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A practical comparison between the methods of determining the focal length of a convex lens

Thill A. Kathum Al-musawi

Physics department- Science college- Al-Muthanna university

E-mail: thillalmusawi@yahoo.com

Abstract:

This study was conducted to determine the best method for determining the focal length of the lens of the lens, and the effect of the value of the thickness of the lens and the focal length in determining the type of method to be followed in the laboratories of optics to obtain the most accurate values and the easiest and fastest. Three methods were chosen to determine the focal dimension, the most used methods in this laboratory, and several convex lenses (with different focal lengths) were used with each method. The software used in its version (R2013a) was used to draw and represent the data.

1-Introduction:

A lens is an optical device which transmits and refracts light, converging or diverging the beam. A simple lens consists of a single optical element. A compound lens is an array of simple lenses (elements) with a common axis. converging lenses are thicker at the middle. Rays of light that pass through the lens are brought closer together, which falls on one side of the converging lens from the other face is broken towards its optical axis (the vertical line, which is the straight line that passes through the centers of the spherical of the two glasses forming the surface of the lens and there is a point in the middle of the lens called the optical center (C) It is not broken. [Chopra, 2016] The lens has a primary focal point (F) Is the point at which the falling rays parallel to and near the optical axis converge after breaking into the lens, while the diverging lens has an imaginary focal point (Fig. 1) [Mohammed et al., 2016]. diverging lenses are thinner at the middle. Rays of light that pass through the lens are spread out.

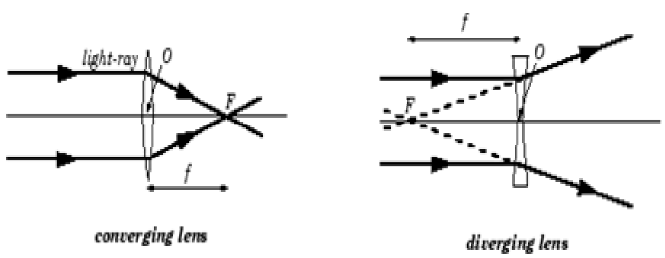

figure (1): convex lens (to left), and concave lens (to right)

The distance between the original focus and the optical center of the lens is called the focal length of the lens and is symbolized by the symbol (f). The focal length can be calculated from the general law of lenses as in the following law [Mohr et al., 2005].

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad (1)$$

(f) the focal length of the lens, its unity (cm) or (m), (u) distance object is from lens, its unity (cm), (v) distance image is from mirror, and its unit (cm).

There are six cases in which the images can be made using the convex lens depending on the distance of the object from the lens and based on the optical axis division, which is greater than twice the focal length and less than the focal length and between the focal length and the focal length. This experience of qualities is the real magnifying image that is in the opposite direction of the object and can be dropped on the screen [Gupta et al., 2017].

2-Materials and methods:

2.1-Materials:

In this study, six convex lenses with different the focal length are used as follows: (5, 10, 15, 20, 25, 30) in (cm), and using a small flashlight as a object, with a (120) cm optical Bench, and screen (30x30) cm.

2.2 Modification methods:

2.2.1-Displacement method:

The basic advantage of the law of lenses is that both the dimensions of the object and the image are reciprocal or conjunctive. This is a proof of the principle of reflectivity. If the direction of the reflected or refracted beam is reversed, it will return from its original path, meaning that the objects of the object and image can be replaced With each other because they are interrelated or reciprocal [Chopra, 2016]. In this way we will fix each time the position of the object and the image (the screen) and change the position of the lens to replace the distance from the lens to the object instead of the distance from the lens to the image and here is the position of the object and image two focal points and we call the positions of the lens with the two locations and in both cases we will get a clear picture Of the object (one enlarged and the other reduced) are the only two possible for each specific distance between the object and the screen [Hadi, 2012].

