Investigative Physics
Activity Units for IQS Physics-S1

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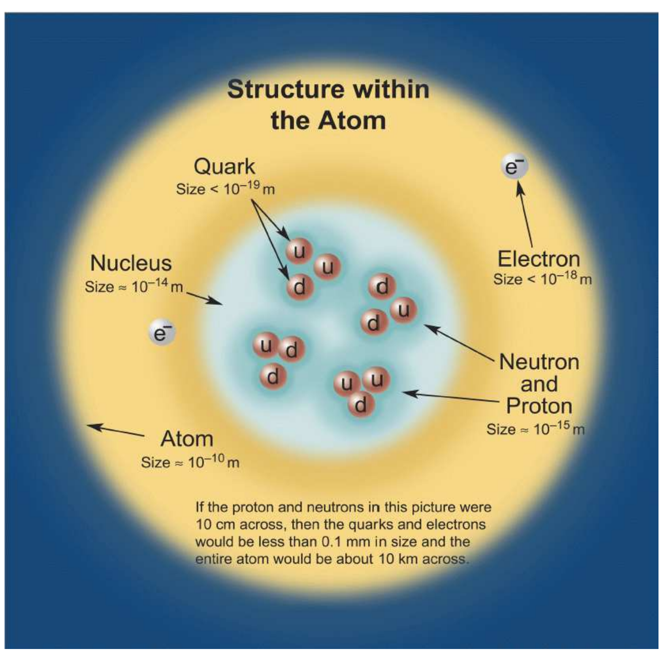
Abstract

The exercises in this manual have been developed to support an investigative physics course that emphasizes active learning. Some of these units have been taken from the Workshop Physics project at Dickinson College and the Tools for Scientific Thinking project at Tufts University and modified for use at the University of Richmond. Others have been developed locally.

The units are made up of activities designed to guide your investigations in the laboratory. The written work will consist primarily of documenting your class activities by filling in the entries in the spaces provided in the units. The entries consist of observations, derivations, calculations, and answers to questions. Although you may use the same data and graphs as your partner(s) and discuss concepts with your classmates, all entries should reflect your own understanding of the concepts and the meaning of the data and graphs you are presenting. Thus, each entry should be written in your own words. Indeed, it is very important to your success in this course that your entries reflect a sound understanding of the phenomena you are observing and analyzing.

We wish to acknowledge the support we have received for this project from the University of Richmond and the Instrumentation and Laboratory Improvement program of the National Science Foundation. Also, we would like to thank our laboratory directors for their invaluable technical assistance.



Cover art: The atom consists of smaller electrons and a nucleus consisting of protons and neutrons. The protons and neutrons, in turn, are formed from objects called quarks and gluons. Courtesy, the American Institute of Physics.

Contents

1 Stefan's Law

Name ______________________ Section ____________ Date ____________

Objective

- To discover the relationship between temperature and the radiation from a light source.

Introduction

Heat transfer via radiation is an essential process in the flow of energy in the atmosphere so it has a large impact on climate change. Stefan's Law relates the power of a radiation source $\mathscr{P}$ (the energy radiated by an object per time) to T, the absolute temperature of the object. In this experiment, you will make measurements of the power emitted from a hot object, namely a Stefan-Boltzmann Lamp, as a function of temperature and reveal that function.

Apparatus

Radiation Sensor	Stefan-Boltzmann Lamp	Ammeter (0-3 A)	Thermometer
Ohmmeter	Voltmeter (0-13 V)	Millivoltmeter	Foam insulation

Predictions

(a) The intensity of a light source is the power radiated per area. For your experiment what do you think will happen to the intensity (and the emitted power) of the lamp as the filament you turn up the voltage and it heats up? Explain your guess.

(b) How do you expect the intensity (and the power) to be related to the temperature T? Will it be linear, exponential (e^{aT}), a power law (T^n), or something else?

Activity 1: Measuring Radiation versus Temperature

To make these measurements we need a device to measure the power $\mathscr{P}$ emitted from the lamp and some way to determine the temperature of the lamp. The radiation sensor in the figure converts the light falling on it into an electrical signal proportional to the power striking the sensor. At the same time the current flowing through the lamp quickly heats the lamp to an equilibrium temperature. The electrical resistance R of the lamp changes with temperature in a known way so if we determine R we can correlate it with the temperature T.

(a) BEFORE TURNING ON THE LAMP, get T_{rel} , the room temperature in degrees Kelvin, (recall $K = ^\circ \mathrm{C} + 273$). Measure R_{rel}, the electrical resistance of the filament of the Stefan-Boltzmann Lamp at room temperature with the ohmmeter on the multimeter. See *Charge Measurements* in **Appendix E: Instrumentation** for more details. Enter your results below.

(b) Set up the equipment as shown in Figure 1. The power supply should be connected directly to the binding posts of the Stefan-Boltzmann Lamp. The voltmeter and the ammeter in the circuit are located on the power supply. The radiation sensor should be at the same height as the filament, with the front face of the radiation sensor approximately 6 cm away from the filament. The entrance angle of the radiation sensor should include no close objects other than the lamp. The ammeter to measure the current is the one on the power supply. Ask you instructor to check the setup before you plug in the power supply and energize the experiment.

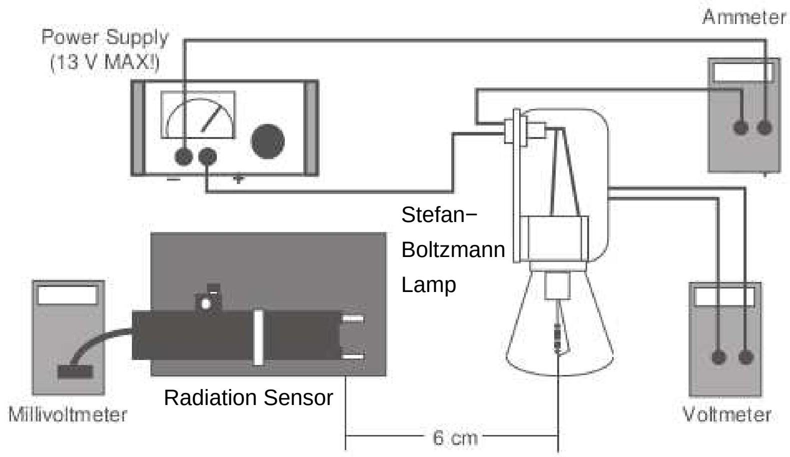


Figure 1: Equipment setup for Stefan's Law.

