Lab 1: Magnitude, Measurement & Motion

Physics 203

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*** PLEASE NOTE: For all experiments in both Physics 203 and Physics 204, each lab *group* will submit *two separate reports*; the detailed requirements and instructions for each are explained at the end of this Lab 1 Manual.

The first of the two reports is a ***Physics Post-Lab***. Methodical completion of each ***Post-Lab*** exercise helps us maintain a clear idea of what we should expect to know (therefore deploy) and what we should not expect to know (therefore figure out) from one laboratory investigation to the next. It is a document designed to sharpen thought and communication among physics students—within, for example, a university classroom. Among other intended educational purposes, each ***Post-Lab*** should help us build a ***Formal*** Laboratory ***Report***, briefly introduced below. The ***Post-Lab*** should therefore always be completed ***<u>FIRST</u>***, ***<u>BEFORE</u>*** the ***Formal Report***.

The second of the two reports is the ***Formal Report***. This document is a complete scholarly accounting of everything you did for a particular laboratory investigation and why. All sections of this ***Formal Report*** are ultimately directed toward the answering of a ***Research Question*** (or, in some cases, up to three related ***Research Questions***): The ***Formal Report*** explains to any and all uninitiated readers precisely how and why a set of data was collected, by what means these data were analyzed, and in what way this analysis—within a specified range of measurement uncertainty—led to a finding that, finally, answered the ***Research Question***.

This ***Formal Report*** is composed and presented in the manner of a research physicist submitting her experimental findings to a ("peer-reviewed") journal. The ***Formal Report***, that is, is formal in the following fundamental sense: Imagine that an intelligent and interested reader is randomly selected from far outside the context of all John Jay syllabi, discussions and experiences; this reader, although familiar with general scientific research, might not even know any physics. Such a reader, with no specific background nor supplementary explanations, should be able to use a properly written ***Report*** in order to reproduce our methods and pursue his own answer to the self-evidently meaningful ***Research Question*** found within. A strong ***Formal Report*** is, in principle, ready for publication.

As you read any of the Lab Manuals for Physics 203 or Physics 204, notice directions that are preceded by three asterisks (***). These refer to steps of measurement or thought that you will be expected to emphasize, and therefore carefully consider, in your ***Formal Report***. Three asterisks essentially mean "Make certain to recall this step even after you have left all your measuring equipment behind".

I. RESEARCH QUESTIONS

All your lab thoughts, designs, actions, measurements, calculations, derivations, general thoughts and *written reports* must begin and end with focused attention toward the ***Research Question***(s).

Always.

Whenever you are not sure what to do or write next, ask yourself, "How can I somehow connect/relate what I just did to the ***Research Question***?" Sometimes the lab hand-outs and/or faculty will strongly suggest specific Research Questions for you to use. Sometimes they will not. When you are presented with a strongly suggested R.Q., we strongly suggest that you use it – unless you actively feel that your research went in an unusual direction and warrants a different questions for a particular reason. When you are not presented with a suggestion, you should assume that the first and last part of your job is to distill and focus all you did in the lab -- down to one (or very few) clear, central and driving questions; then make sure to answer such question(s).

Today's suggested ***Research Questions*** are presented below. They are not a set of three choices; they are one larger question segmented into three parts—all of which are mandatory. This triplet ultimately addresses one item of curiosity, but has been broken into pieces—simply to make our first lab as clear as possible.

A. What is the *average speed* of some arbitrary* aluminum glider as it travels along some arbitrary *air track* that is elevated only to an extremely slight angle?

B. Does this *average speed* **vary** significantly as the glider moves from section to section of the air track? How so?

II. MEASUREMENT: THE UNITS.

A measurement is in many ways a strange thing. But one thing it ultimately appears to be is a comparison. To say that something is "1 meter" long is to say that it is the same length as something else--something else that we all recognize and call a "meter".

