REFEREE RESPONSE

to the Habilitation thesis of David Boris Hayrapetyan entitled "*INVESTIGATION OF ELECTRODYNAMIC AND OPTICAL CHARACTERISTICS OF ZERO-DIMENSIONAL QUANTUM STRUCTURES*" for the degree of doctor of physical-mathematical sciences on specialization of A.04.10 – "Physics of Semiconductors".

Semiconductor quantum dots (QDs) represent a significant shift in the study of nanoscale materials, offering unparalleled control over particle size and shape. These tiny crystalline structures, typically ranging from 2 to 10 nanometers, exhibit distinct optical and electronic properties that differ fundamentally from their bulk counterparts due to quantum confinement effects. This phenomenon occurs when the motion of electrons in the material is confined to such a small scale that quantum mechanical effects become dominant, leading to discrete energy levels. The study of these quantum dots is crucial not only for advancing our understanding of quantum mechanics at the nanoscale but also for unlocking new possibilities in various applications.

The exploration of semiconductor QDs is of utmost importance due to their potential to revolutionize multiple industries. QDs have unique properties like size-dependent emission wavelengths, high quantum yield, and broad absorption spectra. These characteristics make them ideal for applications in areas such as solar energy conversion, light-emitting diodes (LEDs), bio-imaging, and most notably, in the emerging field of quantum computing. In photovoltaics, for instance, quantum dots can be engineered to absorb different wavelengths of light, potentially leading to more efficient solar cells that surpass the limitations of traditional photovoltaic technology. Furthermore, in the medical field, their application in targeted drug delivery and bio-imaging could lead to significant advancements in diagnostics and treatment methods.

The current global landscape of QD technology is marked by rapid advancements and increasing commercial interest. Research and development in this field are growing exponentially, with new discoveries continually broadening the potential applications of quantum dots. One of the most significant areas of advancement is in display technology, where quantum dots are used to create screens with more vibrant colors and higher energy efficiency compared to traditional displays. Additionally, the field of quantum communication and computing is seeing transformative developments due to the unique quantum mechanical properties of quantum dots, such as spin coherence and entanglement. These properties are essential for the development of quantum bits (qubits), which are the building blocks of quantum computers.

Looking ahead, the future of semiconductor QDs appears incredibly promising, with ongoing research aimed at overcoming current limitations and unlocking their full potential. Key challenges include improving the stability and consistency of quantum dots, scaling up their production while maintaining quality, and developing eco-friendly and cost-effective synthesis methods. Overcoming these challenges will be critical for the widespread adoption and application of quantum dot technology. As research progresses, QDs are poised to play a pivotal role in the next generation of technological innovations, potentially leading to breakthroughs in energy, healthcare, and computing that were once deemed impossible.

In conclusion, the exploration of semiconductor quantum dots is not only a journey into the heart of quantum mechanics at the nanoscale but also a crucial step towards a future where the boundaries of technology and science are redefined. The profound implications of their unique properties across diverse fields, from renewable energy to quantum computing, underscore the necessity and urgency of continued research in this direction. As we stand on the brink of a new era of technological innovation, the in-depth study and development of quantum dots represent a vital frontier in our quest to harness the full potential of nanotechnology for global progress and benefit.

The dissertation work aims to explore a range of topics in the realm of quantum dots (QDs). The research begins with an investigation into direct interband light absorption in both spherical and cylindrical QDs, utilizing modified Pöschl–Teller and Morse potentials to offer a more realistic depiction of charge carrier behavior. It then delves into the study of one-electron states in prolate and oblate spheroidal QDs, assessing their potential for applications in near-infrared detectors, optical sensors, and QD LEDs.

A significant part of the study involves analyzing the binding energy and oscillator strength of hydrogen-like donor impurities in strongly oblate and prolate ellipsoidal QDs, using the variational method. Additionally, there is a focus on calculating the states of exciton, negative and positive trions, and biexcitons in these QDs, underlining their utility as sources for both one and two-photon emissions.

The research also investigates the behavior of excitons and biexcitons in ellipsoidal QDs when subjected to intermediate light fields, examining the consequent alterations in optical properties and recombination lifetimes. Furthermore, the work aims to demonstrate the Talbot effect in vertically coupled cylindrical QD ensembles, highlighting their potential in modulated coupling fields.

