Physics 253Q - Modern Physics Syllabus - Fall 2014

Dr. Frosso Seitaridou

Welcome to Modern Physics! This course covers the physical concepts developed in the 20th century. The concepts we will learn this semester are concepts that almost everybody has heard of (e.g., relativity, x-rays, quantum physics, etc.). Needless to say that these concepts have inspired many works of science fiction and, of course, they have many applications in modern technology.

A good understanding of modern physics will help you a) understand modern technology (e.g., GPS, x-rays, etc.), b) hone your thinking skills, c) recognize the philosophical implications these concepts have! Since you have already taken Introductory Physics, by the end of Physics 253Q you will have seen and understood almost all physics concepts! I hope you are excited! In addition, you will conduct on your own some of the original experiments that led to the development of these concepts, and you will also work on your scientific writing skills by writing laboratory reports on these experiments (see below for more details on those.)

Goals of the Course / Learning Objectives

At the end of this course, we will be able to:

1. Have a fundamental understanding of the physical concepts developed in the 20th century.
2. Apply these concepts in order to solve simple problems in modern physics.
3. Recognize the reasons why some of the concepts are subject to different interpretations by physicists.
4. Appreciate the philosophical implications of these concepts.
5. Recognize the physics concepts behind modern technological advances.
6. Develop your skills in scientific writing.

To achieve these goals, we will solve problems, use laboratory exercises, write lab reports, and, depending on interest, I will be giving you some reading assignments that are outside our textbook.

Student work submitted as part of this course may be reviewed by Oxford and Emory faculty/staff for the purposes of improving instruction and enhancing Emory education.

Ways of Inquiry

This course has been designated as an Inquiry course. Since you have taken Physics 151-152 or the equivalent, you have been exposed to the science of physics and have developed a basic understanding of many fundamental physics concepts. Therefore, in Physics 253Q you will be able to explore at a deeper level what makes physics a unique and distinct science. Through this course and the homework assignments, you will be learning what questions physicists ask, what tools they use, and how they discover knowledge. By reflecting on and thinking critically about what and how you are learning, you will be able to become independent learners in this field. You will also appreciate the insight into nature that physics can give you and the connection between physics and other disciplines. For more details on how the “Ways of Inquiry” approach will be applied to this course, please see the last three pages of this syllabus.

Writing Intensive

This course satisfies the Continuing Writing Requirement for eligible students. The basis for this is a) the writing of the solutions to the homework problems, b) the writing of the short lab reports, and c) the writing and revision of the full lab reports. For more details on that, please see the “Homework” and “Lab Reports” sections below.

Important Information

Instructor and Contact Information: Dr. Frosso Seitaridou. You can reach me by emailing at eseitar@emory.edu or by calling my office at 4-8344.

Office Hours: My office is at Pierce 209. I have an open door policy: if I am in the office and the door is open, feel free to come in. We can talk about physics and homework assignments, your student life, and anything else you would like to chat about. You can also email me to make individual appointments.

Prerequisite: Math 112 and either Physics 142 or Physics 152.

Textbook: Tipler and Llewellyn, *Modern Physics*, Sixth Edition.

Homework: All homework assignments (reading and problems) together with their due dates are shown below. It is expected (and you will find it very helpful) that you have done the reading before we talk about it in class.

With regards to the assigned problems, you will be asked to present the solutions in the form of paragraphs. That is, your solutions should contain both text and equations and should be organized in the same way you organize your thoughts and arguments in a paragraph. You can see such a solution every time you read an example in your introductory physics and modern physics textbooks. We will talk about examples of such solutions during class, but there is also an example below, in the section titled “How to solve a physics problem.”

Reading Schedule and Assignments (subject to change depending on the pace of the class, etc.)

