Focal Length of Thin Lenses

Author: Jianping Hou, English version: Bing-Yan Wei
Physics Experiment Teaching Center, NPU

I. Tasks and requirements

1. Prepare the apparatus for this experiment.
2. Study the principles and methods of measuring the focal length of lenses.
3. Measure the focal length of a convex lens and a concave lens by the objective distance and image distance method (It is required to take photos of the overall light path, the readings during measurement and the images on the screen).
4. Measure the focal length of a convex lens by the conjugate method (It is required to take photos of the overall light path, the readings during measurement and the images on the screen).
5. Process the experimental data (uncertainty calculation, complete expression).
6. Write a complete experiment report.
7. For more: (1) Analyze and design one or two other principles and methods of measuring the focal length of the lenses, and compare with the methods in this experiment. (2) Complete the experiments designed by yourself, and compare the results with the objective distance and image distance method and the conjugate method.

II. Objectives

1. Basic training of optical experiments.
2. Adjusting coaxial at the same height and successive approximation adjustment methods.
3. Recording experimental data.
4. Designing multiple measurements.
5. Uncertainty calculation.
6. Attempts to solve problems with multiple methods.

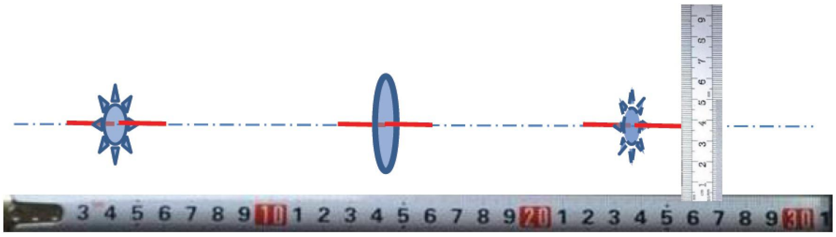
III. Principles and Methods

1. Basic requirements of optical experiments.

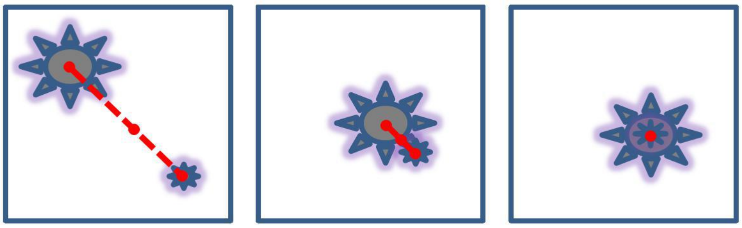
The basic characteristics of the optical experiments are that many devices are made of glass and they should be adjusted precisely, and also the experiments are generally carried out in a dark room. Therefore, we must pay special attention to the safety of the devices during the experiments. Specifically, [Taining 1] **please note**: (1) Do not touch the optical surface of the optical elements (the surface through which light passes or reflects); (2) Put the devices that are not in use temporarily in a safe place that is not easily accessible.

2. Adjust the optical axes coaxial at the same height.

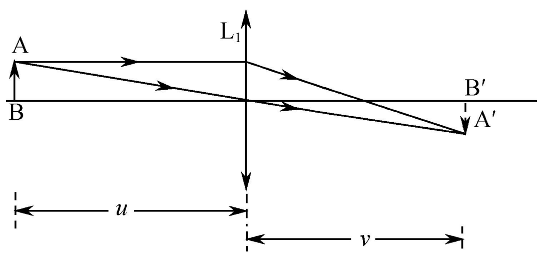
It is required that all the optical elements should be adjusted to be coaxial at the same height during the measurements. That is, the optical center of each element should be on the same axis, and the axis should be parallel to the slideway of the optical bench.



[Training 2] Adjustment method: The adjustment is divided into two steps. The first step is a visual coarse estimation so that the center of each element is at the same height, and the plane of each element is perpendicular to the optical axis (that is, the optical axis of each element is coaxial). You can use a ruler for assistance in this step. The second step is the fine adjustment by the conjugate method. Firstly adjust the distance D between the object and the image screen to be large enough ($D > 4f$, and if the value of f is unknown, you can first use the object distance and image distance method or the parallel light method for rough measurement), and then move the convex lens to clearly form a big image and a small image respectively. Adjust the object or convex lens until the centers of the images coincides. When adjusting the lens, you can use "the big image chasing the small image" or "successive approximation" method, that is, move the lens to make the center of the big image close to the center of the small image until they are overlapped.