A. LENGTH.

i. Come up with your OWN standard of comparison by which you could **MEASURE** a length. This standard could be the length of your index finger, the length of a shoelace, whatever. But before you spontaneously arrive at any old standard, contemplate what might make one standard more useful than another: To what extent is shorter better? To what extent is longer better? One thing may be so obvious that you might neglect to consider it:

*** For something to function as a standard of measurement, it should NOT change its size during the act of measurement. ***

ii. Come up with an official name for your standard of measurement. You will use it throughout the lab.

iii. Now come up with a ***sub-division*** for your standard of measurement. We divide a foot into 12 inches, a meter into 100 centimeters. Into how many EQUAL parts would you like to sub-divide your standard? Again, there are advantages to many, but there are also advantages to few. Consider possible advantages and disadvantages. Then choose wisely.

iv. Come up with an official name for your sub-division.

B. TIME.

i. Repeat the above directions for a standard of TIME. All the issues are the same, but this undertaking is unquestionably more difficult than the above. You will essentially have to "BUILD" something that can function as a clock. This is where the above triple-starred (strange-font) requirement becomes EXTREMELY IMPORTANT!

MAKE CERTAIN that your clock runs faster than the slowest heart-rate found in your lab group.

III. MEASUREMENT: THE ACT.

A. Necessary Equipment

i. Air Track.
ii. Glider.
iii. Your Personal Ruler.
iv. Your Personal Clock.

B. Setup.

1) Connect your air vent to your air track and turn on the vent.

2) Place your glider on the track and observe how it moves.

3) Find a way to send the glider on slow, smooth, consistent trips from one end of the track all the way to the other.

   By "***slow***," we mean having a low average speed. By "***smooth***," we mean not changing speed (whatever you think that looks like). By "***consistent***," we mean that you could send the glider on 10 trips in a row and each trip would pretty close to the same amount of time. By "***from one end of the track to the other***," we mean it starts at one end and goes all the way to the other, every time. If it bounces, that's ok, just ignore the bounce.

   Try starting it at one end and at the other. Try adjusting the tilt. Try letting it move on its own. Try giving it a push with your finger. Try using the rubber band at the end to give it a push. Try adjusting the track to make it more or less slanted.

   but NOTE: do NOT move the glider on the track unless the air vent is ON.

C. Static Measurement: DISTANCE

1) Observe one complete trip of the glider from one end of the track to the other . Use the units of measurement that your group decided on to MEASURE the distance the glider travels in one full one-way car trip.

   CAREFUL: the length of the whole track is not exactly the same as the distance the glider travels when it goes down the track. You have to take into account the length of the glider itself.

2) Write down your result using the standard of measurement YOU created. Do NOT convert into inches or centimeters or any "normal" standard of measurement.

3) In your group's units, write down a conservative estimate of the smallest amount of distance that you can perceive & measure. In other words, if two lengths differed by less than this distance, you would measure them to be the same. This ***minimum measurable distance*** will be called distance UNCERTAINTY.

D. Dynamic Measurement: TIME.

1) You are now ready to begin some time-trials.

2) Set up your group's home-made clock and "start" it the instant a glider is released. "Stop" your clock the instant the glider reaches the bottom. You have now taken a time measurement for a one-way trip.

   NOTE: you will want to allocate labor between you and your partner so as to maximize the accuracy of time measurements for a one-way trip.

3) Write down your time measurement for a one-way trip. Include (your personal) UNITS!

4) In your group's time units, write down a conservative estimate of the smallest amount of time that you can perceive & measure using your clock. In other words, if two times differed by less than this amount, you would measure them to be the same. This ***minimum measurable time*** will be called time UNCERTAINTY.

5) Do 3 more trials of the whole trip, recording time for each trial in your group's units.

6) Repeat instructions (2), (3), and (5) for approximately 3 different ***subsections*** of this basic trip, for example: the first third of the track, the middle third of the track, the final third of the track, etc. It's up to YOU how to divide it up.

   Your GOAL will be to compare the average speed for different sections of the track, to see if and how it CHANGES from one section to another, so choose your sections in a way that will make it possible to do a ***useful*** comparison. Issues you might want to be able to discuss in your lab report include:

   *** is there any consistent difference in speed from one section to another?
   *** if so, does the glider speed up over the course of the trip?
   *** does the glider slow down over the course of the trip?

7) Using your group's units and subunits, measure the LENGTH of each subsection for which you collected data.

