PHYS 1401
General Physics I

EXPERIMENT 1
MEASUREMENT and UNITS

I. OBJECTIVE
 The objective of this experiment is to become familiar with the measurement of
the basic quantities of mechanics and to become familiar with the recording of ex-
perimental data paying special attention to units and significant figures.

II. INTRODUCTION
 The basic concepts of mechanics are **Length, Mass** and **Time**. Every other concept
in mechanics is derivable from these three. The SI units of these concepts are the
meter, m, the **kilogram, kg** and the **second, s**. Definitions of these basic units can
be found in any college physics textbook. You can also find these definitions in the
SI units booklet publised by the National Institute of Standards and Technology
(NIST).
For the purposes of this and future experiments, let us define the **precision** of the
measuring instrument to be **half the size of the smallest division of the instru-
ment.** For the meter stick and the ruler, the smallest division is the millimeter.
Therefore their precision is $0.5\,\text{mm} = 0.05\,\text{cm} = 0.0005\,\text{m}$. Measurements using
either the meter stick or the ruler should be recorded to the nearest tenth of a mil-
limeter. A digital **vernier caliper** has a precision of $0.005\,\text{mm}$. This means that the
vernier caliper gives two extra significant figures over the ruler and the meter stick
and should be used to measure dimensions around $1.0\,\text{cm}$ or smaller.
For a digital instrument, the precision is also half the size of the smallest division.
Most digital instruments have several scales and the precision of each scale is dif-
ferent from the others. If you use the digital scale in the lab to measure the mass of
an object, you will get a reading like $74.5\,\text{g}$. The precision of this scale is $0.05\,\text{g}$.
Significant figures are all the numbers which can be read from an instrument plus
an estimated number (doubtful). Using a ruler or a meter stick the width of this
page is measured and recorded as $W = 0.2165\,\text{m}$. The last digit in this number is
an estimate (doubtful), since it is a fraction (in this case 1/2) of the smallest division
of the scale. The rules for significant figures are the following:

1. The leftmost nonzero digit is the most significant.

2. If no decimal point exists, the rightmost nonzero digit is the least significant.

3. If there is a decimal point, the rightmost digit is the least significant, even if
   it is zero.

4. All digits between least and most significant digits are significant. The fol-
   lowing are examples: the numbers 1834, 18340 and 1000. all have four signif-
   icant figures. The numbers 1000 and 0.0001 have one significant figure. The
   number 1834.0 has five significant figures.

5. A very important principle to remember is that you can NOT improve the precision of your experiment by manipulating numbers in any way. For the purpose of doing calculations:

   (a) When multiplying or dividing several quantities, the number of significant figures in the final answer should not exceed the number of significant figures in the measurement with the least number of significant figures.

   (b) When adding or subtracting, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum. Adding $123 + 5.35$, the answer is 128 and not 128.35. As another example, add the numbers $1.0001 + 0.0003 = 1.0004$. The answer has five significant figures even though one of the terms in the sum, 0.0003, has only one significant figure. Therefore when adding or subtracting, we consider the number of decimal places and not significant figures.

   (c) In intermediate steps of calculations, keep two extra decimal places and then round off properly in the final answer. If you round off to the proper number of significant figures in every calculational step, then it is easy to see how after several steps this could lead to loss of accuracy. Hence, the justification of the above rule.

   (d) The rules for rounding off are simple. First truncate the number to the proper number of significant figures and treat the extra digits as a decimal fraction. Then:

      i. If the fraction is greater than 0.5, round up.
      ii. If the fraction is less than 0.5, round down.
      iii. If the fraction is 0.5, round up only if the least sifnificant figure is odd. This is an esoteric rule whose sole purpose is to avoid a systemic error if one rounds up every time the fraction 0.5.

III. APPARATUS
Ruler, vernier caliper, micrometer, pendulum, stop watch, digital balance.

IV. EXPERIMENTAL PROCEDURE

Procedure (1): Lab Table
If the dimensions of the object being measured are much larger than the precision of the measuring instrument (100 times or more), the instrument is considered very adequate for the measurement and will give fairly "precise" results.