(c) Use Table 1 to collect your results. Fill the top row with headings V (volts), I (Amps), $\mathscr{P}$ (mV), R (ohms), R/R_{rel}, and T (K). You can also create this table in *Excel*, but make sure you save the file and print a copy to put in your notebook.

Table 1: Data table.

(d) Before turning on the power supply turn the voltage dial all the way down (counterclockwise). Now turn on the power supply. The voltage reading should be zero.

(e) To get the electrical resistance R of the lamp we will measure the voltage V and the current I through the lamp and use Ohm's Law $V = IR$ to extract R. The power $\mathscr{P}$ will be measured as a voltage from the millivoltmeter on the multimeter attached to the radiation sensor. Set the voltage on the power supply, V, to the values in the range $1-13\ V$ in steps of 1-2 volts. At each voltage setting, record the current I from the ammeter, and $\mathscr{P}$, the reading on the millivoltmeter.

IMPORTANT: Make each radiation sensor reading quickly. Between readings, place sheets of insulating foam between the lamp and the radiation sensor, with the silvered surface facing the lamp, so that the temperature of the radiation sensor stays relatively constant.

Activity 2: Extracting Stefan's Law

(a) Calculate R, the resistance of the filament at each of the voltage settings with Ohm's Law $R = V/I$. Enter your results in your table.

(b) To determine T, the temperature of the lamp filament at each voltage setting we first need to calculate the relative resistance R/R_{rel}. Do this calculation for each entry in your table and enter the results in your table. Use this ratio and the calibration curve in Figure 2 to find T. Enter your results in the table.

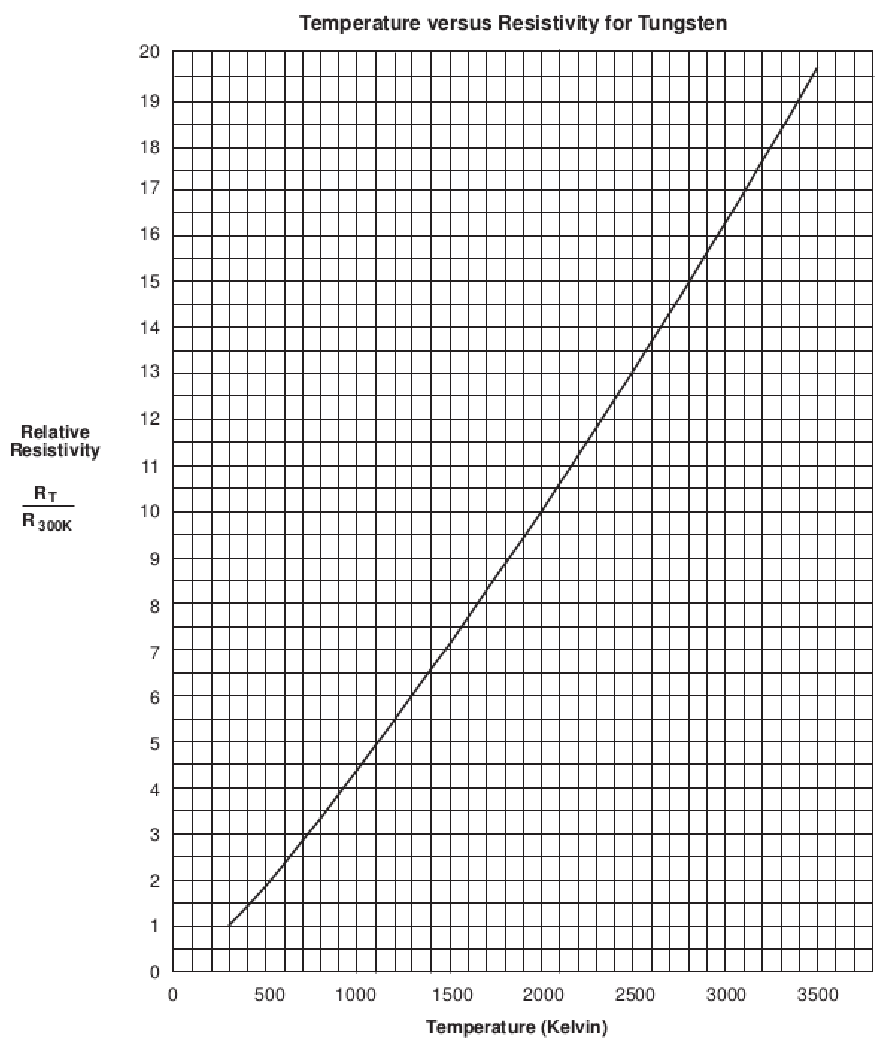


Figure 2: Calibration curve to get the filament temperature.

(c) Plot $\mathscr{P}$ versus T and fit it. Print your plot and insert it into your notebook. Record the fit here. Is the plot linear? Does it follow a power law, *i.e.* $\mathscr{P} \propto T^n$? Does it follow an exponential, *i.e.* $\mathscr{P} \propto e^{aT}$? Record your answer here.

(d) To precisely determine the mathematical form of the your data, make a semi-log plot, *i.e.* plot the common log of $\mathscr{P}$ versus T. If the data follow an exponential curve, then they will form a straight line on a semi-log plot. Show this. Print your plot and insert it into your notebook. Is this plot linear? Do your data lie on an exponential?

(e) Plot the common log of $\mathscr{P}$ versus the common log of T and fit it. This plot can be used to determine if your data follow a power law. Show this too. Print your plot and insert it into your notebook. Record the fit here.

(f) How is the slope of the plot you made in part (e) related to the temperature dependence?

(g) How do your results compare with your prediction?

