## Contents

	Preface	xi
1	INTRODUCTION. HISTORY AND MODERN STUDIES OF	
	LIGHT PRESSURE	1
	1.1 Early Investigations of Light Pressure	2
	1.2 Recent Ideas and Experimental Investigations of Laser	
	Radiation Pressure	5
	1.2.1 Light pressure on macroscopic particles	5
	1.2.2 Resonant light pressure on atomic particles	6
	1.2.3 Radiative atomic cooling	7
	1.2.4 Atomic trapping in light fields	8
	1.3 Studies in the Theory of Atomic Motion in Resonant Light	
	Fields	10
	1.4 Topics of the Monograph	11
	PAKI I	
	FOUNDATIONS OF THE THEORY OF RESONANT LIGHT	
	PRESSURE	13
r	INELLIENCE OF PHOTON PECOLI, ON ATOMIC	
2	MOMENTUM	15
	2.1. Recoil Effect Due to Photon Absorption or Emission	15
	2.1.1. Atom-light field momentum exchange	15
	2.1.1 Atom-ngnt field momentum exchange	17
	2.1.2 Energy exchange	17
	2.1.5 Numerical example: Solitum atom 2.2 Atomic Momentum Eluctuations and Drift Due to Multiple	1/
	2.2 Atomic Momentum Practications and Drift Duc to Multiple Photon Absorption and Emission	18
	2.2 Light Dressure Force on an Atom	21
	2.3 Light Flossife Folce on all Atom	21 21
	2.3.1 Recessary conditions	21
	2.5.2 Shiphile definition	23

v	

26

27

2.4 Atomic Momentum Diffusion

2.4.1 Fluctuational processes

vi	Contents
VI	Contents

	2.4.2 Two types of momentum diffusion	29
	2.5 Scattering of Resonance Radiation by a Moving Atom	31
3	ADIATION FORCE IN A RESONANT LIGHT FIELD	34
5	3.1. Quantum-mechanical Analogue of the Radiation Force	34
	3.1.1 The Ebrenfest theorem	34
	3.1.2 The field of plane wayes. General relations	38
	3.2 Radiation Force in the Field of Plane Wayes	41
	3.2.1 Transition to classical atomic motion	42
	3.2.2 General formulae for the radiation force	43
	3.2.3 Basic restrictions	43
	3.2.4 Calculational procedure for density matrix	
	elements	46
	3.3 Radiation Force in a Nonuniform Light Field	46
	3.4 Radiation Force for a Two-level Atom	49
	3.5 Radiation Force for a Multi-level Atom	51
4	ADIATION FORCE ON A TWO-LEVEL ATOM IN A	
	IONOCHROMATIC LIGHT FIELD	55
	4.1 Plane Travelling Wave	55
	4.2 Counter-propagating Plane Waves	57
	4.2.1 Density matrix equations	58
	4.2.2 Solution of the recursion equations	59
	4.2.3 Multi-resonance structure of the force	61
	4.2.4 Rate equation approximation	69
	4.3 Travelling Gaussian Wave	72
	4.4 Counter-propagating Gaussian Waves	73
	4.5 Crossed Plane Waves	76
5	TOMIC ENSEMBLE EVOLUTION IN RESONANT LIGHT	
	TIELDS	80
	5.1 Atomic Velocity Monochromatization in a Travelling	
	Wave	80
	5.1.1 Velocity distribution deformation due to the light	
	pressure force	81
	5.1.2 Velocity distribution broadening due to diffusion	84
	5.2 Atomic Focusing (Defocusing) in a Light Beam	87
	5.2.1 Influence of the gradient force	87
	5.2.2 Atomic density evolution	89
	5.5 Kadiative Atomic Cooling in Counter-propagating Waves	92
	5.5.1 velocity distribution narrowing	93
	5.5.2 Steady-state distribution 5.4 Padiative Cooling of Bound Atomic Long	94
	5.4 Low frequency ionic oscillations	9/
	5.4.2 High-frequency oscillations	90 00
	J.4.2 High-frequency Oscillations	77

