Preface

This laboratory is to serve as an introduction to experimental research, specifically in measurement techniques related to optics. There is a big step between the "textbook" experiment, and the "real thing". This course will get you acquainted with complex instrumentation that is not usually found in instruction laboratories. It will help develop some experimental skills (among which patience and a steady hand will be needed to perform some tedious — but typical — alignments). As a preparation for the long days and nights of graduate research, this course will provide the right mixture of confidence and diffidence required of the student unleashed alone in the arena of expensive instrumentation.

1 Laboratory organization and reports

Each lab will require more than one week of work even though the students work in pairs. The length of time needed for any given lab will vary. It is assumed that you are here to learn as much as possible. We will do our best to facilitate your learning. Consider this class as an introduction to experimental research. The knowledge that you acquire during the course of this semester is a mixture of well-known as well as little known information. There is a strong element of "doing it for the first time" since these are **not** canned experiments. You will end up getting as much out of the semester as you put into it. You are not expected to complete all experiments listed in this manual.

In the interest of helping you gain greater understanding, there are questions embedded in the text of the labs. They are meant to be another method for the instructor to gauge the depth of your understanding as well as didactic tools for yourself. There are frequently as much insight to be gained from understanding the *questions* themselves as from finding the answers. You do need to answer the questions as well as perform the experiments. ("Yes" and "No" answers are not the best responses.)

Keep a **lab notebook**. Notes on napkins, newspapers, single pages, etc. tend to disappear. Write down all the information that is necessary to repeat the experiment under the same conditions. Keep record of your results, experimental layouts, and errors.

The instructor grades the lab reports as he gets them. I will accept one report/group, with the understanding that each member of the group alternate in the redaction of the report. Grading will be based on **attendance and performance in the lab itself (40%), the lab reports (35%) and the presentation (25%)**. To get credit lab reports must be turned in **no later than one week** after the experiment is finished and before you start with the next experiment. We highly recommend that you **do not** wait until the end of this period to write the reports, especially for some of the longer experiments which require more thought. Students tend to forget the details of involved experiments if they wait too long before submitting their write-ups. Major parts of the lab report should be written during the weeks you do the experiment.
Each report should include:

- Abstract
- Introduction
- Background information (sufficient background to enable you to understand what you were doing . . . 10 years from now). You should not rewrite sections of this lab manual

- Answer to the specific problems and question asked in this booklet
- Procedure, data, error analysis
- Results, conclusion,
- References.

The procedure should say what was actually done, without repeating large amounts of material from the manual. In analyzing the results, remember that each measurement has an associated uncertainty, but that the effect of this uncertainty on the result need not be linear. Have you chosen the condition for which the measurement error least affects the final result?

An increasing number of graduate students have experienced difficulties when nearing completion of their Ph.D. program, because of their lack of previous experience in writing papers and reports. Use a word processor for the writing and embed your graphs into the text. The lab report should look like a paper that you submit to a journal.

Guideline for Figures

Each figure is accompanied by a figure caption. The figure caption contains sufficient information so that the reader can understand what is shown. Both axis of a graph should be labelled. A title followed by the unit should be centered below the abscissa and left of the ordinate. Avoid ambiguity in axis labelling. For instance, $\mathbf{R}(\times 10^{-3})$ is ambiguous, because it is not clear whether the scale number should be multiplied by 10^3 of whether it has already been multiplied by that number. A better labelling would be: **RESISTANCE R (mΩ)**.

Linear scales : the axis should start at 0 (avoid whenever possible graphs with linear scales that start at 1 or 2). Of course, this does not apply to logarithmic scales.

Each point on an experimental graph should be the intersection of two segments, representing the range of the particular data (error bars).

Error Analysis

Experimental data are only complete with meaningful error bars. Also, quantities that you calculate from experimental results must show uncertainty ranges. Use error analysis and error propagation to obtain these uncertainty ranges.

2 Lab Preparation

It is essential that you come prepared to the class. Read the lab instructions carefully. The lab manual is not intended to be a substitute for a textbook. Based on your background and experience you may need to consult an optics text to prepare your experiment. **The lab hours are not the time to prepare for the class.** You should discuss problems and questions that came up while you were preparing the lab with the instructor and/or the TA's before you start with the experiment.

Here is a list of subjects you need to know to complete a certain experiment successfully. Do not be afraid to ask the instructor and the TA if you have questions. The experiments are listed in order of difficulty.

