In physics, the discrete symmetries Charge conjugation (C), Parity (P) and Time reversal (T) play a central role. The Standard Model (SM) [1–4] is the theory which explains the electromagnetic, weak and significant parts of strong interactions. It provides a correct description of all phenomena in particle physics observed to date. Here gravity, which is not included in the SM, is neglected. The SM is the most successful theory we know in (particle) physics. However, it leaves a much deeper understanding open. For instance, the number of particle generations, the origin of parity violation and the fundamental fermion masses. Experimental tests of the SM are motivated to identify new physical processes that would shed light on such as yet not well understood physical facts observed in nature.

One of the urgent physics problems to be addressed is to understand the origin of the dominance of matter over antimatter in the universe, called baryogenesis. In the SM the combined charge conjugation and parity symmetry is violated and has been observed in $K^0$ and $B^0$ meson decay. Such CP-violation is not sufficient to explain baryogenesis [5]. This requires other sources of CP-violation. These can be explored through searches for a permanent Electric Dipole Moment (EDM) of fundamental particles. The existence of an EDM for an elementary particle would violate parity P and time reversal symmetry T. Under the assumption of an invariance of physics under the combined C, P, and T transformation (the CPT theorem [6]) a permanent EDM also violates CP.

In the Standard Model EDMs can exist. They are induced in fundamental particles through CP-violating processes as known from neutral K-meson and

\footnote{We leave the possible embedding of recent neutrino oscillations into the SM outside of our considerations.}
B-meson systems, where they arise from higher order loops. However, they are by several orders of magnitude too small to be observed in the reach of current or planned experiments. Extensions of the Standard Model often lead to EDMs of a measurable magnitude, close to the present experimental limits. Thus, a measurement of a permanent EDM of a fundamental particle in any system (see Table 2.1) would be an unambiguous signature for physics beyond the Standard Model [7]. Because of this unique sensitivity several searches for an EDM are underway worldwide, spanning a wide spectrum of systems and experimental techniques. An experimental signature of an EDM would be the observation of a precession of the particle’s spin in an imposed external electric field. Since the origin of a non Standard Model EDM is not a priori known, the search for this CP-violating effect must be carried out in different systems. The tightest constraints on T-violation come from atomic physics measurements. The best of these at present is an experiment which employs $^{199}$Hg. It yielded an upper limit on an atomic EDM of $2.1 \times 10^{-28}$ ecm [8].

Recently, radium has been identified as a new candidate for EDM searches in neutral atoms [9]. Radium isotopes exhibit a high sensitivity to parity and time reversal violating effects due to their nuclear and atomic structure. The sensitivity to a possible EDM of the nucleons can be orders of magnitude larger than the original particle EDM. This stems from shape deformations of the nucleus. Octupole deformation leads to near degeneracy of states with opposite parity. Several isotopes of radium are known to have this property and theoretical estimates result in a factor 50-500 times enhancement for a nuclear EDM compared to the mercury atom [10, 11]. For example, $^{225}$Ra has a large octupole deformation in the nuclear ground state.

Radium also offers a higher sensitivity to an electron EDM due to its atomic structure [12,13]. According to the available atomic level data one can find almost degenerate levels of opposite parity states, i.e., between $7s7p \, ^3P_1$ and $7s6d \, ^3D_2$ states [14]. In the literature the energy difference is reported as only 5 cm$^{-1}$ and the enhancement of an electron EDM can therefore be as large as 10000 [12, 13]. This can be investigated by sensitive laser spectroscopy methods. Because of these properties radium offers a great potential for (the discovery of) a permanent electric dipole moment both of electron and nucleus.

Atomic physics has played a central role in the development of modern physics in particular in explaining the structure of atoms, in the development of quantum mechanics and the start of the most accurate field theory we know: Quantum Electro Dynamics (QED) [15]. We exploit atomic physics methods because of their potential for precision measurements. Through atomic laser spec-
troscopy, information on the nuclear charge radii, nuclear moments etc., can be obtained. Another modern atomic physics technique is laser cooling and trapping of atoms [16]. This has led to a renaissance in atomic physics. Neutral atoms can be cooled and trapped with the combination of optical and magnetic forces attaining thereby very low temperatures. Large samples of atoms can be kept substrate free and well localized in space. Almost zero first-order Doppler shift, long interaction times and high isotope selectivity can be realized. We plan to utilize atomic physics methods for EDM experiments with radioactive radium.

The rare and rather short-lived (e. g. $^{213}\text{Ra}$) radioactive radium isotopes have to be produced close to the spectroscopy laboratory. The TRIP facility that our group is setting up at KVI, particularly provides the close proximity of isotope production and spectroscopy laboratory [17]. Using heavy-ion beams from the superconducting cyclotron AGOR we studied production of the radioactive radium isotopes. These isotopes are separated from the primary beam and other reaction products using a magnetic separator [18] that is in use since its commissioning in May 2004. The separated high-energy radium isotopes will be thermalized in a thermal ionizer stage and turned into a low-energy beam by Radio Frequency Quadrupole cooler and buncher. A low-energy beam line allows to transfer the ions to traps. They will be neutralized and trapped to carry out the high-precision experiments. This requires development of trapping methods for radium. Until recently it has not been attempted to do laser cooling and trapping on radium.

This thesis describes the first steps towards exploitation of the potential to observe symmetry violating effects in radium. In order to perform spectroscopy we have set up a laser laboratory with a variety of tunable lasers for all wavelengths of importance to these experiments. To perform EDM experiments on radium, two main scientific challenges have to be accepted:

- Determining the spectroscopic properties of radium including verification of transition wavelengths and line strengths.

- Preparing for cooling and trapping of heavy alkaline earth elements.

Because of the radioactivity of radium we have chosen to prepare the cooling and trapping with the homologue barium.

We expand the laser cooling and trapping methods to heavy alkaline earth elements barium and radium. Stable barium is well suited as a precursor for radioactive radium, because of its similar level scheme and chemical properties. We set up a laser laboratory from scratch. Semiconductor diode lasers, laser electronics were built and iodine spectroscopy was established. We investigated the
spectroscopy of metastable $D$-states in barium. In particular, we did the first laser spectroscopy of these states measuring the hyperfine structure and the isotope shifts. The essential input from the spectroscopy of the $D$-states led us to achieve for the first successful slowing of a thermal barium beam with light forces.