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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*: Ch. 1-4). 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 0.005cm). However, if a damaged caliper is used that reads 0.25cm too short, all the measurements would be incorrect. The values may be precise, but they would not be accurate.

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[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. The specifics follow.

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., $g = 9.80\ m/s^2$, $c = 3.0\times10^8\ m/s$), or calculated from equations.

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 a class average.

When comparing values, use the following equations:

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

$$\textbf{\% difference} = \frac{|value_1 - value_2|}{\frac{value_1 + value_2}{2}}\times 100 = \frac{|value_1 - value_2|}{value_{avg}}\times 100 \qquad \textbf{Eq. A-2.}$$

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):

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

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

$$d_i = x_i - \bar{x} \qquad \textbf{Eq. A-4.}$$

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.

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

or

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

APPENDIX A: MEASUREMENT AND UNCERTAINTY

Uncertainty of Measurements: δ

In this lab the ***uncertainty,*** δ (Greek letter, delta), of a measurement is usually 1/2 the resolution (smallest division) of the measuring device. The resolution of a 30-cm ruler is one millimeter (1.0mm), thus δ*x* is:

$$\delta x = \frac{1}{2}(1.0mm) = 0.5mm = 0.05cm\ .$$

For example, an object is measured to be $x \pm \delta x$ = (23.25 ± 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.

To calculate $\delta_{\%} x$, the **percent uncertainty** (which has no units), of a measured value:

$$\delta_{\%} x = \frac{\delta x}{x} \times 100 \qquad \textbf{Eq. A-7.}$$

Propagation of Error
Once the uncertainties for your measurements are known they can be propagated in all mathematical manipulations that use the quantities measured. This allows a reader to know the precision of your work. When we propagate error the following rules apply.

Added or Subtracted Quantities
When measured values are ***added*** (<u>or</u> subtracted) the uncertainties are *added in quadrature* (i.e., combining two numbers by squaring them, adding the squares, then taking the square root). The uncertainty of A, δA, is added in quadrature in Eq. A-8.

$$(x \pm \delta x) + (y \pm \delta y) \Rightarrow A = x + y$$

$$\delta A = \sqrt{(\delta x)^2 + (\delta y)^2} \qquad \textbf{Eq. A-8.}$$

Express this result as A ± δA.

Note that uncertainties are added when measurements are added *or* subtracted.

$$(x \pm \delta x) - (y \pm \delta y) \Rightarrow A = x - y$$

$$\delta A = \sqrt{(\delta x)^2 + (\delta y)^2}$$

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 = 2.40cm + 1.35cm = 3.75cm.

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

Remembering rules for significant figures, we know that δA=0.07cm. Thus,

A ± δA = (3.75 ± 0.07)cm.

Note that the measurement and uncertainty are inside the parentheses, the unit is outside the parentheses. All measured values should be written this way.

A *simpler method for addition & subtraction* where uncertainty is simply added is shown below. While this method is not as accurate as addition in quadrature, which is a calculus derived method, it yields quite reasonable results for most of our applications.

Simple 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 = 2.40cm + 1.35cm = 3.75cm and δA = (0.05cm + 0.05cm) = 0.10cm.

A ± δA = (3.75 ± 0.10)cm.

For two equal uncertainties, the simple method yields a value about 30% *too large*.

Multiplied and Divided Quantities

To determine the *uncertainty* in a product (or quotient):

$x \pm \delta x$, $y \pm \delta y$, $z \pm \delta z$ => $V = xyz$ and

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

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:

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

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.

Uncertainty Example: Multiplied or Divided Quantities

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

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

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

The uncertainty in the area is given by

$$\delta A = A \times \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2} = 3.24cm^2 \times \sqrt{\left(\frac{0.05cm}{2.40cm}\right)^2 + \left(\frac{0.05cm}{1.35cm}\right)^2}$$

$$= 0.13768\text{cm}^2 \Rightarrow 0.14\text{cm}^2.$$

Express the area and its uncertainty as $A \pm \delta A = (3.24 \pm 0.14)cm^2$.

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

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

$A \pm \delta A$, in terms of percent uncertainty, would be expressed as

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

A simpler method for multiplication or division where percent uncertainties are simply added follows. This method yields slightly higher results than the quadrature method as well, but it is quite useful for most of our experiments.

Simple Uncertainty Example: Multiplied and Divided Quantities

First: calculate the percent uncertainty of each quantity.

$$\text{Length} = x \pm \delta x = (2.40 \pm 0.05)cm = 2.40cm \pm \frac{0.05}{2.40} \times 100 = 2.40cm \pm 2\%$$

$$\text{Width} = y \pm \delta y = (1.35 \pm 0.05)cm = 1.35cm \pm \frac{0.05}{1.35} \times 100 = 1.35cm \pm 4\%.$$

Second: add the percent uncertainties. Thus

$$\delta_{\%}A = 2\% + 4\% = 6\%.$$

$$A \pm \delta_{\%}A = 3.24cm^2 \pm 6\%$$

Comparing the simple method (6%) to the quadrature method (4 %) for this example shows that the simple method yields an uncertainty about 30% too large.

APPENDIX A: MEASUREMENT AND UNCERTAINTY

In terms of propagating error, one of the most involved experiments we perform is *Experiment 7: 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

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

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.

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

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

Note how uncertainty is determined for quantities that are multiplied, divided, or raised to a power.

APPENDIX B - COMPUTERS AND SOFTWARE:

iMac

Graphing

Graphical Analysis

APPENDIX B: COMPUTERS and SOFTWARE

iMac OPERATING INSTRUCTIONS

- To **Open** software, a file, or a folder, double click on it with the mouse.
- To **Select** something on a computer means to click on it once with the mouse.
- The **Command** key is on each side of the space bar.
- To **Close** software**: FILE → Quit** **[Command + Q]**
- To **Close** a document or folder, click on the small square at the top left of the document window, or: **FILE → Close Window**. **[Command + W]**
- To **Open** a new document: **FILE → New** **[Command + N]**
- To **Collapse** (minimize) a window, click on the top right corner of the window.
- To **Hide** (minimize) software, click on the icon in the top right corner of the desktop. **Select** hide.
- To **Re-size** a document, click and drag the bottom right corner of the window.
- To **Switch** between different programs, click on the icon in the top right corner of the desktop. All open software will be displayed. Then simply scroll down to the one you need, and select it.

When you have finished your experiment:

ALWAYS close all software: **FILE → Quit** **[Command + Q]**
(Note that closing the window is not enough.)

