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Exploring Cold Free Radical Neutral OH Molecules

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Research using cold atoms has led to novel discoveries in diverse areas such as atom optics, ultra-high resolution spectroscopy, precision measurements, ultracold collisions, optical lattices, and atomic fountain clocks. Extending this cold frontier to molecules offers many new exciting research areas such as molecular quantum collective effects, long-range intermolecular states, molecular dynamics and chemistry in the ultracold regime.

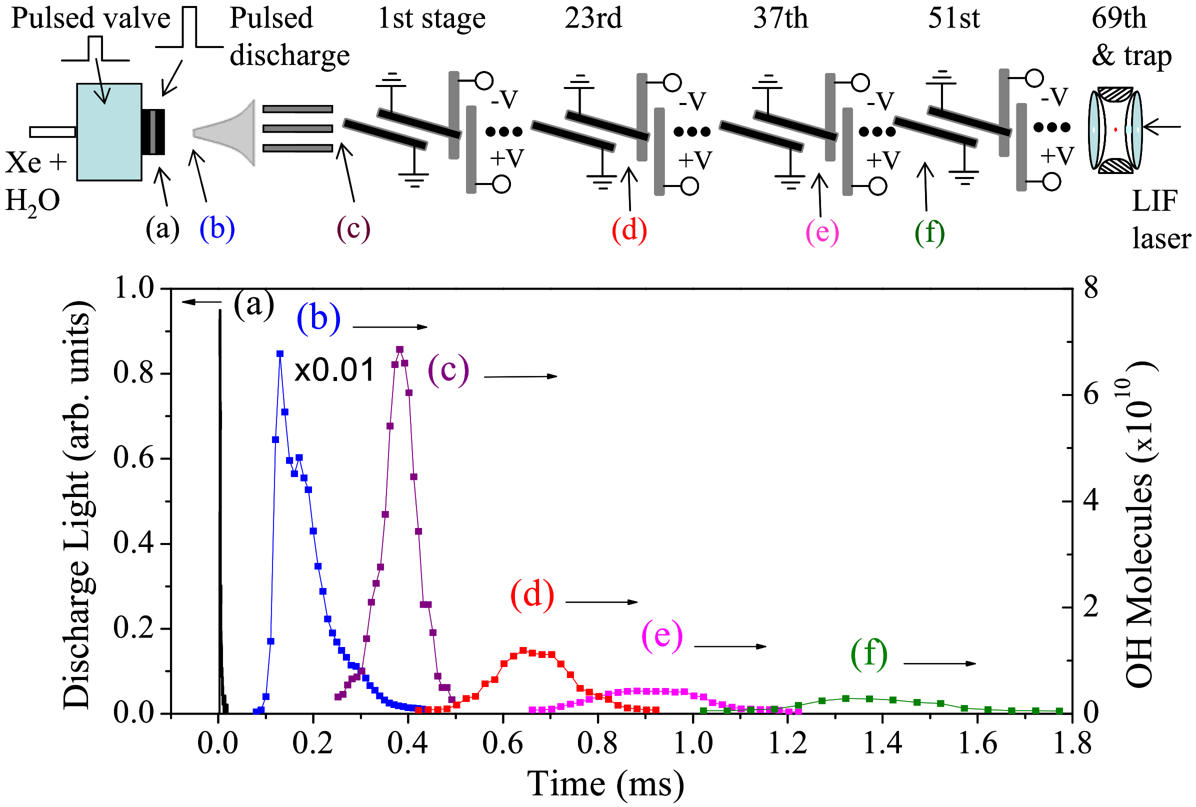

Fig. 1 The OH slower experimental apparatus: (a) shows a light peak generated by the discharge producing the radicals; (b) represents the OH molecular pulse before the skimmer; (c), (d), (e), and (f) depict the OH molecular pulse at various spatial locations as it propagates through the slower.

