# **Section 1: Introduction to Lab Reports and Formats**

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## 1.1: Pre-Lab Report Structure and Grading Summary

Pre-Labs are due at the beginning of each recitation. Once the Pre-Labs have been collected by the TA at the start of class all other submissions will be considered late and will not be accepted. As per class policy, if a Pre-Lab is not submitted by a student at the start of recitation, they will not be permitted to attend the lab in the afternoon unless prior arrangements have been made with the instructor.

Answers to Pre-Lab questions and all other sections of the Pre-Lab **must** be typed. Your work (typed or handwritten) must be attached to your submission for credit. Final answers to questions need to be typed regardless of the method chosen to present your work.

Include the following in your Pre-Lab Report:

* Cover Page (Title, Name, Lab Section, Class, Date)
* Purpose
* Procedure
* Answers to Pre-Lab Questions
* Attached work (if necessary)

**Grade Sheet Summary for Pre-Lab Report**

Heading Points

Cover Page 5

Purpose 5

Procedure 5

Answers to Pre-Lab Questions 15

**Total Points 30**

## 1.2: Short Lab Report Structure and Grading Summary

Include the following in your Short Lab Report:

* Cover Page (Title, Name, Lab Section, Group ID, Class, Date)
* Results and Calculations
* Error Analysis
* Discussion
* References
* Appendices (as needed)
  + Raw Data
  + Etc…

**Grade Sheet Summary for Lab Report**

Heading Points

Title and Format 15

Results and Calculation 35

Error Analysis 20

Discussion 20

Presentation and clarity of Figures and Tables 10

**Total Points 100**

## 1.3: Formal Laboratory Report Structure and Grading Summary

Include the following in your Formal Laboratory Report:

* Formal Cover Page (Title, Experimenters, Name, Course, Semester, Location)
* Abstract
* Table of Contents
* List of Tables
* List of Figures
* Introduction and Theory
* Experimental Procedure

***20 pages maximum, including figures and tables***

* Results
* Error Analysis
* Discussion
* Conclusions
* References
* Appendices (as needed)
  + Raw Data
  + Etc…

**Grade Sheet Summary for Formal Report**

Heading Points

Title Part of Overall

Abstract 20

Table of Contents Part of Overall

List of Tables Part of Overall

List of Figures Part of Overall

Introduction and Theory 10

Experimental Procedure 5

Results 15

Error Analysis 10

Discussion 20

Conclusions 10

References Part of Overall

Appendices and Raw Data Part of Overall

Overall Impression of Report 5

Presentation and Clarity of Figures and Tables 5

**Total Points 100**

## 1.4: Report Cover Sheets

### **1.4.1: Pre-Lab Report**

Include the following Information in your Pre-Lab cover sheet:

* + Title of Experiment: Pre-Lab Report
  + Student Name
  + Lab Section
  + Class Number
  + Date

Example:

Jane Doe

**Introduction to Tensile Testing Laboratory: Pre-Lab Report**

Monday Lab Section

NUCL 325

mm/dd/yyyy

### **1.4.2: Short Lab Report**

Include the following Information in your Lab Report cover sheet:

* + Title of Experiment: Laboratory Report
  + Student Name
  + Lab Section
  + Group ID
  + Class Number
  + Date

Example:

Jane Doe

**Introduction to Tensile Testing Laboratory: Laboratory Report**

Monday Lab Section

Group 1

NUCL 325

mm/dd/yyyy

### **1.4.3: Formal Lab Report**

Include the following Information in your Formal Report cover sheet:

* + Title of Experiment
  + Name
  + Names of Experimenters
  + Lab Section
  + Group ID
  + Class Number
  + Experiment Location
  + Date

Example:

**Tensile Testing: Characterization of Material Failure**

*A Report of the Experiment Conducted by*

*J. Doe, A. U. Goldmen, P. B Leadbody I. M. Radioactive*

*Monday Section, Group 1*

*Written by Jane Doe*

*Armstrong Hall 2191, NUCL 325—Spring yyyy, Purdue University*

*West Lafayette, Indiana 47907-2014, USA*

Submitted mm/dd/yyyy

## 

## 1.5: Formatting Requirements and Technical Writing Tips

***Paper Format:*** Use 8.5 x 11 inch paper, 0.75-inch margins, single-spaced, justified text, Times New Roman font 11 for main text, Times New Roman bold 10-point font for figure and table captions, number pages.

