

APPENDIX A - MEASUREMENT AND UNCERTAINTY:

General Information

Experimental Error

Error Analysis

Uncertainty and Propagation of Error

APPENDIX B - COMPUTERS AND SOFTWARE:

iMac & Logger Pro

Graphing

Graphical Analysis

APPENDIX C - EQUIPMENT:

Vernier Caliper

Dial-O-Gram Balance

Digital Multi-Meter (DMM)

APPENDIX D – MATH REVIEW:

Algebra

Trigonometry

Take-Home Math Exam (Phys 223)

Take-Home Math Exam (Phys 224)

APPENDIX A - MEASUREMENT AND UNCERTAINTY

General Information

Experimental Error

Error Analysis

Uncertainty and Propagation of Error

APPENDIX A: MEASUREMENT AND UNCERTAINTY

GENERAL INFORMATION

Every measurement has some uncertainty. These uncertainties are called errors. “Error analysis is the study and evaluation of uncertainty in measurement.”¹ Measurements are usually made against some standard to compare the object or quantity being measured with some known value. For instance, if the length of a table is measured with a meter stick, the table is being compared to the meter stick, but the meter stick is also referenced to some standard. It is important to keep in mind that any “known” value given as a standard has an uncertainty associated with it. Any measurement you make has an uncertainty associated with it as well.

Error analysis is an interesting and complex subject. As an introduction to this topic, certain experiments will focus on particular types of analysis: statistical analysis, uncertainty of measurements, and propagation of error (propagation of uncertainty). The details follow.

Significant Figures

There are rules for significant figures (lab manual: *Experiment 1* and *Giancoli*: Chapter 1, Section 4). All data should be recorded with the proper number of significant figures in your lab notebook as well as in your lab reports. To prevent rounding errors, keep one more significant figure than is justified until you are finished with your calculations.

Accuracy and Precision

An important consideration in research (laboratory) is the **accuracy** and the **precision** of a measurement. Commonly, these two terms are used as synonyms, but they are quite different. The accuracy of a measurement is how close the measurement is to some “known” value (how small the percent error is; related to systematic and personal error). For instance, if an experiment is performed to measure the speed of light, and the experimental value is very close to the known (accepted) value, then it can be said that the value is accurate. On the other hand, the precision of an experiment is a measure of the reproducibility of an experiment (related to random error).

When performing an experiment, one needs to keep in mind that a measurement that is precise is not necessarily accurate and vice versa. For example, a vernier caliper is a precision instrument used to measure length (the resolution is 0.005 cm). However, if a damaged caliper is used that reads 0.25 cm too short, then all of the measurements would be incorrect. The values may be precise, but they would not be accurate.

¹ Taylor, John R., “An Introduction to Error Analysis”, University Science Books, Mill Valley, CA, 1982.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

EXPERIMENTAL ERRORS

Experimental errors are generally classified into three types: systematic, personal, and random. Systematic errors and personal errors are seldom valid sources of uncertainty when performing an experiment as simple steps can be taken to reduce or prevent them. You will need to discuss “sources of uncertainty” for each experiment when you write a full lab report. Assume you performed the experiment correctly using calibrated equipment. Useful questions to ask yourself for this section of the report are *what is “wrong” with the method* (errors inherent in the method) and *what assumptions are made that are not valid?*

The specifics follow for types of experimental errors.

Systematic Error

Systematic errors are such that measurements are pushed in one direction. Examples include a clock that runs slow, debris in a caliper (increases measurements), or a ruler with a rounded end that goes unnoticed (decreases measurements). To reduce this type of error, all equipment should be inspected and calibrated before use.

Personal Error

Carelessness, personal bias, and technique are sources of personal error. Care should be taken when entering values in your calculator and during each step of the procedure. Personal bias might include an assumption that the first measurement taken is the “right” one. Attention to detail and procedure will reduce errors due to technique.

Parallax, the apparent change in position of a distant object due to the position of an observer, could introduce personal error. To see a marked example of parallax, close your right eye and hold a finger several inches from your face. Align your finger with a distant object. Now close your left eye and open your right eye. Notice that your finger appears to have jumped to a different position. To prevent errors due to parallax, always take readings from an eye-level, head-on perspective.

Random Error

Random errors are unpredictable and unknown variations in experimental data. Given the randomness of the errors, we assume that if enough measurements are made, the low values will cancel the high values. Although statistical analysis requires a large number of values, for our purposes we will make a minimum of six measurements for those experiments that focus on random error.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

COMPARISON of EXPERIMENTAL VALUES

Percent Error and Percent Difference

We frequently compare experimental values with accepted values (*percent error*) and experimental values with other experimental values (*percent difference*).

Accepted values might be found in tables, determined experimentally (e.g., $g = 9.80 \text{ m/s}^2$, $c = 3.0 \times 10^8 \text{ m/s}$), or calculated from equations that assume ideal conditions.

Experimental Values: We often use more than one method to determine a particular quantity in lab, then compare the values, or compare a particular value with the class average.

When comparing values, use the following equations:

$$\% \text{ error} = \frac{|\text{accepted} - \text{experimental}|}{\text{accepted}} \times 100 \qquad \text{Eq. A-1.}$$

$$\% \text{ difference} = \frac{|\text{value}_1 - \text{value}_2|}{\frac{\text{value}_1 + \text{value}_2}{2}} \times 100 = \frac{|\text{value}_1 - \text{value}_2|}{\text{value}_{\text{avg}}} \times 100 \qquad \text{Eq. A-2.}$$

These values are rounded to one or two significant figures, determined by the following:

- Keep only one significant figure unless the value begins with the number one.
- Keep two significant figures if the value begins with the number one.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

ERROR ANALYSIS

Random Error

When analyzing random error, we will make a minimum of six measurements (N=6). From these measurements, we calculate an average value (mean value):

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \dots + x_i}{N} = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6}{6} = \frac{1}{N} \sum_{i=1}^N x_i = \frac{1}{6} \sum_{i=1}^6 x_i \quad \text{Eq. A-3.}$$

To determine the uncertainty in this average, we first compute the *deviation*, d_i :

$$d_i = x_i - \bar{x} \quad \text{Eq. A-4.}$$

The average of d_i will equal zero. Therefore, we compute the **standard deviation**, σ (Greek letter, *sigma*). Analysis shows that approximately 68% of the measurements made will fall within one standard deviation, while approximately 95% of the measurements made will fall within two standard deviations.

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (d_i)^2} = \sqrt{\frac{1}{5} \sum_{i=1}^6 (d_i)^2} = \sqrt{\frac{1}{5} \sum_{i=1}^6 (x_i - \bar{x})^2} \quad \text{Eq. A-5}$$

or

$$\sigma = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + (x_4 - \bar{x})^2 + (x_5 - \bar{x})^2 + (x_6 - \bar{x})^2}{5}} \quad \text{Eq. A-6.}$$

Keep two (2) significant figures for standard deviation.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

UNCERTAINTY OF MEASUREMENTS: δ

In this lab the **uncertainty**, δ (Greek letter, *delta*), of a measurement is usually $\frac{1}{2}$ the resolution (smallest division) of the measuring device. The resolution of a 30-cm ruler is one millimeter (0.1 cm), thus δx is

$$\delta x = \pm \frac{1}{2}(0.1\text{cm}) = \pm 0.05\text{cm}.$$

For example, an object is measured to be $x \pm \delta x = (23.25 \pm 0.05)$ cm. The 5 in 23.25 is estimated. The measurement (23.25 ± 0.05) cm, means that the true measurement is most likely between 23.20 cm and 23.30 cm.

Using multiple measurements of the same quantity, δx can be represented by the standard deviation, σ .

The **fractional uncertainty**, $\frac{\delta x}{x}$, is used to compute the **percent uncertainty**, $\delta_{\%}x$, of a measured value:

$$\delta_{\%}x = \pm \frac{\delta x}{x} \times 100 \quad \text{Eq. A-7.}$$

PROPAGATION OF ERROR

Once the uncertainties of measurements are known, they can be propagated in all mathematical manipulations (*i.e.*, equations) that use measured quantities. This allows a reader to know the precision of your work. Methods required for propagating error vary, depending on the equation(s) used. Always begin by writing the algebraic equation for the quantity first. After determining the uncertainty of a calculated value, round off the uncertainty using the rule stated below. The order of magnitude of the uncertainty (*e.g.*, tenths, thousandths) determines where the calculated quantity must be rounded off, thus limiting the number of significant figures in the calculated quantity.

Uncertainty is rounded to one or two significant figures, determined by the following:

- Keep only one significant figure unless the uncertainty begins with the number one.
- Keep two significant figures if the uncertainty begins with the number one.

Added or Subtracted Quantities

When measured values are **added** (*or* subtracted) the uncertainties are **added in quadrature** (*i.e.*, combining two numbers by squaring them, adding the squares, then taking the square root). If there is a constant, multiply the calculated uncertainty by the constant. The uncertainty of a value A, δA , is added in quadrature in Eq. A-8.

$$(x \pm \delta x) + (y \pm \delta y) \Rightarrow A = Bx + y \quad \text{or} \quad (x \pm \delta x) - (y \pm \delta y) \Rightarrow A = Bx - y$$

$$\delta A = \pm B \sqrt{(\delta x)^2 + (\delta y)^2} \quad \text{Eq. A-8.}$$

Express this result as $A \pm \delta A$. Uncertainties are added when measurements are added *or* subtracted.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

Uncertainty Example: Added or Subtracted Quantities

$$x \pm \delta x = (2.40 \pm 0.05)cm \text{ and } y \pm \delta y = (1.35 \pm 0.05)cm.$$

$$A = x + y = 2.40 \text{ cm} + 1.35 \text{ cm} = 3.75 \text{ cm}.$$

$$\delta A = \pm \sqrt{(0.05cm)^2 + (0.05cm)^2} = \pm(\sqrt{2})0.05cm = \pm 0.070710678cm.$$

Rounding appropriately for uncertainty, we know that $\delta A = \pm 0.07 \text{ cm}$. Thus,

$$A \pm \delta A = (3.75 \pm 0.07) \text{ cm}.$$

Note that the measurement and uncertainty are inside the parentheses, the unit is outside the parentheses. *All* measured or calculated values and their uncertainties must be written this way.

If a quantity is calculated (addition or subtraction only) that involves a constant, multiply the uncertainty by the constant. Examples are equations such as the average of multiple measurements, or average reaction time.

Example

$$t_{\text{avg}} = (t_1 + t_2 + t_3)/3 \quad \delta t = \pm 1/3 \times \sqrt{[(\delta t_1)^2 + (\delta t_2)^2 + (\delta t_3)^2]}$$

APPENDIX A: MEASUREMENT AND UNCERTAINTY

Multiplied and Divided Quantities

When measured values are **multiplied** (or divided), use the following rules. The fractional uncertainty of each measurement is squared and summed; the square root of this sum is then multiplied by the calculated quantity. If a measured value is raised to a power, multiply the fractional uncertainty by the exponent prior to squaring. These uncertainty rules may be best explained by use of examples:

Assume a volume V of a block, calculated from measured dimensions x , y , and z :

$$x \pm \delta x, \quad y \pm \delta y, \quad z \pm \delta z$$

$$V = xyz$$

$$\delta V = \pm V \times \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2 + \left(\frac{\delta z}{z}\right)^2} \quad \text{Eq. A-9.}$$

Express this result as $V \pm \delta V$.

δV can be expressed as a percent uncertainty, $\delta\%V$, by using Eq. A-7. Express the result as $V \pm \delta\%V$.