(e) Stefan's Law is usually expressed as $\mathscr{P} = \sigma A e T^4$ where σ is the Stefan-Boltzmann constant, A is the surface area of the object, and e is a property of the object called the emissivity. From your analysis what did you obtain for the exponent on the temperature T? How does it compare with the expected value?

(h) Collect the results from the class, find the average and standard deviation, and record them here. Do the values agree within experimental uncertainties? Comment on possible sources of error.

(i) Clearly state an equation for Stefan's Law.

A Treatment of Experimental Data

Recording Data

When performing an experiment, record all required original observations as soon as they are made. By "original observations" is meant what you actually see, not quantities found by calculation. For example, suppose you want to know the stretch of a coiled spring as caused by an added weight. You must read a scale both before and after the weight is added and then subtract one reading from the other to get the desired result. The proper scientific procedure is to record both readings as seen. Errors in calculations can be checked only if the original readings are on record.

All data should be recorded with units. If several measurements are made of the same physical quantity, the data should be recorded in a table with the units reported in the column heading.

Significant Figures

A laboratory worker must learn to determine how many figures in any measurement or calculation are reliable, or "significant" (that is, have physical meaning), and should avoid making long calculations using figures which he/she could not possibly claim to know. *All sure figures plus one estimated figure are considered significant.*

The measured diameter of a circle, for example, might be recorded to four significant figures, the fourth figure being in doubt, since it is an estimated fraction of the smallest division on the measuring apparatus. How this doubtful fourth figure affects the accuracy of the computed area can be seen from the following example.

Assume for example that the diameter of the circle has been measured as $.526\underline{4}$ cm, with the last digit being in doubt as indicated by the line under it. When this number is squared the result will contain eight digits, of which the last five are doubtful. Only one of the five doubtful digits should be retained, yielding a four-digit number as the final result.

In the sample calculation shown below, each doubtful figure has a short line under it. Of course, each figure obtained from the use of a doubtful figure will itself be doubtful. The result of this calculation should be recorded as 0.2771 cm^2, including the doubtful fourth figure. (The zero to the left of the decimal point is often used to emphasize that no significant figures precede the decimal point. This zero is not itself a significant figure.)

$$(.526\underline{4}\ \mathrm{cm})^2 = .277\underline{09696}\ \mathrm{cm}^2 = 0.277\underline{1}\ \mathrm{cm}^2$$

In multiplication and division, the rule is that a calculated result should contain the same number of significant figures as the least that were used in the calculation.

In addition and subtraction, do not carry a result beyond the first column that contains a doubtful figure.

Statistical Analysis

Any measurement is an intelligent estimation of the true value of the quantity being measured. To arrive at a "best value" we usually make several measurements of the same quantity and then analyze these measurements statistically. The results of such an analysis can be represented in several ways. Those in which we are most interested in this course are the following:

<u>Mean</u> - The mean is the sum of a number of measurements of a quantity divided by the number of such measurements. (In other words, the mean is the same thing as what people generally call the "average.") It generally represents the best estimate of true value of the measured quantity.

<u>Standard Deviation</u> - The standard deviation (σ) is a measure of the range on either side of the mean within which approximately two-thirds of the measured values fall. For example, if the mean is 9.75 m/s^2 and the standard deviation is 0.10 m/s^2, then approximately two-thirds of the measured values lie within the range 9.65 m/s^2 to 9.85 m/s^2. A customary way of expressing an experimentally determined value is: Mean$\pm\sigma$, or (9.75$\pm$ 0.10) m/s^2. Thus, the standard deviation is an indicator of the spread in the individual measurements,

and a small σ implies high precision. Also, it means that the probability of any future measurement falling in this range is approximately two to one. The equation for calculating the standard deviation is

$$\sigma = \sqrt{\frac{\sum (x_i - \langle x \rangle)^2}{N-1}}$$

where x_i are the individual measurements, $\langle x \rangle$ is the mean, and N is the total number of measurements.

% Difference - Often one wishes to compare the value of a quantity determined in the laboratory with the best known or "accepted value" of the quantity obtained through repeated determinations by a number of investigators. *The % difference is calculated by subtracting the accepted value from your value, dividing by the accepted value, and multiplying by 100.* If your value is greater than the accepted value, the % difference will be positive. If your value is less than the accepted value, the % difference will be negative. The % difference between two values in a case where neither is an accepted value can be calculated by choosing either one as the accepted value.

B Introduction to DataStudio

Quick Reference Guide

Shown below is the quick reference guide for DataStudio.

What You Want To Do	How You Do It	Button
Start recording data	Click the 'Start' button or select 'Start Data' on the Experiment menu (or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	Start
Stop recording (or monitoring) data	Click the 'Stop' button or select 'Stop Data' on the Experiment menu (or on the keyboard press CTRL - . (period) (Win) or Command - . (Mac))	Stop
Start monitoring data	Select 'Monitor Data'on the Experiment menu (or on the keyboard press CTRL - M (Win) or Command - M (Mac))	none

On the Graph Display	In the Graph Toolbar	Button
Re-scale the data so it fills the Graph display window	Click the 'Scale to Fit' button.	
Pinpoint the x- and y-coordinate values on the Graph display	Click the 'Smart Tool' button. The coordinates appear next to the 'Smart Tool'.	
'Zoom In' or 'Zoom Out'	Click the 'Zoom In' or 'Zoom Out' buttons.	
Magnify a selected portion of the plotted data	Click the 'Zoom Select' button and drag across the data section be to magnified.	
Create a Calculation	Click the 'Calculate' button	
Add a text note to the Graph	Click the 'Note' button.	
Select from the Statistics menu	Click the Statistics menu button	
Add or remove a data run	Click the 'Add/Remove Data' menu button	Data
Delete something	Click the 'Delete' button	
Select Graph settings	Click the 'Settings' menu button	

Selecting a Section of Data

1. To select a data section, hold the mouse button down and move the cursor to draw a rectangle around the data of interest. The data in the region of interest will be highlighted.

