

## College Physics II

### Lab 4: Lenses

Peter Rolnick with Taner Edis

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#### Introduction

You are going to find the relationship between the distance of an object from a lens  $O$ , the distance of the image of that object from the lens  $I$ , and the focal length of the lens  $f$ . You will learn more about experimentation from this lab than about light or lenses. If you approach this lab as a recipe to be blindly followed, you will be frustrated. You must think about what you are trying to accomplish, and then figure out what to do on your own.

If you put an object on one side of a convex lens, then there will be an image on the other side of the lens. If the object is glowing, then the image can be projected onto a screen, but for a given object-to-lens distance  $O$  there is only one screen position at which the image will be sharp.  $I$  is the image-to-lens distance when the image is sharp.

The focal length  $f$  of a lens is the image-to-lens distance, when the image is sharp, for an object which is infinitely far away.

To prepare you for the techniques you will use to find the relationship between  $O$ ,  $I$  and  $f$  in this lab, here are some mathematical relationships which you will graph, to get a feel for what these relationships look like. I expect you to use graphical techniques to analyze the data you collect.

Suppose you had two experimental quantities  $x$  and  $y$ . Suppose  $x$  and  $y$  could vary, but not independently. Specifically, no matter what  $x$  was,  $y$  was always whatever it took for  $x$  times  $y$  to equal 1. That is, suppose

$$xy = 1 \tag{1}$$

## ACTIVITY: THE EXPERIMENT

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Make a clear, accurate graph of  $y$  versus  $x$  for equation (1). Now make a graph of  $y$  versus  $x$  for the relationship

$$(x - 2)(y - 2) = 2^2 \quad (2)$$

and note the similarities and differences between your graph of equation (1) and your graph of equation (2).

You will attempt to discover the relationship between  $O$ ,  $I$  and  $f$  by measuring values of  $O$  and  $I$  for many different positions of the object and the lens.  $f$  is constant for a particular lens. By graphing your results, and by trial-and-error guessing based on your graphs, you will decide on one equation which you think expresses the relationship of each of these quantities to the others. You will then check your equation by substituting in measured values and seeing if the equation is true (within the precision of your experiment) for those values. If not, you will have to revise your equation.

Finally, you will test your equation by using it to predict what  $I$  would be for an  $O$  that you have not tried yet. Then you will do the experiment (for that value of  $O$ ), and see if the resulting value of  $I$  agrees, within the uncertainty of your experiment, with the value you predicted. If not, then you may have to revise your equation yet again.

In the end, you will have arrived at an equation relating  $O$ ,  $I$  and  $f$  which you have tested and which you are confident is correct.

## Activity: The Experiment

Set the lens at the center of the optical bench, and keep it at the center throughout the experiment. Set the light (the object) at one end of the optical bench, and set the screen, onto which will be projected the image, at the other.

Now move the screen up and down the bench, and note that, for a particular position of the object, there is only one position of the screen for which the image is in focus. As you move the object closer and closer to the lens, you will have to keep moving the screen further and further from the lens.

Take data by finding  $I$  for a given value of  $O$ . Using as wide a possible range of values of  $O$ , take 10 data points. (You can move the lens as well as the object.) At each point measure  $O$  and  $I$ . Make your measurements as precisely as you are able. In measuring  $O$  and  $I$ , be sure that you get a wide range of values of both quantities. Record the data in a table.

## ACTIVITY: THE EXPERIMENT

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Here is something to keep in mind. Because of the way the bench is marked, you will *not* be measuring  $O$  and  $I$  directly. Rather, you will measure the *position* of each item for a particular data point, and then you will find  $O$  and  $I$  by finding the difference between those positions. Specifically, let's call  $P_O$  the position of the object,  $P_I$  the position of the image when it is in focus, and  $P_L$  the position of the lens. Then:

$$O = |P_L - P_O|$$

$$I = |P_L - P_I|$$

Now you are ready to study the relationship between  $O$ ,  $I$  and  $f$ .  $f$  for the lenses you are using is between 10 and 20 cm. Plot a graph of  $I$  versus  $O$ . What mathematical relationship between  $I$  and  $O$  does the shape of your graph suggest? Test this relationship by seeing if your data points obey it.

What limiting value does  $I$  approach as  $O$  increases, that is, how close to the lens would you expect to find the image if the object distance were very great? What limit does  $O$  seem to approach as  $I$  increases? Do these limiting values appear to be related to any other quantity in the experiment?

Using the above two suggestions as a start, eventually, you are to come up with an equation that relates  $O$ ,  $I$  and  $f$ . You may want to make other graphs of quantities you calculate from  $O$  and  $I$ . You will know if your formula is reasonable by substituting actual data points (more than one!), and seeing if the formula is correct for those data points within the precision of this experiment.

As a final test of your formula, express  $I$  as some function of  $O$  and  $f$  and insert a new (untested) value of  $O$  into it, calculate the  $I$  that it predicts, and check the prediction with your apparatus. See if your measured value of  $I$  agrees with your predicted value, within the precision of this experiment. Be sure to leave your apparatus set up until you have checked your prediction. Again, if necessary, go back and modify your formula.

**Note:** To get the most out of this lab, do *not* jump directly to the correct equation. Let the data lead you there—that is the process I want you to learn about.

### To hand in

- Graphs of equations (1) and (2),

- All data gathered,
- Any additional graphs made,
- All guesses at the relationship between  $O$ ,  $I$  and  $f$ , including guesses that turned out to be incorrect (clearly say which relationship is the one you think is the correct one),
- Equation for  $I$  as some function of  $O$  and  $f$ ,
- Results of your attempt to experimentally verify your prediction.

## Postscript

In this experiment you have found a relationship by what is known as an empirical procedure. The final result was based on observations alone. We did not discuss the theory of lenses at all, and we did not need to.

Much of science consists of measuring, and being able to make predictions about, phenomena which we otherwise do not understand at all. Being able to do this well allows us to, later, come up with a good theoretical model of what is happening. An analytical process, on the other hand, uses a theoretical analysis of a situation to yield a result which can then be tested experimentally. It is characteristic of science that theoretical predictions are tested experimentally and that empirical results are analyzed theoretically.

An excellent example of this interplay between experiment and theory is the development of the quantum theory of the atom. By the end of the nineteenth century, there were excellent data regarding the spectra of the elements, and there were experimentally verified formulas relating the frequency of those spectral lines to each other. Yet, classical physics did not predict the observed spectra, so no one had a clue as to what was going on. But it was just those spectral data and empirically derived formulas which served as the reality check against which the quantum theory of the atom was developed between 1913 and the 1920's. Without careful experimentation, including close attention to precision, we may not have discovered quantum mechanics until much later, or we may not have discovered it at all!