On the experimental proofs of strong time reversal noninvariance in nonlinear optics.

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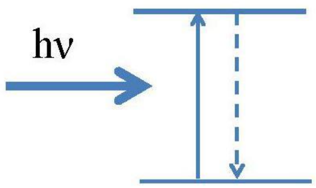
The fact of violation of CP and T invariance has been long discovered and recognized in the field of high energy physics. However, in the field of low-energy physics (optics, conventional quantum physics) is still widely believed, that the laws of physics are symmetric in time. Many years physicists try to find microscopic signs of violation of T-invariance. And they make it by a very exotic way: trying to find the so-called electric dipole moment. It is surprising that nobody now tries to compare directly properties of forward and reversed processes in optics.

The essence of this report is the statement that the time reversal non-invariance is the main physical base of all nonlinear optics. We have a set of direct and indirect experimental evidences, but our physicists prefer not to pay attention to these facts. They are passionate about mathematical descriptions of physical phenomena, and have in this direction a great success.

We have many phenomena in nonlinear optics. All of them have good mathematical descriptions. Practically in each experimental article there is a theoretical section where such descriptions are provided. However, when it is about an explanation of the physical nature of these phenomena, the situation looks painfully: or there are no such explanations at all, or they look helplessly.

It is believed that the non-linear optics emerged after the invention of such powerful sources of radiation as lasers. However, the main mathematical model of nonlinear optics, which describes interaction of two-level system with a resonant radiation had appeared even earlier. The famous Bloch equations were proposed in 1946 to describe the dynamics of two-level system in nuclear magnetic resonance. If the two-level system interacts with resonant radiation, then so-called Rabi oscillations of level's population are observed. If there is a so-called sweeping of resonance conditions, then the directed irreversible transfer of population from initial level on final is observed. The mathematical model well describes the process of adiabatic population transfer. But it does not have any clear physical meaning.



Dynamics of two-level quantum system

Bloch equations 1946

resonance conditions = Rabi oscillations - case of symmetry

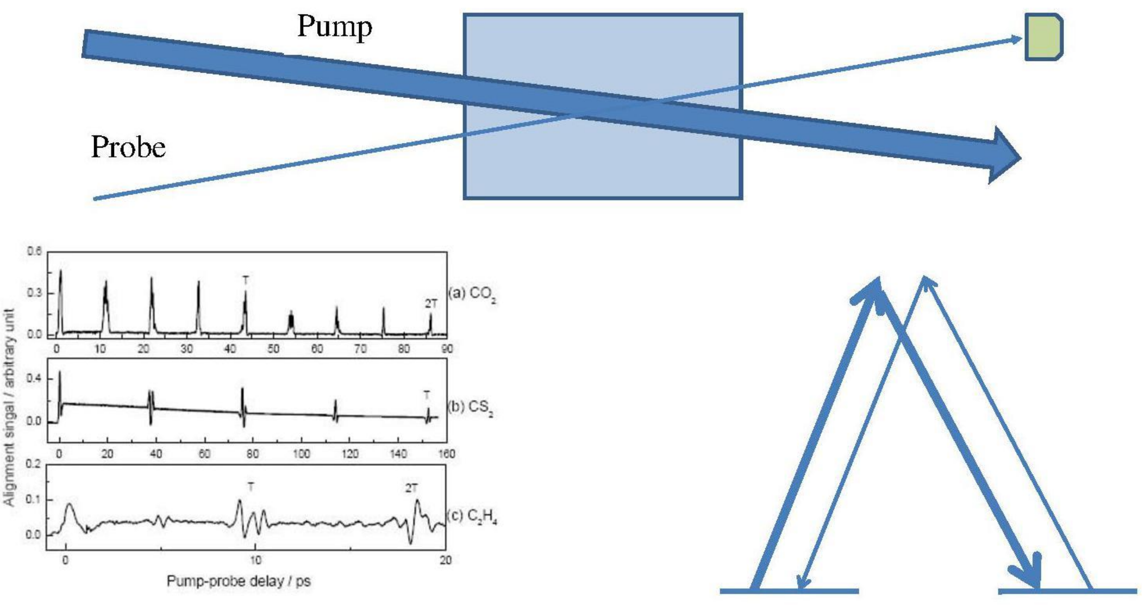
sweeping of resonance conditions = irreversible transfer of population from initial on final level - case of asymmetry

