General Physics Labs I (PHYS-2011)
EXPERIMENT MEAS–2:
Simple Measurements

1 Introduction

This laboratory exercise will be performed over two consecutive weeks. During the first week, students will learn about the techniques used in making measurements in length and mass. During the second week, students will be involved in making measurements in time. There will be only one lab report (worth 20 points) required for this two week lab. This lab report is to be turned in at the beginning of the fourth week's laboratory class.

Today's experiments are designed to provide students with experience in making measurements in length and mass, properly reporting these measurements, and techniques used in analyzing these data. You will use a meter stick, vernier caliper, and micrometer caliper to measure lengths with increasing precision. A laboratory balance will be used to measure mass, and a stop watch and pendulum will be used to measure time.

Every tool or instrument used in making measurements is limited in precision. This limit is typically described in terms of the *least count* of the instrument. This is the size of the smallest division on a scale. The meter stick that will be used today has a least count of 0.1 cm (= 1 mm). Each table of measurements in your lab report must be accompanied by the least count of the instrument used to make the measurement. This provides at least a first estimate of the precision of the measurement. All measurements should be reported to **at least** the precision of the least count.

You should also look carefully at the reading of the measurement instrument when the measurement *should* read zero. If the instrument does not "read zero," this may be a source of *zero error*, which may systematically bias your results. Most of our instruments should have a zero error less than the least count. If this is not true, one needs to properly account for the zero error in recording the results of a measurement. Record the zero error associated with each instrument used to make a measurement and make sure you report this in your lab report.

Each lab station in our *General Physics Lab* will have either two or three students – these students are all **lab partners**. It is a good idea to always have the same group of students as partners for each lab experiment. **Also, all students in a given group are to take turns making measurements for each experiment!** This will help each group identify any inaccuracies in the measurements.

2 Procedure — Week 1

2.1 Length Measurements with a Meter Stick

We will first start off by measuring the length, width, and height of a wooden block using a meter stick. The first thing you should do is to determine the **least count** and record that on your data scrap sheet. With a meter stick, it is usually not obvious if there is a **zero error.** However, one can avoid any possible zero errors by using the '10 cm' mark as to start your length measurements. This way, you can record your zero error (or more accurately, 'zero offset') as +10 cm. Make sure that you make note why you are starting your length measurements at 10.0 cm.

Use the stick to measure the large wooden block or one of the 4 white cardboard boxes located near the front of the room. If you use the large wooden box with the small hook and extruding pegs, ignore the hook and small pegs while making your measurements. Take at least five (5) measurements of each dimension (*i.e.*, length, width, and height) and record your data in a table. In case the object being measured is not uniform, vary the location of your meter stick for each dimension as you make your measurements. For these measurements, **each student is to make 5 measurements for each dimension!** Record these measurements on your "raw data" sheet(s) and present them in you Lab Report in tabular format along with the appropriate number of significant digits.

2.2 Length Measurements with a Vernier Caliper

The **vernier caliper** (shown below in an image taken from the Sargent-Welch Scientific Company) will be used to measure length. It can provide a high precision length measurement using its inside caliper, outside caliper, or depth gauge. It indicates length on a fixed graduated scale (we will use the "centimeter", not the "inch" scale) which is augmented by the movable vernier scale.

