Atoms, Molecules and Photons: From Precision Measurements to Quantum Control

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Extended Abstract of the lecture

Spectroscopy is primarily concerned with making measurements on atoms and molecules, through their interactions with electromagnetic fields. These measurements played a very crucial role in the development of quantum mechanics, in the beginning of twentieth century and related developments in the later years. Spectroscopic measurements are continuing to contribute immeasurably, to our understanding of various atomic/molecular interactions and processes, even today. In a way, spectroscopic measurements encompass practically all endeavors in science and technology, be it basic sciences, astrophysics and astrochemistry, environmental and health sciences or energy generation and development of new industrial processes.

In recent years, however, the new and fast developing scheme in spectroscopy, is the control of the quantum world of atoms and molecules using laser photons. The theme is based on the realization, that light is not only a source of information on the structure of atoms and molecules, but it can also be used to act on, to manipulate them and control their various degrees of freedom. Coherent control, which is based on the atomic/molecular coherence and quantum interference in optical transitions, is an example of control of the internal degrees of freedom by laser photons. The world of coherent control today covers several new aspects of laser-atom/molecule interactions, which include for example, control of chemical reactions, control of the optical properties of a medium, electromagnetically induced transparency and slow light propagation. Laser cooling of atoms is an example of controlling the external degrees of freedom, i.e., velocities and positions, using laser photons to realize atomic samples at unprecedented low temperatures. The field of ultra-cold atoms has expanded enormously in very recent years and it encompasses several new research directions, i.e., quantum degenerate gases, ultra-precision measurements, cold collision physics and atom optics to name a few. Current research in the area of quantum control of atoms and molecules holds an enormous promise, both as a platform for fundamental research and as a generator of new quantum technologies, e.g., ultra-precision atomic clock, ultra-sensitive magnetometer, quantum information processing and communication, and nano-technology.

For over twenty years, we have witnessed this paradigm shift in the outlook of spectroscopy, attempted to adopt it in our work and could succeed in advancing it by a few baby steps. In this presentation, we discuss the ideas underlying this progress with examples provided from our basic and applied work in high-resolution spectroscopy, coherent control and laser cooling and trapping of atoms.