Appendix B

Graphing

Title

Each graph must include a descriptive title that leaves no confusion as to what is being plotted.

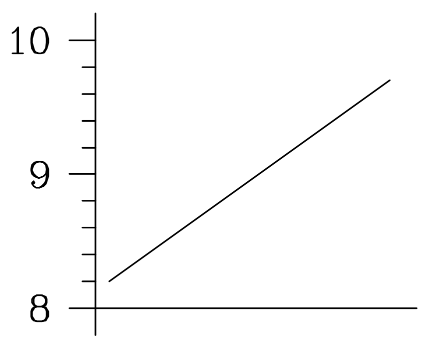
Axes

Each axis must be clearly labelled (including proper units) indicating what is plotted.

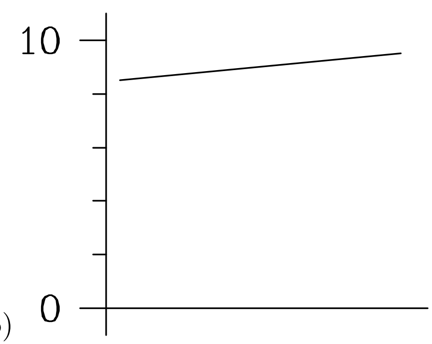
Scales

Axis scales should be chosen so that the graph is as large as possible. Remember that scales *do not* have to start at zero (although they may, if it is appropriate), especially if doing so would make the graph unreadable, as shown below in (b).

(a)



(b)



The scales should also be chosen so that they are easily readable. Suppose you are plotting on graph paper with major divisions of 1 cm and minor divisions of 1 mm (0.1 cm). With scale (a) in the following diagram, it is much easier to estimate between divisions (when taking points to calculate a graph slope, for example) than it is with scale (b).

Graphing Convention

In this laboratory and in other courses, you will often be told to plot "'quantity #1' versus 'quantity #2'" The proper way to plot these is with "quantity #1" on the vertical axis and "quantity #2" on the horizontal axis. In other words, you will be instructed to plot "*vertical* versus *horizontal*".

Figure B.1: (a) 1 mm (on paper) : 1 s; (b) 1 mm (on paper) : 0.9 s

Error Bars

When plotting experimental points on a graph, uncertainties are indicated using "error bars". For any experimental points $(x \pm \sigma x, y \pm \sigma y)$, the error bars will consist of a pair of line segments of length $2\sigma x$ and $2\sigma y$, which are parallel to the x and y axes respectively. These line segments are centered on the point (x, y). The correct point should lie within the rectangle formed using the error bars as sides. The rectangle

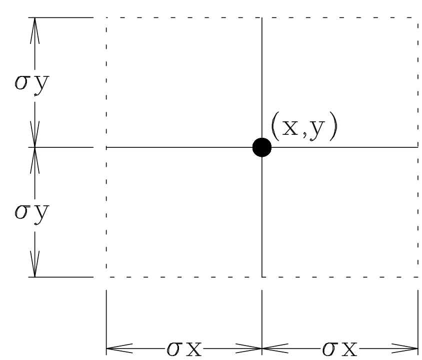


Figure B.2: Error Bars for Point (x, y)

is indicated by the dotted lines in figure B.2. Note that only the error bars, and not the rectangle are drawn on the graph.

Line of Best Fit

To analyze your data (assuming a linear relationship), it is necessary to draw a line of "best fit". This line should approximate your data as much as possible. The best fit line can be determined reasonably well manually (by eye), and the slope determined in the usual graphical manner. There are analytical ways to determine the line of best fit. The advantage of doing this is that all people using the same data will get the same results. One method is to use the "Linear Regression" (LR) function on a calculator or spreadsheet program. Based on the data (i.e. x and y coordinates) given to it, a LR routine will return, among other things, the slope and vertical intercept of the line of best fit.

Be aware that performing a LR analysis on non-linear data will produce meaningless results. The graphs in Figure B illustrate several such cases. These graphs show four different data sets that give identical slopes and vertical intercepts via LR.

You should plot the data points to determine visually if a LR analysis is indeed valid.

Calculating the Slope of a Linear Graph

The slope (m) of a straight-line graph is determined by choosing two points, $P_1 = (x_1, y_1)$ and $P_2 = (x_2, y_2)$, on the line of best fit (not from the original data) and evaluating equation (B.1). Note that the two points