Week	Dates	Section	Assigned Problems and comments (for lab assignments, see below)
1	27-Aug	1.1	
	29-Aug	1.1	
2	1-Sep	No class	Labor Day
	3-Sep	1.2	
	5-Sep	1.2	
3	8-Sep	1.3	Skim spacetime diagrams. Read pages 1-5 from Einstein’s 1905 paper.
	10-Sep	1.3	
	12-Sep	1.4	Due: Ch1: 4*,6,10
4	15-Sep	1.4	Skim muon decay and the spacetime interval.
	17-Sep	1.5	
	19-Sep	1.6	Skim the headlight effect from book.
5	22-Sep	2.1	
	24-Sep	2.2	
	26-Sep	2.2	Due: Ch1: 8, 16,18,20,26,28

6	29-Sep	2.3	
	1-Oct	2.4	Skim creation and annihilation.
	3-Oct	2.4	Due: Ch2: 3,6,8,10,12, and the reading on the Fabric of the Cosmos, ch. 1-3
7	6-Oct	3.1	
	8-Oct	3.2	
	10-Oct	3.3	Due: Ch 2: 16,17,20,22
8	15-Oct	3.4	
	17-Oct	4.1	Due: Ch 3: 2,4,6,13,16
9	20-Oct	4.2	
	22-Oct	4.2	
	24-Oct	4.3	Due: Ch 3: 18,21,28,30,34,39
10	27-Oct	4.3	
	29-Oct	4.4	
	31-Oct	4.5	Due: Ch 4: 2,4,6,8,10,14
11	3-Nov	5.1	
	5-Nov	5.2	
	7-Nov	5.2	Due: Ch 4: 18,19,22,26,28,34,36
12	10-Nov	5.3	
	12-Nov	5.4	
	14-Nov	5.5	Due: Ch 5: 2,6,14,17,18
13	17-Nov	6.1	
	19-Nov	6.2	
	21-Nov	6.2	Due: Ch 5: 24,30,32,38,43
14	24-Nov	6.3	
15	1-Dec	6.4-6.5	
	3-Dec	6.6	
	5-Dec	7.1	Due: Ch 6: 2,4,6,10,16
16	2-Dec	7.2	

* Don't be tricked by the book "organizing" the problems by sections. You will find that in order to solve a problem you might have to look at other sections, sometimes even sections from a different chapter. So keep that in mind for all the problems that are assigned from the book.

<u>Tests and Exams:</u> There will be three tests and one final exam (for dates, see below). The tests will be on the material covered up until that point (the second test will cover the material after the first test and, similarly, the third test will be on the material after the second test). The final exam will be cumulative. There is no such thing as a make-up exam!

<u>Re-grading Assignments:</u> I am very careful when I grade assignments. However, I might make mistakes when I grade. If you would like me to re-grade a test or assignment, your request should be submitted to me **in writing within 24 hours** from the time I give back the graded assignment. Note that such a request will result in me re-grading the whole assignment/test (not just the specific problem you requested).

<u>Attendance:</u> I find attendance and class participation to be vital for this course. You will find the homework to be really easy to do, if you come to class and you actively participate by asking and

answering questions. You are allowed **3 absences regardless of whether you have a valid reason for them or not.** Therefore, I recommend that you save those for when you really need them (e.g., you get sick) instead of skipping class. If you are absent from class on a day when there is an Organic Chemistry or a Math test, 10 points will be taken off of your next Physics test. If you exceed the 3 absences, there will be a 5% deduction off of your final grade for every additional absence. **ATTENDANCE IS MANDATORY FOR LAB SESSIONS**.

Tardiness and Cell Phones: Being late for a class, or having your cell phone ring in the middle of one, is distracting not only for you but also for me and for your classmates. Students who are late for class for more than 5 min will generally not be allowed to attend that day's lecture and will be considered absent. Students whose cell phone rings during class will be asked to leave the classroom and will be considered absent. For the same reason, **I will not allow food or drink during class**, with the exception of a bottle of water.

Grading: **Grades to assignments will be given based on correctness, and, most importantly, on the methodology and presentation you use (see section on "How to solve a physics problem" below).** So, especially for the homework make sure that you start on it early and come to me for help! Grades for the course are assigned on the plus-minus scale. The final grade will be determined based on the following weighting:

Homework: 30%
Exams: 10% each test (30% total), 20% for the final
Lab Reports: 20%

Course Content: Relativity, atoms, wave-particle duality, quantum physics

Important dates: Make sure you include these important dates in your planner/calendar. The actual times for the tests will be determined during class.

Date	Description
Sep. 19, 2014	Test 1
Oct. 17, 2014	Test 2
Nov. 21, 2014	Test 3
Wednesday, Dec. 17, 2014, 2 pm – 5 pm	Final exam: Cumulative

Working with the Honor Code: The Oxford College Honor Code applies to this course as follows:

Tests and final exam: The work presented in these assignments should be your own. No collaboration permitted. You are expected to follow the instructions given by me and abide by the Honor Code. Sharing calculators, pencils, etc., is not allowed

Lab reports: Each student will be submitting his/her own lab report. However, since the experiments will be done in groups of 2-3 students, you are allowed and encouraged to discuss your data and the implications of your data with your lab partner(s).

