REVIEWER'S REPORT

of a thesis submitted for awarding the scientific degree „PhD“ in 4.1-Physical sciences according to the procedure pursued in Faculty of Physics of Sofia University “St. Kliment Ohridski”

The report is prepared by Associate Professor Dr. Sci. Andon Angelov Rangelov from Faculty of Physics of Sofia University “St. Kliment Ohridski” in his capacity of a member of the jury according to order RD38-273/03.06.2024 of the Rector of Sofia University.

Title of the Thesis: "Ultrafine structure of selected states in diatomic molecules"

Author of the Thesis: Velizar Rosenov Stoyanov

I. General description of the submitted documents

1. Data for the submitted documents

The candidate Velizar Rosenov Stoyanov has submitted a dissertation in English, an abstract in English and Bulgarian, a curriculum vitae, a diploma for a completed higher education with a "master's" degree, an order for enrollment in the doctoral program, an order for the extension of the period of the doctoral program, a declaration of authorship, an application for pre-defense, a certificate of the successfully passed exams and the deduction of the candidate with the right of defense, protocol for verifying the originality of a dissertation work, as well as copies of the two publications contained in the dissertation work.

The documents submitted by the applicant for the defense comply with the requirements of the laws and the regulations for the terms and conditions for acquiring scientific degrees and occupying academic positions at Faculty of Physics of Sofia University “St. Kliment Ohridski” (ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ).

2. Applicant data

Belizar Rosenov Stoyanov was born in 1995 in Kyustendil. He graduated from the high school of science and mathematics "prof. Emanuil Ivanov" Kyustendil in 2014.

From 2014 to 2018 he was a full-time student at the Faculty of Physics of Sofia University “St. Kliment Ohridski” specialty "Quantum and Cosmic Theoretical Physics". From 2019 to 2020, he is a master's student in the specialty "Theoretical and Mathematical Physics" again at the Faculty of Physics of Sofia University “St. Kliment Ohridski” From 2017 to 2018, while still a student, he worked as a technician at "IBFotonica" EOOD.

From 2020 to 2024, he is a full-time doctoral student in professional direction 4.1- Physical sciences, specialty: "Physics of atoms and molecules" at the Department of "Optics and Spectroscopy", Faculty of Physics of SU Sofia University “St. Kliment Ohridski”. From 2020 to 2021, while he was a doctoral student, he was also appointed as a physicist in the Research Sector at Sofia University “St. Kliment Ohridski”. From 2022 to 2023, he was appointed as a first-level researcher under the program "Young scientists and post-doctoral students", Faculty of Physics of Sofia University “St. Kliment Ohridski”. From 2023 until now, he has been appointed as a young scientist under the "Sofia University - Marker for Innovation and Technology Transfer (SUMMIT)" project.

3. General evaluation of the scientific achievements of the applicant

a) the scientific publications included in the dissertation meet the requirements of the laws and the regulations for the terms and conditions for acquiring scientific degrees and occupying academic positions at Faculty of Physics of Sofia University “St. Kliment Ohridski” (ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ);

b) scientific publications included in the dissertation work do not repeat those from previous procedures for acquiring a scientific title and academic position;

c) no plagiarism has been proven in accordance with the law in the submitted dissertation work and in the abstract on it.

4. Characteristics and assessment of the candidate's teaching activity

I have no data on the doctoral student's teaching activity.

5. Content analysis of the applicant's scientific and scientific-applied achievements contained in the materials for participation in the competition

Timeliness of the problem

Diatomic molecules are the simplest molecules in nature, yet they represent a significant challenge to both experimental and theoretical physics. They have many more energy levels than atoms because, in addition to electronic motion, diatomic molecules possess vibrational and rotational motion. This results in complex spectra that, although discrete, contain multiple lines that are difficult to detect in experiments. The spectrum, including the frequencies and intensities of these lines, is key to identifying the molecules. The theoretical description of the properties of diatomic molecules, including the quantum energy levels and the corresponding wave functions, is very complex and cannot be achieved with sufficient accuracy only in a purely theoretical way, therefore a number of approximations and empirical fitting parameters are used for their description. In his dissertation, Velizar Stoyanov investigated spectra of the diatomic molecule **KRb** with four different methods and skillfully managed to achieve a good match between theory and experiment for the observed spectra. The given theoretical model (with an effective Hamiltonian) successfully explains the line broadening in $^{39}\mathrm{K}^{85}\mathrm{Rb}$ and their separation into $^{39}\mathrm{K}^{87}\mathrm{Rb}$.

