ME 310 GRADUATE TEACHING FELLOW REQUIREMENTS

ME310 (4 credits) is the SOLE measurement and instrumentation course in the ME curriculum; it lasts one semester, and is offered every semester except summers. There is a full complement of lectures, meeting twice a week for 2 hours at a time (except for the final two weeks when I allow them more time for their project). There are 7 labs, 6 labs requiring lab reports, and 1 (5 week) project requiring a presentation and report, for a total of 15 lab weeks. The focus is not so much on observing physical phenomena classically encountered by ME's, as it is on the measurement and reporting of physical phenomena. The course is notorious among the undergraduate students for requiring a large amount of work and a consequent time commitment. It is notorious among the graduate students as the TF which really does require a full 20 hours per week (some weeks less, some more!). Herewith a brief description of the course activities and requirements which contribute to the GTF load.

Enrollment: Over the past 9 years during which I have kept records, our total enrollment figures have continually but slowly (2-3 per year) climbed, so that as of Fall 2007, we have on the order of 55 students per semester taking the single section of the course. This type of enrollment requires 4 lab sections and consequently 4 GTFs and 4 lab sections. In the spring, often, our enrollment is around 40, thus requiring roughly 3 TF's and 3 lab sections.

Primary ME310 TF requirements *(all time figures are estimates based on my observations over 9 years, and TF feedback. I am not including sporadic maintainence/repair duties, most of which are done offline by our departmental Lab engineers Estano and Campbell):*

- <u>Know the lab subject, and know the BU equipment:</u> I require my TF's to have run the experiment completely before running it with the students – they MUST know the pitfalls before they get in there with students. There is very little that is 'turnkey' in our labs. This requirement entails a fast start, since they are required to run the first lab during the first week of classes. A minimum of 6 hours per lab (set up and run, refresh concepts, verify enough duplicates of equipment exist for up to 4 groups/section depending on experiment, verify every piece of equipment turns on and operates correctly,) plus 10 hours on the project (the project utilizes several different transducers) yields 42 + 10 = 52 hours of work for this aspect per semester.

  52 hours
- <u>Meet the labs:</u> 1 lab section lasts 4 full contact hours. In addition, the TF must set up all necessary apparatus. Because we have some labs for which there is only 1 apparatus (wind tunnel, pipe flow), any given week's section may have 2-3 different setups. Finally, tear-down and storage post-lab is required. A minimum estimate for the weekly hours necessary is 1 set-up plus 4 contact plus 1 teardown = 6 hours/lab week. Though we currently run only 7 lab experiments, we have 9 weeks of labs due to apparatus constraints. Thus, I estimate 54 hours/semester for

this aspect of the work. The project weeks require less setup since the students themselves have individualized setups, but still require at least 4 contact hours for 5 weeks, thus 20 hours/semester.

74 hours

- <u>Grade the lab reports:</u> The extent and nature of reporting required in the laboratory reports is documented below in Appendix B. The students are required to go far beyond "we came, we saw, it matched theory" in their reports. Their reports often exceed 30 pages. In order to grade these extensive lab reports, the TF's must spend time reading every section, there is no shortcut. After doing it myself, and polling my TF's, the consensus is that it takes a TF on average 2 hours per lab report to do a good job. After having past TF's keep detailed hour records, we have fixed our target population ratio to 12 students per TF – note that this implicitly assumes 1 full TF per lab section. Thus, a total of 12*2*7, plus another 3 hours * roughly 4 groups for grading the project, for which they are grading only the groups, not individual lab reports, yields 168 + 12 = 180 hours per semester. Clearly the lion's share of a TF's effort goes towards grading.

  (Why don't we use undergraduate graders for the lab reports? First, despite the '310' label, this is a predominantly senior course, so we lack students. Second, the grading goes far beyond matching up answers from homework solutions manuals.)

180 hours

TOTAL 306 hours/semester/TF

So, recall that my working target based on experience is 12 students per TF. If we discount any other sinks of time, I get conservatively 306 hours / semester per TF. Given a 16 week semester, TF's are thus supposed to work 20 hours / week, or 320 hours per semester. Given the several elements of uncertainty involved in such a calculation, I think my conclusion here should be simply that my target of 12 students per TF is in line with a 20 hour/week figure.

I hope this helps provide a clearer picture of the duties of ME310 TF's.