When a measured quantity is raised to a **power**, the uncertainty is determined by

$$V = x^n y \quad \rightarrow \quad \delta V = \pm V \times \sqrt{\left(n \frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2} \quad \text{Eq. A-10.}$$

Note that the exponent (power) is *inside* the parentheses.

A numerical example is provided on the next page, followed by an example involving many of the rules that have been outlined.

Always: First write the equation for the quantity you want to calculate in algebraic terms (no measured values). *Then* write the uncertainty equation algebraically. Every quantity that has uncertainty must be under the radical. If the equation for the quantity involves addition or subtraction, refer to Eq. A-8. If the equation for the quantity involves multiplication or division, refer to Eq. A-9 and Eq. A-10. If the equation has a mixture of addition/subtraction and multiplication/division, it is best to re-write the equation using only multiplication/division; define new terms as needed.

Always write your equations, algebraically, in terms of the quantities involved. For example, if the equation for the volume of a cylinder involves the diameter and height, do not write the equation for $V \pm \delta V$ in terms of x , y , and z .

Every measurement used to calculate a quantity requires that the uncertainty of the measurement be included, under the radical, when calculating the quantities' uncertainty.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

Uncertainty Example: Multiplied or Divided Quantities

An area, A , and its uncertainty, δA , are to be determined from the following measurements:

$$\text{Length} = x \pm \delta x = (2.40 \pm 0.05)\text{cm}; \quad \text{Width} = y \pm \delta y = (1.35 \pm 0.05)\text{cm}.$$

$$\text{Area is length times width: } A = xy = 2.40\text{cm} \times 1.35\text{cm} = 3.24\text{cm}^2.$$

The uncertainty in the area, δA , is given by

$$\begin{aligned} \delta A &= \pm A \times \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2} = \pm 3.24\text{cm}^2 \times \sqrt{\left(\frac{0.05\text{cm}}{2.40\text{cm}}\right)^2 + \left(\frac{0.05\text{cm}}{1.35\text{cm}}\right)^2} \\ &= \pm 0.13768 \text{ cm}^2 \Rightarrow \pm 0.14 \text{ cm}^2. \end{aligned}$$

Express the area and its uncertainty as $A \pm \delta A = (3.24 \pm 0.14)\text{cm}^2$. Please note that the quantity and its uncertainty are inside the parentheses, the unit is outside the parentheses!

$\delta_{\%}A$ can be determined using Eq. A-7. For this example,

$$\delta_{\%}A = \frac{\delta A}{A} \times 100 = \frac{0.14\text{cm}^2}{3.24\text{cm}^2} \times 100 = 4.3\% \Rightarrow 4\%.$$

$A \pm \delta_{\%}A$ is expressed as

$$A \pm \delta_{\%}A = 3.24\text{cm}^2 \pm 4\%$$

Please note that % is a dimensionless quantity; no parentheses are in the above example.

A comprehensive example of propagating error is on the next page. Think through this example.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

Comprehensive Example

In terms of propagating error, one of the most involved experiments we perform is *Experiment 8: Centripetal Force*, during the first semester of General Physics. It is hoped that you will be able to correctly interpret the uncertainty equations for a particular experiment if an explicit example is provided for a slightly complex situation.

For this experiment, the centripetal force (radial force, F_R) is given by

$$F_R = ma_R = m \frac{v^2}{r}$$

where a_R is centripetal acceleration, m is the mass of the object, v is the speed of the object, and r is the radius of the circular path the object travels. The speed of the object is determined by

$$v = \frac{\Delta d}{\Delta t} = \frac{2\pi rn}{t}$$

where d is the distance the object travels, r is the radius of the circular path, n is the number of times the object traveled this circular path, and t is the time elapsed to travel this distance.

For this experiment F_R and δF_R must be determined using measured values.

$$F_R = \frac{4\pi^2 m r n^2}{t^2}$$

This experiment requires that you measure multiple masses, then add those values to determine the total mass as the digital balance has a limit of 200g. Once the uncertainty of the mass, δm , has been determined (Eq. A-8), it can be used in the following equation to determine δF_R .

$$\delta F_R = \pm F_R \times \sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta r}{r}\right)^2 + \left(2\frac{\delta n}{n}\right)^2 + \left(2\frac{\delta t}{t}\right)^2}$$

Note in the example how uncertainty is determined for quantities that are multiplied, divided, or raised to a power. Consider the equation for F_R and the quantities under the radical. Every measured quantity in the equation belongs under the radical.

APPENDIX B - COMPUTERS AND SOFTWARE:

iMac & Logger Pro

Graphing

Graphical Analysis

APPENDIX B - COMPUTERS AND SOFTWARE

APPENDIX B - COMPUTERS AND SOFTWARE

iMac OPERATING INSTRUCTIONS

To TURN ON your computer, push the power button; it's on the left back side, near the bottom.

The *Command* (used for keyboard shortcuts) key is on each side of the space bar.

To *Select* something on a computer means to click on it once with the mouse.

To *Open software*, a file, or a folder, double-click on it with the mouse cursor.

To *Close software*: click on the *Software Title* → Quit [Command + Q]

To *Close a document or folder*: FILE → Close Window [Command + W]

To *Open a new document*: FILE → New [Command + N]

To *Re-size a document*, click and drag the bottom right corner of the window.

To *Collapse* (minimize) a window, click on the software title, select Hide ... [Command + H]

To *Switch* between different programs, move your mouse cursor to the *Dock* (the dock is at the bottom of your computer desktop). Icons for all open software will be displayed. Select the needed software.

To TURN OFF the computer: *Apple icon* (top left of computer desktop) → Shut Down → Shut Down

When you have finished your experiment:

- ALWAYS close all software: *Software Title* → *Quit* → *Don't Save* [Command + Q]
- Note that closing the software window is not sufficient when using an *iMac*.
- Close all folders; shut down the computer.

LOGGER PRO Software

Always be certain that *Lab Pro* is connected before you open *Logger Pro* software. Connect *Lab Pro* to the

- Computer using the USB cable; do not connect it to the keyboard
- Sensor(s) - **motion detector**: DIG/Sonic 2 port; **force sensor**: CH 1, ±50N; **Thermistor**: CH 1;
- Power supply; plug the power supply into an electrical outlet

If you need to confirm the sensor you are using, a window will open automatically. On the right side of the window, specify the "Interface & Channel" being used, then specify the sensor. Click on "Connect."

To open *Logger Pro* software, open the following folders on your computer:

Software → *Logger Pro 3* → *Experiments* → *Physics with Vernier* (*Exp 14: Heat*, open the "Physical Science with Vernier" folder.)

Then open the specified experiment that is needed for the experiment you are performing.

If you print graphs from this software, File → Page Setup: Orientation: Landscape; File → Printing Options: Enter team names as needed.

When finished with the experiment, close the software: *Logger Pro* → *Quit* → *Don't Save*, then close the folders and disconnect all *Lab Pro* equipment. Turn off the computer.

If software or computer problems develop, close the software, then open it again. If problems persist, close the software, restart the computer, then open the software again. If this fails, ask your TA for help.

APPENDIX B - COMPUTERS AND SOFTWARE

GRAPHING

Consider the slope-intercept equation of a line: $y = mx + b$. If $b = 0$, the equation reduces to $y = mx$. When you graph “y vs. x” and produce a linear (straight line) graph, the slope, m , of the graph is the constant of proportionality. The y -axis is the ORDINATE (dependent variable). The x -axis is the ABSCISSA (independent variable).

Consider two proportional quantities, **A** and **B**. Graphing **A** vs. **B** is equivalent to graphing y vs. x . The resulting linear graph has slope m , which represents the constant of proportionality. When investigating linear functions, if $x = 0$ and $y = 0$, then $b = 0$. When this is true, $(0, 0)$ is a relevant and necessary data point. Always determine if the data point $(0, 0)$ is necessary.

A nonlinear graph is a curve(s); it is not a straight line. Note that a curve does not have a single slope, it has a constantly changing slope (an infinite number of slopes). Always determine if $(0,0)$ is necessary.

A properly drawn graph must have the following components:

- Title
- Axes Labels with Units
- Appropriate Scale
- Appropriate Analysis (refer to Fig. B-3)
- Error Bars (not if graphs are produced by hand)
- Mathematical Analysis after the graph is printed
- Team Names and Date

Graphing by Hand

When plotting your data, you will need to determine the scale based on the range of values. Always choose easily divisible increments for the major divisions (*e.g.*, 2, 5, 25). Your plot should fill most of the graph (refer to Fig. B-1 and Fig. B-2). The same data is plotted on both graphs; only the scales have changed.

Use a *best fit* connecting line when analyzing your graph; do not “connect-the-dots.” A *best fit* line will have about as many data points above the curve as below. If the plot is linear, a ruler should be used.

For example, assume you are graphing *distance vs. time*. If your distance values range from 0 m to 40 m, your y -axis should span 0 to 40 meters, perhaps up to 50 m. If your time values range from 0 to 80 seconds, your x -axis should span from 0 to at least 80 s. Refer to Fig. B-1.

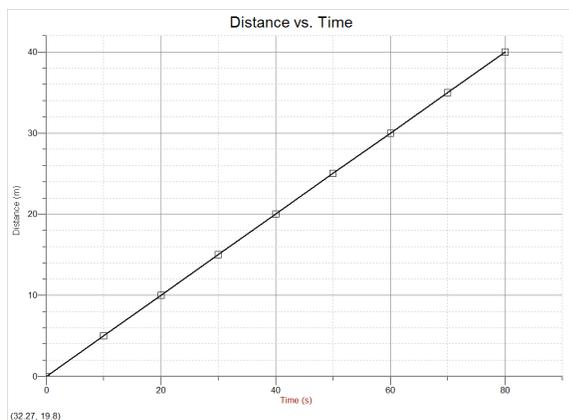


Fig. B-1



Fig. B-2

APPENDIX B - COMPUTERS AND SOFTWARE

Graphing with *Graphical Analysis*

Graphs for physics lab require *Graphical Analysis* software. The software is available at no charge for physics students to install on their home computer. The required *username* is physics. The *password* is physicslabs. Download and install the software on your home computer. To obtain the software, go to the link on your Lab Physicist's Web site or

<http://www.phy.olemiss.edu/Courses/Software/>

If you do not have your own computer, you may need to use public computers; you might need to "Run" the software from the Web site rather than "Download" the software. Weir Hall, Honors College, and UM Library have the software installed for your use on the student computers. Be certain you can print from the computer you are using! Printing is not available for students in the Department of Physics and Astronomy.

Analysis of Graphs

To analyze your graph, fit your data to a *general equation*, and match up the parts to a *known function*. A general equation has the main elements of a particular type of function (equation). The variables used in a general equation can represent many quantities, thus the name. The known function is easy to determine: *What is the equation for the concept or theory you are investigating?* To match up the parts of the two equations, write one below the other, and connect the corresponding parts with a line (match up the parts). To determine the type of general equation you need, consider the following questions:

Is one variable squared? If yes → it is a quadratic equation.

Are there trigonometric functions in the equation? If yes → it is a sinusoidal equation (or tangential, or ...).

Is there an exponential (*i.e.*, the number "e", not an exponent) in the equation? If yes → it is an exponential equation.

If none of the above... is this equation linear? If yes → use the slope-intercept equation of a line: $y = mx + b$.

General Equation ↔ Known Function Examples

Consider the equation for the circumference of a circle, $C = \pi D$. Plot "C vs. D" ("C" on the y-axis, "D" on the x-axis).

$$C = \pi D$$

$$y = m x + b$$

If $b = 0$, the slope m equals *everything else in the equation*, in this case, the number π .

