X-rays are powerful probes of the nanoworld. They penetrate thick samples and, by virtue of their short wavelength, image small objects. Moreover, using elemental absorption edges, they can provide element and chemical species-specific information. In this talk, I will highlight new experiments that use ultrafast laser and x-ray pulses to uncover electron dynamics in molecules and materials. In a ferromagnetic alloy, where the spins can align (i.e. strongly exchange-coupled), an interesting question to ask is if the magnetic moments of the individual elements can decouple on ultrafast time scales. This is an important fundamental question because the underlying physics of all ferromagnetic behavior is the cooperative interaction between individual atomic magnetic moments. Moreover, next generation data storage devices will use heat-assisted magnetic recording. By rapidly heating an Fe/Ni ferromagnetic alloy with a fast laser pulse, we show for the first time that the magnetic moments of Fe and Ni transiently decouple. This breakdown of the exchange interaction in a ferromagnet is likely due to screening by the laser-induced hot electron distribution.[1]

This talk will also discuss using reaction microscope techniques to capture the entire valence shell electron density in a molecule rearranging, from molecular-like to atomic-like, as a bond breaks. This is the first experiment to image the dynamics of multiple electrons in a bond.[2]

Finally, this talk will highlight advances in the extreme nonlinear-optical process of high harmonic generation, allowing attosecond and zeptosecond pulses to be generated in the keV region - essentially realizing a coherent version of the Roentgen x-ray tube on a tabletop.[3, 4]