8) *** ***When finished, you will have written the distance and time measurements for 3 trials for approximately 4 different trip lengths.***

IV. ANALYSIS.

1) For each of the four sections of the trip that you took data for, calculate the AVERAGE time for that subsection.

2) For each of the four sections that you took data for, set up a table of values in which you will record "distance", "average time," "time uncertainty," "average speed" and "average speed uncertainty".

3) Now consider and apply the following definition:

$$AVERAGE\ SPEED \equiv \frac{TOTAL\ DISTANCE}{TOTAL\ TIME}$$

4) For each of your trips, compute the average speed of the car. This average speed should be written down with units. What should the units be?

   NOTE: In order to compute and record this average speed, you will entirely ignore all the information about "uncertainties."

V. UNCERTAINTY.

1) You have a bunch of measurements of distance and time that you got from your trials. These measurements are things like
   `3 pencils & 2.5 pen caps`
   `4 heartbeats`
   `Etc.`
   But of course, you don't mean that the trial took EXACTLY 4 heartbeats. You mean it took ***close*** to 4 heartbeats. How close is it? The answer is the "time uncertainty" value you wrote down in step D.(4). Do you see why?

2) Something we'll say now and justify later: you can use the same uncertainty interval for your AVERAGE times and distances as you used for the actual times and distances you measured in your trials.

3) Given your uncertainty estimates for length and time, devise a means that you find reasonable for relating/combining the two uncertainties into an average SPEED uncertainty for each subsection. This may seem quite challenging. Do your best to figure it out. There are also resources on the course website (lab page) to help you.

4) Write down your best inference for the uncertainty in each of your average speed results. Make sure that somewhere you have clearly written down HOW you arrived at a value for uncertainty in the average speed: both the MATH you did and also the LOGIC or THINKING behind the math.

Writing the Report -- a format required for every lab

Part 1: The ***Post-Lab***

All responses to all four parts of every ***Post-Lab*** must be submitted on clean, separate sheets of paper. The ***Post-Lab*** must be headed with the names of all Lab Group members and each response must somehow make clear precisely what question it is intended to address. No other document or reading should be necessary in order for a reader to follow the meaning and sense of a properly completed ***Post-Lab***.

Post-Labs in Physics 203 have a very specific four-part format. Each part is graded out of 2.5, for a total possible score of 10.0.

The ***Post-Lab*** is designed to help you write your ***Formal Report.*** Therefore, you should always complete post-lab ***first***, AS A GROUP, *then* work on the ***Formal Report***. If you don't have time to work as a group on the post lab, then we STRONGLY RECOMMEND that each group member attempt all questions SEPARATELY on his/her own; that way, the group can compare answers remotely. If the group is not in agreement on the ***Post-Lab***, it will be unable to write a good ***Formal Report***, and any group member who has not worked on the ***Post-Lab*** is not prepared to work on the ***Formal Report***.

For this first Physics ***Post-Lab***, we will now walk through each of the four different parts and explain how it works. At the end of each explanation, the specific Post-Lab question for THIS LAB (Lab #1) is presented in a different typeface and introduced by the phrase <u>WHAT TO DO FOR THIS PARTICULAR (Lab #1) POST-LAB</u>.

ON SEPARATE SHEETS OF PAPER, PLEASE ANSWER THE FOUR QUESTIONS FOUND IN THE FOLLOWING PAGES. THIS IS YOUR POST-LAB for LAB 1.

In future labs, you will simply be given the four particular questions and expected to know how to approach them. They will be of the same four types for every lab.

1. ***Epistemological Table***

BACKGROUND EXPLANATION

If you make a ***claim***, someone might ask you "How do you know?" and, if you consider yourself a scientist, you'd be obliged to ***justify*** your claim. How you justify your claim—how you know what you know—is called epistemology.

(Note! A claim is a <u>full statement</u>; a claim is expressible as a complete sentence of English. But note also that a mathematical equation is a type of sentence: the equals sign is the verb.)

Each Physics Post-Lab will contain an EPISTEMOLOGICAL TABLE like the one shown below. Every Epistemological Table will have two columns: CLAIMS on the left, JUSTIFICATIONS on the right. Each claim will be filled in for you. Your job is to provide a justification for each claim. But, in most cases, you don't have to write much. You just have to pick from one of nine basic categories of knowledge.