1. Basic optics experiments
    - A subset of these experiments is recommended for students with a weak optics background. Before you sign up for these labs consult with the instructor.
2. Wavemeter
    - Michelson interferometer
    - Gaussian beams
    - Transformation of Gaussian beams by lenses
3. Doppler velocimetry
    - Doppler effect
    - Spectrum analyzer
    - Michelson interferometer
    - Spatial filtering using pinholes
4. Aberration
    - Lenses
    - Imaging and ray tracing
    - Principal planes
    - Spherical aberration
    - Chromatic aberration
5. Holography
    - Holography
    - Holographic interferometry
    - Diffraction gratings
6. Fiber optics
    - Gaussian beams and their transformation by lenses
    - Single and multi-mode fibers
    - Diffraction limited focusing and numerical aperture
7. Modelocking
    - Principle of modelocking
    - Acousto-optics modulator
    - Fabry-Perot spectrometer
    - Digital oscilloscopes (sampling theorem)
8. Fourier Optics
    - Fourier transformation

- Imaging using thin lenses
- Gratings and diffraction
- Coherent image formation
- Spatial filtering

9. Polarization

    - Types of polarization
    - wave plates
    - Fresnel's equations
    - Polarization matrices

10. Statistical optics

    - correlation and autocorrelation of signals
    - statistical properties of light
    - Michelson stellar interferometer

3 Safety Considerations

Safety rules and guidelines are designed to reduce the possibility of accidents in routine situations. In a research laboratory where most of the lasers are "home built", and the beam configuration changes daily, there is no "routine", and there is no safety rule or policy that can substitute for an intelligent and careful handling of the equipment. This note is intended to make you aware of the risks in entering the laboratories with high power lasers, as well as the general hazards associated with laser experiments and research.

There is a relatively large concentration of on-going experiments in these laboratories. As a general rule, please do not touch anything that you are not familiar with: the little pain produced by a poorly grounded circuit is only a mild precursor of the tornado that will unleash when the "victim" discover that his/her experiment has been tampered with.

If in doubt, consult the instructor or TA!

Laser classification

The American National Standard Institute (ANSI) has classified lasers according to what they perceive as hazard level. Class IIIb and class IV lasers are considered as hazardous. You will be pleased to know that they have included in class IIIb most of the semiconductor and HeNe alignment lasers!

General rules associated with all class IV lasers:

1. Warning light at the door.
2. Goggles to be worn at all time that the laser is on, *unless* the beam is safely enclosed.
3. Entry to the lab restricted.
4. No person will be admitted to the lab unless he has acknowledged with his signature that he has read and understood this memo.

Additional recommendations

5. Keep the laser beam in one horizontal plane close to the table.
6. NEVER bend down to the table level.

We have purposely chosen to have the optical table surface as low as possible — which is unfortunately not very comfortable, but it reduces the chances of having your eyes at the beam height. NO LOW CHAIR allowed in the lab. Sitting accomodations are limited to high stools.

Be Cartesian and organized in constructing any set-up with class IV lasers. Keep the beams in a plane at a fixed height above the table. Not only are you reducing the probability of blinding someone with a non-horizontal beam, but you will reduce the losses due to beam depolarization. **Do** keep several beam blocks at strategic locations on the table. There should always be a beam block available next to the pump beam (in the case of a laser-pumped laser). Do not move any optical component without blocking the beam first.

Many experiments involve too many wavelengths to make the use of goggles practical. For instance, a parametric oscillator pumped by a Nd:YAG involves 1.06 μm, 532 nm, 355 nm, 860 nm, 1.5 μm, 460 nm. Two patches of tape on the eyes is the only safe goggle for this combination of wavelengths. Therefore, the pump beams should be kept enclosed, and the beam terminating in a beam dump. An effective beam dump is a tube bent at 90°. Experiments using Argon laser pump and frequency doubled Nd:YAG can be enclosed in green absorbing (orange) plexiglas.

No safety rule is a substitute for common sense

(The respectable ANSI members will hate me for writing this, but the examples of accidents listed below make my point. All occurred in laboratories with strictly enforced safety guidelines and rules.)

Dangers of certain lasers

Nd:YAG Laser

The Nd:YAG laser deserves a special mention for being one of the most hazardous of all laser. Its wavelength of 1.06 μm is long enough to be totally invisible, yet short enough to be still transmitted by the cornea, the lens and the fluid of the eye. In Q-switched operation, a 1 mJ pulse at 1.06 μm can cause retinal damage. Accidents can happen in the most sophisticated manner. At Philips Research Laboratories in Eindhoven, a technician was trying to make a longitudinally pumped infrared dye laser. The dye solution, pumped by a Q-switched Nd:YAG laser, was contained in a rectangular cell. The cavity was probably not well aligned, because no lasing was observed along the resonator axis. However, the sides of the cuvette happened to be of good enough optical quality to provide enough feedback for laser oscillation to occur in a direction orthogonal to the expected beam axis. The technician, who was staring at this cuvette, had his eye lined up with that unexpected laser pulse. He immediately lost 90% of the vision in that eye. Some healing occurred and he recovered soon thereafter half his vision.