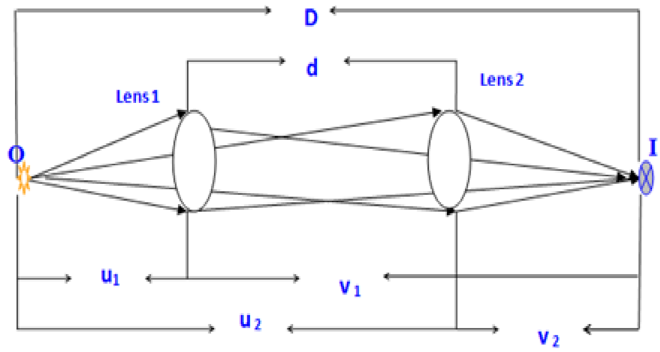

figure (2): Displacement method to find afocal length of convex lenses [Mohammed et al., 2016]

Suppose that (O) and (I) represent two conjugate foci, namely, the object and the screen where the distance between them is (D), then (1) and (2) are the two conjugated lens modes in which we obtain two clear and reduced images (the distance between the topical lens is (d)) as in figure (2) [Mohr et al., 2005].

$$u_1 = v_2 \quad , \quad u_2 = v_1$$
$$u_1 + v_1 = D \, , \quad v_1 - v_2 = u_2 - u_2$$
$$u = \frac{D-d}{2} \, , \qquad v = \frac{D+d}{2}$$

then compensation in the general law of lenses, we get:

$$f = \frac{D^2 - d^2}{4D} \qquad (2)$$

In this way, we find the focal length of the lens by placing the screen at a certain distance from the light source (D). Then we put the lens between the screen and the light object and change its position until a clear picture is formed at a distance of (v1) from the lens. (D) We calculate the focal length of the lens from the relationship (2) after we draw graphically between the values of (D^2-d^2) and the distance of the lens. On the vertical axis as a function of the distance (D) [Al-Khalaf et al, 2012], then we find the slope of the straight line from which we assign the focal length according to this method in the relationship:

$$\text{slope} = \frac{D^2 - d^2}{D} \Rightarrow f = \frac{\text{slope}}{4} \qquad (3)$$

2.2.2- Graphical Method:
from the General Law on Lenses:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow u + v = \frac{uv}{f}, v = \frac{uf}{u-f}$$

$$\therefore (u+v) = \frac{u^2}{u-f} \qquad (4)$$

If u (v) is converted to (y), equation (4) becomes as follows:

$$y = \frac{u^2}{u-f} \qquad (5)$$

Equation (5) represents the hyperbola equation, and its approximate asymptotes are:

$$u = f \qquad , y = u + f$$

by taking equation (5) for (u) we obtain the smallest value, (obviously the maximum value in infinity), as follows [KOZO et al, 1993]:

$$\frac{dy}{du} = \frac{2u\,(u-f) - u^2}{(u-f)^2} = 0 \quad \textit{for a minimum} \qquad (6)$$

from this relationship we get:

$$u = 2f \qquad \textit{for a minimum}$$

From the general equation for lenses when (u = 2f), (v = 2f), and from figure (3) we find that:

$$f = \frac{1}{2}\,OB = \frac{1}{4}\,OA \qquad (7)$$

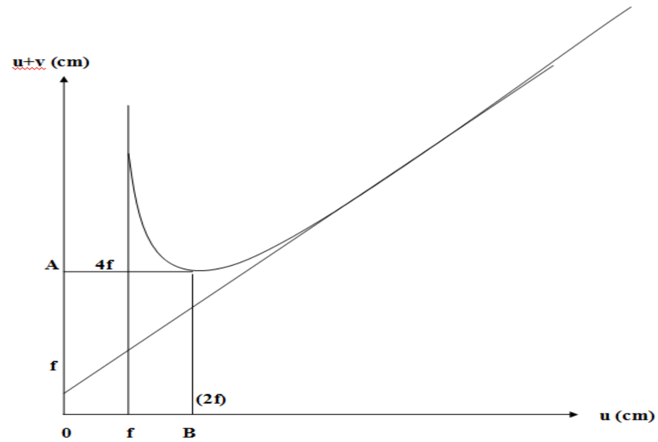

figure (3): Graphical method to find a focal length of convex lenses [Hadi, 2012].

In this method we find approximate value of the focal length of the lens by finding the clearest picture of the laboratory window on a white paper. Then we place the object more than (100cm) from the lens, which represents the distance between the object and the lens. On the screen and calculate the distance away from which the most clear image of this object from the lens (v) [Gupta et al., 2017], then the lens to the object to the successive distances of each value (10 cm), and then find the values of (v) corresponding to each case). In this study, all consecutive intervals (5 cm) were taken to increase the points drawn. Then we draw a graph between the total object dimension and the image of the lens (u+ v) as a function of the dimension of the object (u) to get the extra parts as in Figure (2-3).

