UCD Physics 9A Lab Manual

The Staff of the UCD Physics Dep't

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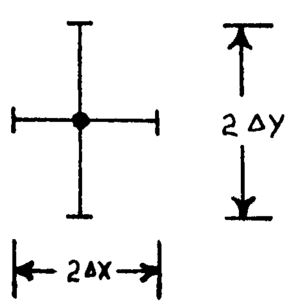
GRAPHING

A graph is not only a useful visual representation of data, it can also be an important tool in analyzing the data. In this section, some of the main considerations in drawing a graph are outlined.

1. Choose the coordinate axes to contain the data points and other necessary features on as large a scale as convenient. In our lab, this generally means using an entire sheet of graph paper for each graph, and choosing scales that will spread the data points as far apart as possible. However, it is also important to leave room for the origin or even for negative values if the graph will be used to extrapolate to those values.

A "Y versus X" graph means the Y axis (usually the dependent variable being measured) is vertical and is called the ordinate, and the X axis (usually the independent variable) is horizontal and is called the abscissa. The graph paper stapled in the report (or bound in the manual) may be viewed directly or from the right, depending on whether more space is needed for the Y axis or the X axis.

2. A graph should have a title. For example, "Distance traveled as a function of time", "Extension of a spring vs. the load", or "v vs. t" if v and t are defined in the report.



3. Plot the points. Remember to include the origin only if it is properly a data point. Each data point must include an "error bar" which shows the uncertainties in the data. An error bar is a line drawn above and below the point a distance equal to the absolute uncertainty in the ordinate, and a horizontal line drawn to the right and left to the point showing the absolute uncertainty in the abscissa.

If the uncertainty in the ordinate or abscissa is so small that the error bar would not be visible, it may be omitted. Thus, if the abscissa is known very accurately, so that its error bars would lie inside the dot representing the data point, it is best to omit the horizontal error bars entirely. Data points without error bars are presumed to be accurate to within the dots shown, but a small circle may be drawn around each data point to make sure it is seen.

4. Draw the graph. After the points are plotted, draw a smooth curve (such as a single straight line) which accurately represents the plotted points. Although it is desirable for the curve to pass through as many error bars as possible, it is not necessary that the curve pass through each point. It is important that the curve is smooth, with the points scattered more or less evenly on both sides of the curve. A correctly drawn curve represents an average of all the measurements and is therefore, in general, a more accurate and convenient expression of the results than the individually measured points themselves. If the curve is nearly a straight line, use a transparent straight edge to draw it; otherwise use a French curve or careful freehand drawing to obtain a smooth curve. Occasionally it is necessary to extend the curve beyond the range of the measurements. This is called an extrapolation and should be indicated by a dotted line.

Any points which are very far from the curve (by substantially more than the error bars) were possibly incorrectly plotted or measured. Check to see that they are correctly plotted; if so, then you might want to repeat the measurement. Any point ignored (or eliminated) because it is discrepant (in disagreement with the others) should be noted and explained. Plotting the graph after each individual measurement will help you catch any gross measurement errors.

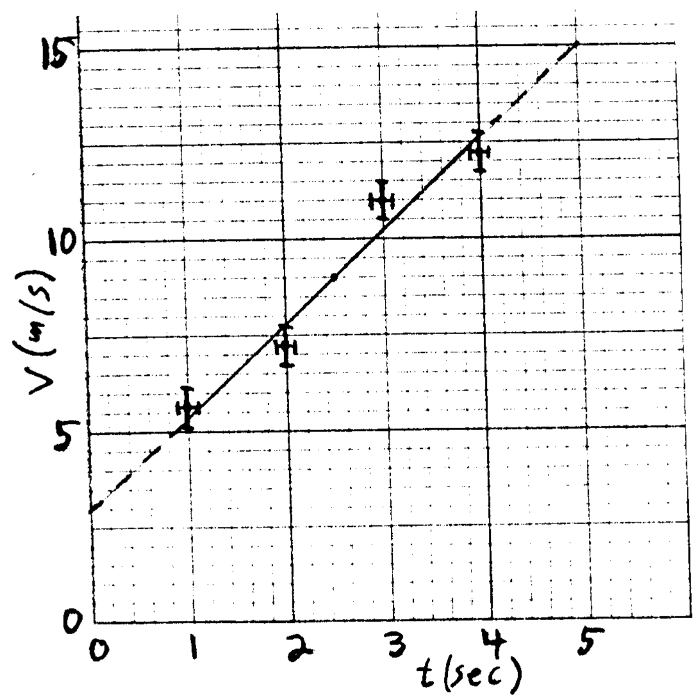
5. As appropriate, use the graph to analyze the data. We have already noted how the graph can indicate discrepant data that should be checked for errors. Careful consideration of the smooth curve can verify or reveal relationships between the variables, and related comments (such as whether the data points are consistent with an expected linear relation) are often required. A graph can also be used to determine numerical values of various physical quantities. In the following example, we will determine a body's acceleration and its unobserved initial velocity.

