Preface (Volume 1)

"All of physics is either impossible or trivial.
It is impossible until you understand it, and then it becomes trivial."

Ernest Rutherford

This book is

1. an attempt to make learning quantum field theory (QFT) as easy, and thus as efficient, as is humanly possible,
2. intended, first and foremost, for new students of QFT, and
3. an introduction to only the most fundamental and central concepts of the theory, particularly as employed in quantum electrodynamics (QED).

It is not

1. orthodox (pedagogically),
2. an exhaustive treatment of QFT,
3. concise (lacking extensive explanation),
4. written for seasoned practitioners in the field, or
5. a presentation of the latest, most modern approach to it.

Students planning a career in field theory will obviously have to move on to more advanced texts, after they digest the more elementary material presented herein. This book is intended to provide a solid foundation in the most essential elements of the theory, nothing more.

In my own teaching experience, and in the course of researching pedagogy, I have come to see that "learning" has at its basis a fundamental three-in-one structure. The wholeness of learning is composed of

i) the knowledge to be learned,
ii) the learner, and
iii) the process of learning itself.

It seems unfortunate that physics and physics textbooks have too often been almost solely concerned with the *knowledge* of physics and only rarely concerned with *those who are learning it* or *how they could best go about learning*. However, there are signs that this situation may be changing somewhat, and I hope that this book will be one stepping stone in that direction.

In writing this book, I have repeatedly tried to visualize the learning process as a new learner would. This viewpoint is one we quickly lose when we, as teachers and researchers, gain familiarity with a given subject, and yet it is a perspective we must maintain if we are to be effective educators. To this end, I have solicited guidance and suggestions from professional educators (those who make learning and education, *per se*, their central focus in life), and more importantly, from those studying QFT for the first time. In addition, I have used my own notes, compiled when I was first studying the theory myself, in which I carefully delineated ways the subject could be presented in a more student-friendly manner. In this sense, the text incorporates "peer instruction", a pedagogic tool of recognized, and considerable, merit, wherein students help teach fellow students who are learning the same subject.

It is my sincere hope that the methodologies I have employed herein have helped me to remain sympathetic to, and in touch with, the perspective of a new learner. Of course, different students find different teaching techniques to have varying degrees of transparency, so there are no hard and fast rules. However, I do believe that most students would consider many of the following principles, which I have employed in the text, to be of pedagogic value.

1) Brevity avoided

Conciseness is typically a horror for new students trying to fathom unfamiliar concepts. While it can be advantageous in some arenas, it is almost never so in education. Unfortunately, being succinct, has, in scientific/technical circles, become a goal unto itself, extending even into pedagogy – an area for which it was never suited.

In this book, I have gone to great lengths to avoid conciseness and to present extensive explanations. I often take a paragraph or more for what other authors cover in a single sentence. I do this because I learned a long time ago that the thinnest texts were the hardest. Thicker ones covering the same material actually took less time to get through, and I understood them better, because the authors took time and space to elaborate, rather than leave significant gaps.

Such gaps often contain ambiguities or possibilities for misunderstanding that the author has overlooked and left unresolved. Succinctness may impress peers but can be terribly misleading and frustrating for students.

2) Holistic previews

The entire book, each chapter, and many sections begin with simple, non-mathematical overviews of the material to be covered. These allow the student to gain a qualitative understanding of the "big picture" before he or she plunges into the rigors of the underlying mathematics.

Doing physics is a lot like doing a jig-saw puzzle. We assemble bits and pieces into small wholes and then gradually merge those small wholes into greater ones, until ultimately, we end up with the "big picture." Seeing the picture on the puzzle box before we start has immense value in helping us put the whole thing together. We know the blue goes here, the green there, and the boundary of the two, somewhere in between. Without that picture preview to guide us, the entire job becomes considerably more difficult, more tedious, and less enjoyable. In this book, the holistic previews are much like the pictures on the puzzle boxes. The detail is not there, but the essence of the final goal is. These overviews should eliminate, or at least minimize, the "lost in a maze of equations" syndrome by providing a "birds-eye road map" of where we have come from, and where we are going. By so doing we not only will keep sight of the forest in spite of the trees, but will also have a feeling, from the beginning, for the relevance of each particular topic to the overriding structure of the wholeness of knowledge in which it is embedded.

3) Schematic diagram summaries (wholeness charts)

Enhancing the "birds-eye road map" approach are block diagram summaries, which I call *wholeness charts*, so named because they reveal in chart form the underlying connections that unite various aspects of a given theory into a greater whole. Unlike the chapter previews, these are often mathematical and contain considerable theoretical depth.

