Introduction to Experimental Evaluation

Graphing

When we investigate any system, we look for relationships between the quantities of interest to us. Often we are limited to investigating the relationship between only two quantities at one time. All other variables must be held constant during the experiment. By examining successive pairs of variables, one can discover how each of the quantities is related to each other.

One of the easiest ways to determine if two quantities are related is to plot them on graph paper. In many cases, the functional relationship can be determined by graphical analysis. If the two quantities are related, then a small change in one variable produces a small change in the other in such a fashion that as we progress through values of one variable the corresponding values of the other variable trace out a curve on the graph paper. In other words graphs represent experimental results. There are many different types of graph paper, such as linear (rectangular coordinate), semi-log, log-log, polar and triangular. We will be concerned with the first three at various times and they are more fully discussed in Appendix 1. For now, we will consider only linear graph paper.

Regardless of the type of graph paper used, there are certain rules to follow in constructing a graph.

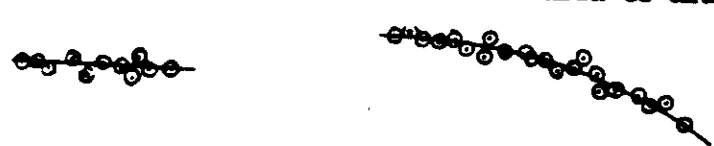
1. Every graph should have a title; the graph tells a story and as such deserves the same consideration as any book. A complete title should include the name of the experiment, the experimenter's name, the date and what the graph represents. All titles and labeling should be done neatly, preferably in block lettering, rather than script.

2. Label each axis with the variable it represents. Include the units and the scale used. The independent variable x, which is under control of the experimenter, is plotted on the abscissa (x-axis, the horizontal axis). The dependent variable y is determined by the independent variable and is plotted on the ordinate (y-axis, the vertical axis). When r is graphed as a function of s, r is plotted on the y-axis and s on the x-axis.

3. When choosing a scale for each axis, make sure each division (block) represents a convenient unit (1,2,5,10), and at the same time, the graph covers as much of the paper as possible for better accuracy.

4. Draw small circles around data points so that, at a glance, a reader can see how many data points were available.

5. Do not connect individual points. A line or curve should be drawn close to but between the points, with about half of them on either side of the curve. A ruler should be used to draw a straight line and a french curve should be used to draw a smooth curve.



(6) In any experiment, the student can estimate the accuracy of his reading due to differences in repeated readings or due to differences of the instrument used. A length measurement may be expressed, for example, as 3.79 $\pm$ 0.05 cm when 0.05 is the estimate of the accuracy of a particular measurement. One indicates this on the graph by drawing "flags" or error bars from the datum point, parallel to the appropriate axis; the distance on each side of the datum point represents the assigned error.

) represents 0.05mm on the scale used.

) represents 0.05mm on the scale used.

(7) Attach the graph to the lab report so that it is convenient for the reader. (The top of the graph should be oriented so that it is either at the top or at the left of the report.)

(8) Errors are really effects of neglected influences (e.g., friction, temperature and pressure variations, etc.) or of the finite accuracy of the equipment on the final result. The experimenter will have deviations in repeated readings and a <u>histogram</u> is a means of statistical analysis which shows the frequency in observing a variable plotted against the value of the variable. Further details about drawing histograms will be supplied by your teaching assistant or Appendix 4 in this manual.

REPORT FORMAT:

The report should contain the following parts:

A. Title and Abstract Page:

The title page should have the title of the experiment, the name of the student, the lab section number, the names of any partners, the date, and an abstract.

An abstract gives the reader the essentials of the experiment in compact form. Examples:

1. The acceleration of a freely-falling body was measured using the Behr free-fall apparatus, in which a falling metal bob has its position marked every 1/60 sec by means of a spark. The value 9.73 ± 0.03 m/sec^2 ($\pm$0.3%) was found, which differs by 0.4% from the accepted value of 9.80004 m/sec^2.

2. By doing a known amount of frictional work on a copper cylinder and measuring the temperature rise, the mechanical equivalent of heat was determined to be (4.22 ± 0.11) joules/cal. This value is in satisfactory agreement with the accepted value of 4.187 joules/cal.

B. Data:

In this section are the original data (not copied), written in ~~permanent ink~~ pencil allowed, in a data table with ruled lines, headed by a symbol defined either in words or on a diagram, with the units used (see the example.) Errors should be lined out, leaving them still readable, so that they may be recovered in case their classification as errors is mistaken. The data should be taken in an organized way, so think about what you are going to do, and then construct the data table. The data sheet should also have: 1) the date; 2) your name; 3) the name of your partner, so designated; and 4) (as mentioned) the initials of your instructor obtained when the completed measurements are approved. Additional columns for entering calculated quantities should be used when practicable. COMPUTER GENERATED :-)

C. Sample Calculation:

A sample calculation shows the equation used, the numbers (with units) substituted, and the numerical result, with units. There should be a sample for each important type of calculation.

