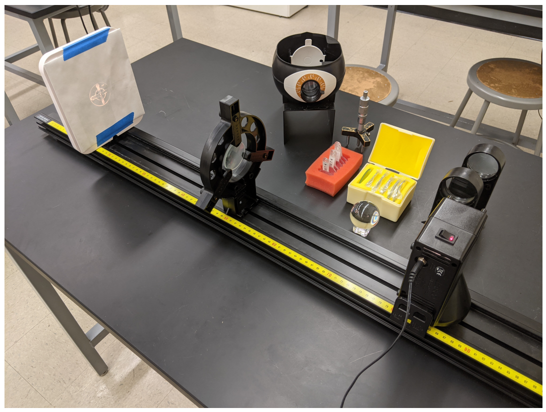
Lab 3

Seeing is Believing (In Uncertainty Propagation)



Physical Models: Optical Power, Lens Equation

Analysis Tools: Propagation of Uncertainty, t-score

Experimental Systems: Convex Lenses, Eye Model, Eye Model Lens Set, Image Screen

Equipment: Flashlight, Multicolor Lasers, PASCO Light Source, PASCO optics track, Caliper, Metersticks

Safety Concerns: Be careful not to look directly into any light sources or to shine them haphazardly at other groups! And be careful handling the glass lenses since they could shatter.

Introduction

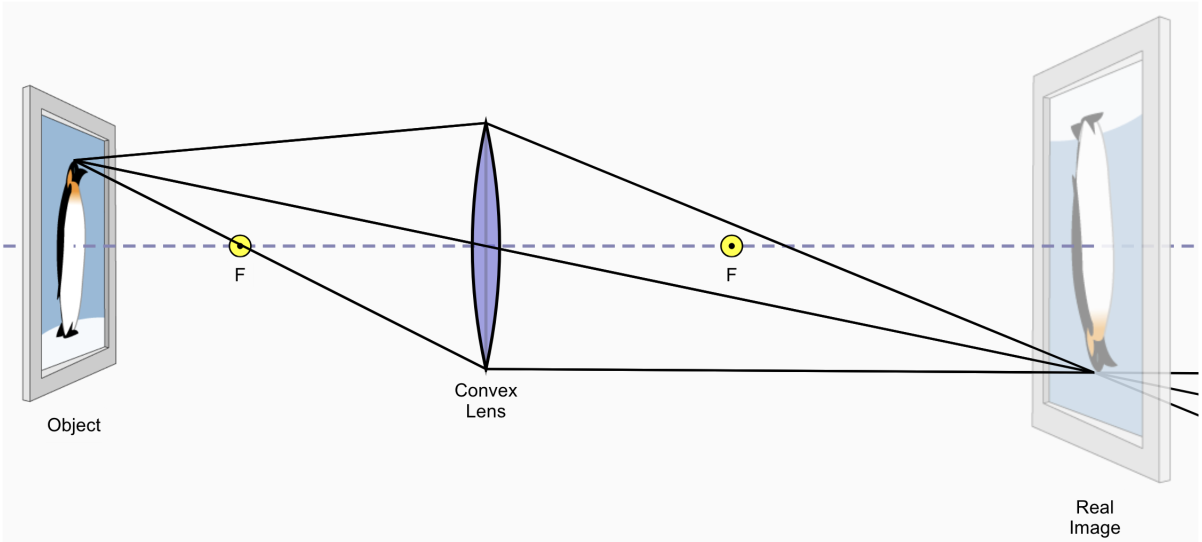
In the Prelab for this week, you explored a model for image formation by **thin lenses**. According to this model, an object placed at a distance d_o away from a lens will produce an image located at d_i according to the relation :

$$\frac{1}{d_o} + \frac{1}{d_i} = P \tag{3.1}$$

where P is a constant (with units of inverse distance) called the *optical power*. In Physics II you'll learn how P is related to the focal length of a lens and a lens's geometry and material. In lab this week we'll investigate how well it accounts for the behavior of image formation by actual lenses.

