FUNDAMENTALS of PHYSICS III ("Modern Physics") *

PHY-2030 SECTION 01, FALL 2017

LECTURE: TTH 1335–1515, LAB: TTH 1515–1615; 129 COUCH HALL

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Office Hours: TBD; 363 Couch Hall

Course Description: An introduction to space-time physics and quantum physics with applications in astronomy, cosmology, solid-state physics, nuclear physics, and particle physics. Four credits. Prerequisite: PHY 2020. Offered Fall Semester.

Course Website: `physics.highpoint.edu/~bbarlow/courses/phy2030/phy2030.html`

Attendance Policy: If you have more than two unexcused absences, you can be withdrawn from the class. I reserve the right to choose whether to withdraw you or not for lack of attendance.

Textbook: *Six Ideas that Shaped Physics* by Thomas Moore (required). We will use the 3rd edition of Unit R (Relativity) and Unit Q (Quantum). These are separate books published by McGraw Hill.

Expectations / Daily Schedule: Expect to work hard, to be challenged, to learn, and to work together. Unlearn what you have learned: many of the ideas we will discuss are not aligned with human intuition. Most days will begin with a reading quiz that covers the chapter content and exercises that you should have completed before coming to class. Reading quizzes and Two-Minute Problems are used for self-evaluation to assess how much you retained from reading the chapter. Daily preparation and participation is **absolutely required** for your success in the class, as well as the success of your classmates. Each class will be arranged according to the following schedule:

- Reading quiz and Two-Minute Problems
- Chapter review and discussion
- Activities and simulations
- Cooperative group problems
- Summary of big ideas

You are expected to do at least five hours of work outside of class each week, including reading, solving problems, and working on your class project.

Grade Policy: We are going to use a different approach to assessment this semester called "Standards–Based Grading" (SBG). Each chapter has a list of standards to be met that you can find on the course website, along with the "evidences" that must be provided for each standard. You will solve problems, write computer programs and do experiments to show your understanding (i.e. proficiency) on each standard. We will have periodic quizzes, exams, and collaborative problem solving sessions where you can demonstrate proficiency on each standard. You will also be given example problems that you can use to show your proficiency. At any time, you can re-assess *up to two standards per week* to demonstrate your proficiency. Your grade is not final until the end of the semester and you can use the entire semester to demonstrate your understanding. However, when being reassessed, it's possible for your proficiency to *decrease* as well. Your current progress on standards will be accessible through a Google doc.

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*I reserve the right to change this syllabus based on feedback from you and what I determine is best for the course.

Using SBG helps address several issues with 'traditional' assessment:

- Sometimes one focuses on points instead of learning.
- When one does poorly on an exam, there is no incentive to study the material that one did not understand. Additionally, one loses the points on that exam even if the material is understood by the end of the semester.
- When you get a grade on an exam, like 70%, it might mean that you understood 70% of the content and do not understand 30%. The overall score does not tell you which concepts/skills you are proficient at and which ones you still need to study or practice. By tying each question on an exam to a standard and grading each question (not the exam), you know exactly which standards you still need to study.
- Cramming for an exam is rewarded, not the habits that lead to life-long learning like persistence and independence.

You will be graded on a 4-pt scale for each standard. To convert each 4-pt standards rating to a percentage score, the following non-linear relationship will be used:

$$\text{Standards}\,\%\,\text{Score} = \left(\frac{\text{Standards Four Point Score}}{4}\right)^{0.7} \times 100 \tag{1}$$

For example, if you receive a rating of "3" on the standard "MQ," that is equivalent to a percentage score of 81.7% for that standard. The rubric for the 4–pt scale is shown below and is borrowed from Aaron Titus and Andy Rundquist (who cites Frank Noschese).

