

Precision measurements in one- and two-electron atoms and molecules

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One- and two-electron atoms and molecules play a key role in atomic and molecular physics. They are sufficiently simple that almost exact *ab-initio* calculations of their energy-level structure and transition frequencies can be performed. Precision measurements of transition frequencies in these systems serve to test these *ab-initio* calculations and the underlying theories, with two possible outcomes. In the case of agreement between experimental and calculated frequencies, the comparison can lead to improved values of physical constants. In the case of disagreement, the comparison may point at incomplete aspects of the theory. Three different experiments will be presented which aim at measuring transition frequencies to highly excited Rydberg states in H, He and H₂ and extrapolate to the ionization energies with high precision.

i) Extensive studies of transitions between low-lying ($n \leq 12$) Rydberg states of H have been carried out and combined with the 2s Lamb shift determination in muonic hydrogen to obtain values of the Rydberg constant and the proton charge radius [1]. We will present our experimental approach to determine the ionization energy of H from measurements of transition frequencies between the metastable 2s $^2S_{1/2}(F = 0, 1)$ states of H and highly excited np -Rydberg states with principal quantum number $n \geq 23$. These transitions, combined with other measured $np \leftarrow 2s$ transition frequencies ($n = 2, 4$) [2, 3] can be used to determine the Rydberg constant independently of the proton rms charge radius.

ii) The long-lived metastable He ($(1s)^1(2s)^1$) atom in its singlet (1S) or triplet (3S) state is an ideal system to perform tests of state-of-the-art *ab-initio* calculations including high-order quantum electrodynamics corrections. In a recent study, Patkóš *et al.* [4] calculated the Lamb shift of triplet helium up to $\alpha^7 m$, and pointed out a possible unknown correction to the 3S and 3P term values, which might explain a discrepancy between theoretical and experimental values of the $3^3D \leftarrow 2^3S$ transition frequency. This discrepancy was confirmed at the 10σ level by Clausen *et al.* [5] who measured the ionization energy of the 2^1S state and combined it with experimental transition frequencies between low-lying singlet and triplet Rydberg states of He to derive the corresponding ionization energies of the 2^3S , 2^3P and 3^3D states.

iii) The dissociation energy D_0 of the hydrogen molecule H₂ with its isotopologues HD and D₂ are ideal for benchmarking *ab-initio* molecular quantum calculations [6] including non-adiabatic, relativistic and QED contributions. The precision and accuracy of the experimental and theoretical values of D_0 approach the level where a comparison can contribute to the determination of physical constants, such as the proton-to-electron mass ratio and the proton rms charge radius [7, 8].

To guarantee a high accuracy and SI re-traceability of the measured transition frequencies, we have recently connected our laboratories to a distribution network of a primary frequency standard from the Swiss metrology institute METAS, in the realm of a Sinergia project of

SNSF [9]. The network currently links METAS, the University of Basel and ETH Zurich in a closed-loop configuration enabling to monitor the acquired phase-noise after a complete roundtrip.

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