In earlier labs you minimized uncertainty through multiple trials and by using more precise equipment. In this lab we'll have to contend with a new source of uncertainty, propagation of uncertainty. Minimizing it

Figure 3.1: Click here to view a PhET simulation of a lens



will involve a different process.

Part 1. Lenses and Uncertainty Propagation

Your goal in this part of the lab is to investigate the model to see how well it describes image formation by a lens. This goal has two components:

- You'll want to investigate if P is truly constant for different combinations of d_o, d_i as the model claims
- For whatever regime you find the model to be accurate, you'll want to measure P to the lowest possible uncertainty.

Quick Check: As usual, let's first explore a bit. Set either of the two PASCO Convex Lenses on the optics track along with the PASCO Light Source and the image screen, as shown in the picture on the previous page.

Make sure the light is plugged in and turn it on. Move the light source, lens, and/or image screen around until you see a sharp image. This may take some tinkering!

Once you've found a configuration which works, you have a single example of d_o and d_i for which you could compute a tentative P. However, as you probably noticed when trying to form the image, there's a lot of uncertainty in d_o and d_i! Your best estimate should be the place where the image is sharpest. But there's likely a **range of values** where the image is indistinguishably sharp. You should tinker and find this range and use it as your uncertainty. This uncertainty will then propagate through to P by way of the uncertainty propagation formula.

Designing Your Experiment: Now design an experiment to systematically investigate whether or not/over what range P is constant and to minimize the uncertainty in P. You'll likely benefit from using the propagation of uncertainty formula and thinking about how to minimize it. Plan to do this for one lens or for the crystal ball.

Refer to the lab rubric for a reminder of what else to consider and what to record.

You don't need to decide everything in advance, this lab will likely require some extra tinkering and revisions, which is perfectly fine.

Whatever you do, make sure to *explore the whole range of object distances available to you given the length of the track*

Check in with Another Group: Briefly discuss your plans with another group. They may provide you with additional ideas and feedback. Note one similarity and one difference between your approaches.

Conducting Your Experiment: Go ahead and give it a shot. You can change your method around while you're at it; you don't need to treat your previous decisions as a contract. Just make sure to record any changes you make.

Above all, try to minimize uncertainty as much as you can!

Extra Guidance: Partial Derivatives and Uncertainty Propagation

Recall that for a single variable $y = f(x)$ uncertainty propagates as:

$$\frac{\delta y}{\delta x} \approx \frac{\partial y}{\partial x} \rightarrow \delta y = f'(x)\delta x \tag{3.2}$$

And that for multiple variables we add individual contributions "in quadrature":

$$\delta y_{total} = \sqrt{\delta y_1^2 + \delta y_2^2 + ...} \tag{3.3}$$

Partial derivatives which may be useful for this lab:

$\frac{\partial P}{\partial d_i} = -\frac{1}{d_i^2}$ $\quad$ $\frac{\partial P}{\partial d_o} = -\frac{1}{d_o^2}$ $\quad$ $\frac{\partial}{\partial P_1}(P_1 + P_2) = 1$ $\quad$ $\frac{\partial}{\partial f}(\frac{1}{f}) = -\frac{1}{f^2}$

Check in with Another Group: Check back in with the same group you discussed things with before. How do your results compare? Note two similarities and/or differences between what you found, and use this to inform your proposals for future iterations. You can also compare if you used different objects.

Forming a Conclusion: Does your data support the model that $1/d_o + 1/d_i$ is a constant? What's your most precise best estimate and uncertainty for P?

Part 2. The Eye and Corrective Lenses

If you use corrective lenses, optical power is something you may have seen before: the prescription for contacts, glasses (monocles?) are usually written as an optical power!

