Preface

Neutrino oscillation is one of the most exciting subjects in elementary particle physics today. It was first confirmed in 1998 by the Super-Kamiokande group from their studies of atmospheric neutrinos. Experimental studies of neutrino oscillation have been rapidly progressing since then, and a number of positive oscillation results have been observed in atmospheric, solar, accelerator, and reactor neutrinos. The implication of the existence of neutrino oscillation is that neutrinos have finite masses and mixings, which are not accounted for in the framework of the standard model of elementary particles. Therefore, the standard model now must be extended to include the new information. Because the neutrino masses are extremely small, it is considered to be unnatural to be included in the standard model similar to the way quark and charged lepton masses are. Therefore, the neutrino oscillation is believed to provide an important new concept that will be a big step toward the unified understanding of elementary particle physics.

The author has been involved in neutrino oscillation experiments since 1996 as a member of the KamLAND and later, Double Chooz groups and has witnessed the rapid progress of neutrino oscillation studies. Along with the work for the experiments, he has given topical lectures on neutrino oscillation in summer and winter schools, as well as a number of university lectures on particle physics. While preparing these lectures, the author felt that although there were good books on neutrinos and neutrino oscillation, many of them were highly sophisticated and were not necessarily useful for experimental students and beginners in this research field.

This book is written with the intention of giving readers an intuitive image of neutrino oscillation by showing concrete examples and numerical values of calculation results. The initial conditions are specified for the general wave functions in order to see the concrete phenomena involved. The probability formulas for the various neutrino and antineutrino oscillation modes, with and without matter effects, are summarized in the Appendix to provide a useful reference.

This book begins, in Chap. 1, with a brief introduction to the motivation for neutrino oscillation study and its history. Explanation of neutrinos and their interactions in the standard model are given in Chap. 2. Neutrino spectra from

various neutrino sources and reaction cross sections are also calculated in Chap. 2. The basics of the particle oscillations are introduced in Chap. 3. In Chap. 4, the ultrarelativistic three-flavor neutrino oscillations are explained in detail and a complete set of the oscillation probabilities for the three flavor neutrinos are calculated. Chapter 4 also deals with the neutrino oscillation-related subjects, such as the matter effect, a paradox from the measurement problem. Chapter 5 introduces the key experiments and their results, and the three-flavor neutrino oscillation parameters are summarized in Chap. 6. A toy model which can approximately predict the observed neutrino mixing patterns is also shown in Chap. 6. Finally, in Chap. 7, possibilities of future experiments are discussed, which include the measurement of the CP violation parameter δ, determination of the Δm^2_{31} mass hierarchy, and the absolute neutrino mass. The issues of the sterile neutrino and neutrino-less double β decay are briefly treated in Chap. 7. In the Appendix, a summary of the parameters and notations, a short review of the neutrino-related Lagrangian, Dirac equation, and a complete set of the neutrino oscillation probability formulas are given. Detailed calculations or lengthy descriptions, which are not appropriate to be in the main text, are also placed there.

While this book was being prepared, the last neutrino mixing angle, called θ_{13}, was finally measured and the door to future neutrino oscillation studies was opened dramatically. The research in this field will be very active and exciting. The author hopes ambitious students and researchers will join us and reveal the secret of the neutrinos together.

Sendai, Japan, December 2014 Fumihiko Suekane

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