(prepared by G. Holt, with comments from former instructor M. Isaacson, and former AM310 TF's P. Edson, C. Thomas, C. Farny, J. Wanderer, T. Chauan, A. McKnight)

Next page: Appendix A, Course description
Appendix B, Lab Report Requirements

APPENDIX A: AM 310 – INSTRUMENTATION AND THEORY OF EXPERIMENTS

Course Description, Fall Semester 2007

ENG AM 310 Instrumentation and Theory of Experiments

2006-2007 Catalog Data:
ENG AM 310 Instrumentation and Theory of Experiments Prereq: ENG EK 303 and ENG EK 307. Designing, assembling and operating experiments involving mechanical measurements; analyzing experimental data. Safety considerations in the laboratory. Wind tunnel testing. Mechanical and electrical transducers for flow, pressure, temperature, velocity, strain and force. Electric circuits for static and dynamic analog signal conditioning. Computer use for digital data acquisition and analysis; instrument control. Professional standards for documenting experiments and preparing reports, including formal uncertainty analysis involving elementary statistics. Interpretation of experimental results. Includes lab. 4 cr, either sem.

Course Schedule:
4 lec hr/ wk, 12 - 4hr. labs per semester

Textbooks:
R.S. Figliola and D.E. Beasley, Theory and Design for Mechanical Measurements, 4th ed. , Wiley, 2006.

J.R. Taylor, An Introduction to Error Analysis, 2nd ed. University Science Books, 1997.

Boston University Course Packet for AM 310, including Lab Manual and Class Handouts, 2006/2007.

Coordinator:
R. Glynn Holt, Associate Professor of Aerospace and Mechanical Engineering

Prerequisites by topic:
1. Basic calculus and differential equations.
2. Free vibration of a spring-mass system.
3. Basic fluid mechanics.
4. Basic circuit theory (both DC and AC).

Goals:
This course has four main goals: 1. To teach techniques for designing experiments and analyzing data; 2. To introduce the operating principles and uses of transducers, output devices and signal conditioning elements of measurement systems; 3. To introduce the concepts of signals and systems and their interaction in both static and dynamic measurements; and 4. To provide hands-on experience conducting experiments in with emphasis on safety, documentation, data analysis, computer use and uncertainty analysis.

Course Learning Outcomes:

As an outcome of completing this course, students will:

1. **Become proficient in designing and implementing experimental solutions to engineering problems,** including static and dynamic mechanical, electrical and thermal measurements, and understanding the tradeoffs between cost, performance and complexity of measurement schemes. (1b, 1c, 3a-c. 4b)

2. **Become proficient in analysis of uncertainty of experimental results,** including the identification of sources and types of uncertainty, combination and propagation of uncertainties, and application of appropriate statistical models for precision uncertainty of finite samples. (1b, 3b, 3c)

3. **Become proficient in reporting and documentation of experimental work** through use of standardized lab reporting policies and requirements. (1b, 2a, 2c)

4. **Gain experience in the operating principles and uses of transducers, output devices and signal conditioning elements of measurement systems,** including flow , pressure, temperature, velocity, strain, force, and optional transduction systems, and including electric circuits for static and dynamic analog signal conditioning, and computer use for digital data acquisition, analysis and instrument control. (1b, 1c)

5. **Gain experience with the concepts of signals and systems and their interaction in both static and dynamic measurements,** including mathematical modeling of such systems' static and time-dependent behavior. (1a, 1b, 1c, 3a)

6. **Gain experience and confidence in self-instruction on the use of data acquisition software and hardware systems,** including standard multifunction analog-digital conversion boards, and LabVIEW or other GUI interface data acquisition control software. (1b, 1c, 5a)

7. **Gain experience in efficient organization and teaming** by performing labs and projects in both self-organized and instructor-organized groups. (2a,2c)

Course Learning Outcomes mapped to Program Outcomes:
(For Program Outcomes, please see attached page or Department web site)

Program:	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	5a	5b	5c	5d
Course:	v	i,ii iii iv v vi	i iv v vi	iii vii		iii vii	i,v	i,ii	i, ii		i	vi			
Emphasis:	3	5	5	3	1	3	5	5	5	1	3	3	1	1	1

Topics:
1. Introduction and definitions related to static measurements and calibration (1 week)
2. Errors, uncertainty, probability, statistics and uncertainty analysis (3.5 weeks)
3. Data analysis and presentation: graphing, curve fitting, linear regression (1.5 weeks)
4. Generalized measurement system and static (0^{th}-order) systems. (2.5 weeks)
5. Transducer fundamentals (1 week)
6. Dynamic measurements: First and second order system responses, complex signals and distortion (2 .5 weeks)