Example: If several values of acceleration are found by measuring distances and times, a sample calculation would look like:

$$a = \frac{2s}{t^2} = \frac{2 \times 1.013 \text{ m}}{(22.1 \text{ sec})^2} = 0.00415 \text{ m/sec}^2 \text{ or } 4.15 \text{ mm/sec}^2$$

a = accel., m/sec^2; s = distance, m; t = time, sec.

D. Measurement Uncertainties and Error Propagation:

This section should contain:

1. A list of each type of measurement, with a numerical estimate of the uncertainty of each type. Examples are given in the lab manual, Appendix 3.

2. An estimate of the propagated uncertainty. Every quantity derived from physical measurements has an uncertainty which depends upon the experimental uncertainties in the individual measurements. Propagation of errors involves the methods for evaluating, from the individual measurements, the uncertainty in the final result. (See your lab manual.) Your teaching assistant (TA) will give you additional rules as needed.

USE STANDARD ERROR ANALYSIS

E. Results:

Included here should be:

1. A neat tabulation of the results, if appropriate. This can often be combined with the table in which you entered your data.

2. A graph (or graphs) presenting the results, if appropriate. (See the example of a graph.) Graphs are valuable in presenting experimental results, and their value is much greater if standard conventions are followed. These conventions include:

   a. Plotting the independent variable (the one set by the experimenter) on the abscissa or horizontal axis, and the dependent variable (the one measured) on the ordinate or vertical axis. This procedure is described as plotting the dependent variable versus the independent; "a versus b" means "a" along the ordinate, "b" on the abscissa.

   b. Labeling each axis with a symbol, a name, and the units used.

   c. Choosing the scale of each axis so that each square represents a convenient magnitude (e.g., 5 meters rather than 4 meters) while at the same time allowing the curve to cover most of the paper.

   d. Drawing a smooth curve close to but between the points, splitting them evenly, if they do not lie on a smooth curve, since the scatter is probably from random error.

   e. Designating measured points by a small dot enclosed in a small circle, triangle, square, etc., so the user can tell at a glance where the measured points are.

   IF COMPUTER GENERATED, PLOT THESE W/ HAND →

   f. Showing error bars or estimates of uncertainty on the measured points if they are large enough to be seen.

   g. Giving the graph a complete title so the viewer can understand it without reading the entire report.

h. Plotting your data on the page facing the table from which they are derived.

3. A discussion of the results and a comparison with theory or another experiment. The discussion should include an appropriate evaluation of systematic errors.

Parts A through E should be in every report. In addition, there is part....

F. Extra-Credit Measurements:

Part F is optional and allows you to obtain up to 20% extra credit on the report if you can modify the experiment in a clever way, take measurements not described in the instructions, and learn something new. Extra credit is not given for simply doing "more of the same", but rather for taking different measurements with a definite goal in mind so that new conclusions can be drawn.

(Note name, symbol, unit)

5 November

Martin Frobisher

Partner: Jane Avril

(Note date, name + partner)

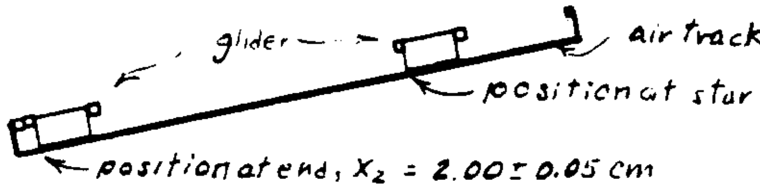
Photon Energy, E, eV	Cross Section, σ, cm²
1.2217	$(0.1 \pm 0.3) \times 10^{-15}$
1.2229	(0.13 ± ")
1.2241	(0.13 ± ")
1.2247	(0.27 ± ")
1.2252	(0.43 ± ")
1.2257	(0.42 ± ")
1.2264	(0.65 ± ")
1.2266	(0.67 ± 0.6)
1.2270	(1.01 ± 0.3)
1.2273	(0.70 ± ")
1.2275	(1.53 ± ")
1.2278	(1.61 ± ")
1.2285	(2.03 ± 0.6)
1.2288	(2.52 ± ")
1.2290	(2.43 ± 0.3)
1.2293	(2.83 ± ")
1.2297	(4.0 ± 0.6)
~~1.2295~~ 1.2300	(3.25 ± 0.3)
1.2308	(4.13 ± ")

(Note error lined out, but still legible)

(Note permanent ink)

(Note instructor's initials)

(Note ruled lines)



8 Sept.

Marie Sklodowska
Partner: John Endicott

Position at start, x_1, cm	Distance, s, $s \equiv \lvert x_1 - x_2 \rvert$, cm	Trial →	1	2	3	4	5	mean time $\bar{t}$, sec, ± rms dev., σ, sec
22.00 ± 0.02	20.00 ± 0.05		1.92	1.79	1.84	1.85	1.91	1.86 ± 0.05
37.00 ↓	35.00 ↓		. . .					
52.00								
. . .								
202.00	200.00		6.08	(etc.) →				5.95 ± 0.09
(Instructor's initials) [illegible]								