Nd:YAG lasers are also the most common sources of CW (continuous wave) laser radiation for industrial application (welding, surface treatment, drilling, surgery, etc.). Beams of 100 W CW power is not uncommon. In an accident at Lawrence Livermore Laboratories, a spurious reflection of a CW Nd:YAG laser happened to be in-line with the eye of one investigator. He was wearing goggles which reflect 99.9% of the laser light. Unfortunately, the 0.1% absorbed by these plastic goggles was sufficient to melt them....

Most Nd:YAG lasers in use in our laboratories are pulsed, either Q-switched or continuously mode-locked. These lasers are frequency doubled to 0.53 μm, to serve as the pump for an oscillator or an amplifier. A dichroic mirror is used at the output of the laser to separate the residual infrared beam, which is dumped in a “blackbody”. The remaining output is visible, which means that one can at least see where the hazardous locations are. Stray reflections are still dangerous! Again:

- Keep the beams horizontal
- NEVER bend down to the table level
- Wear goggles for the wavelengths that are not absorbed by the laser cover.

CO_2 Laser

The CO_2 lasers in use in the department are CW or pulsed, with a maximum average output power of 10 W. At the wavelength of 10 μm, all standard “visible optics” is opaque (it is a lesser evil than the Nd:YAG laser output because it can not reach the retina). Standard machine shop goggles and eyeglasses offer adequate protection against the beam.

- Do not turn the laser on without a “beam stop”.
- Do not insert anything in the beam before estimating where the reflected beam will go (a particularly important precaution if you use plexiglas to measure the beam profile).
- Watch for the reflection from the Brewster windows.
- Keep a respectful distance from the tube and any part of the electrical circuit. The power supply is rated at 20 kV, which is much more than the electric chair.

The Argon Laser

For the same output power, the Argon laser is potentially more dangerous than the Copper Vapor laser because of its highly collimated and narrow beam. Same as for the CO_2 laser, do not insert anything in the beam without thinking first, “Where am I sending the reflection?”. If the beam is to be blocked, the safest “beam stop” is a section of copper tube bent at 90° (it acts as a nearly perfect “blackbody”. A piece of wood or cardboard — as has been attempted too often — is definitely not a good idea.

Do not operate the Argon laser with its cover off for the following reasons:

- Under the cover of the laser head, there are several wires carrying 500 V, 50 A.
- The reflections from the Brewster windows are directed at eye level.

“Safe operation” of the Argon laser implies also care and respect for this very expensive piece of equipment. The rage of the P.I. when you break his laser tube should be considered as more life threatening than a loaded capacitor. Additionally, a replacement tube for an 18 W model costs $30,000.

In order to increase the lifetime of the tube (3 months on the average with normal “tap water” of Texas or New Mexico), a closed loop of temperature regulated de-ionized water has been constructed. The closed loop operates between 100 and 120 psi, far above the maximum pressure that the tubes will tolerate. Opening the inlet valve before opening the return line will put over 100 psi on the laser, and thus shatter the tube. **Leave the valves open at all time**. If for some particular emergency (water leak) a water line had to be closed, always close the inlet first, thereafter the return. In re-opening: open the return line first (which is between 5 and 10 psi). When thereafter the inlet valve is opened, a flow regulator ensures that a nominal cooling flow is provided to the laser. The tube will also break is the cooling flow is not sufficient, or if the cooling water is turned off too soon after the laser has been turned off. Again, to be safe, please do not operate the water valves, and do not turn on/off an Argon laser without asking first.

High Voltage

There is a high voltage associated with nearly every laser experiment - if not with the source, it may be with the detection. Always be aware of the **location of the circuit breakers relevant to your experiment**.

Never assume that a HV circuit is safe because the switch is "OFF". Most high voltage power supplies have a solenoid that discharge the regulating or storage capacitances when the power supply is turned off. Very often, an oxide layer forms on the contact surface, making it able to withstand a few kV. Use a grounding stick to discharge the circuit before touching any part of it.

Never put any part of the body within 10 cm of a gas discharge tube which has any voltage on the electrode. Depending of the applied voltage, the discharge may prefer an unexpected path. It happens that the high fields between the inside and water cooling make a hole in the Pyrex tube of a CO_2 laser. A finger can also provide a good grounding electrode.

Always monitor the voltage when turning on a power supply. Turn off immediately the power supply if there is no indication of high voltage when the regulating potentiometer is turned. It generally means that a relay is not making good contact. If you continue increasing the voltage, air breakdown will suddenly close the contact. At best, the resulting transient will destroy some diodes and/or capacitors in the power supply. The consequences could be more disastrous.

An "interesting" incident occured once in one of our laboratories. When turning up the voltage of a 20kV power supply, the voltage reading did not come up regularly. At one point, there was a noise . . . at the opposite corner of the laboratory. The power supply HV transformer somehow got shorted, which then discharged its HV into the AC neutral line, from there into the power strip, from the power strip to the chassis of an oscilloscope. The noise was due to a bright arc between the chassis of the oscilloscope and the water line. Even a commercial power supply can be fatal!

References