7. Digital data acquisition. (0.5 week)
8. LC filters, RC filters. (0.5 week)
9. Exams. (1 week)

Contribution of Course to Meeting the Professional Component:

Engineering topics: 100%

Computer Usage:

1. All experiments require some degree of computerized data analysis (simple algebra, regression and error analysis, theory comparison) and plotting of data. This is usually accomplished within some commercial spreadsheet program such as Microsoft Excel, or within Matlab.
2. The design project requires automated data acquisition using a standard MIO board on a PC along with near-real-time data analysis and display and optional control using GPIB communications between a PC, a function generator and a digital oscilloscope. The system utilizes an industry-standard software interface (National Instrument's LabVIEW, or Mathworks Matlab). As part of the experiment/project the students must create their own multi-channel data acquisition/control program using LabVIEW in order to give them exposure to the concepts of a graphical programming language and a graphical user interface (GUI).

Laboratory Projects: (Extensive preparation and report required for each, except oscilloscope introduction)

1. Introduction to oscilloscope and multimeter usage (use of digital and analog oscilloscope and digital multimeter to measure static and dynamic signals – only 2-page report required)
2. Filters and operational amplifiers (Decade resistance box, capacitor, superstrip, DMM, counter/timer, function generator, differential power supply, dual trace oscilloscope.
3. Wheatstone bridge and strain measurement (same as Exp. 2, with cantilever beam equipped with strain gages).
4. Flow meters and friction loss in pipes (pipe-flow apparatus, pump, constant head tank, manometer, weigh scale, rotameter, venturi meter, orifice meter, turbine meter, oscilloscope, counter/timer, DMM, pulse to DC converter, 4-20 mA current loop).
5. Marble density/Introduction to formal uncertainty analysis (Dial caliper, standard weights, weigh scale, 50-marble sample)
6. Drag coefficient of a sphere (wind tunnel, standard weights, pyramid force balance, load cells, strain gage conditioner, filter, DMM, oscilloscope, strip chart recorder, incline manometer, Pitot-static tube, wind-speed gage).
7. Temperature measurement and calibration (thermocouples, thermistors, linearizing amplifier, several temperature baths).

Engineering Design:

Design project (5 weeks): Utilizing choice of transducer (digital video imaging, acoustic pulse-echo, optical proximity, magnetic induction encoder, accelerometer, or other) student groups design and implement transduction system to measure the magnitude and phase response of a nonlinear spring-mass-damper system (variable frequency driven spring-mass-damper system, stroboscope, standard weights, weigh scale). The output of their transduction system must be digitized and stored and analyzed on a computer. The digital data acquisition is accomplished with a PC with MIO (A/D, D/A, DIO) card, GPIB card and LabVIEW except for the digital video imaging system, which utilizes a proprietary interface to the Ethernet port of the computer. The students must choose an appropriate method or methods to ensure minimal error over a frequency range of 0 – 7 Hz for the oscillator which possesses a "hard-spring" nonlinearity, with hysteresis and period-doubling behavior near the fundamental resonance. They must consider both analog and digital techniques to overcome the inherent problems. They must perform a design stage uncertainty analysis of their system as well as a full measurement uncertainty analysis of the test data.

In addition, in most biweekly homework assignments, at least one problem has a design orientation.

Communications (Written):

Proper English usage and spelling is required in all laboratory reports, homework and exams, and the term design project. Credit is deducted when poor English interferes with comprehension by a grader.

Safety:

Students are required to conduct a safety inspection of every lab and prepare a section in their lab reports discussing safety concerns. This is worth 5% of their grade.

Probability and Statistics:

Approximately two weeks' worth of lecture time, two weeks' homework and the marble density lab are devoted to developing the methods needed for statistical analysis of data and precision uncertainty analysis. In addition, all subsequent homework, labs and exams explicitly incorporate uncertainty analysis and error propagation.

