for estimates of root production and the capacity of soils to store carbon. If most root biomass is long-lived, the amount of plant carbon used to grow roots has been overestimated in the past. However, if root populations are skewed significantly, the relationship between the mean age of a plant root system and its annual root production (that is, inventory divided by mean age) no longer holds (see the figure).

The total transfer of plant carbon below ground is constrained by measurements of soil respiration and leaf litterfall (*8*). This carbon supports all root functions, not just growth. If less carbon is used to grow long-lived roots, then more must go to ephemeral roots, root exudates, fungi, and root respiration. If carbon cycling through these components returns to the atmosphere quickly, below-ground carbon storage potential may indeed have been overestimated. However, we do not really understand the pathways this carbon takes; some may be retained in soils for many years through microbial recycling or sorption mechanisms.

It remains unclear why some roots survive for years while others die quickly. Radiocarbon and minirhizotron data from the same forest in central Sweden show that roots 0.3 mm in diameter can live for 3 months or 8 years (*9*). Root studies must move beyond sampling based on arbitrary criteria such as diameter. Sampling based on root form and function (*10*) could perhaps be done by focusing on root branching order, length, and nitrogen content, or by relating root function to root age (*11*). Unless we recognize that root behavior is as complex as that of its counterparts above ground, the rules governing transfer of carbon to roots and the role of roots in soil carbon cycling will remain well-kept secrets.

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MATERIALS SCIENCE

A Picosecond View of Melting

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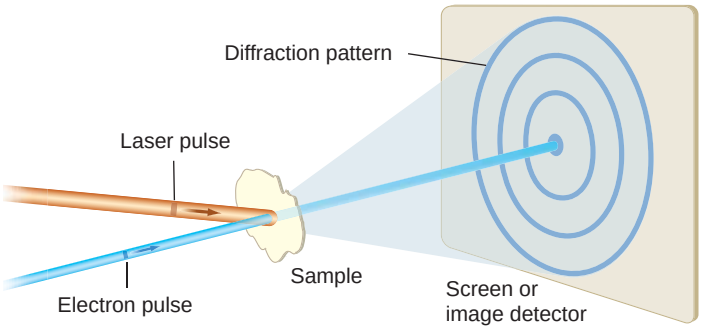
Most information on atomic structure at our disposal today comes from diffraction experiments. When a beam of electrons or x-rays hits a material, part of the radiation is scattered, giving rise to a diffraction pattern from which the atomic structure of the material can be retrieved. However, until recently, only static structures could be observed. This meant that, for example, the extremely fast changes in atomic configuration associated with chemical reactions could not be observed. Only the initial state and the outcome of a chemical reaction could be captured.



Ultrafast time-resolved electron diffraction. A short laser pulse excites the sample by depositing energy in the illuminated area. To monitor the structural changes caused by the laser excitation, a pulsed electron beam is directed onto the excited area, and diffraction patterns are recorded for different delay times between laser pulse and electron pulse. The delay time can be controlled with femtosecond precision.

To directly monitor the changes in atomic configuration underlying the breaking or formation of chemical bonds requires a time resolution of 10^{-14} s (10 femtoseconds) to 10^{-12} s (1 picosecond). On page 1382 of this issue, Siwick *et al*. (*1*) demonstrate electron diffraction experiments with a time resolution of 5×10^{-13} s. On this fast time scale, they can monitor the changes in atomic configuration that occur when an intense short laser pulse causes aluminum metal to melt within a few picoseconds. The work is a new landmark in time-resolved structural investigations.

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Ultrafast electron diffraction was first demonstrated almost a decade ago by Williamson *et al*. (*2*), who achieved a time resolution of ~20 picoseconds. Zewail and co-workers have pioneered picosecond time-resolved electron diffraction studies of chemical reactions in the gas phase (*3*). Subpicosecond x-ray pulses have also been generated, enabling researchers to perform ultrafast x-ray diffraction experiments on laser-induced structural transitions in semiconductor crystals. X-ray diffraction from selected lattice planes of the crystals was measured during and after strong excitation by an ultrashort laser pulse. The long-range atomic order typical of the crystalline state was destroyed within a few hundred femtoseconds (*4*, *5*), indicating that the structural transition from the solid to the liquid state occurred during this very short time.

In a recent extension of time-resolved x-ray diffraction, much more subtle atomic motions that leave the crystalline order intact have been observed. In these experiment, snapshots of the atomic configuration were recorded that revealed a coherent vibrational mode of the crystal atoms set up by a femtosecond laser pulse (*6*).

However, only selected features of the atomic structure could be measured in these x-ray time-resolved diffraction experiments. To date, it has not been possible to obtain more complete structural records, mainly because the weak pulses from today's laser-driven subpicosecond x-ray sources make it very difficult to gather the data needed for a full evaluation of the atomic structure. This limitation should be overcome in the future when much more powerful sources such as x-ray free electron lasers become available (*7*).

Electrons offer a basic advantage over x-rays for the exploration of atomic structure: They are scattered much more efficiently than x-rays. The scattering cross sections (a measure of the strength of the interaction with the atoms) for electron scattering exceed those for x-ray scattering by more than a factor of 10^5. However, it is difficult to squeeze electrons into a short pulse. The reason is that electrons are electrically charged particles, which repel each other. The more electrons in a pulse, the faster the pulse broadens during propagation from its source to the target. This basic difficulty long prevented the generation of sub-