A maximum of **50 points** will be allocated to each Lab Report. They are composed of 6 scored sections, described below. Lab reports are prepared as a group (see below), and everyone in the group receives the same score. Submit your lab reports as .pdf files directly to Canvas (one submission per group, please).

General Guidelines: Read the experimental instructions and plan your lab report ahead. You will see that most of part 1, 2, 3, 4, and some part of 5 of the lab reports can be done before or during the lab section, which will save you a lot time and also help you to achieve a successful experiment.

Report Sections
Please label each section

1. (1 pt) **Title**: Name of experiment, date of the experiment, your name, and all names of your partners. (This part can be done before you come to the lab).

2. (4 pts) **Motivation and Objective***:* State the purpose of the experiment in one or a few sentences. The purpose of the experiment is distinct from the method or apparatus used, rather it is the overall goal(s) or motivation. (This section can be done before you come to the lab).

3. (5 pts) **Experimental Methods**: Describe the method(s) used to carry out the measurements in a general way (the description should not go into trivial details). Plot a diagram of the apparatus (see Lab Notebook section 2 below). Parameters should be defined. For example, in the speed of light experiment the parameters would be the distances between the laser, mirror, and photodetector, and the time interval to be measured on the scope. (This section can be done during the experiment).

4. (5 pts) **Raw Data**: *Every report must include a copy of the raw data*. It is your responsibility to make copies of X-Y graphs, computer printouts or other data collected by the group as a whole. You are also encouraged to include any in-class notes taken during data taking. These may be typed or scanned from your lab notebook. (This section can be done during the experiment).

5. (25 pts) **Results and Analysis**: State the main results of the experiment, including all important numerical results. This should include:

- Graphs with axes labeled and a title or caption.
- Formulas: Refer to definitions of parameters given above. Give reference to the source of formula or derivation if original.
- Names of programs you used (include listing only if you wrote them or made major changes)
- Uncertainty analysis (propagation of errors). *All records of data collection should contain an estimate of the uncertainty of the raw data if appropriate.*

6. (5 pts) **Discussion**: assess the success of the experiment itself. That means results should be compared to literature values (if available), and systematic errors should be addressed: is there a

systematic error, and if so, how do you know? If systematic error is present, what do you believe it arises from, and how might you check that hypothesis?

(5 pts) There is also 5 points for the **style and format**. Please make sure to organize the report and keep your writing/notes neatly (at least readable), which will help TA to grade your reports.

Division of Labor

All group members are responsible for data collection and analysis, you are free to divide that work at your discretion. For Lab 1 (speed of light), the writing of the report can also be divided among group members however you want. However, for all subsequent labs, the **writing** of the lab reports should follow this division of labor:

- *3-person groups*: one person writes section 5, another person writes sections 1, 2, and 6, and the third person writes sections 3-4.
- *2-person groups*: one person writes section 5, and the other person writes all other sections.
- In any case: the student who has written section 5 the fewest number of times in a group will be assigned section 5 (choose at your discretion for multiple minima).

The person writing section 5 should assemble and submit the report. All group members receive the same grade on the report. You are strongly encouraged to work together and proof read each other's work. Also, each student must take responsibility for each section at least once during the quarter; your highest score on each section (that you wrote) will be a component of your final score for the course.

Instructions for Lab Notebooks

Each student should keep a notebook for in-lab work. Notebooks will not be graded but will serve as a resource for your lab report writing. They also serve as an opportunity to build good laboratory practices. They should contain the following information

1. In-class notes and raw data (will be included in the report for experimental methods, and Results and Analysis)

Notes taken in class should conform to proper scientific record-keeping practices. This means that

- Each page should be numbered and dated with the day on which the work was done.
- Notes should be recorded in pen. Errors should be crossed out with a line or two. Do not use white-out, and do not recopy your original notes.
- Notes should be kept neatly. Give yourself space on the page. Lay out tables with columns so that they are easy to fill in and to read.
- *Data should be recorded with proper, stated units*. Failure to follow consistent unit usage is one of the main causes of incorrect work.
- Relevant conditions pertaining to various parts of the experiment are clearly stated, for example, light source, apertures, distances, and so forth (depending on the experiment).
- Specific operations or procedures that would be different from time to time are described in a few sentences.

The above list is neither complete nor minimal: what you record and how will depend on your experiment. *The important point is to record the information one would need to reproduce your results.*

2. Annotated diagrams of the apparatus (for the **Experimental Methods** section of your lab report): These diagrams (there may be one or more, depending on your experiment) should be *original*: drawn by you (not drawn by your partner and not copied directly from the instructions); they should clearly show all of the light paths among the various components; they should clearly indicate any physical characteristics important to the experiment. Complex sub-components of the apparatus should have their own diagrams and annotations.

Annotations are important! The annotations should be copious and indicate the use and function of the various components of the apparatus. The annotations may be written directly on the diagrams or on a separate page.

The annotated diagram serves the purpose of a description of the procedure used in the experiment. Do not write a step-by-step procedure that mimics the steps given in the instructions. However, it is OK to write a few sentences on the overall operation of the experimental apparatus.