Status of Continuous Improvement Review of this Course:

Date: March, 2007 **Reviewed by:** Todd Murray

Prepared by: R. Glynn Holt **Date:** August, 2007

Appendix B: LAB AND LAB REPORT POLICIES AND PROCEDURES:

0. **Groups**
   Organize yourselves into groups of no more than 4 students each. There will be no more than 4 groups per each lab period. Remember that lab reports are done individually.
1. **Notebooks and Reports**
   a. Lab Notebook: Buy at least 1 square-ruled lab notebooks (with page numbers, preferably). They must be similar to National Brand #43-591 or Roaring Spring #77591. You will record all your in-lab data and observations for ALL LABS in this notebook, which is to be turned in at the end of the semester. Identify your notebook on the cover with your name, term and year, course number, and lab partner's names.
   b. Lab Report: Each student will generate a lab report for each experiment, the elements of which are spelled out in the sections below. These reports will be generated on a word processor with inclusion of graphs and plots (typically generated in a spreadsheet or other calculation program) and also with the inclusion of the photocopied pages of the lab notebook corresponding to the experiment.
   c. All entries (notebook especially) must be in permanent ink. Pencil is only used for drawings and graphs. Do not erase or 'white-out' mistakes, cross out with ONE mark and explain. Use only the right-hand side of pages.
   d. Format, content and neatness will be graded. Your writing or typing must be legible, intelligible, and concise but complete. As mentioned above, these reports are stand-alone documents. You may NOT assume that 'everyone knows that'. If you use information from a previous class or from some textbook (even our own) document such.
   e. The pre-lab section of the report is due at the beginning of the lab. The TF will check, sign and date the prelab or you will receive no credit.
   f. The in-lab data section completed in the notebook must also be signed and dated by the TF, or no credit will be received.
2. **Due dates**
   Lab reports are due at the beginning of the subsequent laboratory (which may be 1 or 2 weeks later). LATE LAB REPORTS WILL NOT BE ACCEPTED OR GRADED unless dire circumstances warrant the exception.
3. **Error Analysis**
   An estimate of your errors, their sources and impact on results is required in every lab report. Additionally, SPECIFIC LABS require a full formal uncertainty analysis. I have scheduled 1 free lab period following Lab 6 to ensure adequate time for preparation of the longer and more extensive lab report.
4. **Late or missed labs**
   Only in the most extreme of circumstances will you be allowed to be late or miss a lab and schedule a makeup. These labs require a large amount of overhead in terms of equipment, prep, coordination and manpower, and it is not fair to anyone to reschedule without compelling cause.

5. **Lab Report Content**

I have many sample reports available in office for your perusal. On the following pages you will find a section by section breakdown of what is expected.

6. **Safety**

Safety is paramount. Never work alone. Tie up loose ends: this includes hair, clothing and jewelry. Keep workspaces free of clutter. NO FOOD OR DRINK IS ALLOWED IN THE LAB!

AM 310 LAB REPORT CONTENT AND LAB NOTEBOOK USE

GENERAL INFORMATION

- Start each lab report section on a new page and use only the fronts of pages (or the right-hand-side of your lab notebook). Number your report and notebook pages (by hand in your notebook if you have to).
- Copies of the relevant pages of your lab notebook must be included in your lab report for each experiment when you turn it in post-lab.

PREPARATION BEFORE LAB (Prelab Report Section)

- Title page
- Objectives of lab
- Theory and preparation for analysis
- Appropriate tables of symbols and formulas
- Spot check preparation
- Listing of data needs
- Tentative equipment lists
- Procedure checklist

1. Title Page

This should include only the title of the experiment, the date the experiment was actually done, your name, and all other students who did the experiment with you, using your apparatus.

2. Objectives

Before each lab you must read and understand the lab write up. Then you must prepare your notebook for the lab. First, the objectives of the lab should be stated. This should be a **brief and concise** statement of what the scientific and/or engineering goals of the experiment are (e.g., investigate a phenomenon and/or demonstrate a theorem).

Do not just copy the handout. In the conclusion section at the end of your lab you should return to the objectives to ascertain how well the objectives were realized. Since the conclusions depend on the results of the experiment, what is included in the results section will also depend on the objectives, so check what is asked for (or what will be obtained) in the results section before writing your objectives.

3. Theory

Next, a brief summary of pertinent theory or established empirical evidence related to the experiment should be given. The purpose of this is to clarify what data you are looking for in the experiment and how these data are to be reduced to meet the lab's objectives. It is your responsibility to understand the theory well enough to know what measurements need to be made (e.g., if a Reynolds Number is required, then you need to measure temperature, which will allow you to look up the fluid's viscosity). Also, if the handout asks you to perform a derivation or dimensional analysis, it should be done in this section.

4. Formula Summary

This is a listing of the formulas you will need to find your results from your data and the theoretical values to which you will be comparing them. Also, list the meaning of all the symbols used in your formulas and their units.