***General Technical Writing Tips:***

* Your report is a technical document. It is not a narrative of your experiment.
* Be clear, concise, and objective (your report is not an outlet to vent frustrations).
* Write in the third person. Avoid using the first or second person (I, me, my, we, our, you, your, etc.).
* Do not use contractions (i.e., don’t, can’t, won’t, etc.)
* Avoid fancy punctuation and stick to periods and a minimum of commas.
* Organize the report so it is easy and clear to read. If your grader cannot understand you, they will not continue grading.
* Keeps thoughts separate. Use one thought per sentence, and one sequence of thoughts per paragraph.
* Every equation needs to be given an equation number and all variables need to be defined. Reference the equation by number.
* Table captions–with table numbers—appear *above* tables.
* Figure captions—with figure numbers— appear *below* figures.
* Once a table, figure, or equation has been given a number it should be capitalized in text (Table 1, not table 1).
* Include sample calculations in your Results and Calculations section. The calculations can refer to the governing equation given in the introduction, but should include calculations with your actual data, and show your actual results. Give one sample calculation per *type* of calculation.
* Never waste an entire sentence merely referring the reader to a table or figure: “Ion-beam diameters are shown in Table 2.” Instead, cite the table or figure in a sentence that highlights what is important in that table: “Ion-beam diameters were highest for argon ions of all energies (Table 2).” *If you find that you have nothing important to say about the contents of a table or figure, delete it*.
* For better style, avoid starting a sentence with “There were ...” or “It is...” (or there are, was, is, it was, etc.). For example, “There were significant differences among the exposure rates… ” Instead, rewrite the sentence to read “Significant differences existed among the exposure rates…” or “The exposure rates were significantly different…” depending upon which is more important–the differences or the exposure rates.
* Every measured and calculated value appearing in your report *should have reported error.* Do not wait to include error until after your Error Analysissection of the report, or reprint tables with associated error after including them without error. Include error the first time a value is given, especially when it is given in the abstract.
* When reporting comparative results(higher, greater, slower, etc.), always include what the finding is being compared to:“Tensile strengths for copper annealed at 500·C for 60 minutes were 15% lower than bulk copper values, as seen in Table 3”. Do not leave a reader possibly questioning “greater than what?” Usually it is not obvious.

## 1.6: Technical Writing Glossary

***Title:*** *(for Short Lab Reports, use the title of the experiment; for Formal Reports, develop your own title using the following guidelines)*Include a short, and descriptive title to convey the essential nature of the work to the reader. This is the first thing most readers will see and is what will either catch their attention, or will divert their attention to some other topic or report.

***Abstract:*** *(Formal Lab Reports)* A succinct, **one paragraph** summary of the entire report. By reading an abstract, the reader should be able to learn what work is discussed in the report, what experimental techniques and theory were used to obtain and analyze the data, and finally the key results and implications of them.

The abstract can usually be summarized by: purpose, objectives, major results (with error), and conclusions and implications. Give quantitative comparisons between your experimental results and published values when possible. Do not refer to figures or tables; the abstract should be self-contained. A concise and well-written abstract is essential since typically the abstract is examined first to determine if the paper is worth reading.

***Introduction and Theory:*** *(Formal Report only)* The introduction should describe the methods performed in the lab and in the analysis. It should explain the larger motivation or implication of the work to the reader. This section can also make use of the “Objectives” outlined for a particular lab experiment, but does not have too. Deal with these questions in a straightforward and interesting manner, make sure to cite relevant previous work (*references linked to References section*), and indicate what approach was used in the experiment. Usually the experimental data is either interpreted into a final meaningful result using one or more theoretical interpretations or analyses, or the experimental results are being used to test one or more theoretical descriptions of phenomena. This section should summarize the key elements of the theory used in the data analysis or experimental comparison. A reader should learn the essential assumptions and implications of the theory by reading this section. With the theoretical descriptions, appropriate equations representing what is being said should be included in this section. **If an equation is used in the analysis of the data, it needs to be introduced here**. Depending upon the complexity of the theoretical models being used, the section may also need to make reference to other more in depth theory discussions in which detailed derivations and discussions are given.

