Lab 1: A Thing on a Spring

(Fundamental Implications of Hooke's Law)

Physics 204

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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 first of the two reports is a ***Physics Post-Lab***. The ***Post-Lab*** is an exercise designed to sharpen thought and communication among physics students. Each ***Post-Lab*** will also help you prepare to write the ***Formal Report*** on that lab.

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. In writing it, you will position yourselves as ***researchers*** reporting on an ***experiment***, NOT as ***students*** reporting on a ***lab***.

Both the ***Post-Lab*** and the ***Formal Report*** are explained in detail after the lab instructions (beginning on page 7 of this document). Along with the explanation of the Post-Lab, you will find the specific instructions for ***Post-Lab 1***.

As you read any of the Lab Manuals for Physics 203 or Physics 204, notice directions that are preceded by three asterisks (***). These are steps 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."

A. Research Questions

Everything you do in a lab-- thoughts, designs, actions, measurements, mathematics and writings—will ultimately be aimed at answering 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***?"

Suggestions for Today's ***Research Questions*** are presented below.

1) In Newtons per meter, what is an experimental value for ***K***, the *'stiffness'* constant, for some particular spring?

(This comparatively small and specific question (1) is necessary in order to study the larger and more generalized question (2) below. Question 2 is really what drives this week's work. Like a customary physics research question, it seeks a mathematical function relating an independent variable to a dependent variable.

In addition to variables, however, functions frequently contain at least one constant. One of the constants in the function pursued in this investigation will be generated by the answer to (1), above. The answer to this question (1) should be a number. Like most numbers that represent experimental values, this number will express something meaningful about the world only after it is associated with ***units*** and ***uncertainty***.)

2) If a spring of known stiffness is hung vertically from a ring stand and differing masses are hung from it so as to produce differing oscillations, how does the time ***period*** for oscillation *vary as a function* of ***mass***?

B. Necessary Equipment

1. Ringstand
2. Hooke's Law-Obeying SPRING
3. Various Masses
4. Mass Hook (for attaching mass to spring)
5. Stopwatch
6. Meter Stick
7. Balance (or factory-based knowledge of masses)

C. *Suggested Procedures*

1) Set up a simple mass on vertical spring by dangling the spring from a ring stand and using a mass hook.

2) *** Draw a free-body diagram of the MASS in this situation.

3) Recall that Hooke's Law for an ideal spring is ***F = - Kx*** (where x stands for displacement of mass from spring equilibrium).

4) *** Apply Hooke's Law Newton's 2nd Law to your free-body diagram in order to derive an expression for the ***K*** of a given spring—as a function of ***m***, ***g*** and ***x***). On a vertical spring, you are welcome to use ***y*** instead of ***x*** if you like.

5) Using your general result (expression, "formula") from (4), above, do whatever you need to do to the spring and make whatever measurements you need to make in order to derive ***K*** (in Newtons per meter) for this spring.

   *** ***K*** =____Newtons/meter.

6) Practice subjecting the mass to smooth, steady oscillations (up and down). Practice using your stopwatch to time full cycles (up and down). Practice the idea of allowing for, say, 10 oscillations, timing the total and dividing by 10 to conclude the ***Period*** (***T***, seconds) for ONE full cycle.

7) *** Using the method described in (6), above, measure and record the period for at least ***five*** (5) distinct masses, given ONE fixed spring with ONE ***K***. Set up your results in a data table, such as the one below.

   FOR EACH DISTINCT MASS VALUE, YOU SHOULD DO AT LEAST THREE SEPARATE TRIALS AND AVERAGE THE RESULTS!

   K =_____________Newtons/meter

Mass (*kg*)	*Period (seconds)*

8) *** With Period on the Y-axis , create one neat, careful and large Scatter Plot for this table. A Scatter Plot is simply a graph of points—no trend lines nor connections of any kind. You are encouraged to use software of your choice for these plots. Fully and clearly label (with units) both axes and the graph. When creating a graph, always ask yourself: Is (0,0) a point?

9) Now draw the simplest, smoothest possible "best-fit" or "trend" "line" through the points. This "line" might well be curved. But the idea is that it should be the simplest possible shape that best captures the pattern of all the dots. It will necessarily NOT touch all the points – except (0,0) if you are analytically confident of that one. All the other points are experimental and therefore imperfect. The line should represent an average pattern: It should fall below many of the points by approximately the same amount that it falls above the rest of the points.

10) *** Applying any kind of logic, unit/dimensional analysis, mathematical technique and/or software to this graph, DERIVE:

11) Period (***T***) as a function of Mass (***m***) for a given spring (of known, constant ***K***).

12) HINT a: The function is NOT linear, but it is a well-known and comparatively simple function.