5. Spot Check Preparation

It is almost always desirable to do an analysis of some data points in the lab while the experiment is running. This is called a spot check. A spot check permits you to see if the results make sense, or if the experiment is generating data that is obviously erroneous and either the experiment or your method of analysis needs correcting. As an example, in the Reynolds Apparatus experiment performed in EK 303, you were looking for the Re that corresponds to the laminar to turbulent transition region. Were this lab done in AM310, you would outline in your prelab how to do this (such as viscosity tables and a calculator). Then, during your lab you could check that your results were consistent with the expected values for flow transition.

All AM310 labs include spot checks to help you identify bad data, bad analysis, bad lab technique or faulty equipment. **Sample calculations for spot checks should be prepared in your prelab**. These should include unit conversions and constants to reduce in-lab time. Then in the lab, you will only need to plug in your experimental values. Check during the previous lab what unit conversions will be needed in the next lab.

6. Data Needs

This section should include a list of data needs, including the range of variables the data will be taken over. The purpose of this is to simplify in lab the construction of neat data tables that are easy and informative to read. It also allows you to determine complete list of the data you'll need in lab, to reduce the chance you'll forget or miss a measurement.

Headings for table rows and columns should be devised as well as tentative unit assignments. In this section your tables should be "skeleton" or model tables containing no actual data. **The actual data tables, containing the actual data, must go in the data section (which follows the safety check) in your <u>lab notebook</u> and are to be constructed and filled with data only during the lab.**

7. Equipment List

Next should come a tentative list of equipment. It is a tentative list because there will be probably be some additions to the list to be made in the lab and for information on **equipment make, model number, and serial number**. Also, you will wish to record **stated accuracy** (with calibration data if available) and **instrument resolution** (smallest increment, or least count). Accuracy information can be found in the equipment manuals in the lab for the electronic instruments. You should construct this list in the form of a table and are permitted to fill it in with the unknown information during the lab.

8. Procedure Checklist

The last part of the prelab should be the procedure checklist. Here you will summarize how to set up and run the experiment in a list of brief statements that you then follow in lab. This is to help you to remember when to turn crucial valves so the lab doesn't flood out and when to take crucial data or perform spot checks so you don't have to repeat portions, or all, of an experiment. The labs can become somewhat confusing while in progress and it is not difficult to forget a procedure step, so a good procedure section is of some significance.

Obviously there is a fair amount of work involved in prelab preparation. It is a very significant part of doing an experiment and should not be raced through just prior to lab. The prelab comprises 30% of your lab grade.

LAB NOTEBOOK USE DURING LAB (Inlab Report Section)

- Complete equipment list
- Make and record a safety inspection
- Follow procedure checklist
- Take data
- Perform spot checks
- Note general observations

1. Complete Equipment List

Include the make, model, serial number and accuracy information where applicable. Put this information into the table in your prelab section, or record it directly in your lab notebook.

2. Make Safety Inspection

Before beginning the experiment, consider and note in your lab notebook the safety issues related to this experiment. Include both issues that were addressed (e.g. wearing safety glasses for the Mechanical Second Order Experiment) and also those that were not addressed. For those issues that were not addressed, comment on how the safety of the experiment might be improved in the future. Note that this includes safety FOR the equipment, not just FROM it – you should be aware of the limitations of all equipment you use, and take appropriate steps to ensure no input or output loads exceed those limits.

3. Follow Procedure Checklist

Check off each step as you proceed through the checklist. You should pen in procedure changes if they become necessary. If there is extensive revision of the procedures necessary, you should record the revised procedures in the lab notebook.

4. Take Data

Construct data tables based on the models you developed in your prelab. Record data in these tables in the lab notebook along with appropriate units and other comments (e.g., which of a choice of instruments you were using – e.g., which rotameter – or which scale you were using on your instrument). Be sure to record the **raw** data before you make **any** calculations, e.g., the height of each column of a differential manometer and not just the difference in heights (which would be the result of a calculation and result in the loss of some information – e.g., where on the scales you were working). All data must be recorded neatly and be **easily** legible to the graders (including the units of the data) or else loss of credit will result. The 5% credit given for this section is primarily given for format, presentation, and completeness. More credit will be lost if the data is faulty, leading to poor analysis and results.

5. Perform Spot Checks

Usually you will be told what spot checks to do, but for some labs you are expected to come up with some of your own. Regarding spot checks, it is not enough to simply do them. Comment on what information they supply, e.g. "demonstrates a linear relationship", or , "corresponds to a theoretical expectation", etc. Spot checks should be performed in the data section, near the relevant data. Since spot checks are so important this section is also worth 5%.