2. To unselect the data, click anywhere in the graph window.

Fitting a Section of Data

1. Select the section of data to be fitted.

2. Click on the **Fit** button on the Graph Toolbar and select a mathematical model. The results of the fit will be displayed on the graph.

3. To remove the fit, click the **Fit** button and select the checked function type.

Finding the Area Under a Curve

1. Use the **Zoom Select** button on the Graph Toolbar to zoom in around the region of interest in the graph. See the quick reference guide above for instructions.

2. Select the section of data that you want to integrate under.

3. Click the **Statistics** button on the Graph Toolbar and select **Area**. The results of the integration will be displayed on the graph.

4. To undo the integration, click on the **Statistics** button and select **Area**.

C Introduction to Excel

Microsoft Excel is the spreadsheet program we will use for much of our data analysis and graphing. It is a powerful and easy-to-use application for graphing, fitting, and manipulating data. In this appendix, we will briefly describe how to use Excel to do some useful tasks.

C.1 Data and formulae

Figure 3 below shows a sample Excel spreadsheet containing data from a made-up experiment. The experimenter was trying to measure the density of a certain material by taking a set of cubes made of the material and measuring their masses and the lengths of the sides of the cubes. The first two columns contain her measured results. **Note that the top of each column contains both a description of the quantity contained in that column and its units.** You should make sure that all of the columns of your data tables do as well. You should also make sure that the whole spreadsheet has a descriptive title and your names at the top.

In the third column, the experimenter has figured out the volume of each of the cubes, by taking the cube of the length of a side. To avoid repetitious calculations, she had Excel do this automatically. She entered the formula `=B5∧3` into cell C5. Note the equals sign, which indicates to Excel that a formula is coming. The ∧ sign stands for raising to a power. After entering a formula into a cell, you can grab the square in the lower right corner of the cell with the mouse and drag it down the column, or you can just double-click on that square. (Either way, note that thing you're clicking on is the tiny square in the corner; clicking somewhere else in the cell won't work.) This will copy the cell, making the appropriate changes, into the rest of the column. For instance, in this case, cell C6 contains the formula `=B6∧3`, and so forth.

Column D was similarly produced with a formula that divides the mass in column A by the volume in column C.

At the bottom of the spreadsheet we find the mean and standard deviation of the calculated densities (that is, of the numbers in cells D5 through D8). Those are computed using the formulae `=average(D5:D8)` and `=stdev(D5:D8)`.

C.2 Graphs

Here's how to make graphs in Excel. For those who've used earlier version of Excel but not Excel 2007, note that the locations of some of the menu items have changed, although the basic procedure is similar.

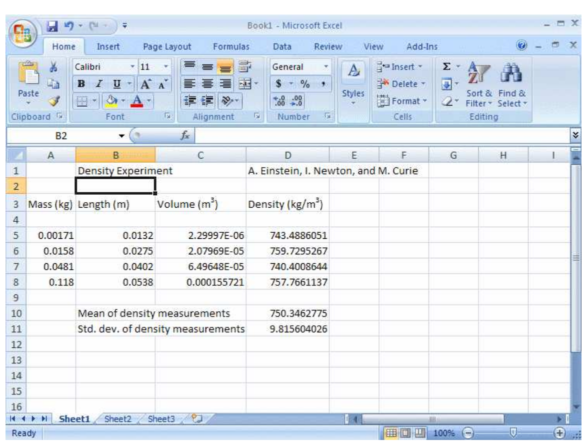


Figure 3: Sample Excel spreadsheet

First, use the mouse to select the columns of numbers you want to graph. (If the two columns aren't next to each other, select the first one, then hold down the control key while selecting the second one.) Then click on the `Insert` tab at the top of the window. In the menu that shows up, there is a section called `Charts`. Almost all of the graphs we make will be scatter plots (meaning plots with one point for each row of data), so click on the `Scatter` icon. You'll see several choices for the basic layout of the graph. You usually want the first one, with an icon that looks like this . Click on this icon, and your graph should appear.

Next, you'll need to customize the graph in various ways, such as labeling the axes correctly. Everything you need to do this is in the `Chart Tools` menu, which should be visible in the upper right portion of the window. (If you don't see the words `Chart Tools`, try clicking on your newly-created graph, and it should appear.) The most useful items are under the `Layout` tab, so click on the word `Layout` under the `Chart Tools` menu. Here are some things to do under this menu:

- The most important item here is the `Axis Titles` menu. You can use this to add labels to the x and y axes of your graph, if it doesn't already have them. Edit the text inside of the two axis titles so that it indicates what's on the two axes of your graph *and the appropriate units.*
- It's probably a good idea to give your graph an overall title as well. The options for doing this are under `Chart Title` (not surprisingly).
- If the graph contains only one set of data points, you may wish to remove the legend that appears at the right side of the graph. After all, the information in the legend is probably already contained in the title and axis labels, so the legend just takes up space. Go to the `Legend` menu and click `None` to do this.
- Sometimes, you want your graph to contain a best-fit line passing through your data points. To do this, go to the `Trendline` menu. The easiest thing to do is to click on `More trendline options` at the bottom, which will bring up a dialog box with a bunch of choices. Excel can fit various kinds of curves through data points, but we almost always want a straight line, so you'll probably choose the `Linear` option. If you want to see the equation that describes this line, check the `Display Equation on chart` option near the bottom. Remember that Excel won't include the correct units on the numbers in this equation, but you should. Also, Excel will always call the two variables x and y, even though they might be something else entirely. Bear these points in mind when transcribing the equation into your lab notebook.

Sometimes, you may want to make a graph in Excel where the x column is to the right of the y column in your worksheet. In these cases, Excel will make the graph with the x and y axes reversed. There are at least two ways to fix this problem. Here's the simpler way: before you make your graph, make a copy of the y column in the worksheet and paste it so that it's to the right of the x column. Then follow the above procedure and everything will be fine. If you don't want to do that, here's another way. Click `Select data` (near the left-hand side under the Chart Tools menu). In the box that pops up, highlight `Series1` and click `Edit`. You should see a box that contains entries for `Series X values` and `Series Y values`. You want to swap the entries in those two windows. (But really, it's much easier to do it the first way.)