13) *** HINT b: Given that the function is not linear, look at your scatter plot and try to think of a comparatively simple, well-known function (shape) that describes it. Write down this function.

14) *** Create a new plot from this function. This graph will be the linearized version of the first graph.

    FOR EXAMPLE: If you recognize the shape of your first graph and think that ***T*** = some function of $\boldsymbol{m^3}$, then cube all your ***m*** values and use these ***cubed m'***s as the new x-axis coordinates. Do not change the T values. That is, plot ***the cube of m, rather than m itself,*** on the x-axis. Use the same y-axis (T) values as you did on the first graph . If your guess was correct, the "best-fit" line for this graph should be approximately straight. Get the slope of this line and you have all parameters for your function! NOTE: This was all an EXAMPLE. The function you will find for your first graph will not involve cubes. It will involve some other exponent. That exponent might not even be a whole number. It might not even be positive.

15) *** Using the slope you found in (14), above, write down the function that describes your linearized graph. It will be something of the form ***T*** = (slope) ***m*** (raised to some exponent).

16) *** Now, relate that slope to the value you originally obtained for K. You are ultimately searching for a relationship that will allow you to write ***T*** as a function of both ***m*** and ***K***. HINT c: UNITS will help enormously in determining how ***T*** is related to ***m***. But they won't help you derive coefficients (pure numbers). For example, in constant acceleration, units may help you see that ***x*** must be directly proportional to at^2, not to ***at***. But you need some other thought process to help see that ***x*** actually EQUALS $\frac{1}{2}at^2$. In this case, we are dealing with something cyclical, so ½ won't be relevant, but **2π** will be . . . You may believe that you have already seen this relationship somewhere—such as in the textbook or on the chalkboard. Excellent. That's helpful background. The question then has to do with the extent to which your slope value corresponds with what you believe this relationship to be.

17) WRITE DOWN THE FUNCTION THAT RELATES ***T***, ***m***, and ***K*** that you found. Remember: ***K*** is still a CONSTANT! Explain how well or badly this function corresponds both to the ***K*** you found and the slope you found for your linearized graph.

18) At the end of the day, Section 2 of your lab report (the "triple-starred" section) CONCLUSION will consist of:

19) *** A clearly labeled diagram for your EXPERIMENTAL SET-UP.

20) *** A value for your first spring's K,

21) *** 2 Graphs (One original, one "linearized"),

22) *** A preliminary function: ***T*** as some function of ***m***. That is, m will be raised to some power (which might or might not be a positive whole number) and then multiplied by some coefficient. That coefficient will be a number with appropriate units.

23) *** A final function: ***T*** as some function of ***m*** and ***K***. That is, m will be raised to some power (which might or might not be a positive whole number) and then multiplied by some coefficient. That coefficient will itself be some function of ***K***.

Post-Labs & Formal Reports:

A GENERAL EXPLANATION which contains
THE SPECIFIC QUESTIONS FOR Physics 204, LAB 1

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The ***Post-Lab***

The ***Post-Lab*** must be printed, stapled, and headed with the names of all Lab Group members (hand-drawn diagrams may be included as long as they are stapled to the other pages and it is clear which question they refer to). All answers must be clearly labeled.

All members of each lab group are expected to contribute to the ***Post-Lab*** and to have read and helped to edit ***the entire Post-Lab*** before it is handed in. The process of completing the ***Post-Lab*** will help to deepen your understand of the lab and prepare you to write the ***Formal Report***.

Every ***Post-Lab*** in Physics 203 has four parts: the ***Epistemological Table (ET)***, The ***Research Design Chart (RDC)***, the ***Counterfactual (CF)***, and the ***Wild Card (WC)***. Although these same four parts appear in each Post-Lab, the specific content of each one will be different for each lab. The specific instructions for each Post-Lab will be found in the ***"Assignment" column*** on the Physics 203 Lab webpage.

Below you will find:

(1) ***a detailed explanation of each of the four sections of the Post-Lab*** and
(2) ***the specific instructions for the Post-Lab for Lab*** 1.

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

*   *   *   *   *

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 full statement; 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 five big categories:

- 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 five big categories break down into nine smaller categories:

- ***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*** ← What is the name of the relevant law/principle?
- ***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
nine
categories listed above in order to complete it.

NOTE: the Justification **MUST INCLUDE**
A category and ALSO some additional information,
e.g.: "derived ***from…***," "measured ***with*** (using)…" "definition ***of…***," etc.