There are a few basic ways you can know something:

- You might have learned it from examining the physical world, either
  - by ***observing*** directly with your senses, or
  - by ***measuring***, with the help of a tool, like a meter stick, or a clock, or a protractor.
- On the other hand, you might have figured it out, using your mind, maybe with the help of thinking tools, like pencil, paper, or computer software. For example, you might have
  - ***calculated*** a number, using an equation, or
  - ***derived*** an equation, using algebra, or
  - made some other kind of ***inference***.
- There are also some things you believe because they were discovered by other scientists and are widely accepted (e.g. that the speed of light is 186,000 miles/second). This is called
  - ***canonical knowledge***
- But some claims are not discovered or figured out. Some claims are just things that some committee of scientists decided—or that we got to decide ourselves. In other words, they're
  - ***definitions***.
- Other claims are things that we can't justify but which we assume. They might be
  - ***fundamental beliefs*** that make all other inquiries possible; or
  - ***convenient assumptions*** that we make under particular circumstances.

So, we have these four big categories of claims:

- Things we learned from examining the world
- Things we figured out by thinking
- Things we believe because other scientists figured them out
- Things that are true because we (or some other scientist) defined them that way
- Things we can't prove but which we assume

And those four big categories break down into nine smaller categories of claims:

- ***Observations*** ← What did you observe?
- ***Measurements*** ← What measuring tool did you use?
- ***Calculations*** ← What equation did you use?
- ***Derivations*** ← What equations was it derived from? When does it apply?
- ***Inferences*** ← How did you draw this inference? Explain your reasoning.
- ***Canonical knowledge*** ← *No further explanation required.*
- ***Definitions*** ← What is it the definition of?
- ***Fundamental beliefs*** ← Name or describe the belief (most of them have names).
- ***Convenient Assumptions*** ← Why is this assumption reasonable in this situation?

So, for each claim in the epistemological table, you will just pick the appropriate category from the eight listed above and then answer the question that appears next to that category

Sometimes, though, it may be unclear what category a claim goes in. A claim might seem to be a combination of multiple categories. Or it might seem like none of them quite fit. Feel free to combine two categories of knowledge in your justification—or even make up a new category!

WHAT TO DO FOR THIS PARTICULAR (Lab #1) POST-LAB:

Reproduce this table in a SEPARATE document or sheet of paper and choose among the ***seven*** categories listed above in order to complete it.

(The first one is done for you)

Claim	Justification
The glider traveled 23 index cards in the first trial.	Measurement using index cards.
Gliders on cushions of air tend not to sit stably.	
The glider took 13 heartbeats to make one complete trip.	
Average speed = $\frac{\text{total distance}}{\text{total time}}$	
The average speed of the glider was 3.1 index cards/click	
The average speed of the glider varied significantly over the course of its trip.	

2. ***Research Design Chart.***

The Research Design Chart begins one measured quantity from your lab and shows how that measurement helped you to answer your ***Research Question***.

The chart has 3 sections:

DATA COLLECTION: Measurement(s) you took or observation(s) you made in the lab.	→	ANALYSIS: Some mathematical or logical analysis you did on those measured quantities or observations.	→	CONCLUSION: How that analysis helped you answer your Research Question

Always write your ***Research Question*** right above your ***Research Design Chart.***

<u>Example</u>

RQ: how does changing the volume of a chamber affect the temperature of a the gas inside the chamber?

We measured the initial length of the chamber and got 7 cm.	→	We substituted these values into the equation for the volume of a rectangular prism: V=W × L × H. We concluded that the initial volume of the chamber was 5cm × 7cm × 8cm = 280	→	Knowing the initial volume of the chamber allowed us to find change in volume, which helped us determine the relationship between change in volume and change in pressure.

IMPORTANT: Do ***<u>NOT</u>*** try to explain the ***whole*** lab in your Research Design Chart! The point of the chart is to take ***ONE*** measurement you took in the lab and show how it ***contributes*** to answering the RQ. No box in the chart should ever have more than about 50 words in it. And the fewer the better!

