The equilibrium positions of atoms in complex molecules can be measured with a breathtaking accuracy of 10^{-13} m (about one-thousandth of a molecular bond length). Knowing the equilibrium structure of molecules allows physicists and chemists to predict how they might behave in different situations, but definite answers to many important questions require the direct observation of molecular dynamics.

Molecular processes, such as the breaking or formation of chemical bonds, have already been investigated by ultrafast pump-probe experiments, which use an intense femtosecond (10^{-15} s) laser pulse to trigger a reaction and a weak time-delayed probe pulse (operating at visible or longer wavelengths) to take snapshots of the subsequent dynamics[4]. But in these studies it is possible to follow changes in the atomic positions of only the simplest molecules. This is because the visible light can only probe the optical properties of weakly bound atomic electrons, from which the atomic positions can be inferred for simple molecules only. By contrast, 'hard' X-rays with wavelengths 5,000 times smaller than visible light can be absorbed or scattered by strongly bound 'core' electrons, providing direct information about the positions of the nuclei. So variation in the absorption or diffraction of hard X-rays can be unambiguously related to dynamic changes in molecular structure regardless of its complexity.

These prospects triggered a worldwide effort to develop sources of ultrashort pulses of hard X-rays. One successful approach has been to strip electrons from atoms (forming a plasma of ions and electrons) and then accelerate the electrons to velocities close to the speed of light using a powerful femtosecond laser pulse. When the energetic electrons re-collide with the atomic cores they produce a short X-ray burst at wavelengths characteristic of the atoms in the target. Such laser-driven sources of hard X-rays have already been used in proof-of-principle demonstrations of ultrafast X-ray absorption and diffraction measurements[5–7].

Hard X-rays can also be created in a particle accelerator known as a synchrotron without the need for any collisions. Synchrotron radiation is emitted by high-speed electrons following a circular path through a strong magnetic field, and delivers pulses typically tens of picoseconds in duration. Last year, physicists produced sub-picosecond bursts of hard X-rays in a synchrotron for the first time by manipulating the electrons radiating the X-rays with a powerful femtosecond laser[8].

The work of DeCamp *et al.*[3] opens an entirely new chapter in controlling the time structure of hard X-rays. The authors modified the transmission of a synchrotron X-ray beam through a germanium crystal on a picosecond timescale by stimulating changes in the crystal lattice with an ultrashort laser pulse. This X-ray 'switch' allows them to modulate hard X-ray beams regardless of their source of emission, and thereby turn the X-rays on and off to generate sequences of pulses, or even shaped pulses, over a wide range of hard-X-ray wavelengths.

The prototype X-ray switch developed by DeCamp *et al.* consists of a thin piece of germanium crystal irradiated by strong femtosecond laser light. By cutting and aligning the crystal in the correct way the authors have created an unusually high transmittivity for the incident hard X-rays. At the exit face of the crystal the transmitted X-ray beam is split into two diffracted beams, which propagate with nearly equal intensities in slightly different directions (Fig. 1). The relative transmittivity and intensity of the two X-ray beams is sensitive to minor distortions in the crystal structure. The exit face of the crystal can be heated up quickly with a femtosecond laser pulse; the heated volume expands, shifting atoms out of their equilibrium position in the lattice (by a process known as acoustic phonon excitation). So the structure of the lattice is perturbed, modifying the transmission of the incident X-ray beam and redistributing energy between the two outgoing X-ray beams. In this way the beams can be switched on and off, or the relative strengths of the two beams can be quickly altered.

When the X-ray switch is in operation the crystal atoms move only a fraction away from their equilibrium position, but this is still sufficient to switch a substantial fraction of X-ray energy from one beam to the other. This experiment beautifully demonstrates the sensitivity of X-ray diffraction to atomic positions, a feature that X-ray structural analysis itself relies upon. The X-ray energy flow into the outgoing diffracted beams is switched within the time it takes the atoms to leave their equilibrium position. This limits the minimum switching time to picoseconds in the current experiment, but the transmission of the X-ray beam can also be affected by small perturbations in the distribution of electrons around the atoms in the crystal lattice. Because electrons are much lighter than the nuclei forming the lattice, such perturbations (referred to as optical phonons) could be generated on a much faster sub-picosecond timescale with a sufficiently short laser pulse. Using electronic instead of acoustic perturbations could bring the switching time down to less than a picosecond, paving the way to eventually creating hard X-ray pulses of femtosecond duration.

How does this method compare with other techniques used to control X-rays on an ultrafast timescale? Laser-driven hard X-ray sources can generate pulses that are shorter than a picosecond but, because they emit photons in all directions, only a fraction of the X-ray photons can be focused on the

NATURE

100 YEARS AGO

Paris was greatly excited on Saturday last when M. Santos Dumont, with his seventh balloon, successfully rounded the Eiffel Tower and returned to the shed at St. Cloud, thirty seconds within the thirty minutes allotted by the Committee of the Deutsch Prize. At the time of the voyage the wind, according to the *Times* correspondent, was blowing at the rate of twelve of thirteen miles an hour. At one period the balloon, travelling at the rate of thirty miles an hour, appeared as though it would collide with the Tower; the aeronaut, however, was able to control its movements without any apparent difficulty, and, as has been said, the journey was accomplished within the time limit agreed upon. M. Santos Dumont is to be congratulated upon the success which has at last attended the untiring efforts put forward by him towards the solution of the problem of aerial navigation.

From *Nature* 24 October 1901.

50 YEARS AGO

The second International Congress on Astronautics was held in London during September 3–8. It was attended by nearly fifty delegates representing societies and groups interested in astronautics from Argentina, Austria, France, Germany, Great Britain, Italy, Spain, Sweden, Switzerland and the United States… The latter part of the London Congress was devoted to a symposium of papers on the general theme of orbital vehicles, their construction and uses. There was general agreement among the speakers that such vehicles are possible from an engineering point of view; the first instrument-carrying vehicles could be built within ten to fifteen years; but man-carrying artificial satellites appear to be much further in the future… The greatest problem of interplanetary flight is that of propulsion, and in his paper "Interplanetary Travel between Satellite Orbits", Prof. Lyman Spitzer discussed a method of applying nuclear energy. It was suggested that an electrically accelerated ion beam could be used for achieving a gas ejection velocity of 100 km./sec. without the use of very high temperatures in the propellant gases. Such a unit could not be built with a large enough thrust/weight ratio to allow it to take off from the surface of a planet. It would be capable of travelling from a close-orbital station about the earth to a similar orbit about any other planet.

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