Consider an equation for exponential decay: $N(t) = N_0 e^{-\lambda t}$. "N" is the number of particles as time progresses; N_0 is the initial number of particles. $e^{-\lambda t}$ can also be written "exp(- λt)". Plot "N vs. t", and analyze the graph:

$$N(t) = N_0 e^{-\lambda t}$$

We want to know λ (lambda), a coefficient that represents the rate of decay.

$$f(x) = A e^{-Cx} + B$$

$B = 0$. The "Information Box" will provide a value for the coefficient "C", which is equal to λ .

Most of the graphs we analyze are linear. When nonlinear graphs are analyzed, follow the same process: Match up parts of the two equations (general equation and known function).

Graphical Analysis has many built-in general equations but not all. You may need to enter (type) the general equation if it is not available; the general equation will be given by the TA or in the procedure if needed.

APPENDIX B - COMPUTERS AND SOFTWARE

Graphical Analysis Instructions

The Data

Data → (Take care of data details before graph details.)

Data Set Options →

Name the data set; keep it short.

Column Options →

Select each data column, and fill in the relevant information. Note that often tabs are available that open additional windows. The style of the point protector must always be “Empty” rather than “Filled.” When uncertainties need to be entered, refer to “Error Bar Calculations.”

Enter The Data →

When entering data that have multipliers: e.g., $3.1\text{ cm} = 3.1 \times 10^{-2}\text{ m} = 3.1\text{E-}2\text{ m}$, type: “3.1 e - 2”.

When entering angle measurements in degrees, Select File → Settings for Untitled → Change the unit to degrees.

If you have multiple sets of data, Select Data → New Data Set

The software will calculate a new data set for you: Data → New Calculated Column → Enter the necessary information.

The Graph

Options → (Click once on the graph to make it the active field.)

Graph Options →

Fill in the relevant information. Except for *Experiment 18: Ohm's Law*, never select “Connect Points” as we will fit data to known functions. When more than one data set is plotted on a single graph, you must enter the label and unit for the y-axis.

Specify the column(s) of data to be plotted on the y-axis as well as the column of data to be plotted on the x-axis.

Do not use the “Right Y-Axis.”

The Analysis (1st Step)

Analyze → Curve Fit →

Select the relevant data set → Select the general equation → Try Fit → OK; or

Select the relevant data set → Define Function → Type the general equation → Try Fit → OK.

We will use “Curve Fit” for all graphs, even if they are linear. The value of all quantities in the general equation is specified in the “Information Box” that will appear on your graph for each data set that you analyze.

The Printing

File →

Page Setup → Always landscape.

Printing Options → Enter names, Date, Page Title, Page Number

File → Print Graph (*Never* use the print icon or File → Print)

File → Print Data Table (if needed)

The Analysis (2nd Step)

On the graph, in ink, write the general equation and, below it, the known function being investigated.

Match parts of the general equation to the corresponding parts of the known function.

Refer to the “Information Box” on the graph. The value of the unknown quantity can be determined, although it may require some algebra. Calculate the necessary quantities. Refer to Fig. B-3.

APPENDIX B: COMPUTERS and SOFTWARE

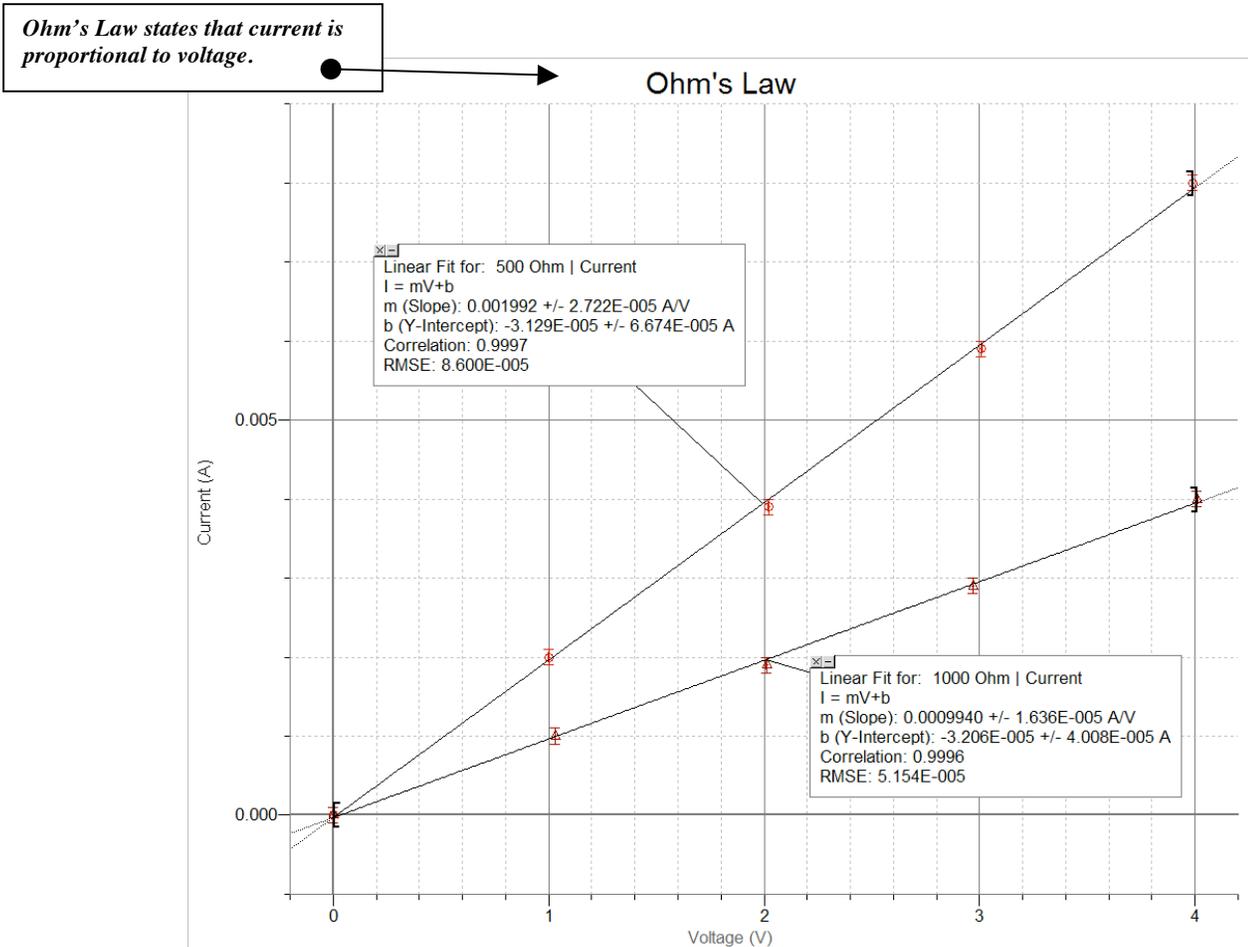


Fig. B-3

General Equation:

$$y = m x + b \quad b = 0$$



Known Function:

$$I = V / R$$

$$m = 1/R$$

$$R_1 = 1/m_1 = 502.01 \, \Omega; \quad R_2 = 1/m_2 = 1006.04 \, \Omega$$

Mathematical analysis is required for every graph of known functions.

The software performs the 1st step of analysis.

You complete the analysis after printing.

Match parts of the general equation to corresponding parts of the known function.

Current I is plotted on the y-axis; electric potential difference V is plotted on the x-axis (I vs. V).

The slope m equals everything else in the equation, in this case, inverse of the resistance R .

Note that 6 of the 7 required graph components are present in this figure.

When you *Print Graph*, the team names and date will print (7th graph component).

Note that the software does the first step in the analysis. After the graph is printed, you must complete the analysis.

APPENDIX B: COMPUTERS and SOFTWARE

You are usually required to print your data: *File* → *Print Data Table...*

Set the printing parameters prior to printing.

	1000 Ohm		500 Ohm	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
1	0.000	0.0000	0.000	0.0000
2	1.030	0.0010	1.000	0.0020
3	2.010	0.0019	2.020	0.0039
4	2.970	0.0029	3.010	0.0059
5	4.010	0.0040	3.990	0.0080
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				

Data Sets are named:
● 1000 Ohm and 500 Ohm

Data Columns are named:
● Voltage, Current.

Units are entered: V, A

Fig. B-4 Data Table

Note: Use *Column Options* to name each data set, name each column of data, enter the unit for each column of data, and the uncertainty of the measurements (*error bar calculations*) before you enter the data.

Two (2) data sets are on this data table. Note that

- Each data set is named
- Each column of data is named
- Unit symbols are entered
- Error Bars (uncertainty of measurement) have been entered; (uncertainties appear only on the graph but only if “empty” geometric figures, such as an empty circle, are chosen).
- If the uncertainty of measurements varies, enter the uncertainty for each measurement in a new column: *Data* → *New Manual Column*. Be sure to set all the parameters (name, unit) for the column of data. Now return to the measurement column of data, *Options* tab, *Select* “Error Bar Calculations,” and specify the appropriate column of data to use for the uncertainty of those measurements.

APPENDIX C - EQUIPMENT

Vernier Caliper

Dial-O-Gram Balance

Digital Multi-Meter (DMM)

APPENDIX C: EQUIPMENT

The Vernier Caliper

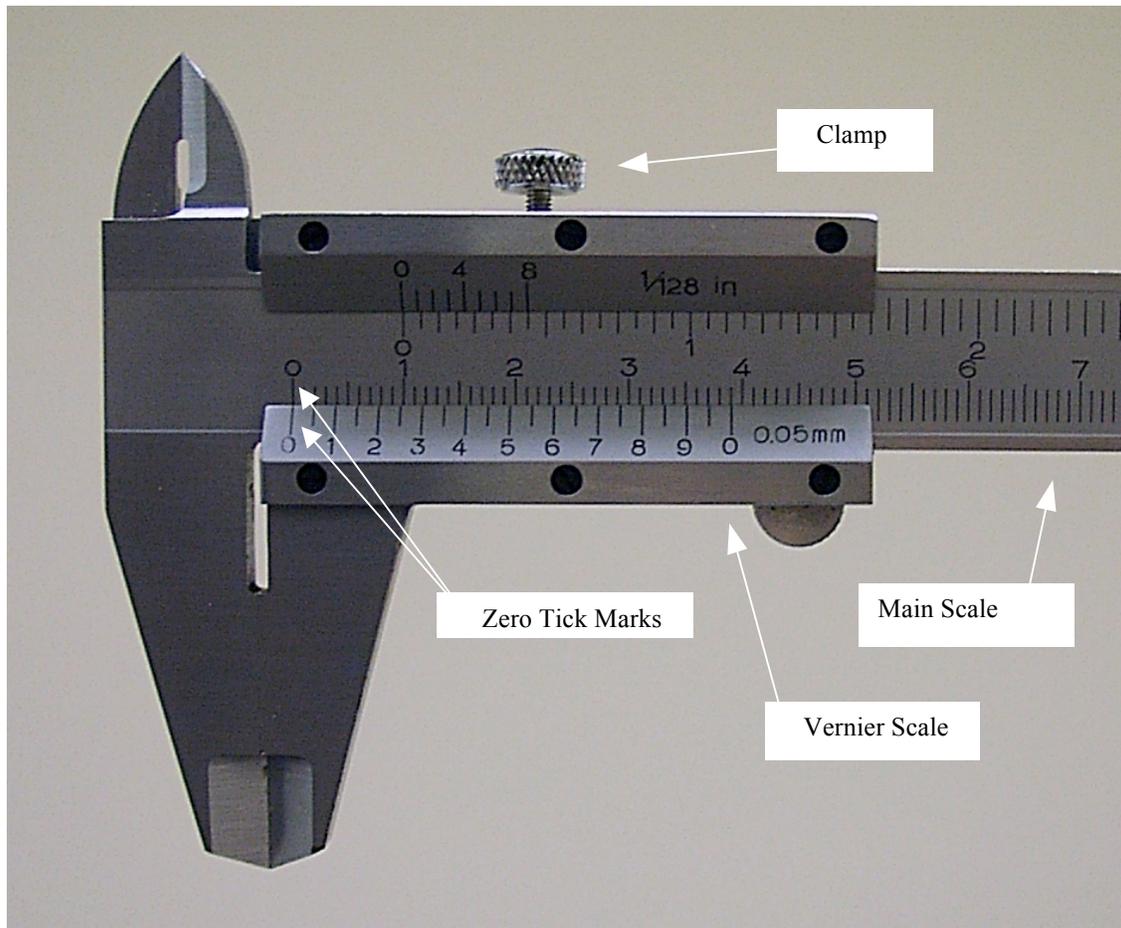


Fig. C-1 Vernier Caliper - Closed

- Note the zero graduation marks (tick marks) on each of the scales (vernier and main).
- We will always use metric units; ignore British units (inches) on each of the scales (the top of this caliper).
- In our lab, the uncertainty of a measurement, δ , is defined as $\frac{1}{2}$ the resolution (smallest unit); the caliper is one of three exceptions. The uncertainty of the caliper is the resolution of the caliper. The vernier scale states the resolution: 0.05 mm (0.05 mm = 0.005 cm). Thus, $\delta = \pm 0.005$ cm for the vernier caliper, allowing a measurement of $(a.bcd \pm 0.005)$ cm.
- Do not over tighten the clamp. Tighten just enough that the vernier scale does not shift.

