Photons, photocounts and laser detection of weak optical signals

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«…Science … is not a refrigerating case for storage of the established trues, but the arena, on which struggle between the people and their flame ideas happens.»

G.Lochak, From Preface to the book "Les Incertitudes D'Heisenberg et L'Interpretation Probabiliste de la Mécanique Ondulatoire of L.deBroglie, Paris, 1982, Gauthier-Villars"

ABSTRACT. The physical nature of photocounts, i.e. current splashes in outer circuit of receiver at detection of weak optical signals is studied. It is shown, that the basic features of photocounts can be explained if to take into consideration the Coulomb instability of weak electronic flow, appearing in the detector under influence of accepted radiation. Many other particle manifestations of electrons can be explained by this way. The laser scheme of detection of weak coherent radiation, essentially using laser radiation pumping, is offered. Thereat electrons, bound in atoms, ions or molecules, are used as an active element of device, but not free electrons, as it is usual. The stabilization of electrons by strong Coulomb field of the atom, ion or molecule nuclea does not allow to manifest their Coulomb instability. As a result photocounts, otherwise, Schottky noises are strongly put down at detection of weak signals.

The detection of light is one of the most fundamental physical processes playing the important role as in nature, so in technique. For example, in nature this process provides a possibility of sight and, hence, to know the surrounding world. In technique the numerous photodetectors allow to make quantitative the process of detection of optical signals and to expand a spectrum of accepted radiations.

Despite of essential successes in engineering perfecting of existing photodetectors the understanding of the fundamental processes of photodetection is founded on ideas of more than fifty years old. This part of physics occurred to be in a shadow of great successes of laser physics and as though was frozen in "a refrigerating case", which mentioned in epigraph. However making laser light sources of high coherence reveals some inconsistencies in the former approaches to the effect of detection and makes this effect even a mysterious a little.

This mysteriousness can be illustrated with the Fig.1. The radiation detector in this figure is given as a shaded rectangle. On the detector input the radiation of high coherence, i.e. the radiation, which amplitude smoothly depends on time, is present. Thereat the specific time of the amplitude change in good lasers is on the order of seconds.

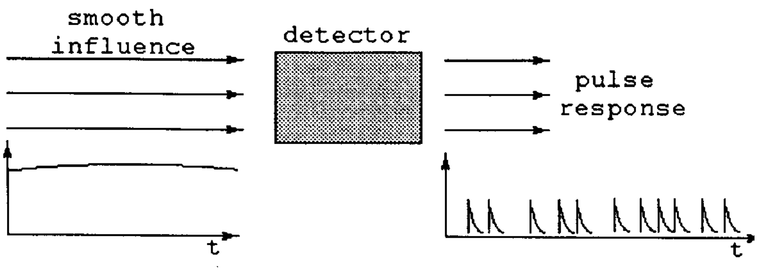

Figure 1. What is the cause of a photocounts?

On the detector output there is a sequence of impulses (photocounts) with specific time about 10^{-8} of the second. It is natural to raise the question - what is a reason of these photocounts. Such problem could not be raised in a prelaser epoch, as light of thermal and luminescent sources was chaotic and supplied enough reasons for origin of photocounts.

It is impossible to tell, that the problem of origin of photocounts is widely discussed in the scientific literature. But usually three possible answers to this problem are implied. The majority of the contributors supposes, that in radiation and, in particular, in coherent radiation there are spatially localized formations called photons, which at interaction with a photocathode lead to photocounts. So, at the investigation of the ***photocount*** statistics they frequently speak about the ***photon*** statistics, meaning just mentioned above localized formations. It is possible to meet a discussion in the literature a problem about, where the photon is going after interaction with a dividing mirror (Fig.2).

Other contributors suppose, that the reason of photocounts consists in a corpuscular nature of electrons. It is supposed, that the discrete electrons, interacting with a wave, which amplitude smoothly depends on time, introduce the discrete features in a response of the radiation detector.

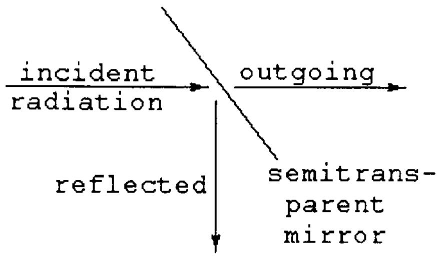

Figure 2. Where does the photon go after dividing mirror?