	<i>Contents</i> v	ii
PART II		
ATOMIC MOTION IN RESONANT LIGHT FIELDS	10	13
6 MICROSCOPIC AND KINETIC DESCRIPTION OF AT	ſOMIC	
MOTION	10	)5
6.1 Microscopic Equations	10	)6
6.1.1 Equations for the Wigner atomic density mat	trix 10	)6
6.1.2 Two types of density matrix evolution	10	)8
6.2 Kinetic Equation for Classical Atomic Motion	11	.3
6.2.1 The Bogolyubov procedure	11	.3
6.2.2 Zero-order approximation. Phase density		
conservation equation	11	.6
6.2.3 First-order approximation. The Liouville equ 6.2.4 Second- and higher-order approximations. T	ation 11	.7
Fokker-Planck equation	11	.8
6.3 Kinetic Equation for the Case of a Spatially Nonunit	form	
Field	12	20
7 ATOMIC MOTION IN A TRAVELLING LIGHT WAVE	E 12	22
7.1 Kinetic Equation for Atoms in a Plane Wave	12	22
7.1.1 Zero-, first- and second-order approximation	1s 12	23
7.1.2 Third-order approximation	12	26
7.2 Kinetic Equation for Atoms in a Laser Beam	12	27
7.2.1 Gaussian light beam	12	27
7.2.2 Light beam with finite frequency spectrum		
bandwidth	13	31
7.3 Asymptotic Velocity Distribution	13	34
7.3.1 Velocity distribution shape	13	34
7.3.2 Third-order corrections	13	38
7.4 Atomic Beam Deceleration and Velocity		
Monochromatization	13	39
7.4.1 Parameters of the deceleration process	13	39
7.4.2 Experimental investigations	12	42
8 ATOMIC MOTION IN COUNTER-PROPAGATING		
WAVES	14	46
8.1 Kinetic Equation for Atoms in a Plane Standing Wa	ve 14	46
8.1.1 The Liouville equation	14	47
8.1.2 Recursion equations	14	49
8.1.3 The Fokker-Planck equation	15	51
8.1.4 Rate equation approximation	14	54
8.2 Diffusive Atomic Scattering by a Standing Wave	1:	>>
0.5 Asymptotic velocity Distribution in a Plane Standin Wave	یع ۱	58
Ware are	1.	50

viii	Contents

8.4 Symmetric Light Fields	161
8.4.1 Axisymmetric field	161
8.4.2 Centrosymmetric field	163
8.4.3 Experimental investigations	166
8.5 Atomic Beam Collimation in Axisymmetric Fields	166
8.5.1 Basic idea and quantitative estimations	167
8.5.2 Experimental investigations	170
8.6 Compression of Atomic Beams by Radiation Pressure	170
8.7 Atomic Localization in a Standing Light Wave Field	178
9 THREE-LEVEL ATOMS IN THE FIELD OF TWO-	
FREQUENCY RADIATION	182
9.1 Population Trapping in a Three-level Atom	182
9.2 Equations of Motion for $\Lambda$ -atom	184
9.2.1 Microscopic equations	184
9.2.2 Kinetic equation	185
9.3 Radiation Force and Diffusion Tensor for $\Lambda$ -atom	189
10 COHERENT ATOMIC MOTION IN A LIGHT FIELD	193
10.1 Atomic Diffraction on a Travelling Wave	193
10.1.1 Probability amplitudes and the wave function	195
10.1.2 Wave packet evolution	197
10.2 Stationary Atomic States in a Standing Wave	198
10.2.1 Equations of motion	198
10.2.2 Eigenstates of translational atomic motion	199
10.2.3 Energy spectrum and dispersion laws	201
10.2.4 Exact resonance	203
10.3 Atomic Diffraction on a Standing Wave	205
10.3.1 Analytical solution for probability amplitudes	206
10.3.2 Momentum distribution density	207
11 LOCALIZED ATOMIC IONS IN THE FIELD OF LASER	
RADIATION	211
11.1 Ion Localization	212
11.1.1 The Penning trap	212
11.1.2 Radio-frequency quadrupole trap	213
11.2 Equations of Motion for Laser Cooled Ions	214
11.2.1 Microscopic equations	215
11.2.2 Kinetic equation	216
11.3 Theory of Ionic Cooling by Laser Radiation Pressure	218
11.3.1 Initial stage of cooling	219
11.3.2 Approach to the stationary state	220
11.4 Experimental Investigations	222
11.4.1 Cooling of MgII ions	222
11.4.2 Cooling of Ball ions	223

Contents	ix
12 SOME APPLICATIONS OF COLD ATOMS AND IONS	226
12.1 Microwave Frequency Standards	227
12.1.1 Use of cold atomic beams	227
12.1.2 Frequency standards based on cold localized ions	229
12.2 Accumulation and Storage of Cold Atoms in Magnetic	
Traps	230
12.2.1 Storage of atoms in a toroidal magnetic trap	230
12.2.2 Injection of atoms into a trap	234
12.3 Optical Frequency Standards	234
12.3.1 Frequency standards based on cold localized	
atoms	235
12.3.2 Frequency standards based on cold localized ions	237
12.4 Experiments with Single Atoms	237
12.5 Conclusion	239
References	241
Subject Index	247