APPENDIX C: EQUIPMENT

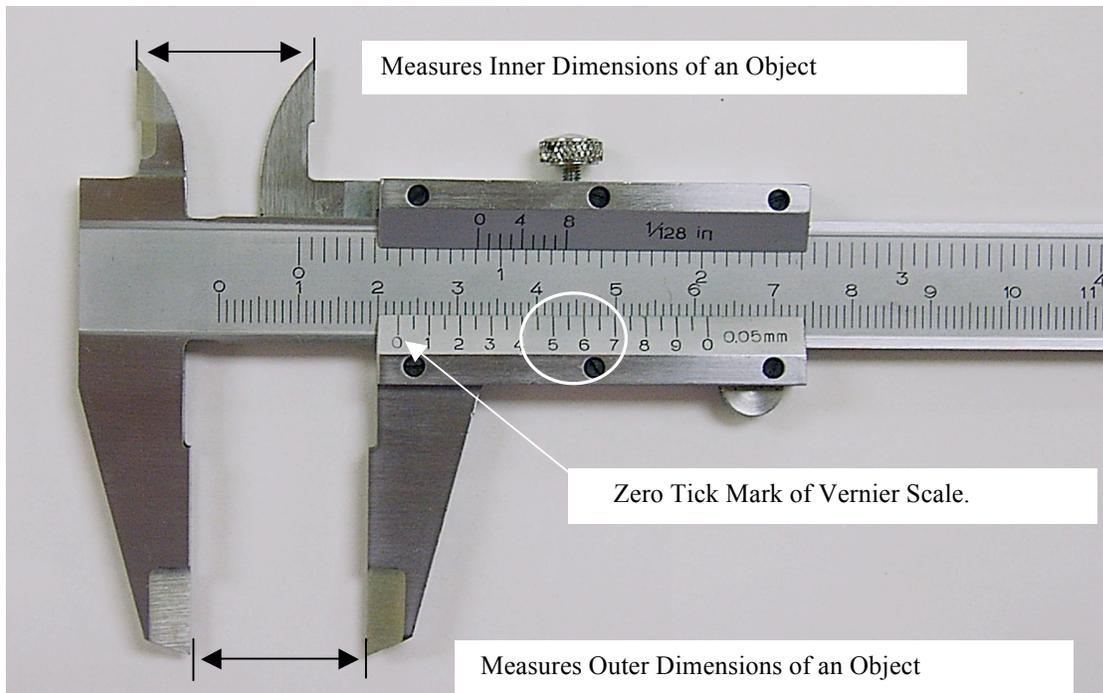


Fig. C-2 Vernier Caliper - Open

- Note that the zero tick mark of the vernier scale has passed the 2.2 position but not the 2.3 position of the main scale. You now have $a.b$ (2.2) of the “ $a.bcd$ cm” measurement.
- To obtain the remaining values, determine the first tick mark (from left to right) on the vernier scale that is aligned with a tick mark on the main scale. In this case, 5.5 is the first alignment and provides cd of your measurement.
- The final measurement reading of the vernier caliper is (2.255 ± 0.005) cm.
- A tutorial is available on your lab computer: **Items for Students** → **YP Vernier**

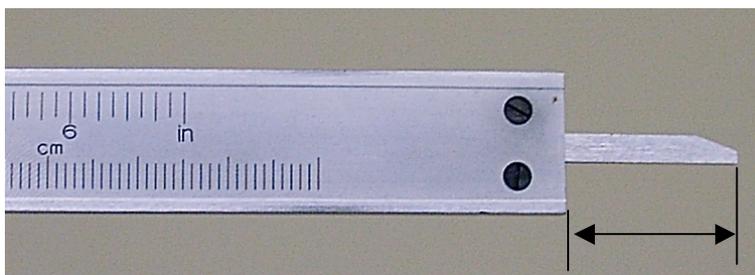


Fig. C-3 Vernier Caliper - End View

Note that as you open the caliper, a device to measure depth is available.

APPENDIX C: EQUIPMENT

The Dial-O-Gram Balance

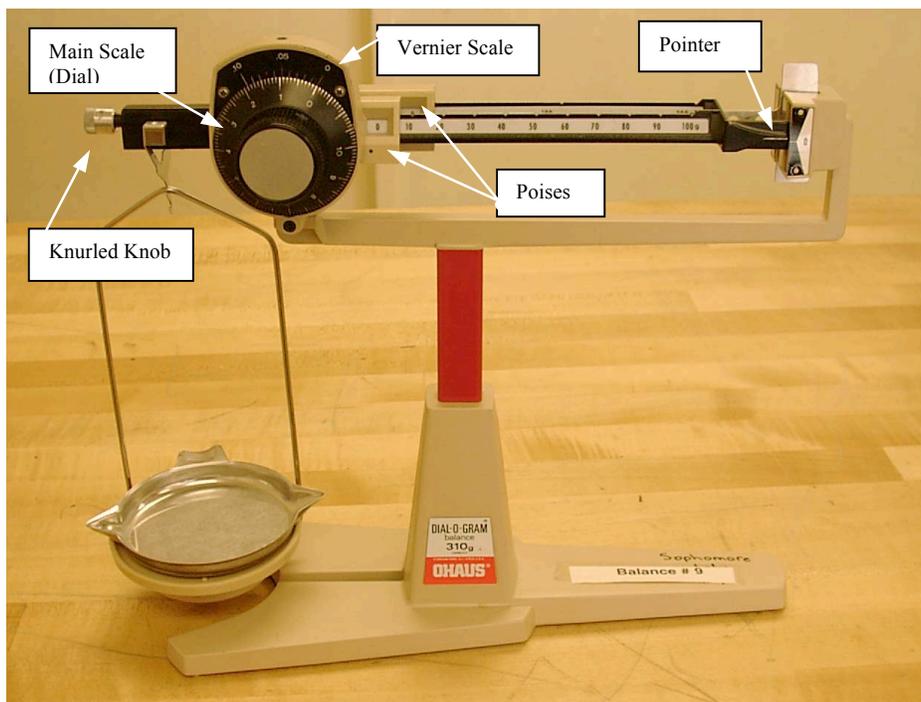


Fig. C-4 Dial-O-Gram Balance

Always calibrate before use. To calibrate, slide all poises (sliding masses) to zero; rotate the dial to zero. When oscillation of the arm has subsided, the pointer on the right end of the arm should align with zero. If necessary, adjust the *knurled balance compensator knob* (knurled knob) at the left end of the balance.



Fig. C-5 Dial zero aligns with vernier zero.

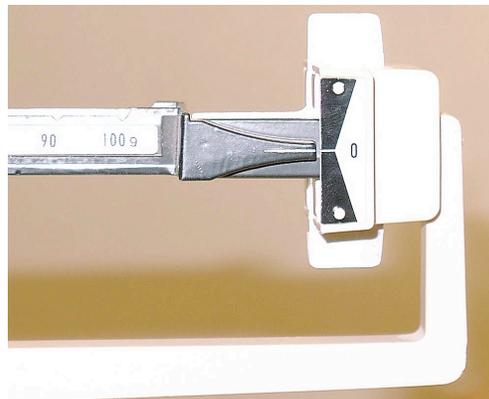


Fig. C-6 Pointer aligns with zero.

APPENDIX C: EQUIPMENT

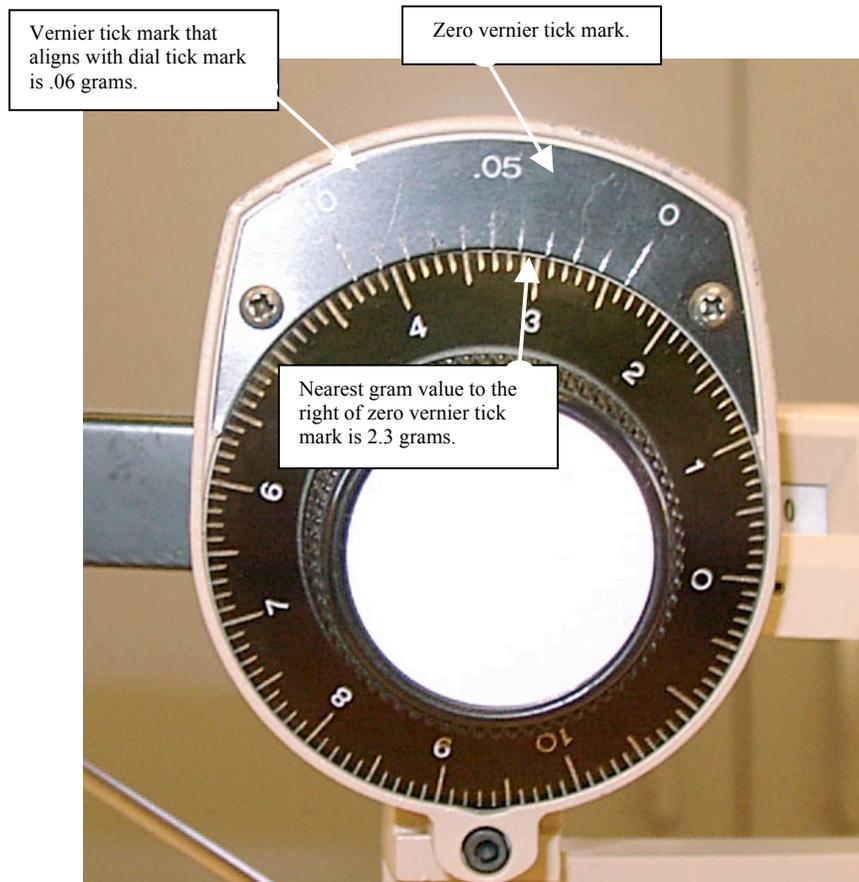


Fig. C-7 Dial and Vernier Scale

A measurement of $(a.bcd \pm 0.005)$ grams can be obtained from a Dial-O-Gram balance. Above the main scale (dial) is a vernier scale. To determine the main scale value, read the nearest gram and tenth of a gram ($a.b$) to the right of the zero vernier graduation ($a.b = 2.3$ grams = 2.3 g).