At last, there are contributors, which connect photocounts with so-called «a reduction of a wave packet», specific for quantum mechanical measurments.

It is shown below, that any of these points of view does not withstand criticism from modern positions. It is offered to interpete photocounts as a consequence of Coulomb instability of the weak electronic flows excited in the detector by the accepted radiation. Now it is an only approach, free from inconsistencies and explaining wide circle of effects, connected with photocounts.

It is shown, that the Coulomb instability, marked above, can be avoided, if to pass from use of free electrons in photodetectors to use of electrons, bound in atoms, ions or molecules. The laser detectors of optical radiation based on this idea are offered. Such detectors are capable to work without photocounts, in other words, without Schottky noise. It is interesting, that the physical process in the laser detectors, is not bound in any way, as it will be visible further, with an absorption of an energy on the order of $\hbar\omega$ and consequently they can react to an energy portion of much smaller magnitude.

1 Photon from the point of view of QED

What is photon. We shall approach to this problem on the ideas of modern quantum electrodynamics, more precisely, on ideas, which follow from the mathematical formalism of QED. Let's mark, that the quantum electrodynamics is a highly reliable theory checked to within many signs after a point; in essence, it is the most precise theory in modern physics.

Usually, at interpretation both theoretical and experimental results they resort also to other ideas, such, for example, as «a reduction of a wave packet», supplementary to mathematical formalism of the theory. These supplementary ideas we shall leave aside for a while.

Essential feature of photon, following from QED, is its ability for to have different forms. Two forms of photon - distributed and packet are considered below. The purpose is to spot, if photon can be considered as spatially localized formation.

Distributed representation. At description of photons in QED some great cubic resonator is usually introduced, in which modes are the plane waves having a discrete set of eigen frequencies and wave vectors. From the quantum point of view such mode is an oscillator and can be in states with various number of photons, and also in other possible states of an oscillator (coherent, squeezed and etc.). If this oscillator is in the one-photon state, the field of this photon is uniformly distributed on all volume of the resonator. As at quantization of field volume of the major resonator directs to infinity after all, the field of a photon occurs to be uniformly distributed in all infinite space. It is completely clear, that such photon can not be a reason of a photocount, as it is not localized spatially. At a multiphoton state there is no localizations of photons also - their composite field is uniformly distributed on all volume of the resonator and, accordingly, on all space after the mentioned above passage to the infinite volume. Thus we can conclude, that the photon introduced in such manner can not cause photocounts.

As such procedure of quantization of an electromagnetic field is described in all textbooks on QED, we shall not develop it and take from this description only operator of the electric field having following form

$$\vec{E}(\vec{r},t) = \frac{i\sqrt{\hbar}}{2\pi} \sum_{\lambda} \int d\vec{k} \sqrt{\omega} \vec{e}_{\lambda}(\vec{k}) a_{\lambda}(\vec{k}) e^{i(\vec{k}\vec{r}-ckt)} + h.c., \qquad (1)$$

where the summing is yielded over two polarizations and $a_\lambda^+(\vec{k})$, $a_\lambda(\vec{k})$ are the spectral densities of operators of creation and annihilation, obeyed to the commutation relation

$$a_i(\vec{k})a_j^+(\vec{k}') - a_j^+(\vec{k}')a_i(\vec{k}) = \delta_{ij}\delta(\vec{k} - \vec{k}'). \tag{2}$$

Packet representation. For packet representation [1,2] we shall introduce operators of creation and annihilation

$$A = \sum_{\lambda=1,2} \int d\vec{k} W_\lambda(\vec{k}) a_\lambda(\vec{k}) \quad , \qquad A^+ = \sum_{\lambda=1,2} \int d\vec{k} W_\lambda^*(\vec{k}) a_\lambda^*(\vec{k}) \quad , \tag{3}$$

where $W_\lambda(\vec{k})$ is some normalized spectral function

$$\sum_{\lambda=1,2} \int d\vec{k} \left| W_\lambda(\vec{k}) \right|^2 = 1, \tag{4}$$

defining, as we shall see further, spectrum of a packet and $a_\lambda^+(\vec{k}) a_\lambda(\vec{k})$ are the densities of operators of creation and annihilation, which are included in the above mentioned expression for the electric field operator of free space. It is possible to be convinced, that these operators obeyed to a commutation relation

$$\left[A; A^+\right] = 1. \left[A; A^+\right] = 1. \tag{5}$$

According to this relation the operators A and A^+ generate a system of stationary states $|n\rangle$ such, that

$$|n\rangle = \frac{A^{+^n}}{\sqrt{n!}}|0\rangle, \quad A|0\rangle = 0. \tag{6}$$