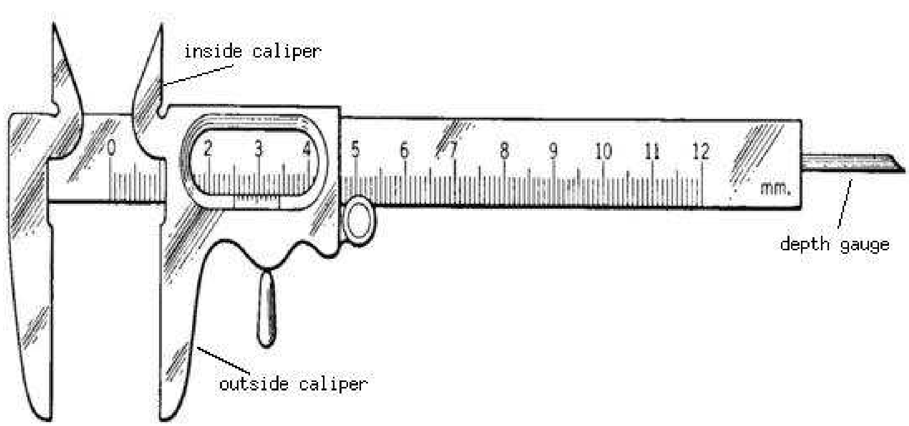

Figure 1: The Vernier Caliper

The vernier scale provides a precise estimate of the nearest tenth of the distance between the smallest divisions on the fixed scale. These smallest divisions are 0.1 cm or 1 mm. The relevant vernier scale is the one below the cm rulings of the fixed scale. The vernier scale has 10 divisions for every 9 divisions on the fixed scale. It works on the following principle illustrated by the figure below.

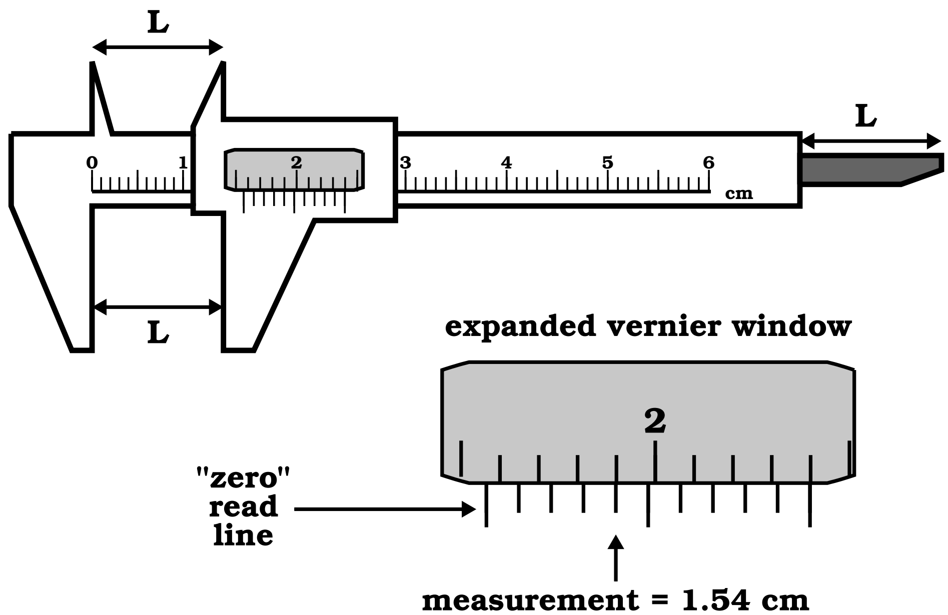

Figure 2: Example on How to Read a Vernier Caliper

In the example figure above, we note that the "zero read line" on the movable component of the caliper is located just past the 1.5 cm marker and just before the 1.6 cm marker on the fixed scale. From this, we know that the length measurement will be somewhere between 1.5 cm and 1.6 cm. Next we examine the fixed scale (upper scale in the "expanded vernier window") and look for where the marker on this fixed scale lines up with the line on the movable component of the of the caliper (the lower scale in the "expanded vernier window"). We see that the alignment takes place with the 4th marker past the zero read line on the movable scale. This means that the length we have measured corresponds to 1.54 cm. From this measurement, we see that a vernier caliper has a precision of 0.01 cm or 0.1 mm.