Close all open folders: **FILE → Close Window** **[Command+W]**
Restart the computer: **Special → Restart**

DO <u>NOT</u> TURN OFF THE COMPUTERS!

APPENDIX B: COMPUTERS and SOFTWARE

GRAPHING

Consider the point-slope 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).

A non-linear graph is a curve; 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). At the bottom of each graph write what the slope represents; if it is linear, write the numeric value also.

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. This method is used frequently; please familiarize yourself with it. When necessary, plot the point (0,0). It is usually necessary.

A properly drawn graph must have the following features:

- Title
- Axes Labels with Units
- Appropriate Scale
- Appropriate Connecting Line (Linear, Parabolic, etc.)
- 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).

Use a *best fit* connecting line when graphing data; do not "connect-the-dots".

For example, assume you are graphing *distance vs. time*. If your distance values range from 0m to 40m, your axis should span 0 to 40 meters, perhaps up to 50 m. If your time values range from 0 to 80 seconds, your time axis should span from 0 to at least 80 s. Refer to Fig. B-1 and Fig. B-2. The same data is plotted on both graphs; only the scales have changed.

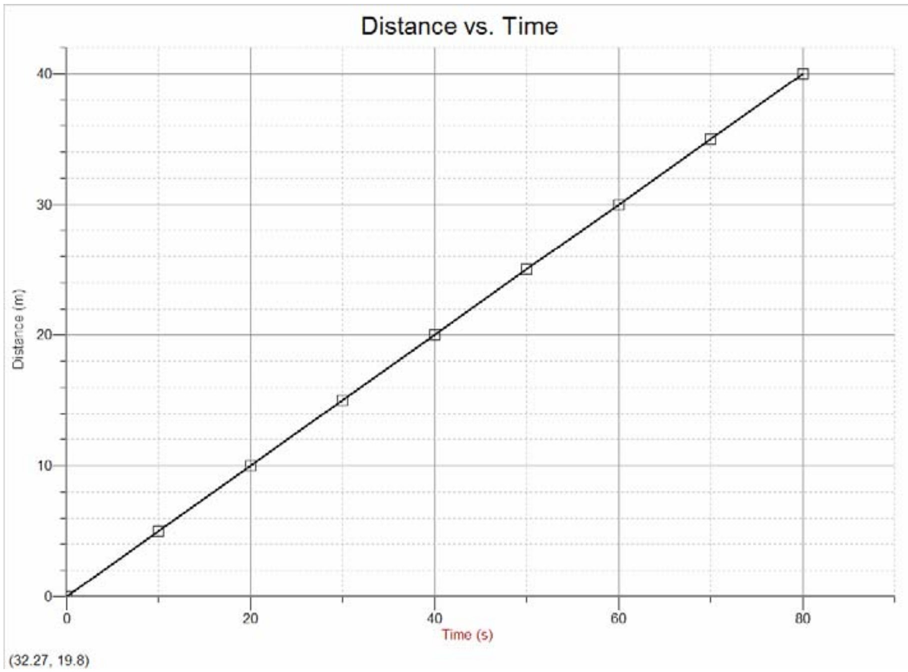
Distance vs. Time
Distance (m)
Time (s)
(32.27, 19.8)

Fig. B-1

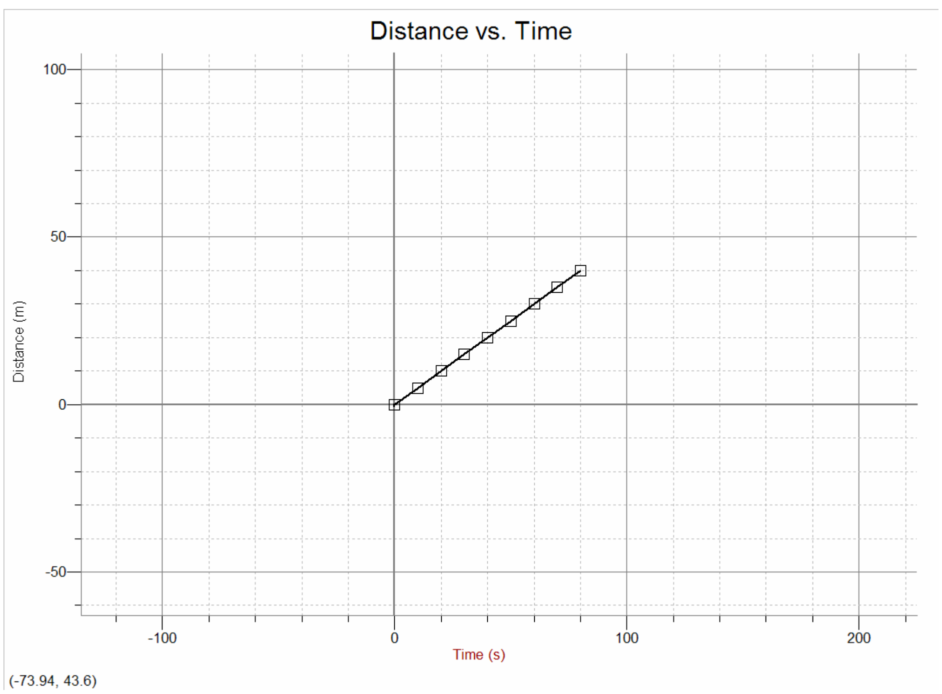
Distance vs. Time
Distance (m)
Time (s)
(-73.94, 43.6)

Fig. B-2

APPENDIX B: COMPUTERS and SOFTWARE

Graphical Analysis Instructions
When you plot data in the lab you will use software titled *Graphical Analysis 3.1*. The software is also installed on the computers in the tutoring room and is available to install on your personal computer at no charge. A link to download the software is available on the lab physicists web sites.

Double-Clicking on an appropriate area of your graph will, in general, open a window that allows you to modify that item. For example, double-clicking at the top center of the graph opens a window where you can enter the title. You may need to *Select* either the data or the graph to make it the active field when you need to set parameters specific to that field (e.g., to display multiple data sets on one graph requires that the graph be the active field, not the data).

To set the parameters for your graph, *Select* the following:

File →

Page Setup → Paper: Letter; Orientation: Landscape; Select *OK*.

Printing Options → Select *Print Footer*; Type each team members' name,

Select *Date*, *Page Title*, *Page Number*; Select *OK*.

Data →

Column Options → Select the column of data you wish to name, type the name, TAB to the *Units* field and enter the appropriate symbol for the unit; Select *Done*.

To plot multiple sets of data:

Data →

New Data Set (Multiple sets of data may be plotted on the same graph.)