Arbitrary state of such packet can be presented as

$$\left|\Psi\right\rangle = \sum_{n=0}^{\infty} \Psi_n \left|n\right\rangle. \tag{7}$$

It is possible to show, that all average values can be expressed through single function, which can be called the shape of the quantum wave packet. An average value of the electric field in the state (7) equals

$$\left\langle \vec{E}(\vec{r},t)\right\rangle = \vec{\Phi}(\vec{r},t)\cdot\left(\sum_{n=0}^{\infty}\sqrt{n}\,\Psi_{n-1}^{*}\Psi_n\right) + \vec{\Phi}^{*}(\vec{r},t)\cdot\left(\sum_{n=0}^{\infty}\sqrt{n}\,\Psi_{n-1}\Psi_n^{*}\right).$$

In this expression function

$$\vec{\Phi}(\vec{r},t) = \frac{i\sqrt{\hbar}}{2\pi}\sum_{\lambda}\int d\vec{k}\,\sqrt{\omega}\,W_{\lambda}^{*}(\vec{k})\,\vec{e}_{\lambda}(\vec{k})\,e^{i(\vec{k}\vec{r}-ckt)} \tag{8}$$

is just the mentioned above function, describing the shape of a wave packet.

The average value of square of the field, proportional to a density of the electrical energy, also can be expressed through the same shape of the wave packet

$$\left\langle \vec{E}^{2}(\vec{r},t)\right\rangle = \left|\vec{\Phi}(\vec{r},t)\right|^{2}\cdot\left(\sum_{n=0}^{\infty} n\left|\Psi_n\right|^{2}\right).$$

It is possible to show generally, that the average values of all degrees of the field can be expressed also through function (8).

Hence, the function $\vec{\Phi}(\vec{r},t)$ describes distribution of the field in any quantum state of the wavepacket. It is possible to say that at packet representation photon is a spatially localized object. In the case of one-photon state function $\vec{\Phi}(\vec{r},t)$ is the shape of this photon. In case of a multiphoton state there is no however spatial separation of a package on any one-photon parts, the fields of all photons are distributed uniformly according to function $\vec{\Phi}(\vec{r},t)$.

Relation (8) allows to conclude, that a magnitude

$$\frac{i\sqrt{\hbar\omega}}{2\pi} W_{\lambda}^{*}\left(\vec{k}\right)$$

is simply the Fourier spectrum of the wavepacket $\vec{\Phi}(\vec{r},t)$. As is known, length of a packet L and the width of its Fourier spectrum $\Delta\omega$ submit to a relation

$$\Delta\omega \cdot L / c \geq 1.$$

Hence, length of a photon $L_{phot} = L$ can be only more than the specific length of a packet (it is just the length of coherence), defined by relation

$$L_{coh} = c / \Delta\omega, \quad \text{i.e.} \quad L_{phot} \geq L_{coh} = c / \Delta\omega.$$

If this relation to apply to photons generated in the lasers of high coherence, it is possible to conclude, that at coherence times about one second the photons have an astronomical length, about 300.000 km. It is completely clear, that such photons can not be cause of photocounts.

It is just the point of view of QED on localization of photon. Sometimes it is supposed, that radiation, even coherent, contains some localized objects which are not described by the mathematical formalism of QED - just they must be ostensibly termed as photons. Such point of view seems naive to us. Quantum electrodynamics is more than half-hundred years old. It is checked up to ten signs after a point and now is the most precise physical theory. Naively to think, that such theory could pass some localized formations in the field.