Four–Point Scale:

0. **Not assessed**: 0 pts
1. **Doesn't meet expectations**: 1 pt
   (a) I need lots of help from my instructor (one-on-one).
   (b) I have low confidence on how to do the skills and need more instruction.
   (c) I need my textbook/notes at all times.
   (d) I do not understand the concept/skills.
   (e) I cannot correctly identify concepts and/or define vocabulary.
   (f) I cannot make connections among ideas or extend the information.
   (g) My responses lack detail necessary to demonstrate basic understanding.
   (h) Cannot articulate most of the main ideas involved in the standard
2. **Approaches expectations**: 2 pts
   (a) I have a general understanding of the content/skills, but I'm also confused about some important parts.
   (b) I need some help from my instructor (one-on-one or small group) to do the skills correctly
   (c) I do not feel confident enough to do the skills on my own
   (d) I need my textbook/notes most of the time.
   (e) I can correctly identify concepts and/or define vocabulary; however I cannot make connections among ideas and/or independently extend my own learning.
   (f) My responses demonstrate basic understanding of some main ideas, but significant information is missing.

3. **Meets expectations**: 3 pts
    (a) I understand the important things about the content/skills.
    (b) I have confidence on how to do the skills on my own most of the time, but I need to continue practicing some parts that still give me problems.
    (c) I need my handouts and notes once in a while.
    (d) I am proficient at describing terms and independently connecting them with concepts.
    (e) I understand not just the "what," but can correctly explain the "how" and "why" of scientific processes.
    (f) My responses demonstrate in-depth understanding of main ideas.
4. **Exceeds expectations**: 4 pts
    (a) I understand the content/skills completely and can explain them in detail.
    (b) I can explain/teach the skills to another student.
    (c) I have high confidence on how to do the skills.
    (d) I can have a conversation about the skills.
    (e) I can independently demonstrate extensions of my knowledge.
    (f) I can create analogies and/or find connections between different areas within the sciences or between science and other areas of study.
    (g) My responses demonstrate in-depth understanding of main ideas and of related details.

Assessments: There will be at least three 100-minute long assessments (exams). They will typically consist of two or three of the following sections: (1) conceptual and numerical multiple choice questions; (2) problem solving; (3) computational modeling. All assessments, including the final exam, are comprehensive and can include any standards that are "live" up to that point in the semester.

Project: You will do a class project that is experimental, computational, or theoretical in nature. The project must be approved by Dr. Barlow. It must be related to topics in the course. There are five categories that the project's grade is based on.

1. level of difficulty
2. level of creativity
3. level of independence
4. completeness (i.e. Does the simulation run and give correct results? or Did you report uncertainties in your measurements? or Did you include relevant background material and references)
5. quality of presentation and/or paper.

For full project credit, each student must:

1. write a paper of appropriate length (5000 words is a rough estimate) that describes the details of your project. LaTeX is required. Templates are at: `http://physics.highpoint.edu/Physics/LaTeX.html`.
2. present your project to the class.

Grade Breakdown:

Proficiency with Standards	80%
Participation/In–Class Assignments	10%
Class Project	10%

Letter grades will be assigned based off of the following scale:

$\geq$ 97	A+
93.0 - 96.99	A
90 - 92.99	A−
87 - 89.99	B+
83 - 86.99	B
80 - 82.99	B−
77 - 79.99	C+
72 - 76.99	C
70 - 71.99	C−
60 - 69.99	D
$<$ 60	F

Extra Credit: No extra credit is currently planned; however, the instructor reserves the right to provide extra–credit assignments to the entire class when deemed necessary. *If* such an opportunity is provided, details will be announced during the lectures.

Honor Code: The High Point University Honor Code asserts that:

- Every student is honor-bound to refrain from conduct which is unbecoming of a High Point University student and which brings discredit to the student and/or to the University;
- Every student is honor-bound to refrain from collusion;
- Every student is honor-bound to refrain from plagiarism;
- Every student is honor-bound to confront a violation of the University Honor Code;
- Every student is encouraged to report a violation of the University Honor Code.

My obligation is to promote academic integrity and to enforce the University Honor Code. This obligation includes appropriately interpreting the Honor Code, promoting conditions favorable to academic integrity, and reporting violations of the Honor Code.

