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

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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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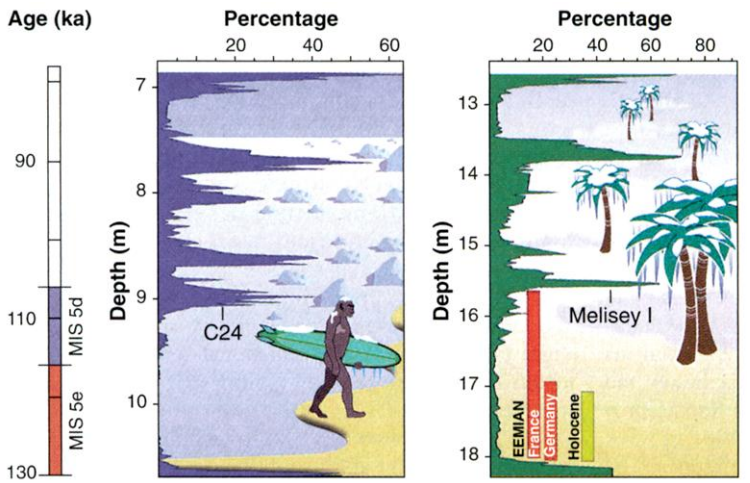
document the amount of seawater removed from the oceans and stored as ice on land. Time is divided into episodes with relatively high and relatively low global ice volume, with lowest ice storage during interglacials. The last episode showing a low ice volume similar to that of today is marine isotope stage (MIS) 5e, which designates the last interglacial. It started 130,000 years ago, peaked at 125,000 years ago, and terminated 116,000 years ago (*4*). During the next substage, MIS 5d, sea level was low and ice volume was high. MIS 5d culminated at 111,000 and lasted until 106,000 years ago (see the figure).

Marine and lagoon sediments deposited during the period of rising sea levels during MIS 5e near the Eem River in Holland contain temperate fauna and pollen of mixed deciduous forests, similar to today. Diatom-rich sediments in Bispingen, northern Germany, which are in part annually banded, show that grasslands replaced the forests of this so-called Eemian interglacial at about the time of the MIS 5e-5d boundary (*5*). Laminated marls in Quackenbruck, west of Hanover, support this conclusion (*6*). These observations are the basis of the prevailing chronostratigraphic model of the last interglacial, in which the Eemian warm climate, some 10 to 11 millennia long, is linked to the oceanic substage MIS 5e. According to this model, the replacement of forests by steppes and open woodlands, which mark the start of the last glacial, occurred about 115,000 to 117,000 years ago all over Europe; this shift to a cold and dry glacial environment in the Northern Hemisphere progressed in step with the gradual ice buildup.

This view has recently been challenged. Surface waters in the central North Atlantic remained warm during much of MIS 5d (*7*). The first major, but relatively short invasion of cool waters and icebergs into the central North Atlantic, labeled C24, occurred during partial retreat of glaciers late in the MIS 5d. Fronval and Jansen (*8*) traced the event in deep-sea cores from the Greenland Sea to the west of Ireland. Assuming a near uniform sedimentation rate during MIS 5, it appears that the C24 event also shows in a core off the Portugese coast, where it is marked by a sharp rise of oxygen isotope ratio in surface water foraminifera (*9*). Pollen in this core also place the demise of forests at this time. A close resemblance of cold water indicators in the central Atlantic core V21-191 with the fluctuations of steppes in Grande Pile, France (see the figure), provides strong support for the correlation. At Grande Pile, the "Eemian" forest lasted throughout much of MIS 5e and 5d (*10*).



Emerging views on the last interglacial. (Left) Marine substages MIS 5e and 5d and the cold water indicator *Neogloboquadrina pachyderma sinistra* in the deep-sea core V29-191 off the Irish coast (*7*). **(Right)** Percentage of nontree pollen in Grande Pile, France (*10*). Duration of MIS 5e, of the Eemian in Grande Pile, France, and in Bispingen, Germany, is shown in red. Equivalent duration of the Holocene is shown in yellow. Time scales were obtained independently by interpolation between 74,000- and 130,000-year-old tie points (*4*) and are untuned. (ka, thousands of years ago.)

In contrast to the central Atlantic, ice-rafting pulses in the Greenland Sea have already been detected in the upper part of MIS 5e. In the Ocean Drilling Program (ODP) 644 core off the coast of Norway, the first noticeable invasion of icebergs is near the MIS 5e-5d boundary (*8*). The disappearance of the forest in Bispingen may be linked to this event.

On the basis of these observations, the prevailing view of an unstable Eemian climate has to be revised. Climate oscillations detected in pollen records in the second half of the forest interval called Eemian in Grande Pile in France appear to be not of MIS 5e but of MIS 5d age. The stepwise replacement of deciduous trees with conifers and the abrupt disappearance of all hardwoods (*11*) accompanied the MIS 5d ice buildup in Spitzbergen and Greenland. Dry spells indicated by magnetic susceptibility in the French Massif Central (*12*) are probably of the same age. Given that only MIS 5e can be justly compared with the elapsed part of the Holocene (see the figure), there is little basis to conclude that the Eemian climate in Europe was more variable than that of the Holocene (*13*).

If this alternative interpretation of the Eemian demise is correct, the transition into the glacial was quite different from the conventional model. Climate in Europe remained stable during the first 10,000 or 12,000 years of the interglacial. The central North Atlantic remained warm throughout much of the initial ice buildup. Iceberg surges, at first minor and limited to high latitudes, were accompanied by cold and dry spells over land. The environmental gradient in the surface ocean as well as inland increased in several pulses. Steppes expanded earlier in Germany than in France. The end of the Eemian forest in Grande Pile came when icebergs surged into the central North Atlantic during the dissipation, not the growth, of the ice sheets.

Current interpretations depend heavily on indirect time estimates based on sedimentation rates and links to astronomic chronology. More absolute ages and annually resolved data sets are needed to replace climatostratigraphic timelines in long-distance correlations. The reconstruction of the processes that drove the interglacial Earth from a period that resembles that of today into a glacial, can teach us a lot about how climate may change in the future.

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