

signal ratio of the system grows as the fifth power of the diameter. To compensate, one wants the longest possible sample chamber. Size is also important because the velocity selection greatly reduces the absorbing population, as do the low pressure and low beam intensity required to minimize pressure broadening and the "saturation broadening" that comes with too high an excitation rate.

Bordé came to JILA in 1973 to work with Hall on expanding the size of his He-Ne system. Increased size presents difficult optical problems. The optics that expand the laser beam and reflect it through the system must be diffraction limited because excessive divergence destroys the precise definition of beam direction upon which the Doppler-free technique depends. As apertures become larger, the tolerable angular content of the beam decreases. By 1975 Hall and Bordé had a He-Ne laser system large enough to study the hyperfine structure of CH_4 at 3.39 microns with a resolution of less than a kilohertz. Comparable advances in spectroscopic technique were being achieved at about the same time by Veniamin Chebetayev at Novosibirsk.

These He-Ne laser spectroscopy systems have the virtue of great stability, but they can only be tuned over a very narrow range around 3.39 microns. In quest of a more broadly tunable system, Bordé returned to Paris in 1975 to build a high-pressure CO_2 laser system. CO_2 has about a hundred lasing transitions in the 10-micron region of particular interest to molecular spectroscopists. Exploiting the Doppler and high-pressure broadening of the lasing gas, one can tune the laser over 300-MHz-wide bandwidths around each of these CO_2 lines. If one can afford to fill the laser with isotopic variants of CO_2 , one gets

enough 300-MHz windows to get 50% tuning coverage of the infrared regime from 9.6 to 11 microns. With so broadly tunable a laser one can study significant portions of the SF_6 ro-vibrational spectrum in detail.

Bordé and his Paris colleagues have built a high-pressure CO_2 laser spectroscopy system that is, by previous standards, enormous. The saturation-absorption cell that contains the low-pressure (10 microtorr) molecular gas under study is 18 m long and 70 cm across. The length of the cell is traversed by laser beams expanded by telescopes to a diameter of 30 cm. With beam diameters so large, the diffraction limit of angular tolerance is less than an arcsecond. The Bordé group has therefore had to devise reflecting corner cubes and other large optical elements within these demanding tolerances. All this is particularly difficult in the infrared, where the eye is of little use in making adjustments.

It is not enough that the bandwidth of the laser source be narrow. It must also be extremely stable. This is a particular problem for CO_2 lasers, which are inherently much less stable than He-Ne lasers. Bordé stabilizes the frequency of his CO_2 laser spectrometer by exploiting a technique pioneered by Hall at JILA. In place of a single laser the Paris group has two CO_2 lasers in tandem, one of which is optimized by stability. This laser is kept at a fixed frequency corresponding to a convenient absorption line of the molecular gas in its saturation cell, thus serving as a stable reference for the second laser, which is optimized for spectroscopy. As the second laser is tuned through the region of spectroscopic interest, its output is mixed with that of the reference laser in an optical heterodyne mixer. The resulting beat

frequency is converted to an electronic signal by a photodetector, providing a feedback signal for a piezoelectric transducer that adjusts the length of the spectroscopic laser cavity.

The present resolution of the Paris spectrometer is better than a kilohertz over a broad wavelength region around 10 microns. At the 38th Symposium on Molecular Spectroscopy, held last summer at Ohio State University, Jacques Bordé, Christian's younger brother and the group's theorist, reported that he and his colleagues had confirmed the Harter-Patterson theory (and the computer diagonalizations) for all parts of the SF_6 spectrum where their many 300-MHz-wide windows and resolution limits have thus far permitted them to look. The high-pressure CO_2 laser bandwidth also overlaps with interesting spectral regions of many other molecules. The Paris group has, for example, been investigating the spectrum of OsO_4 . Aside from its purely academic interest, OsO_4 holds out the promise of being a spectacularly good saturation-absorption stabilizing gas for CO_2 lasers.

With the current state of spectroscopic precision and theoretical understanding of molecular ro-vibrational dynamics comes the promise of what Harter calls "clockwork molecules." By exciting a molecule with just the right frequency of laser light, he foresees, one should be able to nudge it into any state one chooses.

—BMS

References

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New tandem mirror machine starts operation at MIT



The Tara tandem mirror experimental fusion device began operation at the MIT Plasma Fusion Center's new Nabisco Laboratory at the end of March. In recent testing, rf heating has raised the ratio of plasma pressure to magnetic pressure in Tara's central solenoid to 2%, indicating an average ion energy of 2 keV (20 million kelvin), much hotter than the temperature at which the device will ultimately run.

The plasma is confined in the central solenoid of the 25-meter-long device by magnetic mirrors at both ends, each consisting of a quadrupole magnet to provide overall magnetohydrodynamic stability and an axisymmetric magnet set that augments confinement by generating an electrostatic barrier. Tara is similar in size to Livermore's two-year-old upgrade of its Tandem Mirror Experiment. The principal difference between Tara and the upgraded TMX is that the new device is designed to achieve an axially symmetric magnetic field in the central solenoid. The asymmetry of the quadrupole magnets produces asymmetrically twisted field lines in the center of the TMX. This is avoided in the Tara design by physically separating the quadrupoles from the electrostatic barrier plugs, removing the quadrupoles further from the central plasma region. Tara was designed to test theoretical predictions that plasma confinement in a tandem mirror machine will be significantly improved by making the confining field axially symmetric.

Richard S. Post, head of the MIT Plasma Fusion Center's mirror-confinement division (and no relation to Livermore's Richard F. Post), told us that these tests of new design concepts are going forward in conjunction with work on Livermore's much larger tandem-mirror machine, the MFTF-B, scheduled for completion in 1986 (*PHYSICS TODAY*, September 1981, page 22). Tara was built at a cost of \$15 million. The building housing the experiment is an old Cambridge baking plant, donated by Nabisco.