***Experimental Procedure:*** (*Formal Lab Reports*)This section tells the reader what type of apparatus was used in the experiment and how the apparatus was configured for the particular experiments being described within the report. Include block diagrams of the experimental layouts. These do not need to be complex drawings and a diagram of boxes and lines that are clearly labeled will be adequate. Include all connections between equipment where applicable.

This section also needs to have a table listing the experimental equipment used in addition to the block diagram. There are usually items that will not appear in the block diagram that should be included in the list of equipment. Be sure to **list the names and model numbers of the equipment where applicable**. A brief description of the equipment used should be included that lists equipment information such as the tolerances, errors associated with each measurement (just from the equipment), or calibration methods used.

Describe in detail the methods used to take the data for all parts of the experiment. For example, there should be a step-by-step description of how the apparatus was setup and operated, how the measurements were made, and how the data was recorded for subsequent analysis. Do not copy the lab manual for this section!

***Results and Calculations:*** *(Both Formal and Short Lab Reports)* In this section you are answering the question “What did you observe or measure in the experiment?” Report your results and those of other previous studies in the past tense. Do not start a Results section with a reiteration of the experimental procedure. If you did a good job organizing the experimental procedure section, you won’t have to; the reader will know what to expect.

**It is important that this section have words, sentences and actual paragraphs; it is not a jumble of unreadable tables and figures stuck in the middle of the report.** You may be tempted to start the Results section with the number of samples you collected or when and where they were collected. *Such material belongs in the Experimental Procedure section*, ***not*** *in the results section.*

Present the results of the experiments in the order of their importance, listing principal results first and secondary results later. Be sure to point out major features of the data, but do not discuss them or draw conclusions with them here. The actual results should be listed in tables or presented in figures, or sometimes both. Make wise use of tables and figures to help explain quantitative results, and make sure to incorporate the results of your error analysis, especially in the figures (i.e. error bars).

Any calculations used in analysis are to be shown or referenced in the text description within this section. For formal lab reports this can be referencing the equation number, and for short lab reports, this will be in listing the new equation. Sample calculations of these equations also must be included directly (or referenced with an appendix) in the text of this section. Whichever way you chose to include them, they need to be referenced in some way in this section.

Readers will often read the abstract and then jump to this section in a formal report. Thus try to write this section so that it stands on its own. Do not suppress legitimate, valid results that contradict the expectations or theory. Doing so is not only unethical, but it may also mislead you into a false or unsubstantiated conclusion. **NOTE:** you *must* include all requested information from the Lab Description to receive full credit for this section.

***Figures and Tables:*** *(Both Formal and Short Lab Reports)* Well constructed figures and tables can make or break an engineering report and are typically the basis around which the entire report is constructed. Take special care in choosing what figures and tables to include in the report, and how to arrange them.

Clearly label figure axes, data types, etc., so that the conditions of each data set or curve can be easily distinguished. Keep in mind, if you print your report in black and white, the curves need to be identifiable by the data marker. If the final report is printed in black and white, do not refer to the color of the curve in the text of the report because it will not make sense. Also be sure to not cut off figures or tables between pages. All information needs to be presented at once so the reader will not have to take the time trying to remember what the column headings are when reading your tables.

Each figure and table must have a figure number and caption that briefly describes the contents and significance of the information contained therein. Also, each figure and table important enough to be included in the report must be cited and discussed within the text. It is important for organization that the figures and tables appear in the order they are referred to within the text. Be sure to account for error in them both (i.e. numerical and error bar representation).

Do not automatically fit curves to data if there is not a physical reason to fit the equation. Also, do not “connect-the-dots” on figures to demonstrate trends in the data set. To distinguish between data sets, use distinctive data markers. If the figure is too crowded to read consider alternate ways to communicate the data. For example, if 3 materials have been tested under three conditions, generally you do not want to plot all 9 curves together. Consider what you are most trying to highlight --the difference in material, or the difference in treatment. If you are highlighting the difference in material, plot the three materials together for each condition. If you are highlighting the difference in condition, plot the three conditions together for each material. Choosing the best way to present the data will aid in the discussion, and will help to draw more meaningful conclusions.

