Life Science Physics I

Spring 2018 Physics 105 PEngel 173

Instructor:

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Drop-by Informal Office Hours: 7:30 A.M.–5:30 P.M.

Texts:

- *College Physics* by OpenStax College Chapters: 1–16
- *Laboratory Manual for Life Science Physics I*
- `http://www.physics.csbsju.edu/105/`

Grading:

Your grade will be determined by averaging seven scores: total quiz/homework score, total lab score, three exam scores, and the final exam score (which is double-counted). Homework should be completed (`WebAssign`) by midnight on the following class day. Late homework is assessed a 15% penalty; request online an automatic "extension" to submit late homework. The quizzes are 10 minute in-class exams on just completed material. Missed quizzes cannot be made up. The hour exams include both multiple choice and numerical problems. You may use a single-sided $8\frac{1}{2}$" × 11" "formula sheet" to assist you on the exam. The formula sheet should be limited to formulas and definitions—no worked examples. Exam dates are: February 9 (Friday), March 21 (Wednesday), and April 25 (Wednesday). If informed in advance, I may be able to accommodate exam conflicts. The final exam will be comprehensive and have a structure similar to the other exams, but proportionally longer. The final exam has been scheduled for Tuesday May 8, 3:30 P.M..

Lab:

You must be registered in one of the lab sections required for this course. Labs meet Fridays for two hours in the afternoon. Time in lab is limited so prepare for each lab by reading the lab manual *before* lab. Pre-lab exercises (on Canvas) must be turned in one hour before the beginning of lab. Your completed lab report must be turned in at the end of the lab. You will need to purchase two lab notebooks with quad ruled paper (so they can be used for graphs) and a sewn binding (e.g., Ampad #26–251). Read the INTRODUCTION to the Laboratory Manual ASAP for further information on the lab. Note that the first lab is online.

Good lab skills are the key to success in science. Almost certainly your first job in science will not resemble an exam: with lots of pencil pushing on made-up problems; rather it will most resemble lab: where you use equipment to collect data on real—less than perfect—objects.

Questions:

There is no such thing as a dumb question. Questions during lecture do not "interrupt" the lecture, rather they indicate your interests or misunderstandings. I'd much rather clear up a misunderstanding or discuss a topic of interest than continue a dull lecture.

Remember: you are almost never alone in your interests, your misunderstandings, or your problems. You help your classmates by asking questions! If you don't want to ask your question during class, that's fine too: I can be found almost any time in my office (PEngel 132/6) or the nearby labs. Drop in any time!

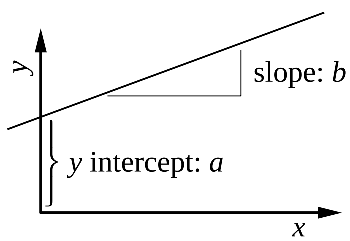
Topics:

This course covers the discoveries of Isaac Newton (1642–1727) and the founders of thermodynamics (e.g., Sadi Carnot (1796–1832), James Joule (1818–1889), William Thomson, 1st Baron Kelvin, (1824–1907), James Clerk Maxwell (1831–1879), Willard Gibbs (1839–1903), and Ludwig Boltzmann (1844–1906)) which are the foundation of the science and technology that transformed the animal powered world of Newton into the mechanized world of today. The basis for Newton's discoveries was that the universe follows mathematical laws, so improvements to technology can be calculated rather than found by trial and error. This idea of a mathematical universe is ancient (e.g., often attributed to Pythagoras (ca. 585–497 B.C.)) so one might wonder why it didn't happen much earlier: Why, for example, didn't Archimedes (287–212 B.C.), often called the Newton of the ancient world, "scoop" Newton and discover the mathematical rules that govern the universe? Imagine: Joseph an auto mechanic rather than a carpenter.

The key discovery that Newton made (and that Archimedes "almost" made) was the differential equation. Differential equations (MATH 337) are probably beyond your current mathematical studies but the basic idea is simple. When you think of an *equation* you may be thinking of something like:

$$y = a + bx$$

which, displayed as a graph of y vs. x, is a line with y-intercept, a, and slope, b:



Equations like this are particularly nice because if you know the numerical values of all the things on the right hand side (x, a, b) you can calculate the value of the thing on the left hand side (y). In some sense such an equation gives the relationship between x and y completely and immediately. For example, in the case of the ideal gas law: $PV = nRT$, if you know the numerical value of any four of the quantities you can calculate the fifth. What Newton discovered[1] was that the fundamental laws of nature are not equations like the above. Instead of giving us the the whole story in one package (an equation) nature's rules focus on change, reporting how things change with time or position. For example, one could equally well describe a straight line by saying it has unchanging slope which translates to the differential equation:

$$\frac{d^2y}{dx^2} = 0 \qquad \text{or} \qquad y'' = 0$$

Thus a differential equation is an equation that includes derivatives, i.e., changes. (A philosophical question: Why are the universe's laws *differential equations* rather than some other sort of magic or mathematics?) A mathematics course in differential equations teaches you how to go from a differential equation, which tells you how things change, to an equation, which gives you the complete story. Science courses then explain which differential equations are used by nature. Remark: mathematics usually uses the generic variable names x and y, whereas in science we're most commonly concerned with how things change in *time*. Thus the thing that in your math class is labeled x will most often in your science classes be labeled t. In this physics class, we'll often be concerned with the position of objects which we'll often label x. Thus to translate from your math class to your physics class: $x \to t$ and $y \to x$. Thus a typical physics equation is:

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

and a typical physics differential equation is:

$$\frac{d^2x}{dt^2} = a \qquad \text{or} \qquad x'' = a$$

A major stumbling block should now be evident. The universe speaks in the language of differential equations and most of you will never take the intro course in that language. Thus the process of translating from the fundamental laws of nature (like Newton's three laws) to the immediately usable equations will sometimes seem mystifying, awkward and uninteresting. One might make the mistake of trying to "learn physics" by memorizing dozens of equations rather than understanding the general equations that apply to any possible situation.

This course will focus on applying Newton's laws of motion to three situations: (A) motion with a constant applied force, (B) motion in a circle at constant speed, and (C) oscillatory motion. Clearly these three situations are a small subset of real life motions. Please realize that Newton's laws explain equally easily all real-life motions, but we need additional mathematical tools to apply them to more complicated situations.

Implicit in the concept "motion" is the idea of change. Nevertheless, physics has discovered quantities that stay constant even as most every common-sense quantity associated with a motion varies. These quantities that stay constant—called *conserved* quantities—provide simple ways of understanding motions. In this course we will be particularly interested in the

[1]Newton wrote: 6accdae13eff7i3l9n4o4qrr4s8t12ux to Leibniz; try Google to decode!

conservation of (A) energy, (B) linear momentum, and (C) angular momentum. (An analogy: when a log burns initially we have wood and oxygen and finally we have hot gases and ash. Everything seems changed. Nevertheless you've learned that the number of carbon atoms stayed constant during the reaction. In chemistry the conservation of atoms during chemical reactions is a great unifying principle.)

Thermodynamics rests on four "laws", which in turn rest on the mechanics of large numbers of particles. While Newtonian mechanics is adequate for much of thermodynamics, various puzzles ushered in "quantum mechanics" ca. 1920.

There are a couple of aspects of this course that make it particularly difficult. First, things do not work the way common sense tells you: often you'll find your intuition misleading you. You step on the car's accelerator and you're pushed back in the seat; common-sense says the cause is "inertia". You round a corner and the books that were sitting on the car seat are thrown to the side; common sense says the cause is "centrifugal force". In this course you will learn that "centrifugal force" and "inertia" play no role in the true explanation of motion. I know it is impossible for you to throw out the understanding of how the world works that you've developed over your lifetime and substitute the correct but weird and abstract laws of motion discovered by Newton. 42 hours of instruction can not overcome a lifetime of experience. I do hope that in a few artificial examples you'll know—but perhaps not truly believe—how the laws of motion apply. Think about it: you've spent a lifetime observing the universe and have come to wrong conclusions about how it works. (But those wrong conclusions are still useful to predict the behavior of your car. A follower of Bokononism would call your conclusions—and Newton's—*foma*[2].) You might now conclude that the human mind was not built to comprehend the true causes of the universe. But the actual result is far stranger than that. First the famous Einstein quote: "The most incomprehensible thing about the universe is that it is comprehensible." Now the true causes of the universe are not yet totally known, and it is quite possible that when/if discovered they will be understandable only to a few thousand physicists. What we already know is that the road to comprehending the universe has been a series of steps. Common sense ideas of how the world works were written down by Aristotle (384–322 B.C.) replacing unwritten ideas that served mankind for the previous million years. Aristotle's physics was good enough to build cathedrals and catapults and is probably accurate enough for the vast majority of people who do not need understand how a bird flies let alone design an airplane. Newton's "$F = ma$" is a tremendous leap forward in understanding, explaining 99% of everyday experience, but it is not the last word. Electrodynamics, statistical mechanics, quantum mechanics, relativity, relativistic quantum field theory. . . , each step forward has been based on the previous steps, in such a way that each advancement seems impossible without the previous (incorrect) steps. (I cannot imagine how quantum mechanics could have been discovered unless Newtonian mechanics had been discovered first.) Thus our growing comprehension as to how the world works has been structured like learning from a good user's manual: the most useful stuff comes first and then each further refinement is explained. While the universe might not be comprehensible in one gulp, it seems there is a step-by-step approach you can follow to understand it. But expect "common sense" to fight every step forward.