I encourage collaboration on homework. I encourage you to work together to solve problems. You may check your work with others. You may use solutions manuals, tutors, books, and any other resource on homework. However, you must know how to solve problems independently so that you can solve unfamiliar problems on exams.

You must do your own work on an exam. You may not look at another persons exam. You may not use any other resource except the equation sheet that is given to you and your calculator. You may not store programs or equations in your calculator, and you may not use data stored in your calculator on an exam. Calculators may only be used to input numerical values and perform calculations.

Violation of the honor code will be handled according to procedures outlined in the Faculty Handbook.

Accommodations: Students who require classroom accommodations due to a diagnosed disability must submit the appropriate documentation to Disability Support in the Office of Academic Services, 4th Floor Smith Library. Requests for accommodations should be made at the beginning of a course. Accommodations are not retroactive. Contact us at http://www.highpoint.edu/disabilitysupport/contacts/, or call Dana Bright 336-841-9361, for additional information.

Table 1: Tentative Schedule of Class Meetings

Day No.	**Date**	**Chapter – Topic**	**Lab (tentative)**
1	22 Aug	R1 – principle of relativity	
2	24 Aug	R2 – coordinate time	
3	29 Aug	R3 – the space-time interval	Speed of Light
4	31 Aug	R4 – proper time	
5	5 Sep	R5 – coordinate transformations	
6	7 Sep	R6 – Lorentz contraction	
7	12 Sep	R7 – the cosmic speed limit	
8	14 Sep	R8 – four-momentum	
9	19 Sep	R9 – conservation of four-momentum	
10	21 Sep	**EXAM 1**	
11	26 Sep	Q1– wave models	Standing Waves / Fourier Analysis
12	28 Sep	Q2 – standing waves and resonance	
13	3 Oct	Q3 – interference and diffraction	Young's Double Slit Lab
14	5 Oct	Q4 – the particle nature of light	Photoelectric Effect Lab
15	10 Oct	Q5 – the wave nature of particles	
16	12 Oct	Q6 – spin	
	16-20 Oct	*Fall Break*	
17	24 Oct	Q7 –the rules of quantum mechanics	
18	26 Oct	Q8 – quantum weirdness	
19	31 Oct	**EXAM 2**	
20	2 Nov	Q9 – the wavefunction	
21	7 Nov	QA – complex numbers	
22	9 Nov	Q10 – simple quantum models	
23	14 Nov	Q11 – spectra	Atomic Spectroscopy
24	16 Nov	Q12 – the Schrödinger equation	Schrödinger Solver
25	21 Nov	nuclear *or* astrophysics (TBD)	
	23-25 Nov	*Thanksgiving Break*	
26	28 Nov	nuclear *or* astrophysics (TBD)	
27	30 Nov	nuclear *or* astrophysics (TBD)	
28	11 Dec	**FINAL EXAM** (12:00pm)	

R = "Six Ideas That Shaped Physics Unit R"

Q = "Six Ideas That Shaped Physics Unit Q"

Table 2: Standards

Chapter	Name	Standard
	LApparatus	I can use a lab apparatus with appropriate technique to make measurements accurately and precisely.
	LReport	I can write a lab report in LaTeX in a style consistent with a journal article that describes the experiment, measurements, and conclusions.
	LJournal	I can review a journal article and write a summary of the article that describes the experimental setup, analysis, and conclusions.
	LFermi	I can solve mathematical problems (e.g., "Fermi" problems) in my head and on paper without the use of a calculator (to within an order of magnitude of the correct answer).
R1	Rel	I can state the Principle of Relativity and can apply it to non-relativistic motion
R1, R2	SR	I can provide evidence for Special Relativity and can apply SR to relativistic motion
R2, R3, R4	Time	I can measure or calculate position, coordinate time, proper time, and spacetime interval, and I know what quantities are invariant.
R5	LT	I can calculate (and compare) spacetime coordinates of an event for observers in different inertial frames.
R6	LC	I can calculate (and compare) length measurements for observers in different inertial frames.
R7	V	I can calculate (and compare) velocity measurements for observers in different inertial frames.
R7	Causality	I can determine whether two events are causally related.
R8, R9	4Mom	I can calculate mass, momentum, energy, and 4-momentum for a particle, and I know which quantities are invariant and which quantities are conserved.
R9	Cons	I can apply conservation of 4-momentum to a system.
Q1	WS	I can describe the modes of a standing wave (whether transverse or longitudinal) whether it is fixed at both ends or free and fixed at each end.
Q2	WI	I can use path difference to predict the interference of two sources of waves at a location.
Q3, Q4	WP	I can provide evidence for wave-particle duality and can apply a particle model or a wave model to a quanton, depending on the experiment.

