Experiment 1
The Metric System and Measurement Tools

Preparation
Prepare for this week's quiz by reading about the metric system in your textbook. Read the introduction to the manual and the first experiment carefully.

Principles
Making measurements is the basis for all science experiments. But measurements only have meaning under certain circumstances. First, everyone has to agree on a system of units. Second, these units have to be standardized and tools have to be calibrated. Third, everyone has to use measuring tools correctly.
In all of the physics experiments you will make measurements using the metric system. This is standard for all science. The metric system is not any more accurate than the English system but since it is based on powers of ten it is much more convenient to manipulate mathematically. It is also used for common measurements in the everyday world in all nations of the planet except the United States and Libya. In this country more and more products are labeled in both English and metric units and eventually the United States will convert to the metric system. Each of you will need to learn the basic units of the metric system.

Units
Every measurement that you make and many values that you calculate will have associated units. A number without its unit is essentially meaningless, and for our purposes, will be wrong. Almost everything you measure this semester will end up with units depending on three basic quantities, length, mass, and time. In the SI system the basic units are the meter, the kilogram, and the second. This used to be called the mks system. In the Gaussian or cgs system the basic units are the centimeter, the gram, and the second.

These basic units are not always the most convenient to use. The kilogram is too large a unit to use for the size of a vitamin C tablet; the meter is too small to use for the distance from here to New Jersey. The SI units can be modified by adding standard prefixes which give the powers of ten by which the unit is multiplied. Some common prefixes, their powers of ten and symbols are:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Power</th>
<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>nano</td>
<td>$10^{-9}$</td>
<td>n</td>
</tr>
<tr>
<td>micro</td>
<td>$10^{-6}$</td>
<td>µ</td>
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<td>milli</td>
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<td>centi</td>
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<td>c</td>
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<tr>
<td>kilo</td>
<td>$10^{3}$</td>
<td>k</td>
</tr>
<tr>
<td>mega</td>
<td>$10^{6}$</td>
<td>M</td>
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Many people just starting in physics have problems in their lab work because they don't have a clear idea of the size of various metric units. If your ruler told you the lab table was four inches across you
would immediately suspect a problem because you know about how big an inch is. Everyone can estimate weight in pounds, but most people raised in American can't estimate mass in kilograms. It is therefore important that you get a sense of various metric measurements so that you can tell if your measurements are reasonable or not.

In this week's experiment you are going to use two tools to measure length, the meter stick and the Vernier caliper.

**The Meter Stick**
The meter stick is one meter (m) long and is divided into one hundred centimeters (cm). Each centimeter is in turn divided into ten millimeters (mm). Therefore you can precisely measure an
object to the nearest millimeter. It is also possible to estimate tenths of millimeters fairly accurately. The meter stick is said to be precise to the nearest millimeter.

It is a good idea to start measuring from the 1 cm or the 10 cm mark on a meter stick since the ends of the sticks tend to become worn and inaccurate. Also, whenever it is possible, place the object to be measured on the meter stick and look straight down at it. This reduces errors induced by parallax, which is the apparent shift of one object compared to another caused by their different distances from the observer.

The Vernier Caliper
The Vernier calipers in the physics labs can be used to precisely measure length to the tenth of a millimeter. If you look at a caliper you will see that it is just like a meter stick, but with a movable scale attached. This sliding scale has eleven lines etched on it, and the distance between the first and the last is exactly 0.9 cm (or 9 mm). The lines represent values from 0 to 10. When the jaws of the caliper are closed the zero on the sliding scale will line up with the zero on the fixed scale. When the jaws are spread the distance between the zero marks will be the same as the distance between the jaws.

To use the caliper first clamp it around the object to be measured. Then look at the zero line on the sliding scale and see where it crosses the fixed scale. Read the first two numbers (cm and mm) from the fixed scale just as you would from a meter stick. To find the last digit, tenths of a millimeter, look at the lines on the sliding scale. One of the lines will line up exactly (or nearly so) with one of the lines on the fixed scale. The lines on the sliding scale are numbered from zero, and the number of the line on the sliding scale that lines up with a line on the fixed scale is the value of the final digit of your measurement (see the diagram). Learning to use a caliper takes practice; your lab instructor will help you if you have trouble.

Accuracy, Precision and Tolerance
The smallest difference that you can detect with a measuring tool is called its precision. A meter stick is precise to the nearest millimeter, the caliper we use in our labs is precise to the nearest tenth of a millimeter. The precision of your instrument determines how many significant digits your record in your data.

The instructions for the experiments you do this semester usually specify the precision of your measurements by telling you the smallest unit to measure. This does not mean that those are the units to use when you record the data. For example, the instructions might tell you to measure to the nearest millimeter. This does not mean that you should record your lengths in millimeters. Read the directions and use common sense to decide what unit to use. If you have doubts, ask your instructor.

The calibration of the tool and the skill and care of the person using it determine its accuracy. For example, if your triple beam balance is out of calibration you may measure something to the tenth of a gram, but the measurement would not be accurate. If you don't position the Vernier calipers correctly, or misread the scale your answer will be precise to the tenth of a millimeter, but the answer will not be accurate.