2 Photoeffect and localization of electrons

Localization of electrons. Let's consider now two other points of view referring a reason of a discrete nature of the output signal of the detector to a corpuscular nature of electron. The key diagram of the vacuum detector of radiation is given on Fig.3. According to the theory of a photoeffect a plane electromagnetic wave interacts with a plane Bloch electronic wave of the valence band of the semiconductor, forming the cathode. As a result of this interaction the plane Bloch electronic wave appears in a conduction band. As its energy is essentially more, than the energy of the wave in the valence band, it rather easily penetrates into vacuum, overcoming a potential barrier.

Thus up to this moment the electron is considered as a wave which is not having any spatial localization. The process of excitation of the electronic wave in the conduction band under influence of the continuous electromagnetic wave happens continuously and, hence, at this stage there is no any indications on a possibility of discrete output signals.

If such description of the electronic wave, just as wave, to prolong up to the anode, any splashes of a current, i.e. photocounts will not arise, since on the one hand continuous wave can not give any splashes of the current, on the other hand - it is well known, that the photocounts arise just at transiting of the electron through the cathode - anode gap and, hence, if they have not arisen to the moment of reaching by the electron wave of the anode, they already will not arise at all. Certainly, such situation will contradict observations, since the existence of photocounts is the well established experimental fact.

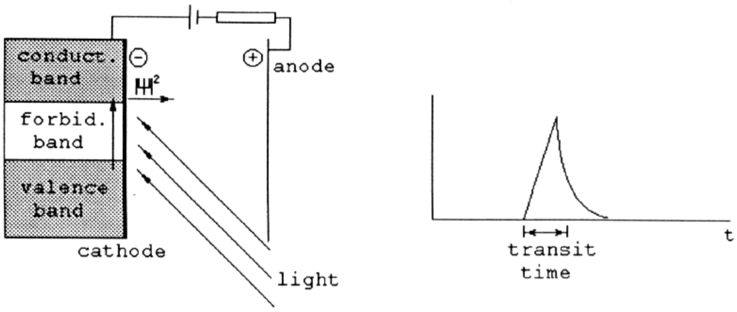

Figure 3. How does electronic wave transmute into particle?

Usually the electronic wave, leaving the cathode, is interpreted as a probability amplitude to find out the localized electron near to the cathode. Thereat «a reduction of a wave packet», occuring at quantum mechanical measurements, i.e. at interaction of a microscopic quantum system with the macroscopic device is usually refered. As the electron becomes the casually localized particle, the photocount arises by a natural manner, as outcome of transiting of a particle through the cathode-anode gap.

However such application of the wave packet reduction is incorrect. Leaving in a leg all modern controversies about a reduction of a wave packet, we shall refer to such authoritative author as von Neumann [3]. He validly specifies, that the wave packet reduction is applicable only in that case, when it is possible to transfer an imaginary surface separating quantum system from the device, including in a quantum system all device or its parts; thereat the picture perceived by the observer should not vary, as the surface, separating a quantum system from the device, is imaginary, and nothing can depend on this imaginary surface. Von Neumann has used great power to show, that such measurements are possible.

But it is not that case, which is used for an explanation of photocounts by means of the wave packet reduction. As told above the shift of boundary between a system, considered quantum mechanically, and device, considered classically, from the cathode to the anode drastically changes an observable pattern - photocounts disappear. Therefore it is necessary to refer the wave packet reduction, if it exists, on a later stage of interaction of a quantum system with observer.

Thus it is necessary to recognize, that the existing ideas about process of detection of optical signals do not give explanations to photocounts, i.e. discrete response of a photodetector to a continuous accepted signal.

3 Photocounts as a manifestation of Coulomb instability of weak electronic flow

We suppose, that it is necessary to give the physical explanation to photocounts which has not been based on miraculous transmutation of a wave into a particle. From our point of view a reason of photocounts is the Coulomb instability of a weak electronic flow appearing in the detector under influence of the accepted radiation. As a result of this instability the flow breaks up to separate one-electron clots, which at the driving from the cathode to anode excite splashes of a current in an external circuit of the detector. These splashes are perceived by the observer as photocounts.

The instability of a weak electronic flow is easy to understand if to recollect about well known Wigner crystallization [4,5]. As it is known, the system of electrons at low density breaks up to the systematically located one-electron clots, which Wigner just termed as electrons. In this crystallization it is possible to allocate two stages. First an instability of the uniform or quasi-uniform electronic distribution and beginning of decay on clots are. Second natural crystallization or self-organization of electronic distribution in stationary Wigner conditions is.

