

Contents

1	Introduction	1
2	Weak Interaction Before the Standard Model	9
2.1	Pauli Hypothesis of Neutrino	9
2.2	Fermi Theory of β -Decay	11
2.3	Fermi-Gamov-Teller Hamiltonian of β -Decay	12
2.4	Violation of Parity in β -Decay	13
2.5	Two-Component Neutrino Theory	14
2.6	μ -e Universal Charged Current. Current $\times$ Current Theory	16
2.7	Theory with Vector W Boson	19
2.8	First Observation of Neutrinos. Lepton Number Conservation	20
2.9	Discovery of Muon Neutrino. Electron and Muon Lepton Numbers	22
2.10	Strange Particles. Quarks. Cabibbo Current	24
2.11	Charmed Quark. Quark and Neutrino Mixing	26
2.12	Summary and Outlook	27
3	The Standard Model of the Electroweak Interaction	29
3.1	Introduction	29
3.2	$SU(2)$ Yang-Mills Local Gauge Invariance	30
3.3	Spontaneous Symmetry Breaking. Higgs Mechanism	35
3.4	The Standard Model for Quarks	39
3.5	The Standard Model for Leptons	52
3.6	Summary and Outlook	60
4	Neutrino Mass Terms	61
4.1	Introduction	61
4.2	Dirac Mass Term	62
4.3	Majorana Mass Term	63
4.4	Dirac and Majorana Mass Term	68
4.5	Neutrino Mass Term in the Simplest Case of Two Neutrino Fields	70
4.6	Seesaw Mechanism of Neutrino Mass Generation	73
4.7	Summary and Outlook	76

5	Neutrino Mixing Matrix	79
5.1	Introduction	79
5.2	The Number of Angles and Phases in the Matrix U	79
5.3	CP Conservation in the Lepton Sector	82
5.4	Standard Parametrization of 3×3 Mixing Matrix	86
5.5	On Models of Neutrino Masses and Mixing	89
6	Neutrino Oscillations in Vacuum	95
6.1	Introduction	95
6.2	Flavor Neutrino States	95
6.3	Oscillations of Flavor Neutrinos	99
6.4	Two-Neutrino Oscillations	107
6.5	Three-Neutrino Oscillations. CP Violation in the Lepton Sector	110
6.6	Three-Neutrino Oscillations in the Leading Approximation	114
7	Neutrino in Matter	121
7.1	Introduction	121
7.2	Evolution Equation of Neutrino in Matter	121
7.3	Propagation of Neutrino in Matter with Constant Density	127
7.4	Adiabatic Neutrino Transitions in Matter	131
8	Neutrinoless Double Beta-Decay	139
8.1	Introduction	139
8.2	Basic Elements of the Theory of $0\nu\beta\beta$ -Decay	143
8.3	Effective Majorana Mass	152
8.4	On the Nuclear Matrix Elements of the $0\nu\beta\beta$ -Decay	156
8.5	Data of Experiments on the Search for $0\nu\beta\beta$ -Decay. Future Experiments	157
9	On absolute Values of Neutrino Masses	159
9.1	Masses of Muon and Tau Neutrinos	159
9.2	Neutrino Masses from the Measurement of the High-Energy Part of the β -Spectrum of Tritium	160
10	Neutrino Oscillation Experiments	165
10.1	Introduction	165
10.2	Solar Neutrino Experiments	167
10.2.1	Introduction	167
10.2.2	Homestake Chlorine Solar Neutrino Experiment	170
10.2.3	Radiochemical GALLEX-GNO and SAGE Experiments	171
10.2.4	Kamiokande and Super-Kamiokande Solar Neutrino Experiments	173
10.2.5	SNO Solar Neutrino Experiment	175
10.2.6	Borexino Solar Neutrino Experiment	178

10.3	Super-Kamiokande Atmospheric Neutrino Experiment	179
10.4	KamLAND Reactor Neutrino Experiment	184
10.5	Long-Baseline Accelerator Neutrino Experiments	187
10.5.1	K2K Accelerator Neutrino Experiment	187
10.5.2	MINOS Accelerator Neutrino Experiment	188
10.6	MiniBooNE Accelerator Neutrino Experiment	190
10.7	CHOOZ Reactor Neutrino Experiment	191
10.8	Future Neutrino Oscillation Experiments	193
11	Neutrino and Cosmology	195
11.1	Introduction	195
11.2	Standard Cosmology	195
11.3	Early Universe; Neutrino Decoupling	205
11.4	Gerstein-Zeldovich Bound on Neutrino Masses	210
11.5	Big Bang Nucleosynthesis and the Number of Light Neutrinos	212
11.6	Large Scale Structure of the Universe and Neutrino Masses	216
11.7	Cosmic Microwave Background Radiation	220
11.8	Supernova Neutrinos	222
11.9	Baryogenesis Through Leptogenesis	225
12	Conclusion and Prospects	231
Appendices		
A	Diagonalization of a Hermitian Matrix. The Case 2×2	237
B	Diagonalization of a Complex Matrix	241
C	Diagonalization of a Complex Symmetrical Matrix	243
References		245
Index		253