Contents

Notation Preface			xiii
			xv
Ι	NON	RELATIVISTIC QUANTUM MECHANICS	1
1	Basi	c Concepts of Quantum Mechanics	3
	1.1	Probability interpretation of the wave function	3
	1.2	States of definite energy and states of definite momentum	4
	1.3	Observables and operators	5
	1.4	Examples of operators	5
	1.5	The time-dependent Schrödinger equation	6
	1.6	Stationary states and the time-independent Schrödinger equation	7
	1.7	Eigenvalue spectra and the results of measurements	8
	1.8	Hermitian operators	8
	1.9	Expectation values of observables	10
	1.10	Commuting observables and simultaneous observability	10
	1.11	Noncommuting observables and the uncertainty principle	11
	1.12	Time dependence of expectation values	12
	1.13	The probability-current density	12
	1.14	The general form of wave functions	12
	1.15	Angular momentum	15
	1.16	Particle in a three-dimensional spherically symmetric potential	17
	1.17	The hydrogen-like atom	18
2	Representation Theory		23
	2.1	Dirac representation of quantum mechanical states	23
	2.2	Completeness and closure	27
	2.3	Changes of representation	28
	2.4	Representation of operators	29
	2.5	Hermitian operators	31
	2.6	Products of operators	31
	2.7	Formal theory of angular momentum	32
3	Approximation Methods		39
	3.1	Time-independent perturbation theory for nondegenerate states	39
	3.2	Time-independent perturbation theory for degenerate states	44
	3.3	The variational method	50
	3.4	Time-dependent perturbation theory	54

P. A. Keys & address (1981).

4	Scatt	ering Theory	63	
	4.1	Evolution operators and Møller operators	63	
	4.2	The scattering operator and scattering matrix	66	
	4.3	The Green operator and T operator	70	
	4.4	The stationary scattering states	76	
	4.5	The optical theorem	83	
	4.6	The Born series and Born approximation	85	
	4.7	Spherically symmetric potentials and the method of partial waves	87	
	4.8	The partial-wave scattering states	92	
II	THE	RMAL AND STATISTICAL PHYSICS	97	
5	Fund	amentals of Thermodynamics	99	
	5.1	The nature of thermodynamics	99	
	5.2	Walls and constraints	99	
	5.3	Energy	100	
	5.4	Microstates	100	
	5.5	Thermodynamic observables and thermal fluctuations	100	
	5.6	Thermodynamic degrees of freedom	102	
	5.7	Thermal contact and thermal equilibrium	103	
	5.8	The zeroth law of thermodynamics	104	
	5.9	Temperature	104	
	5.10	The International Practical Temperature Scale	107	
	5.11	Equations of state	107	
	5.12	Isotherms	108	
	5.13	Processes	109	
		5.13.1 Nondissipative work	109	
		5.13.2 Dissipative work	111	
		5.13.3 Heat flow	112	
	5.14	Internal energy and heat	112	
		5.14.1 Joule's experiments and internal energy	112	
		5.14.2 Heat	113	
	5.15	Partial derivatives	115	
	5.16	Heat capacity and specific heat	116	
		5.16.1 Constant-volume heat capacity	117	
		5.16.2 Constant-pressure heat capacity	117	
	5.17	Applications of the first law to ideal gases	118	
	5.18	Difference of constant-pressure and constant-volume heat capacities	119	
	5.19	Nondissipative-compression/expansion adiabat of an ideal gas	120	
6	Quantum States and Temperature125			
	6.1	Quantum states	125	
	6.2	Effects of interactions	128	
	6.3	Statistical meaning of temperature	130	
	6.4	The Boltzmann distribution	134	