For the vernier caliper measurements, follow these procedural steps:

- First, determine the zero count and zero error of the vernier caliper. Record your results. Be sure you express the zero error in terms of the least count of the instrument.
- Measure and record the dimensions of the small, rectangular wooden block at your work station. Measure each dimension 5 times at different locations on the block and record your data in table format. Make a labeled sketch of the block to clarify your

measured data. The small block is labeled with a number. Be sure to record this number with your data.

- Now make measurements of all the dimensions of the cylindrical object at your work station. Once again make 5 measurements at different locations for each relevant dimension (*i.e.*, diameter and length) and record your data in table format. Provide a labeled diagram indicating how your measurements were made. Calculation of the volume of the cylindrical object is complicated. More than one diameter and length may be needed. Be sure to carefully label each dimension on your diagram. The cylindrical object is composed of either aluminum (dull silver color) or brass (yellowish color). Record the composition. Also, the cylindrical object is labeled with a number, record this number as well.

2.3 Length Measurements with a Micrometer Caliper

For the vernier caliper, we had a factor of 10 increase in precision compared to the meter stick. We now have another factor of 10 increase in precision when we use a **micrometer caliper** (shown below in an image taken from the Sargent-Welch Scientific Company).

⟵ tightening the screw with this end prevents over tightening

Figure 3: The Micrometer Caliper

The micrometer caliper extends the precision of length measurement by another factor of 10 by using a finely pitched screw and a circular (rotating) scale. There are two different versions of the micrometer caliper used in this course, one with the rotating circular scale in half-millimeter increments, and the other in full-millimeter increments. Figure 3 shows the half-millimeter version and the diagram in Figure 4 displays how to read this type of caliper. The location of the circular scale along the scale of the barrel marks the length to the nearest half-millimeter or millimeter. The reading on the circular scale that intersects the line of the barrel's scale gives the additional length in hundredths of a mm.

For measurements made with the micrometer caliper, follow these steps:

- Examine the micrometer caliper and note the least count (note that Figure 4 will help you figure out this value), and measure the zero error. Record this data on your raw data sheet and make sure to include these data in your Lab Report. Practice reading the scale until you are familiar with its operation. **CAUTION: Do not over-tighten the micrometer screw!**
- Measure the diameter of the steel ball bearing located at your work station 5 times. Record your data in table format and calculate the average of your measurements, expressed in the appropriate number of significant digits.

