Attosecond and High Harmonic Pulse Generation from Gases to Solids

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Abstract: Attosecond pulses are generated by electrons that are extracted from a quantum system by tunneling in an intense light pulse, travel through the continuum, but each electron is forced to recollide with its parent ion by the oscillating force of the time dependent electric field. This highly nonlinear process occurs in atoms, molecules and solids and offers unique measurement opportunities for science and technology.

I. Introduction

The first isolated attosecond pulses were produced in 2001. Now, more than a decades later we produce pulses more than 50 times shorter than can be made by any other technology and we have not reached a technical limit yet.

A new form of nonlinear optics ("Extreme Nonlinear Optics") underlies attosecond science. Just as perturbative nonlinear optics, introduced in the 1960s, has powered many advanced applications, extreme nonlinear optics will power equally important advances in the future.

II. Producing Attosecond Pulses

In extreme nonlinear optics, an electron wave packet undergoing classical-like motion under the influence of the electric field of an intense light pulse. When the light field reverses, the wave packet's motion also reverses, allowing the electron to recollide with its parent ion. During this "recollision" a photon can be emitted as the electron returns to its initial state. Repeated each ½ cycle of a light pulse we create high harmonics that can stretch into the soft X-ray region. Single attosecond pulses are formed by controlling the light field so precisely as to allow recollision only during a single ½ cycle of the laser field. Light beams that allow this level of precision are carrier-envelop-phase controlled and they usually are only a few cycles in duration.

III. Measurement

One can think of the production of high harmonics as a form of electron interferometry. Interferometry allows us to characterize the spatial and temporal structure of waves involved – in this case, the electron wave function and wave packet.

Once a pulse is created, it must be characterized. Using electron interferometry (we call it "insitu measurement") we determine both the space and time structure of an attosecond pulse as it is being produced. In addition, measuring an attosecond pulse simultaneously measures the time dependent field of the light beam. One can think of the brief electron excursion between birth and recollision as a gate that allows fast measurement. It is a gate because we only influence its motion during this brief time. Thus, we resolve the field of a light pulse.

IV. Materials for Extreme Nonlinear Optics

Until recently it seemed that gas were the unique home for extreme nonlinear optics and attosecond science. Now high harmonics are produced from the interior of solids. It is important to determine, "is the phenomenon the same in solids as in gases?" I will show that, for the cases we have studied carefully, high harmonics in solids are due to recollision. This opens the opportunity for studying exciton structure and dynamics in solids in direct analogy to studies of orbital structure and dynamics in gases.