

Preface

Beyond Classical Physics is intended to be a sequel to the first-year level *Neoclassical Physics*. I have followed the same pathway, emphasizing the experimental underpinnings of our modern mathematical representations of nature. The focus here is primarily on the microscopic world, where experiments indicate that interactions of the constituents of matter are vastly different from those we observe in macroscopic objects. This world is best described by what we have come to call quantum theory.

As we progress through the text, we shall endeavor to illustrate some of the historical contributions of the practitioners of the day. For example, Albert Einstein provoked a signal change in how physics is practiced with his development of a General Theory of Relativity but Einstein did not work completely in isolation. This text is not intended to be a history of the subject; indeed, we shall not attempt to provide attribution for every equation or experiment. Following such a path would lead to a publication too ponderous to contemplate. Instead, my intent is to provide an introduction to the state of physics at the beginning of the twenty-first century.

When I was a first-year graduate student, my electromagnetics instructor Feza Gürsey made a point of telling the class that Freeman Dyson had proved the renormalizability of quantum electrodynamics as a first-year student. Recently, Gerard t'Hooft had just proven the renormalizability of quantum chromodynamics at the one-loop level, also as a first-year student.

“What,” he queried, “are you working on?”

As he scanned the room, no one was willing to make eye contact, so I suppose that he concluded that ours was another class of misfits, without a single distinguished intellect amongst the lot.

In retrospect and having sufficient time elapsed for Professor Gürsey’s stinging rebuke to have softened, I have come to another interpretation: Gürsey was seeking to challenge us to become relevant, to step beyond the limitations of curriculum and seek the frontiers of knowledge. Students have a natural tendency to follow the curriculum, learning whatever is set forth in textbooks and required in the syllabus. Universities have become complacent in their curriculum development, instead focussing on administrative, accreditation goals that reward adherence to (least common denominator) standards, not innovation. The result is that most students

do not see the frontiers of physics research until they are well into their graduate careers. It is a truly remarkable student who even knows what renormalization means at the first-year graduate level, much less have enough insight to contribute in a significant fashion. This is unfortunate, because renormalization became integrated into the physics literature by the 1950s. Physics has moved well beyond quantum electrodynamics.

I have chosen to include the use not only of *Mathematica* software but also the numerical codes NWChem, that performs electronic structure calculations, and NAMD/VMD that provide molecular dynamics and visualization/analysis capabilities. I recognize that these choices may seem to introduce an insurmountable obstacle to progress but tutorials in their use are available by their developers and the codes are freely accessible. In fact, given adequate computational resources, these codes can be used at the frontiers of research. These days, numerical simulation has risen to new importance. Experiment, of course, provides the defining result but often experiments need interpretation. Simulation, beyond ideal theoretical formulations, provides concrete, if flawed, results that can help to explain experimental results and guide further experimentation.

I have had undergraduate students utilize these codes to good effect. It takes discipline and hard work to become adept with these tools but students are generally quite enthralled with the results that they can obtain. They are brought to the precipice where they can begin to ask significant questions of their own. This is not a small achievement.

While not a lengthy textbook, I expect that there is sufficient material to fill two semesters, particularly if instructors require students to attempt reading the original publications listed in each section. I have found this to be an interesting exercise for students. Even if they do not fully (or partly) comprehend the work, in many cases one finds that the original paper does not mention explicitly the reason why it is cited. Attribution follows reputation, in some instances. In any case, consulting the original literature is still an important step along the pathway to becoming a scientist. I believe it never too early to begin.

That said, I recognize that in so short a work that there are many areas of physics that are not discussed. Again, my philosophy is that students will benefit more from investigating fewer topics in more detail than in pursuing a large quantity of topics, just to say that you've seen Bernoulli's law, in case it comes up in a subsequent class. I believe that if students are properly prepared, they will have the tools to follow any topic that subsequently fires their imagination.

As diligently as I have worked on this text, I admit that there are probably mistakes; I hope there are no blatant falsehoods. Nevertheless, all

errors in the text are my responsibility and I apologize in advance for any particularly egregious examples. This work, of course, would never have been completed without the continual, and unflinching, support of my wife Liz. She has endured the creation of this book without complaint, even as I staggered through the effort. I cannot say thank you enough.

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