
Contents

1	Historical Introduction	1
1-1	The First Period	1
1-2	The Second Period	3
1-3	The Third Period	6
1-4	The Fourth Period	10
	The Neutrino	10
	Left-Right Symmetry, Parity	11
	Violation of Parity Conservation in Weak Interactions	12
	Evidence for $V - A$ Interaction	15
1-5	The Fifth Period	19
2	Simple Theory of Beta Decay: Allowed Spectra	21
2-1	Fermi Formulation for Beta Decay	21
2-2	Beta-Spectrum Shape for Allowed Transitions	25
2-3	Effect of the Nuclear Coulomb Field	29
2-4	The Kurie Plot	35
2-5	The Rest Mass of the Neutrino	37
	The Relation between the Missing Energy and Momentum in Beta Decay	38
	The Detailed Shape of the Beta Spectrum in the Vicinity of Its Upper Limit	39
	Experimental Results	42
3	Classical Beta Decay	43
3-1	The Possible Forms of the Beta Interaction	43
	Invariance Requirements	44
	Selection Rules	45
	Relativistic Formulation	48
	Fierz Interference Terms	52
3-2	ft Values	52
3-3	Classification of Beta Transitions	58
	Superaligned Transitions	60
	The Isobaric Spin Selection Rules in Beta Decay	63
	The Mirror Transitions	68

Allowed Transitions	71
Forbidden Beta Transitions	75
Several Terms Contributing to Forbidden Transitions	75
First Forbidden Spectra	80
Beta Decay of Nonspherical Nuclei	81
Beta Spectrum of RaE	87
The Unique Forbidden Spectra	96
Half-Lives of the Unique Transitions	103
Second- and Higher-Order Forbidden Transitions with $\Delta I = n$ (Order of Forbiddenness)	105
3-4 The Electron-Neutrino Angular Correlation	106
Experimental Methods	107
Interpretation of Results	110
3-5 Beta-Gamma Angular Correlations	113
Angular-Correlation Functions	119
Allowed Transitions	121
First Forbidden Transitions	121
4 Parity Nonconservation in Beta Decay	131
4-1 Significance of Parity Nonconservation	131
Parity Conservation and Neutrino Helicity	131
Searching for Pseudoscalar Quantities	132
4-2 The Polarized Co ⁶⁰ Experiment	134
4-3 The Two-Component Theory of the Neutrino	138
Masslessness of the Neutrino	139
Helicity of the Neutrino	140
4-4 Invariance Under Time Reversal and Charge Conjugation	141
Time Reversal	141
Charge Conjugation	143
The <i>CPT</i> Theorem, <i>CP</i> Invariance	145
Number of Independent Coupling Constants	147
4-5 The Conservation of Leptonic and Muonic Numbers	148
4-6 Polarization of Electrons and Neutrinos in Beta Decay	149
General Formulation of the Electron Polarization	150
The Measurement of the Polarization of the β^\pm Particle	152
The Measurement of the Helicity of the Neutrino	173
4-7 Beta Decay of Polarized Neutrons	176
Angular Distributions of Leptons with Respect to Neutron Spin	177
Testing for Time-Reversal Symmetry	180

4-8	Beta-Gamma (Circularly Polarized) Correlation Experiment	183
	Experimental Methods	186
	Experimental Results	189
	Beta-Gamma (Circularly Polarized) Correlation in the Mirror Transitions $\text{Na}^{24} \xrightarrow{\beta^-} \text{Mg}^{24} \xrightarrow{\beta^+} \text{Al}^{24}$	192
5	The Closely Related Processes	195
5-1	Orbital Electron Capture	195
5-2	Double Beta Decay	200
5-3	Inverse Beta Process	207
	Antineutrino Capture by Protons	207
	Neutrino Capture	210
6	Other Weak Interactions with Leptonic Decays	212
6-1	Decay of the Mu Meson (Muon)	212
	The Michel Parameter ρ .	214
	Energy Dependence of the Asymmetry Parameter	219
	Polarization of Muons and Electrons	225
6-2	Muon Capture	229
	Muon Capture in Hydrogen and Helium ³	232
	Partial Muon Capture in C ¹² and O ¹⁶	237
6-3	Decay of the Pi Meson (Pion)	238
6-4	Strange-Particle Decays	244
7	Recent Developments	249
7-1	Theoretical Formulation of the Universal ($V - A$) Fermi Interaction	250
	Chirality Invariance	250
	The Two-Component Formulation of the Dirac Spinors	252
	Mass Reversal Invariance	254
	Connection with the $V - A$ Interaction	254
7-2	The Theory of Conserved Vector Current	256
	Analogy with Electromagnetism	258
	The Conserved Electromagnetic Current	259
	The Formulation of the Conserved Vector Current Theory (C.V.C.)	260
	Connection between Weak and Electromagnetic Form Factors	261

