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Research Applications of Lasers

Laser light comes in many sizes, shapes, and colors. The most powerful lasers produce intensities as high as 10^{16} watts per square centimeter, one trillion times the intensity at the surface of the sun and enough to cause fusion reactions. Pulses that are 6×10^{-15} second in duration, consisting of three optical cycles, are now available from dye lasers, and wavelengths shorter than 100 angstroms have been generated by x-ray lasers. Such lasers are interesting objects of study in their own right, but the lasers that operate within the limits are the workhorses: commercially available and approaching turn-key reliability. Lasers are increasingly used as tools for scientific research; with them it is possible to open new avenues of inquiry. In this issue of *Science* are three articles—in geophysics, atomic physics, and chemical physics—that present several ways in which lasers are employed as tools in the laboratory.

Hemley, Bell, and Mao describe some of the uses of lasers in laboratory geophysics. Inside the earth, planetary matter is subjected to pressures that approach several million atmospheres and temperatures in the thousands of degrees. Because direct observation is not possible, an understanding of internal structures and transformations can only be achieved by simulation of these extreme conditions. Small amounts of minerals or their constituents are sandwiched between diamond surfaces and subjected to large static pressure, the latter communicated by the calibrated fluorescence of a ruby chip. An infrared laser beam, passing unhindered through the transparent diamond, may heat the tiny sample, thus raising the compressed environment to high temperature. A visible-wavelength laser can probe the sample for Raman and Brillouin resonances, which reveal the subtleties of the dynamics of the earth and other planets. Raman spectra disclose the remarkable phase transitions of minerals under pressure, and Brillouin scattering permits a quantitative measure of the elastic and acoustic properties important in seismic studies.

Itano, Bergquist, and Wineland describe laser spectroscopy of ions held captive in an electromagnetic trap. In these experiments, quantum states are studied with extraordinary precision; from the results we learn more about atomic clocks and fundamental physics. Confined to a small space and freed from the perturbing influence of neighbors, single atomic ions exhibit quantum-mechanical resonances that are exceedingly narrow in comparison with the broad spectral lines of denser matter. A precisely tuned laser can further constrain the atomic motion by radiation pressure. Lasers that are under strict frequency stabilization can be used to record high-resolution spectra of the isolated ion. In other experiments, this trapped performer can be made to execute quantum jumps, abruptly fluorescing and then going dark.

Jankowiak and Small review experiments that reveal much about the properties of solids at temperatures near absolute zero. In particular they discuss "hole-burning" spectroscopy as a means of extracting harmony from chaos. Amorphous materials, glasses and polymers for example, are disordered on a microscopic scale, and this disorder is reflected in the broad optical absorption spectrum of a collection of guest molecules. The confusion caused by this disorder can be cleared away by carefully exciting a limited group of molecules to higher energy states with a narrow-band laser. These chosen few molecules, now absent from the ground state, are represented by "holes" in the spectrum. This select group can be watched closely: the holes will fill up as the guests rush back to their places. The glass structure can change, however, before the guest molecules have returned, and persistent spectral holes are the result. Even at temperatures below 1 K this structural reorganization continues: no longer thermally activated, the glassy rearrangement instead occurs by quantum tunneling. With laser hole-burning spectroscopy, researchers can probe the time scales of these dynamic events over 15 orders of magnitude, obtaining new information about basic properties of an important class of materials, the disordered solids.

Perhaps the most exciting future role for lasers is in those applications at the limits of performance: electronic pulse generation with ultrashort laser pulses, long baseline laser interferometers for gravity wave detection, and the creation of "squeezed" states of light with exotic statistical properties, to name a few. In these explorations, grand discoveries await researchers equipped with the next generation of laser tools.—DAVID F. VOSS