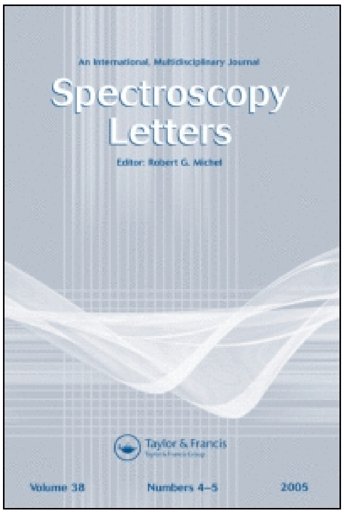

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TOWARDS ATTOSECOND SPECTROSCOPY

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At the present time subpicosecond pulses of laser light as short as $0.5\cdot10^{-12}$ s have been generated and detected and the possibility of $50\cdot10^{-15}$ s pulses generation as a limit is predicted [1]. Nothing has been said about the fundamental physical reasons that determine this limit. The aim of our work is to throw some light upon the general mechanisms that govern the generation of ultrashort photon pulses and other pulses of physical fields of limited short duration. It is also obvious that the pulse duration Δt cann't be shorter than the elementary time length Δt_0 if it exists. So let us search for possible candidates for Δt_0 and look for methods of their generation. There is only one general method available to get automatically shortened pulses of boson fields - the method of boson avalanches [2]. It consists of the following: take an excited particle and put it into a physical resonator for a boson field for getting a boson by means of the spontaneous boson emission process in the resonator in a time τ . If we put $N \gg 1$ equel excited particles into the resonator we shall get a pulse of boson radiation consisting of $\sim N$ bosons in a time $(\tau/N)\cdot\eta$, where η is an interference factor of the order $\eta \sim (\lambda^2/A_0)$ for a radiating disk of square section A_0 and for bosons of wavelength λ . This law was well established for photons generated by solids for which $\tau = 10^{-3}$ s, $A_0 = 1$ cm^2, $\lambda^2 = 10^{-10}$ cm^2 and $N = 10^{19}$ and $\Delta t = 10^{-12}$ s. But these numbers are not the limited ones and we could propose for instance $N = 10^{23}$ and $\tau = 10^{-8}$ s. The result $\Delta t = 10^{-21}$ s will be wrong because in 10^{-21} s photons can travel only through a distance $\Delta l \sim 3\cdot10^{-11}$ cm and a sphere of diameter $\Delta l = 3\cdot10^{-11}$ cm filled with ordinary matter cann't contain 10^{23} particles. It must be said that particles outside of this sphere cann't interact to produce a photon avalanche. So we see that boson avalanches can generate pulses as short as needed if the material is as dense as to fulfill the new condition

$$\frac{\Delta l}{\Delta t} \lesssim c \,, \qquad (1)$$

where Δ l is the dimension of the resonator, Δ t is the avalanche pulse length and c is the speed of light. If the density of the material can be rised without any limit we always can choose the length Δ l as small as needed to fulfill (1). In this way we get to the conclusion of the nonexistence of any limit to the pulse length shortening process.

The existing of an elementary length Δl_0 will drastically change this conclusion because we will be unable to fulfill (1) if Δ l will become shorter than Δl_0. We get a new idea how to estimate the limiting pulse lengthes that can exist in nature:

$$\Delta t_{o\alpha} = \frac{\Delta l_{o\alpha}}{c} \,, \qquad (2)$$

where $\Delta t_{o\alpha}$ and $\Delta l_{o\alpha}$ correspondingly are the limiting pulse duration accounting for the existence of the elementary length $\Delta l_{o\alpha}$ of physical nature α . The elementary times are estimated in the table 1.

Type of interaction	Elementary length l_o	Elementary time interval t_o
α = e electromagnetic int.	10^{-8} cm	$\frac{1}{3}\cdot 10^{-18}$ s
α = s strong int.	10^{-13} cm	$\frac{1}{3}\cdot 10^{-23}$ s
α = w week int.	10^{-17} cm	$\frac{1}{3}\cdot 10^{-27}$ s
α = g gravitational int.	10^{-32} cm	$\frac{1}{3}\cdot 10^{-42}$ s

Table 1. Possible elementary time intervals.

