

Pergamon Press Ltd., Headington Hill Hall, Oxford
Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford,
New York 10523
Pergamon of Canada Ltd., 207 Queen's Quay West, Toronto 1
Pergamon Press (Aust.) Pty. Ltd., 19a Boundary Street,
Rushcutters Bay, N.S.W. 2011, Australia

Copyright © 1974 Pergamon Press Ltd.

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of Pergamon Press Ltd.

First edition 1974

Library of Congress Cataloging in Publication Data

Landau, Lev Davidovich, 1908–1968.

A shorter course of theoretical physics.

Translation of *Kratkii kurs teoreticheskoi fiziki*.

CONTENTS: v. 1. Mechanics and electrodynamics.

--v. 2. Quantum mechanics.

1. Physics. 2. Mechanics. 3. Quantum theory.

I. Lifshits, Evgenii Mikhailovich, joint author.

II. Title.

QC21.2.L3513 530 74-167927

ISBN 0-08-016739-X (v. 1)

ISBN 0-08-017801-4 (v. 2)

Translated from *Kratkii kurs teoreticheskoi fiziki, Kniga 2: Kvantovaya Mekhanika*

Izdatel'stvo "Nauka", Moscow, 1972

Printed in Hungary

CONTENTS

PREFACE	ix
PUBLISHER'S NOTE	x
NOTATION	xi
Part I. Non-relativistic theory	
1. THE BASIC CONCEPTS OF QUANTUM MECHANICS	
§1. The uncertainty principle	3
§2. The principle of superposition	9
§3. Operators	12
§4. Addition and multiplication of operators	18
§5. The continuous spectrum	21
§6. The passage to the limiting case of classical mechanics	24
§7. The density matrix	26
2. CONSERVATION LAWS IN QUANTUM MECHANICS	
§8. The Hamiltonian operator	28
§9. The differentiation of operators with respect to time	29
§10. Stationary states	31
§11. Matrices of physical quantities	34
§12. Momentum	38
§13. Uncertainty relations	42
§14. Angular momentum	44
§15. Eigenvalues of the angular momentum	49
§16. Eigenfunctions of the angular momentum	53
§17. Addition of angular momenta	55
§18. Angular momentum selection rules	58
§19. Parity of a state	62

3. SCHRÖDINGER'S EQUATION	
§20. Schrödinger's equation	67
§21. The current density	69
§22. General properties of solutions of Schrödinger's equation	72
§23. Time reversal	76
§24. The potential well	77
§25. The linear oscillator	81
§26. The quasi-classical wave function	86
§27. Bohr and Sommerfeld's quantisation rule	89
§28. The transmission coefficient	95
§29. Motion in a centrally symmetric field	101
§30. Spherical waves	105
§31. Motion in a Coulomb field	110
4. PERTURBATION THEORY	
§32. Perturbations independent of time	116
§33. The secular equation	121
§34. Perturbations depending on time	123
§35. Transitions in the continuous spectrum	126
§36. Intermediate states	129
§37. The uncertainty relation for energy	130
§38. Quasi-stationary states	133
5. SPIN	
§39. Spin	136
§40. The spin operator	139
§41. Spinors	141
§42. Polarisation of electrons	146
§43. A particle in a magnetic field	149
§44. Motion in a uniform magnetic field	151
6. IDENTITY OF PARTICLES	
§45. The principle of indistinguishability of similar particles	154
§46. Exchange interaction	158
§47. Second quantisation. The case of Bose statistics	161
§48. Second quantisation. The case of Fermi statistics	167
7. THE ATOM	
§49. Atomic energy levels	169
§50. Electron states in the atom	171

§51. Fine structure of atomic levels	174
§52. The Mendeleev periodic system	178
§53. X-ray terms	184
§54. An atom in an electric field	187
§55. An atom in a magnetic field	192
8. THE DIATOMIC MOLECULE	
§56. Electron terms in the diatomic molecule	197
§57. The intersection of electron terms	199
§58. Valency	202
§59. Vibrational and rotational structures of terms in the diatomic molecule	209
§60. Parahydrogen and orthohydrogen	213
§61. Van der Waals forces	215
9. ELASTIC COLLISIONS	
§62. The scattering amplitude	218
§63. The condition for quasi-classical scattering	221
§64. Discrete energy levels as poles of the scattering amplitude	223
§65. The scattering of slow particles	225
§66. Resonance scattering at low energies	228
§67. Born's formula	230
§68. Rutherford's formula	237
§69. Collisions of like particles	239
§70. Elastic collisions between fast electrons and atoms	241
10. INELASTIC COLLISIONS	
§71. The principle of detailed balancing	246
§72. Elastic scattering in the presence of inelastic processes	250
§73. Inelastic scattering of slow particles	252
§74. Inelastic collisions between fast particles and atoms	253
Part II. Relativistic theory	
11. PHOTONS	
§75. The uncertainty principle in the relativistic case	259
§76. Quantisation of the free electromagnetic field	264
§77. Photons	268
§78. The angular momentum and parity of the photon	271

12. DIRAC'S EQUATION

§79. The Klein–Fock equation	275
§80. Four-dimensional spinors	277
§81. Inversion of spinors	281
§82. Dirac's equation	283
§83. Dirac matrices	286
§84. The current density in Dirac's equation	289

13. PARTICLES AND ANTIPARTICLES

§85. \mathcal{P} -operators	293
§86. Particles and antiparticles	296
§87. The relation between the spin and the statistics	300
§88. Strictly neutral particles	301
§89. Internal parity of particles	304
§90. The <i>CPT</i> theorem	307
§91. Neutrinos	311

14. ELECTRONS IN AN EXTERNAL FIELD

§92. Dirac's equation for an electron in an external field	314
§93. Magnetic moment of the electron	315
§94. Spin-orbit interaction	319

15. RADIATION

§95. The electromagnetic interaction operator	322
§96. Spontaneous and stimulated emission	326
§97. Dipole radiation	329
§98. Multipole radiation	331
§99. Radiation from atoms	333
§100. The infra-red catastrophe	335
§101. Scattering of radiation	338
§102. Natural width of spectral lines	343

16. FEYNMAN DIAGRAMS

§103. The scattering matrix	345
§104. Feynman diagrams	350
§105. Radiative corrections	358
§106. Radiative shift of atomic levels	360

INDEX	363
-------	-----

PREFACE

THIS book continues with the plan originated by Lev Davidovich Landau and described in the Preface to Volume 1: to present the minimum of material in theoretical physics that should be familiar to every present-day physicist, working in no matter what branch of physics.

Part I, dealing with non-relativistic quantum theory, follows our *Quantum Mechanics* (Volume 3 of the *Course of Theoretical Physics*). This has been abridged by dropping completely some sections that are of interest only to specialists, as well as numerous details of technique that are intended for those whose profession lies in theoretical physics. This considerable abridgement has naturally meant rewriting a fairly large part of the book. I have nevertheless tried to keep unchanged the manner and style of the exposition, and in no place to allow a simplification by popularising; the only simplification is by the omission of detail. In Part I, the words "it can be shown" hardly occur: the results given are accompanied by their derivations.

This is, however, less true of Part II. The treatment here is based on the *Relativistic Quantum Theory* by Berestetskii, Pitaevskii and myself (Volume 4 of the *Course*), but only the fundamentals of quantum electrodynamics are presented. Here again I have sought to proceed in such a way as to show as clearly as possible the physical hypotheses and logical structure of the theory; but many applications of the theory are mentioned only by way of their results, on account of the frequent complexity of the calculations needed to solve specific problems in this field. In the choice of materials for Part II I have also been guided to some extent by the content of Landau's lectures