

alkali atoms and atomic hydrogen had been magnetically trapped. Then the Harvard group reported² magnetically trapping atomic europium; later the group also trapped atomic chromium.

After the atoms or molecules are thermalized, the helium can be cryopumped away, leaving a thermally isolated, trapped sample. Because this buffer-gas loading method relies on elastic collisions with helium, it is independent of the structure of the trapped sample. That's why it was expected to be handy for molecules, whose complex energy-level structure gets in the way of radiative cooling.

In the new experiments, calcium monohydride is produced, thermalized, and trapped inside a copper cell inside the bore of a magnet. The cell is kept at about 300 mK by a dilution refrigerator. The ³He buffer gas (at densities of 2×10^{16} atoms/cm³) is introduced into the cell.

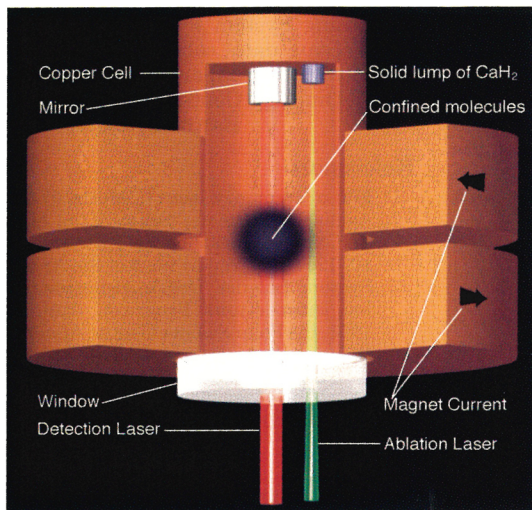
A 20 mJ laser pulse ablates a sample of solid calcium dihydride, which produces the gaseous molecule CaH and H atoms. Because the trapped molecules are thermally distributed, they evaporate over the edge of the trap at a rate that depends on the ratio of the trap depth to the translational temperature (or mean velocity) of the molecules.

The experimenters studied the evolution of the CaH fluorescence spectrum excited by a probe laser. The high-field seekers quickly left the trap. But the low-field seekers remained confined and compressed toward the center of the trap.

The Harvard team fit the spectrum of trapped CaH to a simulated spectrum of a thermal distribution of trapped CaH. That fit yielded 10^8 CaH molecules trapped at a temperature of 400 ± 50 mK. The density of the molecules was 8×10^7 /cm³. The molecules have an exponential decay constant of 0.5 s. They can be observed for more than 2 s, and then the signal becomes obscured by the noise, says Doyle.

Before succeeding with CaH, the experimenters had first tried vanadium monoxide. But when they attempted laser ablation of V₂O₅, lots of dirt was produced, and the cell was depleted of VO in about 50 ms.

The Harvard group will now try to improve the production technique, Doyle says. "Ablation is easy but dirty. We trapped more than half of the low-field-seeking molecules we had." In the Harvard experiments with atomic europium and chromium, after the species was thermalized the helium was cryopumped away. For CaH, the group hasn't succeeded in isolating the molecules because their cryopumping procedure takes about 10 s, longer than the CaH was observable in the trap.



CUTAWAY SCHEMATIC of molecule trap. The 5-cm-diameter cell is anchored to the mixing chamber of a dilution refrigerator, and the magnet is immersed in liquid helium. The superconducting magnet coils generate a spherical quadrupole magnetic trap as deep as 3 tesla. CaH molecules are trapped at 400 ± 50 mK and can be observed for more than 2 s. (Figure from ref. 1.)

For future experiments, the experimenters hope to make a deeper trap or increase their detection sensitivity, or find a more rapid pumping method.

Doyle has a list of 50 promising paramagnetic molecules, including O₂, YbF (which would be good for a search for a permanent electric dipole moment of elementary particles), SiN and CrO.

Other approaches

A number of approaches to molecule trapping are being pursued elsewhere. Recently, Tetsu Takekoshi, Brian Patterson and Randy Knize of the US Air Force Academy reported trapping about 20 translationally cold Cs₂ molecules in an optical potential. The molecules were found to be produced as a by-product of a cold, dense, magneto-optical atom trap. They were loaded into an optical dipole force trap formed at the focus of a CO₂ laser beam; so the trap uses an electric field rather than a magnetic one to form a potential well.

William Stwalley, Philip Gould and their collaborators at the University of Connecticut in Storrs have proposed using multiline Raman cell radiation to optically cool alkali-metal dimers. Another approach to producing cold molecules for trapping, employing photoassociation of laser-cooled alkali atoms, has been proposed by Alex Dalgarno and R. Coté at Harvard and by Y. B. Band and P. S. Julienne at the National Institute of Standards and Technology (Gaithersburg, Maryland).

P. Pillet and his collaborators at Orsay and A. Nikolov and his collaborators at the University of Connecticut have reported direct observations of small numbers of alkali dimer molecules at cold translational temperatures.