In case of the vacuum detector of electromagnetic radiation the electrons pass from the place with a high density of charge inside the cathode in the place with a small density of charge in vacuum. Correspondingly, the tendency to a disintegration of quasiuniform electronic distribution into clots should be exhibited. However, due to nonstationary conditions in the detector in the whole the second stage - the regular crystallization - is not exhibited and the decay on more or less random clots can come true only.

Just these clots, moving in a cathode - anode gap, raise random splashes of a current in an external circuit of the detector, which are perceived by the observer as photocounts. This point of view now is a unique explanation of photocounts, free from noticeable inconsistencies. This point of view is sufficiently expressed by us in the publications [6-16]. We shall not iterate all reasons in its favour in this paper and give only three graphs describing decay of an electronic system into clots. On Fig.4 the energy of a two-electronic cloud as a function of the potential well width is shown. The electronic cloud can be in states with one (1) and two (2) maxima of a charge density. In a wide potential well a state with two maxima, and in narrow potential well - state with one maximum are energy preferable. It means, that at a diminution of an electronic density the cloud breaks up into two Wigner electrons. It confirms the Wigner point of view in specific conditions of a potential well.

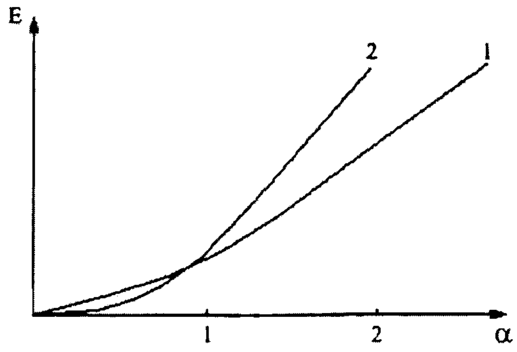

Figure 4. Dependence of the energy of the state with one (1) and with two (2) maximums on the parameter α of the potential well ($(1/\alpha)$ is the width of the potential well).

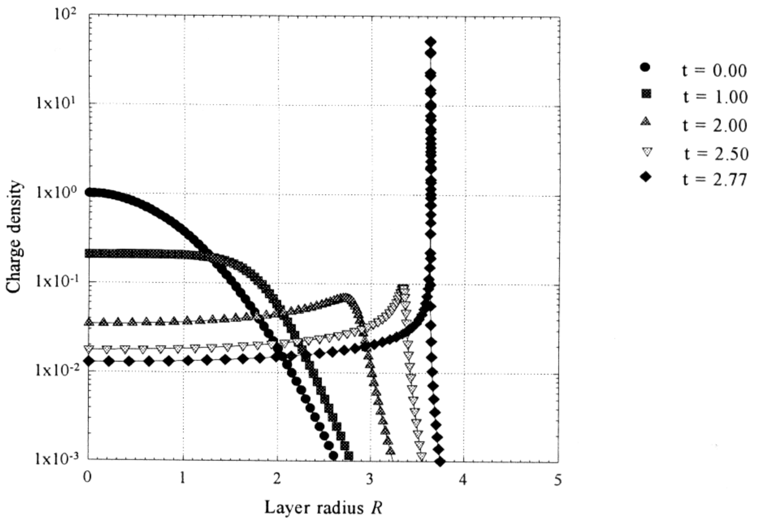

Figure 5. Expanding of charge distribution under influence of its own Coulomb field.

On Fig.5 dynamics of decay of a charged electronic cloud under influence of its own electric field is shown. It is possible to see, that in some instant in a cloud an infinite maxima of a charge density appears on the first sight without any reason. Such situations are qualified in mathematics as catastrophes. Physically it signifies, that the electric field of a concentrated charge has some focusing properties. It is possible to think, that due to this focusing a little diffused clots formed as a result of Wigner instability, will become sharp.

Fig.6 confirms this deduction. The dependence of the width of one-electron clot on distance at its driving in the cathode - anode field and simultaneously in a field of another similar clot is shown. One can see, that the inhomogeneous field of the second clot strongly focuses a moving clot so, that its longitudinal size decreases on some orders. Such clot can excite a sharp splash of current in the outer circuit of detector rather similar to a photocount.