Another aspect of this research is the exploration of parabolic confinement potential in strongly oblate ellipsoidal QDs, especially its ability to control resonance frequency via geometric adjustments. This includes examining the implementation of the generalized Kohn theorem for a gas of heavy holes in lens-shaped Ge/Si QDs, which leads to the formation of a two-dimensional parabolic confining potential.

The dissertation also seeks to obtain analytical expressions for the electron energy spectrum and wave function in core/shell/shell spherical QDs with Kratzer confining potential, studying the resulting dipole and quadrupole moments. Additionally, there is a theoretical investigation into the linear and nonlinear intraband optical properties of colloidal spherical CdSe/CdS core/shell QDs with a central donor impurity.

Further, the research extends to studying the electronic states and optical properties of conical QDs made of GaAs, evaluating their potential as components for QD LEDs. This includes investigating the impact of an external electric field on the electronic states and optical properties of conical QDs, focusing on how it affects electron localization and energy levels.

The thesis, which consists of Introduction, six Chapters, Conclusion and References, comprises 267 pages, contains 83 figures, 15 tables and 334 references. The dissertation begins with a "List of Abbreviations and Notations Used in the Dissertation" followed by an "Introduction" that establishes the relevance of the proposed work, a literature overview, and the current state of the problem, concluding with the main statements of the work.

Chapter I delves into the theoretical investigation of spherical and cylindrical quantum dots with various confinement potential models across different size quantization regimes. It includes an in-depth analysis of spherical quantum dots using modified Pöschl-Teller potential (MPTP) and the study of light absorption in cylindrical quantum dots with MPTP. This chapter also examines the effects of hydrostatic pressure on donor impurity exciton states and interband absorption in cylindrical quantum dots with Morse confining potential.

Chapter II focuses on ellipsoidal and spheroidal quantum dots, investigating the binding energy and photoionization cross-section of hydrogen-like donor impurities in strongly oblate ellipsoidal quantum dots and similar analyses for prolate ellipsoidal and spheroidal quantum dots.

Chapter III is dedicated to the study of excitonic complexes in ellipsoidal and cylindrical quantum dots, including the calculation of binding energy and photoionization cross-sections. This chapter also explores the impact of intense laser beams on these excitonic complexes and the possibility of realizing the Talbot effect in coupled cylindrical quantum dot ensembles.

Chapter IV addresses the implementation of Kohn's theorem in quantum dots with oblate and prolate geometries, including the effects of external magnetic fields and the study of Ge/Si quantum dots with hole gas.

Chapter V investigates the electronic and optical properties of core/shell nanostructures, including linear and nonlinear optical absorption and exciton states in core/shell/shell spherical quantum dots. This chapter also models quantum dots using the finite element method, considering different types of confinement potentials and their effects.

Chapter VI examines the electronic and optical properties of conical quantum dots, including direct interband light absorption, magneto-absorption, and the study of electronic states in the presence of electric fields.

Notwithstanding the very nice work, I have a few small questions and remarks which could give guidelines to improve the thesis:

- Why explore the relativistic adjustment to biexciton energy when it's approximately 10^{-12} meV?
- Coming from the field of first principles methods I would like to see how these findings compare with those derived from atomistic approaches based on Density Functional Theory calculations with different exchange correlation functionals .
- It would be beneficial to conduct studies that consider the anisotropic nature of the dielectric constant and effective mass.
- It would be ideal for all figures to maintain a consistent format, specifically by being in color.
- In the conclusion chapter it would be nice to include an outlook. Every thesis has different topics that are not fully understood or investigated. Including some paragraph on unsolved problems and future work would be very interesting for the readers.

Above mentioned minor remarks, do not affect on the high quality of the dissertation. Certainly, the Habilitation thesis is important contribution to the field of semiconductor nanostructures.

Habilitation thesis satisfies to all requirements of Supreme Certifying Commission of RA, and its author David Boris Hayrapetyan undoubtedly deserves the scientific degree of doctor of Physical-Mathematical sciences.

The Summary of dissertation (autho-referat) correctly corresponds to the contents of dissertation.

Official referee at the Department Material Science, University of Patras

Prof. Christos Garoufalis

I certify the signature of C. Garoufalis

Prof. Emmanouil Paspalakis,

Head of the Department Material Science