Walt's hints for a better long-form lab report
Walter F. Smith, Haverford College, 3-24-10 (updated 3-3-11)

General hints:

- Please read the instructions for long-form reports found on BlackBoard (under Course Materials / Laboratory / Course Scheduling and Guidelines).

The Abstract

- By convention, you should not use the first person in the abstract, meaning that the abstract should be written in the passive voice, e.g. "The radius was measured." However, you should avoid the passive voice in the main body of the paper, and you should use the first person in the main body of the paper, when describing what you did.
- Be sure to include your most important numerical results (with uncertainty) in the abstract.

Methods section

- Quote the manufacturer and model for all major pieces of equipment. You need not quote these for the computer you used.

Grammar and Style (Read this even if you don't think you need to.)

- Most of your report should be in the past tense, because you're describing what you did. For example, "We aligned the tube so that the electron beam formed a circle rather than a helix." The exception is when you describe a typical behavior which is not specifically related to your experiment, e.g., "The internal resistance of a battery limits the current flow." Avoid using conditional tense ("would") and future tense.
- The word "affect" is (usually) a verb: "The current affects the trajectory." The word "effect" is (usually) a noun: "The effect of the current on the trajectory was strong." When "affect" is used as a noun, it means "way of behaving or appearing", e.g. "The minister had a flat affect when giving the sermon, so that much of the congregation fell asleep." When "effect" is used as a verb, it means "carry out", e.g. "I want you to effect this transition as quickly as possible." Therefore it would be incorrect to say, "The current effects the trajectory." or, "The affect of the current on the trajectory was strong."
- Your paper should not contain the word "you", because it is almost always part of an inappropriately informal expression, such as "You connect the battery to the bulb."
- Your paper should be written in the style of a scientific journal article. Avoid colloquial expressions and informality. This does not mean that the tone has to be stuffy.

Uncertainty Analysis

- In the following discussion, the "σ" means the final uncertainty in your reported result. If you're using the multiple trials method, this would be $\sigma_{\bar{x}}$.
- As you'll recall, our usual standard of checking for serious discrepancies is the 3σ test. This applies if you know σ well. For example, if you're using the multiple trials method (see the "Dealing with uncertainties" document on Blackboard), then you would need at least 10 trials to know σ well. If there is no systematic error in the experiment, or flaw in the theory, then 99.7% of the time there should be agreement to within 3σ between theory and experiment. In other words, random sources of error will only cause a discrepancy of more than 3σ in 0.3% of cases. If you have agreement to within 3σ, it is incorrect to say that you have "agreement at the 99.7% confidence level"; if your agreement was to within 1σ, that would be better agreement, yet using the same way of thinking you would say (incorrectly) that there was "agreement at the 68% confidence

level". If you have a discrepancy of slightly more than 3σ, it is also incorrect to say that you have "disagreement at the 99.7% confidence level"; again, if you had a discrepancy of only 1σ, you would not say that you had "disagreement at the 68% confidence level". For the statistical methods used in this class, it is best just to avoid the term "confidence", and merely state how many σ of discrepancy you have. If the discrepancy is less than 3σ, there is no strong indication of a systematic error or flaw in the theory; you could say that there is "reasonable agreement". If the discrepancy is more than 3σ, then there is a strong indication of a systematic error or flaw in the theory.

- If you're using the multiple trials method to find your final uncertainty, and if you have fewer than 10 trials, then you really don't know the standard deviation very well. So, there is uncertainty in your uncertainty. This changes the percentages quoted above. For the e/m experiment, you have five data points; because you're using these to compute the average, we say that there are "four degrees of freedom". You can look up the details for "Student's t-test", but the result is that in this case we expect 5% of the trials to have a discrepancy of more than $3\,\sigma_{\overline{x}}$, and 0.3% of the trials to have a discrepancy of more than $6\,\sigma_{\overline{x}}$. So, for this experiment, if your discrepancy is more than $6\,\sigma_{\overline{x}}$, there is a strong likelihood of systematic error in your experiment or an error with the prediction. If your discrepancy is less than $3\,\sigma_{\overline{x}}$, you can say that your experiment is consistent with the prediction. If the discrepancy is between $3\,\sigma_{\overline{x}}$ and $6\,\sigma_{\overline{x}}$, then there is an indication that there is probably a systematic error in your experiment or an error with the prediction, but you can't be sure.
- The uncertainty σ has the same units as the quantity. For example, you might quote $r = (0.56 \pm 0.01)\ \text{m}$; in this case, σ has the units of meters.
- Whether or not your results show a discrepancy that has a likelihood of 0.3% or less, you should discuss possible sources of systematic error in the experiment, and possible flaws in the theory.
- You should roughly indicate the size of the error that each source of systematic error is likely to cause. For rough arguments like this, you can use the percent uncertainty multiplied by the absolute value of the power. For example, we have $k = n\mu_0 \dfrac{R^2}{\left(R^2 + D^2\right)^{3/2}}$. Very roughly speaking, if we ignore *D*, then *k* is proportional to $1/R$. So, if the percent uncertainty in *R* is 5%, then there is also a 5% uncertainty in *k*. Since *B* is proportional to *k*, and q/m is proportional to $1/B^2$, this results in roughly a 10% uncertainty in q/m. Similarly, if there is a 5% uncertainty in *D*, this very roughly results in a 15% uncertainty in *k* and a 30% uncertainty in q/m.
- For each of these possible sources, you should discuss whether the sign of discrepancy it would cause is the same as the sign you observed (if your discrepancy was significant).
- Random error sources cannot explain discrepancies of more than 3σ (more than $6\,\sigma_{\overline{x}}$ for the e/m experiment), since random error has already been taken into account in determining σ. Therefore, make sure that, when discussing systematic error sources you really are discussing systematic, not random, error sources.

Miscellaneous

- You are encouraged to use the equation editor that is built into Word. To use it, choose Insert/Object/Microsoft Equation. The interface is pretty intuitive. Just close the equation editing window when you're done. <u>If you choose to ignore this advice about using the equation editor, do not use "*" to indicate multiplication.</u>
- When quoting a number such as 0.203, be sure to include the leading zero, i.e. don't write .203.
- When presenting a series of equations, do all the algebra using symbols. Only plug in the numbers at the end. Here is an example:

  $$s = \tfrac{1}{2} g t^2 \Leftrightarrow g = \frac{2s}{t^2}. \quad s = 0.23\text{ m},\ t = 0.05\text{ s} \quad \Rightarrow g = 184\text{ m/s}^2.$$

  <u>Do not</u> include a step (in your report) in which you show the numbers being plugged in, for example, <u>do not</u> write $g = \frac{2s}{t^2} = \frac{2(0.23\text{ m})}{(0.05\text{ s})^2} = 184\text{ m/s}^2$.
- As most of you have already heard from me: <u>**Every time you write a number, include the units!**</u> If you fail to do this, you won't be taken seriously as a scientist.

Conclusions

- Don't overstate what you have shown. For example, if your experiment shows that momentum has been conserved to within 3σ, don't say that you have "proved the conservation of momentum", since momentum conservation might be violated in a different circumstance. Instead say that your results are "consistent with" or "support" the conservation of momentum.