Add the vernier graduation value that aligns with the main scale graduation ($.06$ g $\rightarrow c = 6$).

The smallest unit for the Dial-O-Gram balance is 0.01 g: $\delta = \frac{1}{2} (0.01) \text{ g} = 0.005 \text{ g}$.

We will assume a zero for the thousandths place ($d = 0$) of the measurement to accommodate the order of magnitude (decimal place) of the uncertainty (0.005). Given the width of the tick marks, we claim this is a valid assumption.

Thus the measurement shown is $(a.bcd \pm 0.005 \rightarrow 2.360 \pm 0.005) \text{ g}$.

APPENDIX C: EQUIPMENT

DIGITAL MULTI-METER

A Digital Multi-Meter, **DMM**, measures a variety of electrical quantities, depending on the model used. There are differences among the three models used in our lab; consider carefully (*i.e.*, read and think) as you select the function, scale, and connections.

We will use a DMM to measure **resistance**, **current**, and **voltage**.

- The symbol for *resistance* is **R**; the unit is ohms, Ω (Greek letter, omega). Use an ohmmeter to measure **R**.
- The symbol for *current* is **I**; the unit is amperes, **A** (often shortened to amps). Use an ammeter to measure **I**.
- The symbol for *voltage* (electric potential difference) is **V**; the unit is volts, **V**. Use a voltmeter to measure **V**.

Directions are written for the *Kelvin 200* model {with notations for the other models}.

To specify the required function (**ohmmeter**, **ammeter**, **voltmeter**), select

- 1) **POWER SOURCE:** Turn the dial from OFF to the desired function. Set the switch to DC (Direct Current) or AC (Alternating Current). Assume DC unless specified otherwise as most experiments make use of DC. {Metex: ON/OFF button.}
 - 2) **DIAL:** Select the function the DMM will perform by turning the dial to the appropriate setting as well as the appropriate scale. Always choose the function with the leads unplugged from the device. The various functions on a DMM are denoted by the unit.
 - 3) **JACKS:** The black lead should always plug into the COM jack. Although the color of the wire covering is irrelevant, it is standard to define the black wire as the common (ground). The red lead will be plugged into the $V\Omega$ jack when measuring voltage or resistance. Plug the red lead into the mA {Metex: A} jack when measuring current unless the procedure specifically states that you should use the 10A {Metex: 20A} jack.
 - 4) **LEADS:** You must connect the leads to your circuit properly. Damage to the DMM can occur with improper use.
- **An ohmmeter is used without an external power supply.**
Although current must flow through a circuit or element to measure the resistance, the ohmmeter provides its own current. Therefore, never measure resistance with the power supply connected to the circuit.
 - **An ammeter is always connected in series.**
Current will flow through all available paths. Since we will want to measure the total current at a specific location, the ammeter must not be connected to an element. This may require the removal of a jumper so that the ammeter can be inserted into the circuit.
 - **A voltmeter is always connected in parallel.**
The leads connect to *each end of the same element* as we want to measure the voltage drop (potential difference) across an element.

APPENDIX C: EQUIPMENT



Fig. C-8 Digital Multi-Meters (DMM's)

(Models used in General Physics Labs: Metex, Kelvin 150, Kelvin 200)

Note the multipliers μ , m , K , and M on the different scales. This means you would multiply the digital reading of the DMM by the appropriate multiplier. For example, the $200K$ scale for the ohmmeter means you should multiply the digital readout by 10^3 .

Note also that the DMM will only read values up to the scale value. For example, the $\frac{20m}{10A}$ scale for the ammeter means the DMM will measure current up to $20mA$ if using the mA jack but will measure up to $10A$ if using the $10A$ jack.

APPENDIX C: EQUIPMENT

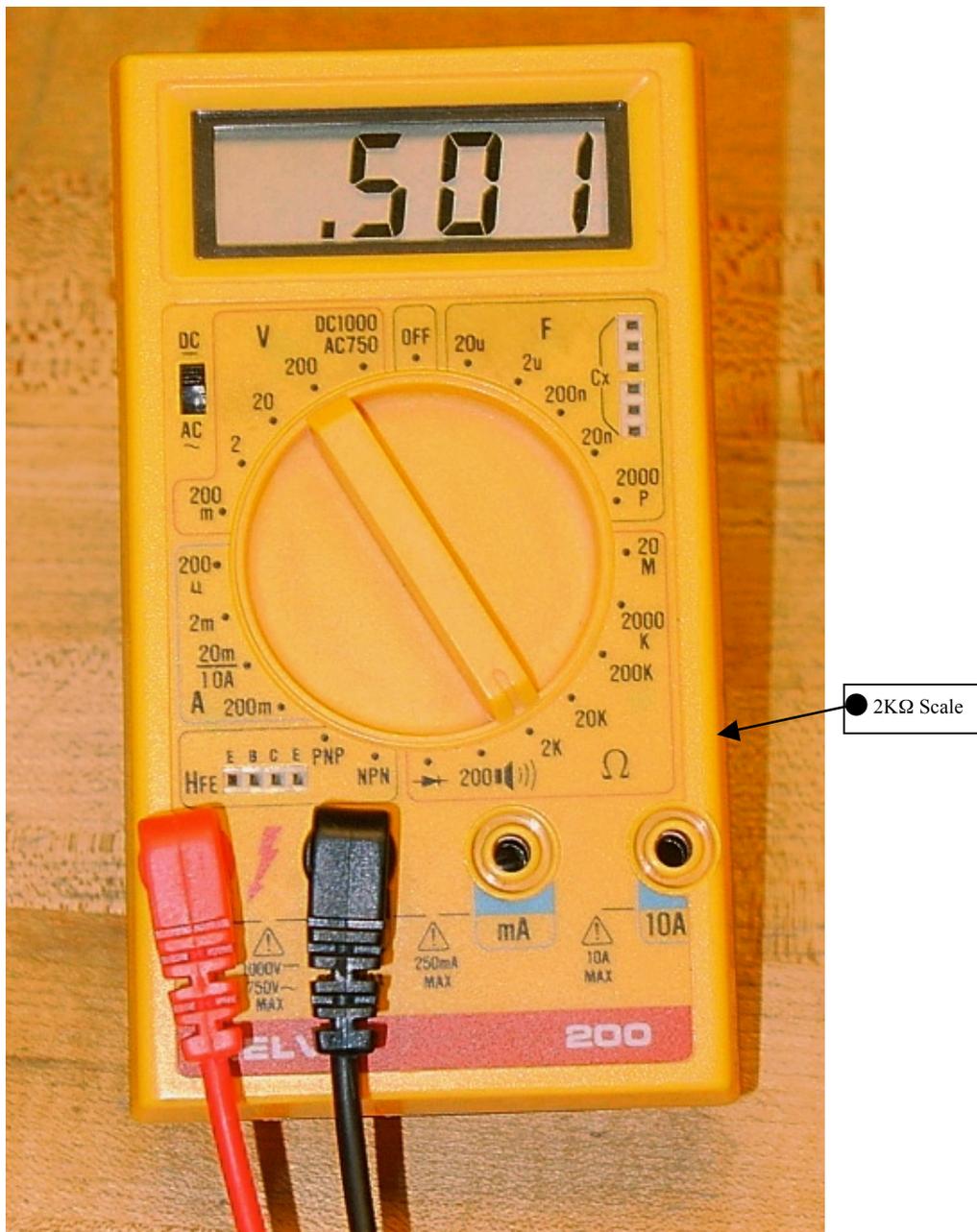


Fig. C-9 Ohmmeter Ohmmeter Reading: $0.501 \times 10^3 \Omega = 501 \Omega$

To use the DMM as an ohmmeter, select

- POWER: DC; turn dial to Ω -function {Metex: ON}.
- DIAL: 2k Ω {Metex: 2k OHM}.
- JACKS: Plug the black lead into COM and the red lead into V Ω .
- LEADS: Place leads on each end of *the same element*.

APPENDIX C: EQUIPMENT

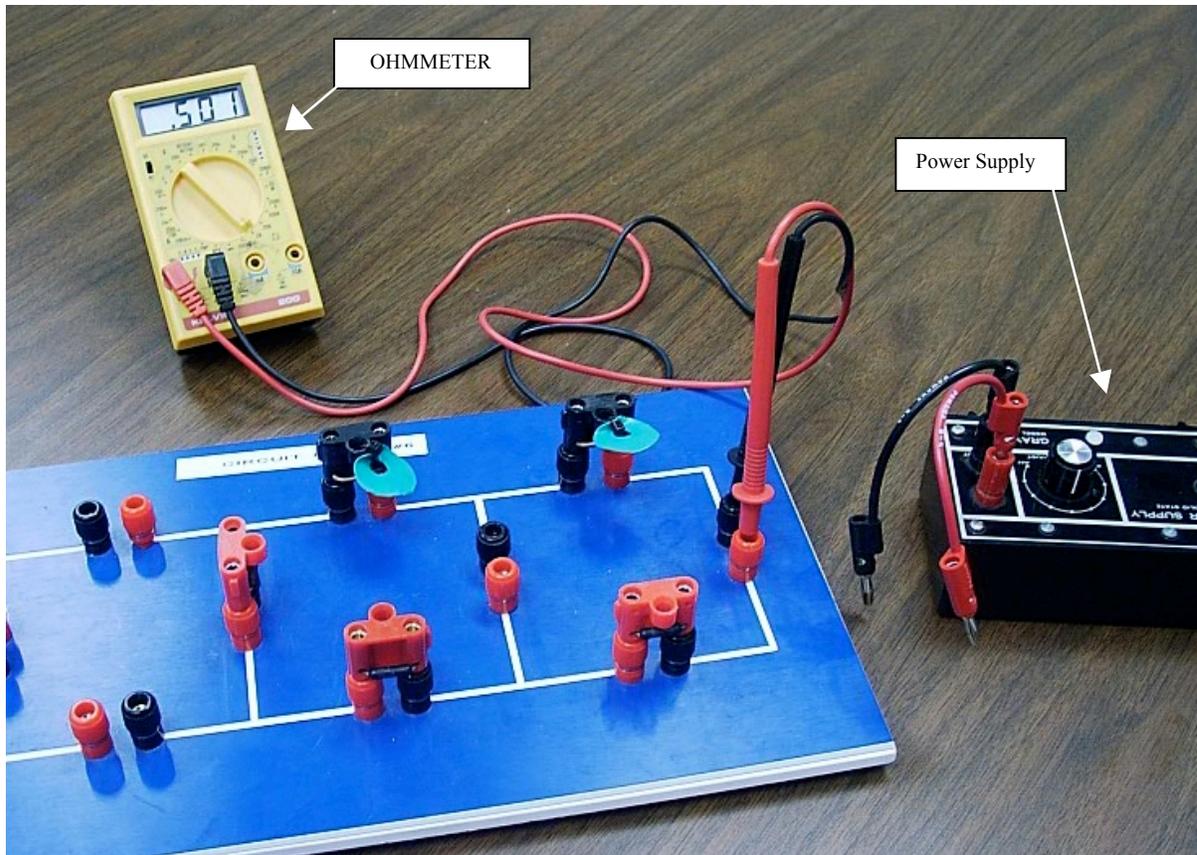


Fig. C-10 Ohmmeter and Circuit Ohmmeter Reading: $0.501 \text{ k}\Omega = 501 \text{ }\Omega$

Note: Power supply is disconnected from the circuit when measuring the resistance of the circuit, R_{eq} .
Note: To avoid confusion, the ammeter is not shown in this figure; we will usually insert the ammeter in our circuits prior to making any measurements of the circuit.