Homework assignments: You are encouraged to work on the assignments **by yourselves first, before consulting other classmates for help.**

Study groups: Even though you cannot work together on tests and exams, you are definitely encouraged to form study groups and study concepts together and explain to each other things about which you were not clear from class or from your reading assignments. However, as mentioned above, you are strongly encouraged to work on the homework assignments by yourself first, before consulting your classmates for help.

Religious Holidays: You need to tell me immediately if any religious holidays will interfere with the course, especially the final exam and tests.

How to Solve a Physics Problem

Your homework assignments will consist of pre-lecture reading assignments, and problems. In your solutions to all problems I expect to see that you solve the problems following several important steps. **This is the proper methodology for solving a physics problem and this methodology is the same for all problems!** Following these steps will ensure that you are learning how to approach a problem and how to develop an organized and methodical solution to a problem.

1. **Read the problem** carefully so that you know what is given and what is asked.
2. **Draw a picture** when applicable.
3. **Label all the quantities** in the diagram, those that are given and those that you need to find. Also, **show your coordinate system if applicable and show which direction you have defined as positive!**
4. **State the Physics Laws** that apply to that problem. For example: ``Particle in 1D box"
5. **Write the law in equation(s) form**.
6. **Solve** the equations and substitute the values. **Always include the units!** Also, **show your work**! You cannot just write the initial equation and then the result. You have to show me the intermediate steps. This way, I can identify the wrong step and help you understand why what you did is not right.
7. **Check your answer**. Do the units match? Does the sign in front of your result make sense? Is the answer too big or too small compared to what you expected?

Since this course satisfies the writing requirement, steps 4-6 above are critical to me for evaluating your work in terms of the quality of writing. You need to explain your thinking process not just via equations, but also with words. For example, your work should look like this:

"Based on the given information for the potential, its form is that of the infinite square well. For this potential, the solution to the Schrodinger equation is given by eq. 6-32 on page 233 from the textbook:

$$\psi_n(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}.$$

If we plug in the appropriate values for n, L, and x as given by the problem, we find that…"

In this example you see that I have identified the concept (Infinite square well), the equation that describes the concept and what I am about to do with this equation, and I have explained the process of my thinking in words. **You are expected to use proper syntax, grammar, punctuation, etc. when you write up your solutions and, of course, in your lab reports,** which are discussed in detail below.

Requirements for the Lab portion of this course

As noted above, the lab portion of the course constitutes 20% of your grade. Even though this 20% will be based on your lab reports, you will not be able to write a lab report that clearly shows your understanding of the experiment unless you follow these steps:

1. Bring your lab handout: You will be given the lab manual at the beginning of the semester. You are expected to have read the handout for each week's lab BEFORE coming to the lab. The laboratory exercises are more advanced than those in Introductory Physics. If you do not read the handout carefully before coming to lab, you will have a hard time understanding what you are doing, which will ultimately show in your report in the form of incomplete and incorrect explanations.
2. Answer all the questions in the lab handout: Some of these questions will require that you spend time at home analyzing the data and drawing graphs. I will definitely be looking for the answers in your lab report (more details on the lab reports later). Failure to present these answers in your lab reports will affect your lab grade.
3. Understand the lab: Experiments require repetition in order to ensure that your data is reproducible. Sometimes students regard this repetition as "busy work." However, remember that at all times you need to be thinking about what your data means, if this is what you expected and why (or why not) and, also, what the reproducibility (or lack of) means. Essentially you are expected to be thinking about what conclusions you can draw from your data. These conclusions should be included in your lab report.