The diameters of the plotted pieces intersect with the axes give the value of the focal length of the lens, The two projection points on the axes of the concave point as in figure (3) give the value of the focal length according to the relationship (7) [Gupta et al., 2017].

2.2.3-Magnification Method:
From the general law of lenses, then divided on (v), we get [Young et al., 2012]:

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$$\frac{v}{f} = \frac{v}{u} + 1 \quad \Rightarrow \quad \frac{v}{u} = \frac{v}{f} - 1 \qquad (8)$$

The magnification (M) is then equal to:

$$M = \frac{v}{u} = \frac{v}{f} - 1 \qquad (9)$$

Equation (9) represents a straight line with a slope equal to (1/f) [Abdullah et al, 1996], figure (4).

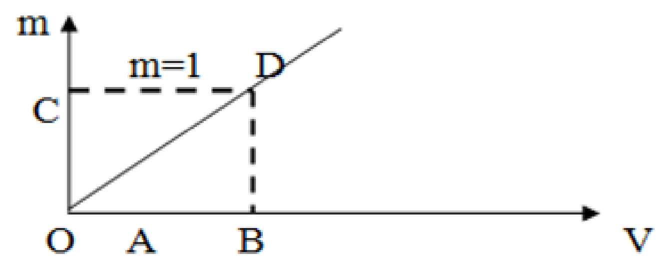

figure (4): Magnification method to find a focal length of convex lenses [Abdullah et al, 1996]

In this method we put the lens at a distance beyond the focal distance of the object, and then adjust the location of the image on the screen after the appearance clearly, and then measure the length of the image, which represents (L), then underestimate the screen after the object consecutive distances and each time we register the site. The image formed and its length [Abdullah et al, 1996]. In this way, the focal length of the lens can be determined by three steps, the first after we draw graphically between the amount of magnification (M) as a function of the dimension of the image, where the focal length can be found as follows:

a) when (M = 1), we get:

$$f = \frac{v}{2} = \frac{OB}{2} \qquad (10)$$

b) when (M = 0), we get :

$$f = v = OA \qquad (11)$$

c) from the slope of the straight line, since the focal length is equal to inverse of the slope:

$$\frac{1}{f} = \frac{BD}{AB} = \text{slope} \qquad (12)$$

3-Results and discussion:

The results of the first method (displacement method) showed that they can be applied to lenses with dimensions (5 cm) and (10 cm). The results were clear and perfect, as in figure (5).

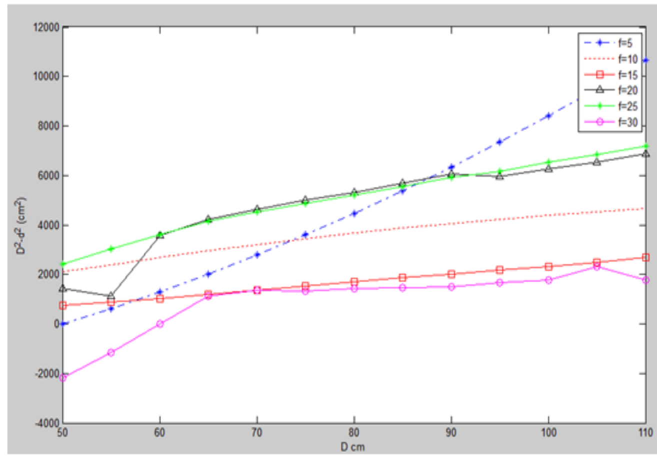

figure (5): graph plotting to find a focal length of convex lenses by displacement method

