Seminar in "Ultra Cold Molecules"

Deceleration of Molecules

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In the past decade deceleration and cooling has been very successful with atoms. Now there is great interest to achieve the same with molecules. This presentation provides an inside view into the idea of experiments with "Time-varying electric fields". These experiments use the Stark effect in high electric fields for deceleration of polar molecules.

Cold conditions are in principle advantageous, because they mean longer observation and interaction times. With cold conditions some fundamental studies can be done with molecules: high precision spectroscopy, cold molecule–molecule collisions, cold chemistry and molecular Bose-Einstein condensation.

Laser cooling is very successful with atoms. The deceleration principle can be described very simplified as deceleration by momentum transfer from a laser-beam under the condition of an absorption-emission cycle in the atom. We find however that molecules are distributed over vibrational states after spontaneous emission, so that it is very difficult to find a closed two-level system in molecules. Laser cooling can thus not be applied for molecules.

The principle setup of the experiments is the following: First bunches of molecules are provided with a supersonic pulsed valve. The gas expansion cools all internal energies and produces bunches with a high average velocity, but very narrow velocity distribution. After exciting the valve the stream of molecules is spatialy selected with a skimmer and afterwards prepared with a laser beam if necessary. In the following they fly through the Stark decelerator and are finally detected with a time of flight method.

Molecules possessing an electric dipole moment gain Stark energy upon entering an electric field when in an appropriate quantum state. This gain in Stark energy is compensated by a loss in kinetic energy. If the electric field is greatly reduced before the molecule has left the electric field the molecule will not regain the lost kinetic energy. By letting the molecule pass through multiple pulsed electric fields they can thus be slowed down and brought to a standstill. The molecules experience additionally a force in the inhomogeneous electric fields towards the minimum electric field (low-field seeking state). This leads to focusing of the beam.

This idea is realized in the 'Stark Decelerator'. This consists of several stages of cylindrical rods placed equidistantly, alternately horizontally and vertically positioned. The fields on the rods are on the order of 10 kV, with fields of 120-200 kV.

In order to decelerate properly the bunch of molecules must be kept together throughout the decelerator. This requires, that the timing sequence of the pulsed field is chosen such that the »bunch« of molecules always has the same phase, i. e. , that the bunch of molecules is always centered around the same equilibrium position on the slope of the potential hill when the fields are switched. Therefore one has to lower the velocity of the potential well, by gradually increasing the time intervals after which the electric fields are being switched.

The time of flight (TOF) measurements show that only a small velocity distribution centered around the central velocity is captured and molecules outside the interval are not affected. This means that only a subset of molecules is decelerated.

This deceleration method is applicable for molecules with sufficient large positive Stark shift in experimentally feasible electric fields, sufficient low initial kinetic energy and sufficient low mass/Stark energy. It has been demonstrated so far with CO, NH_3 (Ammonia), OH, and YbF.

References

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