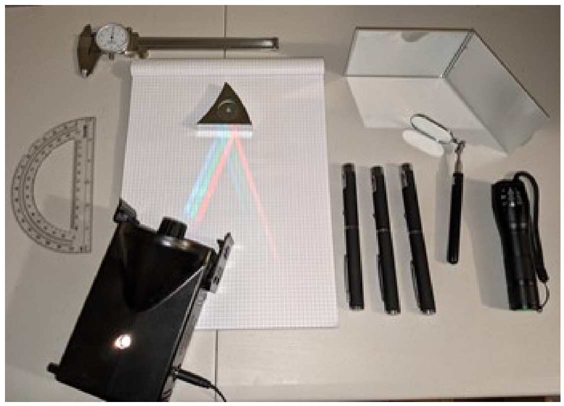
Lab 0

Reflecting on Measurement



Physical Models: The Law of Reflection

Analysis Tools: Mean, Standard Deviation, Standard Deviation of the Mean, Measurement Precision

Experimental Systems: Various Mirrors, PASCO mirror

Equipment: Flashlight, multiple lasers, PASCO light source, caliper, protractor, stopwatch, graph paper

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 mirrors since they could shatter.

Introduction

Each week in lab this semester you'll be designing and conducting experiments to investigate how well various physical theories and concepts from General Physics II apply to real world systems.

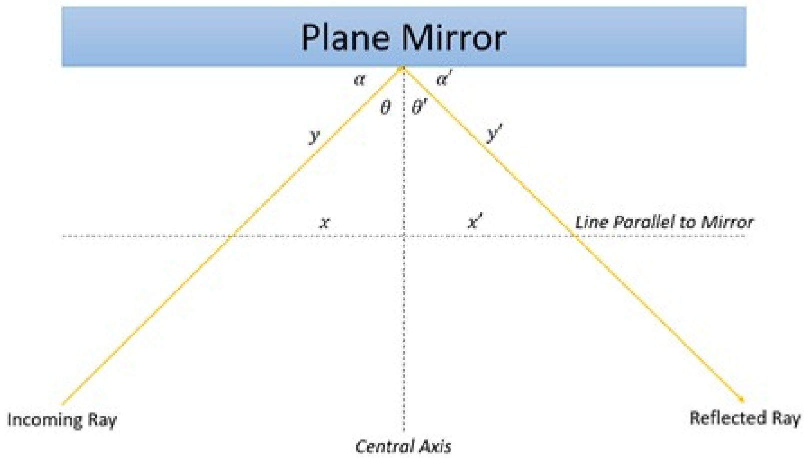
Although we'll supply you with physical models to test, experimental systems to explore, and analysis tools and equipment to utilize, you'll often be given a fair amount of genuine freedom in how you approach each investigation. We hope this freedom will make the course more fun and more meaningful to you. Research also suggests it's a significantly better way to learn experimental physics than following cookbook style instructions. Most importantly, *this is how science actually works*! [1]

But we also realize this format may be new for you and may be challenging in some ways. So in this first lab we'll (1) provide some extra guidance and (2) we'll underline places you should be taking notes. This way you can get comfortable with the format while also reflecting on some things you may (or may not) have learned in earlier lab courses which we'll be building upon this semester.

[1] Holmes and Wieman, "Introductory Physics Labs: We Can Do better", Physics Today January 2018

Part 1. Investigating the Law of Reflection

In the Prelab Activity for this week, you were introduced to the Law of Reflection, a theory of reflection proposed by scientists which claims that when light is reflected off a plane mirror, the incident ray and the reflected ray are completely symmetric with respect to the central axis:



If the scientist's claims are correct, for example, we can deduce that in the picture $\theta - \theta' = 0$, $x - x' = 0$, etc. The Law of Reflection is the physical model we want to test today, and any of these equations represents a quantitative implication of it that we can check in an experiment.

We'll need to select an experimental system, an actual physical mirror, to compare against the model's predictions. Head to the front of the room and select any of the mirrors [2] laid out by your TA and bring it back to your table. We'll see if the scientists' model really does accurately describe reflection off your chosen item.

Quick Check: It's usually a good idea to play around with things a bit before launching into an actual investigation. Try looking into the mirror, try setting it down and shining the flashlight and/or other sources on it, etc. Does it seem like the Law of Reflection applies, at least qualitatively? Make a prediction. Also try out the equipment available to you to help you decide on an experiment.

Designing Your Experiment: In this lab we'll present you with a more detailed walkthrough on how to organize your investigation than usual. In the future we'll leave it more open, (but you'll have a grading rubric to help you make sure you're checking all the boxes).

[2] in this lab we'll underline things that you should record for your writeup

Extra Guidance: Models, Goals, and Method

First, decide on a concrete goal. You can choose if you'd rather measure θ's, x's, or something else.

Then, we need to decide on an experimental system to investigate. You can choose to use the mirror you got from the TA, or the PASCO plane mirror, or something else. Record your prediction for this item.