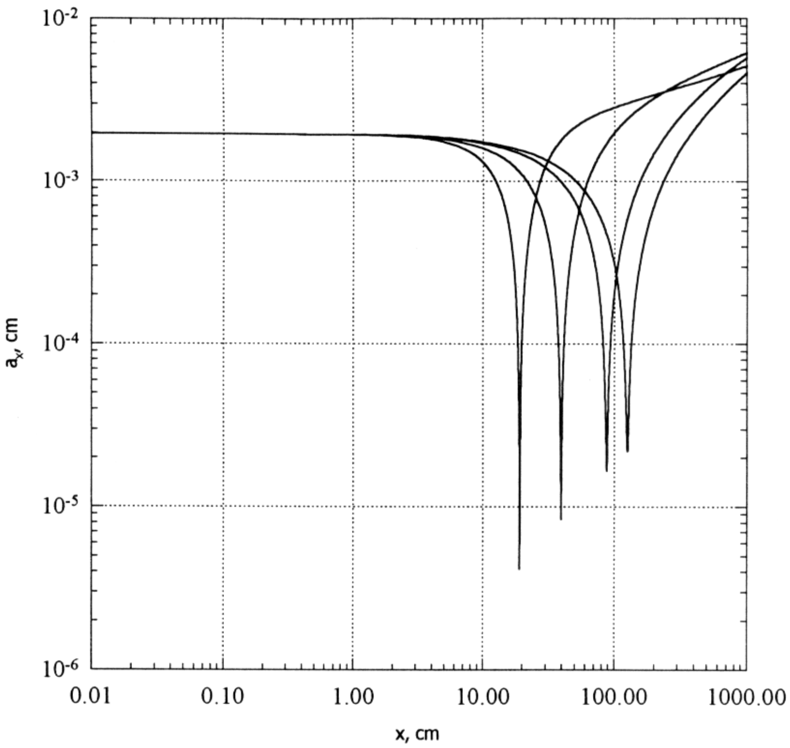

Figure 6. Dependence of the electron wavepacket length on distance at its movement in homogeneous field of strength 50 volts/cm and simultaneously in Coulomb field of other electrons at various initial velocities.

Thus Coulomb instability of quasiuniform electronic distribution allows to explain the basic features of the photocount effect originating at detection of weak optical signals. Now this is a unique consistent explanation of this effect.

4 Reception of signals without photocounts, laser detection

The approach to photocounts advanced above allows to make the important deductions. The photocounts (and, hence, Schottky noises) are not a fundamental effect accompanying process of detection of an electromagnetic signal; they are simply large noise of the detector originating in it itself. As a cause of such noise is the instability of a weak electronic flow, it is possible to struggle with them, stabilizing the electronic system by that or another way. The subsequent account is devoted to description of one of possible modes of use of the stabilized electronic systems, in which photocounts, in other words, Schottky noises will be put down.

Laser detectors of weak optical radiation. As it is shown above, in traditional vacuum detectors of radiation there is a strong Coulomb instability of weak electronic flow, originating in the detector under influence of a detected signal. It directs us on an idea to use in detectors not free electrons, but electrons, bound in atoms, ions or molecules, where they are well stabilized by the strong Coulomb field of the nuclea [17-19]. Further this idea is developed. Detectors, based on use of bound electrons, we shall term as laser detectors, since laser radiation as a source of energy for these electrons plays an important role in them.

The base of the described further device is a system of three-level atoms (Fig.7). It is supposed, that these atoms are in the specially constructed optical resonator, in which there is a resonant, signal mode on the frequency ω of the transition $|0\rangle \leftrightarrow |1\rangle$, and also two resonant modes on the frequency Ω of the transition $|1\rangle \leftrightarrow |2\rangle$. In lack of population on levels $|1\rangle$ and $|2\rangle$ two last modes are degenerated on frequency and are not connected with each other. Thus one of these two modes (pumping mode) is exited, i.e. contains a strong monochromatic pumping field, exited by an exterior laser. The second mode is for excitation of an output signal - further it will be termed as output mode. In the initial state, i.e. before arrival of a signal, it is not exited, that is, does not contain any field.