Lab Reports

Throughout the semester you will write <u>3 full lab reports</u> and <u>several short lab reports</u>.

a) <u>Full lab reports</u>: Each full lab report will be, approximately, 8-10 pages long (including data and figures). For each report, you will be submitting a first draft and then a final draft. After you submit the first draft, I will read it and make comments on it, and return it to you. You will then, if you wish, have a week to revise your first draft and submit your final draft. The evaluation will be done based on the "Physics Lab Report Evaluation Sheet" attached at the end of the syllabus. Full lab reports should contain all the parts listed in the Evaluation Sheet (i.e., title, abstract, introduction, materials and methods, results, discussion, conclusion, and references) and will be written for the following experiments:

1) Measuring the speed of light
2) The Millikan Oil Drop experiment
3) Blackbody radiation

Each full lab report will be due a week after the corresponding experiment is conducted.

b) <u>Short lab reports</u>: For the remaining labs, you will be writing short lab reports, each of which will be approximately 3-4 pages (including data and figures). Short lab reports will contain only the following sections: title, brief introduction <u>that includes a thesis statement</u>, results, discussion (in the short lab reports, the discussion will essentially consist of the answers to the questions in the lab handout <u>that are supported by your results,)</u> and conclusion. Short lab reports will not be submitted in drafts. In other words, for these reports you will not be given the option of revision. Similarly, the short lab reports will be due a week after the corresponding experiment is conducted.

Schedule of Labs

The table below shows the schedule of our labs for this semester. This schedule is tentative and the order of the labs might change depending on the status of the equipment, the pace of the class, etc. Any changes will be announced in advance.

Week	Lab
1	Matlab tutorial
2	Matlab project #1. Short report is due on week 3.
3	Measuring the speed of light: a) Michelson interferometer and b) Speed of Light apparatus. Your full lab report can be on either (a) or (b) – you choose! That's due on week 4.
4	Brownian motion and Microfluidics part 1: Fabricating microfluidic devices (no lab report needed).
5	Brownian motion and Microfluidics part 2: Observing Brownian motion inside Microfluidics. Short report is due on week 6.
6	a) Matlab project #2. Short report due on week 7. b) Also due this week: Research 2 journal papers (one on Microfluidics and one on Brownian motion). Be ready to describe the papers to your classmates. 1-page summary for each paper due on week 7.
7	a) Properties of the electron. Short report due on week 8. b) Submit a 1-page summary for each of the 2 papers you found in week 6b.
8	a) Millikan oil drop experiment (Full lab report due on week 9.) b) Also due this week: Based on the papers you researched and their summaries, is there a <u>**new**</u> question you would like to have answered? Be ready to justify during lab.
9	a) Matlab project #3. Short report is due on week 10. b) Also due this week: a 3-page paper on how you would go about designing an experiment that would address the hypothesis you developed on week 8b.
10	Blackbody radiation (Full lab report is due on week 11).
11	a) Planck's constant apparatus/photoelectric effect (class demo). b) Light emitting diodes. Short report is due on week 12.
12	Atomic spectra. Short report is due on week 13.
13	Franck-Hertz experiment (Short report is due on week 15).
14	No lab – Thanksgiving break.
15	a) Bragg diffraction (no lab report needed). b) Particle in a box (in class).
16	No lab – Reading day

Physics Lab Report Evaluation Sheet

1. Scientific validity and style (16 points)

a. Is it clear that the author has understood the purpose of the experiment, the data acquisition and analysis process, and what the results mean? (2 points)

b. Does the author tell a story in the report as a whole and in each section of the report? Is there a beginning, middle and an end to the story? Is there too much repetition? (a good story should not be repetitive. Also, since you are writing a story, you should <u>avoid lists</u>!) (1 point)

c. Does the author avoid generalizations and vague statements, such as: “There are many applications of relativity in everyday life”? (1 point)
d. Is the author consistent with the style (does not alternate between “we” and “I” and sticks with one tense, etc.)? (1 point)
e. Does the tone indicate what the author did instead of telling the reader what to do? (1 point)
f. Are scientific terms used in their proper meanings? For example, are they referring to “g” as the “gravitational acceleration” instead of just “gravity” or “gravitational force”, etc.? (1 point)
g. Are abbreviations used only for scientific notation and after these abbreviations have been defined? (1 point)
h. Does the author use short but concise sentences that only try to make one point? (1 point)
i. Does the author avoid awkward sentences (i.e., is the syntax proper)? (1 point)
j. Does the author avoid spelling mistakes? (1 point)
k. Are all figures/tables/graphs labeled, titled, with the proper units, and axes labels, etc.? (1 point)
l. Are all figures/tables/graphs easy to see and understand (not too small, not too big, easy to read, etc.) (1 point)
m. Do all figures/tables/graphs have a proper caption? Are the captions descriptive? (1 point)
n. Are all figures/tables/graphs explained and discussed in the main text? (1 point)
o. Is it obvious to the reader what point the author is trying to make by including each figure/table/graph? (1 point)

