Memorial University of Newfoundland
Faculty of Engineering and Applied Science

Engineering 2205

Chemistry and Physics
of Engineering Materials I

Laboratory Manual

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INTRODUCTION

You are familiar with laboratory work through courses taken in earlier semesters in the University and in high school. However, your previous laboratory exercises may have had objectives different from those for the laboratory work in this course. Laboratory work in a course is often intended to help the student understand some important concepts and relationships ("laws"). For, instance, by measuring current through a resistance and the voltage across it you can get a demonstration of Ohm's law. You might even be asked to 'prove' the law. Of course, there is no real need for a student to prove a well established physical law, but performing this kind of measurement can be a useful way to help you understand what the law means.

We certainly expect the laboratory exercises in this course to help you understand some basic materials properties. These exercises do deal with some very basic concepts and properties, and you are expected to *understand* all of them - and not just be able to memorize a formula involving them.

There is, however, another *very important* aspect of the laboratory exercises in this course. While the concepts involved - e.g. yield stress, resistivity, etc - are important as concepts, these are examples of materials parameters *that vary from material to material and between different samples of the same material.* These values often depend on how the materials were manufactured and treated after manufacture. These parameters are *not* constants. They often have to be measured for each particular engineering application. The values of these parameters often have to be specified in a contract or purchase order and checked. Your laboratory exercises are in many respects an opportunity to practice an *engineering measurement*, for which there is no 'right answer' in a textbook or handbook. As an engineer, or on a work term, you may be asked to perform measurements of this kind, e.g. process control measurements, or deal with this kind of measurement done by others. Therefore, we expect you to use these laboratory exercises as a time to develop new skills and habits of careful laboratory work and taking *careful notes* while measuring parameters for which no one knows the 'correct' value beforehand, at least not exactly.

The taking of notes in experiments or in technical observation is an important skill in engineering. They can be an important record in many different contexts. ***Your notes should allow you, and others, to determine what you did and how you did it, and do so any time after you have done the work.*** Your notes should also allow you, and others, to determine how much reliance can be placed in your results, e.g. whether the values obtained are likely to be within 5%, 10%, or whatever percentage, of the true value (*not the value in a handbook* - but the *unknown* real value for that particular sample of the material which you tested).

In this course you will be introduced in stages to different aspects of engineering laboratory work, engineering measurements, and good log book practice in engineering

The class is divided into sections for the afternoons of Tuesday, Wednesday, Thursday, and Friday). For each section there will be four laboratory sessions of about 3 hours in length between 2 to 5 pm. The aim of the laboratory component of this course is re-enforce some of the concepts you will learn in this course, and to help you develop skills in the conduct of experiments and the taking of measurements in the context of engineering. But above all the intent is to help you develop good habits in *recording in writing* what you do using equipment and taking measurements as an engineer.

During the laboratory session you will be introduced to the way you should describe equipment in this course and in similar situations in engineering practice. You will be introduced to some measurement techniques, and to the limitations all measurements suffer from, and you will measure an important materials property. In the second laboratory you will be determining the elastic properties of a rubber O-ring. In the third laboratory you will be measuring the electrical resistivity of two different materials, as a function of temperature. Some "data-crunching" is expected in these exercises, i.e. you will receive some assistance in the handling of these calculations and much of the write-up is expected from you. In the fourth laboratory you will be measuring the thermal conductivity of a metal. This is a an exercise which is relatively simple in principle, but somewhat complex to carry out, particularly due to a number of calculations and estimates involved. In this exercise you will be expected to demonstrate the laboratory and log books skills taught in this course. In the case of all laboratories a group laboratory report is due at the end of the three hour laboratory session.

The Log Book

You will be expected to maintain a logbook on all your work in the laboratory part of this course. Each student must use a <u>bound</u> "physics-chemistry" notebook obtainable in the bookstore, and use it in all laboratories. All the pages must be numbered in sequence *before* the book is used, and every entry dated.

The logbook should contain notes taken when you are given instructions during laboratory periods. The logbook should contain notes on your thoughts as you plan experiments or some measurements. The logbook should also provide a record of the work during laboratory periods and subsequently.

