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Axion-photon conversion in space and in low symmetrical dielectric crystals

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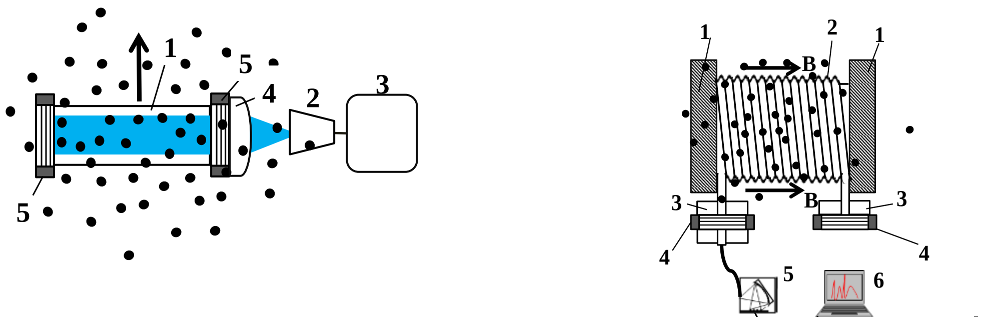
Abstract. The opportunities of axions detection as the result of axion-photon conversion processes in the space and in low symmetrical dielectric crystals are discussed. In accordance with the modern theory predictions, axions are pseudoscalar vacuum particles having very small (0.001-1.0 meV) rest energy. The possibility of axions conversion into photons and vice-versa processes in vacuum at the presence of outer magnetic field has been analyzed before. Pseudoscalar (axion type) modes are existing in some types of crystals. Polar pseudoscalar lattice and exciton modes in low symmetrical crystals are strongly interacted with axions. In this work, optical excitation of axion-type modes in low symmetrical crystals is proposed for observation of axion – photon conversion processes. Instead of outer magnetic field, the crystalline field of such crystals may be used. The experimental schemes for axion-photon conversion processes observation with recording the secondary emission of luminescence, infrared or Stimulated Raman Scattering in some dielectric crystals are discussed.

