

# Molecular and Condensed Matter Physics Laboratory (PHYS 4580)

## Photovoltaic Materials and Device Physics Laboratory (PHYS 6/7280)

Instructors: Prof. Randy Ellingson, Prof. Mike Heben  
Teaching Assistant: TBD

### Course catalog descriptions:

#### PHYS 4580 -- MOLECULAR AND CONDENSED MATTER LABORATORY

[3 hours] Experiments in molecular and condensed matter physics. Measurements and analysis based on techniques such as film thickness and surface morphology, X-ray diffraction, optical absorption, four-point probe and Hall measurements. One four-hour lab and one-hour lecture per week. ***May be offered as writing intensive (WAC section is - 071)***. Prerequisite: PHYS 3320.

#### PHYS 6280/7280 -- PHOTOVOLTAIC MATERIALS AND DEVICE PHYSICS LABORATORY

[3 hours] Fabrication and characterization of solar cell materials and devices, addressing materials science and physics of substrate preparation, absorber and window deposition processes, metal contact formation, and measurement of physical properties. One four-hour lab and one-hour lecture per week. Prerequisite: PHYS 6140/7140.

# **Molecular and Condensed Matter Physics Laboratory (PHYS 4580)**

## **Photovoltaic Materials and Device Physics Laboratory (PHYS 6/7280)**

Things to discuss:

- Scheduling (lecture and lab)
- Experiments
- Lab Open Days/Times
- Lab Reports

# Laboratory Scheduling for 4580, 6280

Each lab session is 4 hours. Additional lab time will be provided to enable students to repeat and/or correct measurements as necessary. Lab will generally be open Wednesday, Thursday, and Friday. Please contact us if the lab is locked during times you need access.

# Your responsibilities, and grading

## GRADING and EXAMS

Only material covered in class or in lab experiments will be used for quizzes. Final grades will be based on:

1. Quizzes: Three quizzes during the semester -- short (10 min.), multiple choice, and closed book, closed notes.
2. Laboratory Notebooks: Bring your laboratory notebook with you to each class, and use it to carefully record notes on procedures, parameters during procedures and measurements, etc. Your notebook will be reviewed every two weeks, with scoring of 2, 1, or 0 points.
3. Lab Reports: We encourage collaboration and significant interaction to support everyone learning as much as possible; however, Lab Reports should represent your own work and level of understanding

### Include the following sections in each lab report:

**Title Section: including** (a) Title of your Report, (b) Your name and the names of lab partners (if any), (c) Date, and (d) Abstract (Purpose of Experiment(s) and major conclusions - approximately 100 - 200 words). The Title section should not be on a separate page – we like to conserve paper where possible.

**Introduction:** information on the need for, and value of, the experiments, and discussion of the general approach.

**Experimental:** details of samples and equipment, including a sketch of the layout and a few words on the function of each major component.

**Results and Discussion:** analysis, appropriate graphs, a thoughtful explanation of the significance of the results, sources of uncertainty, and strengths and weaknesses of the measurement approach.

