**Ultracold and unreactive fermionic molecules**

Suppressed density fluctuations of $^{40}$K$^{87}$Rb gases inhibit molecular collisions and reactions

By Tanya Zelevinsky

Many atomic elements have revealed their wavelike quantum nature at temperatures near absolute zero, and matter waves of molecules, which have richer symmetries and dynamics than atoms, could find diverse applications such as fundamental physics measurements, quantum information, and quantum simulations (1, 2). In the past 10 years, techniques of creating and controlling diatomic molecules in the ultracold regime have blossomed (3). The challenges of producing large numbers of long-lived ultracold molecules, however, had prevented the formation of a truly quantum molecular gas. On page 853 of this issue, De Marco et al. (4) now report the creation of a highly nonclassical gas of potassium-rubidium ($^{40}$K$^{87}$Rb) molecules. Observations of the gas demonstrated that destructive chemical reactions are strongly suppressed in this regime through antibunching effects that arise from Fermi-Dirac quantum statistics.

Classical particles are distinguishable, and interchanging any pair leads to a different configuration. However, quantum particles are identical and can be freely interchanged up to an overall sign change of the wave function. Fermions such as $^{40}$K$^{87}$Rb molecules obey the Pauli exclusion principle that forbids more than one fermion per quantum state. For atoms and molecules, fermionic behavior becomes apparent only at very cold sample temperatures $T$, where de Broglie wavelengths exceed typical separations between the particles. Fermionic quantum degeneracy, characterized by $T$ below the critical Fermi temperature $T_F$, was first observed in a noninteracting gas with K atoms (5).

De Marco et al. now demonstrate quantum degeneracy of molecular fermions at 50 nK, or $T < 0.3 T_F$, by assembling the molecules from exceptionally well-overlapped degenerate atomic gases of K and Rb that have been made extra cold through several steps of laser cooling (6). The assembly procedure involves turning K and Rb atom pairs into giant, barely bound dimers with a magnetic field and then shining a light pulse to increase the binding energy without releasing any excess kinetic energy (7). The energy diagram for the molecules trapped in a focused laser beam (see the figure) shows their occupation of individual quantum states. At $T < T_F$, the lowest trap energy levels are uniformly filled up to the Fermi energy.

Quantum degeneracy affects not only the energy distribution of the particles but also their spatial distribution. In particular, spatial fluctuations in degenerate gases bear a strong signature of the underlying particle statistics: They are enhanced for bosons and suppressed for fermions. This spatial antibunching expected for KRB is shown in the figure, bottom. At $T > T_F$, the gas behaves classically and exhibits regions of spatial lumping or clustering (highlighted in blue). Colder Fermi-degenerate molecules (right) exhibit antibunching behavior. The molecules have a highly uniform density and are largely immune to destructive collisions.

**Antibunching suppresses reactivity**

Quantum gas of fermionic potassium-rubidium molecules ($^{40}$K$^{87}$Rb) is less reactive at temperatures below the Fermi temperature $T_F$.

**Hotter molecules react and leave**

At temperatures $T$ above $T_F$, many lower energy states in the trap are unfilled (left). Warmer molecules in the trap (shown spatially on the right) occupy random positions, leading to density fluctuations and clustering. In the higher-density region (highlighted in blue), molecules are more likely to collide, react, and leave the trap.

**Colder molecules stay chill**

For $T$ well below $T_F$, the lower-energy states have a very high probability of being filled (left). Colder Fermi-degenerate molecules (right) exhibit antibunching behavior. The molecules have a highly uniform density and are largely immune to destructive collisions.

To maximize the effects of the interactions. The strong suppression of reactions in Fermi-degenerate molecular gases could also help realize protocols for quantum-information processing with polar molecules.

**REFERENCES**
