Modern Physics
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Preface: *or, "Notes to a Professor Holding This Book"*

The most obvious difference between the book you're holding in your hand, and other books that cover the same material at the same level, is our emphasis on active learning. So you may be surprised that the first thing we want to tell you is:

We designed our book to support active learning, but also to work great for professors who have no interest in active learning whatsoever.

How do we recommend you evaluate our book? Pick a topic. Read our Explanation, and see if it lays out the material in a way that students will understand. Look over our Conceptual Questions and Problems, and see if they give you the tools to push students from "no understanding" to "basic understanding" to "deep understanding." We think you'll find many ways in which the completely traditional elements of our book are better than other books you may have used for this course.

It is also our goal to support the use of active learning. We believe in research, and an overwhelming body of research says that active learning works.[1] But active learning poses challenges. How do you incorporate active, challenging moments into your already-packed class time without sacrificing content? And even if you want to, how do you come up with the right questions, problems, or activities to get the students constructively engaged? This book makes it easy to experiment with active learning in small ways that take very little extra time, in or out of class. If you find that these experiments are genuinely fast, easy, and (most importantly) effective in increasing student understanding and retention, you may feel emboldened to try a few more.

This Preface will familiarize you with the various elements of the book, and how we envision them being used.

- **Web Site**. We have a lot of content on our Web site, and on occasion we refer to that content in our book. We encourage you to take a look, but even more importantly, tell your students to bookmark the following page, as they will want to return to it often throughout the course:

  `http://www.felderbooks.com/resources`

- **Explanations**. Our Explanations are fairly traditional in many ways. "Here is a description of the photoelectric effect, why its results were so surprising, and how Einstein used the quantum hypothesis to explain those results." We pride ourselves on clear and direct prose that is written to help students understand, rather than to dazzle professors. We carefully explain the difficult or confusing parts, leaving the more mechanical steps to be filled in by students in the Problems. But you can judge all that for yourself.

[1] See e.g. "Active learning increases student performance in science, engineering, and mathematics," Freeman et al, *Proceedings of the National Academy of Sciences of the United States of America*, https://www.pnas.org/content/111/23/8410 (2014).

- **<u>Active Reading Exercises</u>.** The following appears in the middle of the "photoelectric effect" explanation. Before this exercise we discuss the experimental setup, and the classical picture of an electron gradually absorbing energy from an electromagnetic wave.

> **Active Reading Exercise: Photoelectric Predictions in the Classical Model**
>
> Imagine setting up the photoelectric effect and measuring the current of electrons flowing out of Plate B. Based on the classical model of light in the paragraphs above…
>
> - How would an increase in the intensity (or amplitude) of the light—holding frequency constant—affect the time lag, the final current, and the maximum kinetic energy of released electrons?
> - How would an increase in the frequency of the light—holding amplitude constant—affect the time lag, the final current, and the maximum kinetic energy of released electrons?

For motivated students reading the text before class, pausing to try these exercises before reading on will greatly improve their understanding and retention of the material. But many students will not do that, and their first introduction to the material will be in your lectures.

So we would love you to try, just with one or two of these, pausing your lecture at that point. Put a slide up with those questions. Give the students one minute to think about these questions on their own, and then another minute to compare and discuss answers with their neighbors. Research shows that one or two such interruptions, lasting no more than 1-2 minutes each, vastly improve student retention of a 50-minute lecture.

What then? In some cases, we answer the Active Reading Exercise immediately in the text. In such cases (as in the example above), the answer is vital to the next steps in the lecture. So you might pick up your lecture by polling the students about their responses and then discussing the right answer. In other cases, the answer to the Active Reading Exercise is online; you can choose to discuss it in class or tell students that they can find it later.

- **<u>Discovery Exercises</u>.** A Discovery Exercise is a self-guided tutorial meant to take 5-20 minutes *before* the lecture. It can be assigned as homework due the day of the lecture, done in class at the start of the topic, or done in class at the end of the previous topic to prime them for the next class. The students work through some of the math and physics of a topic on their own. If they are able to solve it all, they start the lesson well prepared. If they get stuck, they come into lecture with a clearer sense of what the topic is, and of exactly what they are confused about, and they are ready to learn.

Many Discovery Exercises have one or more "Check Yourself" points where students can check their answers to see if they are on track, so they can keep going to the later parts even if they are stuck on one of the earlier ones.

> We should pause here to emphasize that *we are not urging you to use all the exercises in this book.* We ourselves don't use all of them when we teach! The book gives you a lot of them, so that you can pick and choose.