All things don't need to be measured to the same precision. For example, you would want to know the distance to the next town on the road to within a few kilometers. If you buy a pair of shoes, you want
the length to be right for your feet to within half a centimeter or so. The surface of a reflecting
telescope, like the Hubble telescope should be smooth to within half a wavelength of visible light,
about .00025 millimeter.

When you buy a box of breakfast cereal, its mass will be about 250 grams plus or minus some
amount, probably about half a gram. It is not necessary for the measurement to be any closer than
that, though the government specifies that the average mass of a large group of cereal boxes must
come close to the stated value. This uncertainty is called the tolerance of a measurement. The
tolerances for different measurements depend on the size and importance of the measurement as well
as the use for whatever is being measured. Few people would notice if one of your shoelaces was
three centimeters longer than the other, but they would probably notice if one leg of your jeans was
that much longer than the other.

When you make a measurement you can use your common sense to decide how precise it should be.

Errors
An error that only affects one piece of data is called a random error. A one time mistake in reading
the measurement tool or transposing two numbers as you record the data are examples of random
errors. A mistake that affects all the data is called a systematic error. Using a device that is out of
calibration or consistently misreading the scale are causes of systematic errors.

Linear relationships - Straight line graphs
In experiments we investigate how two or more quantities are related to each other. If two quantities
are linearly dependent on each other, then the relationship between the two is linear and can be
represented by a straight line. Since it is familiar to us, let’s consider two variables, \(x\) and \(y\), that are
linearly related. Where \(x\) is the independent variable and \(y\) is the dependent variable. The equation
representing the relationship is written as

\[
y = mx + b
\]

where the slope is \(m\) and the intercept is \(b\). Notice that if we have a linear relationship, then \(\Delta y/\Delta x = m\), the slope of the line. If we measure data for \(x\) and \(y\), and then plot \(y\) versus \(x\), we should see a
linear trend for the data. If \(x\) and \(y\) are normally distributed random variables, then we can use a
statistical procedure to calculate the slope and the intercept of the equation. The relevant statistical
procedure is called the Least Squares Method (LSM). The LSM provides ways to calculate both the
value and its error or uncertainty for slope and uncertainty.

Say that we have data for \(x\) and \(y\) such as \((x_i, y_i)\), where \(i\) goes from \(1\) to \(n\). If the average of \(x\) is
\(\bar{x}\) and the average of \(y\) is \(\bar{y}\) then according to the least square method,

\[
m = \frac{\sum^n_i (x_i - \bar{x})(y_i - \bar{y})}{\sum^n_i (x_i - \bar{x})^2} \quad \quad \quad b = \bar{y} - m\bar{x}
\]

Thus we have a great way to calculate the slope and intercept for a data set which has a linear
relationship. In practice we do not make this calculation by hand. We simply ask Excel software to
calculate them for us and make the best fit line for the available data.
The following experiment will help you learn about making measurements and doing a best fit line with Excel. We will use this procedure as required in the future and you are expected to be familiar with it.

**Today’s Experiment**
Consider the relationship between the circumference and diameter of a circle. You know it is $C = \pi D$. If you measured the diameters and circumferences of some different size circles and plotted your measurements on a graph, what kind of line would you get? What would the slope and the intercept of the line be? What units would the slope and intercept have? Today you will find out.

**Equipment**
meter stick
Vernier calipers
5 plastic disks with different diameters

The meter sticks are always available in the lab room. Everything else should be on carts in the front of the room.

**Procedure**
1. Use the Vernier caliper to measure the diameter of each disk to the nearest tenth of a millimeter. Wrap strip of paper around each disk and mark the diameter. Use the meter stick to measure the diameter to the nearest millimeter.

2. The least value that the meter stick can be used to record is 1 mm. So you should read all readings to the closest millimeter based on your judgment. Record your data in the table on the answer sheet. Then transfer the data to a table prepared in Excel.

3. Record your data in units of centimeters.

**Analysis - Finding Slope and Intercept**
1. Now draw the best fit line for the data set. In the past you may have plotted the data on graph paper and drawn the best fit line by hand. Instead we are going to use Excel to do this job for us. Using Excel software make a scatter plot of Circumference vs. Diameter. You may want to refer to the Excel instructions video for guidance on making a scatter plot using Excel or seek help from your TA. Video is found at [http://www.physics.gsu.edu/doluweera/excl-2/excl-2.html](http://www.physics.gsu.edu/doluweera/excl-2/excl-2.html). Label the axes and give your graph a title.

2. Look at the data plot to see if your data shows a linear trend. If not, recheck your data and check to see if your data matches what the points in your plot.
3. The next step will be creating the best fit line. Use the “add trend line” feature to add a linear trend line to your data. In Excel, the best fit line is calculated using the LSM. Obtain the equation of the graph write the equation on your answer sheet.

4. Copy your data chart and graph into a Word document. Put the names of all the group members at the top and print a copy for each member of the group.