6. Note general observations

In addition to taking data, general observations that relate to the lab, such as problems and inconsistencies, should be recorded. However, problems that can be corrected by the students (e.g., poor flow meter calibration) should be corrected as well as noted.

ANALYSIS AFTER LAB (Postlab Report Section)

- Analysis
- Uncertainty analysis
- Results
- Discussion and Conclusions

1. Analysis

The analysis should appear in the lab report following photocopied pages from the lab notebook containing the information recorded during lab. It is very important that your analysis is clear to someone who did not do the lab. Therefore, you should annotate it well. Sample calculations for each different type of data point and calculation must be included. Be sure to specify which data point is being used in each sample calculation and to identify the source (including the page number in the lab notebook) of any typical data and reference data you use (e.g. viscosity values). Also, be certain to use and check units. Hint: sometimes it is easier to convert all data into SI units and then do your calculations.

Following the sample calculations, analysis of all of the data points should be summarized in tables, including intermediate as well as final results. The data points used in the sample calculations should also be included in these analysis tables as a check that the analysis behind the tables is working properly. All tables must have titles and clearly labeled columns and rows (variable names and units).

Calibration curves and other curves needed for the analysis of data should also be included in the Analysis Section, however, all results graphs belong in the Results Section only. All graphs must have titles on them indicating what they represent. If there is more than one curve on a graph, clearly distinguish them by different symbols, line types, and/or colors in a legend included somewhere on the graph. Describe the features and parameters of the graph in a figure caption below the graph. The scales of the x- and y-axes must be clearly shown and labeled with variable names and units. Be sure to use the appropriate graph axis type in your graphing application: log-log, semi-log, etc. Graphs should be sized so that they take up most of a report page width.

Sample calculations may be done by hand or using a *symbolic* manipulator program (such as Mathematica or Maple), but the rest of analysis, as well as uncertainty analysis and graphs should be done with a computer (Matlab and Excel are available in the CAD lab). Hand-written sample calculations may be done in the lab notebook for convenience, then photocopied for the report. Alternatively, you may simply leave space in your report pages for the appropriate hand-written calculations.

2. Uncertainty Analysis

The uncertainty analysis should include your estimated elemental experimental uncertainty in each measurand (both bias and precision, identified as such, as well as total uncertainty), statistical analysis of data where appropriate, and uncertainty propagation for formulas and results using partial differential root sum square propagation formulae, and sample calculations). Also, discuss, combine and propagate the uncertainties introduced by your equipment.

Sample calculations must be shown for a single point for each type of measurand and a single example for each type of resultant. Following the sample calculations, uncertainty in all values and results must be calculated and displayed in tables. Due to its great importance, uncertainty analysis counts for 20% of your lab grade on the labs requiring uncertainty analysis.

3. Results

Results should be given in terms of tables and graphs whenever possible (refer to above paragraph on graphs for format). **Do not include intermediate calculations (those belong in the analysis section), just final results in the results tables**. Final results are those you need to meet the objectives of the experiment. Data points should have error or uncertainty ranges indicated, where appropriate, in both tables and graphs (on graphs it should be represented as error bars when possible). **Avoid too many significant figures in reporting results, even intermediate results.**

4. Discussion and Conclusions

In the discussion section you should evaluate your results and discuss the physical meaning of the numbers and graphs. If there are relevant theoretical or empirical results available, compare your results with them, and attempt to explain any discrepancies. Answer any and all questions asked in the procedure section of the lab handout. Mention experimental limitations and ways the lab might be improved. Were the lab's objectives met? Remember to include uncertainty in this discussion. Because it is important to think about and communicate experimental results as well as get them, this section comprises 15% of your lab grade.

ADDITIONAL GRADING

1. Presentation

The presentation quality of your lab report will, at a minimum, be graded for readability, completeness and placement of items in the proper section.

SUMMARY OF LAB REPORT ORDER AND CREDIT

For each experiment, the report in your lab notebook should consist of:

	Section	**Max. Credit**
Prelab	Title page	2%
	Objective	3%
	Theory	4%
	Formula summary	1%
	Spot check preparation	5%
	Data needs	5%
	Equipment list	5%
	Procedure checklist and safety	5%
Inlab	Data	5%
	Spot checks	5%
Postlab	Analysis	10%
	Uncertainty analysis	20%
	Results	10%
	Discussion	15%
All Sections	Presentation	5%