***Error Analysis:*** *(Both Formal and Short Lab Reports)* Describe sources of error and define magnitudes for all uncertainties of the measurements taken in the lab. Analytically derive equations for the error propagation from original measurements to find the total error of the final results (remember: this should have been done in your Pre-Lab, you need only include it in this section and expand as necessary). Include sample calculations of these errors using real data. **All estimated uncertainties need to be included in the body of the report *accompanying any calculated values in figures, tables, and text.***

***Conclusions:*** *(Formal Lab Reports)* This section is a brief summary of the key findings of the experiment. Briefly describe the experimental approach that was used in one or two sentences, and then describe the key results of the work listed in order of importance.

It is important to distinguish between clearly drawn conclusions based upon solid data, analysis, and theory, and conjectures based on speculations of what *might* be drawn from the data, which are not completely validated by the experimental results. Summarize the essential implications of the results. Give suggestions for improvements on the lab. The conclusion is usually longer than the abstract with the inclusion of important discussion points. Do not just copy your abstract and add a paragraph behind it. The conclusion is usually at least half of a page long, sometimes longer. Try to make it as meaningful as possible. The conclusion, next to the abstract, can be a key part of your document that the reader will jump to find the implications of your results.

***Discussion:*** *(Both Formal and Short Lab Reports)* In this section you are answering the question “What do your findings mean, and what are the implications of these findings?” State the major conclusions and the significance of the results. Do not give any vague conclusions. Be assertive; state what you have found, and prove it.

Compare the results of the experiment with theory or listed values. Answer all of the specific questions indicated in the Lab Description. Discuss any possible errors in your method and assumptions, and point out how these possible errors may explain discrepancies in your experiment-theory comparisons.

Avoid the temptation to refer to every detail of your work again. Usually if a reader has made it this far in your report, he will have already read the preceding contents as well. Essentially, your Introduction, Theory, Results, Calculations, and Error Analysis are all tied together in the Discussion. Also, **it is important not to list the answers of the questions that need to be answered for the laboratory**. These questions need to be answered and included in the discussion section as points to consider when discussing the implications of theory and the results. This section needs to go in an organized order of thoughts and conclusions based off of importance.

***Raw Data:*** *(Both Formal and Short Lab Reports)* Raw data may be shown in tabular form or in graphical form. Depending upon the volume of raw data produced in the experiment it may not be practical to list all of it in this section. Judgment is key here. Raw plots can be used to present large amounts of Raw Data neatly in graphical form. If the volume of raw data is modest, then perhaps it might be useful to provide it in a table. It is necessary to include figure and table captions in this section so they can be referenced in the document. Be sure to label sections of your raw data so it is organized and easy to navigate for the reader.

## 1.7: Sample Lab Description

### **Reading Assignment**

**Assignments are from Callister or posted to blackboard. Equations you will need for your quiz, pre-lab, and data analysis may come from supplemental reading.**

Error Reading 1, posted on Blackboard.

### **Objectives**

Every lab has stated objectives. You will need to summarize the objectives for your Pre-Lab, but do not ignore them once the Pre-Lab is complete. Rereading the lab objectives before beginning a report write-up will help focus your data analysis and may help you remember why data was gathered during lab. Often, the lab objectives will also help organize and focus the introduction and theory section of the report.

### **Introduction**

#### Hooke’s Law

In the late 17th century, Robert Hooke developed a spring scale based on a relationship he identified between displacement and load carried for elastic materials. Materials under the influence of a load deform, either by stretching, bending, or compressing. When the load (or force) is removed from the material, some materials (elastic materials) will return to their original shape. Hooke determined that for elastic materials, force and displacement are directly proportional to one another, as seen in Equations 1.7.1 and 1.7.2:

 Equation 1.7.1

 Equation 1.7.2

The constant of proportionality, *k*, became known as the *spring constant*.