Options →

Graph Options → Type a relevant title for the graph; de-select *Connect Lines* if you are graphing a known function; Select the *Axes Options* tab. This window allows you to specify which column(s) of data is plotted on the y-axis and x-axis. You will need to use this window when plotting more than one set of data on the same graph. When plotting multiple sets of data on one graph you will also need this window to designate a single y-axis label (include the symbol for the unit when using this option). Select *Done*.

When entering data that has multipliers, such as 3.1cm, type: **3.1 E exponent** (type: 3 . 1 E – 2)

The software will analyze graphs of known functions for you:

Select the graph →Analyze → Linear Fit (Curve Fit, etc.).

At the bottom of your graph write the slope value (algebraic and, if linear, numeric).

{e.g., m = 1/R = 0.00633 R = 1/m = 157.978 (unit)}

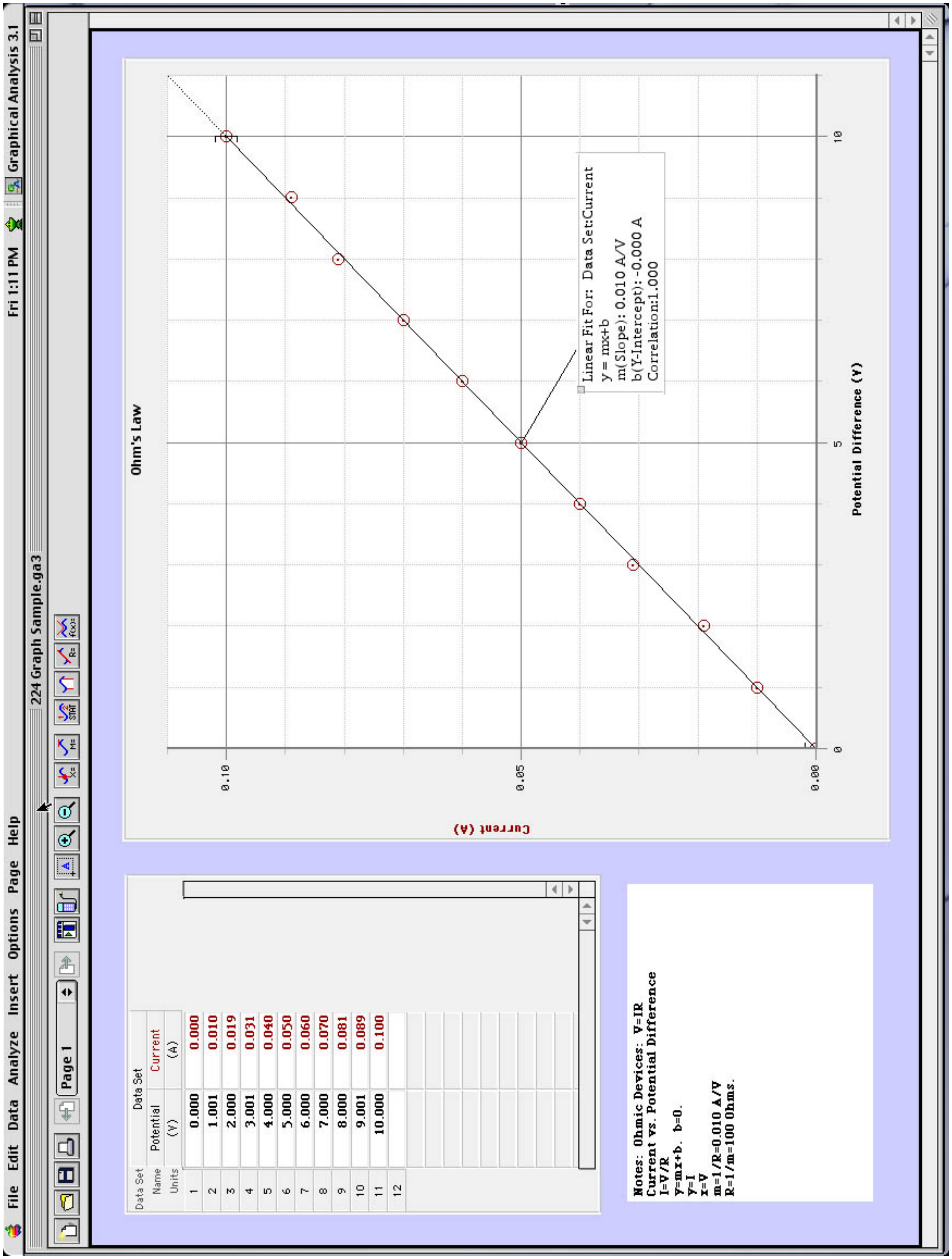
File Edit Data Analyze Insert Options Page Help
Fri 1:11 PM
Graphical Analysis 3.1
224 Graph Sample.ga3
Page 1
Ohm's Law
Linear Fit For: Data Set:Current
y = mx+b
m(Slope): 0.010 A/V
b(Y-Intercept): -0.000 A
Correlation:1.000
Current (A)
Potential Difference (V)
0.00
0.05
0.10
0
5
10
Data Set
Name
Units
Potential
(V)
Current
(A)
0.000 0.000
1.001 0.010
2.000 0.019
3.001 0.031
4.000 0.040
5.000 0.050
6.000 0.060
7.000 0.070
8.000 0.081
9.001 0.089
10.000 0.100
Notes: Ohmic Devices: V=IR
Current vs. Potential Difference
I=V/R
y=mx+b. b=0.
y=I
x=V
m=1/R=0.010 A/V
R=1/m=100 Ohms.

Fig. B-3

APPENDIX C - EQUIPMENT:

Vernier Caliper

Dial-O-Gram Balance

Digital Multi-Meter (DMM)