Learning a computer program line-by-line is immensely harder than learning it with a block diagram of the program, showing major sections and sub-sections, and how they are all interrelated. There is a structure underlying the program, which is its essence and most important aspect, but which is not obvious by looking directly at the program code itself.

The same is true in physics, where line-by-line delineation of concepts and mathematics corresponds to program code, and in this text, wholeness charts play the role of block diagrams. In my own learning experiences, in which I constructed such charts myself from my books and lecture notes, I found them to be invaluable aids. They coalesced a lot of different information into one central, compact, easy-to-see, easy-to-understand, and easy-to-reference framework.

The specific advantages of wholeness charts are severalfold.

First, in learning any given material we are seeking, most importantly, an understanding of the kernel or conceptual essence, i.e., the main idea(s) underlying all the text. A picture is worth a thousand words, and a wholeness chart is a "snapshot" of those thousand words.

Second, although the charts can summarize in-depth mathematics and concepts, they can be used to advantage even when reading through material for the first time. The holistic overview perspective can be more easily maintained by continual reference to the schematic as one learns the details.

Third, comparison with similar diagrams in related areas can reveal parallel underlying threads running through seemingly diverse phenomena. (See, for example, Summary of Classical Mechanics Wholeness Chart 2-2 and Summary of Quantum Mechanics Wholeness Chart 2-5 in Chap. 2, pgs. 20-21 and 30-31.) This not only aids the learning process but also helps to reveal some of the subtle workings and unified structure inherent in Mother Nature.

Further, review of material for qualifying exams or any other future purpose is greatly facilitated. It is much easier to refresh one's memory, and even deepen understanding, from one or two summary sheets, rather than time consuming ventures through dozens of pages of text. And by copying all of the wholeness charts herein and stapling them together, you will have a pretty good summary of the entire book.

Still further, the charts can be used as quick and easy-to-find references to key relations at future times, even years later.

4) Reviews of background material

In situations where development of a given idea depends on material studied in previous courses (e.g., quantum mechanics) short reviews of the relevant background subject matter are provided, usually in chapter introductory sections or later on, in special boxes separate from the main body of the text.

5) Only basic concepts without peripheral subjects

I believe it is of primary importance in the learning process to focus on the fundamental concepts first, to the exclusion of all else. The time to branch out into related (and usually more complex) areas is *after* the core knowledge is assimilated, *not during* the assimilation period.

All too often, students are presented with a great deal of new material, some fundamental, other more peripheral or advanced. The peripheral/advanced material not only consumes precious study time, but tends to confuse the student with regard to what precisely is essential (what he or she *must* understand), and what is not (what it would be *nice if* he or she also understood at this point in their development).

As one example, for those familiar with other approaches to QFT, this book does not introduce concepts appropriate to weak interactions, such as ϕ^4 theory, before students have first become grounded in the more elementary theory of quantum electrodynamics.

This book, by careful intention, restricts itself to only the most core principles of QFT. Once those principles are well in hand, the student should then be ready to glean maximum value from other, more extensive, texts.

6) Optimal "return on investment" exercises

All too often students get tied up, for what seem interminable periods, working through problems from which minimum actual learning is reaped. Study time is valuable, and spending it engulfed in great quantities of algebra and trigonometry is probably not its best use.

I have tried, as best I could, to design the exercises in this book so that they consume minimum time but yield maximum return. Emphasis has been placed on gleaning an understanding of concepts without getting mired down.

Later on, when students have become practicing researchers and time pressure is not so great, there will be ample opportunities to work through more involved problems down to every minute algebraic detail. If they are firmly in command of the *concepts* and *principles* involved, the calculations, though often lengthy, become trivial. If, however, they never got grounded in the fundamentals because study time was not efficiently used, then research can go slowly indeed.

7) Many small steps, rather than fewer large ones

Professional educators have known for some time now that learning progresses faster and more profoundly when new material is presented in small bites. The longer, more moderately sloped trail can get one to the mountaintop much more readily than the agonizing climb up the nearly vertical face.

Unfortunately, from my personal experience as a student, it often seemed like my textbooks were trying to take me up the steepest grade. I sincerely hope that those using this book do not have this experience. I have made every effort to include each and every relevant step in all derivations and examples.

In so doing, I have sought to avoid the common practice of letting students work out significant amounts of algebra that typically lies "between the lines". The thinking, as I understand it, is that students are perfectly capable of doing that themselves, so "why take up space with it in a text?"

My answer is simply that including those missing steps makes the learning process more efficient. If it takes the author ten minutes to write out two or three more lines of algebra, then it probably takes the student twenty minutes to do so, provided he/she is not befuddled (which is not rare, and in which case, it can take a great deal longer). That ten minutes spent by the author saves hundreds, or even thousands, of student readers twenty minutes, or more, each. Multiply that by the number of times such things occur per chapter and the number of chapters per book, and we are talking enormous amounts of student time saved.