A good plan for testing the Law of Reflection is to test out some rays and measure the variables, compute e.g. $\theta - \theta'$ or $x - x'$, etc. for each and see if, overall, this quantity is consistent with the Law of Reflection's prediction that it should be zero. You don't need to decide in advance how many/which rays to measure.

Extra Guidance: Selecting Equipment

You have several options for ways to produce rays of light: a flashlight, laser pointers, the PASCO ray source, etc. Pick one.

Likely you'll want to use the graph paper somehow to trace rays or mark intersections. Record this.

Decide what devices you'll need to measure the angles or distances involved. You have protractors, calipers, the graph paper, and other items to choose from.

Extra Guidance: Uncertainty

We'll have two forms of uncertainty to contend with in this lab:

- Uncertainty from the precision of the measuring devices: Record the precision in the measuring device(s) you chose in accordance with the convention your class agreed on.
- Statistical uncertainty: There are always many random influences on our measurements, which can be reduced through multiple trials. You'll want to measure $\theta - \theta'$, or $x - x'$' , etc. for many rays and find a best estimate and corresponding uncertainty. Record how you will determine the best estimate and uncertainty.

Recall that if the statistical uncertainty becomes less than the precision of your measuring device, you should use the latter to determine uncertainty.

You'll also need to decide the criteria for deciding if the model is accurate. We'll learn increasingly sophisticated ways of doing this as the semester progresses, but for today it'll be good enough to see if the results agree with the prediction within the stated uncertainty. For example if we find that:

$$x - x' = .02 \pm .05 \quad cm \tag{1}$$

Then this would be considered consistent with the model. Record this criterion.

Check in with Another Group: Briefly discuss your plans with another group. They may provide you with additional ideas and feedback.

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 for your final writeup. Make sure all your data is labeled clearly with units, and that you keep track of uncertainty and try to minimize it.

Forming a Conclusion: Does your data support the model? Record a precise statement by citing your data, qualify it by citing your uncertainty, and discuss it in relation to your earlier prediction.
Congrats on completing your first investigation. But science is an infinite enterprise, there's always more we can do and more we can learn. Based on what you found in this Part 1 decide on multiple (at least 3) possibilities for a next iteration of the experiment. Refer to the flowchart for help with this. You won't need to carry out all of these, but they need to be doable in principle.

Check in with Another Group:Check back in with the same group you discussed things with before. How do your results compare? If you note similarities and/or differences between what you did and what you found, this can inform your proposals for future iterations.

Part 2. Revising, Improving, or Expanding Your Investigation

Now what? Labs will typically involve *two* parts. In the first part you'll conduct an investigation like you just did. In the second part you'll either conduct a new, slightly different, investigation, or you'll implement a next iteration of the Part 1 investigation based on your conclusion for that part. Today we'll be doing the latter.

Check in with Your TA: Describe your conclusions to Part 1 and your proposed options for Part 2. They may be able to help you interpret your results and refine/expand your options.

Designing Your Experiment: Select one of the multiple options you outlined in your conclusion to Part 1. Design an experiment for it. Likely it'll be fairly similar to your first experiment with a few changes. It's sufficient to just record what you're doing differently and what the new goal and hypothesis are.

Conducting Your Experiment: Just like in Part 1!

Forming a Conclusion: Just like in Part 1, with two differences. First, rather than giving at least 3 possibilities for a next iteration, decide on a single new one based on what you did in this iteration and record it. You won't have to actually do it, but it's important to know what you would do if you had the time. Second, make sure compare your results in Part 2 with Part 1.

Writing Up Your Lab Notes for Submission

If you've recorded everything as directed in the underlined portions of the manual, you have everything you need for the lab writeup. In this class we typically won't have you write formal lab reports, rather you'll writeup your lab notes in a structured way.

Today we'll provide some extra walkthrough for what we want. You can also refer to the rubric on Canvas. You can either organize/add to the notes you've already taken, or rewrite things from scratch, up to you.

First, make sure your names are at the top along with your table. Write a title of your choice. Then explain what you did in Part 1:

Include a Method Section. Be sure that:

- Your goal is explained and justified, with your prediction stated.
- You record your choice of equipment and measuring devices.
- You record what statistical and analysis tools you needed.
- You record which/how many rays you used.

About a paragraph is sufficient for this! You don't need a step-by-step description that can be exactly reproduced, we just want to know what you did.

Include a Data Section. Be sure that:

- Your Data is presented clearly in appropriate tables and/or graphs with units, labels, and titles.
- Your uncertainties are evaluated/estimated appropriately.
- Any analysis is performed correctly and in accordance with your method.

Then finish out Part 1 with a Conclusion Section. Be sure that:

- Your conclusion is quantitative, addresses your hypothesis, and is appropriately qualified based on uncertainty or other factors that limited your experiment.
- You write out your proposals for possible next steps.

Now do the same thing for Part 2. Recall that, as directed in the instructions, for Methods you only need to explain differences from Part 1, and your Conclusion only needs a single (but new) next step.

Your group only needs to prepare one set of "organized" notes to be graded, but both partners should still attach all the notes they took during lab to it.