Contents	
----------	--

7	Micr	ostate Probabilities and Entropy	141
	7.1	Definition of general entropy	141
	7.2	Law of increase of entropy	142
	7.3	Equilibrium entropy S	144
	7.4	Additivity of the entropy	146
	7.5	Statistical-mechanical description of the three types of energy transfer	147
8	The]	Ideal Monatomic Gas	151
	8.1	Quantum states of a particle in a three-dimensional box	151
	8.2	The velocity-component distribution and internal energy	153
	8.3	The speed distribution	156
	8.4	The equation of state	158
	8.5	Mean free path and thermal conductivity	160
9	Appl	ications of Classical Thermodynamics	163
	9.1	Entropy statement of the second law of thermodynamics	163
	9.2	Temperature statement of the second law of thermodynamics	164
	9.3	Summary of the basic relations	166
	9.4	Heat engines and the heat-engine statement of the second law of thermodynamics	167
	9.5	Refrigerators and heat pumps	169
	9.6	Example of a Carnot cycle	170
	9.7	The third law of thermodynamics	172
	9.8	Entropy-change calculations	174
10	Ther	modynamic Potentials and Derivatives	177
	10.1	Thermodynamic potentials	177
	10.2	The Maxwell relations	179
	10.3	Calculation of thermodynamic derivatives	180
11	Matt	er Transfer and Phase Diagrams	183
	11.1	The chemical potential	183
	11.2	Direction of matter flow	184
	11.3	Isotherms and phase diagrams	184
	11.4	The Euler relation	187
	11.5	The Gibbs–Duhem relation	188
	11.6	Slopes of coexistence lines in phase diagrams	188
12	Fermi-Dirac and Bose-Einstein Statistics		191
	12.1	The Gibbs grand canonical probability distribution	191
	12.2	Systems of noninteracting particles	193
	12.3	Indistinguishability of identical particles	194
	12.4	The Fermi–Dirac and Bose–Einstein distributions	195
	12.5	The entropies of noninteracting fermions and bosons	197

ix

199

III MANY-BODY THEORY

13	Quar	tum Mechanics and Low-Temperature Thermodynamics of Many-Particle Systems	201
	13.1	Introduction	201
	13.2	Systems of noninteracting particles	201
		13.2.1 Bose systems	202
		13.2.2 Fermi systems	204
	13.3	Systems of interacting particles	209
	13.4	Systems of interacting fermions (the Fermi liquid)	211
	13.5	The Landau theory of the normal Fermi liquid	214
	13.6	Collective excitations of a Fermi liquid	221
		13.6.1 Zero sound in a neutral Fermi gas with repulsive interactions	221
		13.6.2 Plasma oscillations in a charged Fermi liquid	221
	13.7	Phonons and other excitations	223
		13.7.1 Phonons in crystals	223
		13.7.2 Phonons in liquid helium-4	232
		13.7.3 Magnons in solids	233
		13.7.4 Polarons and excitons	233
14	Second Quantization		
	14.1	The occupation-number representation	235
	14.2	Particle-field operators	246
15	Gas o	f Interacting Electrons	251
	15.1	Hamiltonian of an electron gas	251
16	Supe	rconductivity	261
	16.1	Superconductors	261
	16.2	The theory of Bardeen, Cooper and Schrieffer	262
		16.2.1 Cooper pairs	267
		16.2.2 Calculation of the ground-state energy	269
		16.2.3 First excited states	277
		16.2.4 Thermodynamics of superconductors	280
IV	CLAS	SICAL FIELD THEORY AND RELATIVITY	287
17	The (Classical Theory of Fields	289
	17.1	Mathematical preliminaries	289
		17.1.1 Behavior of fields under coordinate transformations	289
		17.1.2 Properties of the rotation matrix	293
		17.1.3 Proof that a "dot product" is a scalar	295
		17.1.4 A lemma on determinants	297
		17.1.5 Proof that the "cross product" of two vectors is a "pseudovector"	298
		17.1.6 Useful index relations	299
		17.1.7 Use of index relations to prove vector identities	300
		17.1.8 General definition of tensors of arbitrary rank	301