C.3 Making Histograms

A histogram is a useful graphing tool when you want to analyze groups of data, based on the frequency at given intervals. In other words, you graph groups of numbers according to how often they appear. You start by choosing a set of 'bins', *i.e.*, creating a table of numbers that mark the edges of the intervals. You then go through your data, sorting the numbers into each bin or interval, and tabulating the number of data points that fall into each bin (this is the frequency). At the end, you have a visualization of the distribution of your data.

Start by entering your raw data in a column like the one shown in the left-hand panel of Figure 4. Look over your numbers to see what is the range of the data. If you have lots of values to sift through you might consider sorting your data is ascending or descending order. To do this task, choose the column containing your data by clicking on the letter at the top of the column, go to `Data` in the menubar, select `Sort`, and pick ascending or descending. The data will be rearranged in the order you've chosen and it will be easier to see the range of the data. For an example, see the middle column of data in the left-hand panel of Figure 4. Now to create your bins pick a new column on your spreadsheet and enter the values of the bin edges. Make sure the bins you choose cover the range of the data. See the left-hand panel of Figure 4 again for an example.

You now have the ingredients for making the histogram. Go to `Data` in the menubar, select `Data Analysis`, and choose `Histogram`. You should see a dialog box like the one in the right-hand panel of Figure 4. Click in the box labeled `Input Range` and then highlight the column on the spreadsheet containing your data. Next, click in the box labeled `Bin Range` and highlight the column on the spreadsheet containing the bins. Under `Output Options`, select `New Worksheet Ply` and give the worksheet a name. Click `OK` in the `Histogram` dialog box. You should now see a new worksheet with columns labeled `Bin` and `Frequency` and a new tab at the bottom with the name you put in the `New Worksheet Ply` entry. See the left-hand panel in Figure 5. Your original data are still available on another worksheet (probably labeled `Sheet1`). Now highlight the `Bins` and `Frequency` columns by clicking and dragging across the column headings (the `A` and `B` at the top of the columns in the left-hand panel of Fig. 5). You can then make a graph by following the procedure in Appendix C.2 above. The only difference is that this time you will choose to make a `Column` graph instead of a `Scatter` graph. Make sure you properly label the axes including the units for each quantity. Results should look like the right-hand panel of Figure 5.

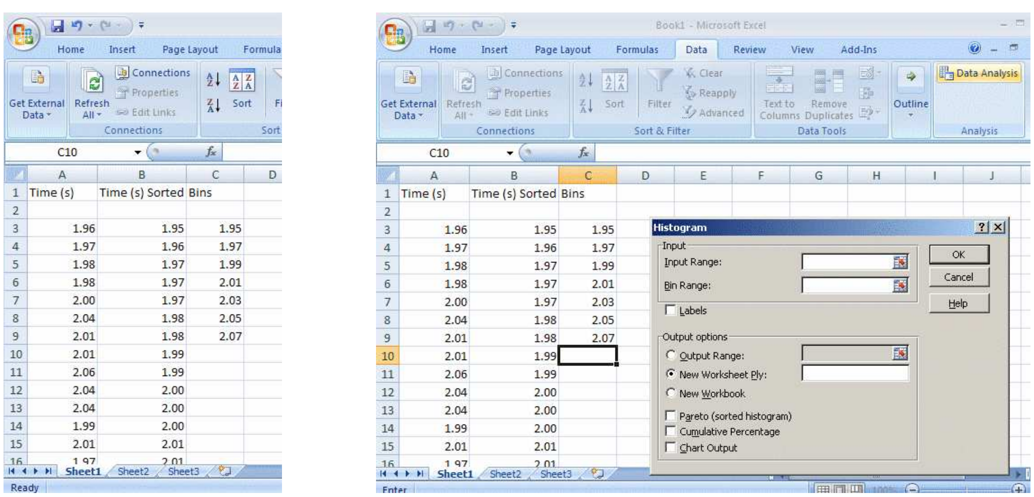


Figure 4: Column data and bins (left-hand panel) and dialog box (right-hand panel) for making a histogram in Excel.

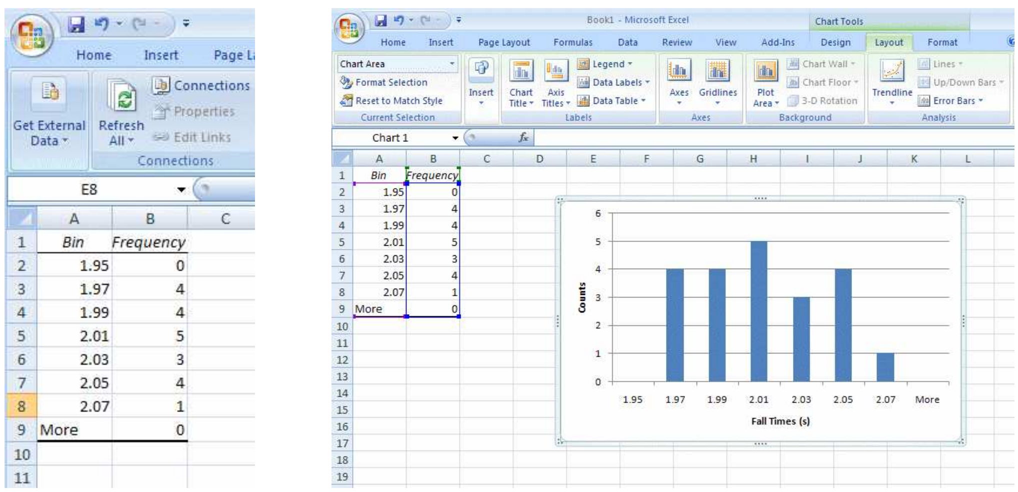


Figure 5: Newly-created worksheet (left-hand panel) and final plot (right-hand panel) for histogram worksheet in Excel.