This is a fantastic situation. We deal with extremely simple quantum system. This is a very simple physical phenomenon that has been studied thousands of times in different ways. This phenomenon has a beautiful mathematical description. But it does not have any physical explanation. Even silly, stupid, nonsense physical explanation is absent till now. Why a fully symmetric case turns into a completely asymmetrical? This situation lasts for more than 70 years - is only slightly less than that for quantum mechanics as a whole.

A similar situation exists with various options of mixing of the photons in the gas and solids, generation of high harmonics, photon echo and so on. There are mathematical descriptions, references to requirements of symmetry, phase synchronism. But the physical explanation, from where these requirements occur, is absent.

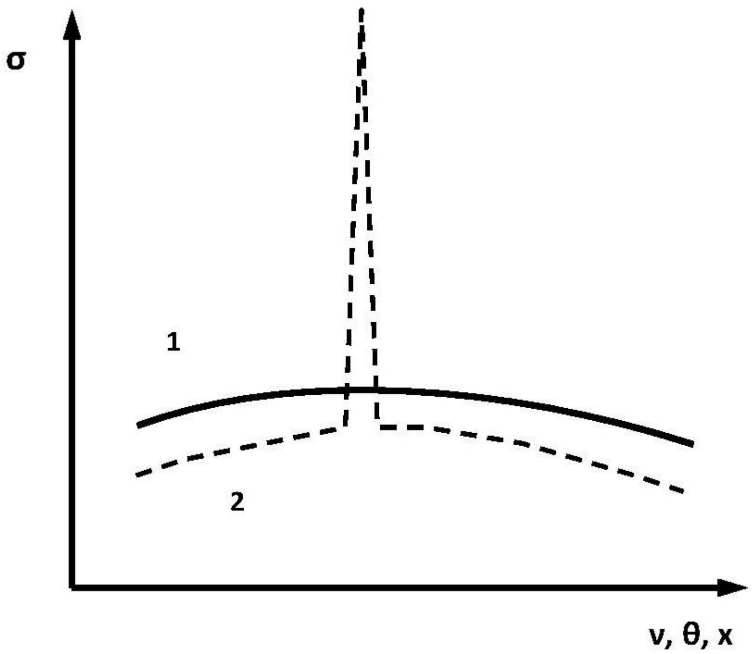
In recent years it has become a popular to study the phenomenon of the so-called field-free alignment of molecules [1]. There is a very powerful nonresonant femtosecond pump pulse affects the molecular gas. Then, the gas is probed with a very weak delayed pulse. As a result, the short bursts of interaction of probe radiation with gas are observed. With a frequency, which is multiple to the quantum period of rotation of molecules. In this case there is an attempt of a physical explanation of the phenomenon. It is believed that in the high-power pumping pulse field the molecules stop to rotate and align along the laser polarization vector. After the end of the pump pulse the molecules continue to rotate at an initial speed. There is the attempt to explain quantum phenomenon with the help of the concepts of classical physics. Our physicists, probably, understand that it is full nonsense, but they don't see any alternative explanation. However, we can easily find an alternative physical explanation, if we recognize the fact of inequality of forward and reversed processes in quantum physics.