	17.2	Introduction to Einsteinian relativity	302
		17.2.1 Intervals	302
		17.2.2 Timelike and spacelike intervals	304
		17.2.3 The light cone	304
		17.2.4 Variational principle for free motion	305
		17.2.5 The Lorentz transformation	305
		17.2.6 Length contraction and time dilation	307
		17.2.7 Transformation of velocities	308
		17.2.8 Four-tensors	308
		17.2.9 Integration in four-space	314
		17.2.10 Integral theorems	316
		17.2.11 Four-velocity and four-acceleration	317
	17.3	Principle of least action	318
		17.3.1 Free particle	318
		17.3.2 Three-space formulation	318
		17.3.3 Momentum and energy of a free particle	319
		17.3.4 Four-space formulation	321
	17.4	Motion of a particle in a given electromagnetic field	325
		17.4.1 Equations of motion of a charge in an electromagnetic field	326
		17.4.2 Gauge invariance	328
		17.4.3 Four-space derivation of the equations of motion	329
		17.4.4 Lorentz transformation of the electromagnetic field	332
		17.4.5 Lorentz invariants constructed from the electromagnetic field	1 334
		17.4.6 The first pair of Maxwell equations	335
	17.5	Dynamics of the electromagnetic field	337
		17.5.1 The four-current and the second pair of Maxwell equations	338
	. – .	17.5.2 Energy density and energy flux density of the electromagnet	ic field 342
	17.6	The energy-momentum tensor	345
		17.6.1 Energy–momentum tensor of the electromagnetic field	350
		17.6.2 Energy-momentum tensor of particles	353
		17.6.3 Energy–momentum tensor of continuous media	300
18	Gener	ral Relativity	361
	18.1	Introduction	361
	18.2	Space-time metrics	362
	18.3	Curvilinear coordinates	364
	18.4	Products of tensors	365
	18.5	Contraction of tensors	366
	18.6	The unit tensor	366
	18.7	Line element	366
	18.8	Tensor inverses	366
	18.9	Raising and lowering of indices	367
	18.10	Integration in curved space-time	367
	18.11	Covariant differentiation	369
	18.12	Parallel transport of vectors	370
	18.13	Curvature	374
	18.14	The Einstein held equations	376

,

	18 15	Equation of motion of a particle in a gravitational field	381
	18.15	Newton's law of gravity	383
	10110		
V	RELAT	IVISTIC QUANTUM MECHANICS AND GAUGE THEORIES	385
19	Relati	vistic Quantum Mechanics	387
	19.1	The Dirac equation	387
	19.2	Lorentz and rotational covariance of the Dirac equation	391
	19.3	The current four-vector	398
	19.4	Compact form of the Dirac equation	400
	19.5	Dirac wave function of a free particle	401
	19.6	Motion of an electron in an electromagnetic field	405
	19.7	Behavior of spinors under spatial inversion	408
	19.8	Unitarity properties of the spinor-transformation matrices	409
	19.9	Proof that the four-current is a four-vector	411
	19.10	Interpretation of the negative-energy states	412
	19.11	Charge conjugation	413
	19.12	Time reversal	414
	19.13	PCT symmetry	417
	19.14	Models of the weak interaction	422
20	Gauge	Theories of Quark and Lepton Interactions	427
	20.1	Global phase invariance	427
	20.2	Local phase invariance?	427
	20.3	Other global phase invariances	429
	20.4	SU(2) local phase invariance (a non-abelian gauge theory)	433
	20.5	The "gauging" of color SU(3) (quantum chromodynamics)	436
	20.6	The weak interaction	436
	20.7	The Higgs mechanism	439
	20.8	The fermion masses	448
Ap	pendices		451
	A.1	Proof that the scattering states $ \phi+\rangle \equiv \Omega_+ \phi\rangle$ exist for all states $ \phi\rangle$ in the Hilbert	
		space \mathcal{H}	451
	A.2	The scattering matrix in momentum space	452
	A.3	Calculation of the free Green function $\langle \boldsymbol{r} G^0(z) \boldsymbol{r}' \rangle$	454
Suj	oplemen	tary Reading	457

459

Contents

xii

Index