

## **Final Technical Report**

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## **Slowing and Cooling Molecules via a Counter-Rotating Supersonic Nozzle**

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The advent of methods for cooling, trapping, and manipulating neutral alkali atoms with laser light provided access to intriguing hyperquantum phenomena, by virtue of achieving deBroglie wavelengths in the nanometer range [1]. To pursue such phenomena with molecules is an enticing prospect, since molecules offer many properties, particularly collisional and chemical interactions, not available with atoms. Dramatic examples involving quantum degeneracy have come from inducing formation of alkali dimer molecules within an alkali atom trap by photoassociation or Feshbach resonances [2]. For most molecules, however, formation from precooled atoms does not appear feasible, and the complexity of vibrational and rotational structure generally thwarts laser cooling. Over the past decade, several other means of slowing and cooling molecules have been undertaken. Yet results thus far remain very limited in scope [3].

The above outlines recent work in our lab that has finally attained a benchmark level of performance for a slow, cold beam source applicable to a wide variety of molecules. Our source, which exploits "inverse seeding" in xenon, can now provide  $\sim 10^{12}$  molecules/sec with velocities as low as  $\sim 15$  m/sec. That corresponds to translational kinetic energies of about 0.3K or less for molecules such as  $O_2$ , NO, and  $CH_3F$ , and deBroglie wavelengths  $\sim 7\text{\AA}$ . The method employs a supersonic nozzle, propelled by a high-speed rotor. Spinning the rotor with peripheral velocities of several hundred meters/sec, contrary to the direction of gas flow from the nozzle, markedly slows the emerging molecular beam in the laboratory frame. The supersonic expansion from the nozzle provides both high intensity and drastic cooling of internal states of the molecules. The high speed rotor also functions as a gas centrifuge, thereby enhancing the supersonic character of the gas flow. The device is applicable to a host of molecules, as it requires no special attributes (such as electric or magnetic moments) other than volatility.

Basic aspects of this method were examined in model calculations and assessed in exploratory experiments some years ago [4]. It remained tantalizing, however, as in practice until now the yield of slow molecules became too meager below about 70 m/sec. The major handicap was strong attenuation of slow molecules by scattering from background gas. Inputting gas into the spinning rotor ( $\sim 40,000$  RPM) is inevitably leaky, and the 360-degree spray of xenon from the whirling nozzle creates an even more important background. Reducing this by supplying improved pumping, liquid nitrogen

cooled shielding, and charcoal absorption of xenon proved challenging but produced key improvements.

We expect that in its current incarnation our slow, cold molecule source should find many applications. It is relatively simple and inexpensive to assemble, as well as compact (rotor only 10 cm long) and versatile. At least for fairly light molecules, it provides translational energies adequately low for spatial trapping by now standard means. It also offers the advantage of cumulative loading of traps. The small size of the source makes it particularly suitable for augmenting experiments employing electric, magnetic, or laser fields to manipulate molecules. As deflections induced by such fields are inversely proportional to translational kinetic energy, using slow molecules can hugely increase the sensitivity and resolution. Indeed, it becomes practical to utilize feeble but ubiquitous interactions, especially the induced electric dipole due to molecular polarizability and magnetic moments resulting from molecular rotation or from nuclear spins [5]. In our future work, we are eager to exemplify some of these applications. We also can now develop designs for a more universal counter-revolutionary supersonic source, capable of slowing a still wider range of molecules without the aid of inverse seeding.

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