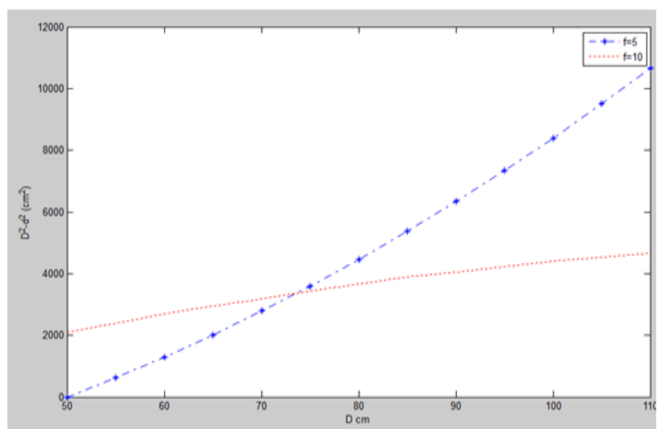

figure (6): graph plotting to find a focal length of convex lenses by displacement method for (f=5 cm) and (f=10 cm)

Figure (5) shows that the best results were calculated by the focal length of the lenses (f = 5 cm) and (f =10 cm). The lines also show the dark blue line and the red line in the diagram (6), If the

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results are set by a ratio equal to (5%) for the lens (f =5 cm), and the ratio equal to (1%) of the lens (f =10 cm), while the figure shows that lenses with a focal length greater than(f = 10 cm) we cannot find its focal length by This way.

These results were calculated by finding the slope of the straight line as follows:

$$Slope = \frac{D^2 - d^2}{D} \qquad \Rightarrow f = \frac{slope}{4}$$

$$\%\ error = \left|\frac{theortical\ value - measured\ value}{theortical\ value}\right| \times 100$$

For the lenses used in this experiment, the focal length (f) is less than (10 cm) and the object is larger than (100 m). This distance is large. The appropriate way to measure the focal length of convex lenses is the symmetric focal length method [KOZO et al, 1993]. After the object or image of the lens is larger than the focal length four times (4f), the focal length is preferred to be calculated according to this method. Equation (2) is derived from relationship (1).

This is due to the fact that this method depends on the formation of two images are conjugated the first is real reduced inverted at a distance between the focus and the center of curvature because the object is more than a distance of twice the focal length (more than the radius of the curve), and the other is real enlarged inverted at a distance greater than twice of the focal length because the object is at a distance less than twice the focal length or subject between the focus and the center of curvature.

While for lenses that are larger than (f =100 mm), the resulting images are not symmetrical for one lens, but rather one image is small and the enlarged images are not formed because the object is more than twice the focal length. This is for the lenses (f=15 cm) (f=20 cm), while the lenses have (f =25 cm) and (f =30 cm) formed images are enlarged only because the object is within the focal length (between the lens and the focal dimension).

The results of the second method (the graphical method), which were drawn as in figure (7).

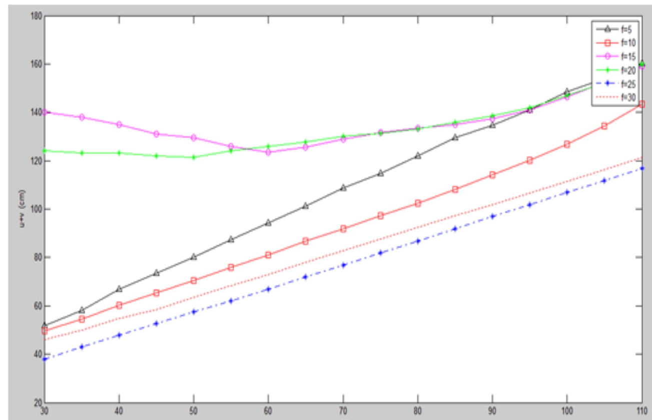

figure (7): graph plotting to find a focal length of convex lenses by graphical method

We note that the results were correct and adjusted for lenses (of =25 cm, 30 cm), as shown in green and pink color. The error ratio in the lens focal length (f =25 cm) was (6%) and (1.46%). The focal point of the horizontal axis is equal to twice the focal length of the lens, while the intersection point with the vertical axis represents four times the focal length of the lens.

For the other four lenses, this method is not valid as it is evident from the representation of the points on the two axes form (8) and the non-formation of the cutoff equation (5), and the behavior of one drawing a straight line and the tendency of this line cannot give the focal length of these lenses.

