INSTITUTE OF THEORETICAL PHYSICS AND ASTRONOMY
V I L N I U S U N I V E R S I T Y

Saulėtekio 3 LT-10257 Vilnius, Lithuania **E-mail: gediminas.juzeliunas@tfai.vu.lt**
Ph. (370-5) 2234642

To the Board of Disciplines of Physical Sciences of the Nicolaus Copernicus University

14 December 2024

Report on a doctoral dissertation by Piotr Gładysz entitled
"Interaction of light with quantum systems of different degrees of symmetry"

The thesis presents the theoretical investigation of the interaction between light and atomic or molecular medium. The species comprising the medium are modelled by two-level systems with broken inversion symmetry or inversion-symmetric three-level systems. The breaking of inversion symmetry appears, e.g., for the polar molecules or the atoms in an external magnetic field, so a permanent dipole moment appears. The thesis can be divided into two parts. The first group of problems presented in the first two articles deals with a medium of two-level species containing permanent dipole moments. It is demonstrated that the permanent dipole moments lead to novel phenomena for the atom-light interaction in the strong field regime, particularly the generation of low-frequency radiation. In the first article of this group, a series of unitary transformations was applied, providing an effective Jaynes– Cummings model, which was subsequently used to analyse the effects of the permanent dipole moment on atom-light interaction. In the second paper, the effects of light propagation were included in solving the Maxwell-Bloch equations. This is important for larger samples where the effects of light propagation must be considered. The second problem of the thesis presented in the third publication deals with the superluminal light propagation in the medium of three-level systems. The optimal situations for superluminal propagation with minimum losses were identified by considering various three-level systems.

In addition to the original results, the thesis contains extensive background material and thus can be helpful for students entering the area. Generally, the thesis is **well-written**, and the results are **presented clearly**.

I have the following minor remarks on the thesis.

1. The list of references containing 56 entries is relatively short and incomplete. For example, there is no work by D. L. Andrews and his group members in the list of references. This group considered the effects of permanent dipole moment on optical nonlinearity in several publications, e.g. L. C.

Dávila Romero and D. L. Andrews, Effects of permanent dipole moments in high-order optical nonlinearity, J. Phys. B: At. Mol. Opt. Phys. 32, 2277 (1999).

2. At the end of Sec. 2.1.3 on p.11, it is written that the magnetic part of the interaction does not contribute to the description of the evolution of the quantum system. This is not always the case. The magnetic interaction affects the fine and hyperfine atomic states and thus is very important in precision experiments which resolve the atomic magnetic sublevels.

3. In the last paragraph of p.16, the effects of incoherent pumping were considered for the two-level system. It is written that incoherent pumping can lead to the complete population inversion, as illustrated in Fig.2.4. Yet it is known that one cannot reach more than half of the population inversion with incoherent pumping of the two-level system, as the stimulated emission prevents the population inversion. For this reason, one cannot get lasing by incoherently pumping two-level systems. Perhaps in Fig.2.4, the population inversion was obtained because the stimulated emission was not included. Note that this is the introductory material and does not affect the original results of the thesis.

4. Using the arbitrary units in fig2.6 (p.20) is not a good idea because. In fact, from the plot, one cannot see how big the electric field should be to get the non-linear dependence of the Rabi frequency.

5. On p.79, it is written, “Superluminal light propagation is typically accompanied by significant absorption that might prevent its observation in realistic samples.” This is not always the case. In the gain-assisted superluminal light propagation experimentally observed in [32], there is a moderate gain rather than absorption.

These minor remarks do not influence the overall very positive evaluation of the thesis, which is original and satisfies the requirements of the Ph.D. work. Furthermore, the thesis represents a significant advance in non-linear atom-light interaction by considering the novel effects of the permanent dipole moment and exploring novel mechanisms of superluminal light propagation. Therefore, I **request a possible award of distinction for the dissertation**.

Sincerely,

Sincerely,

Gediminas Juzeliunas, Prof. Dr.

Distinguished Professor of Vilnius University