Molecular radicals in the search for drifting constants

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Chapter 1

Summary

1.1 Outline of this thesis

This thesis will present the progress towards setting a constraint on the possible time-variation of the proton-to-electron mass ratio using a measurement of a two-photon microwave transition in the $a^3\Pi$ state of CO. This transition between two nearly-degenerate rotational levels is highly sensitive to such a variation. In the planned experiment, a beam of metastable CO is prepared in a pure quantum state by expanding CO into vacuum and exciting the molecules using a narrow-band UV laser system. After passing two resonant microwave cavities that are separated by 50 cm, the molecules are state-selectively deflected and detected 1 meter downstream on a position sensitive detector.

In Chapter 2, to show that we have good control over the production of metastable CO, the $a^3\Pi$ state of CO is characterized by high-accuracy UV spectroscopy. We determined the frequency of the two-photon microwave transition with an accuracy of 0.5 MHz, reducing it's uncertainty by well over an order of magnitude. Furthermore, mass-scaling relations were used to calculate the sensitivity coefficients of a number of transitions between nearly-degenerate levels in different isotopologues. In Chapter 3, cavity ring-down spectroscopy is performed on the $a^3\Pi$ state of two isotopologues of CO, and it is found that the mass-scaling rules for the $a^3\Pi$ state can be used to predict the transition frequencies from $v = 0$, $J < 8$ in $^{12}C^{16}O$ to $v = 1$, $J < 30$ rovibrational levels in both $^{12}C^{18}O$ and $^{13}C^{16}O$ to within the experimental accuracy of 0.2 cm^{-1}. The design of the electro-static deflection field that is used to state-selectively deflect molecules in the microwave measurements is discussed in Chapter 4. Here, the theoretical description used for the design of the deflection field is also used to study two types of storage rings for molecules in high-field seeking states. In Chapter 5 we show that high precision microwave spectroscopy can be performed on CO ($a^3\Pi$) in the planned setup. We measured the $\Omega = 1$, $J = 1$ lambda-doublet splitting around 394 MHz to an accuracy of 10 Hz, and discuss systematic effects that influence the result.

In Chapter 6 the sensitivity to a variation of α and μ is calculated for rotational transitions in the ground states of CH and CD molecules. It is shown

that rotational levels with $\Delta J = 1$ in different Ω manifolds can become nearly degenerate, but the strength of transitions between the two levels converges to zero. This makes these near-degeneracies less interesting for the search for a variation of fundamental constants, leading to the conclusion that a two-photon transition is the best candidate.

In Chapter 7, an outlook towards measuring the highly sensitive two-photon microwave transition is given. A setup very similar to the molecular beam setup used in the one-photon microwave measurement is being planned, changes that need to be made to the setup are discussed in this chapter. As the highly sensitive transition is a two-photon transition, it requires a more intense microwave field. The transition strength is calculated, and a resonant microwave cavity is designed and tested. Also, a higher rotational level needs to be excited by the UV laser, resulting in a higher number of m_J^B sublevels, a smaller deflection and a lower population, the consequences of which are also discussed.