<u>WHAT TO DO FOR THIS PARTICULAR (Lab #1) POST-LAB</u>:

Using the model provided by two figures above, make a ***Research Design Chart*** that applies specifically to what you did in Lab #1. For your measured quantity in box 1, use the length of one of the ***sub***-sections of the trip.

3. ***The Counter-Factual***.

BACKGROUND EXPLANATION.

The Counter-Factual will be a question or set of questions that asks you to consider the implications of something that most probably did NOT happen in your laboratory experience.

Considering these counter-factual scenarios will help you to better understand reasoning that is central to the lab—and therefore to the ***Formal*** Lab ***Report***.

The Counter Factual is usually the ***MOST DIFFICULT*** part of the Post Lab. Take these questions seriously. Think hard about them. Sometimes it will be helpful to draw diagrams or try out numbers and run calculations.

WHAT TO DO FOR THIS PARTICULAR (Lab #1) POST-LAB:

In complete sentences of English, answer the following questions:

You arrived terribly late for lab, and as punishment, your lab partners are making you write the lab report by yourself!

Unit of distance: a soda bottle.
Unit of time: Gabby's heartbeat.
Average Speed for the whole trip = 3.2 bottles/beat.
Average Speed for first half of the trip = 2.8 bottles/beat.
Average Speed for the first third of the track = 2.1 bottles/beat
Average Speed for the first quarter of the track = 1.7 bottles/beat

a) Discuss the unit of distance. What questions do you have about it? What additional info would you need in order to explain this unit in the report.
   HINT: think about what a soda bottle looks like. Think about how it could be used to measure length.

b) What conclusions can you draw about the speed of the glider as it moved along the air track from these data? What factors might explain the data? What could you guess about how your lab partners arranged the track?

c) Later, Gabby reveals to you that she was secretly (and illegally) guzzling coffee while the group was taking the data. How would this affect the data? How would this new information change your conclusions regarding the speed of the glider as it moved along the air track?

4. ***The Wild Card.***

BACKGROUND EXPLANATION.

There is no Background Explanation for something called a ***Wild Card***. It's a wild card! Every Post Lab will have one. It's gonna be ***WILD!***

WHAT TO DO FOR THIS PARTICULAR (Lab #1) POST-LAB:

You have been asked to decode some scientific documents from a long-lost civilization whose ruins have been discovered on a distant planet. In these documents, the scientists from the alien civilization report on the results of some experiments on the movement of various animals on their planet. The scientists took a lot of very precise measurements, but unfortunately all of their measurements were done in their ancient alien units, *Ebeds* of distance and *Ragas* of time. Nobody has any idea how many Ebeds make one meter nor how many Ragas make one second.

The documents contain the following pieces of information:

- A lukurk (some kind of alien animal) can run at a maximum speed of 100 Ebeds/Raga.
- During the first Raga of running, a lukurk usually runs at an average speed of 20 Ebeds/Raga.
- During the second Raga of running, a lukurk usually runs at an average speed of 30 Ebeds/Raga.
- A brubu (some other alien animal) can run at a maximum speed of 45 Ebeds/Raga.

(a) In 1-2 sentences, give some examples of meaningful conclusions you ***can*** draw from the information in the document, ***despite*** being unable to convert Ebeds and Ragas into standard units.

(b) In 1-2 sentences, give some examples of relevant questions that you could ***not*** answer based on the information in the document, ***because*** you are unable to convert Ebeds and Ragas into standard units.

(c) In 2-3 sentences, discuss the following question: ***in general*** what kinds of conclusions ***can*** be drawn and what kinds of conclusions ***cannot*** be drawn when data is provided in unknown units?

Part 2: The ***Formal Report.***

Overview

The ***Formal Report*** is a complete scholarly accounting of everything you did for a particular laboratory investigation and why. All sections of this ***Formal Report*** are ultimately directed toward the answering of a ***Research Question*** (or, in some cases, up to three related ***Research Questions***): The ***Formal Report*** explains to any and all uninitiated readers precisely how and why a set of data was collected, by what means these data were analyzed, and in what way this analysis—within a specified range of measurement uncertainty—led to a finding that, finally, answered the ***Research Question***.

