Summary

"Physics is really nothing more than a search for ultimate simplicity, but so far all we have is a kind of elegant messiness."

– Bill Bryson, A Short History of Nearly Everything

In my opinion, the main task of physics research is to delve deeper into that elegant messiness and try to unravel it a little more, carefully deciphering the code of Nature until it can be presented to our minds with ultimate simplicity. To this end, a wise approach is to measure or observe physical phenomena that are already known but with a new perspective, more detailed and scrupulous, in such a way that a whole new level of information can be extracted. High-resolution spectroscopic measurements are a very powerful tool used by experimental groups around the world for obtaining new information from an experiment. The task is mainly to obtain as much information as possible about the structure of atoms and molecules and the physics behind them by making them interact with radiation (light) that is contained inside a cavity. A beam of molecules will cross this cavity and will be interrogated by the radiation during the time they spend inside it. If the molecules move very fast, the time spent inside the cavity, and therefore the time they are interrogated, will be short, and a limited amount of information can be extracted. To make this time longer, the solution used in this thesis is to reduce the velocity of the molecules by manipulating them with electric fields. Very slow molecules will spend a much longer time crossing the cavity and being interrogated by the radiation, and therefore a greater amount of information can be obtained. With this technique, even fundamental physics theories to which certain atomic or molecular species are specially sensitive can be tested.

The main experimental problem with the achievement of long interaction times is that particles spread out over time due to their temperature and velocities, causing a decrease in density and, hence, a substantial decrease of the number of particles that reach the detector. This directly decreases the resolution of Ramsey spectroscopy, technique which we ultimately want to perform
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with slow molecules. To achieve the highest resolution, the target particles must be cooled so they don’t spread out during the measurement. Cooling techniques that are effective for manipulating atoms, like laser cooling, are highly inefficient or impossible in the case of molecules due to the complexity of their energy level structure. Hence, other techniques for manipulating and cooling molecules are needed. A method that has been proven very efficient is to exploit the Stark effect of a molecule using time-varying inhomogeneous electric fields. When a polar molecule is placed in an inhomogeneous electric field, the uneven distribution of charges gives rise to a net force that can be used to manipulate its overall velocity, temperature and trajectory.

The work shown in this thesis is in summary focused on obtaining a signal of slow molecules that is as large as possible on the detector to be able to reach unprecedented interaction times in molecules. Chapter 1 introduces the importance of slow atomic and molecular species for high-resolution spectroscopic measurements and gives an overview of our efforts on building a molecular fountain to measure the inversion frequency of ammonia. In the fountain, molecules would fly upwards, falling back under gravity and allowing for interaction times in the order of the second. Unfortunately, the low efficiency of usual Stark deceleration techniques did not allow for enough density of slow molecules to be able to see them falling back. In Chapter 2, we try to compensate for the low densities by testing whether a new ionization scheme for the molecules would be more efficient, giving us the possibility to detect more of them. This new scheme uses vacuum-ultraviolet light instead of the ultraviolet light used in the previous scheme. In Chapter 3, we build an unique ion lens that is able to separate the ions corresponding to different velocities of the molecules onto a CCD camera, giving us the possibility to eliminate the background of fast molecules from our signal of slow molecules. Chapters 4 and 5 show the implementation and testing of a new kind of Stark decelerator, a traveling-wave decelerator, which has practically no losses. Via computer control of the varying voltages applied to the traveling-wave decelerator, full manipulation of the molecules can be reached; this is shown in experiments in which we decelerate, trap and cool molecules. Finally, in Chapter 6 we are able to create an ultra-cold sample of ammonia molecules that is released from the trap and recaptured after a variable time. In this experiment, it is possible to observe molecules even after more than 10 ms of free expansion. A spectroscopic measurement could be performed during that time, offering interesting prospects for high-resolution spectroscopy and precision tests of fundamental physics theories.