

Coherent Control and Trapping of Ultracold $^{87}\text{Rb}^{133}\text{Cs}$ Molecules

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The formation of ultracold heteronuclear molecules opens many exciting areas of research, spanning precision measurement, quantum computation, quantum simulation, ultracold chemistry, and fundamental studies of quantum matter. The large electric dipole moments of such molecules allow long-range interactions tunable over length scales similar to the spacing between sites in an optical lattice. Long-lived, trapped samples of molecules with full quantum control of the molecular internal state are crucial to realising many of their applications.

In this work, a sample of up to 4000 $^{87}\text{Rb}^{133}\text{Cs}$ molecules in their electronic, vibrational, rotational, and hyperfine ground state are created at ultracold temperatures in a two-step process. Initially, weakly-bound molecules are formed by magnetoassociation on a Feshbach resonance from a pre-cooled atomic mixture [1]. These molecules are then transferred to their rovibronic and hyperfine ground state by stimulated Raman adiabatic passage (STIRAP) [2]. The transfer is characterised by a precision measurement of the binding energy of the molecule with reference to an offset-free optical frequency comb; we find $D_0 = h \times 114\,268\,135.25(3)$ MHz [3].

We demonstrate coherent control of the rotational and hyperfine state using external microwave fields (see Fig. 1). Spectroscopy of the hyperfine structure of the first excited rotational state $N = 1$ allows us to determine accurate values of rotational and hyperfine coupling constants that agree well with previous calculations. We find that there is significant mixing between hyperfine states principally due to the scalar spin-spin coupling in $N = 0$, and nuclear quadrupole coupling in $N = 1$. Complete population transfer between selected hyperfine levels of the ground, first and second rotational states is performed using one- and two-photon π -pulses [4].

We investigate the interaction between the far-off-resonant light of our optical trap on the molecules. Through high-resolution microwave spectroscopy, we measure the AC Stark shift of the hyperfine states of the ground and first excited rotational states. We demonstrate that the trapping light can couple neighbouring hyperfine states, yielding rich and complex structure with many avoided crossings. This coupling is due to the anisotropic component of the real part of the AC polarizability. We show that this coupling can be tuned by varying the angle of the laser polarization to broaden or narrow select avoided crossings as required and to allow access to previously dark transitions between hyperfine states. This leads to our conclusion where we will be looking towards our future work, where we hope to investigate collisions between our bosonic molecules confined in a 3D optical trap.

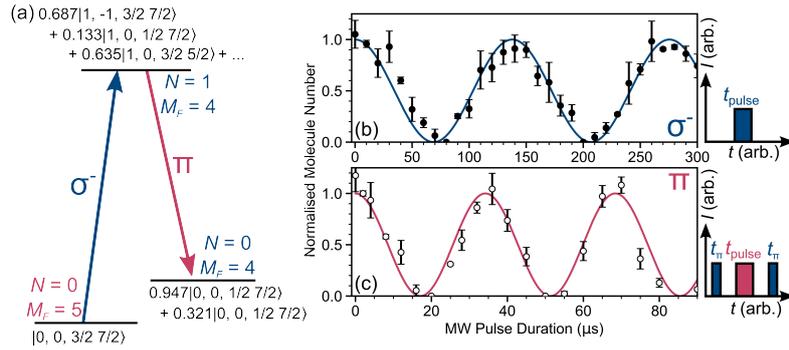


Fig. 1: Coherent population transfer of molecules between specific hyperfine states in rotational levels $N = 0$ and $N = 1$. (a) Transfer scheme followed in this work, where molecules begin in the lowest hyperfine state $M_F = 5$ of $N = 0$. States are described in the uncoupled basis set $|N, M_N, m_{\text{Rb}}, m_{\text{Cs}}\rangle$. (b) Rabi oscillations in one-photon transfer of molecules to the single hyperfine level of $N = 1$ shown in (a). (c) Rabi oscillations in two-photon transfer, using a π -pulse on the first transition and a second microwave pulse with different frequency and polarization to drive transitions to the $M_F = 4$ hyperfine state of $N = 0$ shown in (a). Figure reproduced from [4].

References

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