**Conclusion**

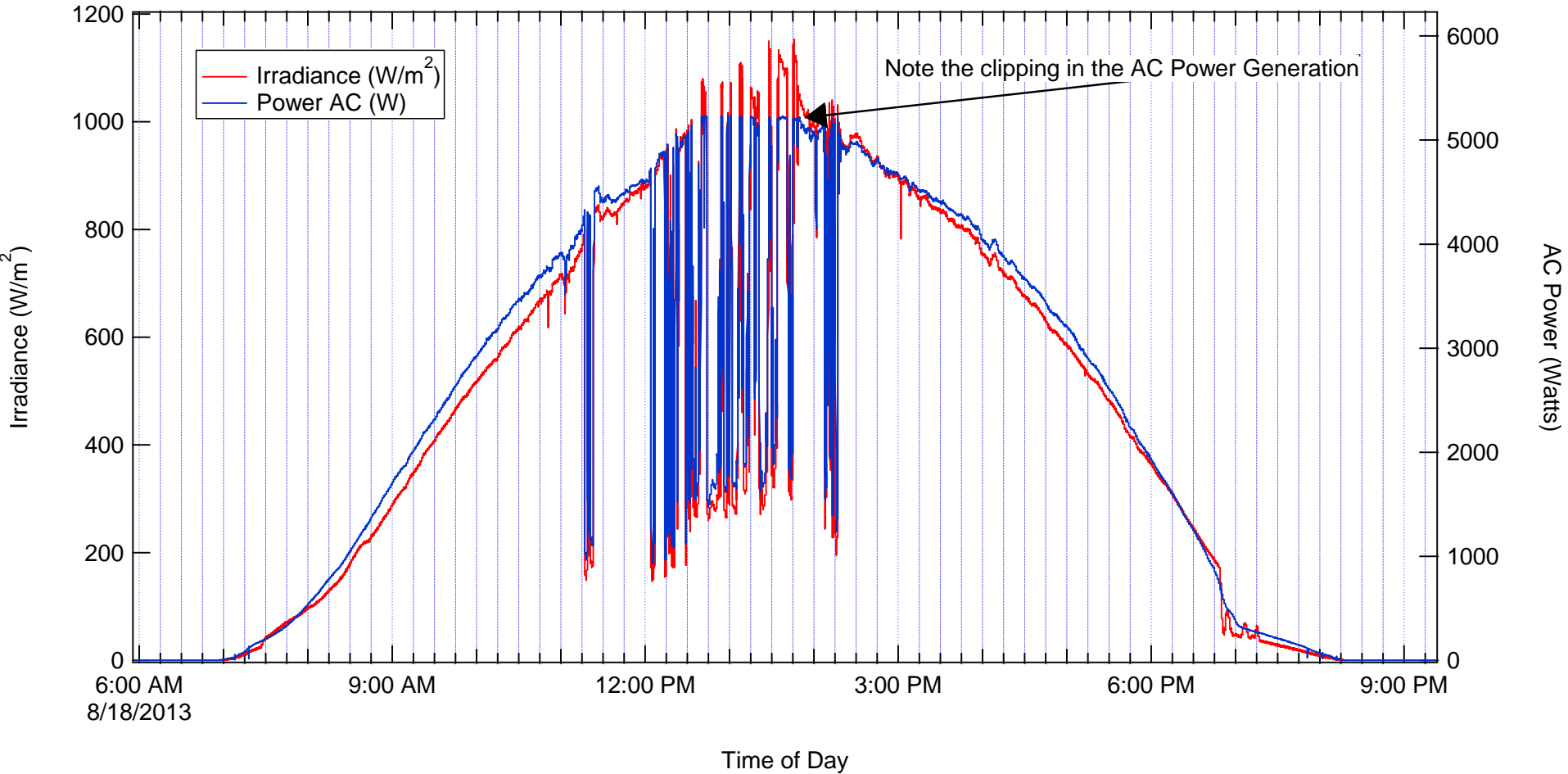
## References

4. Final Project: Your final project will be based on a single 2-hour laboratory session in which you'll be asked to perform or describe specific measurements on a specific photovoltaic material or sample using the equipment, capabilities, and skills you develop during the semester.

## Grading

Grades will be determined according to: Quizzes = 15%, Notebook = 10%, Lab Reports = 55%, and Final Project = 20%.

# Graphs



# Overview Information

- Website:

[http://astro1.panet.utoledo.edu/~relling2/teach/4580.6280.2013/fall2013\\_phys\\_4580.6280.html](http://astro1.panet.utoledo.edu/~relling2/teach/4580.6280.2013/fall2013_phys_4580.6280.html)

- Laboratory location: R1 1070
- LabView – used for *instrument control* (e.g., wavelength control in CM110 monochromator) and for *data acquisition*.
- Igor Pro (graphing and analysis software)
- Safety information.
- Experiment overviews – materials deposition, optical and electrical characterization (metals, transparent conductors, semiconductors), solar cell fabrication, test, and characterization.

