

An ultracold gas of internal-state controlled polyatomic molecules

Alexander Prehn¹, Martin Ibrügger¹, Rosa Glöckner¹, Martin Zeppenfeld¹, Gerhard Rempe¹

¹Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Applications of ultracold ($T < 1\text{mK}$) polar molecules including ultracold chemistry, quantum simulation, high-precision spectroscopy, and hybrid quantum devices for quantum information processing exploit the rich internal level structure and the electric dipole moment of the molecules. These applications demand a high degree of control over both external and internal degrees of freedom triggering the development of novel cooling and control techniques for polar molecules. Focusing on chemically diverse, polyatomic molecules, our group was recently able to achieve two important goals: a large ensemble of formaldehyde (H_2CO) molecules was prepared at both sub-millikelvin motional temperature and with high rotational-state purity.

Specifically, we present direct cooling of formaldehyde to the microkelvin regime [1]. Our method of optoelectrical Sisyphus cooling, which was demonstrated previously with methyl fluoride (CH_3F) [2], proceeds in an electric trap [3]. By cooling the external motion by a factor of thousand and increasing the phase-space density by a factor of 10^4 we generate an ensemble of 300,000 molecules at a temperature of about $400\ \mu\text{K}$. Additionally, the molecules are prepared in a single rotational state with more than 80% purity employing optical pumping via a vibrational transition [4]. These results bring into reach studies of ultracold collisions or spectroscopy with a molecular fountain.

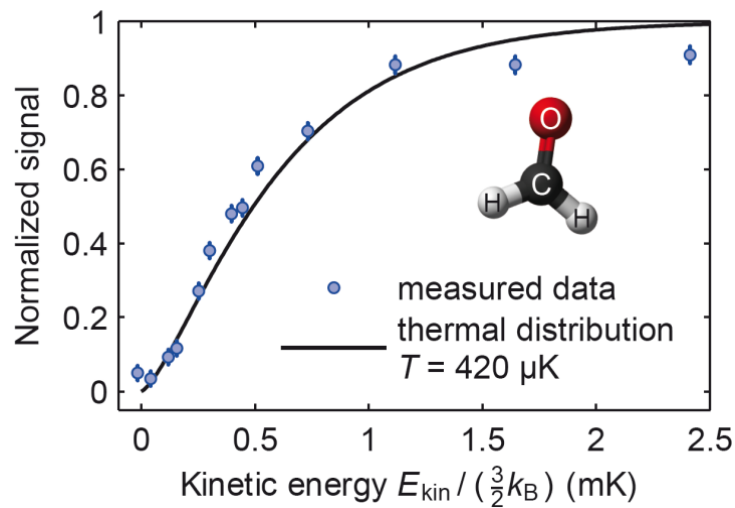


Figure 1. Measured integral of the kinetic energy distribution of the trapped gas of formaldehyde. The solid curve shows the expected distribution for a thermal ensemble at $420\ \mu\text{K}$ in a perfect box potential.

[1] A. Prehn *et al.*, Phys. Rev. Lett. **116**, 063005 (2016).

[2] M. Zeppenfeld *et al.*, Nature **491**, 570 (2012).

[3] B.G.U. Englert *et al.*, Phys. Rev. Lett. **107**, 263003 (2011).

[4] R. Glöckner *et al.*, Phys. Rev. Lett. **115**, 233001 (2015).