Suppose the velocity of a ball undergoing constant acceleration has been measured as a function of the time, with uncertainties of ± 0.5 m/sec for each velocity and ± 0.1 sec for each time, as shown:

t(sec)	V(m/sec)
1.0 ± 0.1	5.6 ± 0.5
2.0 ± 0.1	7.2 ± 0.5
3.0 ± 0.1	11.0± 0.5
4.0 ± 0.1	12.2± 0.5

The corresponding graph is shown below. We draw the best (in our judgment) straight line through the data. The curve is a straight line because we expect the acceleration, *a*, to be constant, and then *V* and *t* are linearly related by

$$V = V_0 + at.$$



VELOCITY OF THE BALL AS A FUNCTION OF TIME

The (unmeasured) initial velocity V_0 can be determined by extrapolating the straight line to t = 0 where we find the intercept V_0 = 3.0m/sec. The acceleration is the slope of the line,

$$a = \frac{\Delta V}{\Delta t} = \frac{V_b - V_a}{t_b - t_a} = \frac{15.0 - 3.0}{5.0 - 0.0}\ \frac{\text{m/ s}}{\text{sec}} = 2.4\frac{m}{s^2},$$

where (t_a, V_a) and (t_b, V_b) are any two points on the line, chosen as far apart as possible in order to minimize the effects of imprecision in reading the coordinates. Students should avoid the common mistake of using two original data points to determine the slope, since this is equivalent to throwing away all the remaining data. Note that the slope depends on the units along the axes, and then is not equal to the tangent of the angle of the line.

The following section ("Least Squares") discusses analytic methods of fitting a straight line to data points. One of the results derived there is very useful for our graphical methods. That is equation (25), which simply states that the best straight line must pass through the average data point. To use this in our example, we calculate the average time and velocity as

$$\bar{t} = \frac{1.0 + 2.0 + 3.0 + 4.0}{4} = 2.5\text{sec and}$$

$$\bar{V} = \frac{5.6 + 7.2 + 11.0 + 12.2}{4} = 9.0\frac{m}{s}$$

and plot that as a single point (with no error bars since it is not a data point). Now we can draw many lines through that average point and select the one that fits the data points best or simply (as shown) draw the one best line. We could also draw a pair of lines (through the average Point) with barely acceptable slopes (one with the largest acceptable slope - the other with the smallest acceptable slope) and use them to estimate the uncertainty range of the slope. This is simpler than (and usually more reliable than) the equivalent methods of LS Equations 27 and 32, both of which require calculating at least four sums to fairly high precision.

Incidentally, the uncertainty in the average velocity as given by UNC Eq. (16),

$$\sigma_{\bar{V}} = \frac{\pm 0.5}{\sqrt{4}} = \pm 0.25\frac{m}{s}$$

is the same as given by LS Eq. (18) *or* (31). *The uncertainty in the slope as given by LS Eq.* (32) *is simply*

$$\sigma_a = \frac{\sigma_{\bar{V}}}{\sigma_t} = \frac{\pm 0.25 m/s}{1.12\text{sec}} = \pm 0.2\frac{m}{s^2}$$

where σ_t *is the RMS variation of the measurement times* t_i *as*

$$\sigma_t^2 = \frac{(1-2.5)^2 + (2-2.5)^2 + (3-2.5)^2 + (4-2.5)^2}{4}.$$