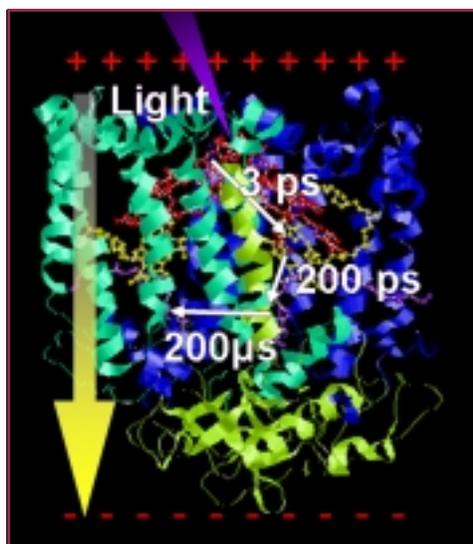


Ultrafast Chemistry

Studying Ultrafast Chemical Processes and Structures in “Slow Motion”

Chemical reactions are driven by fundamental processes, such as molecular vibrations, internal rotations, and bond formation, that occur in as little as a few femtoseconds (a few millionths of a billionth of a second). To better understand these processes, Argonne researchers have developed ultrafast laser and x-ray techniques to make movies and snapshots capturing the molecular activities of chemical reactions in “slow motion.”

Ultrafast investigative tools — such as femtosecond optical spectroscopy, time-resolved x-ray absorption spectroscopy, and ultrafast pulsed electron and x-ray probes — permit scientists to gain insight into the chemical reactions involved in natural photosynthesis, solar energy conversion, molecular devices, and photocatalysis.



Femtosecond Optical Spectroscopy

Some of the best examples of ultrafast chemistry are the solar energy conversion and storage that occur naturally in plants during photosynthesis. Measuring the rates of light-induced electron transfer as functions of the protein surroundings of the chromophores and the temperature can provide insight into how to construct artificial systems for solar energy conversion (Figure 1).

Studying transient photochemical reactions is vital to understanding the fundamentals of solar energy conversion and storage, which can lead to new solar energy technologies. Using ultrafast optical spectroscopy, Argonne research has shown that photochemically active molecular aggregates transfer electrons to silver nanoparticles upon photoexcitation (Figure 2).

Figure 1. Probing natural proteins' photosynthesis reaction centers provides insight into solar energy conversion.

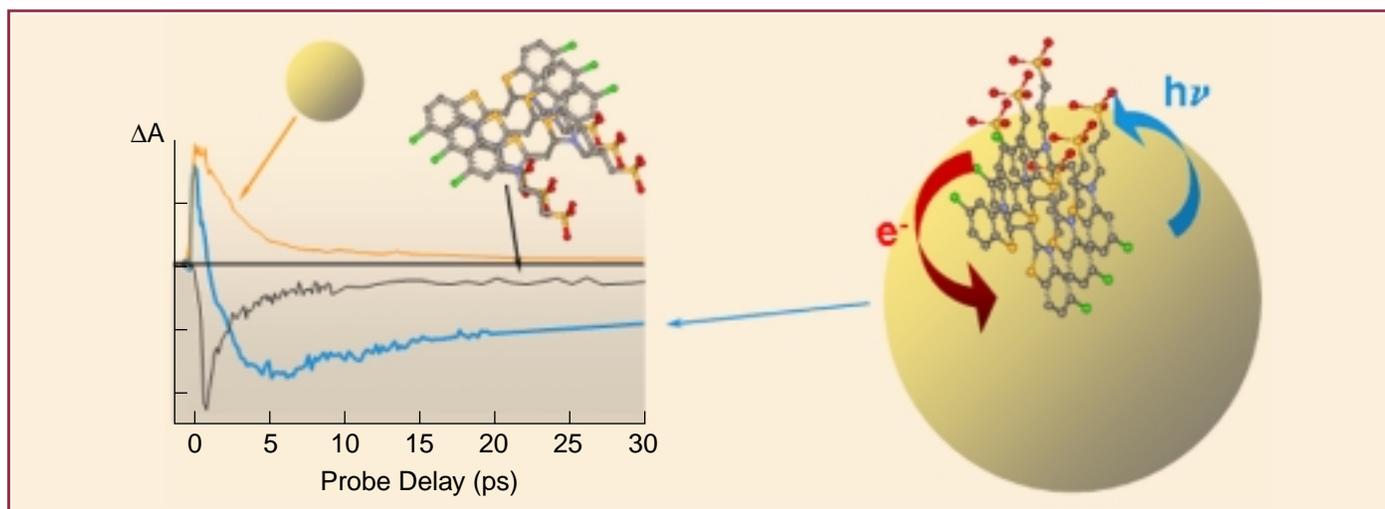


Figure 2. Understanding transient photochemical reactions on nanoparticle surfaces is vital for developing nanophotonics.