Doyle believes it should be possible to load multiple species—for example, alkali atoms with atomic hydrogen or atoms with molecules. He expects that the dual trapping of alkali atoms with

hydrogen might greatly enhance the number of Bose-Einstein condensed hydrogen atoms. Another possible application is to condensed matter physics, to create a Fermi degenerate gas of weakly interacting atoms. "You could study superfluidity or optical transitions," says Doyle.

Stwalley believes that trapped, cooled molecules will lead to molecule optics, the counterpart of atom optics. And, he says, it may be possible to produce a molecule laser, somewhat comparable to the already produced atom laser. It would be a beam of molecules in the same vibrational, rotational and electronic state.

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Revisiting the Rain of Cometary Snowballs

It's an intriguing idea: A steady rain of kiloton minicometes of loosely packed ice, pelting the top of the atmosphere at a rate of about a dozen per minute could, over geological time, account for most of the water in the oceans, and who knows what else. That's the picture suggested last year¹ by Louis Frank and John Sigwarth at the University of Iowa, based on their observations with the Visual Imaging System (VIS), the Earth camera built by Frank and carried aboard NASA's Polar orbiter. (See PHYSICS TODAY, July 1997, page 18.)

An important part of Frank and Sigwarth's evidence was what appeared to be a steady patter of large, transient dark splotches in Earth's ultraviolet dayglow, imaged from above by

the VIS. That evidence has now been rather harshly challenged. In the 1 October issue of *Geophysical Research Letters*, Forrest Mozer, James McFadden and colleagues² at the University of California's Space Sciences Laboratory in Berkeley argue that the clusters of dark CCD pixels that Frank and Sigwarth took to be evanescent holes bored into the upper atmosphere by minicometes were nothing more than instrumental noise.

Having combed through one day's worth of raw data made available by the Iowa group and the group's public catalog of almost a million dark pixel clusters recorded by the VIS during a four-month interval last year, the Berkeley critics point particularly to the absence of the expected inverse-square correlation between apparent spot size and flux with the widely varying altitude of the spacecraft's very eccentric polar orbit. They also argue that the Iowa group's method of removing stray signals due to energetic particles traversing the camera actually produced spurious images of atmospheric holes. From a computer simulation of the VIS camera's noisy response to uniform illumination, Mozer and company have convinced themselves that Frank and Sigwarth's atmospheric hole results are "fully explained by instrumental effects without the need to invoke geophysical phenomena."

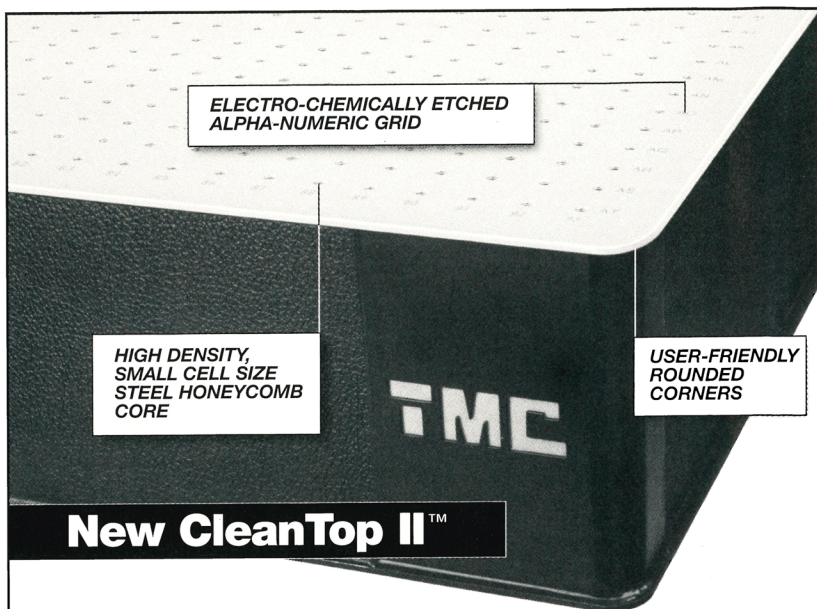
That conclusion may please the many skeptics who have been wondering all along how the putative rain of minicometes could have escaped the notice of other instruments scrutinizing the upper atmosphere or, for that matter, the surface of the Moon. But it has certainly not made an apostate of Louis Frank. "They can say nothing about our ultraviolet emission data, which are a crucial part of our evidence," he told us. Imaging by the light of prominent atomic-oxygen and hydroxyl-radical UV emission lines, presumably from the photodisintegration of water molecules in sunlight, he and Sigwarth produced spectacular multiple-exposure images of what appeared to be extended trajectories of minicometes approaching the Earth.

"In a long paper soon to be published,"³ Frank told us, "we discuss all the instrumental and geophysical issues in comprehensive detail."

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