Fig. C-11 Ohmmeter and Resistor Ohmmeter Reading: $0.200 \text{ k}\Omega = 200 \text{ }\Omega$

Connect ohmmeter to resistor to measure the resistance of an element, R_i . If your resistor has a double-banana plug, you can simply plug it into the jacks instead of using wire leads.

APPENDIX C: EQUIPMENT

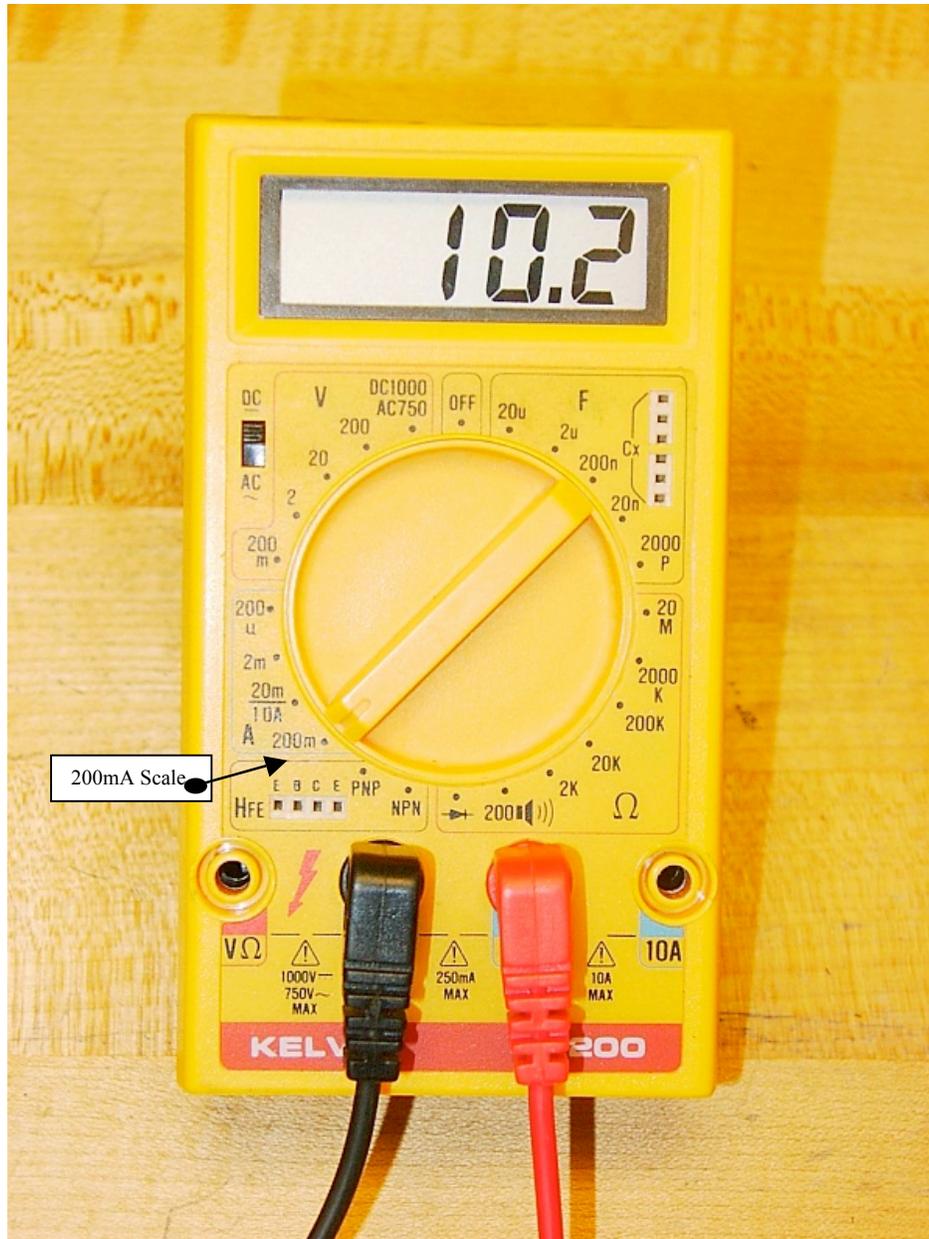


Fig. C-12 Ammeter Ammeter Reading: $10.2 \times 10^{-3} \text{ A} = 0.0102 \text{ A}$

To use the DMM as an ammeter, select

- **POWER:** DC; turn dial to A-function {Metex: ON; Kelvin 150: Turn dial to DCA}.
- **DIAL:** Turn to the appropriate scale on A {Metex and Kelvin 150: DCA}.
- **JACKS:** Plug the black lead into COM and the red lead into mA {Metex: A}.
- **LEADS:** Place leads into circuit in *series* (current travels from one element, through the ammeter, into a different element).

APPENDIX C: EQUIPMENT

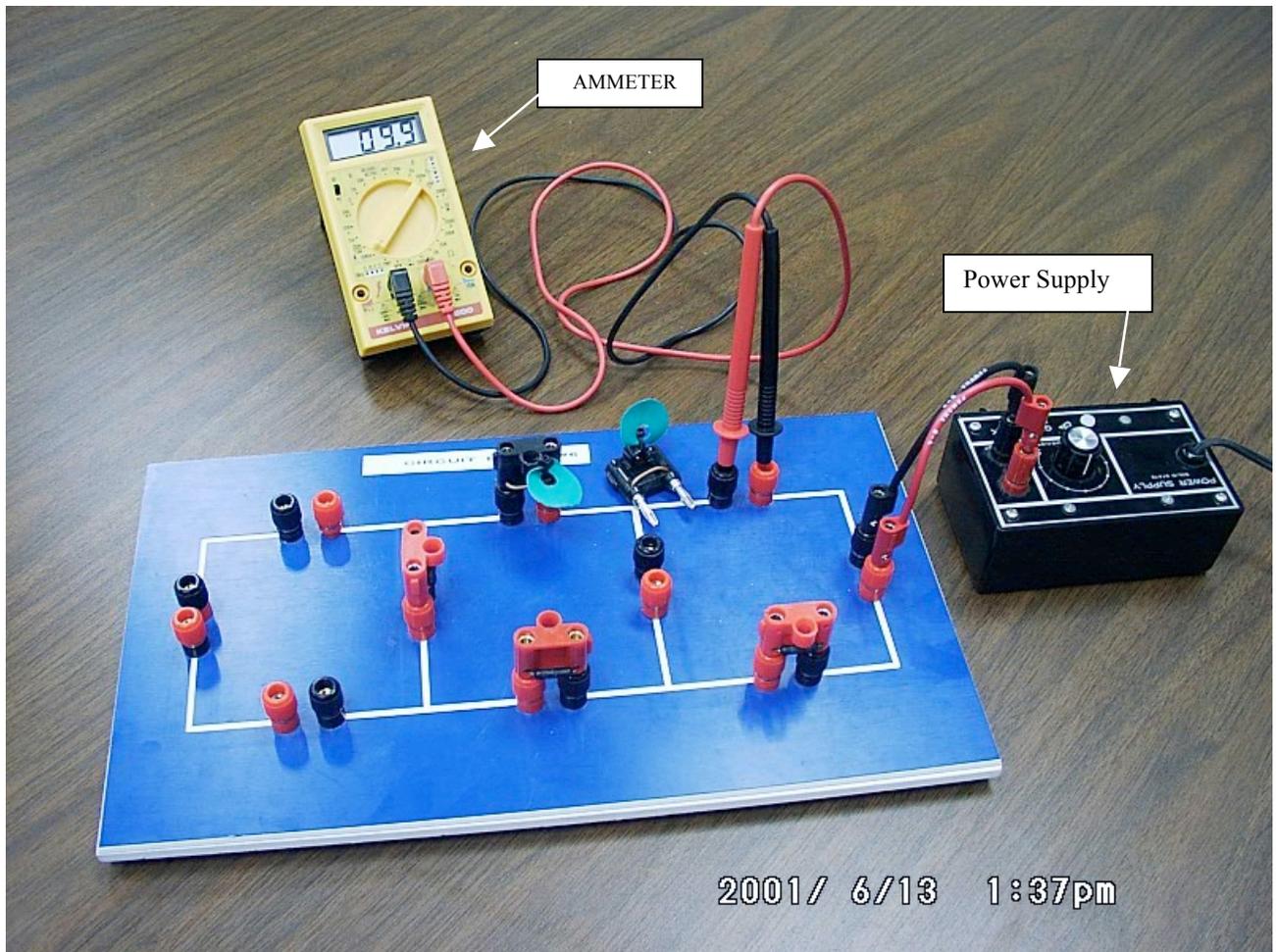


Fig. C-13 Ammeter and Circuit Ammeter Reading: $9.9 \text{ mA} = 0.0099 \text{ A}$

Note: The ammeter is connected in series. A jumper has been removed from the circuit so that the ammeter can be inserted, in series, to measure the current. When the current needs to be measured at a different location, remove the ammeter and replace the jumper. Power supply is connected, set to specified voltage.

Note: To avoid confusion, the voltmeter is not shown in this figure. We often need both devices connected when analyzing circuits.

APPENDIX C: EQUIPMENT



Fig. C-14 Voltmeter Voltmeter Reading: 5.27 V (20V DCV: no multiplier)

To use the DMM as a voltmeter, select

- **POWER:** DC, turn dial to V {Metex: ON; Kelvin 150: Turn dial to DCV}
- **DIAL:** 20V {Metex and Kelvin 150: 20 DCV}
- **JACKS:** Plug the black lead into COM and the red lead into VΩ
- **LEADS:** Place leads on each end of *the same element*

APPENDIX C: EQUIPMENT

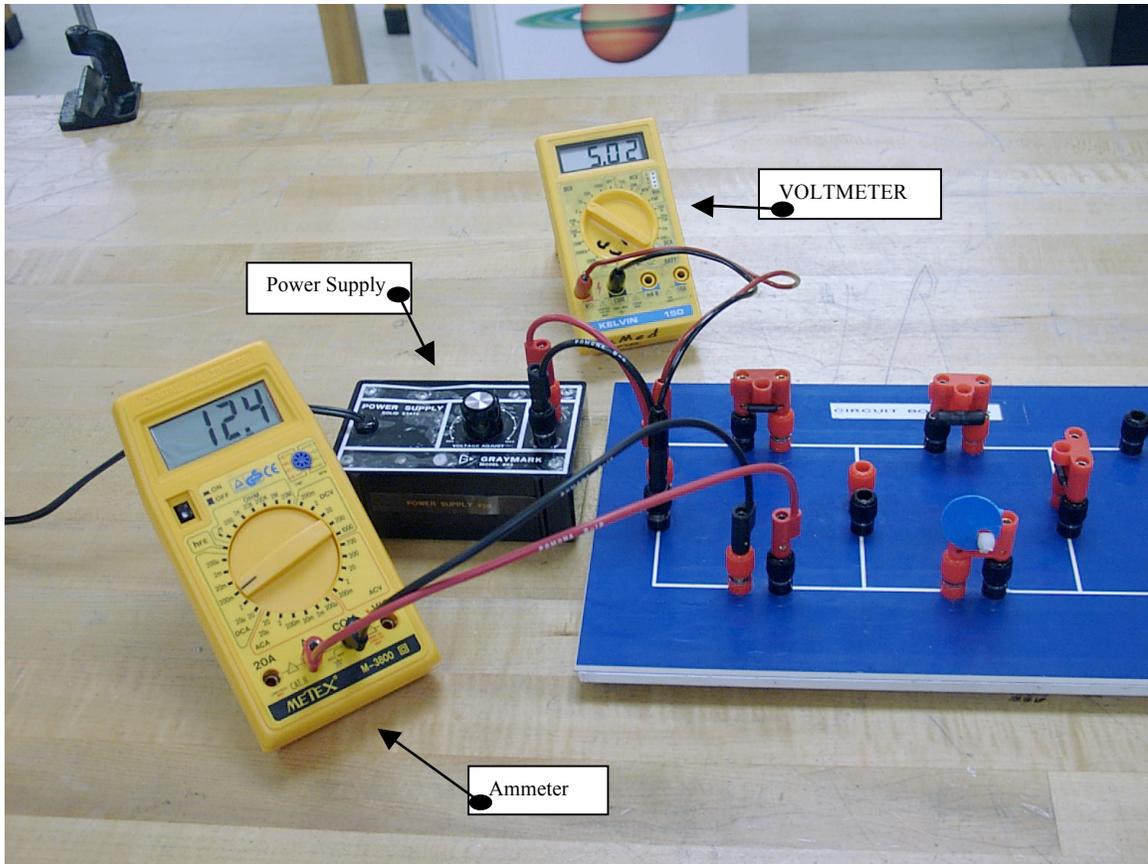


Fig. C-15 Voltmeter and Circuit Voltmeter Reading: 5.02 V

Note: The circuit is complete, power supply is connected to the circuit, plugged into the electric outlet, and set to specified voltage. The voltmeter is connected in parallel to the power supply as it measures voltage *across* an element in a circuit. Connect the voltmeter *at the circuit*, not at the power supply. The ammeter should be connected in your circuit prior to setting the voltage of the circuit.