D Video Analysis

Making a Movie with "Windows Live Movie Maker"

To make a movie, perform the following steps:

1. Make sure the camera is connected to a USB port on your computer. Close all windows, applications, programs, and browsers.
2. Click the **Start** button in the lower-left corner of your screen and type 'movie maker' in the Search programs and files box. Once the search results appear, click on **Windows Live Movie Maker** under **Programs**. After movie maker starts, close any pop-up windows that may appear.
3. Click the **Webcam Video** button. A webcam video window opens. Enlarge the video frame by dragging the vertical line on the right side of the video frame.
4. Position the camera 2-3 meters from the object you will be viewing. Adjust the camera height and orientation so that the field of view is centered on the expected region where the object will move.
5. Place a meter stick or an object of known size in the field of view where it won't interfere with the experiment. The meter stick should be the same distance away from the camera as the motion you are analyzing so the horizontal and vertical scales will be accurately determined. It should also be parallel to one of the sides of the movie frame. Make sure that the meter stick is not far away from the central region of field of view, and that it is perpendicular to the line of sight of camera.
6. One member of your group should perform the computer tasks while the other does the experiment.
7. To start recording your video, click **Record**. When you are done, click **Stop**.

   Save the video on your Desktop with a unique name that you can easily identify. The video will be saved in Windows Media Video format, i.e. with extension wmv. (Do not save the video as a Movie Maker Project file.)

Analyzing the Movie

To determine the position of an object at different times during the motion, perform the following steps:

1. Start up Tracker by going to **Start** → **All Programs** → **Physics Applications** → **Tracker**. When **Tracker** starts it appears as shown below. The menu icons and buttons that we will use are identified by arrows.
2. Click the **Open Video** button on the toolbar (see figure below) to import your video. After your video is imported, Tracker will warn you that the video frames don't have the same time duration. This is okay since Windows Live Movie Maker uses a variable frame rate. Click **Close** on the warning window to ignore Tracker's recommendation.
3. Click the **Clip Settings** button (see figure below) to identify the frames you wish to analyze. A clip settings dialog box appears. Here, you only need to identify and set the start and end frames. Leave everything else in the dialog box unchanged. To find and set the start frame, drag the player's left slider to scan forward through the video, and stop when you get to the first frame of interest. Now, the start frame is set and the corresponding frame number should be displayed in the dialog box. If not, then click on the **Start Frame** in the dialog box, enter the number of the frame (printed in the lower right part of the Tracker window), and click outside the box. Then, click the **Play video** button to go to the last frame in the video. Next, drag the player's right slider to scan backward through the video to find the last frame of interest. Stop when you get to the frame of interest. Now, the end frame is also set and the corresponding frame number should be displayed in the dialog box. If not, then click on the **End Frame** in the dialog box, enter the number of the frame, and click outside the box. Finally, click the **OK** button to close the dialog box, and then click the player's **Return** button to return to the start frame.

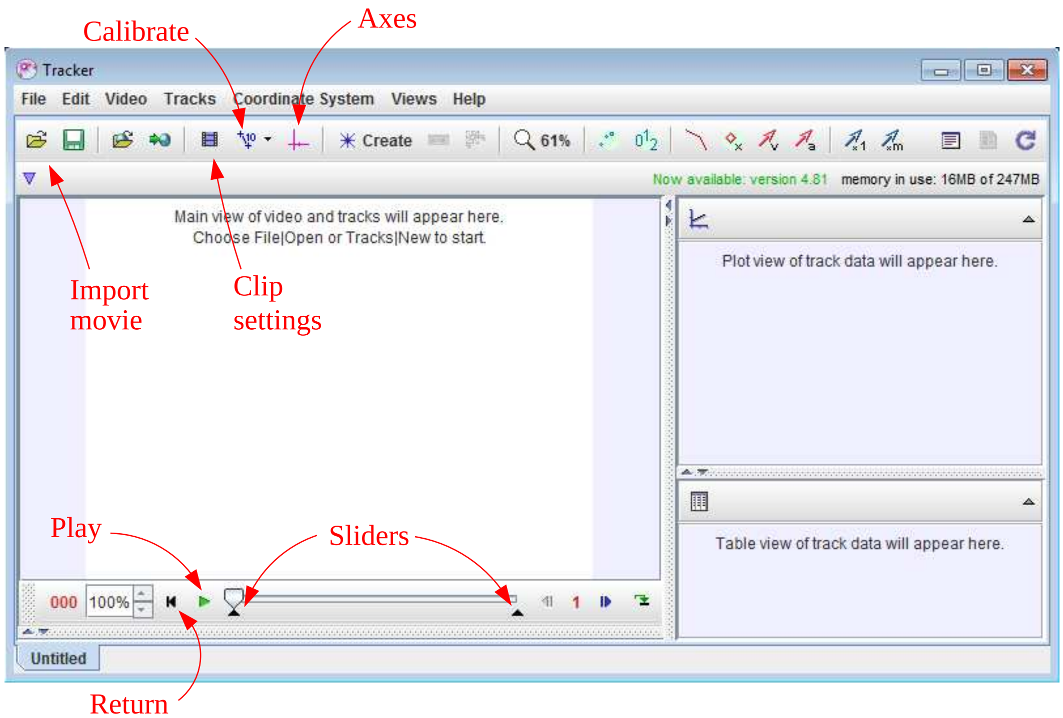


Figure 6: Initial **Tracker** window for video analysis.

4. Click the **Calibration** button (see the figure) and select the **calibration stick**. A blue calibration line appears on the video frame. Drag the ends of this blue line to the ends of your calibration meter stick. Then click the readout box on the calibration line to select it. Enter the length of the meter stick in this box (without units). For example, if your calibration meter stick is 1.00 meter long, enter 1.00 in the box and then click outside the box to accept the value or hit **Return**. At this point, you can right-click the video frame to zoom in for more accurate adjustment of the ends of the calibration stick. Right-click the video again to zoom out.

5. Click the **Axes** button (see the figure) to set the origin and orientation of the x-y coordinate axes. Drag the origin of the axes to the desired position (in most cases the initial position of the object of interest). Click the video outside the origin to fix the position of the origin. To change the orientation (angle) of the axes, drag the x axis. Click the video to fix the new orientation.

