X-Rays and Extreme Ultraviolet Radiation : Principles and Applications

Chapter 7. HHG Homework Problems

7.1 Describe the High Harmonic Generation (HHG) process? What is the three step model? Why does the process typically lead to only odd harmonics? What are some of the greatest advantages of HHG? Give five areas of break-through science opportunities recently demonstrated, or which you would like to propose?

7.2 What are typical laser wavelength and intensities used in HHG? Why not lower laser intensity? Why not higher laser intensity? What are the advantages of various gases? What HHG energies are achievable with these laser and gas parameters? Calculate the electron excursion distance for a an electron after tunneling free from a neon atom at the focus of a 40 fsec FWHM pulse at 800 nm wavelength and a focal intensity of 4 x $10^{14}\,\mathrm{W/cm^2}$. How does the phase of the driving 800 nm electric field at the time of tunneling free from the neon atom, the 'time of birth', affect the return energy to the vicinity of the parent ion? What affects the likely hood of a recombination with that ion? What is a typical likelihood of recombination, and what is a typical overall efficiency for the HHG process?

7.3 For a Bohr model hydrogen atom in the focal plane of an 800 nm wavelength, 4 x $10^{14}\,\mathrm{W/cm^2}$ laser pulse, what is the ratio of laser electric field to the nuclear field felt by an n= 1 electron? What is the time required for an n= 1 electron to complete one orbit of a Bohr atom?

7.4 Describe phase matching of the IR driving laser pulse, typically at 800 nm wavelength, and that of the harmonic pulses in the extreme ultraviolet (EUV) and soft x-ray regions? What controls the phase velocities of the IR and harmonic waves? How does this affect the available depth of interaction in the selected gas? Why is this described as a 'dephasing distance' rather than a coherence length? Can you write an equation for the dephasing distance? Can you see how this can be extended. To what degree do N^2 effects play a role here? Can absorption also limited the interaction region?

7.5 What is the depth of focus (DOF), twice the Rayleigh range, of an 800 nm laser pulse brought to a focal diameter of 100 μm FWHM? What is the corresponding rms focal radius? What is the corresponding $1/e^2$ radius? [See Chapter 4, page 110]. How does the DOF grow with increased focal radius?

7.6 Estimate the relative spectral bandwidth, $\Delta\lambda/\lambda$, of a mid-range high harmonic. Consider how many cycles harmonic h will consist of for a laser pulse of N cycles. Model the resulting electric field wave train (rectangular or Gaussian envelope), then apply a Fourier transform from the time domain to the frequency domain. Express your result in terms of a FWHM for the concomitant intensity envelope.

7.7 Can you estimate the degree of spatial coherence of HHG radiation? Why is it so high? Why is coherence so important to the HHG process? Can you estimate the longitudinal coherence length for a single HHG pulse? How can single HHG pulses be separated from a comb of harmonics?

7.8 How Are attosecond (asec) pulses generated? How is the duration of such a short pulse measured? Please include a diagram. What spectral bandwidth is required to generate an 80 asec FWHM pulse?

7.9 Most HHG experiments are performed in noble gases. For a typical gas density of 2 Torr argon (see Appendixes A.4, A.5 and the Periodic Table on the inside back cover) what is the density of argon atoms and what is the distance between atoms? How does this compare with the excursion distance of a liberated electron at the focus of a 780 nm wavelength, 2.5 fsec FWHM duration laser pulse focused to an intensity of 10^{14} W/cm^2? As interest grows in studying HHG emission from solids, how might the greater atomic densities affect the HHG process?