3. Measure the focal length of a convex lens by the objective distance and image distance method. Adopt an object, the convex lens, and a screen to form a clear image, and measure the distance between the object and the lens $\boldsymbol{u}$ and the distance between the lens and the clear image $\boldsymbol{v}$. The focal length can be obtained by: $\boldsymbol{f_1 = u * v/(u+v)}$.



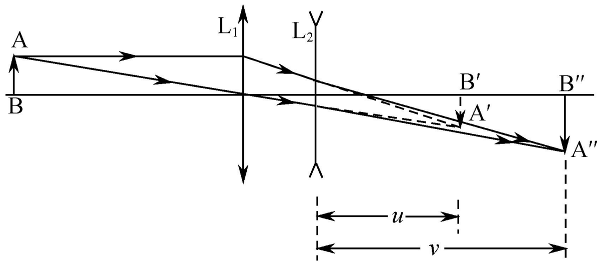
[Training 3] **Data recording:**

unit: __cm__ (**Notes**: The value of the scale division of the ruler is 0.1cm, and the readings should have been estimated to 0.01cm. However, as this experiment is not conducted on the optical bench, the exact position of the optical center of the devices cannot be accurately determined. Therefore the error limit of the measuring instrument can be taken as 1, 2, or 3mm according to the actual situation, and the measurement readings can be estimated to 1mm.)

	X_{AB}	X_{L1}	$X_{A'B'}$	u=|X_{L1}-X_{AB}|	v=|$X_{A'B'}$-X_{L1}|
1					
2	?	?	?		
3	?	?	?		
Average					

[Training 4] Note: This sub-experiment only requires a single time measurement. If one wants multiple measurements, it is recommended to keep two of the object, the convex lens and the image screen still after the first measurement and move the other one to find the clearest image position.

4. Measure the focal length of a concave lens by the objective distance and image distance method. A convex lens should be adopted to form a **virtual object** (Attention: adjust the distance between the convex lens and the object to ensure the image on the screen is smaller than the object, so that it is relatively easy to get the real image in the next procedure), and the real image can be obtained on the screen by the combination of virtual object and the concave lens. Measure the distance between the virtual object and the concave lens u and the distance between the concave lens and the clear real image v, then the focal length can be calculated by: $f_2 = u*v/(v+u)$. Attention: As the virtual object is on the right side of the concave lens, u should be taken as a negative value.



Attention: When the concave lens is added to the optical path for coaxial adjustment, it is only necessary to adjust the concave lens so that the image center after the concave lens is added coincides with the center of the former image formed by the convex lens.

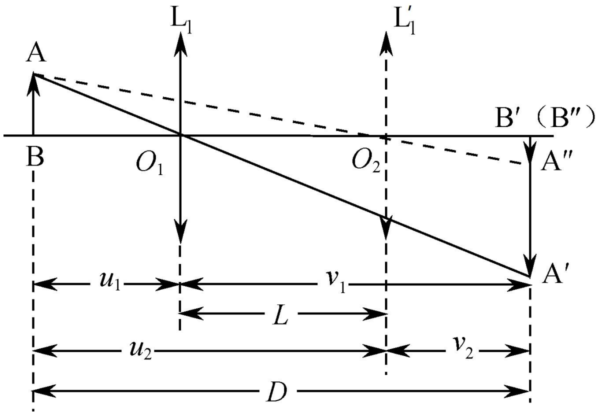
[Training 3] **Data recording:**

unit: cm (The readings can be estimated to 0.1cm.)

	X_{L2}	$X_{A'B'}$	$X_{A''B''}$	u=-|X_{L2}-$X_{A'B'}$|	v=|$X_{A''B''}$-X_{L2}|
1					
2	?		?		
3	?		?		
Average					

[Training 4] Note: This sub-experiment only requires a single time measurement. If one wants multiple measurements, it is recommended to keep the object and the convex lens still after the first measurement and move the convex lens or image screen to find the clearest image position X_{L2} from the left and right sides to the center respectively.