Taking account of the fact that in contamporary technology only electromagnetic interactions are exploited no densities higher than 10^{23} particles per cm^3 can be achieved. Therefore only one atom can generate a pulse of attosecond duration $\Delta t_{oe} = \frac{1}{3}\cdot 10^{-18}$ s and this is the elementary time interval in the electromagnetic domain of interactions.

Strong interactions inside the nuclei will compress matter to the nuclear matter density. Therefore nucleus can generate a pulse of radiation of duration $\Delta t_{os} = \frac{1}{3}\cdot 10^{-23}$ s. But Δt_{os} coinsides with the elementary time interval $\Delta t = (4.40 \pm 0.06)\cdot 10^{-24}$ s proposed in [3].

If we go on further with the same ideas we can imagine that the week interactions can compress matter to higher than nuclear densities. Then our Table 1 predicts a new elementary time interval $\Delta t_{ow} = \frac{1}{3} \cdot 10^{-27}$ s. Finally gravitational interactions will create regions of still higher densities and the gravitational elementary time interval $\Delta t_{og} = \frac{1}{3} \cdot 10^{-42}$ s appears.

Our point of view can give also some information about the structure of elementary particles. If an experiment will reveal some resonance that has the width $\Delta\gamma \sim 1/\Delta t_{og}$, one can argue that inside the elementary particles there exist regions of very high matter density. The elementary time dynamical spectroscopy may be called chrononsecond spectroscopy. The real value of a chronon will be the matter of new discoveries in elementary time spectroscopy.

Femto-, atto- and chrononsecond physical effects will be confined to very small volumes and the technique to defect them cann't be the same as was developed in the picosecond time domain. At the moment we can indicate the following possibilities. First of all atomic time standards will be replaced by intranuclear and intraparticle chronon time standards. To measure the length of a time interval connected with a physical process, this process must be incorporated into a step of a nuclear or elementary particles reaction. So the measurement will be confined into a small space-time volume and the reaction outcome and products will give the information about desired time interval length. Attosecond process time lengths already have been measured in this way [4]. Another possibilities are the comparison of width of resonant particle states with the measure of the corresponding lifetimes on the ground of the Heisenberg uncertainty principle. But in this case we must be sure that the width has dynamical origin and is not due to overlapping lines. We so pose the question of the existence of unhomogeneous linewidths in the domain of nuclear and elementary particle spectroscopy.

If γ- and X-laser type devices will be launched [5], it will be possible to generate phase memory effects to attosecond duration. It is well established [6] γ- and X-photon echoes will detect the difference between mechanisms of homogeneous and unhomogeneous widths in nuclear reactions. New possibilities arise if we establish de'Broglie wave phase clocks by splitting beams of fast particles and recording afterwords the interference pattern of the split beams. One part of the beam will be the undisturbed reference beam or the phase clock and the other part of the beam will interact with space-time volume of investigated interactions. The neutron spin echo [7] already discovered may be an example for performing a phase clock.

We will discuss now a few examples of how existing photoelectronic registrators may be operated to get one or two order of magnitudes

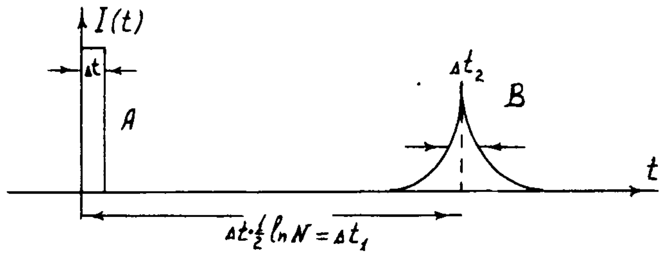

Fig.1. Boson avalanche time lens. A and B correspondingly the exciting pulse and the photon avalanche signal. Instead of Δt we can measure Δt_1. I(t) is the intensity of the signal.