APPENDIX C: EQUIPMENT

The Vernier Caliper

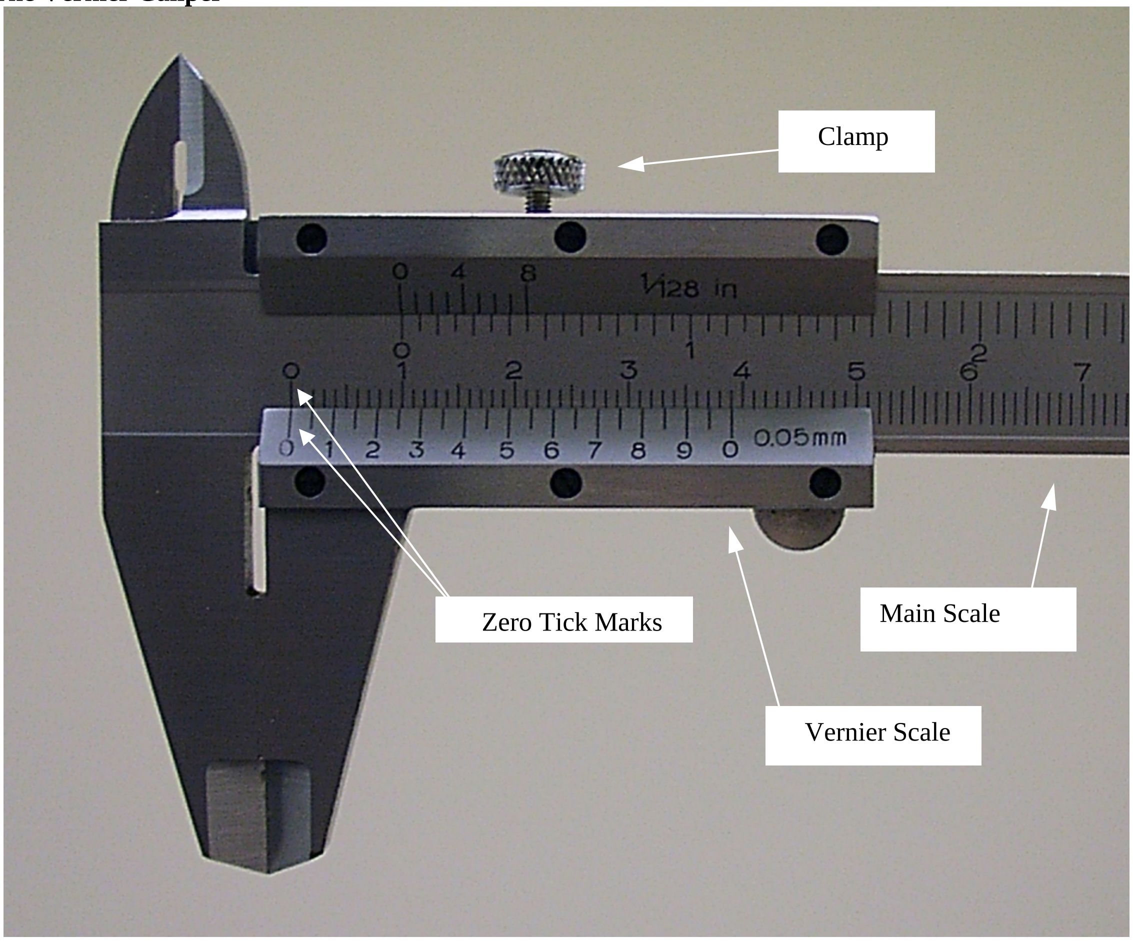

Fig. C-1: Vernier Caliper - Closed

- 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), with the exception of the caliper. The resolution of the vernier scale is 0.05 mm (equals 0.005 cm). Thus, $\delta = 0.005$ cm for the vernier caliper, allowing a measurement of *(a.bcd ± 0.005) cm*.
- Do not over-tighten the clamp. Tighten just enough that the caliper does not shift.

APPENDIX C: EQUIPMENT

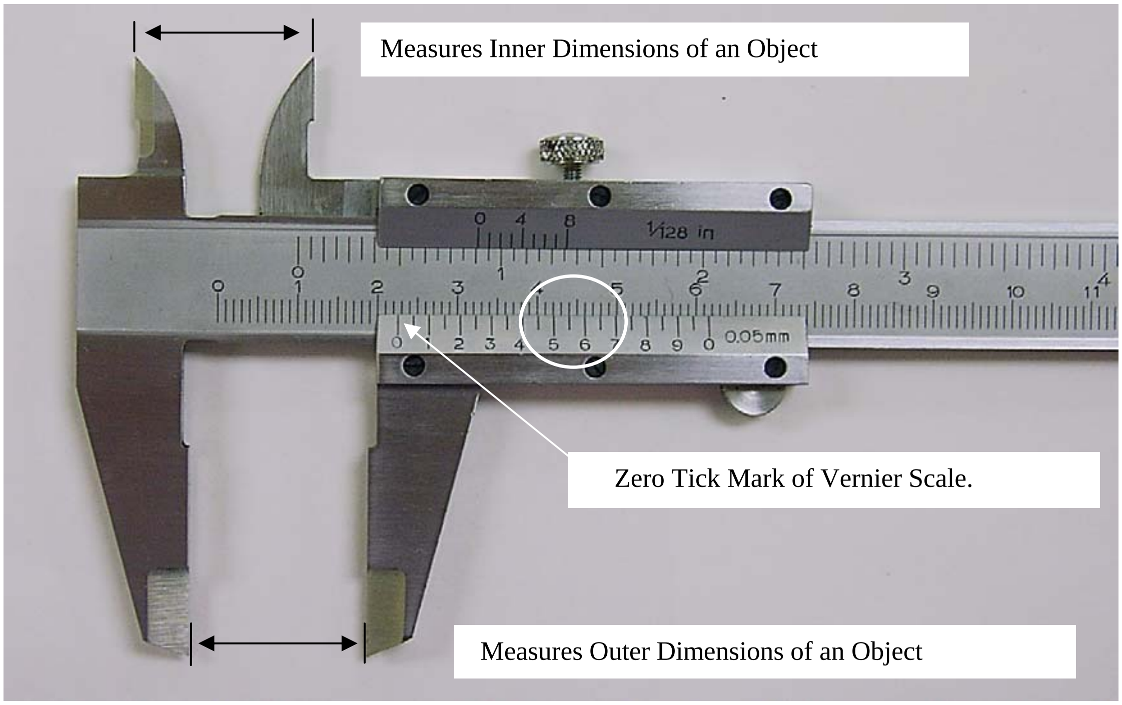

Fig. C-2: Open

- 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.
- There is a tutorial available on your lab computer: **Items for Students → YP Vernier**

