such as *Drosophila* that have few bona fide pseudogenes (*10*).

Petrov *et al.* (*3*) examined multiple sequences of a LINE (long interspersed nuclear element) from 10 species of the Hawaiian cricket, which has a genome size about 11 times that of *Drosophila*. They present a phylogenetic tree of DOA elements. The terminal branches of this tree show evidence of relaxed selection in the form of equal numbers of changes in all three codon positions across the coding region. (In coding regions of functional genes, the substitution rate of nucleotides in the third position of the codon is generally higher than in the first and second positions; in pseudogenes all codon positions have similar substitution rates.) Their key finding is that in *Laupala* the average rate of deletion per substituted nucleotide in the LINE is significantly lower, and the average size of deletions significantly smaller, than in *Drosophila*. This translates into a rate of DNA loss for the cricket that is 40-fold slower than that for the fruit fly. Consistent with its markedly bigger genome, the pattern of deletions in *Laupala* is more similar to that in mammals than to that in *Drosophila*, even though *Laupala* is an insect.

It will be interesting to see how widely the inverse correlation between deletion spectrum and genome size holds up across diverse taxa. In mammals there is already a suggestion that the deletion spectrum (as estimated from processed pseudogenes) may differ according to genome size (*11*). By using degenerate PCR primers to identify a non-LTR element in *Laupala*, Petrov *et al.* (*3*) provide an experimental approach that should be applicable to almost any group of organisms. At a deeper level, why should creatures such as *Drosophila* and *Laupala* show such differences in tolerance or permissiveness toward excess DNA? Do these variations reflect intrinsic differences in the mechanisms of DNA replication or other genomic processes, or is this an adaptive trait or just plain chance? More information of the type provided by Petrov *et al.* as well as data from genome sequencing of diverse model organisms, should be useful in addressing these and related questions.

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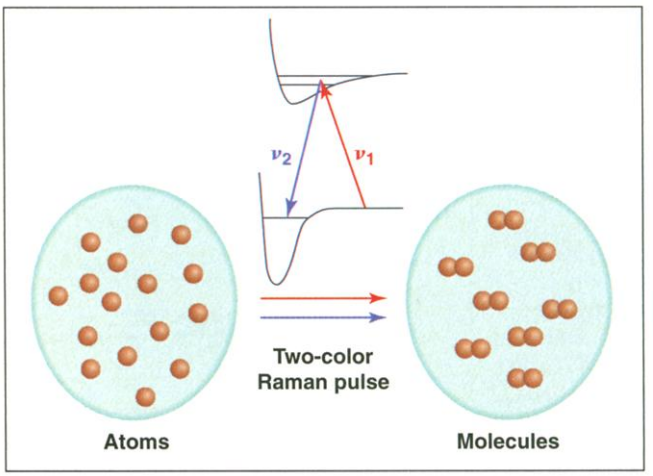
PERSPECTIVES: ULTRACOLD MATTER

Molecules at Rest

C. J. Williams and P. S. Julienne

In this issue (*1*), a group from the University of Texas reports producing rubidium dimers that are essentially at rest, by assembling them from ultracold Rb atoms in an atomic Bose-Einstein condensate (BEC). The report (see page 1016) contains several important accomplishments: the first observation of molecule formation in a BEC, an ultraprecise measurement of a molecular binding energy, and the first measurement of the interaction energy between a condensate and a molecule.

The development of cold or monoenergetic sources of matter has led to revolutionary breakthroughs in fundamental science and applications alike. Nowhere is this more obvious than in the use of lasers as light sources. Monoenergetic sources of atoms, neutrons, electrons, and ions have also provided new tools with wide-ranging applications in physics, chemistry, and biology. More recently, the production of cold, trapped neutral atoms, after a decade of progress in laser and evaporative cooling that reduced temperatures from 1 K to 1 nK, led to the observation of Bose-Einstein condensation of dilute atomic gases (*2*). An atom laser (*3*)—a coherent matter wave analogous to the photon laser—has now also been demonstrated. Cold, neutral trapped atoms and BECs are proving to be powerful tools for extending our understanding of atomic physics and of the collective properties of quantum fluids and are finding applications in precision atomic clocks and gyroscopes and in atom lithography.



Stimulated Raman production of molecules from an atomic Bose-Einstein condensate. The graph shows the ground and excited state potential energy curves for a pair of atoms. Two atoms in their ground state are optically coupled by lasers of frequency ν_1 and ν_2 to a bound dimer vibrational level with a binding energy of $h(\nu_1 - \nu_2)$. In the experiment, the frequency difference was controlled to much better than 1 kHz. Neither laser was resonant with an excited state vibrational level, and loss of coherence by excited state spontaneous radiative decay was therefore not a problem. The left and right pictures indicate a complete coherent interconversion between atomic and molecular forms of the condensate. Wynar *et al.* (*1*) only converted a fraction of atoms to molecules.

