Statement

of the Dissertation work

for obtaining the educational and scientific degree "Doctor"

in professional field 4.1 Physical sciences,

under the protection procedure in the Faculty of Physics (FzF)

of Sofia University "St. Kliment Ohridski "(Sofia University)

The statement is written by: Prof. Vera Marinova Gospodinova, IOMT-BAS

as a member of the scientific jury according to Order № RD 38-251 / 23.05.2022 of the Rector of Sofia University.

Topic of the dissertation: " Application of Coherent Quantum Control Schemes in Classical Physics"

Author of the dissertation: Muhammad Al-Mahmoud

I. General description of the submitted materials

1. Data on the submitted documents

Candidate Muhammad Al-Mahmoud has presented a dissertation on "Application of Coherent Quantum Control Schemes in Classical Physics", Abstract of the Dissertation and the mandatory table for Physics from the Regulations on the terms and conditions for obtaining scientific degrees and holding academic positions in Sofia Univeristy "St. Kliment Ohridski", according to which the candidate has 50 points per group of indicators A and 30 points per group of indicators D, according to the additional requirements of Physics Department - 1 point of indicator E 25, 1 point from publications in indicator E 27 (significant contribution of the candidate) and 8 points from participation in conferences (indicator E 30). The candidate Muhammad Al-Mahmoud participated in the procedure with a total of 90 points.

The presented Dissertation is written in 160 pages and consists of an Introduction Part, 7 Chapters and a Conclusion, accompanied by a list of publications, participations at international conferences and seminars and bibliography. The illustrative material consists of 50 figures. The list of cited literature includes 332 titles. Abstract of the Dissertation is written in Bulgarian and entirely on the structure and content of the dissertation, emphasizing the most important results and achievements. It is written on 51 pages and contains 15 figures.

The documents submitted for the defense by the candidate fully comply with the requirements of the Law on the Protection of Scientific and Technological Information and Practice and the Regulations on the Terms and Conditions for Acquisition of Scientific Degrees and Holding Academic Positions at Sofia University "St. Kliment Ohridski" (PURPNSZADSU).

2. Details of the candidate

Muhammad Al-Mahmoud graduated with a Bachelor's degree from the University of Lebanon, Lebanon in 2015, and then, in the period 2016-2019, studied for a Master's degree at Lorient University, Metz, France. In 2018 he began a doctoral dissertation on the European project EU Horizon-2020 ITN 76507 at Sofia University, in the group of Prof. DSc. Nikolay Vitanov (Quantum Optics and Quantum Information, Department of Theoretical Physics), under the supervision of Assoc. Prof. DSc Andon Rangelov.

Muhammad Al-Mahmoud has a number of specializations at the Technical University, Darmstadt, Germany (in the period October-Dec 2019), at the University of Metz, France (2017-2021), at the Institute of Solid State Physics at BAS in 2019, at the University of Paris Saclay University, Paris, France (2018), at the Max Planck Institute for Quantum Optics Munich, Germany (2019).

3. General characteristics of the scientific achievements of the candidate

The dissertation focuses on analogies between classical physics and quantum mechanics such as: (i) analogies between coherent quantum control techniques and some classical systems, such as light polarization manipulation and nonlinear frequency conversion in a lossless and scattering medium, or (ii) analogies between the non-Hermitian quantum system with three states and the cascade generation of a nonlinear frequency in a lossy medium, as well as on the demonstration of their applications.

The main aim of the dissertation is to design sensitive classical systems stable and broadband, analogous to the quantum systems, which are successfully manipulated by coherent quantum control schemes (for example by composite pulses). The tasks set in the dissertation are mainly theoretical and are based on the application of mathematical formalism to the Jones matrix used to describe the evolution of polarization states in a sequence of wave plates used to construct polarization rotators. As a result, two types of devices have been successfully designed and experimentally demonstrated: (i) a non-reciprocal polarization wave plate, the action of which depends on the direction of light propagation, and (ii) an input insulator independent of input polarization, with two levels of insulation. The presented demonstrations open new opportunities for practical applications.

The dissertation is written based on an Introductory Part, 7 chapters and a conclusion, as well as bibliography. The **Introduction** part is an overview and is dedicated to analogies as a strategy for analyzing and acquiring new knowledge about various natural phenomena based on a mathematical approach. Briefly, with examples, quantum-classical analogies, classical-classical analogies, the analogy between optics and mechanics, as well as the quantum-quantum analogy are considered, where completely different systems, modeled by comparable mathematical equations, reveal a surprising unity. **Chapter 2** covers several sequential quantum control techniques, such as composite pulses (CPs) and Rapid Adiabatic Passage (RAP), which are used to manipulate two-state quantum systems. The concept of manipulating quantum systems with three states with a decaying intermediate state is also discussed. In the following chapters, their classical analogies are used. **Chapter 3** discusses some classical systems that are initially sensitive,

such as polarization manipulation and nonlinear frequency conversion, including optical parametric amplification and cascade nonlinear frequency conversion in a scattering medium. The author proposed and theoretically demonstrated a new design of a composite and broadband polarizing rotator, applying composite pulses in polarization optics, consisting of only three wave plates, two half-wave plates and one full-wave plate for the central wavelength. In addition, this chapter discusses the idea of a non-reciprocal polarization switch based on a combination of a reciprocating switch and non-reciprocal rotators. **Chapters 2 and 3** serve as a theoretical introduction to the entire dissertation.

