

---

Advances in ATOMIC,  
MOLECULAR, and  
OPTICAL PHYSICS

---

Serial Edited by  
Ennio Arimondo  
Louis F. DiMauro  
Susanne F. Yelin

Volume 67



# CONTENTS

<i>Contributors</i>	<i>ix</i>
<i>Preface</i>	<i>xi</i>
<b>1. Application of Excitation Cross-Section Measurements to Optical Plasma Diagnostics</b>	<b>1</b>
John B. Boffard, Chun C. Lin, and Amy E. Wendt	
1. Introduction	2
2. Background: Atomic Processes and Electronic Structure of Rare Gases	9
3. Background: Plasma Diagnostics	25
4. Sample Application: Measuring the Electron Temperature Using Ar( $2p_x \rightarrow 1s_y$ ) Emission Lines	44
5. Diagnostics With Other Sets of Emission Lines	53
6. Concluding Remarks	70
Acknowledgments	72
Glossary	72
References	72
<b>2. Quantum Optical Memory Protocols in Atomic Ensembles</b>	<b>77</b>
Thierry Chanelière, Gabriel Hétet, and Nicolas Sangouard	
1. Introduction	78
2. Photon Echo Memories	79
3. Slow-Light Memories	97
4. Certifying the Quantum Nature of Light Storage Protocols	120
5. Conclusion	140
Appendix A. Strong Pulse Propagation	141
Appendix B. Photon-Counting Measurements	142
Acknowledgments	143
References	144
<b>3. Quantum Control in Multilevel Systems</b>	<b>151</b>
Ignacio R. Sola, Bo Y. Chang, Svetlana A. Malinovskaya, and Vladimir S. Malinovsky	
1. Introduction	152
2. Rabi Oscillations in a Two-Level System	157

3. Adiabatic Control in a Single Qubit	159
4. STIRAP in Multilevel Quantum Systems	174
5. Phase-Controlled Two-Qubit Quantum Gates	179
6. Molecular Wave Packets: Electronic Transitions in Molecules	187
7. Strong Field Solutions: Dynamics in Light-Induced Potentials	196
8. Toward Automation: Quantum Optimal Control Theory	221
9. Summary and Outlook	238
Acknowledgments	240
References	241
<b>4. Zeeman Spectroscopy in Penning Traps</b>	<b>257</b>
Günter Werth, Sven Sturm, and Klaus Blaum	
1. Introduction	258
2. Penning Traps	259
3. Electron $g$ Factors in Multielectron Ions	262
4. The $g$ Factor in Few-Electron Systems	265
5. Experiments	273
6. The $H_2^+$ Ion	281
7. Impact on Fundamental Particle Data and Fundamental Constants	283
8. Impact on Nuclear Physics	289
9. Future Experiments	290
10. Conclusion	291
Acknowledgments	292
References	293
<b>5. Radio-Frequency Spectroscopy as a Tool for Studying Coherent Spin Dynamics and for Application to Radio-Frequency Magnetometry</b>	<b>297</b>
Witold Chalupczak, Rachel M. Godun, and Szymon Pustelny	
1. Introduction	298
2. Basic Concepts	300
3. Theoretical Background	300
4. Experimental Instrumentation	300
5. Experimental Signals and Simulation Results	300
6. Conclusions	330
References	330
Further Reading	330

<b>6. New Physics Searches Using Precision Spectroscopy</b>	<b>337</b>
Chad Orzel	
1. Introduction	338
2. Spectroscopy and Fundamental Physics	340
3. Frequency Measurements and Atomic Clocks	342
4. Tests of QED	350
5. Time Variation of Fundamental Constants	355
6. Electric Dipole Moment Searches	363
7. Conclusion	369
Acknowledgments	370
References	370
<b>7. The Hong–Ou–Mandel Effect With Atoms</b>	<b>377</b>
Adam M. Kaufman, Malte C. Tichy, Florian Mintert, Ana Maria Rey, and Cindy A. Regal	
1. Introduction	378
2. Experiments	381
3. Explanation of the Hong–Ou–Mandel Effect and Many-Particle Interference	386
4. Entanglement and the Hong–Ou–Mandel Effect	397
5. Interaction in Two and Many-Particle Interference	406
6. Entanglement Entropy	414
7. Concluding Remarks	420
Acknowledgments	421
References	421
<b>8. Negative Index Materials Using Atomic Transitions: Progress and Challenges</b>	<b>429</b>
Deniz D. Yavuz and Zachary N. Buckholtz	
1. Introduction	430
2. Negative Refraction Using Atomic Transitions	435
3. Experimental Implementation in Rare-Earth-Doped Solids	439
4. Magnetic Response in a Europium-Doped Crystal	443
5. Left-Handed Waves: EIPM Scheme	454
6. Conclusions	459
Acknowledgments	460
References	460
Further Reading	464