Field-free alignment of molecules



From N. Xu et al., OPTICS EXPRESS 14, 4992 (2006)

Inequality of forward (absorption of a photon) and reversed (the subsequent its stimulated emission) processes is schematically presented in the figure. They are very different. This is not the result of a sick brain. This is a direct and unambiguous consequence of concrete experimental results. In two words. There is infrared multiple photon excitation of polyatomic molecules phenomenon. Here the excitation of molecules by laser radiation occurs through the unexpectedly intense far wings of the absorption lines [2]. It is important that this is a real continuum of absorption. With this in mind, the other pump-probe experiments in molecular beams directly and clearly show that the forward and reversed processes are very different from each other [3]. According to the spectral width, they differ by five orders of magnitude. And the evaluation of the difference of differential cross sections gives value more than three orders of magnitude.

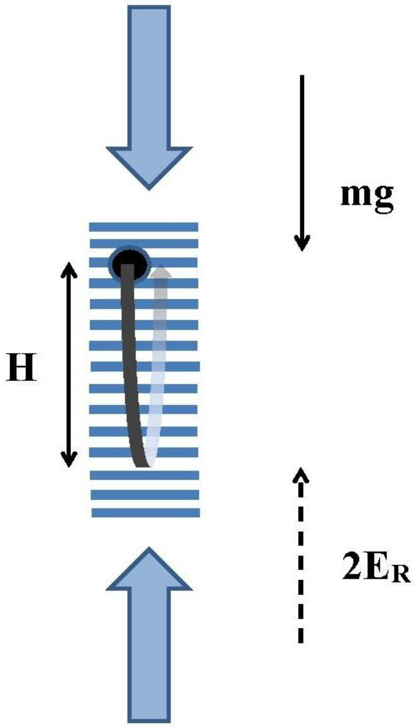


The supposed shapes of dependences of cross-sections for forward (1), backward and reversed (2) transitions from such parameters as the frequency (ν), angel (θ), position of the particle in space (x).

On the basis of such inequality of the forward and reversed processes the physical nature of the discussed above phenomena are very easily and naturally explained. In particular, in the so-called field free molecular alignment phenomenon under the action of the pump pulse the forward Raman transitions between the lowest degenerated levels of molecules occur. And the weak probe pulse creates reversed into the initial quantum state transition with high differential cross section. This transition happens only at the same orientation of the molecule as upon the forward transition. Any stop of molecular rotation is not required.

A simple and natural explanation of the physical nature of a variety of effects in nonlinear optics is in turn an indirect proof of the time reversal non-invariance in quantum physics. But we have also still quite direct experimental evidences. Such a proof is well-known Bloch oscillations of cold atoms in a vertical optical lattice [4, 5]. Here cold atoms fall freely in a vacuum under gravity. The vertical optical lattice is formed by two oppositely directed laser beams. The proposed physical explanation assumes that antinode of a standing wave are potential barriers which can reflect atoms. The main problem of this explanation is that the amplitude of oscillation of the atoms does not coincide with the period of the optical lattice. This amplitude is usually much greater than the lattice period. Then you have to assume the existence of the so-called superfluid regime, when the atoms are able to tunnel through a number of potential barriers.