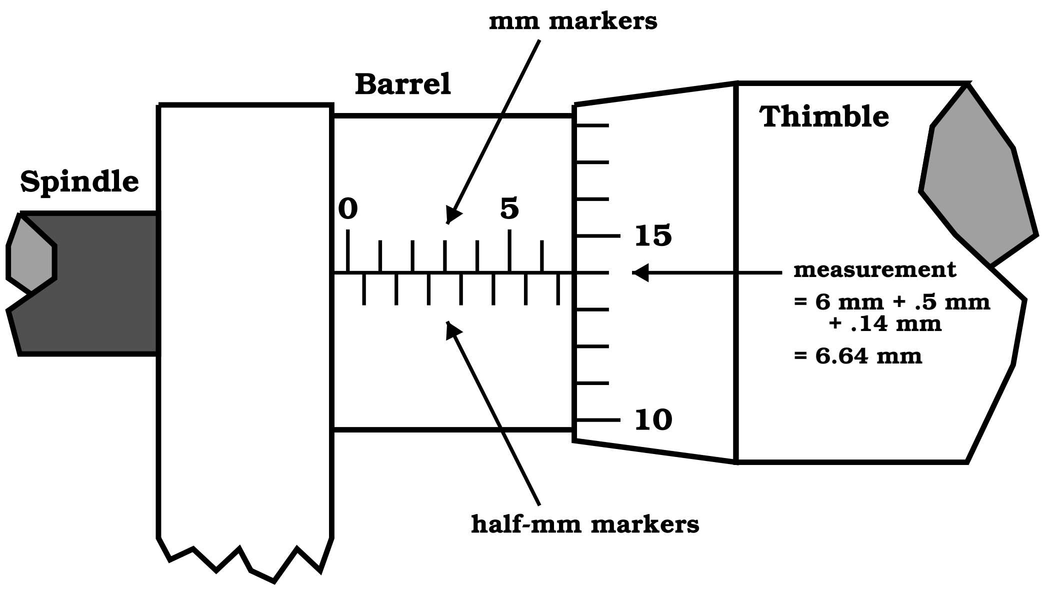

Figure 4: Example of How to Read a Micrometer Caliper

2.4 Mass Measurements with a Beam Balance

The precision beam balance (shown below in an image from PASCO Scientific Instruments) will be used to measure mass. The Ohaus triple-beam mechanical balance (shown in Figure 5) has been a standard weighing instrument in undergraduate physics laboratories for decades. It's accurate, easy to use, and durable. One places the object on the steel plate, then move the balancing mass(es) on the horizontal tracks until the indicator on the right side points to the '0' (zero) mark. Then one takes the sum of the readings on each of the scales to determine the measured mass of the object. Determine the least count and zero error of the balance and record this data.

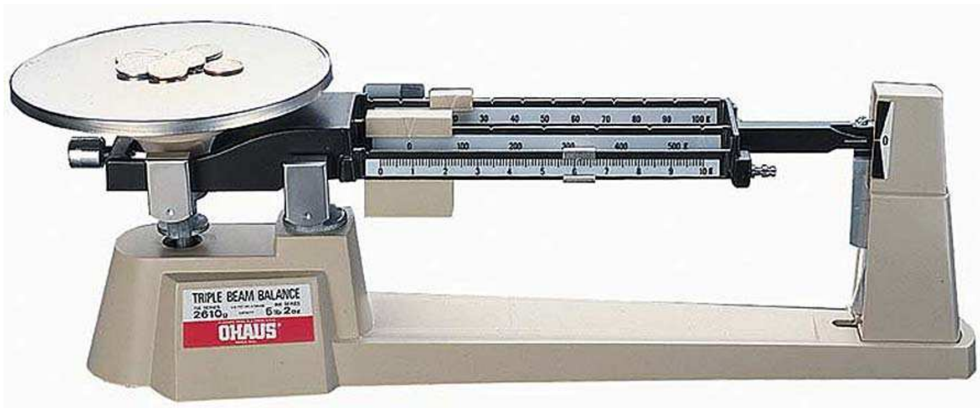

Figure 5: The Ohaus Beam Balance

Measure the masses of the small, rectangular wooden block (5 times) and the cylindrical object (again 5 times). Record your measurements in table format. Then calculate the average mass of the block and the average mass of the cylinder, expressing your results with the appropriate number of significant digits. Can you figure out a way to measure the mass of the steel ball bearing? If not, ask your instructor for help. Measure the mass of the steel ball bearing (5 times) and record the data in table format along with the calculated average expressed in the appropriate number of significant digits.

3 Calculating Density

The final portion of this experiment today is to calculate the densities of the material for each items measured with the vernier and micrometer calipers. The mass density (ρ) is defined as mass (m) per unit volume (V):

$$\rho \equiv \frac{m}{V} \, ,$$

where the '$\equiv$' symbol means *defined to be*. Use the data collected in the previous parts of today's experiments to determine the densities (in gm/cm^3) of the small wooden block (which is made of walnut), the brass (or aluminum) cylindrical object, and the steel ball bearing. Be sure to record your results in terms of the correct number of significant digits. Here are the equations for the volumes of each object:

$$V_{\text{block}} = L \cdot W \cdot H$$
$$V_{\text{ball}} = \frac{4}{3} \pi r^3$$

The volume of the cylindrical object will include combinations of $V_{\text{cyl}} = A \cdot h = \pi r^2 \cdot h$. Remember that you want the volume of the brass or aluminum present.

