Instructor Notes for Physics 2020 Laboratory/Recitation

Overview:

This is a writeup of a 2020 lab sequence which was prepared/modified over the spring, summer, and fall of 2005. It has evolved from the 6-lab sequence which had previously been developed for 2020 and was used for several years. The course itself has evolved to incorporate the heavy usage of participatory “concept tests”, and the lab sequence included here has borrowed heavily from the “tutorial” style labs at other universities.

Among the changes incorporated into this sequence is the number of labs. Physics 2020 had previously held 6 labs and 6-7 recitations, but it was found that the recitation sections had limited usefulness to the students, and were often a source of frustration for both the students and the TA’s. We have therefore extended the number of labs to 10, with the intention that recitations only be held during the weeks preceding exams. The 10 performed labs can be chosen (by the instructor at the beginning of the course) from a set of 12 which are prepared here.

The second major change in this sequence is the style/format of the labs themselves. The format mimics the “tutorial” style of the University of Washington, which has been found to considerably enhance the learning experience of the students at this level. The labs are presented as a set of guided questions to be filled out and answered during the lab period. No additional lab notebook is required – the answers can be filled out directly onto the printed lab writeup.

Additional notes are provided here pertaining to the structure of the labs, the TA meetings, grading, etc., but of course these are all merely suggestions to be taken at the instructors discretion. The hope is that the lab part of 2020 is completely described here, and this can form a baseline from which the instructor can take what they like.

Lab Structure:

Each week a new lab writeup will become available on the course web-site (as a PDF). The students should print out a copy of the writeup and bring it to lab. Additionally, the students should fill out their answers to the pre-lab questions before arriving to lab. (If it is set up, the students should log on and fill in their answers to the pre-lab questions via computer.)

At the very beginning of lab, the TA should walk through the class and initial all of the pre-lab answers, as a verification that they were done before the lab period.

During the first 15-30 minutes of the lab period, the TA should hold a group discussion with the class. This should include a discussion of the pre-lab questions and an overview of the basic concepts needed for that week’s lab. This can include an introduction to any new equipment, and any demos that are relevant. The discussion can center on the “suggested talking points” which are presented at the end of this document.

(Side note: It is very useful to unplug or otherwise disable the equipment before the lab period, so that the students are not distracted during the discussion period.)

Once the discussion period is over, the students should break up into groups of 3-4 and work through the lab together. While they can perform the experiments and discuss the results as a group, each student should write up their own answers. The TA should wander from group to group, answering and asking questions. The TA’s should be encouraged to spend at least a few dedicated minutes with each group discussing some challenging question – either one that the group has asked the TA, or one that the TA has asked the group. Additionally, the TA’s should be encouraged to answer students’ questions by asking their own leading questions, rather than simply telling the answers. Once their labs are completely filled out, the students are free to leave.

The lab writeups should be turned in **at the conclusion of the lab period**. This should be stressed and enforced – turning in a writeup several days later or without actually attending the lab session deprives all of the students of the valuable group discussions.

Lab Sequence:

This package contains 12 labs. While there is time to cover all 12 in a semester, it is useful for the students to have a recitation during the week preceding an exam. Given the school breaks and recitation weeks, it is advised to perform labs 1-8, then choose two of the remaining four for a total of 10 labs. The choice of which labs to perform should of course reflect the lecture material.

Lab 1 : Charges and Electrostatics
Lab 2 : Electric Fields and Potentials
Lab 3 : DC Circuits I
Lab 4 : DC Circuits II
Lab 5 : Magnetism
Lab 6 : AC Circuits
Lab 7 : E/M Waves
Lab 8 : Lenses and Telescopes
Lab 9 : Diffraction and Interference
Lab 10a : The Hydrogen Spectrum and Rydberg Constant
Lab 10b : Relativity
Lab 10c : The Wave Nature of Matter
Lab 10d : Temperature and Thermodynamics

Free Exam Questions:

At the end of each lab writeup, there are two “potential exam questions”. These are not to be turned in, but merely used by the students as a study guide. On each exam, include one or two of the questions from the pool of “potential exam questions” (with minor edits). Inevitably you will receive email from students asking for the answers to these questions (or even asking you to post the answers on the web!). We have found that it is useful/educational to discuss these questions with the students during office hours, but otherwise the answers should be figured out among the students.

Grading Guidelines:

It is recommended to use a 10-point grading scale for each lab, as follows:

- 3 points for pre-lab
- 5 points for reasonable attendance & completion of lab
- 2 points for excellent writeup

Additional guidelines/recommendations can be found in the “2020 Student Guide”.

Recommendation for Makeup Labs:

The last week of the semester can be designated “makeup lab week”, during which one setup of each experiment should be set up in the lab area. TA’s should come at their normal times.