7-3	The Consequences of the C.V.C. Theory and the Significant Experimental Evidence	263
	Equality of g_V and g_μ	263
	The $B^{12} - C^{12} - N^{12}$ Experiment	268
	The $\pi^+ \rightarrow \pi^0 + e^+ + \nu$ Decay	273
	The Beta-Alpha Angular Correlation in the Li^8 and B^8 Beta Decays	275
	Other Weak Processes	279
	Nonrenormalizability of the Axial-Vector Interaction	283
	The Cabibbo Hypothesis	284
7-4	The Question of an Intermediate Boson in Weak Interactions and the Observation of Two Neutrinos in High-Energy Neutrino Reactions	288
	The Possible Existence of an Intermediate Boson	288
	The Two-Neutrino Question	291

APPENDICES

I	Nonrelativistic Transformations	301
I-1	Physical Concepts	301
	Rotation and Space Inversion	301
	Parity Invariance	303
	Time Reversal	304
I-2	Mathematical Formalism	304
	Infinitesimal Rotations	305
	Space Inversion	308
	Time Reversal	309
II	The Dirac Equation and Free-Particle Wave Functions	313
II-1	Background	313
II-2	Summary of the Dirac Equation and Dirac Matrices	315
	Dirac Matrices	315
	Hamiltonian Form of the Dirac Equation	316
	Covariant Form of the Dirac Equation	316
II-3	Free-Particle Solutions of the Dirac Equation	318
	Solutions in Terms of Two-Component Spinors	318
	Explicit Form	319
II-4	Theory of Positrons	321
	Negative-Energy States	321
	Dirac Hole Theory	322

	Feynman's Theory	322
II-5	Particles of Zero Rest Mass	323
III	Relativistic Transformations	326
III-1	Physical Concepts	326
III-2	Transformation Properties of Wave Functions and Bilinear Combinations under Proper Lorentz Transformations	328
	Wave Functions	328
	Adjoint Wave Functions	329
	Bilinear Combinations	330
III-3	Inversion Operations P , T , and C	331
	Space Inversion P	331
	Time Reversal T	332
	Charge Conjugation C	334
	The CPT Operation	336
IV	Simple Derivations for Allowed Transitions	338
IV-1	Vector Interaction	338
	$e-\bar{\nu}$ Angular Correlation for Vector Interaction	338
	Polarization of Neutrinos	340
	Polarization of the Emitted Electrons	341
	Transformation of Coupling Constants under Charge Conjugation	342
IV-2	Application of Trace Method and Projection Operators	343
	The Trace Method	343
	Projection Operators	345
	$e-\bar{\nu}$ Angular Correlation for Vector Interaction	347
IV-3	Scalar Interactions and Fierz Interference	348
	Lepton Polarization	348
	$e-\bar{\nu}$ Correlation	348
	Mixed S and V Interaction	349
IV-4	Gamow-Teller Interaction	349
	Lepton Polarizations for Axial-Vector Interaction	349
	$e-\bar{\nu}$ Correlation for Axial-Vector Interaction	349
	General Combination of Interaction	351
V	Calculation of Gamow-Teller Matrix Element According to Single-Particle Model	352

VI	Beta Decay of Polarized Nuclei	354
VI-1	Lepton Wave Functions	354
VI-2	$0 \rightarrow 0$ Transition	356
VI-3	$I \rightarrow I - 1$ Transition	356
VI-4	Beta Decay of the Neutron ($\frac{1}{2} \rightarrow \frac{1}{2}$)	359
VII	Properties of Muon Decay	362
VII-1	Interaction Matrix Element	362
VII-2	Transition Probability	365
VII-3	Electron Energy Spectrum	367
VII-4	Electron Angular Distribution	367
VII-5	Total Decay Rate	368
	References	369
	Index	389