Compare your results with the accepted values of the densities given in the Table 1. Note that "compare" here means calculate the % error or % difference, *whichever is more appropriate.*

Table 1: Mass Densities of Various Materials

Material	**Density (gm/cm^3)**	**Density (kg/m^3)**
aluminum	2.73	2730
steel	7.80	78$\underline{0}$0
brass	8.74	8740
walnut	0.670	670

This is a two-session experiment. You should complete all of the items in Sections 2 & 3 of this experiment for this week's session, and Section 4 in next week's session.

4 Procedure — Week 2

4.1 Time Measurements with a Pendulum

Consider a pendulum bob of mass m hanging from a support rod at a distance L from the pivot point. If the pendulum bob is moved θ degrees from the equilibrium position (defined by a vertical line pointing towards the ground) and released, the bob will oscillate back and forth about the equilibrium position (see Figure 6a on the next page). Assuming there is no friction between the support rod and the axis on which the rod is connected, this oscillation will continue as a result of the forces acting on the pendulum bob: the tension acting along the support rod and the weight of bob, $w = mg$. These forces add to produce a resulting force that is tangential to the curved "dashed" path in Figure 6a. This tangential force acts to restore the pendulum to its equilibrium position.

The period T of a simple, or ideal, pendulum is defined as *the time required to complete one cycle of the pendulum.* A "complete cycle" is defined by the pendulum bob returning to its starting position. To demonstrate this, consider Figure 6a. The pendulum bob is drawn as a filled-in circle connected to the support rod (*i.e.*, the solid line) at an angle θ from the vertical equilibrium position. If the pendulum bob starts from the extreme right side of the oscillation (*i.e.*, the right end of the dashed curved line), half a cycle occurs when the pendulum moves through the equilibrium position and continues to the extreme left side of the oscillation (*i.e.*, the left end of the dashed curved line). The "full" cycle is complete when the pendulum moves in the opposite direction through the equilibrium position and ends up back to where it started. If the pendulum oscillates at small angles ($\theta < 15°$), then