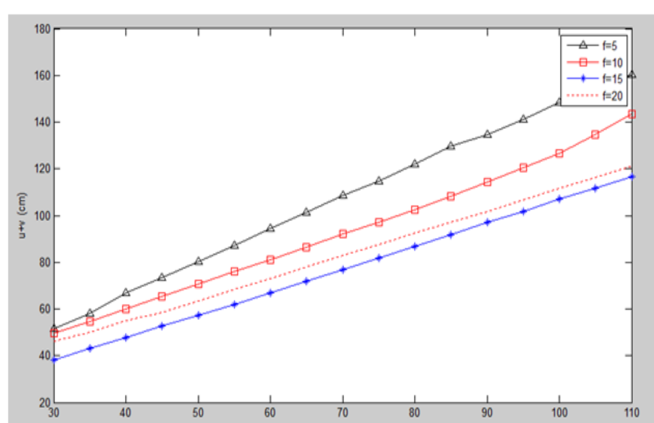

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figure (8): graph plotting to find a focal length of convex lenses by graphical method for lenses have focal length less than (25 cm)

The third method is painted as in figure (9), The results were appropriate for the lenses with (f =15 cm) and (f=20 cm). As shown in black and blue, the error percentage in the focal length of the lens (f=20 cm). Is equal to (8%), equal to (3%) for the lens (f=15 cm), and the focal length is calculated according to relationships (10-12).

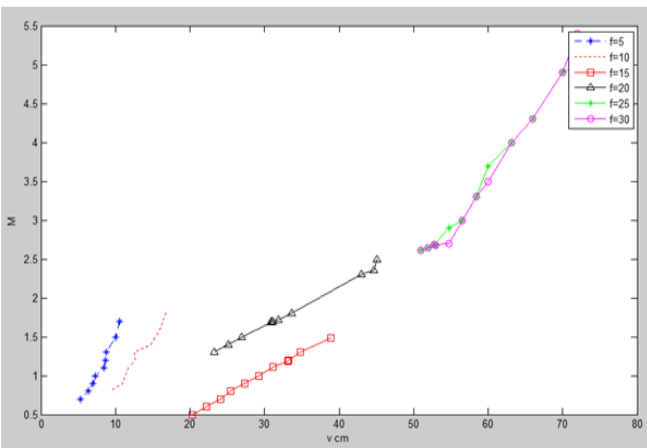

figure (5): graph plotting to find a focal length of convex lenses by magnification method

The other lenses did not achieve the focal length equations, and the data were not suitable for finding the focal length of the lenses according to this method as shown in figure (10), and the lines of these lenses, blue, red, green and pink, intersect with the horizontal axis In the positive part this means the relationship needed to find the focal dimension when (M=0) does not obtain.

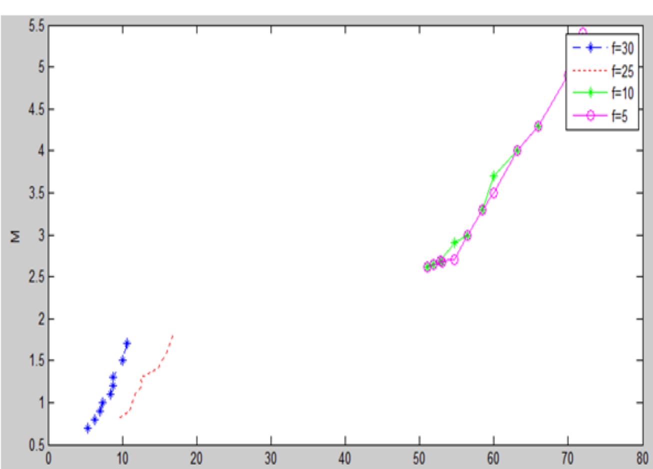

figure (5): graph plotting to find a focal length of convex lenses by graphical method for (10 cm>f<25cm)

The position of the object at a distance of approximately twice the focal length is the starting point for any experiment of the convex lens. In this position the object and image dimensions are equal and the magnification is equal to one. Therefore, when the object is changed from the lens (2f) to (f) and the (v) change from (2f) to the infinity, and the image will be smaller and this is what we observe for the lenses with large thickness (with a small focal length), but when increasing the distance of the object from the lens of (f) to (2f), we observed the image change from infinity to (2f) [Mohammed et al., 2016], for the lenses with small thickness with a focal length).

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