Preface to the Second Edition

What one fool could understand, another can.
—R. P. Feynman[1]

Appreciating the appreciators

It has been nearly six years since this book was published on March 10, 2003. Since authors often think of books as their children, I may liken the flood of appreciation from readers, students, and physicists to the glorious report cards a bright child brings home from school. Knowing that there are people who appreciate the care and clarity crafted into the pedagogy is a most gratifying feeling. In working on this new edition, merely looking at the titles of the customer reviews on Amazon.com would lighten my task and quicken my pace: "Funny, chatty, physical. QFT education transformed!," "A readable, and re-readable instant classic on QFT," "A must read book if you want to understand essentials in QFT," "One of the most artistic and deepest books ever written on quantum field theory," "Perfect for learning field theory on your own," "Both deep and entertaining," "One of those books a person interested in theoretical physics simply must own," and so on.

In a *Physics Today* review, Zvi Bern, a preeminent younger field theorist, wrote:

> Perhaps foremost in his mind was how to make *Quantum Field Theory in a Nutshell* as much fun as possible. . . . I have not had this much fun with a physics book since reading *The Feynman Lectures on Physics*. . . . [This is a book] that no student of quantum field theory should be without. *Quantum Field Theory in a Nutshell* is the ideal book for a graduate student to curl up with after having completed a course on quantum mechanics. But, mainly, it is for anyone who wishes to experience the sheer beauty and elegance of quantum field theory.

A classical Chinese scholar famously lamented "He who knows me are so few!" but here Zvi read my mind.

Einstein proclaimed, "Physics should be made as simple as possible, but not any simpler." My response would be "Physics should be made as fun as possible, but not

[1] R. P. Feynman, *QED: The Strange Theory of Light and Matter,* p. xx.

any funnier." I overcame the editor's reluctance and included jokes and stories. And yes, I have also written a popular book *Fearful Symmetry* about the "sheer beauty and elegance" of modern physics, which at least in that book largely meant quantum field theory. I want to share that sense of fun and beauty as much as possible. I've heard some people say that "Beauty is truth" but "Beauty is fun" is more like it.

I had written books before, but this was my first textbook. The challenges and rewards in writing different types of book are certainly different, but to me, a university professor devoted to the ideals of teaching, the feeling of passing on what I have learned and understood is simply incomparable. (And the nice part is that I don't have to hand out final grades.) It may sound corny, but I owe it, to those who taught me and to those authors whose field theory texts I studied, to give something back to the theoretical physics community. It is a wonderful feeling for me to meet young hotshot researchers who had studied this text and now know more about field theory than I do.

How I made the book better: The first text that covers the twenty-first century

When my editor Ingrid Gnerlich asked me for a second edition I thought long and hard about how to make this edition better than the first. I have clarified and elaborated here and there, added explanations and exercises, and done more "practical" Feynman diagram calculations to appease those readers of the first edition who felt that I didn't calculate enough. There are now three more chapters in the main text. I have also made the "most accessible" text on quantum field theory even more accessible by explaining stuff that I thought readers who already studied quantum mechanics should know. For example, I added a concise review of the Dirac delta function to chapter I.2. But to the guy on Amazon.com who wanted complex analysis explained, sorry, I won't do it. There is a limit. Already, I gave a basically self-contained coverage of group theory.

More excitingly, and to make my life more difficult, I added, to the existing eight parts (of the celestial dragon), a new part consisting of four chapters, covering field theoretic happenings of the last decade or so. Thus I can say that this is the first text since the birth of quantum field theory in the late 1920s that covers the twenty-first century.

Quantum field theory is a mature but certainly not a finished subject, as some students mistakenly believe. As one of the deepest constructs in theoretical physics and all encompassing in its reach, it is bound to have yet unplumbed depths, secret subterranean connections, and delightful surprises. While many theoretical physicists have moved past quantum field theory to string theory and even string field theory, they often take the limit in which the string description reduces to a field description, thus on occasion revealing previously unsuspected properties of quantum field theories. We will see an example in chapter N.4.

My friends admonished me to maintain, above all else, the "delightful tone" of the first edition. I hope that I have succeeded, even though the material contained in part N is "hot off the stove" stuff, unlike the long-understood material covered in the main text. I also added a few jokes and stories, such as the one about Fermi declining to trace.