6. Click the **Create** button (see the figure) to track the object of interest in the video. From the menu of choices select **Point Mass** for the track type. Make sure the video is at the start frame, which shows the initial position of the object of interest. Mark this position by holding down the **shift key** and clicking the mouse (crosshair cursor) on the object. As the position is marked, the video automatically advances to the next frame. Similarly, mark the position of the object on this and subsequent frames by holding down the **shift key** and clicking the mouse. Do not skip any frames.

   After marking the position on the end frame, you can adjust any one of the marked positions. Advance the video to the frame where you would like to make a fine adjustment. Right-click the video frame to zoom in and drag the marked position with the mouse.

   If you would like to track additional objects, repeat the procedure outlined here for each object.

7. **Plotting and Analyzing the Tracks:** The track data (position versus time) are listed in the Table View and plotted in Plot View sections of the Tracker screen. Click the vertical axis label of the plot to change the variable plotted along that axis. To plot multiple graphs, click the **Plot** button, located above the plot, and select the desired number.

Right-click on a plot to access display and analysis options in a pop-up menu. To fit your data to a line, parabola, or other functions, select the **Analyze** option. On the Data-Tool window that opens up, click on the **Analyze** tab at the top of the plot and check the **Curve Fits** box. Select the fit type from the **Fit Name** drop-down menu. Make sure the **Auto Fit** box is checked.

Note that the curve fitter fits the selected function to the data in the two leftmost columns of the displayed data table. The leftmost column, identified by a yellow header cell, defines the independent variable, and the second leftmost column, identified by a green header cell, defines the dependent variable. So, to fit the data in other columns, their corresponding headers must be dragged to the two leftmost columns.

8. **Printing and Exporting Data:** Track data can also be easily exported to Excel for further analysis by copying the data from the data table to the clipboard and pasting into Excel. Click the **Table** button, located above the data table in the table view section of the main screen, and select from the displayed list the data you would like to display in the data table. Select the desired data in the table by clicking and dragging, then right-click and choose **Copy Data** from the pop-up menu. Now, paste the data into Excel. To print out the displayed plot or data table on Tracker's screen, right-click on the plot or table and choose Print from the pop-up menu.

E Instrumentation

Introduction

Being both quantitative and experimental, physics is basically a science of measurement. A great deal of effort has been expended over the centuries improving the accuracy with which the fundamental quantities of length, mass, time, and charge can be measured.

It is important that the appropriate instrument be used when measuring. Ordinarily, a rough comparison with a numerical scale, taken at a glance and given in round numbers, is adequate. Increasing precision, though, requires a more accurate scale read to a fraction of its smallest division. The “least count” of an instrument is the smallest division that is marked on the scale. This is the smallest quantity that can be read directly without estimating fractions of a division.

Even at the limit of an instrument’s precision, however, accidental errors — which cannot be eliminated — still occur. These errors result in a distribution of results when a series of seemingly identical measurements are made. The best estimate of the true value of the measured quantity is generally the arithmetic mean or average of the measurements.

Other errors, characteristic of all instruments, are known as systematic errors. These can be minimized by improving the equipment and by taking precautions when using it.

Length Measurement

Three instruments will be available in this class for length measurements: a ruler (one- or two-meter sticks, for example), the vernier caliper, and the micrometer caliper.

The Meter Stick

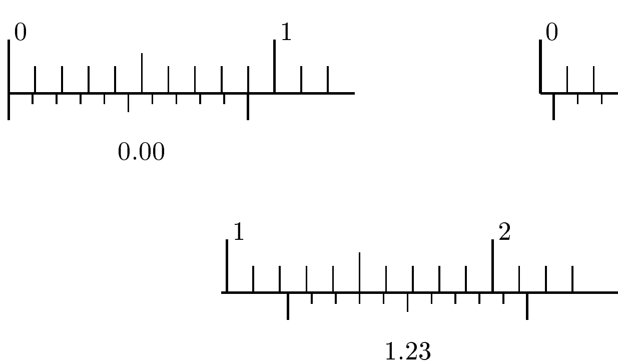
A meter stick, by definition, is 1 meter (m) long. Its scaled is divided, and numbered, into 100 centimeters (cm). Each centimeter, in turn, is divided into 10 millimeters. Thus 1 cm $= 10^{-2}$ m, and 1 mm $= 10^{-1}$ cm $= 10^{-3}$ m.

When measuring a length with a meter stick, different regions along the scale should be used for the series of measurements resulting in an average value. This way, non-uniformities resulting from the meter stick manufacturing process will tend to cancel out and so reduce systematic errors. The ends of the stick, too, should be avoided, because these may be worn down and not give a true reading. Another error which arises in the reading of the scale is introduced by the positioning of the eyes, an effect known as parallax. Uncertainty due to this effect can be reduced by arranging the scale on the stick as close to the object being measured as possible.

The Vernier Caliper

A vernier is a small auxiliary scale that slides along the main scale. It allows more accurate estimates of fractional parts of the smallest division on the main scale.

On a vernier caliper, the main scale, divided into centimeters and millimeters, is engraved on the fixed part of the instrument. The vernier scale, engraved on the movable jaw, has ten divisions that cover the same spatial interval as nine divisions on the main scale: each vernier division is $\frac{9}{10}$ the length of a main scale division. In the case of a vernier caliper, the vernier division length is 0.9 mm. [See figures below.]



Examples of vernier caliper readings

To measure length with a vernier caliper, close the jaws on the object and read the main scale at the position indicated by the zero-line of the vernier. The fractional part of a main-scale division is obtained from the first vernier division to coincide with a main scale line. [See examples above.]

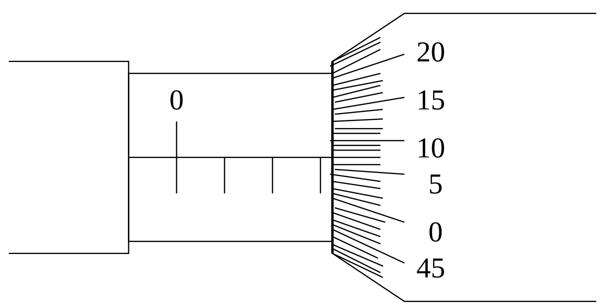
If the zero-lines of the main and vernier scales do not coincide when the jaws are closed, all measurements will be systematically shifted. The magnitude of this shift, called the zero reading or zero correction, should be noted and recorded, so that length measurements made with the vernier caliper can be corrected, thereby removing the systematic error.