2. Title (2 points)

a. Are you interested in reading the report after looking at the title? (1 point)
b. Does it provide a one-sentence description of the whole report? (1 point)

3. Abstract (5 points)

a. Does the abstract provide a one-sentence summary from each of the subsequent sections (except for the references)? Is the abstract well balanced? (for example, does it have too much information for one of the sections of the report at the expense of the other sections?) (1 point)
b. Are these sentences connected logically to each other in a smooth way? (avoid lists!) (1 point)
c. Does the author avoid mentioning unnecessary details that the reader can only understand after reading the report? (the author <u>cannot</u> assume that the reader knows the experiment) (1 point)
d. Does the author avoid referring to equations and figures via the use of their numbering (e.g., equation 2, figure 3, etc.)? (1 point)
e. Are the important results/highlights of the experiment mentioned, with specific numbers, when appropriate? (1 point)

4. Introduction (8 points)

a. Is there a story? Does the author start with the concept under investigation, the equations that describe it, the derivations from one equation to the next, the point of the experiment? (1 point)
b. Have <u>all</u> the necessary concepts and equations been introduced and derived? (1 point)
c. Are the derivations <u>explained</u> step by step (instead of just listing each step)? (1 point)
d. Are all equations given their own line and number? (1 point)
e. Are all the <u>new</u> variables defined (including SI units) after each equation where they first appear? (1 point)

f. Are all the important variables explicitly stated? (important variables are those that you measure, calculate, etc. If a variable appears in a figure/table, then it is definitely an important variable) (1 point)

g. Does the author avoid referring to details that the reader can only know after reading the whole report (i.e., the author <u>cannot</u> assume that the reader knows the experiment)? (1 point)

h. Is there a thesis statement (i.e., what will the author try to accomplish by doing this experiment, what is the hypothesis)? (1 point)

5. Materials and Methods (4 points)

a. Is a figure provided that explains the setup? Is the figure referenced in the main text? (1 point)

b. Are the important components of the setup indicated on the figure? (1 point)

c. Are important details of the setup and procedure stated and <u>explained</u>? (1 point)

d. Will a person unfamiliar with the experiment be able to reproduce it after reading this section? (Is it easy to understand the setup based on the author's description?) (1 point)

6. Results (7 points)

a. Are all results presented in a way that conveys the point the author is trying to make (i.e., use a table instead of a graph, etc.)? (1 point)

b. Are the results/tables/figures explained in the main text? (1 point)

c. Is the order in which the results are presented logical? (1 point)

d. Are important intermediate results included (even if they are not directly asked in the lab handout)? (1 point)

e. Does the author specifically state which results are raw, calculated, intermediate, etc.? (1 point)

f. For the calculated results, does the author explain how the calculation was made by referring to equations from the Introduction? (1 point)

g. Has the data analysis been done correctly? (1 point)

7. Discussion (4 points)

a. Does the author discuss the results by referring to equations from the Introduction and connecting them to figures/tables/graphs or important calculations from the Results section? Are the answers to the questions in the handout smoothly incorporated in this section? (1 point)

b. Are the sources of error listed and <u>explained</u> in a way that is <u>consistent with the results</u>? (1 point)

c. Has the author discussed if the hypothesis was verified based on the results/data? Has the author explained the reasons why the hypothesis has been verified or not? (1 point)

d. Are improvements to the experiment listed and discussed? Is it clear how these suggestions will improve the experiment? (1 point)

8. Conclusion (2 points)

a. Does the author provide a summary of the experiment with all the highlights reviewed? (1 point)

b. Is the author specific when listing the applications of the concepts and equations described in the report? (1 point)

9. References (2 points)

a. Does the author use the appropriate format for the references? (1 point)

b. Are <u>all</u> references included? (1 point)

Total number of points: 50 points

Ways of Inquiry

Physics 253Q: Modern Physics with Laboratory

Physics 253: Modern Physics with laboratory, is a course that is required of all students interested in majoring in physics. It is also one of the electives for mathematics and computer science. This course explores some of the major physical concepts that were developed in the 20th century by following them in their historical context. For the laboratory portion of this course, the projects and experiments are designed so that you will either learn a technique that is currently commonly used in research or reproduce the experiments that led to the discovery of the physical concepts. Some of these experiments were awarded Nobel Prizes! In addition, you will be required to design an experiment that will answer a question (of your choosing) on Brownian motion by using a popular experimental technique in the area of biophysics (i.e., microfludic technology.)