Bloch oscillations of cold atoms in vertical optical lattice



$$H = h^2 / 2m^2\lambda^2 g$$

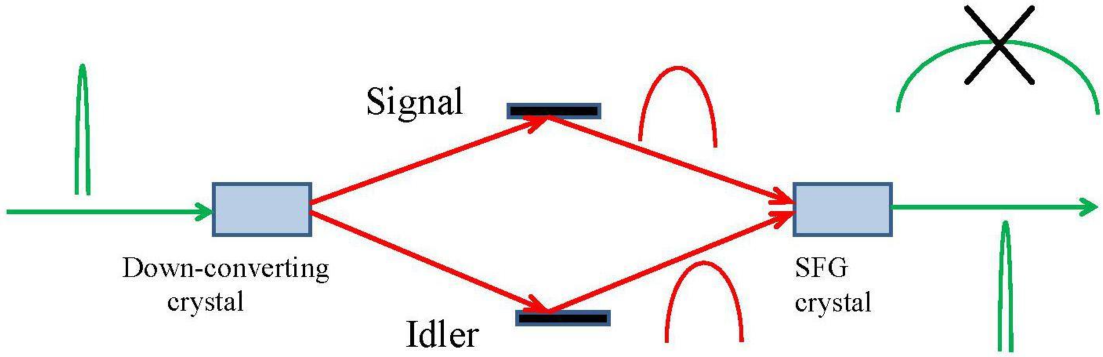
$$T = 2h/mg\lambda$$

Of course, there is a beautiful mathematical description of the phenomenon based on the Gross-Pitaevskii equation. But this description in direct or indirect way assumes that the motion of atoms in an optical lattice is due to the spatially asymmetric scattering of photons. The atom absorbs a photon from the upward beam and emits a photon in the direction of downward beam. As a result, the atom receives double recoil momentum and returns to the starting point of the space. From this the formulas for the amplitude and period of oscillations are derived. The wavelength of the laser radiation is included in these formulas because it affects the magnitude of the recoil momentum. If to raise the installation from the first floor of the building to the second, then the point of atom's reflection will shift because of the gravity changes.

Thus, we have two different explanations of the physical nature of the phenomenon: the presence of potential barriers in an optical lattice and a highly spatially asymmetric scattering of photons. If two opposite ideas coexist in one head, then the doctors, seem, call it as schizophrenia. But our scientists feel themselves fine in this state. They talk about potential barriers, double well, tunneling and use the mathematical model which is based on the fact of a highly spatially asymmetric scattering of photons. At the same time, there are no reliable experimental proofs for the existence of potential barriers in an optical lattice. We have again a situation when the quantum phenomenon is tried to be explained on the basis of the principles of classical physics. It is obvious that the idea of potential barriers in an optical lattice is the myth, phantom. In reality, we have the experimental fact of high spatial asymmetric scattering of photons, which is a direct consequence of the enormous inequality of differential cross sections of forward and reversed processes.

Another direct experimental evidence of time reversal non-invariance in nonlinear optics we can see in the splitting and mixing of photons in nonlinear crystals [6]. Here, the laser radiation with a very narrow spectral distribution is split into two beams (signal and idler), each of which has a very wide spectral distribution. Then these two beams are mixed again in another nonlinear crystal. It is expected that by mixing the two beams with a broad spectral distribution the beam with even broader distribution will appear. However, experiments show that in this case the initial radiation with very narrow spectral distribution is mainly regenerated.

Splitting and mixing of photons in nonlinear crystals



Thus, we have three direct and a lot of indirect experimental evidences of the inequality of the forward and reversed processes in nonlinear optics. Recognition of this fact immediately leads to a very interesting conclusion: quantum system must have a memory about its initial state. Without such a memory it will not be able to distinguish between the direct and reversed processes. What is the carrier of this memory? Whether the memory is local or nonlocal? Such memory looks like as a physical equivalent of the concepts of entanglement, superposition of states, entropy.

It is usually said that the entanglement is the essence of quantum mechanics. The physical sense of this term is unclear, although some scientists are trying to quantify its magnitude. Maybe somewhere there is a mathematical definition of this term. But physical definition of the term 'entanglement' is absent till now. However, now we can give physical definition to this term. *Entanglement is a memory of quantum system about its initial state, which manifests itself through inequality of differential cross-sections of forward and reversed processes.*

We can study a memory of quantum system through measurement of differential cross sections of forward, reversed, partially reversed quantum transitions. For the case of Bloch oscillations of cold atoms in a vertical optical lattice we can (during the time of free fall of the atom) to transfer it to another quantum state, to return it back and so on. In all these cases we shall observe a change in the probability of preservation of the Bloch oscillations. This is the characteristic of the differential cross section of reversed or partially reversed transitions. These are not very difficult experiments but until now nobody did it. Because of the scientists do not understand with what kind of thing they deal with. The main problem here seems to be that the experimenters will work in this direction only if the theorists will say that this is good.

So, in conclusion, we should understand that physical laws in quantum physics are not symmetrical in time. And in the nonlinear optics we everywhere deal with this fact.

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