According to the modern high energy physics theory [1-4], the Universe undergone the phase transition from homogeneous to local density space ordering state. The soft mode, responsible for symmetry lowering of vacuum, is predicted. Such mode should be total symmetrical one and should be described by scalar field with corresponding scalar elementary particles – “amplitudons” (Higgs bosons) [4-7]. Beside this, T-inversion violation in high energy physics resulted in the conclusion of the pseudoscalar elementary particles (Nambu – Goldstone bosons or “phasons” particles) with nonzero rest mass existence. Now such pseudoscalar particles are known as axions: Weakly Interacting Subelectronvolt Particles (WISP) [8-11]. WISP is expected to have the very small rest energy: 0.001...1.0 meV [12,13] The axions as pseudoscalar particles are described by wave function, changing the sign under inversion of space and mirror reflections transformations. The actual topics of modern physics is the prediction of the presence in Universe the dark matter (total share 0,23) and dark energy (total share of 0.73). The astrophysical data result in the conclusion [12-16] that one of the candidates for dark matter elemental particles are axions — pseudoscalar vacuum particles with the very low rest mass and relativistic dispersion law – WISP. “Cold” (the slowest) axions are nonrelativistic (Newtonian) particles. “Hot” (fast) axions are relativistic and move with the velocity, close to the velocity C_0 of light in vacuum. There are proposals of other candidates of dark matter elemental particles: WIMP (Weakly Interacting Massive Particles), having the rest energy about 1.0 keV; neutrino; neutralino and so on. According to the estimates obtained from astrophysical data, the equilibrium concentration of axions in our part of the galaxy is about 10^{-24}g/cm3. Accordingly axions with the lowest rest mass must be in Bose-Einstein condensate state even at room temperature. Now the opportunity of axions detection and generation in the presence of strong external magnetic field is discussed [14-18]. In this case explores two effects: 1) the detection of photons, emerging as the result of relativistic axion - photon conversion at strong magnetic field in vacuum; 2) the detection of photons, emerging as the result of Newtonian axion - photon conversion at strong magnetic field. In [17-20] on the dynamics of stars with masses 8...12 Solar masses, the conclusion was made about the processes of photon-axion conversion inside stars at the presence of strong magnetic field and was estimated the efficiency of photon-axion conversion for such processes. In works [14-18] it was suggested the possibility of "hot" axions creating with energy 2-3 eV in the laboratory on the base of "Light shining through wall" (Primakov-effect) experiments. The powerful laser source and strong outer magnetic field have been used. However the secondary signal of photons in "Light shining through wall" experiments was very small (~10^{-8}1/s) for hopeful detection. In this paper we analyze the opportunity of axion-photon and photon–axion conversion processes observation in dielectric media, recently proposed in works [21-30]. The new experimental schemes to implement the generation and detection of axions in the laboratory are presented. In accordance with the known group theory, phonons and excitons states of molecules and crystals are classified by irreducible presentations (races) of the corresponding symmetry groups. Pseudo scalar presentations have characters equal to unity for proper rotations and to minus unity for improper one (inversion, mirror place and mirror rotation). We have analyzed the selection rules for one-photon processes: infrared (IR) and ultraviolet (UV) emission or absorption, and for two-and three-photon effects: Raman and Hyper Raman scattering, Two-Photon Emission and Two-Photon Excited Luminescence, for a number of liquids (water, ethanol, glycerin) and crystals (sodium nitrite, aluminum oxide, calcite, lithium niobate and some amino acid crystals). In these media pseudo scalar modes are presented. In some substances pseudo scalar modes are "silent", i.e., are forbidden as for Raman and also for one-photon (IR or UF) spectra. In several crystals the excitation or destruction of pseudo scalar state may be permitted by selection rules as a result of one photon processes (absorption or emission). Such situation takes place for C_{2h} point group (see Table 1). From this table we can see that "Z"–type polar phonon (polariton) relates to the same irreducible presentations as pseudoscalar one. Thus under resonant intersection between polariton dispersion curve $(\omega^2 = \frac{C_0^2 k^2}{\varepsilon(\omega)})$ and axion dispersion branch $(\omega^2 = \omega_a^2 + C_0^2 k^2)$ the polariton-axion conversion processes should be realized without applications of outer magnetic field but due to the lowering of the symmetry as a result of crystalline field presence, corresponding to C_{2h} –point group. The examples of crystals, having C_{2h} –point group symmetry, are stilbene, antracene, KGW and others. So the excitation of A_2 – type (pseudoscalar) lattice-polariton or exciton-polariton modes in dielectric crystals permits us to observe the axion - photon and photon axion conversion processes by means of registration of emission due to absorption and luminescence processes, The same properties have the crystals ($BaWO_4$, $BaMoO_4$, $PbWO_4$, $PbMoO_4$), described by C_{4h}, C_{6h}, and others point symmetry groups. The experimental scheme for observation of resonant axion-polariton conversion processes is illustrated by Fig.1a. Dark points correspond to high energy axions, generated by Stars, Sun or dark matter of Universe. After absorption of axions in crystals as a result of axion - pseudoscalar polariton resonant interaction the luminescence emission may be detected by receiver 2 (see Fig. 1a). Now there are known the luminescent fibers, consisted from the low symmetrical scintillating microcrystals, having the pseudoscalar polar modes, active for one photon absorption or emission processes. So the experimental schemes for resonant axion – pseudoscalar polariton conversion processes with long size fibers may be also created (see Fig.1b). In such type experimental scheme the additional (outer) magnetic field also may be applied (see Fig.1b). At the case of sodium nitrite and some amino acid crystals (C_{2V} point group) pseudo scalar modes are not polar are allowed for two-photon (Raman) processes, but forbidden for one–photon emission (IR or UV). In these type structures pseudo scalar modes should have high Q-factor and high intensity in spontaneous Raman

Scattering. As the result there is the opportunity to observe the photon axion conversion processes by means of pseudoscalar modes excitation with the help of Stimulated Raman Scattering (SRS) or Two-Photon Absorption and registration of Two-Photon Emission (TPE) signal by detector 10 (see Fig.2a).

Table 1. Characters of presentations and selection rules for one- and two-photon processes of C_{2h}-point group; a_i and a_{ij} – are vector and the second order tensor components correspondingly; ps-pseudoscalar presentations components; V- vector presentation; $[V]^2$ – the presentation of symmetrical squared of the second order tensor.