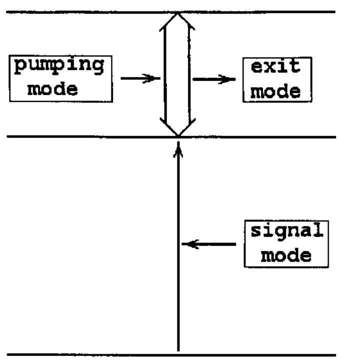

Figure7. Interaction of three-level atoms with electromagnetic modes.

The principle of the detector operation consists in the following. Before arrival of a signal to the signal mode atom, not being in a resonance with the pumping field and practically not interacting with it, remains in a state $|0\rangle$. After arrival of a signal on frequency ω at the level $|1\rangle$ appears some population. Thereat under influence of the strong pumping field the passages between levels $|1\rangle$ and $|2\rangle$ begin and an oscillating dipole moment on frequency Ω appears, which raises a field in the output mode. The problem is to show, that the output signal can be essentially more than the input one. Besides it is necessary to spot the specific time of increase of the output signal. The examination will be carried out in the so-called half-classical approximation, when the processes in atoms are explored within the framework of quantum mechanics, while all fields are considered as classical. It is considered the case, when the time of increase of the output signal is less than time of the phase (cross) relaxation of active atoms in the medium.

The amplitude $u(t)$ of the output mode field is slowly varying function of time and submits to the equation

$$\dot{u}(t) = \frac{2\pi ic}{\Omega} j'(t), \tag{1}$$

where $j'(t)$ is the amplitude of the negative-frequency part of a current $j(t)$ and is also slowly varying function of time. This current consists of the partial currents of separate atoms interacting with three fields.

The state of three-level atoms interacting with fields of three modes, is described by density matrix

$$\begin{gathered}\rho = \rho_0|0\rangle\langle 0| + \rho_{01}|0\rangle\langle 1| + \rho_{02}|0\rangle\langle 2| \\ + \rho_{10}|1\rangle\langle 0| + \rho_1|1\rangle\langle 1| + \rho_{12}|1\rangle\langle 2| + \rho_{20}|2\rangle\langle 0| + \rho_{21}|2\rangle\langle 1| + \rho_2|2\rangle\langle 2|.\end{gathered} \tag{2}$$

In the interaction representation density matrix submits to the equation

$$\partial\rho / \partial t = -i[W_i; \rho], \tag{3}$$

where

$$W_i(t) = [\varsigma(t)|2\rangle\langle 1| + \varsigma^*(t)|1\rangle\langle 2|] + [\beta|1\rangle\langle 0| + \beta^*|0\rangle\langle 1|] \tag{4}$$

and

$$\varsigma(t)=\alpha+\gamma(t),\ \alpha=-ie\Omega ur/\hbar c,\ \beta=-ie\omega u_i r_i/\hbar c,\ \gamma(t)=-ie\Omega u_o(t)r_o/\hbar c, \quad (5)$$

- magnitudes describing interaction of atom with mode fields, $u, u_i, u_o(t)$ - negative-frequency amplitudes of the vector potential, correspondingly, of modes pumping, signal and output,

$$r=\vec{v}(0)\vec{r}_{21},\ r_i=\vec{v}_i(0)\vec{r}_{10},\ r_o=\vec{v}_o(0)\vec{r}_{21} \quad (6)$$

- projection of matrix elements of the electron coordinate to the normalized amplitudes $\vec{v}, \vec{v}_i, \vec{v}_o$ of pumping, signal and output modes at the atom location, i.e. at the coordinate origin (due to the mode normalization $\overline{v^2}\cong 1/V$, where V is the mode volume). The magnitudes, relevant to the pumping mode, do not carry any index, magnitudes, relevant to signal and output modes, are marked by indexes $i(in)$ and $o(out)$. Since the amplitude of the output mode field, proportional to $\gamma(t)$, slowly varies with time, this field is not monochromatic. Its average frequency supposed to be equal to Ω, identical to the transition frequency of atom and pumping frequency.