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Table 2 – continued from previous page

Chapter	Name	Standard
Q5	MQ	I can use the mathematics needed to describe the state of a quanton, including complex algebra, the inner product of two complex vectors, probability, and normalization.
Q5, Q6	Qrules	I can recite and apply the "rules of the game" of quantum mechanics.
Q7, Q8	Qenergy	I can derive energy eigenvalues for various systems and can relate energy eigenvalues to a spectrum of photons emitted or absorbed.
Q10	Qpsi	I can write a VPython program to calculate Psi numerically for a given value of E and graph Psi(x). I can use this program to find the energy eigenvalues of a system.
Q12, Q13	Nuclei	I can use simple principles to estimate the sizes of nuclei and calculate their binding energies.
Q13, Q14	Decay	I can describe the main types of radioactive decay and calculate decay rates.
H1	DM	I can derive equations for the masses of simple galaxies and justify the existence of dark matter using observations from the literature.
H2	GR	I can state the the Principle of Equivalence and use it to make predictions concerning the behavior of light and other objects in gravitational wells.
H3	COS	I can derive simple cosmological models describing the structure and evolution of the universe.
H4	DE	I can use arguments from first principles and observations in the literature to justify the existence of dark energy.

Table 3: Evidence (up through Q10)

Chapter	Name	Evidence
R1	Rel	I can state the Principle of Relativity and can apply it to non-relativistic motion
	Rel.1	I can design a test for whether a reference frame is inertial or not and can identify inertial reference frames.
	Rel.2	I can state the Principle of Relativity.
	Rel.3	I can derive the Galilean transformation equations for position and velocity and can use them to make predictions of what an observer in a particular inertial reference frame would measure.
	Rel.4	I can describe how clocks are synchronized in Newtonian Relativity and what measurements observers in inertial reference frames will agree on.
R1, R2	SR	I can provide evidence for Special Relativity and can apply SR to relativistic motion
	SR.1	I can explain the ”problem with electromagnetic waves” and the experiment(s) that showed the non-existence of the ether.
	SR.2	I can describe how clocks are synchronized in Special Relativity.
	SR.3	I can convert between SI units and SR units.
	SR.1	I can sketch and interpret worldlines on a spacetime diagram.
R2, R3, R4	Time	I can measure or calculate position, coordinate time, proper time, and spacetime interval, and I know what quantities are invariant.
	Time.1	I can define coordinate time, proper time, and spacetime interval and can describe how each quantity is measured. I can use a geometric analogy with spacial coordinates to describe each quantity, thus comparing plane geometry and spacetime geometry.
	Time.2	I can explain why events that are simultaneous in one inertial frame are not simultaneous in another frame.
	Time.3	Use the metric equation to calculate spacetime interval.
	Time.4	I can explain the Twin Paradox using a spacetime diagram and a calculation of spacetime interval for each twin.
	Time.5	I can calculate the number of muons remaining after x number of half-lives, and I can explain, using the metric equation, why fewer muons decay than is predicted by classical physics.
	Time.6	I can calculate the proper time along a curved worldline traversed by an inertial clock moving at constant speed.

