# Long-lived entanglement of molecules in magic-wavelength optical tweezers

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Ultracold polar molecules are a promising platform for quantum science and new quantum technologies. Their rich internal structures are ideal for densely storing quantum information and their long-range interactions provide a mechanism for information transfer. However, these properties make molecules highly sensitive to their environment, affecting their coherence and utility in some quantum-science applications.

Here, we show how these problems can be overcome by preparing molecules in an exceptionally controlled environment. We assemble individually trapped ultracold RbCs molecules [1] and transfer them into magic-wavelength optical tweezers. We encode information in the molecular rotational levels and achieve multisecond coherence times [2]. This long-lived coherence is simultaneously realisable for many rotational transitions, which we exploit to encode spin-1 dynamics in the molecules' rotational structure. Using this encoding, we perform quantum multiparameter estimation with a generalised Ramsey sequence to precisely measure the energies of rotational transitions.

In this pristine environment, we can resolve and exploit hertz-scale dipolar interactions between pairs of molecules in order to entangle them [3]. We entangle molecules using both spin-exchange interactions and direct microwave excitation and prepare two-molecule Bell states with fidelity $0.924^{+0.013}_{-0.016}$. This fidelity is primarily limited by leakage errors. In our experimental platform, we can detect and correct for these errors to achieve a corrected entanglement fidelity $0.976^{+0.014}_{-0.016}$. The second-scale entanglement lifetimes are limited solely by these errors, and we show how the entangled pairs of molecules can be used as quantum-enhanced sensors of local and global perturbations.

The extension of precise quantum control to complex molecular systems will enable their additional degrees of freedom to be exploited across many domains of quantum science. In particular, long-lived molecular entanglement unlocks opportunities for research in quantum-enhanced metrology, ultracold chemistry, and the use of rotational states in quantum simulation, quantum computation, and as quantum memories.

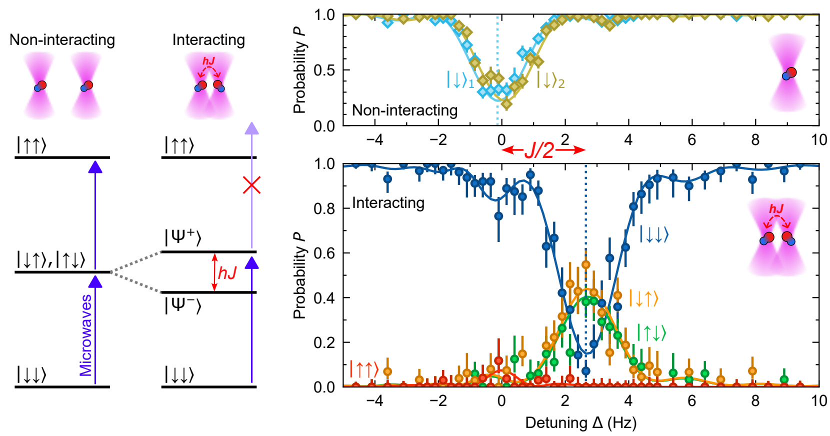


Figure 1: Microwave spectroscopy of interacting molecules. Left: Energy levels of molecules in the non-interacting and interacting cases. Right: Microwave spectroscopy of single molecules (upper panel) and pairs of molecules (lower panel). We resolve hertz-level interactions between pairs of molecules which we use to entangle them.

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**References**

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