# Overview of Experiments

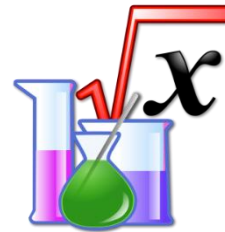
- Introduction to software and hardware
- Light spectrum measurements
- Optical characterization of thin films (transmission, reflection, and absorbance)
- Electrical characterization (metals, transparent conductors, semiconductors)
- Solar cell test and characterization
- Lock-in detection, Data Acquisition (DAQ) -- Analog-to-Digital Conversion, data analysis and reconciliation
- Units – importance of proper handling of units, and use of S.I. units wherever possible (provide conversion information)
- Error analysis and error propagation

A. Experimental Practices  
B. Graphing and Analysis with Igor Pro  
C. Intellectual Honesty

Week of Aug. 19, 2013

## IGOR Pro

- *Runs on Mac OS X and Windows*
- *Fast Display of Large Data Sets*
- *Interactive Data Exploration*
- *Journal–Quality Graphics*
- *Powerful Curve Fitting*
- *Extensive Data Analysis & Statistics*
- *Image Processing*
- *Data Acquisition Support*
- *Built-In Programming Environment Supports Analysis and Automation*
- *Customizable User Interface*
- *Used by Scientists and Engineers Worldwide Since 1989*



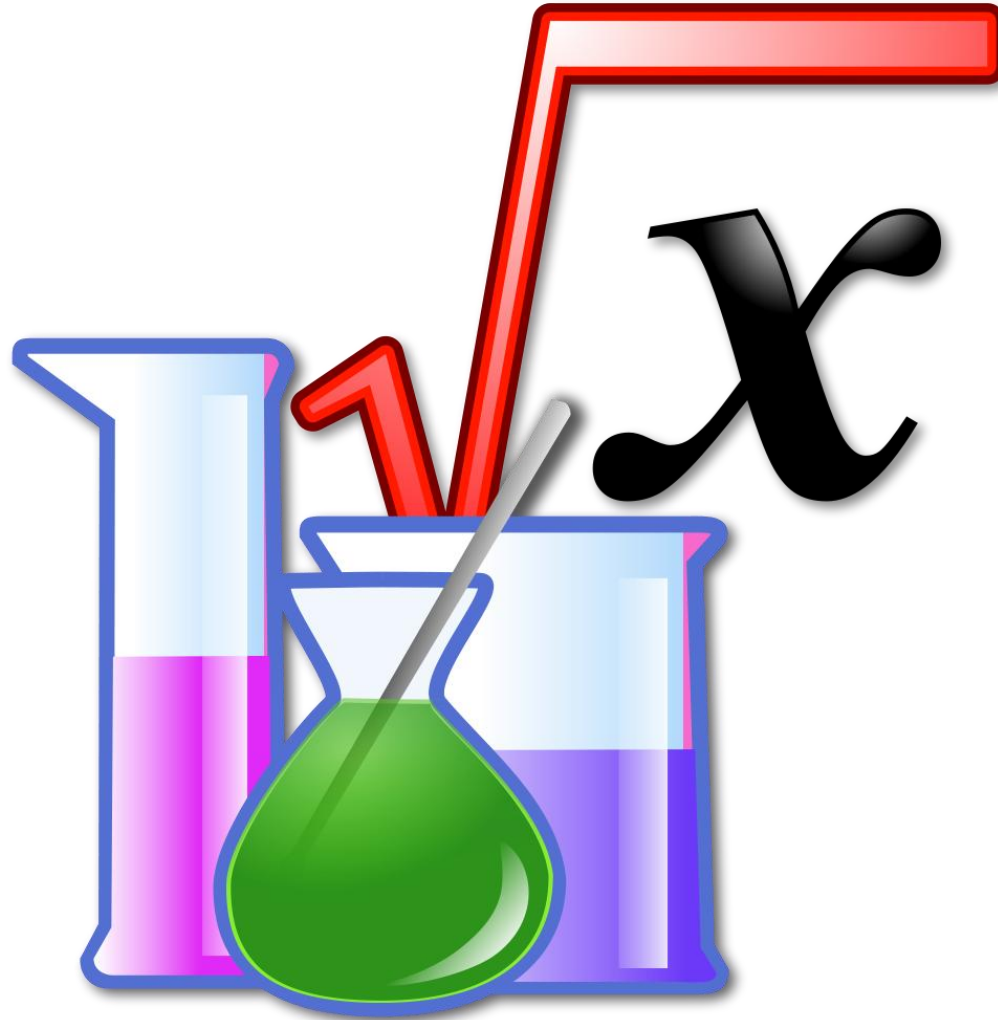
**Molecular and Condensed Matter Lab  
(Physics 4580)  
PV Materials and Device Physics Lab  
(PHYS 6/7280)**

