with the light source.

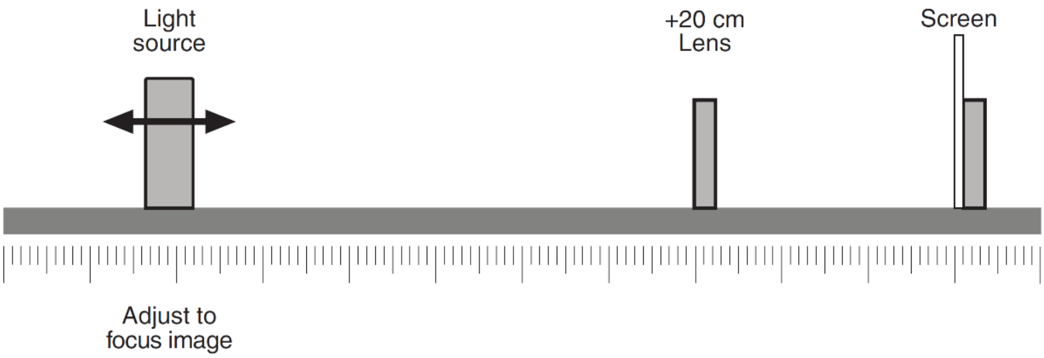

Figure 11: Experiment setup for steps 6-7 of Part B.

6. Remove the negative lens from the bench (**Figure 11**), the image on the screen should go out of focus.
7. Slide the light source to a new position so that a clear image is formed on the screen (do not move the positive lens or the screen). Record the bench position of the light source.

Analysis

1. Calculate the object distance o (the distance between the initial light source position and the negative lens) and the virtual image distance i (the distance between the negative lens and the virtual image). Remember that it is a negative value.
2. Calculate the magnification M of the virtual image and state whether it is upright / inverted.
3. Draw a scaled diagram (without the rays) showing the positions of the light source (initial), both lenses, the screen, and both the real and virtual images. Use arrows (↑) to depict the objects and images, using different heights and directions to denote their respective magnifications.

Table 2: Measurements for Part B.

<table>
<tr><th>Initial position of light source (cm)</th><th>Position of −15 cm lens (cm)</th><th>Image properties</th><th>Position of +20 cm lens (cm)</th><th>Position of screen (cm)</th><th>Final position of light source (cm)</th></tr>
<tr><td rowspan="3">10.0</td><td rowspan="3">30.0</td><td></td><td rowspan="3">65.00</td><td rowspan="3"></td><td rowspan="3"></td></tr>
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Part C: The Telescope

The purpose of this activity is to construct a simple telescope and to measure its magnification.

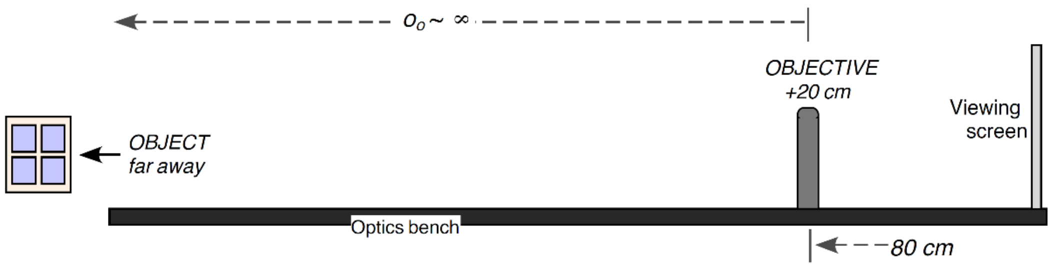

Figure 12: Experimental setup for Part C.

Measurement

1. Set the optics bench such that its **0 cm** end points toward an open window in the laboratory (see **Figure 12**). Dim the lights inside the laboratory. Speak to a lab assistant if you need help to open the blinds / locate the light switches.
2. Mount the **+20 cm lens** (objective) at the **80 cm** mark. Install the viewing screen at the end of the track.
3. Move the viewing screen towards the lens until a sharp image of the object is seen. Make fine adjustments and record the exact positions along the track of the objective lens and the first image in **Table 3**.
4. Record in **Table 3** if the first image is (a) upright / inverted; (b) enlarged / reduced; and (c) real / virtual.
5. Mount the **+10 cm lens** (eyepiece) **10 cm** behind the first image. This should make the separation between the lenses **~30 cm** (i.e. the telescope's length), plus or minus any small adjustment made in step 3.
6. Remove the viewing screen. With only one eye open, look through the eyepiece directly toward the object. Move the eyepiece forward or backwards a little bit, as needed, until you comfortably see a very sharp, enlarged image of the object. Record the position of the eyepiece. (note: you should not be squinting / forcing your eye into focus).