Second, since the universe follows mathematical laws, in order to understand the universe you must be able to *do* mathematics. In this course we will use most of the mathematics you've learned over your lifetime: arithmetic, geometry, trigonometry, algebra, and a touch of calculus. Trying to recall the mathematics you learned a couple of years ago and apply it in new situations is challenging. The best tonics for this problem are to ask lots of questions and work lots of problems. (Yes, work problems that are not assigned.) In addition carefully study the "Problem Solving Tactics" sprinkled throughout our textbook and read the advice recorded on the class web page. If you want to brush up on your math, the MATH SKILLS CENTER[3] is there to help.

One final point: it is important to remember that the subject of our study is not the book; it is nature. This course will serve you best if you try to apply what you are learning to the world you experience everyday.

[2]Kurt Vonnegut, Jr created the religion of Bokononism in his book *Cat's Cradle*. Foma are the useful lies of that made-up religion. Vonnegut actually knew something about how the universe works. He wrote that "freshman physics is invariably the most satisfying course offered by any American university." I hope you'll agree when this course is over!

[3]HAB 004 and PEngl 232; Available help includes videotaped lessons, test/workbooks, computerized review lessons, practice problem sheets and live tutoring assistance.

Schedule

Day		Date	Text	Topics	Exams	Labs (Fridays)
1	M	Jan 15	1.1–1.4	Introduction, units, prefixes		
2	W	Jan 17	2.1–2.4	Position, Velocity, Acceleration		
3	F	Jan 19	2.2–2.8	Constant Acceleration Problems		Uncertainties
4	M	Jan 22	2.2–2.8	Problems & Graphs		
5	W	Jan 24	3.1–3.3	Vectors	Quiz 1	
6	F	Jan 26	3.4–3.5	Two Dimensional Motion		Data Analysis
7	M	Jan 29	4.1–4.5	Newton's Laws	Quiz 2	
8	W	Jan 31	4.5–4.8	Applications		
9	F	Feb 2	5.1–5.2	Friction		Free Fall
10	M	Feb 5	5.3	Hookes Law, stress, strain	Quiz 3	
11	W	Feb 7	1.1–5.3	Review		
12	F	Feb 9	1.1–5.3	**Math & Motion**	**Exam 1**	Projectile Motion
13	M	Feb 12	6.1–6.3	Angular position and velocity		
14	W	Feb 14	6.3–6.4	Centripetal Acceleration		
15	F	Feb 16	6.5–6.6	Gravity & Orbits	Quiz 4	Kinetic Friction
16	M	Feb 19	7.1–7.3	K.E., Work & P.E.		
17	W	Feb 21	7.4–7.6	Conservative forces, energy conservation		
18	F	Feb 23	7.7–8.2	Power, momentum, impulse	Quiz 5	Ballistic Pendulum
19	M	Feb 26	8.3–8.5	Momentum conservation, collisions		
20	W	Feb 28	8.6–8.7	2-D collisions, rockets	Quiz 6	
21	F	Mar 2	9.1–9.4	Torque & Equilibrium		
Spring Break						
22	M	Mar 12	9.4–9.6	Levers, applications	Quiz 7	
23	W	Mar 14	10.1–10.3	Angular acceleration, moment of inertia		
24	F	Mar 16	10.4–10.7	Rotational energy, angular momentum		Rotational Motion
25	M	Mar 19	6.1–10.7	Review	Quiz 8	
26	W	Mar 21	6.1–10.7	**Energy, Momentum, Rotation**	**Exam 2**	
27	F	Mar 23	11.1–11.5	Fluids, density, pressure		
28	M	Mar 26	11.6–11.9	Archimedes principle		
29	W	Mar 28	12.1–12.3	Fluid flow, Bernoullis Equation		
Easter Break: Friday–Monday						
30	W	Apr 4	12.4–12.7	Poiseuilles Law, viscosity	Quiz 9	
31	F	Apr 6	13.1–13.3	Temperature, Ideal Gas Law		Archimedes Principle
32	M	Apr 9	13.4–13.6	Kinetic theory of gases		
33	W	Apr 11	14.1–14.3	Heat capacity, phase changes		
34	F	Apr 13	14.4–14.7	Conduction, convection, radiation	Quiz 10	Fluid Drag
35	M	Apr 16	15.1–15.3	First, Second Laws of Thermodynamics		
36	W	Apr 18	15.3–15.5	Cycles, heat engines, refrigerators		
37	F	Apr 20	15.6–15.7	Entropy & Second Law	Quiz 11	Gas Behavior
38	M	Apr 23	11-15	Review		
39	W	Apr 25	11-15	**Thermodynamics & Fluids**	**Exam 3**	
40	F	Apr 27	16.1–16.4	Hookes Law, periodic motion		Lab Practical Exam
41	M	Apr 30	16.5–16.8	Oscillation Energy, damping		
42	W	May 2	16.9–16.11	Waves, superposition	Quiz 12	
43	F	May 4	1–16	Review		
	T	May 8	1–16	Everything!	**Final Exam**	