Claim	**Type of Justification**
a) The cylinder hanging from our spring had a mass of approx. .45 kg.	
b) The cylinder hung at a location that was approx. .03 m below our spring's original equilibrium position.	
c) $K = \frac{mg}{y}$	
c) Our spring had a spring 'stiffness' constant, ***K***, of approx.. 105 Newtons/meter.	
d) When a mass of .45 kg was hung from our spring, the period for one vertical oscillation was approx. 4.3 seconds.	
e) As the amount of mass hung from our spring is increased, the period of spring oscillation will increase.	
f) The period of oscillation for one spring (of fixed stiffness) varies in direct proportion with the square root of the mass attached to it.	
g) The period of oscillation for various springs attached to one fixed mass varies in inverse proportion with the square root of the stiffness of such springs.	
h) A spring of stiffness ***K*** = 150 N/m attached to a mass of 150 kg will take approximately 2π seconds to complete one full oscillation.	

2. *Research Design Chart*.

BACKGROUND EXPLANATION.

The chart begins with your ***Research Question*** and shows how you proceeded from data collection FOR at least ONE MEASUREMENT all the way toward an answer for that ***Research Question*** (***RQ***).

Note: For this and all future ***Post-Labs***, you need only select ONE particular ***RQ*** and one particular data thread for depiction in a ***Chart***.

<u>ALWAYS write your ***RQ*** right above your ***Research Design Chart***</u>

The chart has 3 sections:

DATA COLLECTION: ***One*** set of measurement(s) you took or observation(s) you made in the lab. (***Not all*** the measurements from the whole lab!)	→	ANALYSIS: The mathematical or logical analysis you did on the measured quantities or observations from Box 1. (***Not all*** the analysis you did in the whole lab!)	→	CONCLUSION: How that analysis helped you answer your Research Question. (You must ***connect*** Box 2 to your RQ!)

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, width & height of the chamber and got 7 cm, 5 cm, and 8cm, respectively.	→	We substituted these values into the equation for the volume of a rectangular prism: $V = W \times L \times H$. We concluded that the initial volume of the chamber was $5cm \times 7cm \times 8cm = 280\ cm^3$	→	Knowing the initial volume of the chamber allowed us to compare that to the volume after the chamber was compressed, which allowed us to see the change in volume, which helped us determine the relationship between change in volume to change in pressure.

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

Using the model provided by the two figures above, make a ***Research Design Chart*** that applies specifically to at least ONE MEASUREMENT you made in Lab #1.

3. *The Counter-Factual*.

BACKGROUND EXPLANATION.

The counter-factual question will be different for every post lab, but it will always be a question (or questions) that asks you to consider the implications of something that probably did **NOT** happen in your actual laboratory experience.

The purpose is always to identify, scrutinize, test or challenge some kind of reasoning that is central to the lab—and therefore to the ***Formal*** Lab ***Report***.

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

In complete sentences of English, answer the following TWO questions:

a. Imagine that you did everything in this experiment precisely as you did in the actual lab, EXCEPT one thing: you utterly forgot to get a ***K*** value for your spring. It is too late to go back to the lab and you have all the numbers and your logic at your disposal, so you go ahead and draft a full and beautiful formal report anyway.

   i. in what specific ways (if any) would this omission of the ***K*** value change your final answer to the Research Question?

   ii. in what specific ways (if any) would this omission of ***K value*** NOT change your final answer to the Research Question?

b. Now we're back in the real world: you *did* collect all data and made all calculations (etc) thoroughly – including ***K***. You and your lab partners all draft your own reports and then you get together to compare answers and distill one spectacular final version. At your meeting, one of your lab partners raises the following concern:

   Our spring oscillates vertically, but from the moment we started measuring, plotting and analyzing ***<u>actual oscillations*</u>****, we never once made any reference to gravity. Nothing about 9.81 m/s*^{2} *or mg is anywhere in our data tables or our graphs or our final conclusion! Gravity must be doing something, yet our final function for period does not depend on g in any apparent way – not even in a constant way. We must be missing something!*

   * That is, once we knew how strong our spring was and actually started using it to derive a relationship.

   i. Is your lab partner correct? Why/How not? Be specific and thorough. And thoughtful. There are different possible ways to explain this, but none of them is some quick formula that you once memorized.

   ii. If gravity does not affect your final answer to the Research Question, then why did we choose to investigate springs in a vertical orientation? Assuming that physicists prefer to keep things as simple as possible, how might this seemingly distracting choice have helped the investigation?

4. The Wild Card.

BACKGROUND EXPLANATION.

There is no 'Background Explanation' for something called a ***Wild Card***. We claim that you know that. Our justification is "by definition of ***Wild Card***". In other words, each week the ***Wild Card*** is one final piece of written reflection for which you are responsible – but which can appear in any form — whether familiar or unfamiliar.