In this part of the lab, we'll investigate how corrective lenses can assist vision. In order to do this, we'll need to think about *combinations* of lenses. A simple model we might suspect describes combining lens is:

$$P_{combined} = P_1 + P_2 \tag{3.4}$$

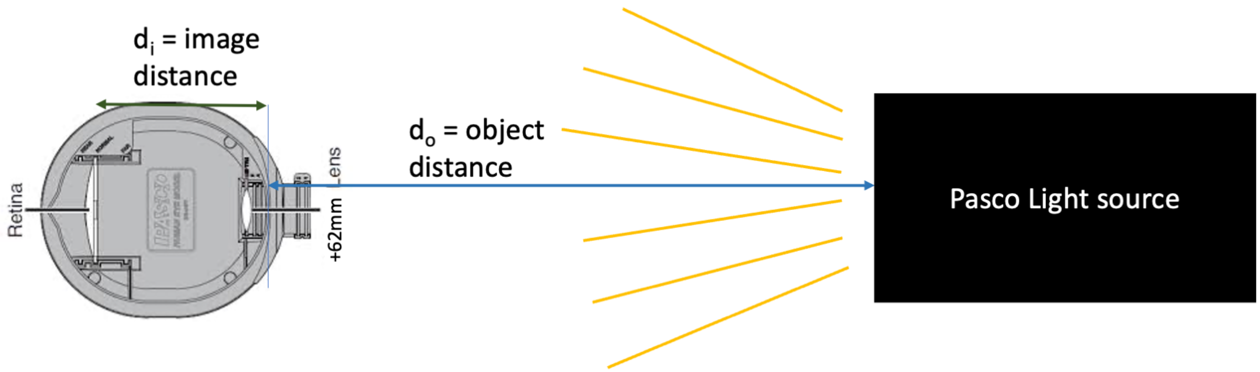
Of course it may or may not be so simple!

Quick Check: Fill the eye model with water up to a couple centimeters from the top using the sink at the front of the room. Remove the PASCO convex lens and image screen from the track and replace it with the

Eye Model (facing the light source).

As with a real eye, light goes into the pupil and projects onto the retina in the back, which can detect an image. In the eye model there's probably no image on the retina at the moment. That's because the eye relies on an internal lens to produce an image on the retina, just like the convex lenses we've been working with!

Place the small lens labeled $+62mm$ on the inside of the eye model in the *septum* slot. Move the eye model and/or light source around until an image is formed. This is how the eye works!

