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Review of Piotr Gładysz thesis entitled „Interaction of light with quantum systems of different degrees of symmetry"

The doctoral thesis of Piotr Gładysz explores the theory of light interaction in media composed of two- and three-level systems. The two-level systems possess a permanent dipole moment and broken inversion symmetry, while the three-level ones exhibit inversion symmetry. The light generation and propagation phenomena in these media is relevant for many experiments using different platforms, in particular with cold atoms, ions and molecules, and holds potential applications in quantum communication tasks. The topic is both innovative and unique within the country, aligning closely with global research trends in the foundational aspects of quantum optics theory.

The thesis is based on the candidate's original research results, presented in three publications. According to the provided declarations, the PhD student performed the majority of the research work, including both numerical and analytical calculations, and played an important role in preparation of manuscripts. This highlights the candidate's ability to conduct scientific research with a notable degree of independence. It is worth noticing that Piotr Gładysz is a co-author of two additional publications, including one in *Nature Communications*, which represents a high level of achievement at this stage of their academic career.

The thesis is well-written, making it relatively easy to read. It offers a good foundation in quantum optics theory for the description of two- and three-level systems as well as the principles of light generation and propagation in such media. The detailed presentation of technical aspects reflects the Author's clear understanding of the fundamental formalism and its interpretation.

The doctoral thesis contributes to the theory of the radiation propagation and superluminal pulse propagation. While the topic has been addressed in the literature, many nuances have been overlooked due to the computational complexity of systems coupled to light. Consequently, deriving analytical solutions that provide clear interpretations and deeper insights has remained challenging. The original contribution of Piotr Gładysz lies in the development of a theoretical framework based on the generalized Jaynes-Cummings model and the Bloch-Maxwell equations,

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applied to two types of systems driven by a classical plane-wave electromagnetic field. The thesis presents several analytical results on this topic, complemented by numerical calculations, demonstrating the author's deep understanding and innovative approach to the problem.

In the first paper, Piotr Gładysz explores polar two-level systems in the ultra-strong coupling regime under external light beams. He analytically solves the system's dynamics using a series of unitary transformations, which reduce the description to the standard Jaynes-Cummings model with modified parameters. In particular, the coupling strength is transformed into a nonlinear dependence on the field amplitude. This approach reveals new effects, such as modifications in the emission spectrum directed toward different frequency channels.

A particularly intriguing conclusion from this work is the potential to enhance coherence in such quantum systems. This finding suggests exciting possibilities for engineering system coherence on demand by toggling the coupling with light. Could such a scenario enable periodic, time-dependent coherence, and what implications might this have for quantum system control?

Another question arises concerning the nature of the light beam: what would happen if one considers a quantum coherent state for the light? Specifically, how would the presence of a permanent dipole moment alter the standard collapse-and-revival dynamics?

In the second paper, the Author examines specific two-level polar molecules with broken inversion symmetry, focusing on their performance in generating coherent radiation. The novelty of this work lies in the detailed analysis of propagation effects, which have not been previously explored in the context of such systems. The Author performs careful analysis of various parameter regimes, including spontaneous emission and collisional relaxation, to classify the resulting amplitude and frequency of the generated signal.

However, one aspect remains unclear: why does the contribution from the Rabi frequency alone drive the generation of low-frequency radiation? Is this mechanism feasible under realistic experimental conditions?

In the final paper, Piotr Gładysz investigates subluminal and superluminal pulse propagation in three-level systems, focusing on the V, Λ, and ladder configurations. A particularly straightforward approach to achieving superluminal pulse propagation is identified in the ladder configuration, involving two laser pulses. The results demonstrate negative group velocities and a approach to limiting values of the group index. These findings offer new possibilities for practical realizations of superluminal propagation in rubidium vapors, especially when compared to the more extensively studied Λ configuration.

The Author’s careful analysis raises the question: could the properties of the considered medium be used to dynamically steered from subluminal to superluminal propagation using laser pulses? If so, what experimental conditions would be required to achieve such a scenario?

In summary, this doctoral dissertation makes a significant contribution to the theory of signal emission and propagation in two- and three-level systems, with a focus on the influence of permanent dipole moments and specific symmetries. The results presented in the thesis enhance our understanding of these systems and the critical role of various symmetries. Particularly noteworthy are the elegant analytical results for the Rabi frequency in polar systems and the insights into superluminal pulse propagation in ladder configurations. Even the simplified scenarios analyzed in this work provide valuable perspectives for experimental implementation, highlighting the practical relevance of these theoretical advancements.

I conclude that mgr Piotr Gładysz presented a very good doctoral thesis which meets the formal and customary requirements for doctoral dissertations and I recommend its admission to subsequent stages of the procedure, including the public defense.

I also believe that this doctoral thesis deserves distinction, as it introduces a novel and straightforward approach to realizing superluminal pulse propagation in ladder systems. This idea has the potential to be experimentally implemented in the near future. The results presented in the thesis not only deepen our understanding of light-matter interactions but also open up exciting opportunities for controlling pulse dynamics in quantum systems, paving the way for significant advancements in this field.

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