#### Springs

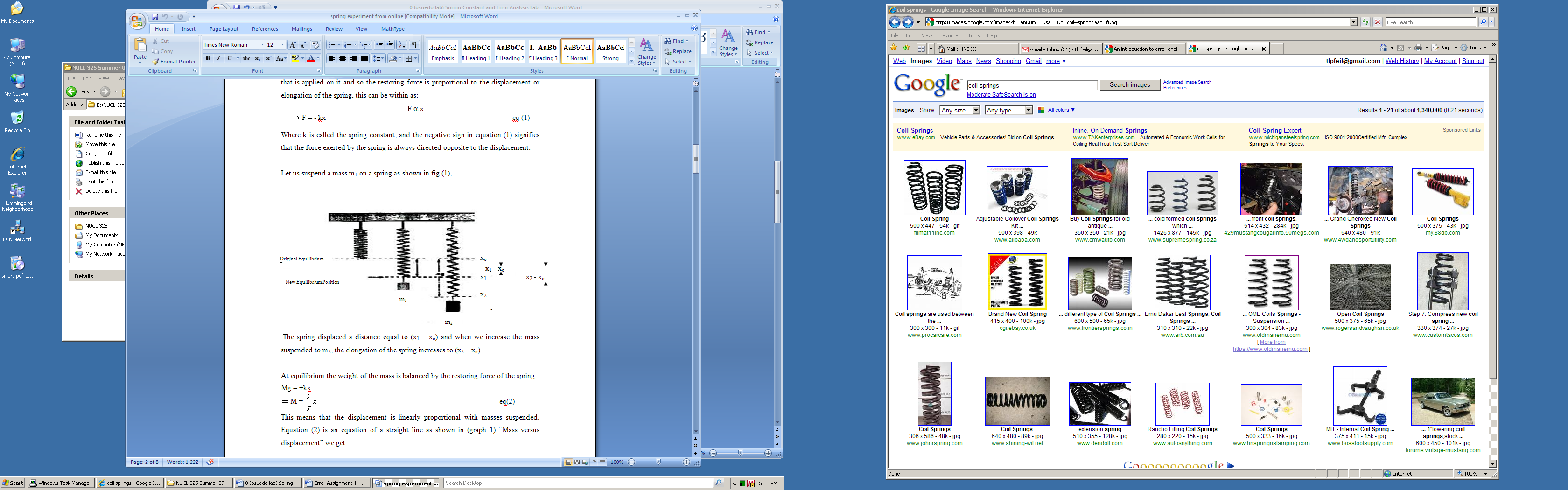
Springs are elastic objects used to store mechanical energy. Simple, non-coil springs (such as tree branches) have been used throughout human history, a good example being the bow and arrow. During the industrial revolution, coil springs (the most common form of springs used today) were widely developed for use in machinery.

Springs can be grouped as compressive, tensile (or extensive), or torsional depending on the force and deformation they experience. Unless their elastic limit is exceeded, springs will return to their original shape after a force is removed. In this lab we will be evaluating coiled, steel, tensile springs.

It is important to note that the response of springs to an applied force is analogous to the behavior of bonds between atoms, which will be reiterated in the *Introduction to Tensile Testing*  Laboratory.

#### Determining the Spring Constant, k

When hung vertically, a spring naturally displaces a certain degree under its own weight to an equilibrium point. At this point the restoring force of the spring is equal to the force of gravity acting on the mass of the spring. When additional mass is added to the end of the spring, the spring will extend and displace a given distance. If more mass is added, more displacement will occur. After the weight is removed, if the elastic limit of the spring has not been exceeded, the spring will return to its original length. This process is illustrated in Figure 1.7.1.



New Equilibrium Position

Original Equilibrium Position

m2

Figure 1.7.1: Spring System masses and displacements

When no masses are added to the system (equilibrium) the restoring force of the spring is balanced by the force of gravity acting on the mass of the spring, shown in Equation 1.7.3

 Equation 1.7.3

When mass 1 (m1) is added, the spring displaces a distance of (x1-xo); when mass 2 (m2) is added, the spring displaces a distance of (x2-xo).

Using the spring constant *k*, we can see that the displacement of the spring is linearly proportional to the weight in the system.

