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Cold Polar Molecules and Applications

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Cold polar molecules lead us to new territories such as engineered quantum simulation, quantum computation, quantum condensed systems, quantum collision dynamics and to searches for physics beyond the Standard Model. The electric dipole moment that polar molecules carry is the key. Applied laboratory electric fields can effectively mix opposite parity rotational states, inducing dipoles with the strength of a full atomic unit. These dipoles interact strongly with external fields and with each other at long range – features that can be used to produce new many-body effects and control internal and external molecular degrees of freedom. New explorations and applications are envisioned for polar molecules. For example, placed on an optical lattice, molecules may provide a "toolbox" for creating spin-lattice Hamiltonians. Similarly, electric dipoles could be used as a quantum bits. For these and other reasons, considerable effort is focussed on making high density samples of trapped polar molecules. There are several approaches being taken to produce such high phase-space density samples of ground-state polar molecules with approximately 40 groups engaged in, or launching, an effort. Our approach to cold polar molecules starts with buffer-gas cooling. Cold helium gas is used to cool molecules from their initial production temperature (usually ≈100-1000 K) to around 1 K. Once cold, molecules can be loaded into traps or extracted in the form of a beam. Recent work in our group has led to results on spin relaxation in Σ state diatomic molecules, trapping of new species, demonstration of a novel high flux cold molecular beam technique and a proposal for an improved search for the electron electric dipole moment. Along with these results, a short introduction to the other methods of cold molecule production will be given.