(Example, abbreviated, of data sheet showing various ways of definition)

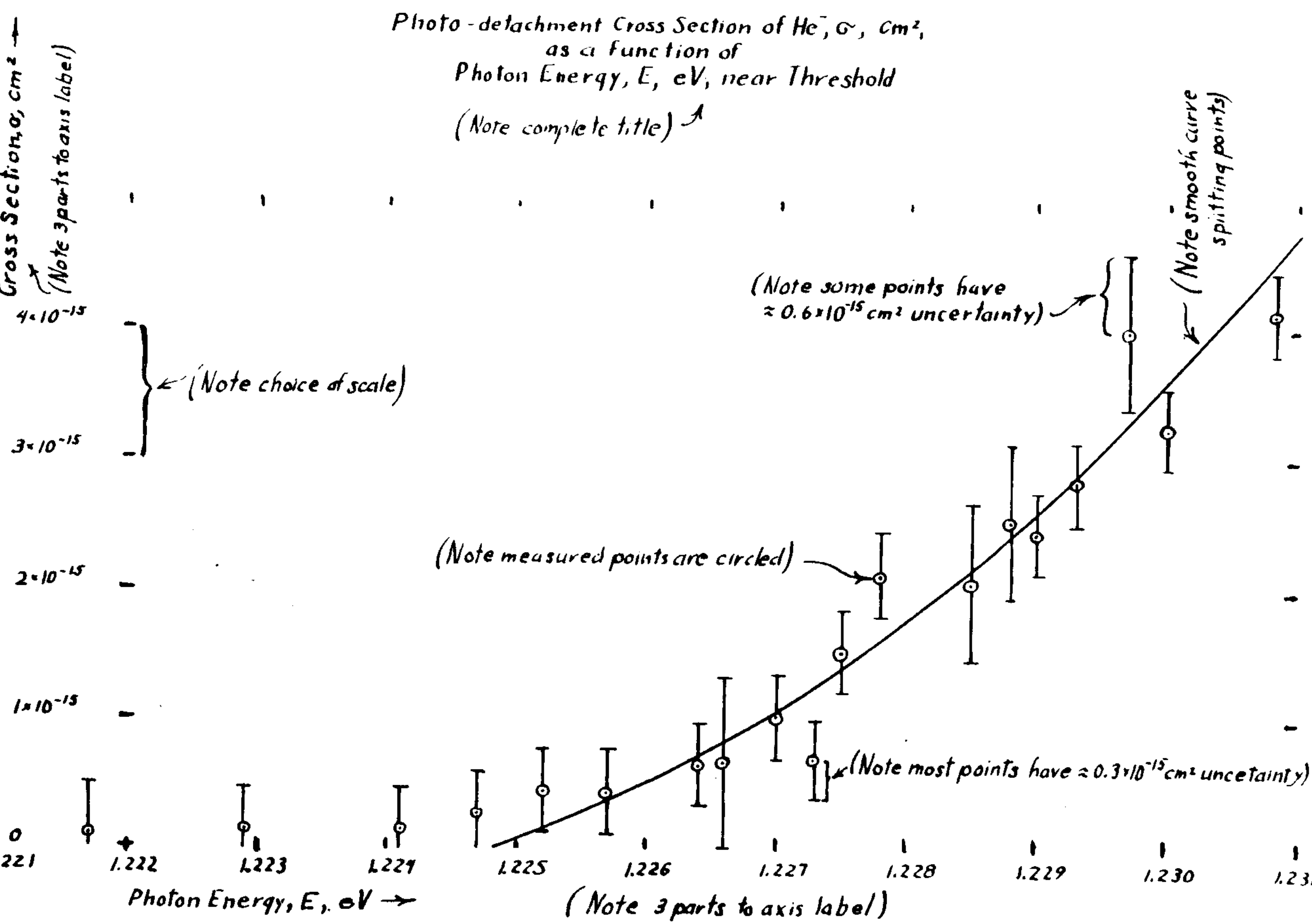


Photo-detachment Cross Section of He⁻, σ, cm²,
as a function of
Photon Energy, E, eV, near Threshold
(Note complete title)
Gross Section, σ, cm²
(Note 3 parts to axis label)
4×10⁻¹⁵
3×10⁻¹⁵
2×10⁻¹⁵
1×10⁻¹⁵
0
(Note choice of scale)
(Note some points have ≈ 0.6×10⁻¹⁵ cm² uncertainty)
(Note smooth curve splitting points)
(Note measured points are circled)
(Note most points have ≈ 0.3×10⁻¹⁵ cm² uncetainty)
1.221
1.222
1.223
1.224
1.225
1.226
1.227
1.228
1.229
1.230
1.231
Photon Energy, E, eV
(Note 3 parts to axis label)