You are not being given a rigid format for your logbook notes, nor are you given extensive written operating instructions or printed diagrams of the equipment. You are expected to use common sense in your note taking and produce your own sketches of the equipment following the principles which will be discussed and demonstrated aimed at ensuring that diagrams *explain* the principles on which equipment works and was used, and not just a picture of what the equipment looks like.

Photocopies of diagrams from textbooks or diagrams by other students are not acceptable. Notes on loose sheets are also not acceptable. ***<u>Raw data must be entered directly into a log book.</u>*** *<u>It is not acceptable to note such data first on a loose sheet, for transfer later into the logbook</u>.* Furthermore, raw data (i.e. experimental measurements taken in the laboratory) taken by one student in a group must be copied by hand by all other students in the group. Photocopies of raw data are not acceptable. There may be occasion to use a spreadsheet for repetitive calculations based on the raw data, in which case the computer printout may be attached to the notes. All the steps in calculations in the spread-sheet must be listed in the logbook, and the spread-sheet should be checked by carrying out at least one complete sequence of calculations "by hand" (using a calculator, as appropriate, to check the spread-sheet.)

Logbooks in professional engineering and science practice often serve as a record (sometimes for legal purposes) of the work done and you are expected to follow a format that is normal for such purposes. Therefore your notes, including data entries, should be clear and readable, ***in ink*** (drawings are the only items acceptable in pencil). Corrections and amendments are perfectly OK but should be made clearly by crossing out the words or numbers to be corrected so that it is still evident what has been corrected. *"Whiteout" is not acceptable.* The basic criterion is that anyone reading your notes can follow what you have done, and use your data. This means that your notes should be clear and contain all relevant information. Logbook entries on tests and measurements should be done on the spot, straight after the work, not sometimes afterwards from memory, or from separate notes.

Don't forget to record the *units* in which data is collected, and organize the data in appropriate tables, set out with enough space for all the data you expect to collect.

As noted above, these laboratory sessions where you conduct experiments are not just occasions when a scientific law or concept is demonstrated or tested. You should already have studied the concepts involved using your textbook and laboratory manual, *before you come to the laboratory*. It is important that you come to each laboratory session with a basic understanding of the material properties to be measured in the laboratory. Lectures given in classes immediately prior to the laboratory sessions may have dealt with these properties, but you may have to use knowledge which you should have acquired much earlier, and you may have to look at parts of the textbook yet to be covered.

Notes and sketches of equipment, notes on procedures followed, measurements and observations made, are to be recorded *during* the laboratory sessions, not subsequently from memory or other students' notes. The logbooks may be examined during a laboratory session and will be kept for examination after several of the sessions for a check that they contain all that should be written during the session.

The logbook entries will be initialled and lines drawn in them to indicate what was, and was not, recorded in them prior to and during each laboratory session.

Logbooks are due for final marking one week after the final session. The evaluation of your record and write-up of the final laboratory exercise will be major part of the total mark for the laboratory part of the course, along with how you have completed the other portions of the laboratory exercises.

The following criteria will be important in the evaluation:

Neatness: This does not mean that you are expected to, or should, write a draft only to copy into the logbook. On the contrary, if you do this you are likely to lose marks however neat the result! ***You must write, enter data, and draw directly into the book***. If you are not a tidy writer, this is an opportunity to try to develop and practice neatness in notes. That will be of some considerable help to you in later professional work. Think ahead before you start a table of data or a drawing. Keep you script from being large. Avoid scrawls. Remember that the data will in many cases be used for further calculations. Discuss this with colleagues and with an instructor. If you think this is likely then leave a space for additional columns. Draw column lines neatly. Don't forget to note units. Don't make your drawings tiny so that they are difficult to interpret. You have plenty of space in a logbook, so use it! ***Do not use "white out"***. Corrections should be made using neat lines across the data or words concerned so that the original is still legible, perhaps adding an explanation. (If corrections are made after the date of the original entry it is common practice to initial and date the correction, as well as an explanation).

Clarity, completeness and timeliness of laboratory record: It is important when you conduct an experiment and take measurements that the description of the equipment (including diagrams), the work done, and the record of data, is entered in the logbook at the time you do the work and take the measurements, that is before you leave the laboratory room on the day of the laboratory. You will lose marks for copying from another laboratory write-up. It is OK to process data and discuss results later. In this course this applies particularly to laboratories 2, 3 and 4.