The University of Toledo

Instructors: R. Ellingson, M. Heben



# Experimental Methods and Practices



# Key Elements of the Scientific Method

Scientific method: ask and answer scientific questions through experiment and observation.

The steps of the scientific method are to:

1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Perform experiment and collect data
5. Analyze data
6. Interpret data and draw conclusions that serve as a starting point for new hypothesis
7. Publish results
8. Retest (frequently done by other scientists)

The iterative cycle inherent in this step-by-step methodology goes from point 3 to 6 back to 3 again.

It is important for your experiment to be a fair test. A "fair test" occurs when you change only one factor (variable) and keep all other conditions the same.

# Thoughts on the Scientific Method

Ibn al-Haytham (Alhazen, 965–1039), pointed out the emphasis on seeking truth:

*Truth is sought for its own sake. And those who are engaged upon the quest for anything for its own sake are not interested in other things. Finding the truth is difficult, and the road to it is rough.*

According to William Whewell (1794–1866), "invention, sagacity, genius" are required at every step in scientific method. It is not enough to base scientific method on experience alone; multiple steps are needed in scientific method, ranging from our experience to our imagination, back and forth.

# Scientific Method: Beliefs and Biases

Eadweard Muybridge's (1830 – 1904) studies of a horse galloping



The Epsom Derby (1821) by Géricault, Jean Louis Théodore. Oil on canvas.

# Igor Pro 6.1

Mobius - Igor Pro 6.04

File Edit Data Analysis Macros Windows Graph Misc Help Motofit

Using Igor.hf

- Data Browser**

The Data Browser is an extension that lets you navigate through the different levels of data folders.

Procedure

```

Function makeMobius(pointsx,pointsy,tmin,tmax)
  Variable pointsx,pointsy,tmin,tmax

  Variable i,j,s,arg,ds,tt,dt
  Make/O/N=(pointsx,pointsy,3) mobius
  ds=2*pi/(pointsx-1)
  dt=(tmax-tmin)/(pointsy-1)

  for(i=0,i<pointsx;i+=1)
    s=i*ds
    for(j=0,j<pointsy;j+=1)
      tt=tmin+j*dt
      arg=1+cos(s/2)*tt
      mobius[i][j][0]=cos(s)*arg
      mobius[i][j][1]=sin(s)*arg
      mobius[i][j][2]=tt*sin(s/2)
    endfor
  endfor
End
    
```

Igor Reference.hf

**laguerreGauss**(*p, m, i*)

The LaguerreGauss function returns the normalized product of the associated Laguerre polynomials and a Gaussian. This function is typically encountered in solutions to physical problems where it represents the radial solution with an additional factor  $\exp(i^*m*\phi)$  which is not included in this case. The laguerreGauss is given by

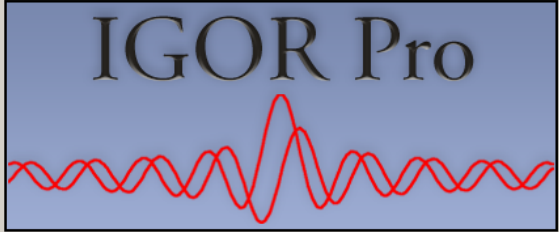
$$U_{pm}(r) = \left[ \frac{2p!}{\pi(m+p)!} \right]^{1/2} (\sqrt{2r})^m L_p^m(2r^2) \exp(-r^2).$$

See Also

[Gauss](#), [hermiteGauss](#).