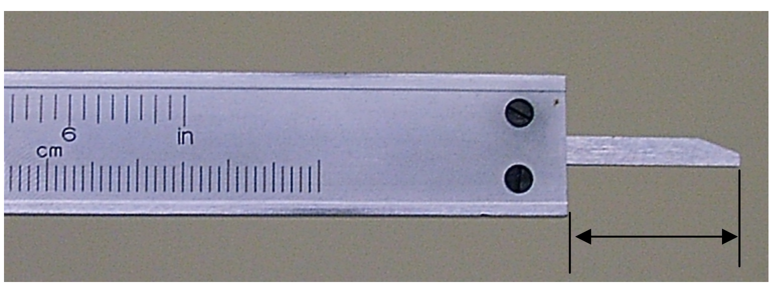

Fig. C-3: End View

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

The Dial-O-Gram Balance

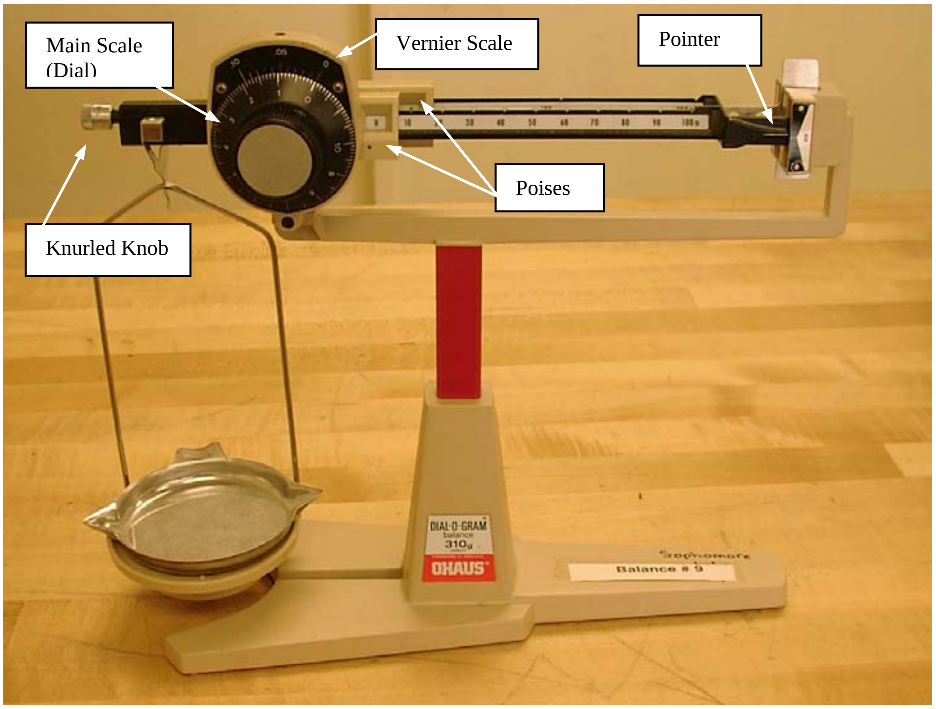

Fig. C-4 Dial-O-Gram Balance

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.

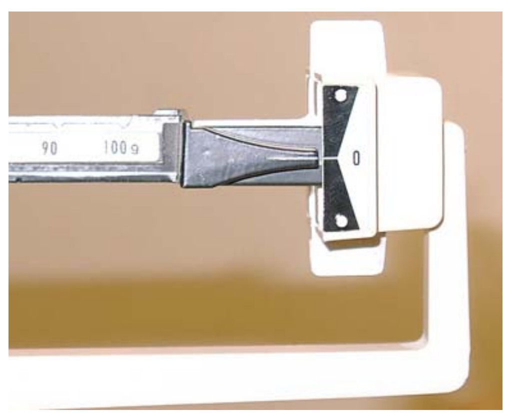

Fig. C-6 Pointer aligns with zero.

APPENDIX C: EQUIPMENT

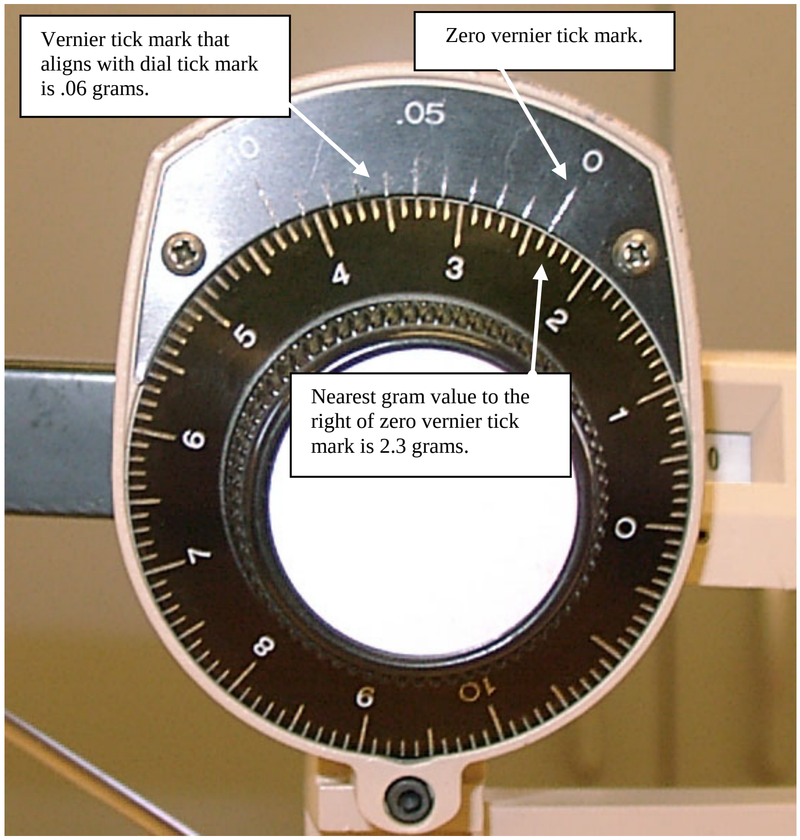

Fig. C-7 Dial and Vernier Scale

A measurement of *(a.bcd ± 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 = 2.3g).*

Add the vernier graduation value that aligns with the main scale graduation *(.06g → c=6).*

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

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).

Thus the measurement shown is *(a.bcd ± 0.005 → 2.360 ± 0.005)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 between 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* (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 circuit. 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 VΩ 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, one never measures 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