As with the first edition, I will maintain a web site http://theory.kitp.ucsb.edu/~zee/nuts2.html listing the errors, typographical or otherwise, that will undoubtedly come to my attention.

Encouraging words

In the quote that started this preface, Feynman was referring to himself, and to you! Of course, Feynman didn't simply understand the quantum field theory of electromagnetism, he also invented a large chunk of it. To paraphrase Feynman, I wrote this book for fools like you and me. If a fool like me could write a book on quantum field theory, then surely you can understand it.

As I said in the preface to the first edition, I wrote this book for those who, having learned quantum mechanics, are eager to tackle quantum field theory. During a sabbatical year (2006–07) I spent at Harvard, I was able to experimentally verify my hypothesis that a person who has mastered quantum mechanics could understand my book on his or her own without much difficulty. I was sent a freshman who had taught himself quantum mechanics in high school. I gave him my book to read and every couple of weeks or so he came by to ask a question or two. Even without these brief sessions, he would have understood much of the book. In fact, at least half of his questions stem from the holes in his knowledge of quantum mechanics. I have incorporated my answers to his field theoretic questions into this edition.

As I also said in the original preface, I had tested some of the material in the book "in the field" in courses I taught at Princeton University and later at the University of California at Santa Barbara. Since 2003, I have been gratified to know that it has been used successfully in courses at many institutions.

I understand that, of the different groups of readers, those who are trying to learn quantum field theory on their own could easily get discouraged. Let me offer you some cheering words. First of all, that is very admirable of you! Of all the established subjects in theoretical physics, quantum field theory is by far the most subtle and profound. By consensus it is much much harder to learn than Einstein's theory of gravity, which in fact should properly be regarded as part of field theory, as will be made clear in this book. So don't expect easy cruising, particularly if you don't have someone to clarify things for you once in a while. Try an online physics forum. Do at least some of the exercises. Remember: "No one expects a guitarist to learn to play by going to concerts in Central Park or by spending hours reading transcriptions of Jimi Hendrix solos. Guitarists practice. Guitarists play the guitar until their fingertips are calloused. Similarly, physicists solve problems."[2] Of course, if you don't have the prerequisites, you won't be able to understand this or any other field theory text. But if you have mastered quantum mechanics, keep on trucking and you will get there.

[2] N. Newbury et al., *Princeton Problems in Physics with Solutions,* Princeton University Press, Princeton, 1991.

The view will be worth it, I promise. My thesis advisor Sidney Coleman used to start his field theory course saying, "Not only God knows, I know, and by the end of the semester, you will know." By the end of this book, you too will know how God weaves the universe out of a web of interlocking fields. I would like to change Dirac's statement "God is a mathematician" to "God is a quantum field theorist."

Some of you steady truckers might want to ask what to do when you get to the end. During my junior year in college, after my encounter with Mandl, I asked Arthur Wightman what to read next. He told me to read the textbook by S. S. Schweber, which at close to a thousand pages was referred to by students as "the monster" and which could be extremely opaque at places. After I slugged my way to the end, Wightman told me, "Read it again." Fortunately for me, volume I of Bjorken and Drell had already come out. But there is wisdom in reading a book again; things that you miss the first time may later leap out at you. So my advice is "Read it again." Of course, every physics student also knows that different explanations offered by different books may click with different folks. So read other field theory books. Quantum field theory is so profound that most people won't get it in one pass.

On the subject of other field theory texts: James Bjorken kindly wrote in my much-used copy of Bjorken and Drell that the book was obsolete. Hey BJ, it isn't. Certainly, volume I will never be passé. On another occasion, Steve Weinberg told me, referring to his field theory book, that "I wrote the book that I would have liked to learn from." I could equally well say that "I wrote the book that *I* would have liked to learn from." Without the least bit of hubris, I can say that I prefer my book to Schweber's. The moral here is that if you don't like this book you should write your own.

I try not to do clunky

I explained my philosophy in the preface to the first edition, but allow me a few more words here. I will teach you how to calculate, but I also have what I regard as a higher aim, to convey to you an enjoyment of quantum field theory in all its splendors (and by "all" I mean not merely quantum field theory as defined by some myopic physicists as applicable only to particle physics). I try to erect an elegant and logically tight framework and put a light touch on a heavy subject.

