Read Me: About Labs in Physics 9

The Purpose of Labs

There are many reasons to include a mandatory lab component to the Physics 9-series. Among the benefits to a STEM education are:

- experiencing physical phenomena first-hand, to supplement the mathematically-abstract experience of lectures and problem-solving
- learning very broadly how one can go beyond what just intuitively seems right and actually *test an idea* by devising an experiment
- learning experimental skills, like minimizing errors and controlling for irrelevant factors
- learning data analysis skills, like using graphs and statistical examination
- learning to use uncertainty analysis to determine when a proposition is confirmed or refuted by the data

Some of the earliest labs in Physics 9A are somewhat less about physics, and more about developing some of these skills. At that point not a lot of physics has been learned yet, and these skills are needed throughout the 9-series.

Experiment Types

There are four basic varieties of experiments that will occur in these labs. Occasionally an experiment may have elements of more than one of these types.

- **Simple, repeatable, observations –** These are the most informal sorts of experiments. They typically do not involve a lot of mathematical modeling, and instead are focused on more general features. The most challenging aspect of these kinds of experiments is objectivity – the experimenter must come into them with an open mind, simply documenting what is observed without constructing elaborate explanations for what they are witnessing. One of the worst mistakes that can occur in these is to inadvertently "put your thumb on the scale" (introduce human error) because a certain result is expected. You should go to great lengths to avoid this critical error.
- **Confirmation of a Single Hypothesis** – A prediction is made regarding the outcome of a specific scenario. The result is never *exactly* what is predicted, but the amount of uncertainty measured and computed is used to determine if the experimental result is "close enough" to the predicted to result to be considered a confirmation.
- **Independent Confirmations –** Armed with the theoretical background to compute a physical quantity, the experimenter devises two separate, completely independent experiments to measure that value. Each experiment gives its own result and its own uncertainty range, and the goal is to check if the two experiments confirm the same number within these uncertainties.
- **Choose the Better Theory** – Two mathematical models are proposed to explain a single observed phenomenon. The experiment seeks to determine which of the two theories best describes the relationship between the variables present.

Typical Elements of Lab Meetings and Reports

Below is a list of common tasks performed in laboratory meetings, and items included in submitted lab reports:

- Short test runs of an apparatus are performed to "get a feel" for what is going to happen, and to assist in designing the setup in an optimal manner. These do not include actual data acquisition, and also should not be overused – some variation in results is expected, and variation is not an indication that the design needs to be tweaked indefinitely.
- Careful runs of the apparatus are performed, with multiple experimenters observing or playing a role in maintaining a smooth operation.
- Multiple runs are taken for each data point, to reduce statistical uncertainty. Sometimes the statistical uncertainty is computed and included in the analysis, other times just an average result of a few runs is used (because the statistical uncertainty only contributes a very small amount to the overall uncertainty). Doing this also helps weed-out weird anomalous runs where something unexpected and unnoticed happens (i.e. the removal of rogue data).
- Data tables are created (and included in the lab report). These include both raw data and values computed from that data, and are organized in a fashion that's easy for someone reading the lab report to review.
- Graphs (virtually always linearized – see here for more details) are produced, and best-fit curves (i.e. lines) are used to draw conclusions about the mathematical model used to explain the phenomenon tested in the experiment.
- Uncertainties of two types are computed:

- statistical – standard deviations of measurements with random errors introduced by the imperfect apparatus or by human involvement
  - estimated – educated guesses about how accurately one can expect a measuring device to function.
- Lab reports are written with contributions from all group members. The text does not need to be verbose or overly-details, but should get to the point and include most or all of the following points:
  - what you set out to test (explain the problem)
  - how you set up your apparatus to accomplish the test
  - what you expect to see (hypothesis)
  - your results (data tables, graphs, computations, general discussion, etc.)
  - checking to see if your results confirm the hypothesis to within the uncertainties (it is okay if this is not confirmed – staying agnostic about the final result is an important quality)
  - an accounting of the weaknesses in your apparatus or procedure, and suggestions for how these can be improved in future attempts

Organization of Reports

You are not required to follow a specific template for the format of your lab reports. However, it might be helpful to keep things organized in your head to follow something resembling this:

- **Goal** – Give a description of what you hope to accomplish or learn in this particular lab.
- **Hypothesis** – If the lab is one in which an hypothesis is tested, then expressing it explicitly is a good idea.
- **Procedure** – Give a details description of what you did in your experiment, from the preparation/calibration of the equipment, to the method of taking data. It is tempting here to sometimes give some numbers you recorded, but for the sake of organization it's a good idea to resist this. Also, while it is appropriate at times to give a short explanation of why you did something a certain way, this should be kept very brief, or this section will start treading heavily on the later section on analysis.
- **Data** – Display all the data you recorded, without including any discussion of what it means. This includes one-time measurements as well as tables. It's okay to include computed values (if, for example, every recorded number needs to be squared to be put into a graph), but save the main calculations toward a result for the next section.
- **Analysis and Conclusions** – This includes everything else:
  - physics that needs to be explained to get to your answer (free-body diagrams, algebra, etc.)
  - graphs and calculations of final results or uncertainties
  - a description of likely sources of error, and ways to improve the experiment (i.e. reducing errors/uncertainties)
  - final narrative that ties together the results of the experiment vis-a-vis the goal and/or hypothesis

A Final Word

These labs are intentionally not set up to be "cookbook" exercises. There will be some guiding questions to answer in the lab report, and some hints for how to proceed, but for the most part, the design of the experiment and the layout of the lab reports are up to you (your time is limited, so don't get too fancy with this). Keep in mind that you have two goals: The first is to convince yourself of the conclusion (i.e. perform a detail-oriented experiment), and the second is to write a clear lab report that conveys a convincing argument to the reader. Pro-tip for successful experimenters: Try to be more skeptical of your own work than the audience you seek to convince.
