Report on the PhD degree dissertation of Mr. Georgi DOBREV

in view of obtaining the degree of Doctorate from St. Kliment Ohridski University
and the Lyon 1 University
in the framework of a co-tutelage supervision between the Lyon 1 University in Lyon, France and
the St. Kliment Ohridski University in Sofia, Bulgaria.

Mr. Georgi DOBREV has presented in his dissertation entitled "Laser spectroscopy for coherent manipulation and state-specific probing of atoms and molecules" the ensemble of works realized in the framework of this thesis in co-tutelage between the Lyon 1 University and the St. Kliment Ohridski University. These works have been performed within three projects respectively carried out in three laboratories in St. Kliment Ohridski University in Sofia, in the German National Metrology Institute in Braunsweig (PTB), and in Lyon 1 University in Lyon. The common background of these three projects is the laser spectroscopy of quantum systems such as atoms or molecules, either in the form of excitation spectroscopy or in form of absorption spectroscopy. The purpose of the collection of works is to realize coherent manipulations of atoms and molecules, in the point of view of their translational degree of freedom as well as in the point of view of their internal states. The possible applications of the concerned fundamental researches can involve the preparation of condensed quantum systems, the improvement of the performance of an atomic clock based on a cesium atomic fountain, and the investigation of the spectroscopic data of transition metal hydride radicals such as FeH, NiH and NiD, completing spectroscopic database for Astrophysics.

The dissertation of 159 pages is organized in three Parts corresponding to the three projects realized in this PhD work. The technical contents are presented in fourteen chapters through the above mentioned three Parts. The whole is preceded by a general introduction and followed by an appendix where the author specifies his personal contributions in the three projects. The dissertation is well organized, the text written with good English and illustrated with clear and informative figures. Inside each of the three Parts, relatively independent each other, there is always an introduction, a presentation of the specific theoretical background, a description of the used or realized experimental setup, and a presentation and discussion part for the obtained results. A bibliography is provided respectively for each of the three Parts of the dissertation.

In the Part I, the author describes the realization of an experimental setup in the St. Kliment Ohridski University intended to test the theoretical predictions of the experiments to be performed with coherent manipulation of Ca atoms. After a brief presentation of the energy structure of the Ca atom, the setup is described in detail through its main parts of the vacuum system, the oven, and the detection system using laser-induced fluorescence (LIF). The LIF signal is then shown, demonstrating the proper operation of the atomic beam. The further works are planned to improve the frequency stability of the developed laser diode for LIF operation and to add phase-controlled laser beams for sequential and coherent excitations of the atomic beam.

The Part II of the dissertation is devoted to the works realized in the German National Metrology Institute for the improvement of an existing cesium atomic fountain clock (CSF2). The principle of such improvement is loading the fountain optical molasses with a low-velocity intense source (LVIS) generated with the help of a modified three-dimensional magneto-optical trap (MOT). In such modified version of MOT, the trapping force is slightly unbalanced for one of the three axes. Such unbalancing is in addition limited in the central part around the axis in question. This leads to an accelerating force which expels a beam of cold and dense atoms towards the fountain molasses along the unbalanced MOT axis. In this Part, the hyperfine structure of the cesium atom and the principle of laser cooling of neutral atoms are first recalled. The author describes then the atomic fountain clock CSF2 at PTB. The current configuration and performance are presented in detail. The influencing factors on the frequency stability of a fountain atomic clock and on the noise of a local oscillator are analyzed. The author concludes in the necessity of increasing the number density of the atomic beam loading the fountain molasses. Loading with a LVIS is therefore proposed as a solution to improve the performances of the PTB fountain atomic clock. In the dissertation, the experimental setup for the generation of LVIS is described in detail. Preliminary results of the fountain molasses loading with the LVIS is shown together with the effect of the repumping laser. The optimized slow atomic beam is then characterized in terms of its velocity and its flux. The author finally presents the operation of the CSF2 fountain atomic clock with the LVIS loading. The measured clock instability of $\sigma_y(1s) = 2.7 \times 10^{-14}$ is close to that of a primary fountain atomic clock of $\sigma_y(1s) = 1.6 \times 10^{-14}$, loaded from a decelerated Cs atomic beam.

In the Part III of the dissertation, the works realized in Lyon and in Sofia about high resolution spectroscopy of transition metal hydride radicals are presented. The motivation of these works is to provide spectroscopic data for interpretation of astrophysical observations. These data include magnetic-field-free transitions frequencies, relative line intensities and effective g-factors. A coaxial discharge source and a hollow cathode sputtering source have been respectively built in Sofia and in Lyon for the preparation of NiH, FeH and NiD radicals. The first source has been used to detect differential absorption spectrum of NiH radicals as well as its Zeeman shifts. With the second source, the high-resolution spectroscopy on the Zeeman effect in FeH radicals has been performed. LIF Zeeman spectra of FeH have been obtained with the developed setup. The analysis of the obtained spectra leads to the determination of the reduced Landé factor for the $F^4\Delta$ state as a function of *J*. In the last chapter of the dissertation, a setup which couples the sputtering source to a cavity ring-dawn spectroscopy (CRDS) detection system is presented for highly sensitive detection of rotational distribution in NiH and NiD radicals. The development of this new setup is described in detail. The performance of the setup is presented in terms of the scan reproducibility and the sensibility of molecular concentration determination.

In conclusion of my report, Mr. Dobrev has presented an ensemble of works realized in the framework of a PhD thesis in co-tutelage between the Lyon 1 University and the St. Kliment Ohridski University. A large amount of result has been obtained which represents at the same time, technical performances and fundamental advances in the domain of coherent manipulations of quantum systems such as atoms and molecules. Such performances and advances are at the cutting edge of the precise and sensitive laser spectroscopies for various applications in fundamental researches, time and frequency standards as well as Astrophysics. The presented dissertation shows a clear structure, well-chosen materials as well as a careful language. In addition, the presented results have been published in three peer-review journals, which certifies furthermore the quality and the significance of the performed researches. I recommend therefore that Mr. Dobrev defends his thesis before the examining committee, and that if he satisfies the examiners in the oral examination he should be awarded a Doctoral Degree from the St. Kliment Ohridski University and the Lyon 1 University.

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