The Micrometer Caliper

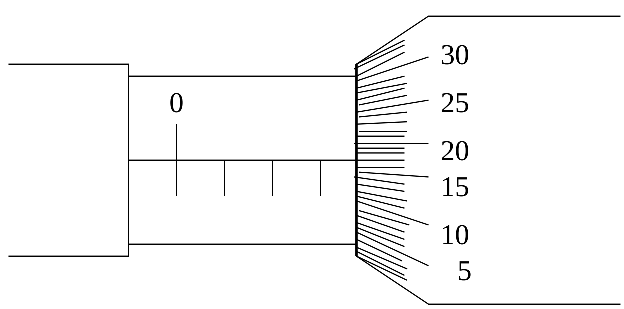
A micrometer caliper is an instrument that allows direct readings to one hundredth of a millimeter and estimations to one thousandth of a millimeter or one millionth of a meter (and, hence, its name). It is essentially a carefully machined screw housed in a strong frame. To measure objects, place them between the end of the screw and the projecting end of the frame (the anvil). The screw is advanced or retracting by rotating a thimble on which is engraved a circular scale. The thimble thus moves along the barrel of the frame which contains the screw and on which is engraved a longitudinal scale divided in millimeters. The pitch of the screw is 0.5 mm, so that a complete revolution of the thimble moves the screw 0.5 mm. The scale on the thimble has 50 divisions, so that a turn of one division is $\frac{1}{50}$ of 0.5 mm, or 0.01 mm.

Advance the screw until the object is gripped gently. Do not force the screw. A micrometer caliper is a delicate instrument.

To read a micrometer caliper, note the position of the edge of the thimble along the longitudinal scale and the position of the axial line on the circular scale. The first scale gives the measurement to the nearest whole division; the second scale gives the fractional part. It takes two revolutions to advance one full millimeter, so note carefully whether you are on the first or second half of a millimeter. The result is the sum of the two scales. (See examples below).



0.307 cm



0.367 cm

As with the vernier caliper, the zero reading may not be exactly zero. A zero error should be checked for and recorded, and measurements should be appropriately corrected.

Mass Measurement

Three kinds of instruments will be available to determine mass: a digital scale and two types of balances. The operation of the first instrument is trivial, and so will not be explained here.

Please understand that with each of these instruments we are really comparing weights, not masses, but the proportionality of weight and mass allows the instruments to be calibrated for mass.

The Equal-Arm Balance

The equal-arm balance has two trays on opposite sides of a pivot. The total mass placed on one tray required to balance the object on the other gives the mass of the object. Most equal-arm balances have a slider, as well, that can move along a scale and allow for greater precision than the smallest calibrated mass available. Typically, this scale has 0.5 g divisions.

The Triple-Beam Balance

The triple-beam balance, so-called because of its three slider scales, can be read to 0.1 g and estimated to half that. With an object on the tray, the masses of the different scales are slid to notches until balanced. Get close with the larger masses first and then fine-adjust with the smallest slider.

Time Measurement

Time measurements in this course will be made either with a computer or with a stop watch. This first is out of your control.

The Stop Watch

The stop watches you will use in class have a time range of from hours to hundredths of a second. There are two buttons at the top: a stop/start button and a reset button. The operation of these should be evident, although once the watch is reset, the reset button also starts the watch (but doesn't stop it). Please be aware of this feature.

Charge Measurements

The magnitude of charge is among the most difficult measurements to make. Instead a number of indirect measurements are undertaken to understand electric phenomena. These measurements are most often carried out with a digital multimeter

The Digital Multimeter

The digital multimeters available for laboratory exercises have pushbutton control to select five ac and dc voltage ranges, five ac and dc current ranges, and six resistance ranges. The ranges of accuracy are 100 microvolts to 1200 volts ac and dc, 100 nanoamperes to 1.999 amperes ac and dc, and 100 milliohms to 19.99 megaohms.

To perform a DC voltage measurement, select the DCV function and choose a range maximum from one of 200 millivolts or 2, 20, 200, or 1200 volts. Be sure the input connections used are V-Ω and COMMON. The same is true for AC voltage, regarding range and inputs, but the ACV function button should be selected.

For DC current choose DC MA (for DC milliamperes), while for AC current choose AC MA. Your choices for largest current are 200 microamperes or 2, 20, 200, or 2000 milliamperes. Check that the input are connected to MA and COMMON.

There are two choices for resistance measurement: Kilohms (kΩ) and Megohms (20MΩ). The input connectors are the same as when measuring voltage, namely V-Ω and COMMON. The range switches do not function with the Megohm function, but one of the range buttons must be set. The maximum settings for Kilohm readings are 200Ω or 2, 20, 200, or 2000kΩ.

Calibrating Force Sensors

1. Connect force sensor to Pasco interface (in port “A”).

2. Open the *DataStudio* application that you will use to perform the lab.

3. With NO force applied to force sensor, press TARE button on side of force sensor. This sets the sensor to zero. This is the ONLY time you will press the TARE button.

4. Click “Setup”.

5. Click “Calibrate Sensors”.

6. Set 1st calibration point to 0 newtons, press upper “Read from sensor” button.

7. HOLDING SENSOR VERTICALLY (with hook down), hang 200g from sensor, set 2nd calibration point to 1.96 newtons, press lower “Read from sensor” button.

8. Click “OK”. Force sensor is now calibrated for the rest of your experiment. Close “Calibrate Sensors” window, close “Setup” window.

9. While still holding the force sensor still, press “Start”. Graph should now show a reading of 1.96 N. Press “Stop”.

10. Try hanging a different mass from the force sensor; press “Start” and check that it is reading correctly.