Clear and appropriate statements of results: Results should not be difficult to find. Often it is a good idea to re-state or collect the results together at the end of the record, using only the number of significant digits that are appropriate considering the possible uncertainty, which also should be stated.

Your write-up on laboratory 4 will be key evidence of what you have learned in this course on logbook practice, but what you have written on laboratories 2 and 3 will also be important.

LABORATORY # 1: VERNIERS AND UNCERTAINTIES

OBJECTIVE:

The objective of this laboratory is to become familiar with the practical use of vernier calipers and micrometers for making linear size measurements as well as accounting for errors and the uncertainty of measurement.

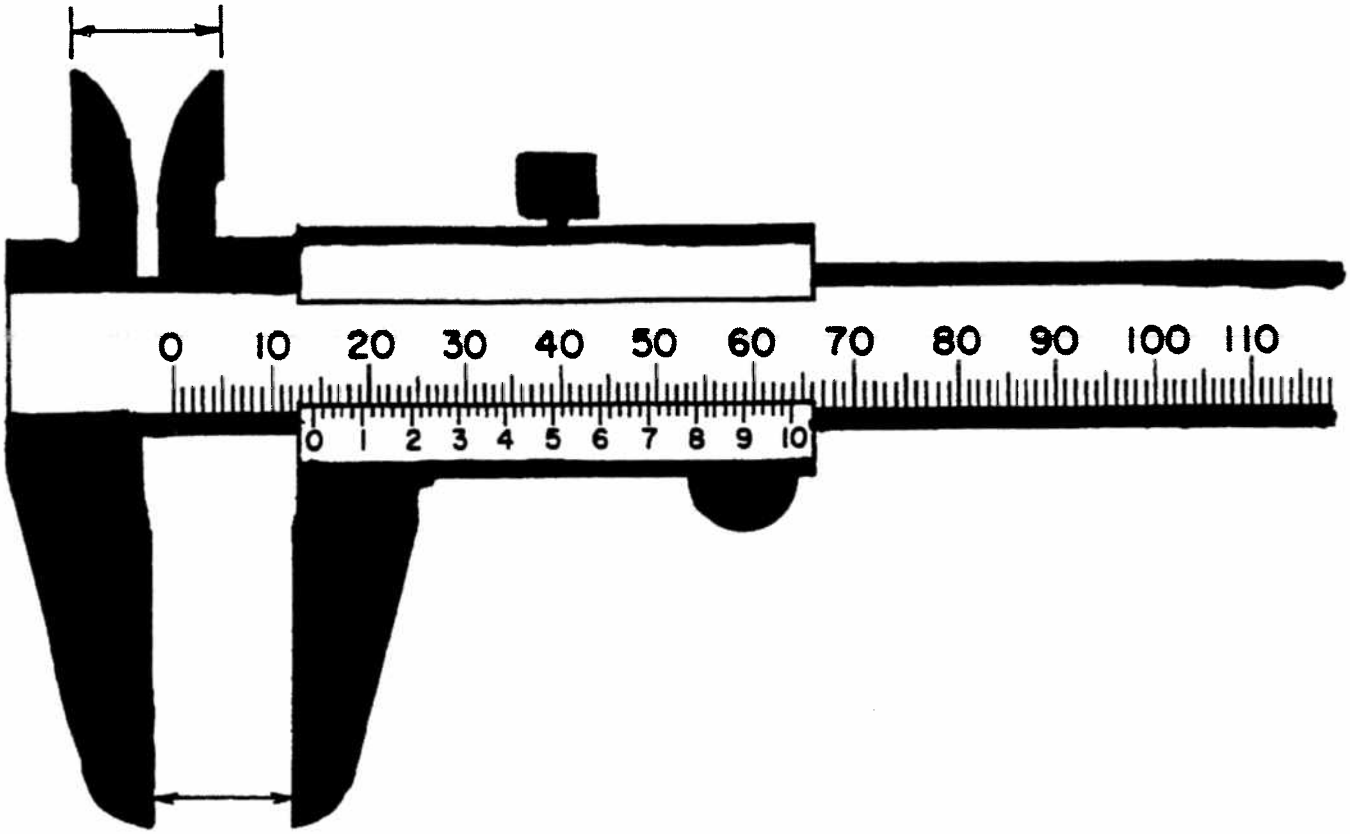
THEORY:

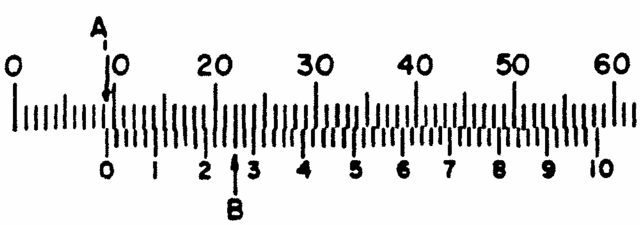
Vernier scales are used in many instruments with which one measures distances and angles, such as vernier calipers and micrometers. The principles of verniers and micrometers will be described and practice provided in their use.

All measurements involve some uncertainty, due to errors in the instruments used and errors in their use. When a measurement can be repeated many times, it is possible to apply statistical concepts to the measurement and derive values for the precision and accuracy involved. But even when there is only one measurement or only a few repeats, it is still possible to derive an outside estimate of the uncertainty. It is important in most calculations of a parameter derived from a number of other values, to identify the values that contribute most to the uncertainty in the parameter and be able to estimate the magnitude of that uncertainty.

Metrology is the study of measurement science. The simplest and most commonly used instrument for making linear measurements is a ruler or tape measure with a graduated scale on it. With these scales a direct reading can be taken with an accuracy limited to the smallest division, for example 1 mm. The smallest dimension on the rule is normally the size of the uncertaintly for the measurement expressed as plus or minus ±1mm in the case of a metric ruler.

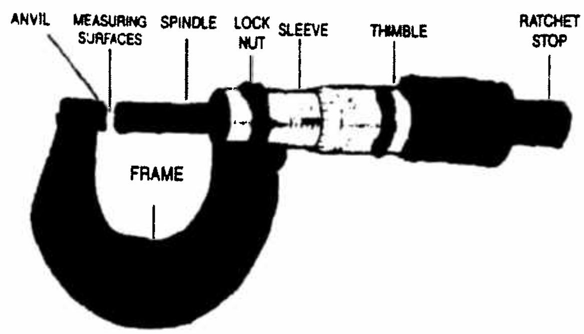
Vernier calipers are instruments or guages that perform the same function as a ruler or tape measure however they have a graduated beam and a sliding jaw with a vernier. The two jaws of the caliper contact the part being measured and the dimension is read where the sliding jaw scale meets the beam scale, plus the addition of the value at the matching graduated lines. The jaws on vernier calipers can be used to measure the inside and outside dimensions of parts. The first reading on the vernier caliper is taken where the 0 (zero) mark on the mm scale has passed a certain value of say 9 mm at point A. The next reading is taken by estimating where both the top and bottom corresponding lines find the best match at say 26 or 0.26 mm which gives an overall reading of 9 + 0.26 = 9.26 mm.