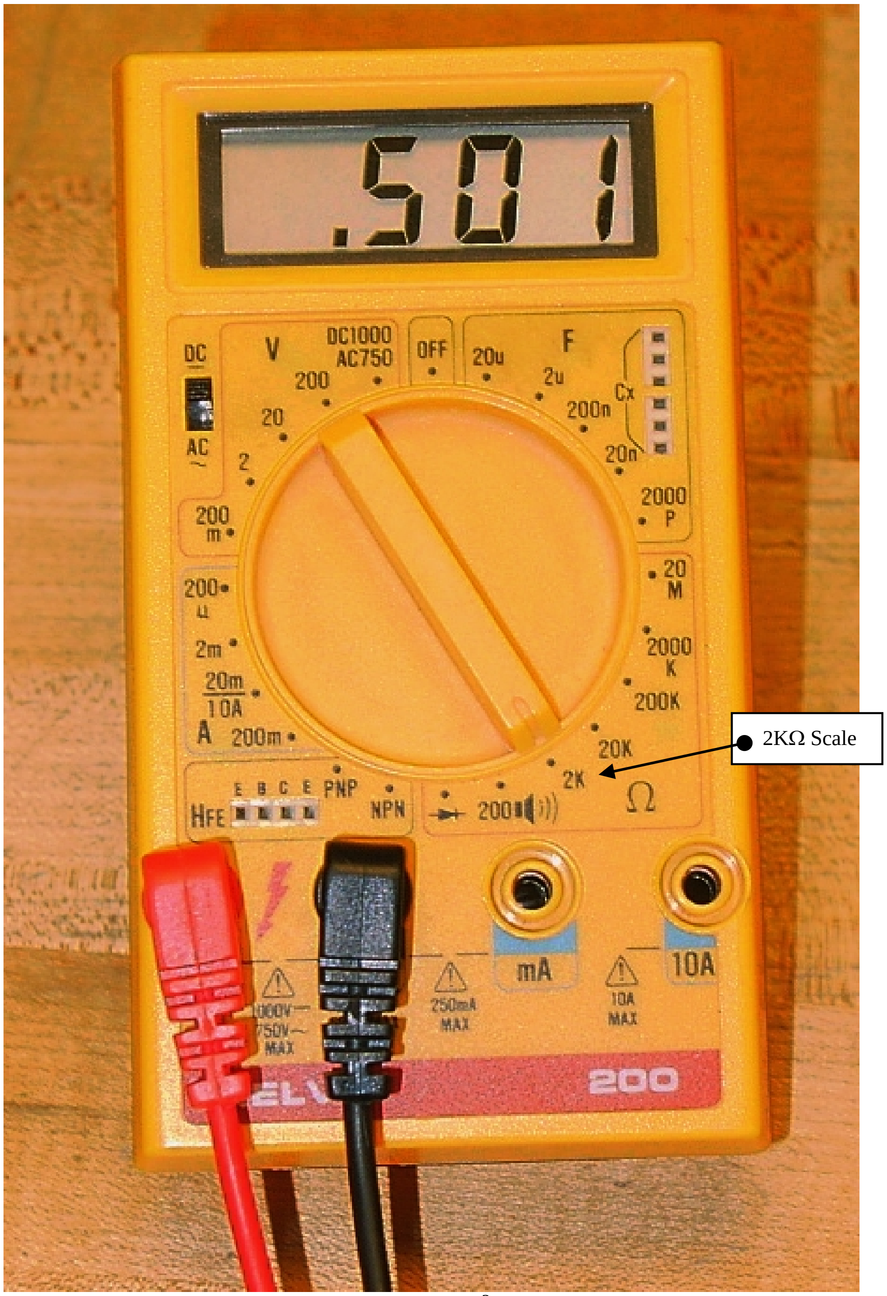

Fig. C-9: Ohmmeter Ohmmeter Reading: $0.501{\times}10^3\,\Omega = 501\ \Omega$.

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 VΩ.
- LEADS: Place leads on each end of *the same element*.

APPENDIX C: EQUIPMENT

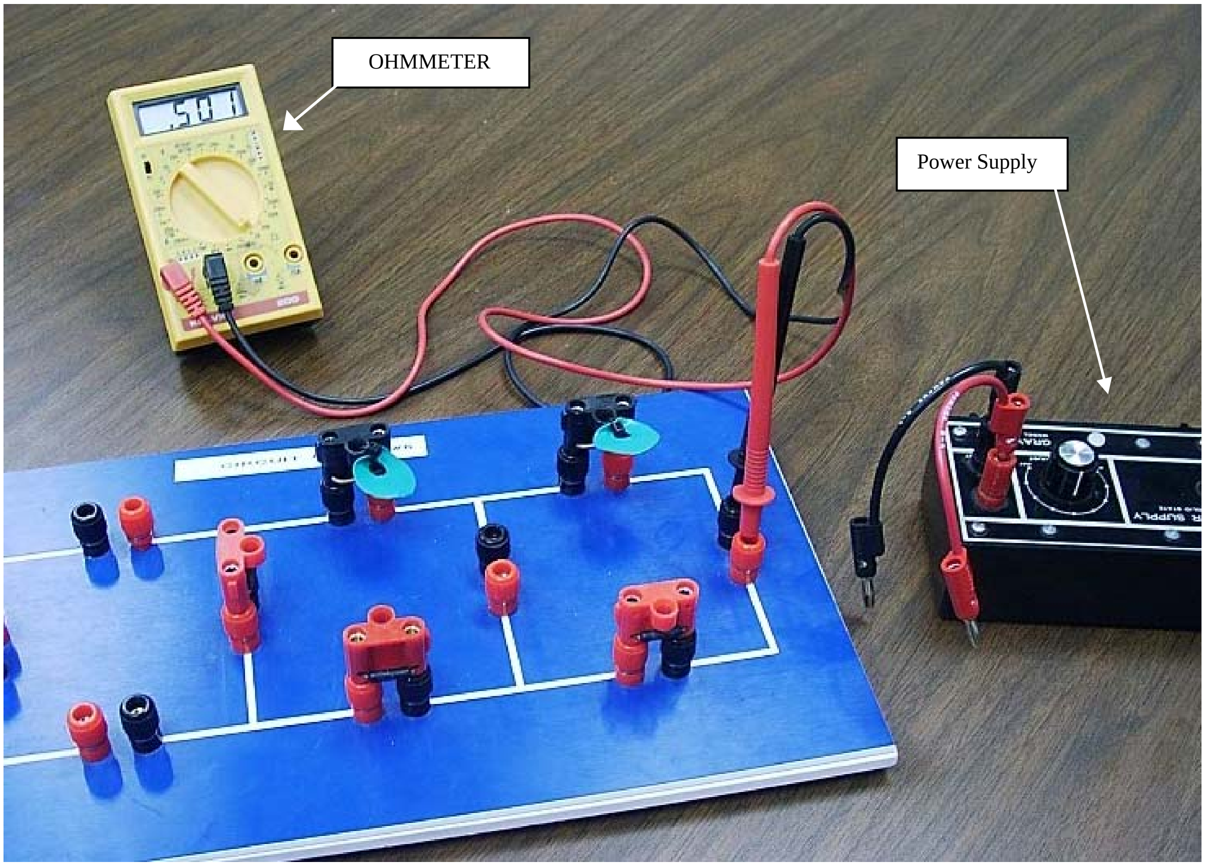

Fig. C-10: Ohmmeter and Circuit Ohmmeter Reading: 0.501 kΩ=501 Ω.
Note: Power supply is disconnected when measuring the resistance of the circuit, R_{eq}.
Note: To avoid confusion the ammeter is not shown in this figure; we will usually insert the ammeter in our circuits prior to making any measurements of the circuit.