Unlike atoms, molecules have complicated internal vibrational and rotational structure and are therefore poor candidates for laser cooling. Although molecules are routinely cooled internally to a few kelvin with the use of supersonic expansions, they still have high translational velocities. Recently, several approaches have been developed for producing and detecting translationally cold molecules (*4*). At Harvard, Doyle's group (*5*) has developed an approach to trap cold molecules using a magnetic trap in a cryogenic helium refrigerator. The resulting molecules are not only translationally but also vibrationally and rotationally cold. With this method, 10^8 CaH molecules have been trapped at 400 mK. Meijer's group at Nijmegen (*6*) has used deceleration of neutral dipolar molecules using time-varying inhomogeneous fields to decelerate CO molecules to around 15 K. Further reductions in temperature are expected with this general tech-

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nique for polar molecules. Much colder molecules, with translational temperatures of a few hundred microkelvin, can be made by photoassociation of a pair of colliding atoms in a magneto-optical trap (*7–10*). These molecules are typically rotationally cold but tend to be vibrationally excited.

Wynar *et al.* (*1*) assembled their molecules by using a coherent two-photon Raman process that photoassociates a pair of atoms in a ^{87}Rb BEC (see the figure). This approach produces molecules in a single quantum state, in contrast to molecule formation in a magneto-optical trap, where spontaneous radiative decay of an excited photoassociated molecule results in a distribution over many ground rotational and vibrational states. In (*1*), the molecules are produced without mechanical rotation in a single, weakly bound vibrational state, only 636 MHz below the energy of two free atoms. The Raman process is such that the molecules receive negligible photon recoil momentum.

Because the atoms in the BEC are nearly at rest, with velocities of only a few millimeters per second, the molecules are also essentially at rest. Their temperature, which was not measured, is on the order of 100 nK or less. The extremely low velocities of the atoms and molecules yield a high-precision, nearly Doppler-free, molecular spectroscopy. Such precision spectroscopy of molecular energy levels could be used to accurately determine van der Waals coefficients for long-range interatomic potentials, to refine the scattering lengths that determine condensate properties, and to look for weak relativistic effects in long-range potentials.

One limitation of the current experiment is that once produced, the molecule is likely to undergo an inelastic collision with an atom in the condensate. This will result in ejection of an atom and a molecule from the trap by converting vibrational energy of the molecule into translational energy of the atom-molecule pair. Calculations on ultracold collisions of helium with molecular hydrogen have shown that rate constants for such collisions can be exceptionally large when the vibrational quantum number is large but are relatively small when the vibrational quantum number is small (*11*). Thus, it will be very important to determine the extent to which vibrationally excited molecules are stable with respect to collisional loss processes.

A recent set of experiments (*12*, *13*), although not designed to make or detect molecules, sheds light on these collisional loss processes. A magnetic field was used to tune a molecular bound state close to the energy of a pair of atoms in a ^{23}Na BEC. These results have been interpreted in terms of collisional formation of molecules in the condensate (*14–16*). In this case, the "molecule" is only a transient scattering resonance at the same energy as the atoms. The exceptionally large three-body rate constants measured for condensate destruction are explained by assuming a large rate constant for vibrational relaxation of the "molecule" when it collides with a condensate atom. This is consistent with the calculation (*11*) of large relaxation rate constants for highly excited molecular vibrations. Under appropriate conditions, a time-dependent ramp of the magnetic field may actually make stable molecular states from colliding atom pairs (*17*). A similar possibility exists with the use of frequency-chirped light (*18*). However, the collisional relaxation of such molecules would still be problematic.

The Raman photoassociation technique may ultimately be able to produce a pure molecular condensate. In this case, scientists will have succeeded in taking a coherent set of atoms in a single macroscopic quantum wave function and, with a couple of laser pulses, converting them reversibly into a set of molecules. Exotic properties have been predicted for such condensates, such as molecular solitons (*19*) or liquid-like chacteristics (*20*), but destructive inelastic collisions may prevent experimental realization. However, more complex laser pathways or additional laser intensity might enable the production of molecules in either the ground vibrational state or a state with small inelastic rates.

Sources of cold molecules are now at our disposal; study of their properties and development of applications are soon to come. For example, Wynar *et al.*'s techniques (*1*) could be modified to give two units of photon recoil momentum to the molecules. This might be a way to produce a coherent "molecular laser" analogous to the atom laser (*3*).

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PERSPECTIVES: PALEOCLIMATE

The Last Interglacial

George J. Kukla

The climate of the past 10 millennia, the Holocene, has been portrayed as uniquely benign and stable, with no past equivalent in the Pleistocene. In the core from the Greenland Ice Core Project (GRIP), the temperature proxies of the interval representing the last interglacial, around 125,000 years ago, fluctuate wildly, in striking contrast to the uniform Holocene section of the same core (*1*). Observations supporting large variability of the last interglacial are reported from around the world. But there are also plentiful arguments to the contrary. Other ice cores in Greenland and Antarctica (*2*) show little difference in the variability of the Holocene and the older interglacial sections. North Atlantic waters stayed uniformly warm, and temperate flora flourished in interglacial forests in Europe. So who is right?

At a symposium held last October at Columbia University (*3*), several questions were asked to resolve the dilemma. Are the geologic records continuous and the sedimentation rates reasonably uniform? Is the interpretation of the climate proxies correct? Most importantly, do the periods ascribed to the last interglacial at different locations refer to the same time interval? And did the last interglacial last as long as the elapsed part of the Holocene?

The best information on past global climates comes from deep-sea sediments. Isotopic oxygen ratios in the carbonate shells of bottom dwelling foraminifera

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