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Specific Format and Sequence of Sections: In BRIEF

i. **Title Page**: title, date, section number, authors.
ii. **Abstract**: a summary of that includes your research question and your conclusion (with uncertainty interval), as well as a VERY brief (1-3 setences) overview of your methods.
iii. **Introduction**: some background on the topic; underlying knowledge; why this research is interesting/important.
iv. **Research Question**: The QUESTION AT THE HEART OF THE EXPERIMENT. It was to answer this question that you did EVERYTHING you did in the experiment!
v. **Data Collection:** what you measured and how you measured it: similar to that which is sometimes known as *Materials & Methods*.
vi. **Diagram:** not a photograph, not something off the internet—an original rendering of your experimental design, fully labeled with all variables & constants.
vii. **Analysis:** everything you did to your data after you collected it (math, logic, graphing, etc.). In other words, a thorough step-by-step narrative that both quantitatively and qualitatively explains how a trend, relationship and/or generalized finding was ultimately inferred from the data.
viii. **Uncertainty:** a precise explanation of the uncertainty associated with each individual (type of) measurement as well as a meaningful application of the combined uncertainty for all measurements taken together.
ix. **Conclusion:** a clear, concise and final answer to your Research Question(s), explicitly including uncertainty.
x. **Appendices**.

Sections explained in greater detail

1) **Title Page.**

Title of Lab
Date
Lab Section Number
All members of Lab Group: Listed in alphabetical order by last name.

2) **Abstract.**

One paragraph. A clear, concise yet quantitative summary of what you did and found in your experiment. It is a distillation of (headline for) the whole document to come. Put another way, the abstract is an expansion of the conclusion. It is the reason anybody would want to turn the page and read the entire report. It can stand on its own as the "Sneek Preview" or "Readers Digest" version of your whole report: If you were to present your report at a conference, then the abstract would be advance printed in the conference literature. The abstract must explicitly contain the R.Q., the answer to the R.Q. and a couple to a few sentences summarizes the methods deployed in order to get from the former to the latter.

3) Introduction.

Also one paragraph. This one provides a brief bit of physics background: which particular physics thoughts are treated as known but somehow provoking by the research team before they walk through the laboratory door? How do these assumptions lead to a curiosity that finds shape as a ***Research Question***. The introduction section offers a bit of freedom to place the entire report into some kind of helpful context. The specific context might vary from lab group to lab group, but, no matter what, the introduction must and will always culminate in an explicit statement of the Research Question.

4) The Research Question.

Pose a clear and direct question that best captures the curiosity your investigation seeks to address: the question toward which all your planning, tinkering and thinking were ultimately pointing. Your question should be as concise as it can possibly be, but it does have to make sense on its own. The report starts and ends with the question. Colleagues read your report in order to understand what you found to be the answer and how: Nobody should have to read the report in order to understand the question in the first place. The question itself, therefore, must mention any conditions/context in which it operates. The question, moreover, must somehow be of generalized interest or at least generalizable application. We can all grow curious about some one-shot-deal particular instance of something that suddenly demands our attention, like a well-timed 3-point shot in the local high school basketball championship, but we would find it quite challenging to raise a question of global interest and reproducibility about that one specific event.

A constructive ***Research Question*** generally asks about a relationship between two quantities—one that we alter deliberately and continually (the ***independent variable***) and one that we observe in order to find out how nature tends to respond to such changes (the ***dependent variable***). In order to confine the scope and significance of these two variables, an implicit "if… then" usually underlies the question—whether or not the words "if… then" are actually used. "How fast does it go?" might be a question, for example, but it is NOT a ***Research Question***. Even, "How fast does a marble roll?" is not quite a ***Research Question***.

This is an example of a strong and realistic Research Question for Physics 203: "Given a long and approximately smooth slide, how does the average speed of a rolling marble depend on the slide's angle of elevation?"

5) Data Collection.

Provide a thorough and specific narrative that explains in plain, fluid English what you actually ***did*** with your set-up: what measurements you took and how you related them to one another. Here, you will refer to specific numbers ***only*** insofar as they provide clear ***examples*** for your flowing explanation. You are focusing more on *types* of numbers (variables, constants, etc.). This explanation should be one that any reasonable person could read and follow. All the details of specific trials will be covered in your tables, graphs and other prior steps. Place all tables and graphs in 'Appendices' and refer to these appendices in your findings section.