- **<u>Math Interludes</u>.** How much math have the students in a Modern Physics class been exposed to? How much have they comfortably mastered? The answers vary tremendously from school to school. It is likely that most students at this level are comfortable with basic trigonometry and introductory calculus. They are probably less familiar with multivariate functions [a traveling wave $y = A\sin(kx - \omega t)$ for instance] even if they have seen them. They may not have seen complex numbers since high school. They may or may not have worked with partial derivatives, iterated integrals, spherical coordinates, and partial differential equations. If you glibly assume that students have mastered all these topics, or will pick them up as they go, the result may be frustration and superficial understanding. We devote short sections to these topics at the points where they are needed for the continued development of the physics.

  For math topics that are not prerequisite to your course, you might want to devote class time to covering these sections. For math topics that are prerequisite to your course, you might consider assigning a few homework problems from these sections to alert students to topics they might need to review.

- **<u>Questions</u>.** Questions appear after the Explanation in each Section. Unlike Problems, they require little or no calculation. Many (but not all) are multiple choice, and can be asked in class with clickers or other response systems. The Questions are categorized into three groups.

  - **Quick Checks.** Fast, easy, true/false or multiple choice questions. You might use some of them in mid-lecture as a way of saying "Are you with me here?" These could also be assigned as "reading check" assignments. Quick Checks are not suitable for use as ConcepTests because they are more tests of simple factual knowledge than true tests of conceptual understanding.

  - **Conceptual Questions/ConcepTests.** These are harder conceptual questions that probe the ideas presented in the section. Many of these questions match Eric Mazur's idea of a "ConcepTest," a challenging question you can ask students to discuss and debate with each other in class (e.g. with "think-pair-share").

  - **For Deeper Discussion.** A student who understands the topic presented in a section should be able to answer most of the Quick Checks and Conceptual Question/ConcepTests, perhaps after some work and discussion, but may still struggle with the "Deeper Discussion" questions. This struggle can be immensely valuable, especially if it leads to discussion and debate! These questions make great extra credit problems, topics for class discussions, or extra challenges for highly motivated students. We recommend bracketing these with a caveat like "I don't necessarily expect you to get the right answer, but I do expect you to show me some real thought."

- **<u>Problems</u>.** The last part of each section is Problems, which in many ways look like the problems you would see in any other textbook. The first difference you may notice is that we have many more of them. (In our experience, professors almost always want more problems than they have been given.) The Problems marked as "Explorations" push deeper into real-world applications or advanced concepts, and might be appropriate for extra credit or as group projects.

In many cases, derivations that are traditionally done in Explanations are done entirely or in part in our Problems. Our goal is to provide enough scaffolding to guide the students successfully through the derivations. For the derivations you really want your students to learn, we strongly believe the students will understand and retain them better if they do them (or at least attempt them) on their own before they see them from you.

- **Computer Problems.** Using computers to solve problems is a crucial skill for physics students, but over-reliance on computers can prevent students from learning crucial skills. Our goal is not to dictate the right balance, but to support you wherever you find it. Scattered throughout our Problem sections are problems marked with an icon indicating that they require use of a computer. (We don't mark problems that simply require a graphing calculator.) You could have the students do these problems with Wolfram Alpha, Mathematica, Matlab, Excel, or any other program. If you don't want computation in your course, don't assign these problems.

One early reviewer of our book wrote about this Preface: "A reader would get the idea that all that sets your book apart is those structures. What about how you organize and treat the content, and your writing style, and most important, how your treatment makes these nonintuitive concepts more graspable than they usually are?"

We are gratified that this reviewer identified so many of the attributes that *we* think distinguish our book. But there's no reason for you to take our word (or his) for all that: you can compare our Explanations and Problems to your favorite textbook, and we hope you will agree that we explain physics more clearly.

One reviewer also said that our Preface needed a "dynamite ending" (and apparently felt that "If you don't want computation in your course, don't assign these problems" didn't hit the mark). So let's pull up from the details to the big picture.

For the two of us, at different times and in different schools, our Sophomore-level Modern Physics courses came as life-changing revelations. Fast-moving objects do *what?* Individual photons do *what?* You're saying this stuff *really happens?*

We want to share that stunned feeling with students. We want them to gather around a conference table with Einstein, Bohr, and Schrödinger, and try to craft a coherent theoretical model to explain the startling experimental evidence. We want them to become comfortable with the mathematical processes involved, and simultaneously to see how the underlying physics defies their intuition. One of our working titles for this book was *Childlike Wonder and Differential Equations.* We want them to see all that in their introduction to special relativity and quantum mechanics: say, the first seven chapters.

After that the mission changes somewhat, from learning basic theories to seeing how those theories were applied in the 20th and 21st centuries. The students move downward from atoms to nuclei to quarks, and move upward from the solar system to the galaxy to the origin and fate of the universe. No course covers all of that in one semester, but you may find some of it worth sharing, even at a cursory level, so that your students can see the progress that has been made—and the open questions that they themselves may help to answer some day.