In spite of the image conjured up by Zvi Bern of some future field theorist curled up in bed reading this book, I expect you to grab pen and paper and work. You could do it in bed if you want, but work you must. I intentionally did not fill in all the steps; it would hardly be a light touch if I do every bit of algebra for you. Nevertheless, I have done algebra when I think that it would help you. Actually, I love doing algebra, particularly when things work out so elegantly as in quantum field theory. But I don't do clunky. I do not like clunky-looking equations. I avoid spelling everything out and so expect you to have a certain amount of "sense." As a small example, near the end of chapter I.10 I suppressed the spacetime dependence of the fields φ_a and $\delta\varphi_a$. If you didn't realize, after

some 70 pages, that fields are functions of where you are in spacetime, you are quite lost, my friend. My plan is to "keep you on your toes" and I purposely want you to feel puzzled occasionally. I have faith that the sort of person who would be reading this book can always figure it out after a bit of thought. I realize that there are at least three distinct groups of readers, but let me say to the students, "How do you expect to do research if you have to be spoon-fed from line to line in a textbook?"

Nuts who do not appreciate the *Nutshell*

In the original preface, I quoted Ricky Nelson on the impossibility of pleasing everyone and so I was not at all surprised to find on Amazon.com a few people whom one of my friends calls "nuts who do not appreciate the *Nutshell*." My friends advise me to leave these people alone but I am sufficiently peeved to want to say a few words in my defense, no matter how nutty the charge. First, I suppose that those who say the book is too mathematical cancel out those who say the book is not mathematical enough. The people in the first group are not informed, while those in the second group are misinformed.

Quantum field theory does not have to be mathematical. I know of at least three Field Medalists who enjoyed the book. A review for the American Mathematical Society offered this deep statement in praise of the book: "It is often deeper to know why something is true rather than to have a proof that it is true." (Indeed, a Fields Medalist once told me that top mathematicians secretly think like physicists and after they work out the broad outline of a proof they then dress it up with epsilons and deltas. I have no idea if this is true only for one, for many, or for all Fields Medalists. I suspect that it is true for many.)

Then there is the person who denounces the book for its lack of rigor. Well, I happen to know, or at least used to know, a thing or two about mathematical rigor, since I wrote my senior thesis with Wightman on what I would call "fairly rigorous" quantum field theory. As we like to say in the theoretical physics community, too much rigor soon leads to rigor mortis. Be warned. Indeed, as Feynman would tell students, if this ain't rigorous enough for you the math department is just one building over. So read a more rigorous book. It is a free country.

More serious is the impression that several posters on Amazon.com have that the book is too elementary. I humbly beg to differ. The book gives the impression of being elementary but in fact covers more material than many other texts. If you master everything in the *Nutshell,* you would know more than most professors of field theory and could start doing research. I am not merely making an idle claim but could give an actual proof. All the ingredients that went into the spinor helicity formalism that led to a deep field theoretic discovery described in part N could be found in the first edition of this book. Of course, reading a textbook is not enough; you have to come up with the good ideas.

As for he who says that the book does not look complicated enough and hence can't be a serious treatment, I would ask him to compare a modern text on electromagnetism with Maxwell's treatises.

Thanks

In the original preface and closing words, I mentioned that I learned a great deal of quantum field theory from Sidney Coleman. His clarity of thought and lucid exposition have always inspired me. Unhappily, he passed away in 2007. After this book was published, I visited Sidney on different occasions, but sadly, he was already in a mental fog.

In preparing this second edition, I am grateful to Nima Arkani-Hamed, Yoni Ben-Tov, Nathan Berkovits, Marty Einhorn, Joshua Feinberg, Howard Georgi, Tim Hsieh, Brendan Keller, Joe Polchinski, Yong-shi Wu, and Jean-Bernard Zuber for their helpful comments. Some of them read parts or all of the added chapters. I thank especially Zvi Bern and Rafael Porto for going over the chapters in part N with great care and for many useful suggestions. I also thank Craig Kunimoto, Richard Neher, Matt Pillsbury, and Rafael Porto for teaching me the black art of composing equations on the computer. My editor at Princeton University Press, Ingrid Gnerlich, has always been a pleasure to talk to and work with. I also thank Kathleen Cioffi and Cyd Westmoreland for their meticulous work in producing this book. Last but not least, I am grateful to my wife Janice for her encouragement and loving support.