Asking the "right" questions: What (fundamental) questions will you learn to ask when dealing with this discipline?

In introductory physics the main goal for us is to answer the question of "Why?": Why do things work the way they do? In order to answer this question we learned some fundamental physical concepts.

For modern physics, the question of "Why?" of course, still remains. However, in addition to this fundamental question, there are other equally important questions that are addressed in this course. Since in this course we are following the development of the physical concepts in chronological order, we are looking at how one scientific discovery led to the next and what questions one scientific discovery left unanswered that the next discovery addressed. By following the original experiments and the associated discoveries, you will learn to ask and answer the following questions: What were the unanswered questions that this experiment and theory is trying to answer? Why was the experiment designed in this way? Why does the theoretical formula have this form? How was the data obtained and how is the data supporting (or not) the hypothesis? What important implications and applications does this discovery have? Why or why not is this work groundbreaking? Why was this work awarded the Nobel Prize? All these questions get to the heart of the scientific method and of how progress is made in physics. A handout of these questions will be given to you at the beginning of the semester. Furthermore, for each concept learned, you will need to ask: What does this mean? How can this concept be applied?

Using the "right" tools: What methods of analysis and argument will you learn to help you investigate questions in this discipline?

In the lecture part of the course, we will be discussing the questions outlined in (1) as we learn about the various famous experiments that were conducted throughout the 20th century. For example, in the case of the Michelson-Morley experiment, one of the first experiments encountered in this course, we will be discussing how this experiment was addressing the question of the elusive ether, how the experiment was designed and the data was obtained, and what the conclusion was. Then, in the laboratory, you will be using the scientific method, the technique of the Michelson-Morley experiment, namely the Michelson interferometer, and techniques for data analysis in order to experimentally measure the speed of light. In other words, you will be learning different experimental and data analysis techniques that you can then use in order to conduct new but related experiments and analyze the data obtained in those experiments.

In order to fully understand the physical concepts, you will be asked to analytically solve homework problems and, on three occasions, write code in a programming language (Matlab). In addition, in your writing assignments (this course satisfies the continuing writing requirement) you will be asked to thoroughly address the questions outlined in (1) in your lab reports. Finally, throughout the semester, you will be asked to use the scientific method in order to design an experiment that will answer a question of your own choosing about Brownian motion using microfluidic devices. Though you will not be able to conduct the experiment that will answer this question due to limited equipment, you will be asked to thoroughly describe how you chose this question (based on your literature search) and how you would go about setting up and conducting the experiment and analyzing your data. Essentially, you will be applying the scientific method and the methods of analysis and argument that you have learned by conducting the famous experiments of the 20th century.

Actively practicing inquiry: How will you "discover" knowledge in this course? How will you actively practice the process of inquiry?

You will be discovering knowledge in this course using a variety of activities and assignments. In class, we will be discussing the questions listed in (1) above. Through discussion, you will be able to discover the necessity of asking these questions. Furthermore, you will be asked to read a couple of original papers (e.g., Einstein's 1905 paper where he develops special relativity) in order to see what the questions were that the author was trying to address and how he/she went about doing that. For the laboratory portion of the course, in many cases you will be using a lab manual where the background and procedure for each experiment are described. However, in your lab reports you will be asked to describe and explain in detail what you did and why. It amazes me when I see how much knowledge you end up discovering on your own when you are asked to explain something in detail. Furthermore, as mentioned in (2) above, you will be asked to design your own experiment. You will have to decide on the question that you will have to answer by researching published literature in the area of microfluidics and Brownian motion. Then, you will have to design an experiment that, in addition to microfluidics, uses some of the other techniques that you learned throughout the semester. Though the experiments themselves will not be conducted (due to lack of equipment), you will be asked to explain in detail how you would set up and conduct your experiments, and how you would acquire and analyze your data. Essentially, you will actively practice the process of inquiry by finding your own question and discussing how you would go about answering it.

Meta-level reflection: How will you be asked to reflect upon, question, and appreciate the way of inquiry used in this discipline?