To set the voltage for the circuit: Connect the voltmeter to the circuit in parallel with the power supply, insert the ammeter at the location specified in the schematic, then adjust the power supply to the required voltage.

APPENDIX D ~ MATH REVIEW

Algebra

Trigonometry

Propagation of Error Example

Take-Home Exam (Phys 223)

Take-Home Exam (Phys 224)

APPENDIX D: Math Review

A great deal of information can be obtained by first considering the type of equation being investigated.

Is one variable squared? If yes → it is a quadratic equation.

Are there trigonometric functions in the equation? If yes → it is a sinusoidal equation (or tangential, or ...).

Is there an exponential (*i.e.*, the number “e”, not an exponent) in the equation? If yes → it is an exponential equation.

If none of the above ... is this equation linear? If yes → use the slope-intercept equation of a line: $y = mx + b$.

Consider the *kinematic equations* below (from Exp 5: Projectile Motion).

$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$	Quadratic in Time
$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$	Quadratic in Time
$v_x = v_{0x} + a_x t$	Linear
$v_y = v_{0y} + a_y t$	Linear
$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$	Quadratic in Velocity
$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$	Quadratic in Velocity

We will use other types of equations this year as well:

$$F_B = ILB\sin(\theta) \quad \text{Magnetic Force is Sinusoidal as the Angle Varies}$$

$$N = N_0 * e^t \quad \text{Exponential Growth (Your calculator has the function } e \text{.)}$$

APPENDIX D: Math Review

Algebra

General Physics requires mastery of college-level algebra and trigonometry.

If it has been some time since you used this level of math, it is important that you refresh your knowledge and skills. Your text for physics lecture may have a math appendix; if it does, please read through it to be certain you have the math knowledge required.

This appendix is a simple summary of math that is frequently used in General Physics lab. Some experiments will require more advanced knowledge.

Solve for x means that the variable x is on one side of the equation, everything else in the equation is on the other side. If x is the only variable, the equation has a unique solution (has only one correct answer).

If unique solutions are required, the number of unknowns *must* equal the number of equations.

Consider the equation for the circumference of a circle: $C = \pi D$. There is 1 equation and 2 unknowns; there is no unique solution. Refer to Fig. D-1. *Any* point on the line is a correct solution. There are an infinite number of correct solutions.

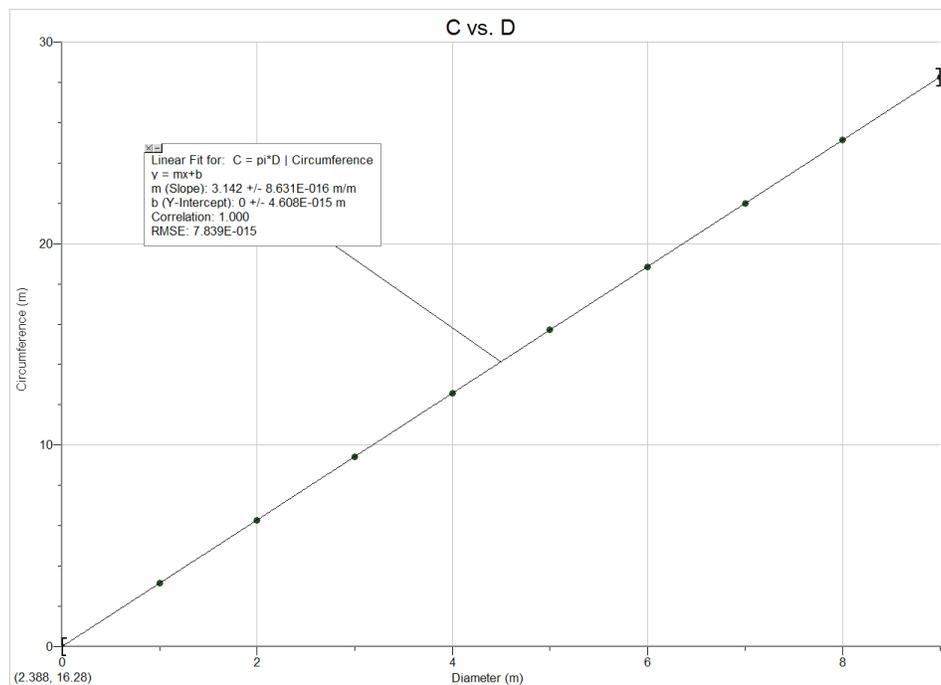


Fig. D-1 Linear Plot

APPENDIX D: Math Review

Solving 3 equations with 3 unknowns is required in lab. The variables are the unknowns.

Four different methods are provided here to help you. The first method offered is the *substitution method*:

Choose one of the equations; if all 3 equations have all 3 unknowns, it does not matter which one you choose first. If this is not the case, remember you need to *eliminate* an unknown! Choose the equation that has all 3 unknowns. Designate this equation as Eq. 1. Solve Eq. 1 for one of the unknowns (it does not matter which one).

Substitute Eq. 1 into a second equation; designate this second equation as Eq. 2.

Note that the substitution *must* eliminate an unknown.

Designate the last equation as Eq. 3.

You now have 2 equations with 2 unknowns: Eq. 2 and Eq. 3.

Choose either Eq. 2 or Eq. 3, then solve it for an unknown;

Substitute the value of this unknown into the remaining equation.

Note that the substitution *must* eliminate an unknown.

You now have 1 equation and 1 unknown.

Solve the equation; substitute this value into the previous equation.

Solve the equation; substitute this value(s) into the first equation.

Solve the first equation. Done. Check your answer.

Example for “Solving 3 Equations with 3 Unknowns”

Given the following 3 equations, solve for x , y , and z :

$$x = y + z$$

$$1.5 - 3x - 4z = 0$$

$$-1.5 - 5y + 6x = 0$$

Choose the equation that has all 3 unknowns.

Designate this equation as Eq. 1. Solve Eq. 1 for one of the unknowns: z .

$$\text{Eq. 1: } x = y + z \rightarrow z = x - y$$

Substitute Eq. 1 into a second equation; designate this second equation as Eq. 2.

$$\text{Eq. 2: } 1.5 - 3x - 4z = 0 \rightarrow 1.5 - 3x - 4(x - y) = 0 \rightarrow 1.5 - 7x + 4y = 0$$

Choose Eq. 2 or Eq. 3, then solve it for an unknown: Eq. 2.

$$\text{Eq. 2: } 1.5 - 7x + 4y = 0 \rightarrow x = (1.5 + 4y)/7$$

Substitute the value of this unknown into the remaining equation:

$$\text{Eq. 3: } -1.5 - 5y + 6x = 0 \rightarrow -1.5 - 5y + 6 * [(1.5 + 4y)/7] = 0$$

Solve the equation:

$$-1.5 - 5y + 9/7 + 24y/7 = 0 \rightarrow 24y/7 - 5y = 1.5 - 9/7 \rightarrow -11y/7 = 3/14 \rightarrow y = (-7/11) * (3/14) = -0.136$$

Substitute this value into the previous equation and solve the equation:

$$\text{Eq. 2: } x = (1.5 + 4y)/7 \rightarrow x = [1.5 + 4 * (-0.136)] / 7 \rightarrow x = 0.137$$

Substitute these values into the first equation, and solve the equation:

$$\text{Eq. 1: } z = x - y \rightarrow z = 0.137 - (-0.136) \rightarrow z = 0.273$$

Done. Check your answer... !

APPENDIX D: Math Review

A second method available to you is *Cramer's Rule*. Consult a linear algebra text.

A third method is an online calculator that solves 3 equations with 3 unknowns: <http://www.1728.com/unknown3.htm>

A fourth method is to use *Mathematica* software; it is installed on your computer in lab. When you have finished measuring ϵ_i and R_i and disconnected the batteries (Exp. 20), simplify your equations. Open the *Software* folder, open *Mathematica*. Type the 3 equations using the format shown below; it is followed by an example. Note that the "s" is capitalized, there are no spaces, the "equals" symbol is entered twice, and squared or curly brackets are not the same as parentheses. When you finish entering the information, use the "enter" key on the number pad, not the "enter" or "return" key on the main keyboard. Note that the same variables you used in the equations are specified at the end. The following makes use of spaces so that it is easier for you to read. (If you have a different version of this software, there may be small changes.)

Solve{equation1, equation2, equation3}, {I1, I2, I3}

Solve[{25x + 12z - 1.5 == 0, -40y + 12z == 1.5, x == y + z}, {x, y, z}]

The coefficients of the variables x, y, and z (I_1, I_2, I_3) are the *measured* resistances of your circuit.

Solving a quadratic equation is easily accomplished by use of the *quadratic formula*.

A quadratic equation means that one variable is squared.

To use the quadratic formula, the equation must first be in the correct form: $ax^2+bx+c=0$.

The coefficients are a, b , and c ; $a \neq 0$.

The coefficient of x^2 is a , the coefficient of x^1 is b , the coefficient of x^0 is c .

The quadratic formula is $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

$7x^2 - 3x = 5$ is a quadratic equation. $7x^2 - 3x - 5 = 0$ is the required form to use the quadratic formula.

The coefficients for this equation are $a = 7, b = -3$, and $c = -5$.

To use the quadratic formula, substitute the coefficients (*i.e.*, a, b, c) into the formula.

$$x = \frac{-(-3) \pm \sqrt{9 - (4)*(7)*(-5)}}{(2)*(7)}$$

Solve the equation. *Note* that a quadratic equation will *always* have 2 solutions. An equation involving a variable raised to any power n has n solutions. For example: $y = x^7, n = 7$. There are 7 solutions.

APPENDIX D: Math Review

Trigonometry

An angle is measured *from the +x-axis, in a counterclockwise direction* unless specified otherwise.