It is recommended that students are only allowed to make up **one** lab from the semester during makeup week – otherwise the students tend to not take lab attendance seriously, and pile up the makeup labs for the final week.

TA Meetings:

Weekly meetings with the TA’s are typically held on Friday afternoons. One setup can be prepared for the following week’s lab. The instructor should go through the “preamble” to the lab, as if the TA’s are the students. The instructor and the TA’s should then go through the entire lab together, practicing the use of the equipment, covering all of the talking points, and discussing any predicted difficulties.

Talking points and prerequisites from lecture:

Lab 1 : Charges and Electrostatics

Talking Points:

1. Describe difference between static and moving charge. (What does "static" mean?)
2. Describe the mobile behavior of electrons in metals.
3. Contrast conductors with insulators in terms of electron mobility.
4. Describe how and why charge on a metal distributes itself on the surface. (Analogy: if all of us in the room wanted to get as far away from each other as possible, where would we go?)
5. Describe what happens when a charged object is brought close to a piece of metal.
6. The section on charging by induction (p. 5) is the heart of the lab. Be sure that the TA's know this, and that they ensure that each lab group spends sufficient effort and thought on this part.

Prerequisites from lecture:

1. What is a charge?
2. Like charges repel, opposites attract.

Lab 2 : Electric Fields and Potentials

Talking Points:

1. Spend some significant time discussing the question "what is a field". Be sure that the students understand that the field is derived from the force on a test charge.
2. When considering fields and forces, it is critical to separate the source charge from the test charge. Of course all charges create fields and impose forces, but when considering a field in terms of a test charge, the source and test charges can easily be confused.
3. Spend some significant time discussing the question "what is potential". A very good analogy for this is gravitational potential energy, gravitational fields, and gravitational force. Introduce equipotential diagrams. Use the analogy of a topographical map of the mountains. The twist to the analogy is that electrons want to roll uphill…
4. Go over what an equipotential curve is. Use the foils from the lab as examples.

Prerequisites from lecture:

1. Introduction of electric fields
2. Introduction of electric potential

Lab 3 : DC Circuits I

Talking Points:

1. Go over the banana plug connectors for the resistors and bulbs. Make detailed drawings on the board.
2. Demonstrate how to measure the resistance of a resistor or light bulb.
3. Part II is the heart of the lab. Be sure that each group fully understands what is happening in this part. Spend time with each group going over this.

Prerequisites from lecture:

1. Explain how a light bulb is constructed.
2. $P=IV$, which is proportional to brightness
3. Ohm's law

Lab 4 : DC Circuits II

Talking Points:

1. Demonstrate how to measure current through a resistor/power-supply combo.
2. Halfway down page 4 (relating I, V, and R through Ohm's law) is the heart of the lab. Be sure that each group fully understands how to answer this part.

Prerequisites from lecture:

1. Ohm's Law
2. Brightness P=IV
3. Complete circuits / current conservation

Lab 5 : Magnetism

Talking Points:

1. Go over Right Hand rule and discussion of current in a magnetic field.
2. Advise the students in lab to be careful not to:
   a. magnetize the tables, or stands
   b. that the compasses can get flipped if you rub the permanent magnets on them.
   c. the trapeze can get caught, so make sure it swings freely.

Prerequisites from lecture:

1. Current causes magnetic field, right-hand rule
2. How magnets attract repel / N & S
3. Earth as a magnet

Lab 6 : AC Circuits

Talking Points:

1. How the oscilloscope works (both in terms of operating and in terms of reading time/div etc).
2. Get the students to ask for help when stuck on observing signals (the oscilloscopes are finicky).
3. Conceptual frame of what Faraday's law is.
4. Covering the idea that current creates magnetic field, *changing* magnetic field creates current, basis of generators and motors.

Prerequisites from lecture:

1. TA's need to have some training on the oscilloscope
2. Lens' law
3. Faraday's law

Lab 7: E/M Waves

Talking Points:

1. This lab is to develop an understanding of what E/M waves are
2. The REPRESENTATION of E/M waves is critical
3. How E/M waves are made (electronic transitions or from oscillating electrons)
4. Connect to the E-field

5. Possible connection to what a field is in general

Prerequisites from lecture:

1. E-field
2. Sine wave representation
3. E & B representations and propagation of fields

Lab 8 : Lenses and Telescopes

Talking Points:

1. real and virtual images
2. ray tracing methods
3. connecting to examples in real life (magnifying glass, focal points etc)

Prerequisites from lecture:

1. geometric optics
2. focus
3. $1/i + 1/o = 1/f$

Lab 9 : Diffraction and Interference

Talking Points:

1. Emphasize constructive / destructive interference
2. Why one shows up vs. the other
3. Review interference (generally little d (bigger size) - > smaller spacing)
4. Review diffraction (generally big D (smaller size) -> larger envelope)
5. Combine diffraction with interference
6. Practice resolution of eye. (calc)

Prerequisites from lecture:

1. Wave propagation
2. Representations of plane wave propagation (sine wave, plane wave (wavefronts), propagation vectors)
3. $n\lambda = d\sin(\theta)$

Lab 10a : The Hydrogen Spectrum and Rydberg Constant

Note that these spectrometers are flaky, and the discharge lamps are quite flaky.