In the lecture part of the course, you will be asked to discuss your readings of the textbook, where the experiments are described, and of the original papers. These readings, and especially the original papers, are examples of the application of the scientific method. I find that discussions help you reflect upon your reading, as they give you the opportunity to hear the thoughts and questions of your classmates, better express your own questions and thoughts, and question each other.

In the laboratory, the application of the scientific method provides opportunities for that kind of reflection, questioning, and appreciation. In your lab reports, you will be asked to think about your experiment and your data. For example, when you describe the error associated with your data, you will have to discuss the limitations of your experimental setup and how you would improve it. You will also need to think about how your data verifies or falsifies your hypothesis. In addition, by applying the scientific method in your own independent research projects, you will be able to reflect on your own experimental data, your own hypothesis, and your own overall experiment. Finally, by thoroughly studying - and in many cases conducting - some of the original, Nobel-prize winning experiments, you will also learn to appreciate the way knowledge is discovered in physics and what constitutes an important scientific breakthrough.

Increasingly independent investigation: How, specifically, will your investigations become more independent over the course of the semester?

For the lecture portion of the course, at the beginning of the semester I will be explicitly posing the fundamental questions listed in (1) to you. I will also be helping you find the answers to these questions through the reading assignments. However, as the semester progresses, I will be asking you to have these questions in mind while you do the reading and, also, provide the answers to these questions on your own, without my guidance.

For the laboratory portion of the course, at the beginning of the semester you will be conducting experiments that are outlined in detail in the laboratory manual. However, a month into the semester you will start working on your own original research project. You will still continue to conduct the experiments outlined in the lab manual, but you will also have the freedom to explore directions in your own original projects. You will be independent in your original project and I will serve only as a consultant that you can bounce ideas off. This type of consultation does not take away your "independence," as I find that consultation and discussion of new ideas are what physicists use in order to improve upon their experiments. In other words, as mentioned in (3) above, I find this consultation and discussion to be an integral part of "discovering" knowledge.

Connections to something bigger: What specific "real-world" questions, interdisciplinary connections, or ethical issues will you explore in an attempt to deepen your understanding and appreciation of the class content?

In modern physics, it is quite easy to find "real-world" questions that deepen your understanding. Such real-world questions involve applications of the concepts learned: How does the GPS work? What are x-rays and why are they so widely used for medical diagnosis? What are the disadvantages of frequent use? These are some examples of applications involving the physical concepts learned in this class. In addition, some of the concepts learned have consequences of religious, philosophical, and ethical character that are imperative. For example, when discussing quantum mechanics, the question of multiple universes (the many-worlds interpretation) naturally arises. Similarly, when talking about particle physics and its relation to the atomic bomb. These kinds of questions also emphasize the interdisciplinary character of the knowledge obtained in this course. Furthermore, you will get to make interdisciplinary connections via your own research projects: you will be asked to use the technique of microfluidics, which has been used extensively in the area of biophysics, biochemistry, bioengineering, and other interdisciplinary fields, and design an experiment that extends your understanding of Brownian motion, a concept that has applications in many fields, such as biology, chemistry, physics, and materials science. In your independent project you will be asked to combine these two areas of microfluidics and Brownian motion in order to develop your own cross-disciplinary question.

Appropriate assessment for inquiry-based learning: What specific assignments will you be asked to do, to demonstrate your increased abilities in reading critically, writing, analyzing, or speaking with clarity?

As mentioned earlier, this course also satisfies the continuing writing requirement. As a result, you will be asked to use written work in order to communicate your findings and your understanding. For the lecture assignments, your solutions to the problems will be in the form of paragraphs, in the same way that a textbook presents the solution to an example problem. You will be asked to follow the solution format, which is described in the syllabus, and guide the reader through your thought process as you develop the solution. In the laboratory portion of the course, you will be asked to write 7 short lab reports, 3 full lab reports, and one paper on your research project. All of these assignments will require that you analyze your work (experiment, data, hypothesis, etc.) critically. The full lab reports will also consist of all the parts of a published research paper (abstract, introduction, materials and methods, results, discussion, and conclusion.) Furthermore, you will be able to submit your full lab reports and your research paper in drafts. This way you can receive feedback not only on the quality of your writing but, also, on the depth of your critical analysis.

With regards to reading critically, you will be asked to read original papers. By making use of the questions outlined in (1), you will be able to develop the habit of reading published work in a critical manner. Though speaking with clarity is not a formal component of the course, during the class discussions you will be asked to express your thoughts in a clear and concise manner.