Symmetry and Its Breaking in Quantum Field Theory

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PREFACE

Physics is always difficult, though it is extremely interesting. Many times I thought I understood it sufficiently profoundly, but after some time, it turned out that my understanding of physics was far from satisfactory. In particular, field theory has special complexities which may not be common to other fields of research. The symmetry and its breaking are most exotic and sometimes almost mysterious to even those who can normally understand the basic physics in a clear manner.

In this textbook, I focused on presenting a simple and clear picture of the symmetry and its breaking in quantum field theory. For this purpose, I explained physics of elementary field theory of fermions interacting by gauge fields as well as by four body fermion fields. In this respect, the interpretation of the basic field theory is repeatedly done such that physicists including graduate students may understand the essential points of the symmetry breaking in this textbook.

Also, this book is intended for researchers who look for the basic problems in their investigations. In many fields of research, field theory is used as a computational tool. In this regard, I present some elaborate technical tools which are quite useful and sometimes incentive for new ideas in fundamental researches.

In physics, deeper understanding is more important than quicker understanding. In particular, graduate students should realize that, if someone else can understand the basic physics very quickly, then he is most likely a good interpreter of the textbook knowledge. Slow but deep understanding of physics is most important since it should definitely take much time to understand physics in depth. The shortest path of understanding physics is only one of many paths, and interesting physics may well be found in the paths which are far from the shortest one.

Physics must be simple once we understand it all. For example, I believe that QCD can surely describe the strong interaction physics. However, it may well be difficult to justify the perturbative calculation of the interactions between quarks, unless the gauge independence of the quark-quark interactions is guaranteed. In other words, when the unperturbed as well as interaction Hamiltonians are gauge dependent, we should make it sure that any physical quantities evaluated perturbatively are indeed gauge invariant, which seems to be very difficult.

In this textbook, there are quite a few issues which are still debating. I believe that the present understanding of the basic field theory in this textbook must be reasonably good, and as far as physics of the symmetry and its breaking is concerned, it should be the best of all. The spontaneous symmetry breaking of the global symmetry is by now understood in this textbook in terms of a simple physics terminology, and there is nothing mysterious from the standard way of understanding physics. However, it is still not yet settled whether the local gauge symmetry can be broken in terms of Higgs mechanism or not. At least, the gauge fixing for the non-gauge field is physically not at all easy to understand. For this problem, we need a lot to think over in future what should be physical observables in the Higgs mechanism.

This textbook contains a brief description of the lattice field theory even though it is not directly connected to the symmetry breaking physics. Still it may be interesting for readers to understand the basic point of the lattice field theory. For example, the continuum field theory must be richer than the lattice version, and it is most likely true that the lattice field theory can give only limited information on the continuum field theory, particularly when the latter keeps some symmetry while the former does not.

In Appendix, I explain some elementary physics so that readers may grasp the essence of the symmetry breaking phenomena in fermion field theory with little advanced knowledge. In some sense, Appendix can be read in its own interests since it includes non-relativistic quantum mechanics, Dirac equation and Maxwell equation, in addition to the notations which are often used in field theory. At the same time, Appendix contains some new physics interpretation for bosons, Dirac fields and quantization procedure. In particular, I believe that the first quantization of $[x, p_x] = i\hbar$, etc. may well be the result of the Dirac equation in that the Dirac Lagrangian density can be derived from the gauge principle as well as the Maxwell equations without involving the first quantization procedure. In the final chapter of Appendix, I briefly explain the renormalization in QED which is the most successful theory in quantum field theory. The perturbation theory is not the main issue of this textbook, but nevertheless readers may learn the essence of the renormalization scheme and renormalization group in quantum field theory.

The motive force of writing this textbook is initiated by Frank Columbus who understands the importance of the new picture of spontaneous symmetry breaking physics prior to experts and has encouraged me to write it into a textbook form. Indeed, I started to write this book from intensive discussions and hard works with my collaborators on this subject to achieve deeper but simpler understanding of the symmetry and its breaking in quantum field theory.

I should be grateful to all of my collaborators, in particular, Tomoko Asaga, Makoto Hiramoto, Takashi Homma, Seiji Kanemaki, Sachiko Oshima and Hidenori Takahashi for their great contributions to this book. Quite a few physicists and students also helped me a great deal for their critical reading of this manuscript. However, it is trivial to note that any mistakes in this book are entirely due to my carelessness.

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