Analysis

1. Use the recorded positions to determine the following distances:
   a. Distance from the objective lens to the first image (i_o).
   b. Distance from the first image to the eyepiece lens (o_e).
2. Use **Equation 1** to calculate the distance from the eyepiece to the final image (i_e).
3. Calculate the magnification of the second image (M_e).
4. Calculate the total magnification (M) of the telescope.
5. Calculate the theoretical total magnification of the telescope (M_{theo}) using the known values of f_o and f_e, and find the percentage discrepancy of the experimental value.

Table 3: Measurements for Part C.

Position of objective lens (cm)	Position of screen (cm)	Image properties	Position of eyepiece (cm)
80.0			

Part D: The Microscope

The purpose of this activity is to construct a simple microscope and measure its magnification. In this part, the **+10 cm lens** will be the objective, while the **+20 cm lens** will be the eyepiece.

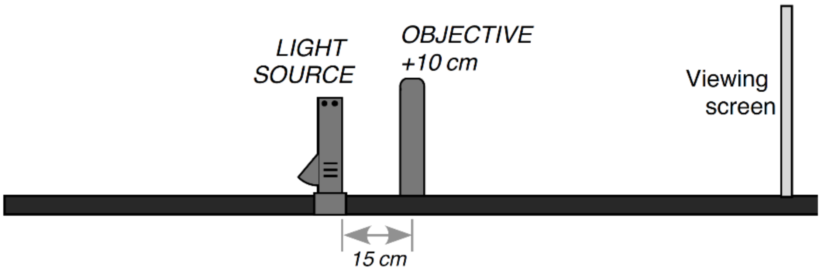

Figure 13: Experimental setup for Part D.

Measurement

1. Mount the **+10 cm lens** at the **60 cm** mark.
2. Install the light source at the **45 cm** mark (**15 cm** behind the **+10 cm lens**), with the crossed-arrows facing the lens. Install the viewing screen on the other side of the lens, as illustrated in **Figure 13**.
3. Move the viewing screen towards the lens until a sharp image of the crossed-arrows is seen. Record the location of this first image in **Table 4**.
4. Record in **Table 4** if the first image is (a) upright / inverted; (b) enlarged / reduced; and (c) real / virtual.
5. Mount the **+20 cm lens** directly behind the viewing screen.
6. With your eye very close to the **+20 cm lens**, look through the lens as you move it back away from the viewing screen. Stop when you are comfortably seeing a sharp and enlarged image of the **back** of the viewing screen (you can put your lab manual behind the screen to help you to focus).
7. Remove the viewing screen, and remove the light source.
8. Use a rubber band to hold a copy of the grid against the viewing screen.
9. Place the screen with the grid in the exact same position where the light source used to be. The very small message written in the middle of the grid will be the object we want to see through the microscope.
10. Look through the eyepiece and move your head around to find the image of the small message. You may need to move this lens just slightly to focus it. Move the grid, if needed, to centre the message in your field of view. Record the position of the eyepiece.

Analysis

1. Use the recorded positions to determine the following distances:
   a. Distance from the light source to objective lens (o_o).
   b. Distance from objective lens to the screen (i_o).
   c. Distance from the back of the screen to the eyepiece lens (o_e).
2. Use **Equation 1** to calculate the distance from the eyepiece to the final image (i_e).
3. Calculate the magnification of the images, M_o and M_e.
4. Calculate the total magnification of the microscope (M).

Table 4: Measurements for Part D.

Position of light source (cm)	Position of objective lens (cm)	Position of screen (cm)	Image properties	Position of eyepiece (cm)
45.0	60.0			

REFERENCES

1. PASCO, Instruction manual for *Beginning Optics System* (Model No. OS-8459).
2. PASCO, Instruction sheet for *Adjustable Lens Holder* (Model No. OS-8474).
3. PASCO, Instruction sheet for *Basic Optics Light Source* (Model No. OS-8470).
4. Hernández, C. A. (2010). *The Telescope and the Microscope*, PASCO Complete Experiments (Model No. EX-9988).

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