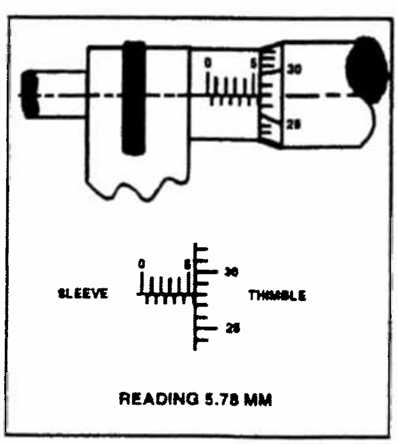


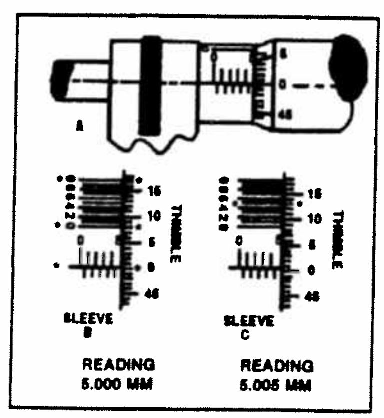


A :	: 9 mm
B :	: 0.26 mm
C :	: 9.26 mm

Micrometers are commonly used for measuring the thickness and inside or outside dimensions of parts. They come equipped with a threaded spindle, graduated thimble and graduated sleeve. The sleeve also contains some horizontal lines used in the final measurement calculation. The idea is to rotate the thimble counter clockwise which opens the spindle away from the anvil for inserting a part. The thimble can then be rotated clockwise to close the spindle in on the part snug (thimble will snug and then loosely over rotates) but not too tight to make a measurement. The first reading is taken from the sleeve where each division is equal to 0.5 mm. The second reading is taken from the thimble and it accounts for the last portion of the 0.00 to 0.50 mm increment. The third and final reading is taken from the horizontal lines that match up on the sleeve and this accounts for the 0.000 to 0.009 portion of the measurement.







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EXPERIMENTAL:

During this laboratory your lab group will be given a vernier caliper and a micrometer and a variety of objects for measurement.

UNCERTAINTIES:

The following contains some background theory on uncertainties in experimental data and in properties derived from them.

Uncertainties in experimental data and in properties derived from them

A simple approach

The problem

Hey, Boss! I think the strength of the steel bar is 330.4529MPa, but I may be out by 46.9606Mpa!
Thanks, that's a pretty accurate measurement, I like all those figures!

Suppose you are required to provide a client or boss with the value of some materials property that you have measured, such as the elastic modulus, the yield strength, electrical resistivity, or thermal conductivity. Can you be reasonably sure that the value you quote is within 10%, say of the true value, or is it likely that the error is greater, or less?

How would you know how big the error could be? Actually, it might be better to refer to *uncertainty* rather than error, because, hopefully, we are not usually dealing with mistakes that the word "error" might imply. However, the term "error" is commonly used.

The uncertainty in a measurement.

Winning the Lotto is random, what is getting up in the morning? **(Psst - probably a biased action - always late by the same amount!)**

An error can be *random or non-random.* A random error will vary in size and sign each time you repeat the measurement. Where random errors are involved, you may have good reason, before you even make any measurement, to place outer limits on the range of uncertainty you are dealing with, but within such limits the measurements will be randomly distributed about a mean. For instance, in a length measurement which appears to be 1.000m when measured with a cloth tape, you may be quite reasonably sure the true length is between 0.970m and 1.030 m taking into account even the worst quality possible in the tape. However, each time you use that tape to measure the same dimension, you get a slightly different value, say 1.001, 1.002, 0.999, 0.998, and 1.001 in a random order. You have no way of knowing with any one such measurement how far it is from the mean value of such a series, until you have enough measurements from which to calculate the mean with some accuracy. Obviously you cannot know what the mean value will be until you have taken enough measurements from which to calculate the mean. Even the calculation of a mean involves some uncertainty, and becomes more precise the more values you have to calculate the mean from. The spread in the individual measurement values about the mean will be due to some random effect. That spread is an indication of the *precision* of the measurement. The difference between the average value and the true value is known as the *bias,* which is likely to be non-random and fixed in one direction, about the same each time you repeat a series of measurements.

It usually requires quite a number of repeated readings to determine the magnitude of a random error, using a statistical measure for that such as the standard deviation. The number of readings needed to determine a bias depends on how big the bias is in relation to the scatter of repeated readings, i.e. on how big the bias is compared with the precision, and on how precisely you want to know the bias. You may be able to get useful estimate of bias from just one measurement, if the bias is large enough.

Not including mistakes, the error in a particular measurement could be due to several causes including the following.

If the digital display on the bathroom scale says I'm 356.96 lb that must be right!

Calibration error in the instrument used. In any particular instrument the error could be an *offset* in one direction, a bias, resulting in a correction you can either add or subtract from a measurement if you know what the offset is. A voltmeter might read 5.00 volts when the actual voltage is 4.98 volts, say. You might not know this unless you can check the voltmeter using a standard source of potential or a voltmeter you can put more trust in. It is often useful to make the same measurement with several instruments and compare the readings. The range of values you obtain can be taken as an indication of the possible calibration error. This applies to any instrument: ruler, thermometer, voltmeter, etc. Manufacturers often state the possible calibration error on the instrument, perhaps as a percentage of the range plus a fixed value. This is a guarantee that for all the instruments of this kind that they produce, the difference between the true value and what the instrument reads will be *within the range* given by this specification. An individual instrument may be more accurate than this specification, and the offset involved may be quite stable, but no instrument should have an offset greater than the specification.