3. Analysis of results (for the **Results and Analysis** section in the report)
It is a good idea to run quick preliminary analysis of your data while you do the experiment. This helps prevent major errors in data recording as well as making clear any calibrations that may need to be done. Preliminary analysis should be noted as such. In general, however, most analysis will be done after data collection is over.

The specifics of the analysis will vary according to the experiment, but the following general guidelines pertain:

Graphs should take up at least a half-page, with a plot area filling most of that space. The axes should be labeled with the specific quantity and its unit. If the quantity does not have a unit or is arbitrary, make sure that is clear. The data set should fill most of the area of the graph, unless it is important to show its relationship to some point on the coordinate axes, such as zero.

Data points should not be connected by line segments. Data points should have error bars indicating the uncertainty of the data. Any lines drawn on the data sets should represent fits to the data or theoretical predictions. If more than one thing is plotted on a graph, a legend should be provided.

Spreadsheets should contain clear column and row headings and a description of what is being calculated. Any cells outside of the main tables should be annotated so that the meaning of their contents is obvious. *Do not assume the grader can decipher your spreadsheet by reading the numbers themselves*. *Uncertainty calculations* should be clearly laid out. Indicate how you feed in various uncertainties into your calculations and whether you have chosen to ignore the uncertainty in some quantities. You will need this information when you discuss the causes of uncertainty in your written portion.

Computer programs should be printed out and included in your report. Give comments within your code or else written on the paper stating what each part of the program does. In a computer program the variable names should be short but meaningful, for example: refractionIndAir, speedLight, focalLeng2, or slitWidth3. The names should be identified with hardware components or measured or derived quantities.

Formulas that are used to calculate results with spreadsheets, programs or even by hand should be written on or near the relevant parts of the report. Any formulas should be defined: state what they are for, and define any variable that may be unclear.

Final results should be clearly placed and labeled and should be stated using correct significant digits with uncertainty and with correct units. If a result does not have units, state that it is "unitless". An effort should be made to compare your results to other results, if they may be found. You may need to run a literature search to determine whether your result agrees with a previously determined value. You are not absolved of needing to compare your results to the literature just because such values may not be stated in the experiment instructions. When you find a result to compare to, you must cite the source with enough information so that anyone could locate it. Many measurements are of known quantities (such as the speed of light), whereas other measurements may depend on apparatus specifics.

In either case, *you must assess the quality of your results and determine whether you think they are reasonable or not, based upon a coherent physical argument*.

Treat *random uncertainty* first. To start, make sure you have included all parameters in your uncertainty analysis, at least insofar as you consider whether they contribute importantly to the final value of your uncertainty, as presented in the summary abstract. Then, after you have propagated the uncertainty using the usual techniques, check your percentage uncertainty against the percentage uncertainty of each of the parts that went into this final value, and determine the most important contributors. Finally, discuss why these factors are the most important. (It may be useful to make a table of the various contributors to your uncertainty to help you sort them out, but this should not appear in your written discussion.)

Systematic error should be addressed. A systematic error certainly exists if the expected value of what you measure lies outside the range of accepted values of well-known quantities, although there may be other indicators of systematic errors. It should be clear whether your result more than about 2 sigma away from what you wanted. If this is true, then you need to decide what aspect of the apparatus or method could cause this effect. Be qualitative in your discussion first, for example, could a change in the gain of some amp or a shift in a calibration factor account for the discrepancy? Then be quantitative: how much of a change in that parameter is necessary to cause the change in the result that you see? Is such a change a reasonable possibility? If it is, you have a good candidate for a "source of systematic uncertainty"; if not, you should keep looking.

The discussion of uncertainty should be a critical assessment of the sources of uncertainty in your results. You need to provide a sensible, logical, physical argument based upon your own experiment, not unsupported speculation. In other words, do not cite a source of uncertainty that you cannot prove is evident in your results.

Academic Honesty

Students working together are encouraged to discuss their analysis and results with each other (and with other students) but must independently generate their own written reports.

The way in which you estimate your uncertainties must ALWAYS be clearly shown. If you copy text from the lab instructions, you are wasting space. You are asked to give a brief statement in the introduction; this means in YOUR words.

When you quote a result that is not in many optics or physics texts, you need to give a citation, whether you obtain the results from the Internet, a book, or a friend. Best of all is to show how you got the result.

For example, the definition of reduced mass needed for experiment 2 is in many texts, but how you use the wavelength splitting you measure to deduce the mass ratio of deuterium to hydrogen is something that needs to be explained. If you copy something from the Internet, give the complete link for the source. If you copy from a book, give the author(s), title, and year published. Plagiarism is an offense punishable by expulsion from the university. If you don't know the meaning of the word plagiarism you might wish to look at the following:
http://depts.washington.edu/grading/issue1/honesty.htm
http://www.engr.washington.edu/org/processes/miscpolicy.htm

To quote from the second:

ALWAYS make very clear reference to the source of the material you use and put the material taken in "quotation marks," no matter where you find it. This is perfectly acceptable and legitimate. DO NOT try to rewrite or change another person's work and pass it off as your own this is very difficult to do and is easily detected. You can always use published writings as long as you give a formal reference and acknowledgment of the source. If the information comes from a conversation with a professor or another student, give their name and recognition that it is their thought.