Dispersion Dependences for Polariton–Axion Waves in Tryptophan Crystals

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Abstract—Dispersion dependences of electromagnetic waves in tryptophan crystals are constructed taking into account photon–axion conversion processes in the low-symmetry tryptophan crystal field. It is shown that a peculiarity associated with the intersection of dispersion curves of electromagnetic and axion waves appears in the frequency range of unitary polaritons, corresponding to the unity refractive index. In the intersection region, hybrid polariton–axion quasiparticles called axitons are formed. The dispersion relation for axitons in the visible and infrared spectral regions is derived. The conditions for photon–axion conversion near the exciton absorption edge of tryptophan in the ultraviolet spectral region are determined.

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When an electromagnetic wave propagates in a medium, the interaction of electromagnetic radiation with polar vibrations of a dielectric medium occurs. As a result, polariton waves are formed in a dielectric medium, which are accompanied by oscillations of both the electromagnetic field and purely mechanical vibrations of polar type [1–3]. In the first stage of the study, the polariton wave properties in an infrared spectral region were determined [4–6], which correspond to photon–phonon polaritons. Later on, polariton waves formed as a result of the interaction of electromagnetic waves with dipole-active excitons were also studied. In this case, resonances were observed in the ultraviolet spectral region [7].

Based on the elementary particle theory and taking into account reliable astrophysical data, it was predicted that the so-called axion waves exist in vacuum along with electromagnetic waves [8–13]. Electromagnetic wave quanta are photons which, in symmetry properties, are classified as vector bosons. In the case of axion waves, elementary excitations (axions) are pseudo-scalar bosons.

In the last decade, works on the development of experimental setups for observing axions are performed [10–13]. In the developed setups, it is planned to use laser radiation conversion to axion waves in the presence of a strong magnetic field whose magnetic induction vector is perpendicular to the laser beam. In this case, according to the selection rules, photon–axion conversion processes become allowed due to symmetry reduction to group $C_{\infty h}$ because of the presence of an external magnetic field. We note that symmetry can be reduced even without an external magnetic field, due to low point symmetry of the lattice. Thus, observation of photon–axion conversion processes is expected in a material medium whose symmetry is identical to or below the symmetry of the external magnetic field. Such a possibility can be implemented in dielectric crystals whose point symmetry group is $C_{6h}, C_{4h}, C_{2h}, C_2$, and so on.

In this study, we analyze the interaction of photons with axions in low-symmetry dielectric media by the example of tryptophan crystals whose point symmetry is $C_2$. The spectrum of lattice vibrations of this crystal contains low-frequency dipole-active modes for which polariton waves are formed in the infrared spectral region. Near the electronic absorption band, dipole-active Frenkel excitons and corresponding exciton polaritons exist in this material. We posed the problem of analyzing the interaction of polaritons and axions in a low-symmetry dielectric medium by the example of this crystal.

Tryptophan is one of proteinogenic amino acids, an indole derivative. It can exist in the left ($L$), right ($D$), or racemic ($DL$) forms [14]. Point symmetry group $C_2$ of tryptophan crystals is a subgroup of group $C_{\infty h}$, i.e., the photon–axion conversion is allowed by selection rules due to the internal field symmetry in
The substitution of Eq. (8) into (4) leads to the equation

\[ \omega^6 - \omega^4 \left[ (\omega_a')^2 + (\omega_{0ps})^2 + c_0^2 k^2 \right] \left( 1 + \frac{1}{\epsilon_{\infty}} \right) \]