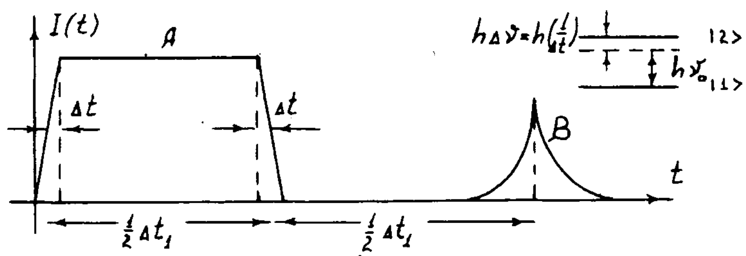

Fig.2. Boson edge echo time lens and time compression. Edge echo B is generated by a wide pulse A with fast rise time which can be measured by the mismach $\Delta\nu$ between the mean frequency of the pulse ν_0 and the atom level spacing $\nu_0 + \Delta\nu$. $1/2\,\Delta t_1$ is the A pulse length. The time compression ($\Delta t_1/\Delta t$) may be of the order of 10^2.

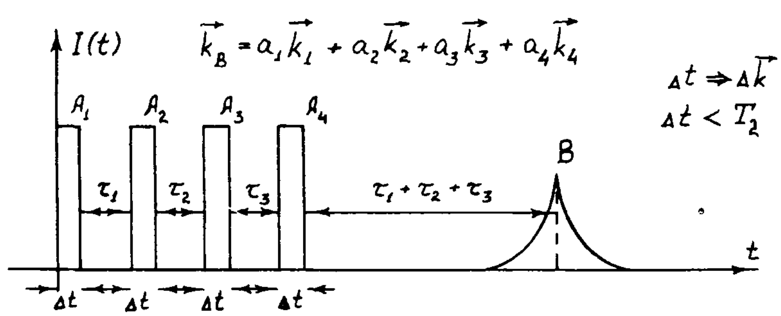

Fig.3. Multiple pulse space-time interval conversion. The echo B can be detected in the absence of time resolution simultaneously with the exciting pulses $A_1, \ldots, A_4$ in a direction $\vec{k}_B$ not coinsiding with $\vec{k}_1, \ldots, \vec{k}_4$.

time resolution enhancement by means of phase memory effects. This will mean the measuring of 1 fs photon pulses by means of 0.1 ps devices. The photon avalanche [2] method consists of the following. We have a system of two level atoms and we invert the populations of the system with a powerful and very short pulse of duration Δt that we are unable to measure. After a time $\Delta t_1 \sim (\frac{1}{2}\cdot \ln N)\cdot \Delta t$ we will see the avalanche signal of duration $\Delta t_2 \sim \Delta t$, where N is the number of excited atoms. In this manner instead of measuring Δt we can measure $\Delta t_1 \gg \Delta t$ and calculate the value of Δt (fig.1). If $N = 10^{22}$ we have an enhancement of time resolution of the order of $(\Delta t_1/\Delta t) \sim 25$. The edge echo-es also can enhance the time resolution of the time equipment (fig.2). First of all the edge echo signal will be compressed relative to the original pulse length and its time length equals the rise time Δt of a solitary exciting pulse duration $\frac{1}{2}\cdot \Delta t_1$. If we know the transition frequency $\nu_a = \nu_0 + \Delta\nu$ of the two level system and the mean frequency ν_0 of the exciting pulse, the difference $\nu_a - \nu_0 = \Delta\nu$ gives us an estimate $\Delta t \sim (1/\Delta\nu)$ for the rise time Δt. A second way to get the value of Δt consists of comparing the known irreversible relaxation time T_2 of the two level system with Δt, because the occurence of the edge echo tests the validity of the unequality $\Delta t < T_2$. The same consideration holds also for the usual echo signals.

The echo technique has some other advantages for attosecond pulse detection as the multiple pulse space-time interval conversion (fig.3) [8].

The direction of the echo signal will not coinside with the direction of the exciting pulses directions. So we will be able to detect the echo simultaneously with the exciting pulses in the absence of enough time resolution. From this fact we can state that $\Delta t \ll T_2$ and from the nutation frequency we can estimate the length Δt of the exciting pulses so

$$I(t) \propto \theta(t) = |\langle 1|\mu|2\rangle| E \hbar^{-1} \Delta t = 2\pi \nu_n \Delta t, \qquad (3)$$

where θ (t) is the nutation angle, E is the field amplitude, $\langle 1|\mu|2\rangle$ is the appropriate matrix element of the dipole, I(t) is the echoes radiation pulse.

We conclude with the remark that the realm of attosecond and still more advanced spectroscopy in our opinion will be one of the most fascinating and thrilling ocupations of physicists to come, because it may be connected with the resolution space-time structure problem and stimulation of the speed of nuclear computing devices.

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