Graphical Solutions

Unit: Laboratory & Measurement

NGSS Standards: N/A

MA Curriculum Frameworks (2006): N/A

AP Physics 1 Learning Objectives: N/A

Skills:

- Use a graph to calculate the relationship between two variables.

Language Objectives:

- Understand and use terms relating to graphs.

Notes:

Most experiments in a high-school physics class involve finding a mathematical relationship between two quantities. While it is possible to simply measure each quantity once and calculate, an approach that measures the relationship across a range of values will provide a better result.

As mentioned above, a good rule of thumb for quantitative experiments is the **8 & 10 rule**: you should have at least 8 data points, and the range from the highest to the lowest values tested should span at least a factor of 10.

Once you have your data points, arrange the equation into $y = mx + b$ form, such that the slope (or $^1/_{slope}$) is the quantity of interest. Then accurately plot your data and draw a best-fit line. The slope of this line will be the quantity of interest (or its reciprocal).

For example, suppose you wanted to calculate the spring constant of a spring by measuring the displacement caused by an applied force. The equation is $F_s = kx$, which means a graph of F_s *vs.* x will have a slope of k.

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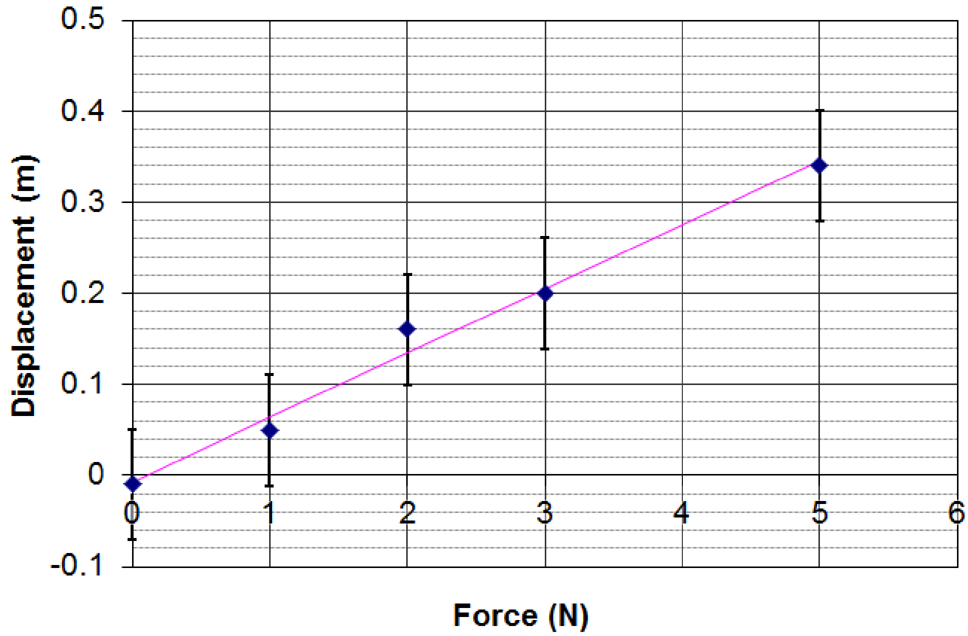
1. Plot your data points, expressing your uncertainties as error bars.

2. Draw a best-fit line that passes through each error bar and minimizes the total accumulated distance away from each data point. (You can use linear regression, provided that the regression line passes through each error bar.) If the line cannot pass through all of the error bars, you need to determine what the problem was with the outlier(s). You may disregard a data point in your calculation *only* if you can explain the problem in the way the data point was taken that caused it to be an outlier.



The above graph was plotted with force (the independent variable) on the *x*-axis and displacement (the dependent variable) on the *y*-axis. The slope of the best-fit line is 0.072.

Note, however, that the spring constant is defined as $\frac{\text{force}}{\text{displacement}}$ (measured in $\frac{\text{N}}{\text{m}}$), which means the spring constant is the reciprocal of the slope of the above graph. $1/0.072 = 14.0\,\frac{\text{N}}{\text{m}}$.

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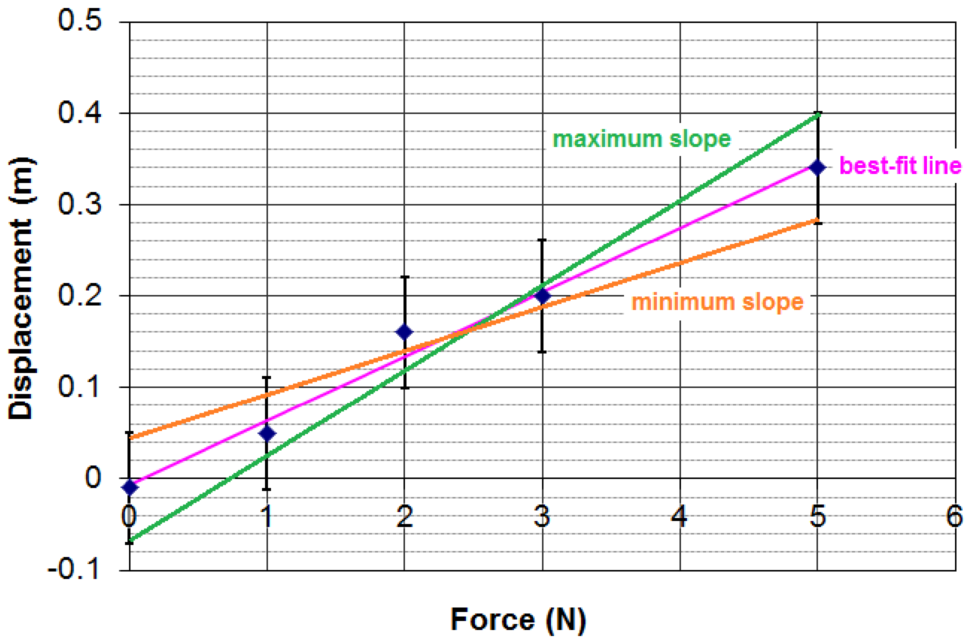
3. Draw the lines of maximum and minimum slope that can pass through all of the error bars. These are the maximum and minimum values of your calculated value. These give you the range, from which you can calculate the uncertainty (±, which will be covered later).



4. Your answer is the slope of your best-fit line, and the uncertainty (±) is the difference between the slope of the best-fit line and the maximum or minimum slope, whichever gives the larger uncertainty.

   The line with the largest slope that goes through the error bars (shown in green) has a slope of 0.093, which represents a spring constant of $10.8\,\frac{\text{N}}{\text{m}}$, and the line with the shallowest slope that goes through the error bars (shown in orange) has a slope of 0.046, which represents a spring constant of $21.6\,\frac{\text{N}}{\text{m}}$. The larger difference is $7.6\,\frac{\text{N}}{\text{m}}$, so this is our uncertainty. We would therefore express the spring constant as $(14.0 \pm 7.6)\,\frac{\text{N}}{\text{m}}$.

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