1. Using a meter stick, measure the length and the width of the lab table and record them in meters. This reading should have five significant figures, the last digit being a fraction of a millimeter (which is an estimate). Record your

data in data table (1) in units of meters (m) in column (2), centimeters (cm) in column (3) and millimeters (mm) in column (4). Use scientific notation any time the data or the calculation is larger than 1000.

2. Calculate the area of the table top in m^2, cm^2 and mm^2 and enter it in the data table. Remember the units. When you multiply the numbers, you also must multiply the units.

Procedure (2): Rectangular Block

1. Using a ruler, measure the dimensions of the rectangular block in cm and record your measurement in data table (2), column (3). The precision of the ruler is a half a millimeter (0.5 mm), the same as the meter stick.

2. Convert the dimensions to m in column (2) and mm in column (4).

3. Calculate the surface area of the block $A = 2LW + 2LH + 2WH$ and enter it in your data table in m^2, cm^2 and mm^2. Note: $1\,cm = 0.01\,m = 1 \times 10^{-2}\,m$ and $1\,mm = 0.001\,m = 1 \times 10^{-3}\,m$.

4. Calculate the volume of the block, $V = LWH$, and enter it in your data table. Remember the units!

5. Using a digital scale (or triple beam balance), measure the mass of the block and record it in column (3) in grams (g) and in column (2) in kilograms (kg). $1\,g = 0.001\,kg$.

6. Calculate the density of the block of wood $\rho = M/V$ in (kg/m^3) (column 2) and (g/cm^3) (column (3).

Procedure (3): Cylindrical Block

1. Here we will repeat procedure (2) using a cylindrical block instead of rectangular and using a **vernier caliper** instead of the ruler. The precision of the caliper is 0.005 mm which is 100 times smaller than the precision of the ruler which is 0.5 mm.

2. Using a vernier caliper, measure the diameter and the height of the cylindrical block and record them in (mm) in column (4), in (cm) in column (3) and in (m) in column (2).

3. Calculate the surface area (including the top and the bottom) and the volume of the block. $A = 2(\pi r^2) + 2\pi r H$ and $V = \pi r^2 H$. Remember the units!

4. Measure the mass of the cylindrical block and calculate its density as you did with the rectangular block. Enter the values in the data table.

5. Inspect the measurements and calculations of the last two procedures and make a comment on the improved precision in the latter procedure.

Precedure (4): Time Measurement

1. In this procedure, we will measure the period of a pendulum. The period of a pendulum is the time it takes the pendulum bob to swing back and forth once returning to its starting point. If the period of the pendulum is around one second, then we need to use a clock which has a precision which is much less than 1 s.

2. Make a pendulum where the length of the string is about 1 m. Pull the bob to the side until the angle with the vertical is 20°. Using a digital stop watch, measure the time it takes the pendulum to make 10 oscillations and record this time in data table (4).

3. Calculate the period of the pendulum, T. Remember the units.

4. It should be noted here that a source of error in this procedure is the reaction time of the person handling the stop watch. This is the time difference between the actual release of the pendulum bob and the start of the stop watch. Also at the end of the measurement, generally there will be a difference between the end of the last oscillation and the stopping of the stop watch. Based on this observation, do you think it is wise to measure the time for just one oscillation?

5. If your answer to the above questions is "yes", then you should try measuring just one oscillation 10 different times and see how much variation there is among the 10 readings.

V. ANALYSIS

1. Do all the calculations required to fill in the data tables. Make sure you round off your answers to the proper number of significant figures and give the units of all measured and calculated quantities.

Data Table (1): Lab Table			
Length, L			
Width, W			
Area, A			
Data Table (2): Rectangular Block			
Length, L			
Width, W			
Height, H			
Surface Area, A			
Volume, V			
Mass, M			XXXX
Density, ρ			XXXX
Data Table (3): Cylindrical Block			
Diameter, d			
Radius, $r = d/2$			
Height, H			
Surface Area, A			
Volume, V			
Mass, M			XXXX
Density, ρ			XXXX
Data Table (4): Pendulum			
Time for 10 oscillations, t =			
Period, T =			