About Igor Pro

Version: 6.0.4.0



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P.O. Box 2088 / Lake Oswego, Oregon 97035 / USA  
(503) 620-3001 / sales or support@wavemetrics.com  
[www.wavemetrics.com](http://www.wavemetrics.com)

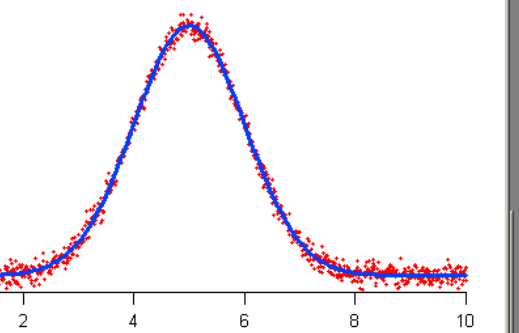
OK License...

lameStr)

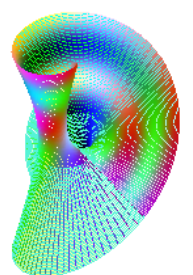
forms a string containing a semicolon-separated list of keywords object in a page layout or overall properties of the page layout. Info is to allow an advanced Igor programmer to write a procedure

biarts

TestWave



Gizmo0\_1



- Display TestWave
- Make/O/N=1000 TestWave
- SetScale/i x,0,10, TestWave
- TestWave = Gauss(x,5,1)+gnoise(.01)

StatsCircularTwoSample1

- StatsCMSDcdf
- StatsCochranTest
- StatsContingencyTable
- StatsCorrelation**
- StatsDExpCDF
- StatsDExpPDF
- StatsDIPTest
- StatsDunnettTest
- StatsErlangCDF
- StatsErlangPDF
- StatsErrorPDF
- StatsEValueCDF
- StatsEValuePDF
- StatsExpCDF
- StatsExpPDF
- StatsFCDF
- StatsFPDF
- StatsFriedmanCDF

help

**StatsCorrelation**(*waveA* [, *waveB* ])

The StatsCorrelation function computes Pearson's correlation coefficient between two real valued arrays of data of the same length. Pearson r is give by:

$$r = \frac{\sum_{i=0}^{n-1} (waveA[i] - A)(waveB[i] - B)}{\sqrt{\sum_{i=0}^{n-1} (waveA[i] - A)^2 \sum_{i=0}^{n-1} (waveB[i] - B)^2}}$$

Here *A* is the average of the elements in *waveA*, *B* is the average of the elements of *waveB* and the sum is over all wave elements.

**Details**

If you use both *waveA* and *waveB*, then the two waves must have the same number of points

Ready

# Igor Pro 6.1 (www.wavemetrics.com)

The screenshot displays the Igor Pro 6.10A software interface. The main window is titled 'Getting Started.ihf' and contains the following content:

- Getting Started**

This help file contains overview and guided tour material and constitutes an essential introduction to Igor Pro. The main sections are:

  - [Introduction to Igor Pro](#)
  - [Guided Tour 1 - General Tour](#)
  - [Guided Tour 2 - Data Analysis](#)
  - [Guided Tour 3 - Histograms and Curve Fitting](#)

We strongly recommend that you read at least the first two sections.

The material in this help file is duplicated in Volume I of the Igor Pro PDF manual which is accessible through the Help menu.
- Introduction to Igor Pro**

Igor is an integrated program for visualizing, analyzing, transforming and presenting experimental data. Igor's features include:

  - Publication-quality graphics
  - High-speed data display
  - Ability to handle large data sets
  - Curve-fitting, Fourier transforms, smoothing, statistics and other data analysis
  - Waveform arithmetic
  - Image display and processing
  - Combination graphical and command-line user interface
  - Automation and data processing via a built-in programming environment
  - Extensibility through modules written in the C and C++ languages

Some people use Igor simply to produce high-quality, finely-tuned scientific graphics. Others use Igor as an all-purpose workhorse to acquire, analyze and present experimental data using its built-in programming environment. We have tried to write the Igor program and this manual to fulfill the needs of the entire range of Igor users.