6) Diagram.

Begin with a clearly labeled diagram of your experimental set-up. Any variable or constant to which you refer in your findings section must first be established as a label in the diagram. This is NOT a photograph of your apparatus. While you may certainly also provide captured images, you must first provide a hand-drawn or computer-created schematic that reveals just the essential elements of the set-up. It is your job to decide and convey what is important and therefore worthy of a label: such as an algebraic variable or constant.

This is also NOT an image that you grabbed off the internet. We actually require that you prove that the image is original. If it is a hand-drawn image, you must hand in the original sheet of paper on which you did the drawing, and it should be signed by the artist. If it is a computer-generated image, you must hand in an editable document in the program you used to create the image: if you used Photoshop, hand in a .psd; if it you used Word, hand in a .doc; if you used Pages, hand in a zipped Pages folder.

7) Analysis

The ***Analysis*** section explains everything you did to the data after you collected it: mathematical calculations, graphing, logic, etc.. But it is more than just that: it is a written explanation of the **thinking** that brought your research team from a bunch of seemingly disconnected raw measurements (dots on a page) all the way to some general discovery about the world. As you go further into this course and 204, and labs become more mathematically and logically complex, the ***Analysis*** will become an increasingly important part of the lab report.

Of everything you do in the laboratory, this type of dot-connecting most closely resembles that which you will have to do in order to prepare for and take physics exams. Your narrative began with a description of measuring procedures and measurement results. Here, it will proceed to a discussion of how/why all these numbers mean anything with regard to one another. Such apparent meaning and connection is that which allowed the R.Q. to be experimentally tested in the first place. So, the analysis (body of the report) is where you show everything that you did with, for and from the measurements you made. This is the part where raw numbers evolve into thoughts, relationships and results.

Here, you will establish and use mathematical equations. Center every equation on its own line of text. Never use an equation unless every term has been explained (by means of the diagram) and unless the relationship is also developed in CLEAR ENGLISH.

8) Uncertainty.

Fully discuss the minimum systematic uncertainty associated with each measurement. Then show how these uncertainties combined to create one final uncertainty in your finding. Use this final uncertainty to relate your ultimate finding to your ***Research Question***. This section often provides the most challenge to students, but it is crucial. All measurements are associated with some amount of quantifiable uncertainty—even measurements made by computers. Uncertainty in measurement distinguishes experimental science from pure mathematics, pure philosophy and, indeed, pure drivel.

Compute and combine all uncertainties by the method explained in the first lab of both Physics 203 and Physics 204.

9) Conclusion (Finding).

Conclude with what you ultimately, finally found out (or learned, discovered, confirmed or emphasized) at the end of the laboratory investigation. This ultimate finding will generally (although not always) be a relationship between one variable and another. It will often be expressed as an equation. No matter what it is, the ultimate finding must be clearly explained -- both quantitatively (as a mathematical equation) and qualitatively (in words). THE CONCLUSION MUST EXPLICITLY ANSWER THE RESEARCH QUESTION(S). It must, moreover, include and make meaningful use of your uncertainty range. Your conclusion must ultimately communicate a finding, that is, that relied in some important way on physical experimentation, observation and measurement—on, that is, science. If there is no acknowledgment of uncertainty, then you have not answered a scientific research question. Quite possibly, rather, you have dissected some definitions. You might even have thrust into some theology. Most vexingly, though, you might have just flirted with some falsehoods. In physics, we can be comfortable not knowing what we think. But we would prefer not to think that we know what we do not. So don't be wrong. Just be uncertain.

Within a range of uncertainty, conclude by answering your ***Research Question***.

10) Appendices

Here, you will include all graphs, data tables, supplementary diagrams, etc. You refer to them throughout your Methods & Findings section (for example, "see Appendix I: Graph of Spring Period vs. Spring Mass). By isolating all data and figures, your narrative becomes a far smoother reading experience than otherwise. Even graphs (etc.) that are vital to your analysis should be placed in appendices and then referred to at the appropriate time.