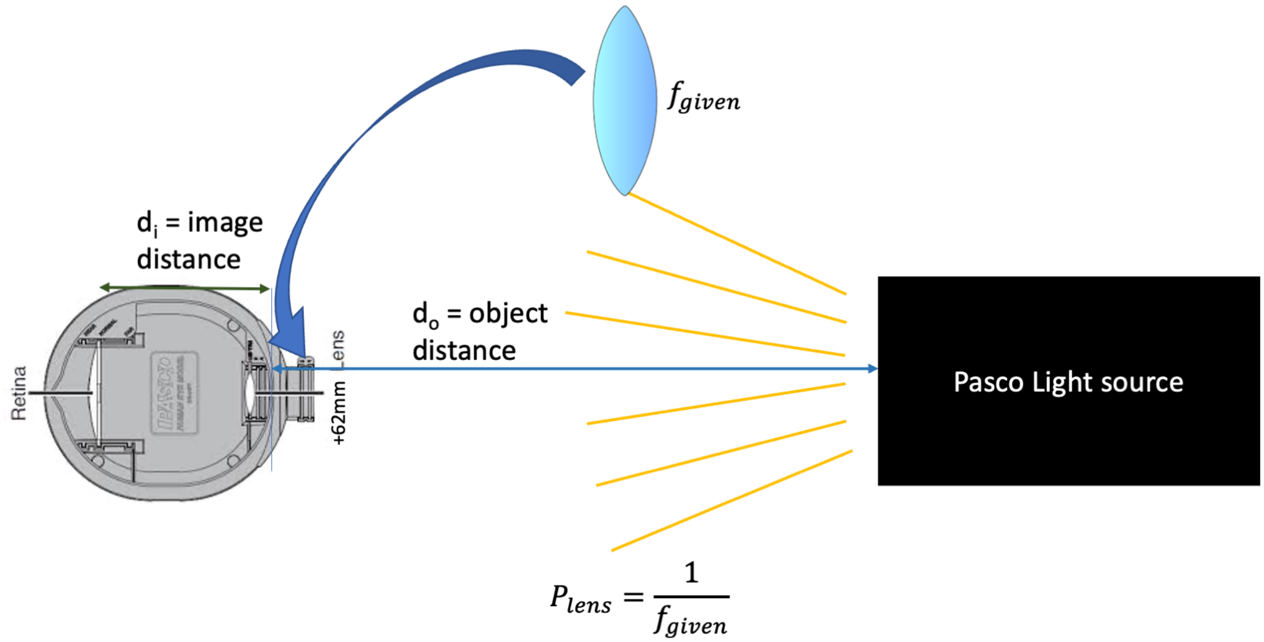


$$P_{eye} = \frac{1}{d_o} + \frac{1}{d_i}$$

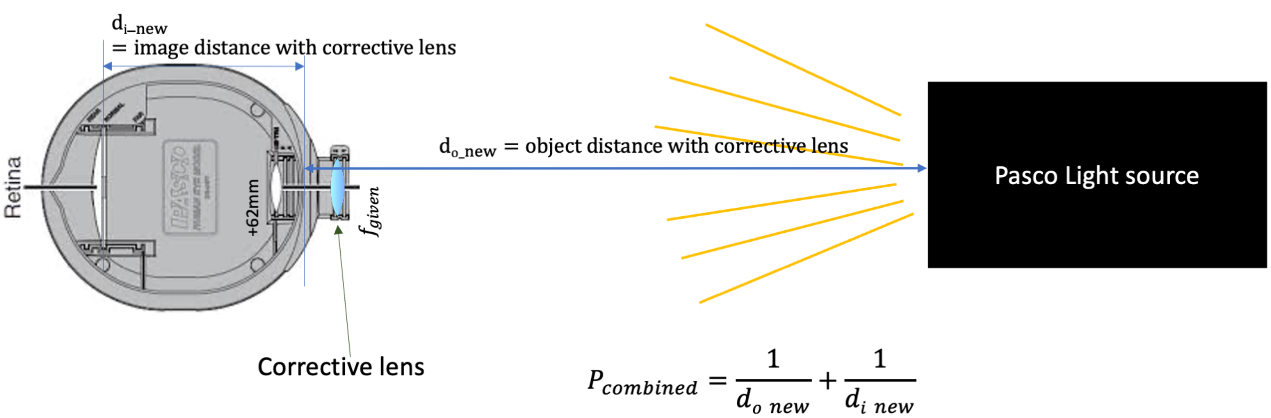
Now try moving the retina screen to "near sighted". This represents the difference in the shape of an eye for a near sighted person. The image is formed in a location behind the retina and the image is blurry! The eye must be moved closer to the object in order to see a clear image. Try this.

Now try moving the retina to "far sighted" The image will blur again. In a far sighted individual, the eye is unable to adjust its focal length to compensate for its different shape. The image is formed in a location in front of the retina! In order to obtain a clear image, the eye must move further away. Try this.

But wait, there's more! Instead of moving the eye closer or further away from an object, we could instead add *a corrective lens* in front of the eye. Try adding new lenses *in front of the eye* and/or changing the object distance until you get a clear image for a near sighted or far sighted configuration.



Now you've found examples of d_o and d_i for the eye on its own, which could give you P_{eye}. You've also added a lens in front of the eye, which is labeled with a focal length, and $P_{lens} = 1/f$. And finally you've found a d_o and d_i for the combination of eye+lens, from which you get $P_{combined}$



According to the model for power addition we should have: $P_{combined} = P_{eye} + P_{lens}$ But is this true?

Designing Your Experiment: Design an experiment that does the following:

- Investigates whether or not $P_{combined} = P_1 + P_2$ is an accurate depiction of how optical power works for multiple lenses. You should find multiple configurations for this (i.e., normal, nearsighted, farsighted).

Conducting Your Experiment: Conduct the experiment as planned. In this case, you should worry less about minimizing uncertainty. Focus on finding new examples of image formation with lens combinations. Remember that you can change the location of the retina to get more combinations

Forming a Conclusion: What did your new experiment reveal about the combination of optical power? What configurations allowed you to correct near- and far-sighted vision?

Writing Up Your Lab Notes for Submission

Write up your notes for Part 1 and Part 2 in an organized way according to the rubric provided.