The interface also shows a table on the left with the following data:

Point	Unused
0	

The status bar at the bottom indicates 'Ready'.

## Igor Pro information (please note)

<http://www.wavemetrics.com/support/demos.htm>

Download the IgorPro Demo (available for either Mac or Windows), and use this information for the S/N and the Activation Key.

Serial Number:

Activation Key:

# Error (uncertainty) analysis

See also: [http://teacher.pas.rochester.edu/PHY\\_LABS/AppendixB/AppendixB.html](http://teacher.pas.rochester.edu/PHY_LABS/AppendixB/AppendixB.html)

$$z = f(x, y)$$

$$\Delta z = \frac{\partial f(x, y)}{\partial x} \Delta x + \frac{\partial f(x, y)}{\partial y} \Delta y$$

For uncorrelated errors:

$$\Delta z = \left[ \left( \frac{\partial f(x, y)}{\partial x} \Delta x \right)^2 + \left( \frac{\partial f(x, y)}{\partial y} \Delta y \right)^2 \right]^{\frac{1}{2}}$$



## Error (uncertainty) analysis – example using Activity of $^{241}\text{Am}$ source

$$A = \frac{C}{\frac{\pi s^2}{4\pi r^2}} = \frac{C(4r^2)}{s^2}$$

Where  $C$  is count rate,  $r$  is the distance to the detector, and  $s$  is the radius of the detector.

$$\Delta A = \frac{\partial}{\partial C} \left( \frac{4Cr^2}{s^2} \right) \Delta C + \frac{\partial}{\partial r} \left( \frac{4Cr^2}{s^2} \right) \Delta r$$

$$\Delta A = \frac{4r^2}{s^2} \Delta C + \left( \frac{4C}{s^2} \right) (2r) \Delta r$$

In “quadrature”, if these errors are uncorrelated:

$$\Delta A = \left[ \left( \frac{4r^2}{s^2} \Delta C \right)^2 + \left( \frac{8Cr}{s^2} \Delta r \right)^2 \right]^{\frac{1}{2}}$$

## Error (uncertainty) analysis – multiple value r.m.s. approach

Another approach to evaluating the uncertainty relies on a straightforward calculation of the root mean square and the standard deviation. In the case of your Activity measurements, you could compute the RMS value as well as the SD. You should still assess your uncertainty through error propagation, as the uncertainty may very well exceed the SD.

Definition of the root mean square from Wikipedia:

“...the [square root](#) of the [arithmetic mean](#) ([average](#)) of the [squares](#) of the original values...”

In the case of a set of  $n$  values  $x_1, x_2, \dots, x_n$ , the RMS value is given by:

$$x_{rms} = \sqrt{\frac{x_1^2 + x_2^2 + \dots + x_n^2}{n}}$$

The **standard deviation** is given as follows, where there are  $N$  values and  $\mu$  is the arithmetic mean:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$$

# Lab Reports:

Ensure individual reports represents your own words and understanding, even when data is shared.

- Show what you have learned – describe the experiment (background, what is measured, important steps, how things fit together, origins and magnitude of the uncertainties);
- Label your graphs carefully – ensure that the reader knows what is graphed. Include units on each axis label, and on other quantities (refer to syllabus for more detailed info).
- **Avoid plagiarism:** understand what you read, know the points you want to make, and restate the ideas in your own words. You'll learn more this way, and avoid potentially big problems.



# The First Experiment – Intro to Hardware and Software

- Familiarity with the experimental workstation – software and hardware elements
- Opening and running LabVIEW programs; writing simple LV programs
- Using the monochromator and light source
- Light detection using the thermopile detector
- Optical chopping of a steady-state light beam
- Using the DAQ device
- Recording light intensity vs. time data points using LV
- Writing your data to a file
- Fitting a function to your data; extracting meaningful information from the fits.