Generating molecules by supersonic expansion cools internal degrees of freedom and thus only the lowest energy states are significantly populated. Subsequently, the translational velocity of the molecules in the laboratory frame can be removed by exploiting the Stark shift associated with polar molecules[1] and utilizing time-varying electric fields. Our selection of the hydroxyl radical is motivated from both its extensive relevance to astrophysics and physical chemistry, as well as recent theoretical studies on cold collisions and controlled interactions between OH molecules. *In-situ* observation of laser-induced fluorescence (LIF) along the beam propagation path with a counter-propagating laser beam allows for detailed characterization of phase space manipulation of OH free radicals. Fig. 1(a) shows the pulsed discharge light flash, signaling production of OH. Fig. 1(b) is a time-of-flight spectrum taken by LIF of the OH molecules just before entering the skimmer. Figs. 1(c), 1(d), 1(e), and 1(f) reveal the longitudinal spreading of the molecular pulse, due to the finite temperature of the pulse, as it propagates down the slower under transverse guidance by static electric fields.

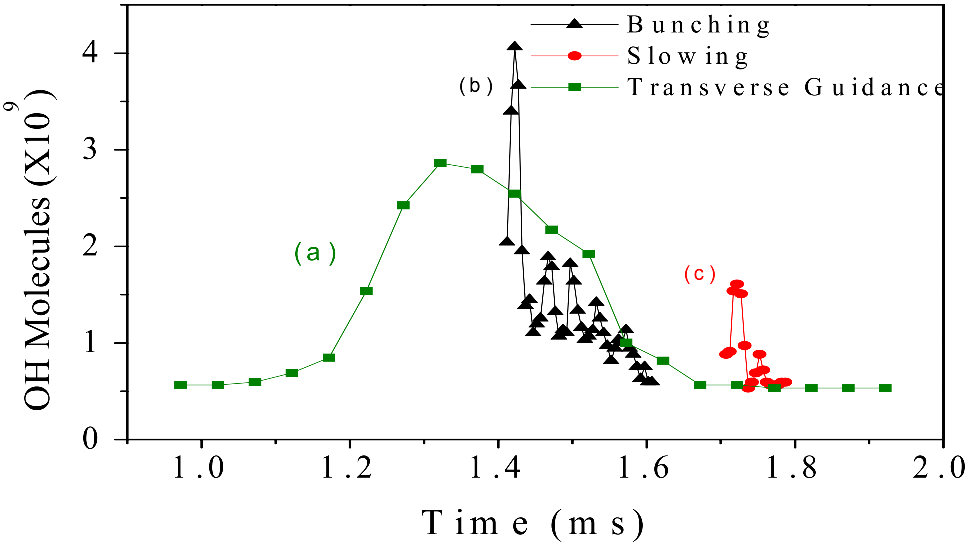

Fig. 2 Electric fields control the molecular pulse: (a) molecules under static guiding fields (trace (f) in Fig. 1); (b) synchronous switching transports the molecules; (c) molecules are slowed. Note that for (b) and (c) only half the pulse is visible because the electric fields shift the molecular energy levels via the Stark interaction.

In contrast, Figure 2 (b) and (c) show LIF signals observed at 51 stages within the slower under inhomogeneous electric fields switched with precise timing. Similar to Fig.1, trace (a) shows the molecular packet under static transverse guiding fields, whereas Fig. 1(b) demonstrates bunching of molecules, as the electric fields are switched at a rate to match the pulse's mean velocity. This switching effectively creates traveling potential wells in which molecules are trapped, producing the peak (trapped region) and valley (anti-trapped region) structure observed. By chirping the switching frequency, the molecules' speed can be decreased (Fig. 2(c)); this results in the molecular peaks arriving later in time, relative to the bunched peaks. Our latest results in phase space manipulations, slowing, and trapping of the hydroxyl radicals will be presented.[2]

References

1. H. L. Bethlem *et al.*, Nature (London) **406**, 491 (2000).
2. J. R. Bochinski *et al.*, submitted for publication (2003).