Chapter 4 links the approach presented in Chapter 2 with the polarization manipulation in Chapter 3 in order to build stable and broadband polarization rotators. Two devices have been designed, a non-reciprocal optical wave retarder and a polarization-independent optical isolator based on the idea of a non-reciprocal polarization switch. The device thus proposed can be used as a half-wave plate in one direction and a quarter-wave plate in the opposite direction. Another example is the arbitrary deceleration of the wave in one direction and zero deceleration in the opposite. **Chapter 5** is devoted to the transfer between three quantum states through a decaying intermediate state with cascading nonlinear frequency generation in a lossy medium. The analogy between the non-Hermitian quantum system with three states and the cascade generation of a nonlinear frequency in a lossy medium in order to sustainably generate new frequencies in nonlinear crystals is presented. Numerical simulations for $LiNbO_3$ crystals are also presented.

Chapter 6 presents a universal non-reciprocal wave plate design based on a combination of a reciprocal and non-reciprocal polarizing rotator placed between two quarter-wave plates.

Chapter 7 presents an input polarization-independent optical insulator (Sanyak configuration) built using two non-reciprocal polarization switches

The **conclusion** presents general conclusions and points of view.

The results of the research were published in 5 articles (3 of them with quartile Q1 and 2 with quartile Q2 - both belonging to group I), as 4 of the publications were with impact factor and one with SJR. The scientific publications included in the dissertation fully meet the minimum national requirements (under Art. 2b, para. 2 and 3 of the Law on Public Procurement) and respectively to the additional requirements of Sofia University “St. Kliment Ohridski ”for acquiring the educational and scientific degree“ Doctor ”in the professional field 4.1 Physical Sciences. In addition, the scientific publications included in the dissertation do not repeat those of previous procedures for acquiring a scientific title and academic position. There is no legally proven plagiarism in the submitted dissertation and abstract.

The dissertation is written at a very high professional level, it is designed very precisely with illustrations and figures, important formulas and equations are presented, which makes it very balanced. I should note that it will undoubtedly be of great benefit to future students, PhD students and learners.

4. Characteristics and assessment of the teaching activity of the candidate (if there is a requirement in PURPNSZADSU for this)

Muhammad Al-Mahmoud has a prominent teaching career, such as teaching at the Université de Lorraine, Metz, France in 2019 and the University Institute of Technology (IUT), where he conducts experimental and theoretical training in Electricity, Electromagnetism, Motorization and Systems. In the period 2017-2020 he conducted freelance training at the University of Metz, France, teaching lessons for high school students on topics: Physics, Mathematics and Programming

In 2014-2016 he was engaged in school teaching at the Modern Educational School, Lebanon to students from 7th, 8th and 9th grade in mathematics and physics.

In 2012-2016 he conducted freelance training in Lebanon - Lessons for students from primary and secondary schools on topics: Physics, Mathematics and Chemistry

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

The author has provided 5 new scientific contributions (theoretical and experimental), which I fully accept and support.

As a **new scientific contribution**, including theoretical and experimental part, the analogy between the technique of composite pulses and the polarization of the light in order to design a stable and broadband polarization rotator of three wave plates should be noted. Also, a new theoretical scientific contribution is the introduction of "defects" at certain places in the quasi-phase synchronism of a nonlinear crystal, and an analogy has been reached with composite impulses from quantum physics. This analogy aims to make optical parametric amplification stable and broadband.

Another **new, theoretical scientific contribution** is the analogy created between a three-level quantum system and a decaying intermediate state with cascade frequency generation in a nonlinear lossy medium. This analogy allows the losses from the environment to become an advantage in the generation of the new frequency. It should be noted the first designed non-reciprocal polarization wave plate, the deceleration of which depends on the direction of light propagation, which is a new scientific contribution, including theoretical and experimental part

The **most significant theoretical and experimental contribution** is the demonstrated new type of optical nsulator, independent of the light polarization, composed of two non-reciprocal wave plates in the Sagnac configuration. The most important advantage is that there is no difference between the optical paths of the two orthogonal polarizations, which allows to maintain the polarization between input and output.

Muhammad Al-Mahmoud has presented 4 publications in impact factor journals such as Physical Review Applied (IF 4.985); Applied Sciences (IF 2,679); Journal of Optics (IF 2.516); Applied Optics (IF 1.980) and OSA Continuum (SJR 0.53, Q2). In 4 of them, Muhammad Al-Mahmoud is the leading author, and in the table of information on compliance with the minimum national requirements and the minimum requirements of the Physics Department, Muhammad Al-Mahmoud has indicated that he has made a significant contribution. I believe that the research

conducted, the results obtained and the profiled contributions are personal work of Muhammad Al-Mahmoud.

8 participations in international conferences and 4 presentations at seminars are indicated. 8 independent citations were noted.

6. Critical remarks and recommendations

I have no critical remarks

7. Personal impressions of the candidate

I do not know the candidate personally, but I attended his online pre-defense held in May 2022 and I am with excellent impressions of the scientific results and the way they have been presented. I should also note that the candidate works in a very strong and world-renowned team, with the leading Bulgarian and foreign scientists, including Prof. Germano Montemezzani, which undoubtedly leads to the professional growth and experience of the doctoral student.

8. Conclusion

After getting acquainted with the presented Dissertation, Abstract and other materials, and based on the analysis of their significance and the scientific and applied contributions contained in them, I confirm that the scientific achievements of Muhammad Al-Mahmoud fully meet the requirements of ZRASRB and the Regulations for its application and the respective Regulations of 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 field and no plagiarism has been established in the dissertation, abstract and scientific papers submitted at the competition

I give my positive assessment of the dissertation and fully support the award of the educational and scientific degree "Doctor".

II. OVERALL CONCLUSION

Based on the above, I recommend the scientific jury to award the educational and scientific degree "Doctor" in the professional field 4.1 Physical Sciences, to Muhammad Al-Mahmoud.

24.06.2022 Reviewer: Prof. DSc. Vera Marinova

(academic position, scientific degree, name, surname)