

LASER FUNDAMENTALS

SECOND EDITION

WILLIAM T. SILFVAST

School of Optics / CREOL
University of Central Florida



PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa
<http://www.cambridge.org>

First published 1996
Reprinted 1999, 2000, 2003

First edition © Cambridge University Press
Second edition © William T. Silfvast 2004

This book is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2004

Printed in the United States of America

Typeface Times 10.5/13.5 and Avenir *System* AMS-TeX [FH]

A catalog record for this book is available from the British Library.

Library of Congress Cataloging in Publication data

Silfvast, William Thomas, 1937–

Laser fundamentals / William T. Silfvast. – 2nd ed.

p. cm.

Includes bibliographical references and index.

ISBN 0-521-83345-0

I. Lasers. I. Title.

TA1675.S52 2004

621.36'6 – dc21

2003055352

ISBN 0 521 83345 0 hardback

Contents

<i>Preface to the Second Edition</i>	page xix
<i>Preface to the First Edition</i>	xxi
<i>Acknowledgments</i>	xxiii
1 INTRODUCTION	1
OVERVIEW	1
Introduction	1
Definition of the Laser	1
Simplicity of a Laser	2
Unique Properties of a Laser	2
The Laser Spectrum and Wavelengths	3
A Brief History of the Laser	4
Overview of the Book	5
SECTION 1. FUNDAMENTAL WAVE PROPERTIES OF LIGHT	
2 WAVE NATURE OF LIGHT – THE INTERACTION OF LIGHT WITH MATERIALS	9
OVERVIEW	9
2.1 Maxwell’s Equations	9
2.2 Maxwell’s Wave Equations	12
Maxwell’s Wave Equations for a Vacuum	12
Solution of the General Wave Equation – Equivalence of Light and Electromagnetic Radiation	13
Wave Velocity – Phase and Group Velocities	17
Generalized Solution of the Wave Equation	20
Transverse Electromagnetic Waves and Polarized Light	21
Flow of Electromagnetic Energy	21
Radiation from a Point Source (Electric Dipole Radiation)	22
2.3 Interaction of Electromagnetic Radiation (Light) with Matter	23
Speed of Light in a Medium	23
Maxwell’s Equations in a Medium	24
Application of Maxwell’s Equations to Dielectric Materials – Laser Gain Media	25
Complex Index of Refraction – Optical Constants	28
Absorption and Dispersion	29

Estimating Particle Densities of Materials for Use in the Dispersion Equations	34
2.4 Coherence	36
Temporal Coherence	37
Spatial Coherence	38
REFERENCES	39
PROBLEMS	39
SECTION 2. FUNDAMENTAL QUANTUM PROPERTIES OF LIGHT	
3 PARTICLE NATURE OF LIGHT – DISCRETE ENERGY LEVELS	45
OVERVIEW	45
3.1 Bohr Theory of the Hydrogen Atom	45
Historical Development of the Concept of Discrete Energy Levels	45
Energy Levels of the Hydrogen Atom	46
Frequency and Wavelength of Emission Lines	49
Ionization Energies and Energy Levels of Ions	51
Photons	54
3.2 Quantum Theory of Atomic Energy Levels	54
Wave Nature of Particles	54
Heisenberg Uncertainty Principle	56
Wave Theory	56
Wave Functions	57
Quantum States	57
The Schrödinger Wave Equation	59
Energy and Wave Function for the Ground State of the Hydrogen Atom	61
Excited States of Hydrogen	63
Allowed Quantum Numbers for Hydrogen Atom Wave Functions	66
3.3 Angular Momentum of Atoms	67
Orbital Angular Momentum	67
Spin Angular Momentum	68
Total Angular Momentum	69
3.4 Energy Levels Associated with One-Electron Atoms	70
Fine Structure of Spectral Lines	70
Pauli Exclusion Principle	72
3.5 Periodic Table of the Elements	72
Quantum Conditions Associated with Multiple Electrons Attached to Nuclei	72
Shorthand Notation for Electronic Configurations of Atoms Having More Than One Electron	76
3.6 Energy Levels of Multi-Electron Atoms	77
Energy-Level Designation for Multi-Electron States	77
Russell–Saunders or <i>LS</i> Coupling – Notation for Energy Levels	78
Energy Levels Associated with Two Electrons in Unfilled Shells	79
Rules for Obtaining <i>S</i> , <i>L</i> , and <i>J</i> for <i>LS</i> Coupling	82
Degeneracy and Statistical Weights	84
<i>j-j</i> Coupling	85
Isoelectronic Scaling	85

REFERENCES	86
PROBLEMS	86
4 RADIATIVE TRANSITIONS AND EMISSION LINEWIDTH	89
OVERVIEW	89
4.1 Decay of Excited States	90
Radiative Decay of Excited States of Isolated Atoms – Spontaneous Emission	90
Spontaneous Emission Decay Rate – Radiative Transition Probability	94
Lifetime of a Radiating Electron – The Electron as a Classical Radiating Harmonic Oscillator	95
Nonradiative Decay of the Excited States – Collisional Decay	98
4.2 Emission Broadening and Linewidth Due to Radiative Decay	101
Classical Emission Linewidth of a Radiating Electron	101
Natural Emission Linewidth as Deduced by Quantum Mechanics (Minimum Linewidth)	103
4.3 Additional Emission-Broadening Processes	105
Broadening Due to Nonradiative (Collisional) Decay	106
Broadening Due to Dephasing Collisions	107
Amorphous Crystal Broadening	109
Doppler Broadening in Gases	109
Voigt Lineshape Profile	114
Broadening in Gases Due to Isotope Shifts	115
Comparison of Various Types of Emission Broadening	118
4.4 Quantum Mechanical Description of Radiating Atoms	121
Electric Dipole Radiation	122
Electric Dipole Matrix Element	123
Electric Dipole Transition Probability	124
Oscillator Strength	124
Selection Rules for Electric Dipole Transitions Involving Atoms with a Single Electron in an Unfilled Subshell	125
Selection Rules for Radiative Transitions Involving Atoms with More Than One Electron in an Unfilled Subshell	129
Parity Selection Rule	130
Inefficient Radiative Transitions – Electric Quadrupole and Other Higher-Order Transitions	131
REFERENCES	131
PROBLEMS	131
5 ENERGY LEVELS AND RADIATIVE PROPERTIES OF MOLECULES, LIQUIDS, AND SOLIDS	135
OVERVIEW	135
5.1 Molecular Energy Levels and Spectra	135
Energy Levels of Molecules	135
Classification of Simple Molecules	138
Rotational Energy Levels of Linear Molecules	139
Rotational Energy Levels of Symmetric-Top Molecules	141
Selection Rules for Rotational Transitions	141

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.