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Chapter	Name	Evidence
	Time.7	I can derive and use the bionomial approximation.
	Time.8	I can describe and give examples to explain the relationship between coordinate time, spacetime interval, and proper time.
R5	LT	I can calculate (and compare) spacetime coordinates of an event for observers in different inertial frames.
	LT.1	I can draw a two-observer diagram, with correctly sloped t' and x' axes and correctly calibrated scales, and can plot and read the spacetime coordinates of events.
	LT.2	I can use a two-observer diagram to transform coordinates of an event from one frame to another frame and can use the two-observer diagram to solve problems and make predictions.
	LT.3	I can use the Lorentz Transformation Equations (and Inverse Lorentz Transformation Equations)
R6	LC	I can calculate (and compare) length measurements for observers in different inertial frames.
	LC.1	I can state an operational definition for the length of an object.
	LC.2	I can use a two-observer diagram to determine the length of an object as measured in an Other frame.
	LC.3	I can calculate the Lorentz contraction of an object
R7	V	I can calculate (and compare) velocity measurements for observers in different inertial frames.
	V.1	I can use the Einstein velocity transformation equations to calculate the velocity of an object measured by an observer in an Other frame (or alternatively, the Home frame).
R7	Causality	I can determine whether two events are causally related.
	Causality.1	I can determine whether the interval between events is timelike, lightlike, or spacelike and can describe how each interval is measured.
	Causality.2	I can determine whether two events are causally related.
	Causality.3	I understand The Cosmic Speed Limit and that it results from Causality being consistent with the Principle of Relativity
	Causality.4	I can show that the classical definition of momentum as p=mv is inconsistent with the Principle of Relativity and Conservation of Momentum

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Chapter	Name	Evidence
R8, R9	4Mom	I can calculate mass, momentum, energy, and 4-momentum for a particle, and I know which quantities are invariant and which quantities are conserved.
	4Mom.1	I know the definition of mass as the magnitude of the 4-momentum of an object, and I know that it is the same for observers in different inertial reference frames (i.e. it is invariant).
	4Mom.2	I can write the total energy of a particle in terms of its rest energy and kinetic energy, in both SR units and SI units.
	4Mom.3	I can use the equations in Figure R8.4, and I know where each equation comes from.
	4Mom.4	I can use Einstein transformation equations to transform the 4-momentum of an object in one inertial frame to the 4-momentum of the object measured in another inertial frame.
	4Mom.5	I can sketch and interpret an energy-momentum diagram.
R9	Cons	I can apply conservation of 4-momentum to a system.
	Cons.1	I can apply conservation of 4-momentum to a system, including a system with photons. I know that photons have no mass but do have energy and momentum (E=p).
	Cons.2	I know that the mass of a system is generally different than the sum of the masses of its parts; I can explain why this is the case using conservation of energy and E=m+K; and I can give an example showing this to be true.
	Cons.3	I can use a momentum-energy diagram to show conservation of 4-momentum for a system.
Q1,Q2	WS	I can describe the modes of a standing wave (whether transverse or longitudinal) whether it is fixed at both ends or free and fixed at each end.
	WS.1	I can derive equations Q2.8a and Q2.8b.
	WS.2	I can state the superposition principle and can add waves graphically and algebraically.
	WS.3	I can describe the shape of a reflected wave at an interface between two media or at a boundary with a fixed or free end.
	WS.4	I can derive equation Q1.9 and can use it to describe the motion of various pieces of the medium for a standing wave.
	WS.5	I can identify the boundary conditions and can calculate the frequency of the normal modes of a standing wave.

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Table 3 – continued from previous page