**Final answers to questions must be typed.**

### **Pre-Lab Assignment**

The Pre-Lab assignment includes the reading listed above and questions are assigned at the end of this write up before the procedure. Pay close attention to the procedural steps and follow the instructions given for your Pre-Lab formatting and submission.

### **Materials**

*You should bring:*

1. Calculator
2. Lab Manual

*We will provide:*

1. Box of springs (rated *k* of 2.95 ± 0.05 N/m)
2. 11 Masses (g): 1, 3, 5, 10, 20, 40, 60, 80, 100, 120, 140
3. Base, hanger, and support rod for spring suspension
4. Meter stick

### **Laboratory Procedure**

1. Choose a spring randomly from the box.
2. Suspend your spring horizontally from the hanging rod.
3. Attach a mass hanger directly to the bottom of the hanging spring.
4. Allow the spring to come to an equilibrium position.
5. Record the position to the bottom of the mass hanger relative to the meter stick.
6. Repeat steps 3-5 for all masses.
7. Using the same spring, repeat steps 3-6 three times.

**Laboratory Data Sheets**

*Most labs will have Laboratory Data Sheets for you to collect data during lab in addition to the data you will collect electronically. All electronic data will be posted to blackboard. REMEMBER: IT IS YOUR RESPONSIBILITY TO SHARE DATA WITH YOUR CLASSMATES UNLESS OTHERWISE INDICATED BY YOUR TA.*

**Note that each measurement has bias uncertainty that was recorded by the student during lab.**

#### Spring Constant Data

The data for the sample spring lab is given below.

Equilibrium Length: **24.00 cm (±0.05cm)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Mass **(g) ±1%** | Location **(cm) ±0.05cm** | | | | |
| Trail 1 | Trial 2 | Trial 3 | Trial 4 |
| **1.00** | **24.28** | **24.36** | **24.37** | **24.38** |
| **3.00** | **24.94** | **25.05** | **25.02** | **25.03** |
| **5.00** | **25.6** | **25.68** | **25.67** | **25.69** |
| **10.00** | **27.13** | **27.35** | **27.34** | **27.35** |
| **20.00** | **30.65** | **30.66** | **30.65** | **30.62** |
| **40.00** | **37.23** | **37.33** | **37.25** | **37.32** |
| **60.00** | **43.9** | **43.95** | **43.94** | **43.95** |
| **80.00** | **50.58** | **50.58** | **50.6** | **50.6** |

#### Equipment Data:

**The bias data of each piece of equipment is recorded in the Equipment Data section as well to ensure the student knows the source of error for the measurements**

Meter stick : estimated uncertainty: 0.05 cm

Masses : rated uncertainty of 1%

### **Report and Discussion Points**

*Read the Report and Discussion Points before going to lab. This will help you focus your time and make sure you gather all the data that you need to during lab to answer the Discussion Questions. If you wait until the last minute to read the Discussion points, you may not have gathered all the equipment, or other necessary data that you needed to during lab.*

**Ask questions of your TA during the lab about the discussion points. They will be happy to answer you, and it will make your lab time more meaningful.**

**Do not number your responses in your report. Your report should read like a document.**

*In your Results and Calculations:*

1. Include a table similar to the one in the Lab Data Sheet with force and displacement replacing mass and location. Include an additional column with the average k for each force.
2. Determine the nominal value of the spring constant *k.*
3. Determine the total uncertainty in the nominal *k* value. (Remember: Both precision and bias uncertainties are present. Evaluate them separately and combine. Be sure to include your derivation in the Error Analysis Section).
4. Plot the average displacement for the four trials against the force. Include error bars. Fit a line to your data.

*In your Discussion Section:*

1. Discuss the significance of *k* as it applies to the stiffness of a spring.
2. Discuss the sources of error in the experiment and their relative effect on the overall uncertainty in *k.*
3. Discuss the significance of the line fit from problem 4 above.

### **References**

Beckwith, Thomas G., Roy D. Marangoni and John H. Lienhard. Mechanical Measurments; Fifth Edition. Addison-Wesley Publishing Company, 1993.

## 

## 1.8: Example Lab Report Sections

### **1.8.1: Abstract Examples**

The following are examples of *very simple and basic* abstracts based on the sample lab from the previous section. Keep in mind that as this was a simple lab example, the abstract is simple and is short as there is only one result to report. You can expect that as your labs will be more complicated, your abstracts should be longer to report all the relevant results, etc.