Manufacturers often aim at ensuring that the calibration error is no more than the smallest scale division, or the lowest digit displayed. For instance a digital display of 4.98 volts should have a calibration error of no more than 0.01 V.

As noted, this kind of error or uncertainty is *usually not random*. You may be able to determine what the offset is by checking the instrument against one you trust more, or against a standard. If you know the offset you can correct your readings for the offset, so you have much less error due to this cause. If at all possible, you should calibrate an instrument to determine the offset. Many instruments can be adjusted to reduce an offset.

When you determine an offset, and adjust an instrument an instrument to reduce an offset, that measurement, or adjustment, can only be done do a certain degree of accuracy, i.e. within a certain uncertainty subject to some random effects, including your skill, the same as any measurement. Furthermore, the offset may change with time, introducing more uncertainty. This kind of uncertainty in the offset error is similar to the uncertainties discussed below in cause and effect.

The resolution of the instrument scale. The scale on the instrument imposes a limit to the resolution of a measurement. If the scale is analogue, such as a metre stick or an older voltmeter, there is limit to the number of significant figures you can read. You will be able to read to the smallest divisions used on the scale, and often estimate to some fraction of that smallest division, such as a fraction of a millimetre, perhaps as little as two-tenths of a millimetre on a ruler. On a digital display you can obviously read all the digits shown, i.e. the resolution is one unit at the smallest digit place. While it is tempting to assume that the instrument has been made to some accuracy better than the smallest division or digit displayed, it is nevertheless worth checking the calibration of any instrument, including ones with digital displays.

The value being measured changes while you measure, as a fluctuation up and down or a drift in one direction. In this case you should watch the reading for some time and estimate the range of the fluctuation or drift in the time it takes you to make the reading from the moment of concern. One partial remedy for this is to ensure that readings are taken at a fixed time interval, which is the same for all measurements, biasing them all by the same amount.

NOW WHICH END OF THE THERMOMETER SHOULD I PUT IN THE TEST TUBE?

The reading may depend on the way you hold the instrument or look at its scale. This effect can mean that you get different readings each time you repeat the measurement. Different people may also get different readings on the same parameter. This could be a random error, especially if several people take the readings at different times.

USE COMMON SENSE !!!!!

What's common sense?

A discussion of all the different reasons for some errors in a measurement can be quite lengthy and quite complicated. It all boils down to being aware that a measurement may not be as accurate as it may seem. You should, whenever possible, repeat a reading several times, and you should always be cautious about the accuracy of the instrument, the stability of the object or parameter, and your skill in carrying out the measurement.

With each measurement try to decide just how big the error might be, using your common sense, ***even if you only make one measurement***.

Is it likely to be 1 degree, 1 mm, 1mV, or whatever, or is it likely to be a percentage of the reading, i.e. a bigger absolute value for a bigger reading, such as 0.5 mm in a reading of 20 mm, but 2 mm in a reading of 100 mm?

Make your judgement on the basis of the care with which the instrument appears to have been made, the smallest digit shown on its display or marked on its scale, any likelihood that it may be out of adjustment.

The error in a calculated value.

Once you calculate a parameter derived from several different measured parameters, the derived value is affected by errors in all the measurements.

For instance if you calculate the volume of a cylinder the errors in measuring the length and the diameter combine to produce an error in the calculated volume. Say you measure both diameter and length with a possible error of 1mm. The diameter is measured to be 10mm and length 100mm. That means that the diameter error could be 10%, the length error could be 1%.
Since volume= diameter ^{2} x π x length / 4 = diameter x diameter x π x length / 4, this means that 10% error in diameter could affect the volume twice, while the length error of 1% only affects volume once.

An error in any one parameter will affect a value calculated from it by the same percentage. Thus a 1% error in length will affect the volume by 1%. However, a 10% error in the diameter would affect the volume twice, i.e. by 2x10%, or 20%! So in judging the effect of individual errors we must pay more attention to those in which the error has the biggest effect as a percentage.