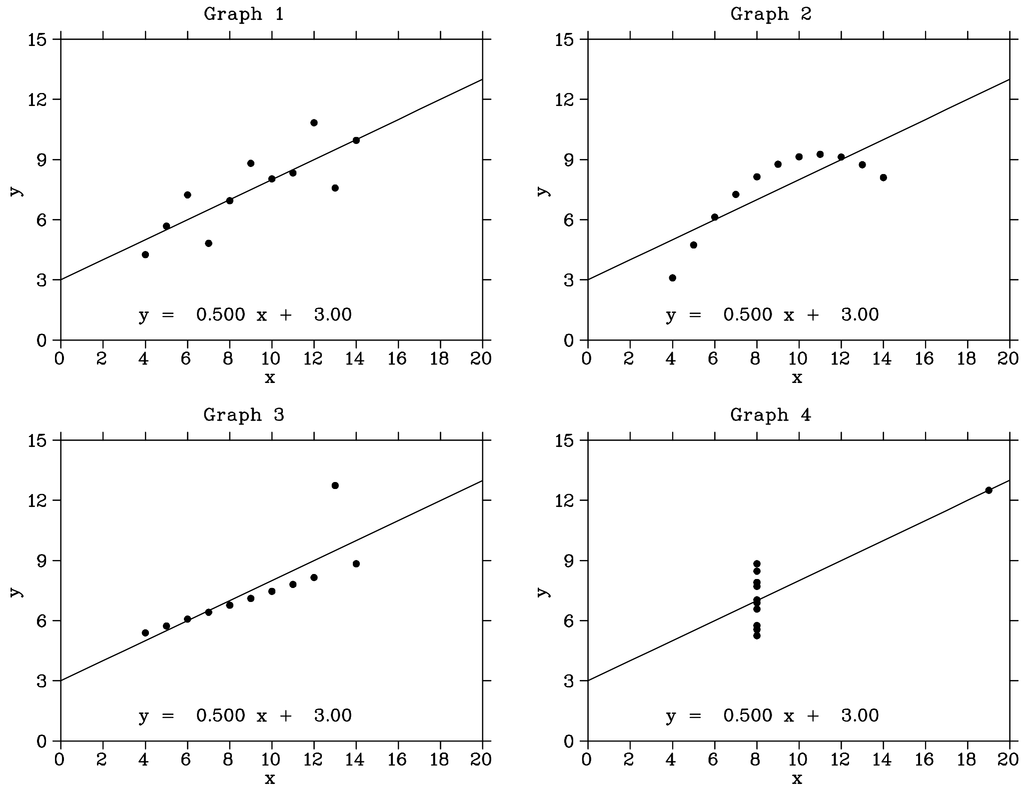
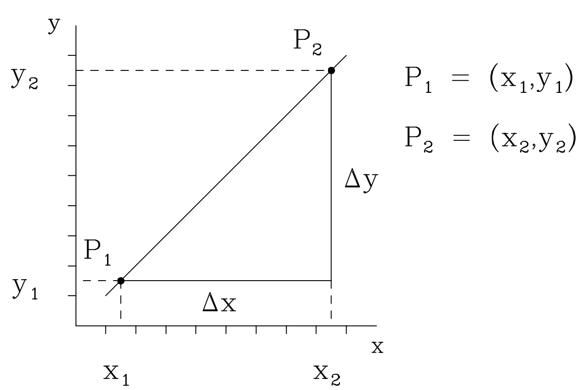


Figure B.3: Four graphs producing identical linear regression results

should be as far apart as possible.



$$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} \qquad \text{(B.1)}$$

Calculating the Uncertainty of the Slope of a Linear Graph

Consider figure B.4 showing data points for a linear relationship (in this case, the position of an object measured over a period of several seconds). The slope of the line formed by the data points is taken to be the slope of the line which best fits the points (line 2). To determine the uncertainty, lines 1 and 3 are drawn. They give the maximum and minimum slopes, respectively, which satisfy the data points. The uncertainty can be taken as one-half the difference between these two slopes, as in equation (B.2).

$$\sigma(\text{slope}) = \frac{\text{slope}_{\text{max}} - \text{slope}_{\text{min}}}{2} \tag{B.2}$$

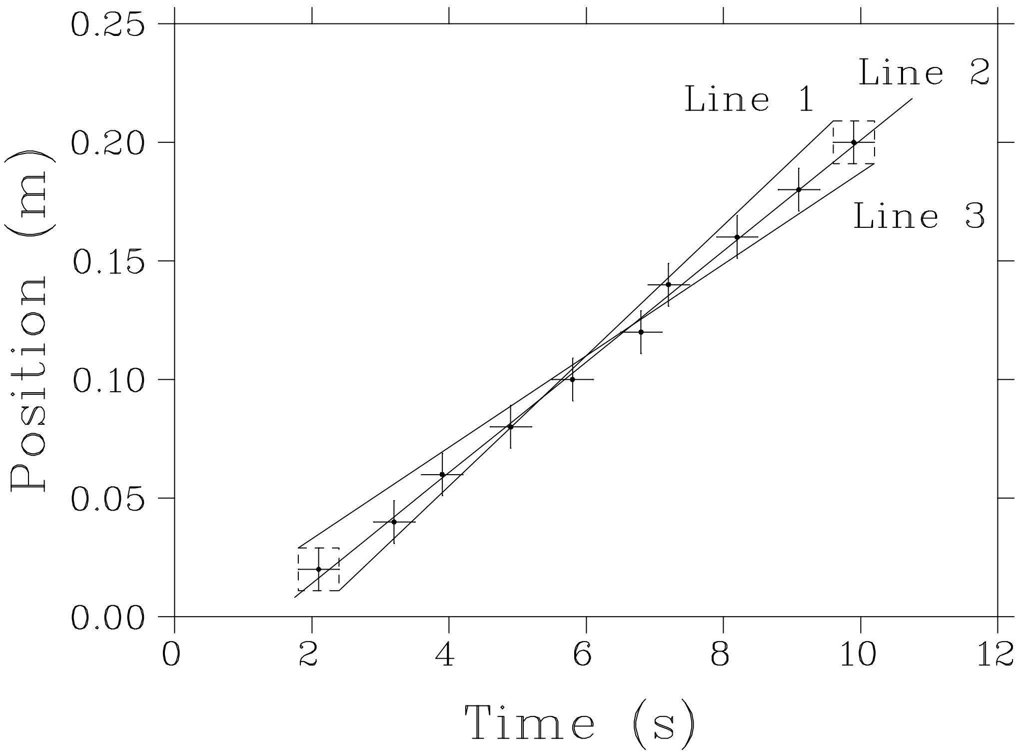


Figure B.4: Lines of maximum slope (line 1), best fit (line 2), minimum slope (line 3)

Line	Slope (or speed) (m/s)
1	0.0275
2	0.0233
3	0.0193

Therefore the slope of the relationship plotted (the speed of the object) in figure B.4 is 0.023 ± 0.004 m/s.