Precision spectroscopy of cold formaldehyde in an electric trap

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Ultracold molecules are ideal systems for the investigation of fundamental physics. The rich internal structure renders them perfect candidates for measuring a variation of physical constants such as the proton-electron mass ratio and the fine structure constant. Due to high internal electric fields they are also well suited for measuring the electron's electric dipole moment. All these experiments require the highest attainable precision calling for trapping to increase interrogation times as is being done for atomic optical clocks. For neutral molecules however, in particular polyatomic molecules, there are few to none experiments combining spectroscopy with cooling and trapping. In our group we use optoelectrical Sisyphus cooling [1] to prepare large ensembles of up to $3 \cdot 10^5$ formaldehyde molecules (H_2CO) at sub-millikelvin temperatures [2]. Molecules are cooled and stored in an electric trap [3] which provides a box-like potential with a tunable and homogeneous offset field. Furthermore, we have good control over the internal state of the molecules and are able to prepare them with a purity of over 80 % in a single rotational state by optical pumping [4]. This setup provides us with an ideal environment to perform precision spectroscopy.

Here, we present microwave spectroscopy of trapped formaldehyde on a magic transition between rotational levels $J = 4$ and $J = 5$ with a splitting of 364 GHz. Tuning the trap's homogeneous electric field appropriately allows us to essentially eliminate Stark broadening which up to now has been the limiting factor, broadening transition lines on the order of MHz. We now achieve linewidths down to 3.8 kHz corresponding to an accuracy of 10^{-8} limited by the Doppler effect. By applying this technique to even colder molecules, which are readily available in our experiment, measurements with unprecedented precision for polyatomic molecules seem feasible.

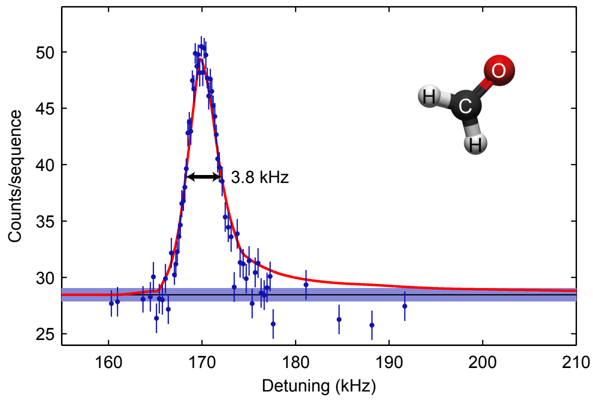

Fig. 1: Doppler-limited rotational transition line between $J = 4$ and $J = 5$ of trapped formaldehyde at 364 GHz. Measured data shown in blue and theoretical lineshape in red. Theory takes into account the energy distribution of the molecules and the electric field distribution in the trap.

References

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