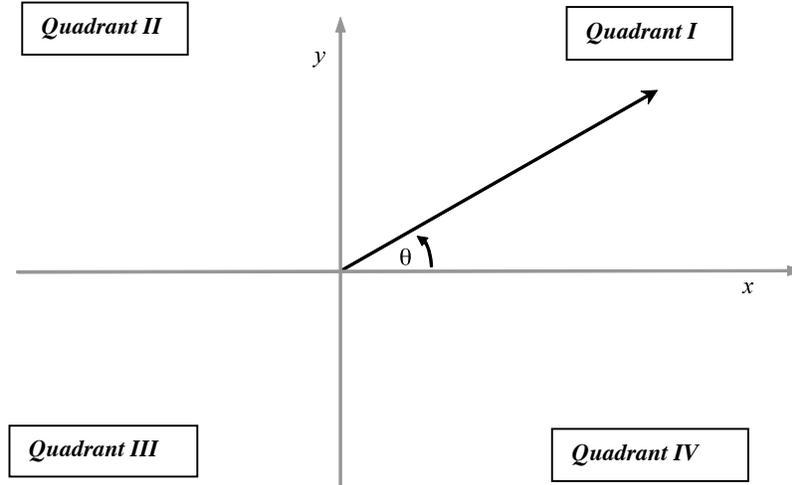


Fig. D-2 Cartesian Graph

The sum of the angles of *any* triangle equals 180° . $180^\circ = \pi$ (radians).

Pythagorean Theorem states that $a^2 + b^2 = c^2$; we often use other variables: $x^2 + y^2 = r^2$ (refer to Fig. D-3).

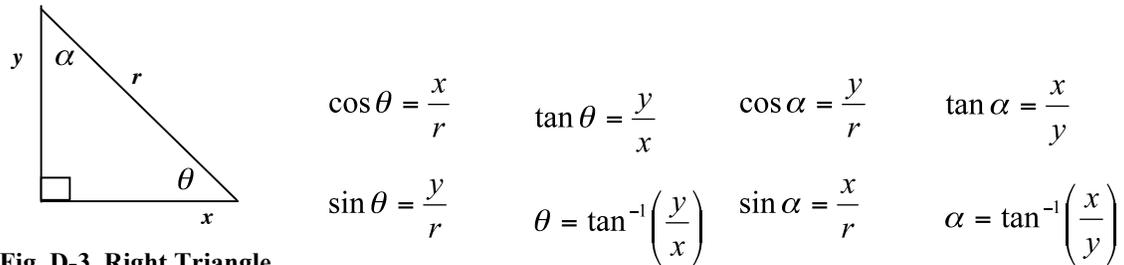


Fig. D-3 Right Triangle

Note that the $\cos \theta = \sin \alpha$, etc.

Note that to solve a trig function for an angle, you must take the inverse of the trig function.

When using a calculator to determine the inverse tangent of an angle, your calculator may give you an angle that is in the wrong quadrant [calculated angle will only be in quadrant I (+ θ) or quadrant IV (- θ)].

To determine the correct quadrant, consider the \pm sign of the argument: If x is negative, the angle *must* be in quadrant II or III; if y is negative, the angle *must* be in quadrant III or IV. If both x and y are negative, the angle *must* be in quadrant III (refer to Fig. D-2).

If the calculated angle is in the wrong quadrant, simply add 180° to the calculated angle.

APPENDIX D: Math Review

If an angle is measured in radians, the arc length s equals the radius r times the angle θ (refer to Fig. D-4).

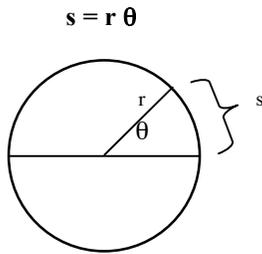


Fig. D-4 Arc Length

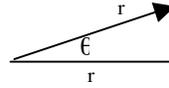


Fig. D-5 Small Angle Approximation

If an angle is small and measured in radians: $\sin \theta \cong \tan \theta \cong \theta$ (refer to Fig. D-5).

Consider a circle of radius r (refer to Fig. D-6).
The circumference C of the circle is $C = 2\pi r$.
The area A of the circle is $A = \pi r^2$.

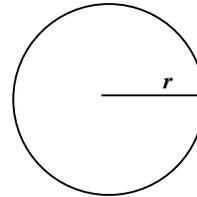


Fig. D-6 Circle of radius r

Consider a right-circular cylinder of
radius r and height h (refer to Fig. D-7).
The volume V of the cylinder is $V = \pi r^2 h$

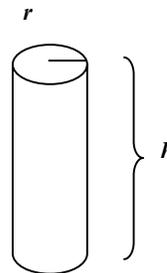


Fig. D-7 Right-Circular Cylinder
radius r , height h

Propagation of Error Example

Assume the density (ρ) and uncertainty of density ($\delta\rho$) are to be determined for a cylinder using a caliper to measure the dimensions (diameter, height) and a digital balance to measure mass.

The equations for volume and density are:

$$V = \pi D^2 h / 4 \quad \rho = m / V.$$

Once you have written the algebraic equation for the quantities, write the equations for the uncertainty of those quantities. Refer to *Appendix A* for details.

$$\delta V = \pm V [(2 * \delta D / D)^2 + (\delta h / h)^2]^{1/2}$$

$$\delta \rho = \pm \rho [(\delta m / m)^2 + (\delta V / V)^2]^{1/2}$$

The measured values are:

$$(D \pm \delta D) = (2.345 \pm 0.005) \text{ cm}$$

$$(h \pm \delta h) = (5.025 \pm 0.005) \text{ cm}$$

$$(m \pm \delta m) = (14.56 \pm 0.01) \text{ g.}$$

To determine $V \pm \delta V$, insert the necessary values into the equation, then calculate:

$$V = \pi(2.345\text{cm})^2(5.025\text{cm})/4 = 21.702594 \text{ cm}^3 \rightarrow V = 21.703 \text{ cm}^3$$

(Keep at least one more significant figure ...)

$$\delta V = \pm 21.703 \text{ cm}^3 [(2 * .005\text{cm}/2.345 \text{ cm})^2 + (.005\text{cm}/5.025\text{cm})^2]^{1/2} = 0.0950 \text{ cm}^3$$

(Round to one significant figure ...)

$$V \pm \delta V = (21.70 \pm 0.10) \text{ cm}^3$$

(Recall that the uncertainty dictates the significant figures in the quantity.)

$$\rho = 14.56\text{g}/21.70 \text{ cm}^3 = 0.67096 \text{ g/cm}^3$$

$$\delta \rho = \pm 0.67096 \text{ g/cm}^3 [(0.01\text{g}/14.56 \text{ g})^2 + (0.10 \text{ cm}^3/21.70 \text{ cm}^3)^2]^{1/2} = 0.003126 \text{ g/cm}^3$$

$$\rho \pm \delta \rho = (0.671 \pm 0.003)\text{g/cm}^3$$

(Recall that the precision of the quantity and the precision of the uncertainty must always match.)

APPENDIX D: Take-Home Math Exam ~ Phys 223

Name _____ **Section** _____

Be careful to read the instructions, show your work, and include units as necessary.

Use the symbols specified. No partial credit for math exams. One point (1 pt) per question.

Solve each equation for x:

1. $y = 7x - 6 + 2x$

2. $5x = 2x - 7 + y$

3. $3x^2 - 4 = x$

4. *Solve for x and y (2 equations with 2 unknowns) using substitution:*

$$2x + y = 3$$

$$y - 2x = 9$$

Consider a sphere of radius r.

5. $V =$ _____ (volume)

6. $A =$ _____ (surface area)

Consider a circle of diameter D.

7. $C =$ _____ (circumference)

8. $A =$ _____ (area)

Refer to Figure 1 for questions 9 through 11:

9. $V =$ _____ (volume)

10. $C =$ _____ (circumference)

11. $A =$ _____ (surface area)



**Figure 1: Solid Right-Circular Cylinder,
Height h , radius r .**

APPENDIX D: Take-Home Math Exam ~ Phys 223

12. Consider a triangle. How many degrees and radians are there?

_____, _____.

Refer to Figure 2 for questions 13 through 19.

Answer in terms of x , y , and r .

13. Pythagorean Theorem: _____

14. $\cos \alpha =$ _____

15. $\sin \beta =$ _____

16. $\sin \alpha =$ _____

17. $\cos \beta =$ _____

18. $\tan \alpha =$ _____

19. $\tan \beta =$ _____

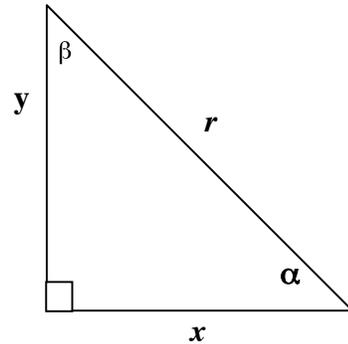


Figure 2: Right Triangle

Simplify the following expression:

20. $9z + 3 - 7x + 2z - 3x - 8 + 5z - 3y$ _____

Convert the following:

21. 55 mph = _____ m/s

22. 162.56 cm = _____ (answer in terms of height, feet and inches, e.g., 6'1")

23. $1 \text{ cm}^3 =$ _____ m^3

Use the quadratic formula to solve the following equation:

24. $9x^2 + 7x = 2$

25. $\sqrt{x} = x$ to the power _____

APPENDIX D: Take-Home Math Exam ~ Phys 224

Name _____ Section _____

Be careful to read the instructions, show your work, and include units as necessary.

Use the specified symbols. No partial credit for math exams. One point (1 pt) per question.

Solve each equation for x:

1. $y = 7x - 6 + 2x$

2. $5x = 2x - 7 + y$

3. $3x^2 - 4 = x$

4. *Solve for x and y (2 equations with 2 unknowns):*

$$2x + y = 3$$

$$y - 2x = 9$$

Exponents

5. $x^4 x^3 = x$ to the power _____

6. $x^4 / x^3 = x$ to the power _____

Consider a circle of diameter D.

7. $C =$ _____ (circumference)

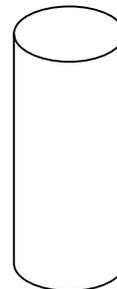
8. $A =$ _____ (area)

Refer to Figure 1 for questions 9 through 11:

9. $V =$ _____ (volume)

10. $C =$ _____ (circumference)

11. $A =$ _____ (total surface area)



*Figure 1: Cylindrical Tube;
Height h , radius r .*

APPENDIX D: Take-Home Math Exam ~ Phys 224

12. Consider a triangle. How many degrees and radians are there?

_____, _____.

Refer to Figure 2 for questions 13 through 19.

Answer in terms of x , y , and r .

13. Pythagorean Theorem: _____

14. $\cos \alpha =$ _____

15. $\sin \beta =$ _____

16. $\sin \alpha =$ _____

17. $\cos \beta =$ _____

18. $\tan \alpha =$ _____

19. $\tan \beta =$ _____

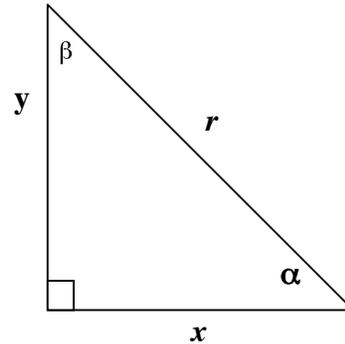


Figure 2: Right Triangle

Simplify the following expression:

20. $9I_3 + 3 - 7I_1 + 2I_3 - 3I_1 - 8 + 5I_3 - 3I_2$ _____

Convert the following:

21. 55 mph = _____ m/s

22. 162.56 cm = _____ (answer in terms of height, feet and inches, e.g., 6'1")

23. $1 \text{ cm}^3 =$ _____ m^3

Use the quadratic formula to solve the following equation:

24. $9x^2 + 7x = 21$