Students learn very little, if anything, doing algebra. They recapture a lot of otherwise wasted time that can be used for actual learning, if the author types out the missing lines.

8) Liberal use of simple concrete examples

Professional educators have also known for quite some time that abstract concepts are best taught by leading into them with simple, physically visualizable examples. Further, understanding is deepened, broadened, and solidified with even more such concrete examples.

Some may argue that a more formal mathematical approach is preferable because it is important to have a profound, not superficial, understanding. While I completely agree that a profound understanding is essential, it is my experience that the mathematically rigorous introduction, more often than not, has quite the opposite result. (Ask any student about this.) Further, to know any field profoundly we must know it from all angles. We must know the underlying mathematics in detail *plus* we must have a grasp on what it all means in the real world, i.e., how the relevant systems behave, how they parallel other types of systems with which we are already familiar, etc. Since we have to cover the whole range of knowledge from abstract to physical anyway, it seems best to start with the end of the spectrum most readily apprehensible (i.e., the visualizable, concrete, and analogous) and move on from there.

This methodology is employed liberally in this book. It is hoped that so doing will ameliorate the "what is going on?" frustration common among students who are introduced to conceptually new ideas almost solely via routes heavily oriented toward abstraction and pure mathematics.

In this context it is relevant that Richard Feynman, in his autobiography, notes,

> *"I can't understand anything in general unless I'm carrying along in my mind a specific example and watching it go....(Others think) I'm following the steps mathematically but that's not what I'm doing. I have the specific, physical example of what (is being analyzed) and I know from instinct and experience the properties of the thing."*

I know from my own experience that I learn in the same way, and I have a suspicion that almost everyone else does as well. Yet few *teach* that way. This book is an attempt to teach in that way.

9) Margin overview notes

Within a given section of any textbook, one group of paragraphs can refer to one subject, another group to another subject. When reading material for the first time, not knowing exactly where one train of the author's thought ends and a different one begins can oftentimes prove confusing. In this book, each new idea not set off with its own section heading is highlighted, along with its central message, by notations in the margins. In this way, emphasis is once again placed on the overview, the "big picture" of each topic, even on the subordinate levels within sections and subsections.

Additionally, the extra space in the margins can be used by students to make their own notes and comments. In my own experience as a student I found this practice to be invaluable. My own remarks written in a book are, almost invariably, more comprehensible to me when reviewing later for exams or other purposes than are those of the author.

10) Definitions and key equations emphasized

As a student, I often found myself encountering a term that had been introduced earlier in the text, but not being clear on its exact meaning, I had to search back through pages clumsily trying to find the first use of the word. In this book, new terminology is underlined when it is introduced or defined, so that it "jumps out" at the reader later when trying to find it again.

In addition, key equations – the ones students really need to know – have borders around them.

11) Non-use of terms like "obvious", "trivial", etc.

The text avoids use of emotionally debilitating terms such as "obvious", "trivial", "simple", "easy", and the like to describe things that may, after years of familiarity, be easy or obvious to the author, but can be anything but that to the new student. (See "A Nontrivial Manifesto" by Matt Landreman, *Physics Today*, March 2005, 52-53.)

The job I have undertaken here has been a challenging one. I have sought to produce a physics textbook which is relatively lucid and transparent to those studying quantum field theory for the first time. In so doing, I have employed some decidedly non-traditional tactics, and so anticipated resistance from main stream publishers, who typically have motivations for wanting to do things the way they have been done before. Their respective missions do not seem, at least to me, to be focused primarily on optimizing the process of conveying knowledge.

As an example, a good friend of mine submitted a graduate level physics text manuscript, with student friendly notes in the margins, to one of the world's top academic publishers. He was ordered to remove the margin notes before they would publish the book. Not wanting to fight (and lose) this kind of battle over methodologies I employ, and consider essential in making students' work easier, I have chosen a different route.

I also anticipate resistance from some physics professors who may consider the book too verbose and too simple. I only ask them to try it and let their students be the judges. The proof will be in the pudding. If comprehension comes more quickly and more deeply, then the approach taken here will be vindicated.

If you are a student now, appreciate the pedagogic methodologies used in this book, and end up one day writing a text of your own, I hope you will not forget what advantage you once gained from those methodologies. I hope you will use them in your own book. Above all, I hope your presentation will be profuse with elucidation and not terse.

Good luck to the new students of quantum field theory! May their studies be personally rewarding and professionally fruitful.

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February 2013