It is useful to have the lights off / dimmed if possible.

Talking Points:

1. The different ways to make light (electronic transistions vs. blackbody radiation)
2. Bohr model of electron
3. Continuous vs. discrete (optical emission).

Prerequisites from lecture:

1. Line radiation from electronic transitions, and blackbody radiation.

Lab 10b : Relativity

Talking Points:

1. TA's must spend some time doing an example or two of relativity problems, and must prepare ahead of time how to keep the various reference frames straight. Perhaps have the TA's practice explaining the reasoning underlying a simple time dilation problem. This can obviously be extremely confusing to the students, especially if the TA's get mixed up in their explanations.

Prerequisites from lecture:

1. Basic tenets of special relativity:
   a. The laws of physics are the same in all inertial reference frames.
   b. The speed of light in vacuum is a constant (c = 299792458 m/s) and is independent of the motion of its source.
2. Some practice with (and examples of) time dilation and/or length contraction.

Lab 10c : The Wave Nature of Matter

Talking Points:

1. Clearly this section of the course (i.e. the whole modern physics section) can be confusing to the students. Stress that once you get past the concept that the particles exhibit wave behavior, they act similarly to the waves that we have seen before (i.e. EM light waves), so that we can test for the wave behavior by using our old friend the double-slit interference pattern.
2. Be sure that each group doesn't get stuck calculating the energy, momentum, and wavelength of the electrons. Once they see it done, it is relatively easy, but sometimes they don't know how to even start.
3. Be sure that each group understands the geometry of the crystal diffraction. The students have a tendency to gloss over this part and just look at the formula, but if they take the time to understand it (i.e. where the factor of 2 comes from and why the waves are interfering), this can be fundamentally helpful to their understanding of interference in general.

Prerequisites from lecture:

1. Review of wave-interference relationships (double slit diffraction patterns).
2. Relationship between particle energy, momentum, and de Broglie wavelength.

Lab 10d: Temperature & Thermodynamics

Talking Points:

1. By the end of the lab, students should have a good intuition on what it means for two gas species to be in thermal equilibrium.
2. Relationship between kinetic energy, average kinetic energy, and Temperature.

Prerequisites from lecture:

1. Ideal gas law.
2. Physical concept of pressure.

Equipment List for Physics 2020 Labs

Lab 1 : Charges and Electrostatics

Electroscope

Various plastic rods

Grounding plates

Paper towels

Empty soda cans

Lab 2 : Electric Fields and Potentials

Transparency foils of E-field vectors and equipotential curves (4 different foils)

Paper printouts of E-field vectors and equipotential curves (4 different pages)

Tracing paper (available from Xpedx paper, 1960 32nd St., (303) 786-8708)

Lab 3 : DC Circuits I

Digital multimeter

DC power supply

Automotive light bulbs (2x)

Banana-plug mounted resistor set (one 15 Ω, one 40 Ω, one 1500 Ω, and two 3000 Ω)

Mounting board

Various cables with banana-plug ends

6V batteries (2x)

Lab 4 : DC Circuits II

Digital multimeter

DC power supply

Automotive light bulbs (2x)

Banana-plug mounted resistor set (one 15 Ω, one 40 Ω, one 1500 Ω, and two 3000 Ω)

Mounting board

Various cables with banana-plug ends

Lab 5 : Magnetism

Bar magnet

Compass

Trapeze setup (stand, wire trapeze, battery holder with batteries, telegraph-key switch, and connecting wires)

Lab 6 : AC Circuits

Oscilloscope

Signal generator

Speaker

Microphone

BNC cables

Banana-plug cables (various lengths)

BNC-to-banana adaptors

Electric motor setup (stand with loop, battery holder with batteries, telegraph-key switch, bar magnet)

Lab 7 : Electromagnetic Waves

None, except your wits (and chalk)

Lab 8 : Lenses and Telescopes

Telescope setup.

Lab 9 : Diffraction and Interference

HeNe laser

Cornell plate

Laser/plate stand and target

Lab 10a : Relativity

None

Lab 10b : The Wave Nature of Matter

None

Lab 10c : The Hydrogen Spectrum and Rydberg Constant

Project Star spectrometer

Hydrogen discharge tube

Variety of “mystery” gas discharge tubes (He, Ne, Ar, etc.), labeled in code

Lab 10d : Temperature & Thermodynamics

Laptop PC