C_{2h}	E	$C_2(z)$	σ_h	I	a_i	a_{ij}	ps
A_g	1	1	1	1		xx,yy,zz,xy	-
A_u	1	1	-1	-1	z		+
B_g	1	-1	-1	1		xz,yz	-
B_u	1	-1	1	-1	x,y		-
V	3	-1	1	-3			
$[V]^2$	6	2	2	6			



a b

Figure 1. Experimental schemes for observations of resonance axion-polariton conversion processes in dielectric crystals(a) and fibers(b);(a)- 1- monocrystals; 2-detector of infrared or ultraviolet (luminescent emission) emission; 3-computer; 4-lens; 5-mirrors; arrow show the direction of crystalline or outer magnetic fields;(b)-1,3-fixers; 2-luminescent fibers;4-mirrors;5-detector;6-computer.

Fig.2b illustrates the setup for observing “Light shining through wall” - Primakov-effect in dielectric crystals, having pseudoscalar polar excitons. Such properties are revealed by stilbene, antracene, naphthalene, POPOP, PPO, BaWO4,BaMoO4, PbWO4, PbMoO4 , Tb(NO3)3x5H20 and others crystals. In this case the UV laser source (1) excite the photoluminescence in scintillating crystal 5 with emitting of polar pseudoscalar excitons (polaritons), resonantly interacting with the corresponding axions (dark points at Fig.2). Axions penetrate through the wall 9 and result in the resemble photoluminescence in crystal 6. Spectrometers 7 should detect the luminescence emission from both crystals 5 and 6. The signal

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of the luminescent emission from crystal 6 is waited enough strong because of resonant character of axion–polariton interaction and due to the small group velocity of exciton polaritons with small wave vector.

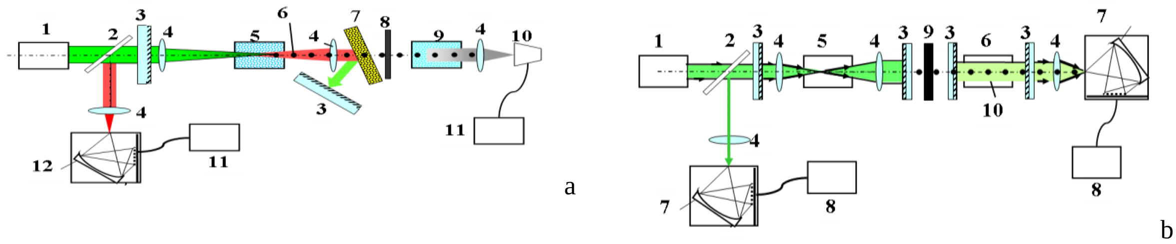

Figure 2. Experimental schemes for observation of one-(a) and two-(b)photon-axion conversion processes with realizing of “Light shining through wall” -Primakov-effect; (a)-1-high power pulsed laser source; 2-semitrasparent plate; 3-dielectric mirrors; 4-lens; 5-crystal for SRS excitation;6-SRS emission;7-photonic crystal; 8-opaque wall; 9- crystal for TPE emission;10 –detector of IR photons; 11-computers; 12-spectrometer for Raman spectra recording; (b)- 1- UV laser source; 2-semitrasparent plate; 3-dielectric mirrors; 4-lens; 5-crystal for luminescence excitation;6-crystal for luminescence emission;7-spectrometer; 8-computer; 9- opaque wall;10 –the secondary emission after wall.

Thus it is proposed the optimization of experimental installations for the detection of axion-photon conversion processes by means of using of dielectric crystals, having lattice or exciton pseudoscalar modes. Such crystal has low symmetry, described by point group C_{2h}, C_{4h}, C_{6h}, C_{2v} and others. For the first group of such crystals pseudoscalar modes have the same symmetry race as polar one. In this case axion-polariton conversion processes are permitted by selection rules without application of outer magnetic field. The using of scintillating fibers with resemble symmetry properties gives the opportunity to essentially increase the length of photon-axion interaction. For the generation of “hot” axions it is proposed to use laser for exciting of SRS and resonance photoluminescence on pseudoscalar modes in low symmetrical crystals. Thus the proposal to observe axion-photon processes in low symmetrical dielectric crystals opens the new opportunities for generation and detection axions in laboratory.

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