Multi-Photon Quantum Interference

Zhe-Yu Jeff Ou

Multi-Photon Quantum Interference

Springer

Zhe-Yu Jeff Ou
Department of Physics
Indiana University-Purdue University Indianapolis
Indianapolis, IN 46202

Library of Congress Control Number: 2007922125

ISBN 978-0-387-25532-3 e-ISBN 978-0-387-25554-5

9 8 7 6 5 4 3 2 1

springer.com

For my parents,
who did so much for me.

Preface

Quantum interference, as a fundamental phenomenon of quantum mechanics, is what makes quantum physics different from classical Newtonian physics. Optical interference has played some essential roles in the understanding of light. It has fascinated Dirac, the pioneer of the quantum theory of light, since the very beginning, as seen in his famous statement on photon interference: "*Each photon ... interferes only with itself. Interference between different photons never occurs.*" Feynman, who was one of the founders of quantum electrodynamics, wrote, in his well-known lecture series on physics, that the interference phenomenon "*has in it the heart of quantum mechanics..., it contains the only mystery.*" As we explore into the quantum regime in the 21st century, we will find even more presence of quantum interference in our life.

Most commonly-occurring interference phenomena are optical interference, in the form of some beautiful interference fringe patterns. These phenomena have been well-studied by the classical theory of coherence, and documented in Born and Wolf's classic book *Principle of Optics*. In terms of the language of photon, these phenomena can be categorized as the single-photon interference effect and described by the first part of Dirac's statement given above. On the other hand, in the situation when more than one photon is involved, the second part of Dirac's statement is not correct. In this book, we try to understand the phenomena of quantum interference through the multi-photon effects of photon correlation. Our major concern is the temporal correlation among photons and how it influences the interference effect. Because of this, we resort to the multi-frequency description of an optical field.

The multi-photon interference effects discussed in this book will find their applications in many of the quantum information protocols, such as, quantum cryptography and quantum state teleportation. However, the emphasis of this book is on the fundamental physical principle in those protocols. Therefore, we will not cover the broad topics of quantum information processing. Nevertheless, readers may find the multi-frequency description of optical fields to be a good complement to the single-mode treatment found in most discussions on quantum information, and closer to a real experimental environment.

This book is organized into two parts. The first part deals mainly with the two-photon interference effect. The second part studies the effects of more than two photons. In addition to the interference effects, Chapter 2 is devoted to the generation and the spectral properties of a two-photon state in the process of parametric down-conversion, which is the main photon source for the effects studied in this book. We also investigate the coherence of the multi-photon source in Chapter 7, which is the preparation for Chapters 8-10. The complementary principle of quantum mechanics is demonstrated in a quantitative fashion in Chapter 9, when we discuss the relation between photon distinguishability and multi-photon interference effects.

This book is based on a tutorial lecture series held during the Yellow Mountain Workshop on Quantum Information in 2001. I would like to thank Professor Guang-can Guo of the University of Science and Technology of China for inviting me to the workshop and for his generous support.

Indianapolis, September, 2006 *Zhe-Yu Jeff Ou*

Contents