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An Introduction on New Interactions of Light and Matter

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A revolutionary advance in science came with the advent of the laser more than forty years ago, and from the field of nonlinear optics that was thereby spawned. A distinguishing feature of this work was the ability to realize new types of coherent interactions between material media and the electromagnetic field. These developments have of course been profoundly important both for science as well as for the technical base of modern society.

Over the past decade, another revolution has taken place with the creation of new nonlinear interactions between single atoms and light quanta (i.e., photons). A distinguishing feature of this work has been the realization of completely new capabilities in a manifestly quantum domain that has propelled Optical Science into a previously unexplored domain for fundamental investigations of the interaction of light and matter.

My contributions to this revolution have been enabled by a decades-long quest to achieve strong coupling within a rather esoteric setting, namely that of cavity quantum electrodynamics (QED). A major milestone for my work was the demonstration in 1995 of a quantum phase gate for two beams of light. Roughly speaking, my colleagues and I achieved a quantum transistor with single photons, which had properties suitable for the implementation of quantum logic and perhaps ultimately for the construction of quantum computers.

More recently, my research group at Caltech has explored the mechanical consequences of strong coupling, and observed single atoms bound in orbit by the mechanical forces associated with single photons in an optical cavity. Our system provided a new form of microscopy for sensing atomic motion in free space with sensitivity near the standard quantum limit (SQL). Another advance enabled by strong coupling has been the first realization of a laser that operates with one, solitary atom and that generates a regularized stream of photons as its output.

By employing the same system of one atom trapped in an optical cavity, my group recently made the first observation of photon blockade. This work was motivated by the close analogy with Coulomb blockade for electron transport in

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small metallic and semiconductor structures. In our experiment, the presence of only one photon blocked the passage of a second photon through the atom-cavity system.

On the one hand, these experiments are fundamental investigations of the nature of the inter-action of light and matter. However, one of my principal motivations has been a long-standing quest to harness these capabilities as tools for new scientific and technical advances. One area in which I have been particularly interested is the realization of complex quantum networks for quantum information processing and metrology, for which I coined the name the quantum internet. Indeed, in 1998 my group achieved the first bona fide realization of quantum teleportation by sending a beam of light from one side of a table to another without the beam having physically propagated through the intervening space. This work is part of a larger effort to lay the conceptual and technical foundations for the eventual implementation of quantum networks.

Title of Work honored with the Berthold Leibinger Zukunftspreis 2006:
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