***Example 1:***

An experiment was performed to find the spring constant, k, of a steel spring. The spring constant was determined statically by measuring its elongation when subjected to varying loads. The resulting value of k was found to be 2.94 ± 0.026 N/m, a value equal to the nominal rated value of the spring within allowable error. The spring's behavior followed Hooke's law to within the limits of accuracy of the experiment.

*(55 words)*

***Example 2:***

The purpose of this experiment was to measure the spring constant of a steel spring. The relationship between the force applied to a spring and the displacement of the spring from its rest length was investigated. Various masses were hung from the springs and the vertical displacement was measured. A spring constant of 2.94 ± 0.026 N/m was found. These results confirmed Hooke’s Law, Fs = -kx.

*(67 words)*

***Poor Abstract Example* –** *Too long, with too much detail and unnecessary information. (The worst problems are underlined.)*

The purpose of this experiment was to determine the spring constant k of a steel spring. First we investigated the relationship between the force applied to a spring and the displacement of the spring from its rest length in order to verify Hooke’s law. We hung masses of 0.01 kg, 0.20 kg, 0.30 kg, 0.04 kg, 0.05 kg, 0.06 kg, 0.70 kg, and 0.80 kg from the springs, and recorded the vertical displacements. We made four measurements for each mass hung from the spring and used the average of the four values in order to reduce random error. In this method, the main cause of error was measurement.We found a spring constant of k = 2.94 ± 0.026 N/m. Our results confirmed Hooke’s Law, the well known relationship that the magnitude of an elastic restoring force on a spring is directly proportional to the displacement of the spring. This relationship is named after the 17th century scientist Hooke who studied it

**Should be in Introduction**

**Should be in Experimental Procedure and not in first person**

*(162 words)*

\*Remember, the abstract should be concise and must contain enough relevant information to be thorough!

### **1.8.2: Introduction Example**

The spring constant, k, of a given spring can be found through relating the elongation the spring undergoes while loaded under a known force. If a weight of mass *m* is hung from one end of an ordinary spring, it will apply a force *W* on the spring proportional to the gravitational constant, as shown in Equation 1.8.1

Equation 1.8.

*W=mg*

where *W* is the force loading the spring, *m* is the mass of the weight, and *g* is the gravitational force.

Under the force of the applied mass the spring will stretch a distance *x* from equilibrium. The elongation, or displacement (*∆x*) of the spring can be calculated through Equation 1.8.2.

*x0-x = ∆x* Equation 1.8.2

*x0* is the equilibrium position of the spring, *x* is the displaced position of the spring, and *∆x* is the elongation of the spring.

When loaded under the force *W*, an equal and opposite restoring force, *F,* is created in the spring, which opposes the pull of the weight. If *W* is not so large as to permanently distort the spring, then *F* will restore the spring to its original length after the load is removed. The magnitude of this restoring force is directly proportional to the stretch, as shown in Equation 1.8.3.

*F = -k∆x* Equation 1.8.3

The constant *k* is called the spring constant, *F* is the restorative force of the spring, and *∆x* is the elongation of the spring. Equation 3 is commonly known as Hooke’s Law, and is used to describe not only the restorative force of springs, but also the force felt between displaced atoms.

In combining Equations 1.8.1 and 1.8.3, it is apparent that plotting *F* as a function of *Δ l* will demonstrate a linear portion, as shown in Equation 1.8.4.

*F = mg = - k* Δ *x* Equation 1.8.4

This therefore provides confirmation that the spring follows Hooke's Law and enables the determination of the spring constant, *k*.

### **1.8.3: Results and Calculations Example**

**Columns that contain the same error for each value can have the error listed at the head of the column**

Force and displacement for Trials 1-4 are given in Table 1, along with the average displacement for all four trials and nominal spring constant for each displacement. The nominal spring constant was found from the average k for all trials to be 2.94 ±0.026 N/m.

