

Ultracold Collisions of Molecules

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Ultracold molecular samples are rapidly becoming an experimental reality, thanks to an array of new techniques, including photoassociation [1], buffer-gas cooling [2], Stark slowing [3], and expansions from moving jets [4]. These experiments will broaden studies of high-precision spectroscopy, present novel collision dynamics, and may ultimately produce new classes of degenerate Bose and Fermi gases with comparatively strong, anisotropic interaction potentials. Central to understanding the properties of ultracold molecules is the need to understand their collisions. This poster presents preliminary results on ultracold molecular collision dynamics, drawing on two experimentally relevant situations: buffer-gas loading of molecules into magnetic traps, and scattering of polar molecules.

Buffer-gas loading of molecules into a magnetic trap, experimentally demonstrated in [2], relies on reducing the translational temperature of the molecules via collisions with a cold (~ 0.5 K) helium buffer gas. For this process to be successful, the rate of elastic collisions that cool the gas must be sufficiently higher than the rate of spin-changing inelastic collisions that can produce trap loss. I have computed these rates for molecular oxygen, in a rigid rotor approximation [5, 6]. The results, summarized in Figure 1, suggest that elastic collisions are indeed substantially more frequent than inelastic collisions, which bodes well for the cooling process. Moreover, inelastic rates are suppressed for the isotope $^{17}\text{O}_2$ (Fig. 1(b)) relative to $^{16}\text{O}_2$ (Fig. 1(a)). This difference lies in the different fine structure of the two isotopes.

A second area of investigation concerns polar molecules, which experimenters have begun to slow electrostatically [3]. Here a main issue is the influence of anisotropic interaction potentials that fall off relatively slowly, i.e., as the inverse cube of the intermolecular separation R . For s-wave collisions, I find that the lowest energy adiabatic potential energy curve for the interaction of polar molecules is well approximated at large R by

$$-\frac{\bar{C}_6}{R^6} - \frac{\bar{C}_4}{R^4}. \quad (1)$$

In this expression the effective C_6 coefficient \bar{C}_6 can be of order 10^6 atomic units for “typical” polar molecules, and it is weakly dependent on the strength of an external electric field. The effective dispersion coefficient \bar{C}_4 by contrast vanishes in zero electric field, but becomes the dominant interaction as the field grows, thus completely altering the interaction and hence the scattering. The field dependence of these coefficients suggests an ability to control collision dynamics with the field, at field strengths as small as several hundred V/cm [7].

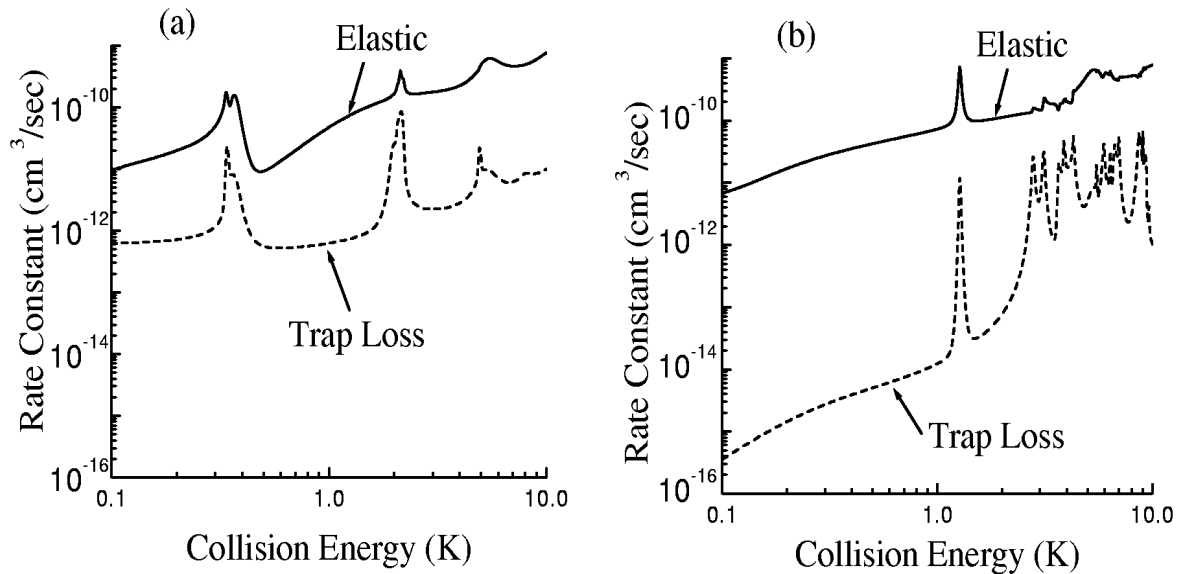


Figure 1: Collision rate constants for scattering of ^3He with $^{16}\text{O}_2$ (a) and $^{17}\text{O}_2$ (b) molecules at low temperature. In each case the solid line represents the elastic scattering rate, while the dashed line shows the rate for those collisions that produce untrapped spin states. The fact that elastic rates are generally far larger than trap loss rates implies that buffer-gas cooling should be quite effective [5, 6].

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