Preface

Attosecond science is the art of controlling and measuring phenomena that occur in the timescale of 10^{-18} seconds. Very much in the same way as the invention of the microscope revealed a thitherto unobserved world to the scientists of the 17th century, attosecond technology is opening up a vast field for discovery to the scientists of the present day. If the aim of a microscope is to magnify the image of small objects in order to observe their tiniest features, the goal of attosecond technology is to take *movies* of ultrafast phenomena in slow motion, in order to reveal its dynamics in the shortest time intervals.

The atomic unit of time is 24 attoseconds; therefore to speak about attosecond science is tantamount to time-resolved electron dynamics in its natural timescale. The properties of matter, in whichever state, are largely determined by its electronic structure. Likewise, any change of these properties, through a chemical reaction or as a response to an external field, is ultimately driven by the electron dynamics. Therefore, it is not difficult to realize that the implications of controlling this dynamics are enormous for many areas of science, from atomic physics to materials science or biochemistry. As the 20th century was the era of the study and control of the *structure* of matter, we can affirm that the 21st will see the dominance of the *dynamics* of matter at its most fundamental level.

The advancement of ultrafast science has been closely connected with the development of lasers. When the first visible laser was demonstrated in 1960, very few could anticipate the huge impact that this little device would have in the history of science. The ultrafast revolution started with the invention of Q-switching for the generation of nanosecond pulses soon after the discovery of the laser itself. The development of the mode-locking technique, together with the finding of laser materials with a broad gain bandwidth, led to the generation of the first sub-picosecond pulses in 1974. These lasers have already originated a whole new branch of chemistry, dubbed femtochemistry.

The following step down in timescale required another breakthrough in laser technology: the invention of Chirped Pulse Amplification or CPA. This technique has allowed the generation of terawatt (10^{12} Watts) laser pulses with table-top systems, and it has spread out dramatically the research in ultraintense laser-matter interactions. As it turns out, the concept of *ultraintense* is intimately linked to that of *ultrashort*. The best example is seen in the process of high-order harmonic generation, where a high intensity laser field is capable of rivalling the Coulomb field experienced by the electrons in an atom, and drives the electron motion back and forth, generating high energy photons in the process. As the oscillation period of a near-infrared laser field is of the order of femtoseconds, the controlled motion of the electrons, and the radiation emitted subsequently occurs in a sub-femtosecond timescale. Currently, high-harmonic generation and related processes like above-threshold ionization and non-sequential double ionization, made possible by high-intensity lasers, are the gateway to the attosecond world.

We can distinguish two main areas of activity in the current endeavours of attosecond science: the development of attosecond light sources, and the measurement and control of attosecond phenomena. In the first, the ultimate goal is to achieve a source of fully-controlled high-energy isolated few-attosecond pulses which may then be used for ultrafast pump and probe experiments, non-linear XUV spectroscopy, etc. The first part of this book reviews the present status of these efforts, including the not less challenging task of fully characterizing the ultrashort pulses.

The second main area of activity in attosecond science, covered in the second part of this book, is exploring and demonstrating different methods to measure and control the dynamics of electrons in atoms, molecules and solids, either in pump and probe schemes using XUV attosecond and IR femtosecond pulses, or directly driving the electron motion with an intense IR laser field. Some of these techniques have already produced spectacular results.

Attosecond science is a young discipline and it is bound to undergo a dramatic development in the next few years. Research in the field is very active as it can be verified from the remarkable increase in the number of publications with the keyword *attosecond*, from barely 20 in the year 2000 to more than 250 in 2012. Some anticipated breakthroughs are the arrival of free-electron lasers at the attosecond regime, the generation of microjoule-energy keV attosecond pulses from relativistic laser-plasma interactions, the sub-cycle shaping of light waveforms, and the introduction of attosecond time resolution into well-established techniques of microscopy and electron diffraction, to name a few.

We hope this book will serve as a guide to newcomers to the field as well as a reference for the most experienced but, specially, we hope it will inspire a new generation of scientists to accomplish the just started conquest of the attosecond world.

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