OPINION REPORT

of a thesis submitted for awarding the scientific degree „PhD“ in 4.1-Physical sciences (Scientific specialty: Physics of atoms and molecules) according to the procedure pursued in Faculty of Physics of Sofia University “St. Kliment Ohridski”

The report is prepared by Associate Professor Dr. Nikolay Ivanov Minkovski from Department of Mathematics, Physics and Informatics, Faculty of Forest Industry of University of Forestry, Sofia, 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 PhD Thesis: Velizar Rosenov Stoyanov

I. General description of the submitted documents

1. Data for the submitted documents

The candidate Velizar Stoyanov has submitted a dissertation in English (172 pages) and an Abstract in Bulgarian and English (58 pages), as well as the mandatory tables for Physical PhD from the Regulations on the conditions and procedures for acquiring scientific degrees and occupying academic positions at SU "St. Kliment Ohridski". Other documents (Curriculum Vitae, Plagiarism Check Report, a diploma for a completed higher education with a "master's" degree etc.) supporting the applicant's achievements are also presented.

The documents submitted by the candidate for the defense correspond to the requirements of the ЗРАСРБ, ППЗРАСРБ and the Regulations for the terms and conditions for acquiring scientific degrees and occupying academic positions at SU "St. Kliment Ohridski" (ПУРПНСЗАДСУ).

2. Applicant data

The candidate Velizar Stoyanov graduated from the high school of natural science and mathematics "prof. Emanuil Ivanov" in Kyustendil in 2014. In 2018, he obtained a bachelor's degree, and in 2020 - a master's degree in Theoretical and Mathematical Physics at the Faculty of Physics of the Sofia University. From 2020 to 2024, he is a full-time doctoral student at the Department of "Optics and Spectroscopy" at the Faculty of Physics, Sofia University in professional direction 4.1. Physical Sciences, in the doctoral program "Physics of Atoms and Molecules" with supervisor Prof. Dr. Sci. Asen Pashov.

During his studies, he worked as a technician at IBPHOTONIKA, a company specializing in laser technology. He was employed as a physicist at the Research Sector at the "St. Kliment Ohridski" University. He participated in the Program "Young Scientists and Postdoctoral Fellows" as a First Level Researcher (R1) and in the Project "Sofia University - Marker for Innovation and Technology Transfer (SUMMIT)" as a Young Scientist (First Level) (R1).

3. General evaluation of the scientific achievements of the applicant

a) the scientific publications included in the dissertation meet the minimum national requirements (according to Art. 2b, paras. 2 and 3 of ЗРАСРБ) and, accordingly, the additional requirements of Sofia University "St. Kliment Ohridski" for the acquiring of the educational and scientific degree "doctor" in the relevant scientific field and professional direction; The publications are two, one in the Journal of Quantitative Spectroscopy and Radiative Transfer with an Impact factor of 2.3 and a rank of Q2 and the second in the Journal of Physics: Conference Series, which is with SJR. The results of the dissertation were presented by Velizar Stoyanov in four poster sections at international conferences - The 26th International Conference on High Resolution Molecular Spectroscopy, 2022, Prague, Czech, The Twenty-eighth Colloquium on High Resolution Molecular Spectroscopy, 2023, Dijon, France, General International Conferences of the Balkan Physical Union · 11th BPU – Belgrade, 2022, Serbia and Twenty-third International Summer School on Vacuum, Electron and Ion Technologies, 2023, Sozopol, Bulgaria.

. In July 2024, he also participated with a poster at the Conference on Advanced Topics in Photonics (CATP'2024), Sofia, Bulgaria, where he was awarded the best poster.

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

c) there is no proven plagiarism in the submitted dissertation and abstract. A Protocol for checking the originality of a dissertation with a maximum similarity of 8%, which is minimal, is attached.

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

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

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

The dissertation is aimed at a theoretical and experimental study of the fine and ultrafine structure of the spectra of diatomic molecules. As such, the KRb molecule was chosen. It is a representative of the heteronuclear alkaline dimers such as NaK, KCs, NaRb, LiCs. Their detailed knowledge is important, they find applications for obtaining ultracold atoms, for Bose-Einstein condensate, for obtaining Feshbach resonances, for accurate determination of the electron-proton mass ratio, potential application in quantum computers. This also determines the relevance of this dissertation thesis.

The dissertation consists of 9 chapters, with the first and second being introduction, in Chapter three to Chapter five the theoretical model is successively described with the successive reaching of the full effective Hamiltonian. Chapter six presents the theory of two of the spectroscopic methods used in the experiments - saturation spectroscopy and double optical resonance spectroscopy. Chapter seven describes the experiment and the experimental results. In the Chapter eighth, a comparison of the experimental and theoretical results is presented, and in the last Chapter – summary and conclusions.

The main results are aimed at a theoretical and experimental study of the fine and hyperfine structure of the (B, c) levels. Four types of spectroscopy were used – Doppler-free

saturation spectroscopy, Filtered laser excitation spectroscopy, Laser induce fluorescence spectroscopy and Optical-optical double resonance saturation spectroscopy. Each method has its advantages and disadvantages, but none of them is prioritized in the dissertation. I would also recommend a fifth method - laser photoionization spectroscopy, in this field it has also been successfully applied for alkali dimers, for example for $^{39,39}K_2$ in the article by Leutwyler et al. in Chem. Phys. 1980, vol. 48. The experiment in the dissertation is difficult, but it was carried out professionally at a high technical level. It is very rare to implement four spectroscopic methods in one dissertation thesis; this fact can only be welcomed. Two isotopologues $^{39}K^{87}Rb$ and $^{39}K^{85}Rb$ were investigated. For the former, line broadening is observed for the $B^1\Pi(v'=2)$-$X^1\Sigma(v''=0)$ transition, while for the latter, splitting is observed. The theoretical model describes this fact reasonably well using the spin-orbital and Fermi-contact interactions.

As a positive point of the dissertation is also the given direction for future research, for example to investigate the hyperfine structure of the lowest triplet $a^3\Sigma^+$ state. Transitions of it have been observed with the laser-induced fluorescence (Fig. 7.7), but this spectrum is only for demonstration without detailed identification of the individual spectral lines and transitions.

6. Critical notes and recommendations

I have no major critical remarks. My recommendation is to use only one type of physical units. For example, “wavenumber” are used throughout, only the observed fluorescence signal uses a “wavelength” (900 nm instead of 11,100 cm^{-1}) in the text of the thesis.

For the literature cited (104 cited sources), my recommendation is to present a general list, rather than dividing the citations into books and separate citations of scientific papers.

At the end of the dissertation, the contributions should be presented more precisely and more clearly.

Despite these and some other inaccuracies, the overall impression of the dissertation is a very good, coherent and logically constructed theoretical part, a concise and detailed description of the experiments carried out, a high-level dissertation combining precise experiment and convincing theory.

7. Personal impressions of the candidate

I have no personal impressions of the candidate.

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 meet the requirements of ЗРАСРБ and the Regulations for its application and the relevant Regulations of the Sofia University "St. Kliment Ohridski" for acquiring the educational and scientific degree "doctor". In particular, the candidate satisfies the minimum national requirements in the professional direction 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 thesis of Velizar Rosenov Stoyanov.

II. GENERAL CONCLUSION

Based on the above, I recommend the scientific jury to award the educational and scientific degree "doctor" in professional direction 4.1 Physical sciences to Velizar Rosenov Stoyanov.

30 August 2024 Prepared opinion:

(Assoc. Prof. Dr. Nikolay Ivanov Minkovski)