5. Measure the focal length of a convex lens by the conjugate method. According to the f value calculated from the first experiment, set the distance between the object and the image screen D greater than 4 times the focal length f, that is, D>4f. Move the lens and record the positions of the convex lens when you get the clear images (a big one and a small one) on the screen, and then you can get the distance between this two positions of the lens L. The focal length of the convex lens can be calculated by: $f = \dfrac{D^2 - L^2}{4D}$.



[Training 3] **Data recording:**

unit: cm (The readings can be estimated to 0.1cm.)

	X_{AB}	$X_{A'B'}$	***D***=|X_{AB}-$X_{A'B'}$|	X_{L1}	X_{L1}'	***L***=|X_{L1}-X_{L1}'|
1						
2						
3						
Average						

Note: This sub-experiment requires a single measurement of ***D*** and multiple measurements of ***L***. Keep the object and the image screen still. Move the convex lens and record its positions X_{L1} and $X_{L1'}$ when you get the clearest images.

6. [Training 5] Data processing is required after completing the above measurements.

(1) Calculate the average of each directly measured quantity. The number of significant digits is the same as the measured data. Attention: Although the value of u, v, D, L, etc. is obtained by subtracting the two positions, this is essentially the same as the readings obtained from a metric ruler. Therefore, these are all directly measured quantities when calculating the uncertainty

(2) Substitute the average value of each directly measured quantity into the formula to calculate the focal length. The significant digits can be reserved by 4 digits in advance. In this step attention should be paid to the following format: physical quantity name = symbolic formula = data substitution formula = result (unit). E.g., $f_1=u*v/(u+v)$=27.92*27.83/(27.92+27.83)=13.94cm

(3) Calculate the type A, type B, and absolute uncertainty of each directly measured quantity.

(4) Use the uncertainty transfer formula to calculate the uncertainty of the focal length with 1 to 2 significant digits. For details, please refer to the requirements in the

calculation of uncertainty in the introduction class.
(5) For the specific format and requirements of the complete expression, please refer to the corresponding content in the introduction class.

IV. Preparation of apparatus

1. A soft ruler for measuring clothes or a tape that can be locked can be used as the optical bench when they are laid flat on the ground or table.

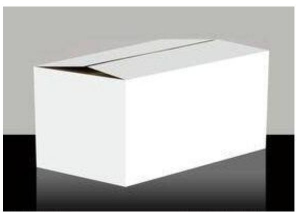

2. Magnifying glasses or presbyopic glasses can be used as convex lenses.


3. A convex lens can be made by a bottle:
https://jingyan.baidu.com/article/27fa7326b3b2e546f8271ff5.html


4. Myopic glasses can be used as concave lenses. Or you can make one by gluing the two convex pieces in Tip 3 back to back.


5. Selection of objects and light sources: (1) Use a shaped LED lamp as a combination of the light source and the object. (2) Use a flashlight as the light source, and draw a pattern on the frosted glass or plastic film as an object.

6. A white wall, a regular white box, or a non-white box sticked with a piece of flat white paper can be used as the screen.



7. The above devices can stand upright and the position and direction can be adjusted with the support of foam, and the height can be adjusted by stacking books and papers.

V. Requirements for the Report.

1. Theory: Discuss the theory or the principle and methods of the experiment.
2. Apparatus: List the ready-made or self-made experimental instruments and devices, and attach the photos.
3. Procedures: List the experimental steps and attach photos or small videos of the process.
4. Experimental data and processing: Calculate the results of the focal length and calculate the uncertainty and complete expression.
5. Analysis of the experimental results: Analyze the reasons of errors or deviations, make improvements, and then conduct and record the experiment again and compare the results.

The following is an example: object-a ring-shaped LED lamp, convex lens-presbyopic glasses, image screen-a white box.

6. Improvement: [Training 6] Try some other methods, such as parallel light convergence, self-collimation method, laser light method, etc. Briefly describe its principle, compare the measurement results, and analyze and have a discussion.