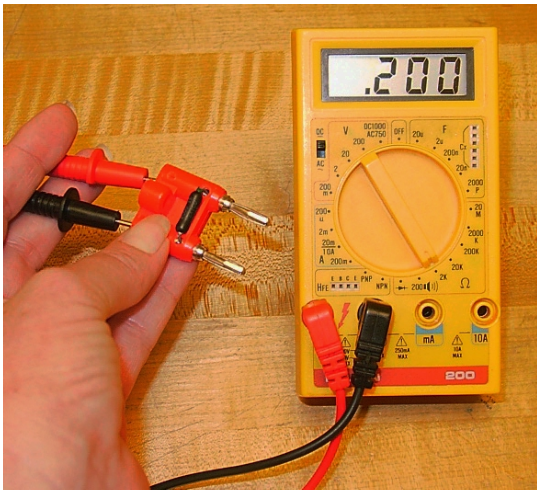

Fig. C-11: Ohmmeter and Resistor Ohmmeter Reading: 0.200 kΩ=200 Ω.
Connect ohmmeter to resistor to measure the resistance of an element, R_i.

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

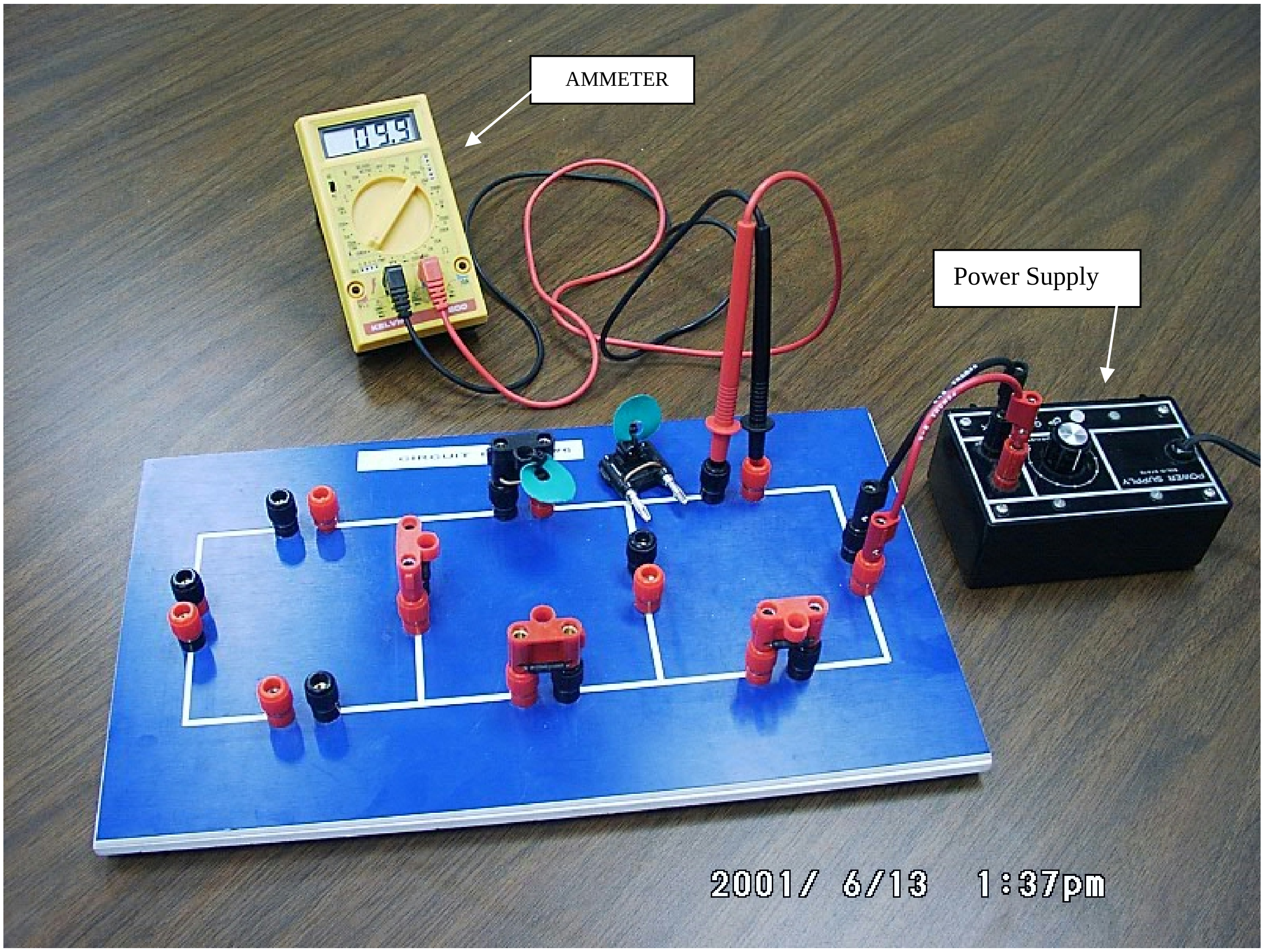

Fig. C-13: Ammeter and Circuit Ammeter Reading: 9.9 mA = 0.0099 A.

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.