Polycyclic aromatic hydrocarbon (PAH) radical cations are formed in many chemical processes, such as organic synthesis, photochemistry, radiation chemistry, and astrochemistry. Femtosecond optical spectroscopy reveals that PAHs can absorb large amounts of radiation and undergo exceptionally fast electronic-to-vibrational energy conversion, thus dissipating the excess energy in less than 200 femtoseconds (Figure 3).

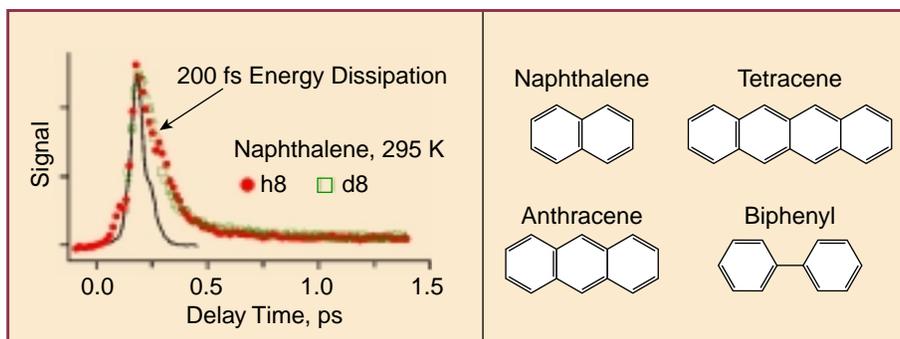


Figure 3. Probing natural photosynthesis reaction center proteins provides insight into solar energy conversion.

Time-Resolved X-Ray Absorption Spectroscopy

Using light, Argonne researchers induced electron transfer in a copper complex to produce a different, short-lived geometric configuration. Evidence of this ultrafast structural change (Figure 4) was captured by means of x-ray spectroscopy. These studies are enhancing our understanding of molecules that experience structural changes and might serve as “molecular motors” or “molecular switches” in nanotechnology applications.

Ultrafast Pulsed Electron and X-Ray Probes

Ultrafast electron and x-ray sources are required to follow atomic movements during chemical reactions. Argonne has developed a tabletop terawatt laser system (Figure 5) that will produce electron and x-ray pulses shorter than 100 femtoseconds for ultrafast studies. The laser’s output exceeds 20 TW (20 trillion watts) and is focused onto a helium gas jet located in an interaction chamber. The laser beam’s intense electric field strips electrons from the helium atoms and accelerates them to nearly the speed of light with energies in excess of 10 million electron-volts.

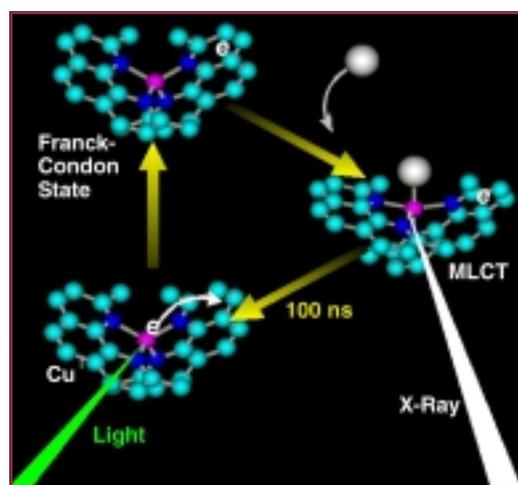


Figure 4. Light-induced changes in a molecule’s geometric configuration can make it function as a “molecular motor” or “molecular switch” in nanotechnology applications.

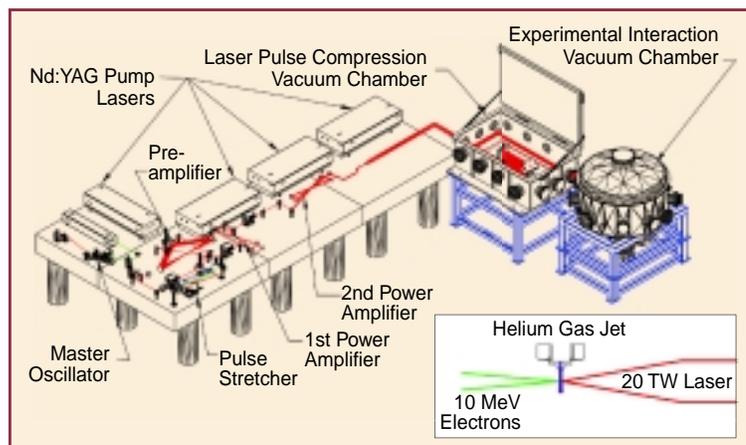


Figure 5. A tabletop laser system developed at Argonne strips electrons from helium atoms and accelerates them to nearly the speed of light.

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