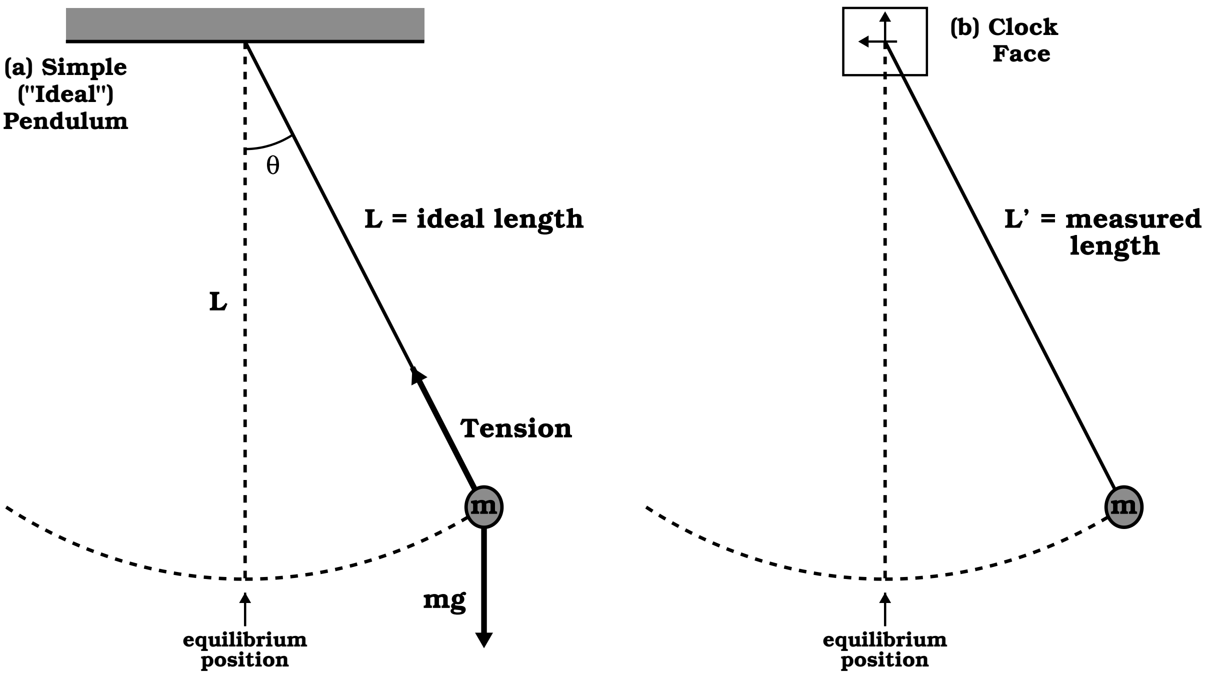

Figure 6: The ideal pendulum and the clock pendulum.

the period of oscillation depends only on the length of the support rod and the gravitational acceleration g.

For this experiment, we will be using a **clock pendulum**, whose motion we approximate as being that of a simple pendulum, located on the front wall in the room as drawn in Figure 6b. Whereas we have a support rod length of L in our ideal pendulum, we will represent the length of our clock pendulum as L'. **The length of the clock pendulum support rod has already been measured by the staff of the Physics and Astronomy Department, and its length is $L' = 82.1$ cm.** Note that this length has 3 significant digits.

4.2 Procedural Steps of Time Measurements

For this experiment, follow these steps. As always, record all of data on your 'raw' data sheet(s) and present this data in a neat and orderly way in your Lab Report.

- Use a stopwatch provided at your work station to measure the total time t_{50} required to complete 50 complete (*i.e.*, 'full') cycles of the clock pendulum, using the extreme **left-side** of the oscillation as your start/stop points (remember that a complete cycle will involve the pendulum bob moving through the equilibrium position twice, once moving towards the right and the second moving towards the left). Have one student in your group handle the stopwatch and the other keep track of the total number of oscillations. Carry out this experiment 3 times, swapping out various members of your lab group so that each member carries out each duty at least once. Then record these 3 measurements in a table and calculate the average of these measurements – this average will be your t_{50} parameter.

- Now calculate the period of the pendulum with

$$T_{50} = t_{50}/50.0 \ ,$$

this assumes you can count the number of complete oscillations to the nearest tenth of a period. Be sure to note the *practical* limitation of precision of the stopwatch, and express t_{50} to the correct number of significant digits.

- Next measure the period of the pendulum with the computer timing system, using an infrared photogate at start and stop the computer timer. Your instructor will demonstrate this measurement and provide you with the resulting value. This too will be carried out 3 times and the resulting average of these measurements will be designated with the parameter T_c.

- The theoretical value of the period of an *ideal* (*i.e.*, simple) pendulum may be calculated as:

$$T_\circ = 2\pi\sqrt{\frac{L}{g}} \ ,$$

where L is the length of the pendulum support rod, in cm, and g is the gravitational acceleration at the Earth's surface. For Johnson City, TN, this acceleration is $98\underline{0}$ cm/s^2 = 9.80 m/s^2. Assume the clock pendulum behaves like an ideal pendulum and calculate its theoretical period $T_\circ$.

- Set up a table to make *appropriate* comparisons of the theoretical value $T_\circ$ with your measured value T_{50} and the computer measured value T_c. Assume T_c is the "accepted" value for the period. Should you use a % difference or a % error for this comparison?

- A pendulum whose characteristics are well known can be used to measure the gravity at different locations. Suppose that the pendulum we have been using ($L = 82.1$ cm) is taken to the surface of the Moon, and its period is measured to be $T_{\rm M} = 4.480$ s. Calculate the acceleration due to the Moon's gravity from this data and compare it to the accepted value of $g_{\rm M} = 162.2$ cm/s^2 = 1.622 m/s^2.