Advances in ATOMIC, MOLECULAR, and OPTICAL PHYSICS

Serial Edited by Ennio Arimondo Paul R. Berman Chun C. Lin

Volume 60



Advances in ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

VOLUME 60

Editors

ENNIO ARIMONDO University of Pisa Pisa, Italy

PAUL R. BERMAN University of Michigan Ann Arbor, Michigan

CHUN C. LIN University of Wisconsin Madison, Wisconsin

EDITORIAL BOARD

P.H. BUCKSBAUM SLAC Menlo Park, California

M.R. FLANNERY Georgia Tech Atlanta, Georgia

C. JOACHAIN Universite Libre de Bruxelles Brussels, Belgium

J.T.M. WALRAVEN University of Amsterdam Amsterdam, The Netherlands

ADVANCES IN ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

Edited by

E. Arimondo

PHYSICS DEPARTMENT UNIVERSITY OF PISA PISA, ITALY

P. R. Berman

PHYSICS DEPARTMENT, UNIVERSITY OF MICHIGAN ANN ARBOR, MI, USA

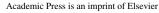
C. C. Lin

DEPARTMENT OF PHYSICS, UNIVERSITY OF WISCONSIN, MADISON, WI, USA

Volume 60



AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK OXFORD • PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE SYDNEY • TOKYO





Author's personal copy



Time-Domain Interferometry with Laser-Cooled Atoms

B. Barrett^a, I. Chan^a, C. Mok^a, A. Carew^a, I. Yavin^b, A. Kumarakrishnan^a, S. B. Cahn^c, and **T. Sleator**^d

^aDepartment of Physics & Astronomy, York University, 4700 Keele St., Toronto, ON M3J 1P3, Canada ^bDepartment of Physics & Astronomy, McMaster University, 1280 Main St. W, Hamilton, Ontario, Canada L8S 4M1 ^cDepartment of Physics, Yale University, New Haven, CT 06511, USA ^dDepartment of Physics, New York University, New York

^dDepartment of Physics, New York University, New York, NY 10003, USA

Contents	1.	Introduction and Description of Two-Pulse	
		Standing Wave Interferometer	121
		1.1 Introduction	121
		1.2 Calculation of the Signal	123
	2.	Time-Domain Atom Interferometer	
		Experiments—Atomic Recoil	129
		2.1 Introduction	129
		2.2 Experimental Work	132
		2.3 One-Pulse Atom Interferometer	134
		2.4 Two-Pulse Atom Interferometer	137
		2.5 Multi-pulse atom interferometer	146
	3.	Lattice Interferometry	151
		3.1 Introduction	151
		3.2 Description of the Interferometer	152
		3.3 Calculation of the Signal	153
		3.4 Experimental Results	154
	4.	Frequency-Domain AI Experiments	159
		4.1 Frequency-Domain Measurements	
		of Recoil	159
		4.2 Experimental Details	161
		4.3 Results and Discussion	161

Advances in Atomic, Molecular, and Optical Physics, Volume 60, Copyright © 2011 Elsevier Inc. ISSN 1049-250X, DOI: 10.1016/B978-0-12-385508-4.00003-6. All rights reserved.

Author's personal copy

120

B. Barrett et al.

	4.4 Frequency Synthesizer	162	
	4.5 Measurements of Rotation	163	
5.	Time-Domain AI Experiments—Gravity	165	
	5.1 Introduction	165	
	5.2 Theoretical Background	165	
	5.3 Experimental Setup	168	
	5.4 Measurement of g	169	
	5.5 Future Prospects	170	
6.	Internal State Labeled Interferometer	171	
	6.1 Introduction	171	
	6.2 Effect of a Uniform Magnetic Field		
	on the MGFID	174	
	6.3 Effect of a Uniform Magnetic Field		
	on the MGE	178	
7.	Coherent Transient Effects	180	
	7.1 Introduction	180	
	7.2 Experimental Setup and Results	183	
	7.3 Discussion	184	
8.	Superfluorescence in Cold Atoms	186	
	8.1 Introduction	186	
	8.2 Experimental Details	189	
	8.3 Results and Discussion	190	
Ack	Acknowledgments		
	References		

Abstract A single-state grating echo interferometer offers unique advantages for time-domain studies of light-matter interactions using laser-cooled atoms, including applications that involve precision measurements of atomic recoil, rotation, and gravitational acceleration. To illustrate the underlying physics, we first discuss the output signal of the interferometer in the absence of spontaneous emission. The influence of spontaneous emission, magnetic sublevels, and the spatial profile of excitations beams on matter wave interference in a two-pulse interferometer is described, followed by a discussion of transit time limited experiments using a multipulse technique that offers several advantages. We also examine the enhancement in signal size achieved by a lattice interferometer. The sensitivity of the interferometer to magnetic gradients and gravitational acceleration is discussed along with extensions to frequency-domain studies of atomic recoil and rotation. Applications of coherent transient effects and echo techniques associated with internal state labeled interferometers that utilize magnetic sublevels of a single hyperfine state are considered for precise measurements

Author's personal copy

Time-Domain Interferometry with Laser-Cooled Atoms

of magnetic interactions such as atomic g-factor ratios. The article concludes with an overview of the suitability of the traditional two-pulse photon echo technique for measurements of atomic lifetimes and studies of superradiant emission in laser-cooled samples.

1. INTRODUCTION AND DESCRIPTION OF TWO-PULSE STANDING WAVE INTERFEROMETER

1.1 Introduction

Matter wave interference has intrigued scientists since the early days of quantum mechanics. It was not until the late 1980s, however, that the field of atom interferometry was born. There have been a series of beautiful experiments carried out over the past two decades that have probed the fundamental nature of matter wave interference using atom interferometers (Berman, 1997). These include interference of "large" objects and of biomolecules (Hackermüller et al., 2004), interference of independently prepared particles (Andrews et al., 1997), and the origin of quantum mechanical complementarity (Durr et al., 1998). Advances in microfabrication techniques and the development of laser-cooling and trapping for neutral atoms has opened up many new possibilities for constructing atomic interferometers (Keith et al., 1988; Weiss et al., 1993). Besides testing the fundamental nature of matter wave interference, atom interferometers play an essential role in many high-precision measurements of fundamental constants, such as the fine structure constant α and the Newtonian constant of gravity. They offer an independent method for determining these constants that expands our understanding of the fundamental nature of physical laws (Cladé et al., 2006; Fixler et al., 2007; Weiss et al., 1993). Moreover, precise measurements of quantities such as the local gravitational field hold promise for technological advances in navigation and mineral exploration (McGuirk et al., 2002).

This article discusses the physics and various extensions of a particular atom interferometer design developed at New York University (NYU) in the mid-1990s (Cahn et al., 1997). The interferometer involves the interaction of a set of pulsed laser fields with a sample of laser-cooled Rb atoms in a magneto-optical trap. A schematic of the experimental setup of this interferometer is shown in Figure 1. The principle of the NYU interferometer is that the interaction of an off-resonant optical standing-wave pulse (made up of traveling waves with k-vectors k_1 and k_2) with a two-level atomic system effectively modulates the atomic ground-state energy with a spatial period $2\pi/q$, with $q = k_2 - k_1$. The pulse therefore acts as