General overview of the dissertation work

The presented dissertation is mainly an experimental and partly theoretical study of different spectral lines of the diatomic molecule **KRb**. The dissertation is written in good English in a volume of 178 pages and includes 31 figures, 5 tables and 104 literature titles. The abstract is written in English and Bulgarian and correctly reflects the content of the dissertation. The dissertation is structured in 9 chapters, with chapters 1 and 2 being introductory. Chapters 3, 4 and 5 systematically present the theoretical model, later used together with numerical methods, to explain the experimentally obtained spectra. Chapter 6 examines in detail the theoretical justification of two of the total four spectroscopic methods used in the dissertation, namely saturation spectroscopy and double optical resonance spectroscopy. In chapter 7 the experiment is presented and the main experimental results are given. Chapter 8 compares experimental results with theoretical predictions using numerical simulations. Chapter 9 provides a summary. Although I struggled to distinguish the contributions in the thesis, I think they are classified as follows:

1. obtaining **KRb molecules** from a furnace and finding the optimal operating mode;

2. construction of an experimental set-up including furnace lasers and spectral schemes;
3. **KRb** spectra by four different methods;
4. development of a theoretical model for the **KRb spectra** taking into account the fine and hyperfine structure of the rotational levels.

The results of the dissertation are reflected in two publications, one in *the Journal of Quantitative Spectroscopy and Radiative Transfer* (*JQSRT*) and one in *the Journal of Physics: Conference Series* . In all works, the dissertation is the first author of two and therefore has a leading role.

6. Critical notes and recommendations

The doctoral dissertation is written in very good English, the presentation is clear. The structure of the thesis also makes it easy to understand, but what I find difficult is understanding the contributions in the thesis. I would recommend that the contributions in the dissertation be separated into a separate chapter or appendix.

I have a few questions that I would like answered during the defense:

1. In the thesis, four different spectroscopic methods were used to take the spectra of **KRb** . Why are spectra taken by all these methods?
2. On page 127 of the dissertation figure 7.3 shows parts of the saturation spectroscopy spectrum and excitation spectroscopy with additional filtering. It is noteworthy that there is no correspondence of some of the spectral lines between the two methods. For example, the transition $(v\,0-0)\,c-X\,R\,Q\,(48)$ which is visible in filtered laser excitation spectroscopy, is absent in saturation spectroscopy. There is also the opposite discrepancy, the line of $(2-0)\,P\,(43)$ seen in saturation spectroscopy is absent in filtered laser excitation spectroscopy. It seems to me that this difference cannot be explained only by the line widths and resolution of the two methods. Can you explain these differences?
3. If you had to choose just one spectroscopic method now, which one would you choose and why?

7. Personal impressions of the candidate

I know Velizar Stoyanov even as a bachelor student, because I gave him a course on electrodynamics of continuous media in 2017, when Velizar was in the 3rd year of his bachelor's education. Velizar immediately emerged as an excellent student and in my humble opinion is in the top 1% of the best students I have ever tutored. I will never forget that I was very impressed by Belizar's ability to solve problems quickly in an unconventional way, as well as his curiosity and desire for knowledge. In 2018, I had the pleasure of being a reviewer of Velizar Stoyanov's experimental bachelor's thesis on the topic "Optical supercontinuum generation", which Velizar wrote under the supervision of Assoc. Prof. Ivan Bachvarov from the Faculty of Physics of SU "St. Kliment Ohridski". It was then that I saw for the first time how Velizar excelled as a scientist as well, conducting extensive experimental research. In 2019, I led Velizar Stoyanov and a course on "Quantum Transitions" for the Master's program "Theoretical and Mathematical Physics". Again, I was left with excellent impressions of Velizar, but in 2019 I saw Velizar not only as an excellent student but also as a young scientist with great potential. Of course, such young people with potential are not to be missed, and I suggested that Velizar continue his education in our theoretical quantum physics group, but he preferred to combine theory and experiment, and therefore began his doctoral studies in the group of Prof. Asen Pashov. I have to admit that at the time I regretted that theoretical physics had lost Velizar, but now when I read his dissertation I see how Velizar combines theory and experiment in a unique way. For me, Velizar grew up and became a real physicist, who is not only a theorist and not only an experimenter, but perfectly combines both.

8. Conclusion

After having familiarized myself with the presented dissertation work, Abstract and other materials, and based on the analysis of their significance and the scientific and scientific-applied contributions contained in them, **I confirm** that the scientific achievements of Velizar Rosenov Stoyanov meet the requirements of the laws and the regulations for the terms and conditions for acquiring scientific degrees and occupying academic positions at Faculty of Physics of Sofia University “St. Kliment Ohridski” (ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ).

In particular, the candidate satisfies the minimum national requirements in the professional field and no plagiarism has been found in the dissertation, abstract and scientific works submitted for the competition.

I give my **positive** assessment of the dissertation work of Velizar Rosenov Stoyanov.

II. GENERAL CONCLUSION

After getting acquainted with the presented Dissertation, Abstract and other documents, based on the analysis of their significance and scientific and applied scientific contributions, herewith I confirm that the scientific achievements of Velizar Rosenov Stoyanov meet the requirements of the law (ЗРАСРБ) and of the Regulations for its application and the relevant Regulations of Sofia University "St. Kliment Ohridski" for obtaining the scientific degree "PhD" in 4.1. Physical Sciences. No plagiarism was found neither in the Dissertation, nor in the Abstract and in the scientific papers submitted for the procedure.

31 July 2024 Prepared by review :

(Assoc. Prof. Dr. Sci. Andon Angelov Rangelov)

Andon Rangelov

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