Not all uncertainties should be treated as percentages. For instance, it makes no sense to express a 1deg uncertainty in a temperature measurement of 20°C, as a 5% uncertainty. The zero on some temperature scales is a matter of convenience and convention and really an arbitrary choice. The same temperature uncertainty converted to the Fahrenheit scale would be a much smaller percentage value of the Fahrenheit temperature because the zero on that scale would be at a lower real temperature. However, if you are dealing with a temperature *difference* between two temperature readings, you may be interested in the expressing the uncertainty in the difference as a percentage of that difference.

The cumulative effect of separate errors is often referred to as the "propagation of errors", and quite complex rules and formulae have been developed to deal with it. In the materials course laboratory, as in many other course laboratories, it is hardly worth going to this length. Many of the rules you may learn in a science course on the treatment of errors only really apply in situations where readings have been repeated many times so that it is possible to get good statistical measures of the random effects involved. Also, our aim here is not to teach you more formulae to memorize, but rather to help you become more critical of measurements you or others make, and acquire a realistic sense of the accuracy and inaccuracy of such measurements and parameters calculated from them.

In this course laboratory it is far more important that you try to *understand* the causes of uncertainty and get a feel for the effects of uncertainty and learn to accept that real measurements are often much less certain than you might have thought.

In your future work this could be a very valuable practical insight. You should also understand better the need in many situations to be sceptical of any one measurement, the need to check any measurement carefully, and the need to repeat measurements several times. In this course we expect you to

Look at all the parameters used in a calculation.
Estimate just how big the uncertainty is in each case.
Convert that uncertainty into a percentage of the measurement, *where it is appropriate.*
See whether it enters into the calculation as a square, cube, or other power, and estimate accordingly how it might affect the calculated value.
Pick the measurements that affect the result the most and add their contributions to get the possible total percentage error.

Remember that it is better to err on the safe side. It is safer to assume a larger error than a smaller one.

Significant figures

As a general rule the final result should only have as many significant figures as the parameter with the smallest number of significant figures used in calculating the result. This follows from the rules on uncertainty. However, if, for instance, the initial parameter used with the smallest number of significant figures is 0.76, and the result of the calculation is 0.00012528 it would be appropriate to quote the result as 0.000125, as to quote it as 0.00013 would provide much more uncertainty in relation to the result (1 out of 13) than the uncertainty in the value 0.76 (1 out of 76).

However, you should also consider the total uncertainty of the result in deciding on the number of significant figure to use in the result. If, for instance, the estimate of uncertainties leads you to think that the final result could be uncertain to plus or minus 20%, it would be silly to quote the result as 0.000125. 0.00013 would be better and you should still state that the uncertainty is 20%. If your estimate of uncertainties adds up to, say 19.65% it would also be silly to quote that, the uncertainty, to so many significant figures; just call this 20%. It is unlikely that an estimate of uncertainties can be that precise. In general, uncertainties should not be stated to more than two significant figures; one significant figure may well be enough.

Summary

Consider the uncertainties in each of the parameters used in calculating the final result, and work out the total effect of these uncertainties on the final result. State the magnitude of your estimate of the uncertainty. Be conservative, i.e. cautious. Don't state a result with less uncertainty than you can truly claim. It is better to overestimate the uncertainty than underestimate it.

LABORATORY # 1
VERNIERS AND UNCERTAINTIES

Lab Group Members:
Section/Day: (i.e. 1a/Tues 3a/Wed 5a/Thur)____________________
1.________________________
2.________________________
3.________________________
4.________________________

Vernier Calipers:

1. Washer (i) thickness______________________________
(ii) outer diameter______________________________
(iii) inner diameter______________________________

2. Bolt (i) length______________________________
(ii) head diameter______________________________
(iii) shaft diameter______________________________
(iv) thread pitch______________________________

3. Nut (i) thickness______________________________
(ii) outer diameter______________________________
(iii) inner diameter______________________________

4. Nail (i) length______________________________
(ii) head diameter______________________________
(iii) shaft diameter______________________________

5. Tack (i) length______________________________
(ii) head diameter______________________________

Micrometer:

1. Washer (i) thickness______________________________
(ii) outer diameter______________________________

2. Nut (i) thickness______________________________
(ii) outer diameter______________________________