Chapter	Name	Evidence
Q2	WI	I can use path difference to predict the interference of two sources of waves at a location.
	WI.1	I can calculate the path difference at a given location from two sources and can predict whether it will result in total constructive interference or total destructive interference or something in between.
	WI.2	I can calculate the locations of bright fringes in a double-slit experiment, and I can describe how fringe spacing depends on wavelength and slit spacing.
	WI.3	I can calculate the locations of dark fringes in a single-slit experiment.
	WI.4	I can use the Rayleigh Criterion to describe whether two point sources can be resolved.
	WI.5	I can use a single-slit interference apparatus to determine the wavelength of a light source, including uncertainty.
Q3, Q4	WP	I can provide evidence for wave-particle duality and can apply a particle model or a wave model to a quanton, depending on the experiment.
	WP.1	I can describe the photoelectric effect experiment and can use the photon model for light to explain the results, explain and interpret a graph of maximum kinetic energy vs. frequency, and make predictions.
	WP.2	I can use a photoelectric effect apparatus to conduct an experiment to measure Planck's constant and the work function of the metal.
	WP.3	I can calculate the energy of a photon and relate energy to frequency (or wavelength) of light.
	WP.4	I can relate the number of photons per second incident on a surface and intensity of light for a given power of a light source. I also understand the difference between a point source of light and a beam of light in terms of how its intensity varies with distance.
	WP.5	I can compute the deBroglie wavelength of a particle.
	WP.6	I can apply conservation of energy to a charged particle traveling between two charged plates to compute the particle's deBroglie wavelength.
	WP.7	I can interpret results of the double-slit experiment for particles by treating them as waves.

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Chapter	Name	Evidence
	WP.8	I can compute the angles for constructive interference in the Davisson-Germer experiment.
Q5	MQ	I can use the mathematics needed to describe the state of a quanton, including complex algebra, the inner product of two complex vectors, probability, and normalization.
	MQ.1	I can do complex algebra.
	MQ.2	I can compute the intensity required to have a single photon traverse a given distance with a certain probability that there will only be one photon (at any instant) within the given range.
	MQ.3	I can find the inner product of two complex vectors.
	MQ.4	I can normalize a complex vector.
Q5, Q6	Qrules	I can recite and apply the "rules of the game" of quantum mechanics.
	Qrules.1	I can look at a series of Stern-Gerlach devices and can predict the probability of an electron being aligned or anti-aligned with a given axis (x, y, z, theta) based on observations of various SG experiments. (Note: this involves understanding how making a measurement affects the electron's state and how recombining electrons of different spins affects the probability of a measurement.)
	Qrules.2	I can write each of the "rules of the game" of quantum mechanics.
	Qrules.3	I can apply the Outcome Probability rule to the spin of an electron.
	Qrules.4	I can apply the Superposition rule to the spin of an electron.
	Qrules.5	I can apply the Time-Evolution rule to the spin of an electron.
	Qrules.6	Given a wavefunction, I can calculate the probability of measuring the position of an electron within a given range Delta x.
	Qrules.7	Given a graph of a wavefunction, I can calculate the probability of measuring the position of an electron within a given range Delta x.
	Qrules.8	I can calculate a normalization constant so that a wavefunction is normalized.
	Qrules.9	I can identify whether a wavefunction is valid or not.

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Chapter	Name	Evidence
Q7, Q8	Qenergy	I can derive energy eigenvalues for various systems and can relate energy eigenvalues to a spectrum of photons emitted or absorbed.
	Qenergy.1	I can derive the energy eigenvalues for a particle in a box and can sketch an energy diagram showing the eigenvalues.
	Qenergy.2	I can derive the energy eigenvalues for an electron in a hydrogen atom using the Bohr model.
	Qenergy.3	I can derive energy eigenvalues for other hydrogen-like systems.
	Qenergy.4	I can use Conservation of Energy to calculate the wavelength (and energy) of a photon emitted or absorbed by a particle in a box.
	Qenergy.5	I can sketch a spectrum diagram that shows the photon energies associated with certain transitions for a particle in a box.
	Qenergy.6	I can use Conservation of Energy to calculate the wavelength (and energy) of a photon emitted or absorbed by a quantum oscillator.
	Qenergy.7	I can derive the energy eigenvalues and the energies of photos emitted and absorbed for a single-electron atom.
Q10	Qpsi	I can write a VPython program to calculate Ψ numerically for a given value of E and graph $\Psi(x)$. I can use this program to find the energy eigenvalues of a system.
	Qpsi.1	I can find the energy eigenvalues for a hydrogen atom.
	Qpsi.2	I can find the energy eigenvalues for a harmonic oscillator.
	Qpsi.3	I can find the energy eigenvalues for a quanton in a well.