

Magneto-Optical Trapping of Aluminium Monofluoride

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Laser cooling and magneto-optical trapping of molecules has largely been limited to species with $^2\Sigma$ electronic ground states. While these systems have enabled major progress in ultracold molecular physics, they typically support only a limited set of rotationally closed optical transitions and often involve chemically reactive species. Molecules with singlet ground states offer an attractive alternative, providing enhanced chemical stability and access to additional transitions relevant for precision spectroscopy and narrow-line cooling.

Here we demonstrate the magneto-optical trapping of aluminium monofluoride (AlF), a deeply bound molecule with a $X^1\Sigma^+$ electronic ground state. The MOT operates on the strong $A^1\Pi \leftarrow X^1\Sigma^+$ transition near 227.5 nm, whose $Q(J)$ branch provides rotationally closed optical cycling transitions. Using this scheme we observe a MOT containing approximately 6×10^4 molecules for the $J = 1$ level, and we further demonstrate trapping of more than 10^4 molecules in the $J = 2$ and $J = 3$ rotationally excited levels. This feature sets AlF apart from molecules laser-cooled and trapped thus far, for which MOTs in levels beyond the first excited rotational level are considerably more complex.

The successful laser cooling and trapping of AlF establishes a new class of molecules with singlet electronic ground states as viable candidates for ultracold experiments. AlF is unique among laser-cooled molecular species in possessing a vibrationally diagonal, spin-forbidden $a^3\Pi \leftarrow X^1\Sigma^+$ transition, which features three rotationally closed Q branches. The metastable $a^3\Pi$ levels provide promising opportunities for narrow-line laser cooling, precision spectroscopy, and coherent manipulation of molecular internal states.

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