Table 1.8.1: Force, Displacement, and Spring Constant for Trials 1-4

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Force (N) ±1%** | **Displacement (x10-2 m)** | | | | | **Spring Constant (N/m)**  **Note that the number of significant figures in the answer is consistent with the least number of significant figures** |
| **Trail 1**  **±0.07** | **Trial 2**  **±0.07** | **Trial 3**  **±0.07** | **Trial 4**  **±0.07** | **Average** |
| 0.00981 | 0.28 | 0.36 | 0.37 | 0.38 | 0.35±0.05 | 2.8±0.2 |
| 0.0294 | 0.94 | 1.05 | 1.02 | 1.03 | 1.0±0.05 | 2.91±0.08 |
| 0.0491 | 1.60 | 1.68 | 1.67 | 1.69 | 1.66±0.04 | 2.96±0.05 |
| 0.981 | 3.13 | 3.35 | 3.34 | 3.35 | 3.29±0.11 | 2.98±0.05 |
| 0.196 | 6.65 | 6.66 | 6.65 | 6.62 | 6.65±0.02 | 2.95±0.03  **Columns that contain differing error values should report the individual error after the appropriate value** |
| 0.392 | 13.2 | 13.3 | 13.3 | 13.3 | 13.3±0.05 | 2.95±0.03 |
| 0.589 | 19.9 | 19.9 | 20.0 | 19.9 | 19.9±0.05 | 2.95±0.03 |
| 0.785 | 26.6 | 26.6 | 26.6 | 26.5 | 26.6±0.05 | 2.95±0.03 |
| 0.981 | 33.2 | 33.3 | 33.2 | 33.3 | 33.2±0.06 | 2.95±0.03 |
| 1.18 | 39.9 | 39.9 | 39.8 | 39.8 | 39.8±0.06 | 2.95±0.03 |
| 1.37 | 46.5 | 46.5 | 46.5 | 46.4 | 46.5±0.05 | 2.96±0.03 |

A plot of the restoring force of the spring as a function of displacement is given in Figure 1.8.1. Note the linear relationship between the force and the displacement of the spring, with the slope equal to the spring constant, as plotted in excel. The LINEST function in excel was used on the data set to give a slope of 2.954 ±0.00126 N/m

**Each data point shows error bars. Use the “Custom Error Bars” option to display the error values you calculate**

**For this lab, it was appropriate to display a linear fit to the data to demonstrate Hooke’s Law. The coefficient shown here will be compared to the calculated spring constant.**

Figure 1.8.1: Restoring force as a linear function of displacement, supporting Hooke’s Law

**Note the equation references from the Introduction section**

Displacement was calculated in all cases by subtracting the equilibrium location of the spring (24 cm) from the position on the spring in each case using Equation 1.8.2. Force on the spring from the hanging mass was calculated in all cases by multiplying the mass of the weight by the acceleration due to gravity using Equation 1.8.1. The spring constant *k* was calculated in all cases using Hooke’s Law, given in Equation 1.8.3. Sample calculations of these equations are displayed below.

Sample calculations for 1 g weight:

**Sample Calculations can be given in the text of the report**

*Δx = x-xo=24.28x10-2m-24x10-2m = 0.28x10-2m*

*F = mg = (1.0g) (1 kg/1000g) (9.81 m/s2) = 0.00981 N*

*k = F/ Δl = 0.00981N/(-0.35x10-2m)=2.8 N/m*

### **1.8.4: Error Analysis Example**

Initial bias error from both the equilibrium location and the measured location was first calculated for all cases to be 0.07x10 -2 m:



To calculate the error for the average *k* values, Equation 1.8.5 was used:

Equation 1.8.5



*x* is the average displacement, *F* is the restoring force, and *σx* and *σF*are found through Equations 1.8.6 and 1.8.7 respectively.

Equation 1.8.6



Equation 1.8.7



Δ*x* is the precision error in the displacement, is the displacement bias error for each trial, *F* is the restorative force, and *g* is the force of gravity (assumed constant therefore).

To calculate the total value in the nominal (average) *k* value, Equation 1.8.8 was used:

Equation 1.8.8

**Sample calculations can also be included in an Appendix. Just be consistent within your report!**



where is the average of all of the averate *k* error values for each trial, and is the standard deviation of the average from all the trials (see Appendix A for sample calculation).

