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The “hot” appeal of cold and ultracold molecules

The field of *cold* (1 mK–1 K) and *ultracold* (< 1 mK) molecules has timidly followed the revolution made by cold and ultracold atoms (and ions) in Atomic and Molecular Physics. Due to the additional degrees of freedom available in molecules and consequently the far more complex energy level structure, the production and applications of cold/ultracold molecules have presented complexities and challenges for experiments. However, recent experimental achievements open up new frontiers in this endeavour and the impact of creating ensembles of cold and ultracold molecules is expected to go well beyond the focus of traditional molecular science. Quoting the recent review paper by Carr, De Mille, Krems and Ye in the special issue ”Focus on Cold and Ultracold Molecules” of the New Journal of Physics: *cold and ultracold molecules may revolutionize physical chemistry and few-body physics, provide techniques for probing new states of quantum matter, allow for precision measurements of both fundamental and applied interest, and enable quantum simulations of condensed-matter phenomena.* In this Colloquium direct methods to slow or select pre-existing molecules will be briefly mentioned while the focus will be on the indirect methods linking together ultracold atoms. In particular, I’ll refer to photoassociation, taking Cesium molecules as a case. Having participated to recent experiments carried out in Pierre Pillet group at the Laboratoire Aimé Cotton, Orsay, I’ll report on the cooling of the vibrational internal degree of freedom of Cs_2 dimers. Our method is based on a simple non coherent optical pumping process to depopulate the undesired excited vibrational levels and to accumulate molecules into an arbitrary selected ‘target’ vibrational level. Since in this “Kastler type” optical pumping of molecules the coherence of the light is not concerned, simple broadband diode lasers could be used to prepare optical closed systems towards direct laser cooling of molecules. Results obtained so far from our experiments on translationally cold Cs_2 molecules will be detailed:

i) vibrational cooling into the lowest vibrational level v = 0 of the singlet $X_1\Sigma^+g$ ground electronic state by a shaped broadband femtosecond laser;
ii) transfer of a large fraction of the initially present molecules into a selected vibrational level, for example v = 1, 2, 7, by exploiting ultrashort pulse shaping techniques based on liquid crystal spatial light modulator;
iii) vibrational cooling by a collimated broadband diode laser operating below threshold, i.e. by an incoherent light source.

Extension to rotational cooling and quantum degeneracy will be eventually considered.