The ***Wild Card*** might require another simple diagram or another 'counter-factual' paragraph of writing (things already done) or it might ask you to communicate your understanding in a manner you have not previously considered – such as "knit a sock puppet who can perform a one-act pantomime play about the particle's acceleration". The reason for a ***Wild Card*** is that each particular experiment raises its own particular issues and concerns. Often, particular issues are best expressed by means of their own particular modes of expression. (Usually, there are more effective and precise ways to convey physics findings than by means of a sock puppet.)

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

In complete sentences, answer the FOUR questions below & on the next page.

Imagine the following: You have a dim recollection of some web-site about some book you dreamed about reading once. Somewhere in that resource, someone of authority seemed to be discussing springs and oscillations and functions and you could have sworn you saw the following:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

(Of course, just because you read something somewhere doesn't mean that it's true. And even if you read something in an extremely trustworthy place, it's still quite plausible that the reading is about one context and you came to the reading thinking about some other context. Nonetheless, the claim above does seem to have something to do with something relevant to some of our thoughts here…)

a) If you remember and use the above claim while you write up your formal report, are you cheating? Why or why not? Even if the "dim recollection" scenario mentioned above does not apply to you – even if you swear that you have never seen this equation before in your entire life – you have now read this paragraph which includes the equation. You are now thinking about all this with reference to the lab. So, are you cheating? Why or why not?

For the sake of continuity and completion, let us assume that the answer to (a) , above, is “no”. Let us assume, further, that you, in response to (a), you provided extremely thoughtful and convincing reasons for such an answer. Then:

b) Do you *need* the above relation ($T = 2\pi\sqrt{m/k}$) in order to complete the experiment and obtain an answer to the Research Question? ***Could*** you get from data to a conclusive function (for period with respect to mass) if you have never seen this relation before?

c) Assume that you don’t, in fact, need the above equation, but that you are allowed to use it. What, then, is an ethical yet helpful way to make use of this apparent outside knowledge? How might you deploy your awareness of the above equation in pursuit of better understanding and a better lab report?

d) Assume that you would like to ‘check’ if your final and conclusive answer to the Research Question is correct. Remember that your final conclusion, if it truly answers the question, will *not* be one particular number for one particular spring.

   Your conclusive answer to the Research Question will be a relationship: a mathematical function of one dependent variable expressed in terms of one independent variable.

   Given that, describe what specific mathematical process you could do in order to check the apparent ‘correctness’ of your final conclusion. Be extremely specific!

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***(***s***). 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. A strong ***Formal Report*** is, in principle, ready for publication.

THE SECTIONS OF THE FORMAL REPORT, IN BRIEF

Ultimately, a complete Physics 203/204 Formal Report will have TEN sections. However, not all sections are assigned for every report. Your first report will have only four sections. Future reports will contain more sections, and we will teach each section as we assign it.

Below, you will find a description of *all ten* sections, *in the order they should appear in a complete report*. Please refer back to this list throughout the semester.

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**.

<u>Sections explained in greater detail</u>

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 quantitative summary of what you did and found in the 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. The abstract must contain the R.Q. (exact wording), the answer to the R.Q., along with any relevant uncertainty, and 1-3 sentences summarizing the methods.

3) Introduction.

Also one paragraph, ***the Intro is NOT a summary***. It provides a 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 thoughts 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.

4) The Research Question(s).

The question towards 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***. Nobody should have to read the report in order to understand the question. The question, therefore, must mention any conditions & context that are needed to understand it.

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 useful ***Research Question*** *usually* 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 it responds 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 a ***Research Question***. A ***Research Question*** looks more like this: "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***: how you physically set up the experiment, what your trials consisted of, and what measurements you took. This explanation should be one that any reasonable person could read and follow. You will refer to specific numbers ***only*** insofar as they provide clear ***examples*** for your flowing explanation. Place all raw data in tables (and gaphs, etc.) in the 'Appendices' section. In Data Collection, simply refer the reader to *the specific table* in the Appendices where each group of data can be found.

6) Diagram.

DRAW a clearly-labeled diagram of your experimental set-up. ***Any spatial variable or constant to which you refer in your findings section must be labeled in your 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.

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 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.

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. 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. The analysis closely resembles what you will have to do in order to prepare for and take physics exams.

All equations used in your work should appear in the Analysis. ***Center every equation on its own line of text***, and explain every variable appearing in the equation.

8) Uncertainty.

Discuss the minimum systematic uncertainty associated with each measurement. Then show how these uncertainties combine 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 EITHER of the TWO methods explained in the "About Uncertainty" document linked near the top of the Lab webpage.

9) Conclusion (Finding).

The conclusion is where you give THE ANSWER TO THE RESEARCH QUESTION. It must include and make meaningful use of your uncertainty range. Your conclusion must ultimately communicate a finding that relied in some important way on physical experimentation, observation and measurement—and which therefore must contain some uncertainty. If there is no acknowledgment of uncertainty, then you have not answered a scientific research question. 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.