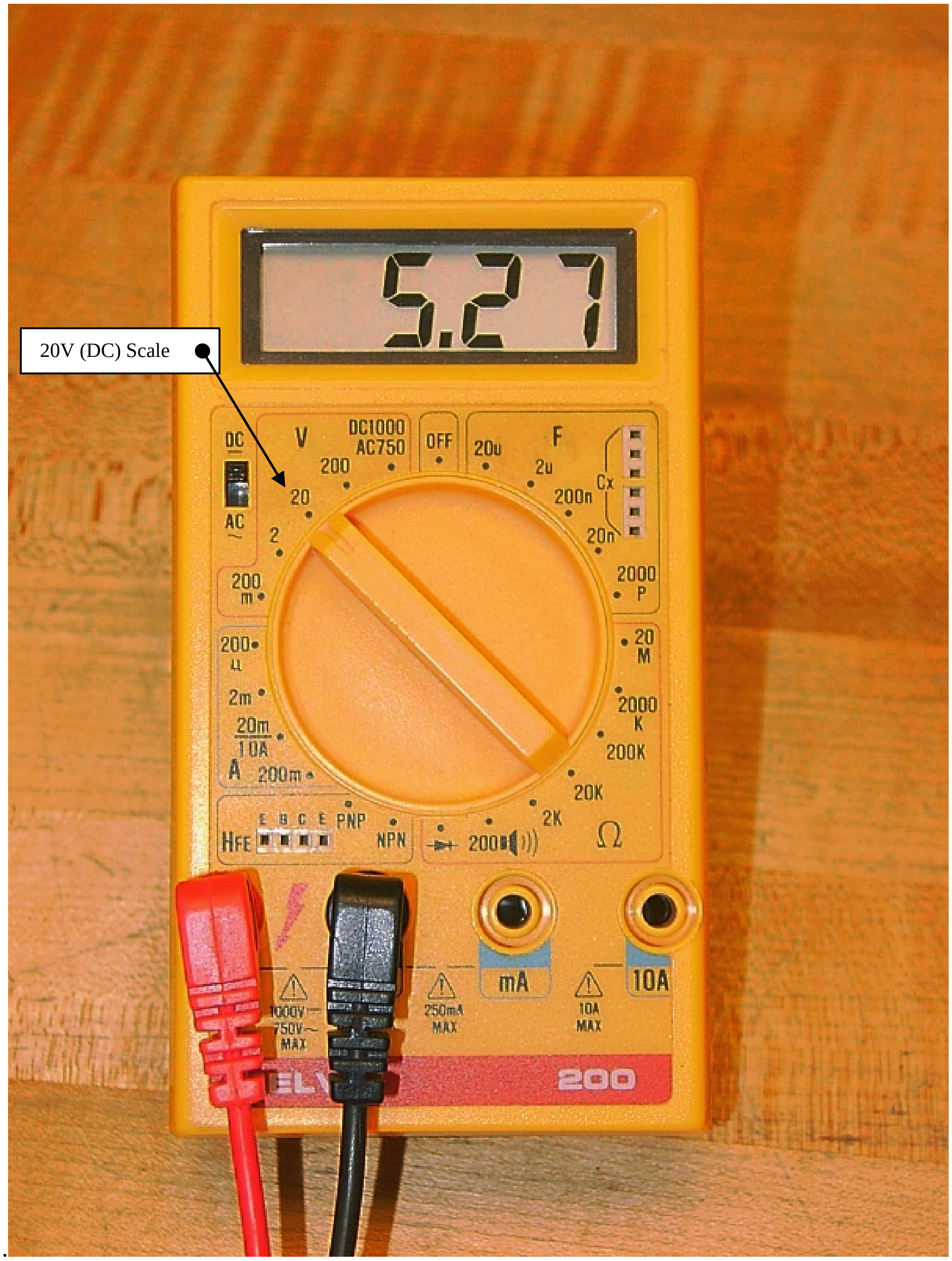

Fig. C-14: Voltmeter Voltmeter Reading: 5.27 V. (20V DCV: No multiplier.)
To use the DMM as a voltmeter, select:

- **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

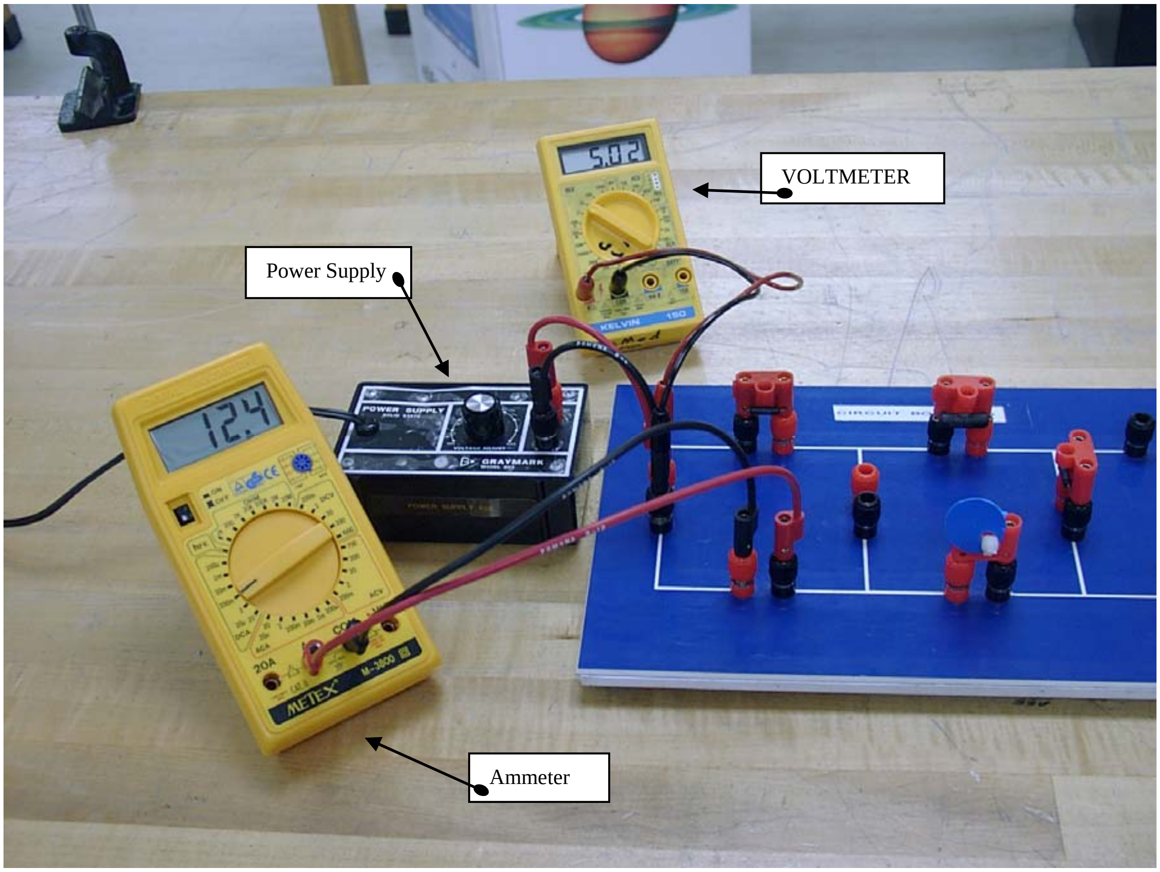

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Fig. C-15: Voltmeter and Circuit Voltmeter Reading: 5.02 V.
Note: The circuit is complete, power supply plugged in and set to specified voltage. The voltmeter is connected in parallel, as it measures voltage *across* an element in a circuit.
The ammeter 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.