The operator of the polarization current $j(t)$ of all atoms, exciting the output mode, in a dipole approximation equals

$$j(t)=n\int d\vec{r}\vec{v}_o(\vec{r})\vec{j}(\vec{r},t)\cong\frac{e}{m}n\vec{v}_o(0)\langle 2|\vec{p}|1\rangle e^{i\Omega t}|2\rangle\langle 1|+h.c.=$$
$$ien\Omega r_0 e^{i\Omega t}|2\rangle\langle 1|+h.c.,$$

where n is the number of active atoms, $r_0=\vec{v}_o(0)\vec{r}_{21}$ and $\vec{r}_{21}$ is the coordinate matrix element of the $|2\rangle\to|1\rangle$ transition. The average value of the current, exciting the output mode, at an instant t equals

$$\langle j(t)\rangle=Sp\big(j(t)\rho(t)\big)=ien\Omega\left(r_o\rho_{12}e^{i\Omega t}-r_o^*\rho_{12}^*e^{-i\Omega t}\right), \quad (7)$$

where $\rho_{12}(t)$ is the element of density matrix of atom, only important for definition of a current.

Supposing, that the input signal is weak and on all the time interval, under interest, population of the lower level varies a little and remains approximately equal unity, in the third order of the perturbation theory for the element $\rho_{12}(t)$ of density matrix expression

$$\rho_{12}(t) = i|\beta|^2 t \int_0^t dt_1 \cdot t_1 \left(\alpha^* + \gamma^*(t_1)\right). \tag{8}$$

is obtained. Hence, due to equations (1), (5), (7) and (8) for $\gamma(t)$ obtain

$$\dot{\gamma} = -\xi^2 t \int_0^t dt_1 \cdot t_1 \left(\alpha + \gamma(t_1)\right), \quad (\xi^2 = 2\pi\varepsilon^2 \Omega \omega^2 n |r_o|^2 |r_i|^2 |u_i|^2 / \hbar c). \tag{9}$$

Dividing the equation (9) by t and differentiating the obtained equality over t, we come to equation

$$t\ddot{\gamma} - \dot{\gamma} + \xi^2 t^3 \gamma + \xi^2 t^3 \alpha = 0. \tag{10}$$

General solution of this equation has the following form

$$\gamma(t) = -\alpha + A\sin\left(\xi t^2 / 2\right) + B\cos\left(\xi t^2 / 2\right), \tag{11}$$

and in view of the initial conditions $\gamma(0) = 0$ and $\dot{\gamma}(t)/t\,|_{t=0} = 0$, we come to the following expression for a response of an output mode on a coming signal

$$\gamma(t) = -\alpha\left[1 - \cos\left(\xi t^2 / 2\right)\right]. \tag{12}$$

Thus after arrival of the input signal, i.e. field u_i, in time $\tau = \sqrt{2\pi/\xi}$ in the output mode a field becomes approximately equal to the pumping field, much greater, than the signal field. This specific time τ of the detector response should be less than or equal to time of the phase relaxation τ_0. The magnitude ξ^2 can be written in the form

$$\xi^2 = \left(\frac{e^2}{\hbar c}\right)^2 \frac{(2\pi c)^4 |r_o|^2 |r_i|^2}{V_i\lambda_i \cdot V_o\lambda_o} Nn, \tag{13}$$

where n is the number of atoms interacting with modes, N is the number of photons in a signal mode, V_i, V_o are the volumes of signal and output modes, λ_i, λ_o are the wavelengths of the signal and output radiation. If to put $\tau \cong \tau_0$, this formula determines that minimum number of photons, which should be present at the signal mode, in order that during detection time on the order of τ_0 the amplitude of the output mode field could grow up to the maximum value. Thus this parameter determines sensitivity of the considered device to the input signal.

Supposing $\xi^2 = (2\pi)^2 / \tau_0^4$, we find, that at number of photons in the signal mode, equal

$$N = \frac{V_o\lambda_o \cdot V_i\lambda_i}{(2\pi)^2 \varepsilon^2 c^4 |r_{12}|^2 |r_{01}|^2 n\tau_0^4}, \tag{14}$$

where $\varepsilon = e^2 / \hbar c$ is the fine structure constant, the field in the output mode in time τ_0 will increase up to the maximum value. For estimations we shall let, that transversal sizes of modes are about a wave length λ, and their longitudinal size of the order $10^2 \cdot \lambda$. The sizes of both modes are approximately identical. Time interval τ_0 for estimations let's assume equal approximately 10^{-8} sec. The concentration of active atoms $n_0 \cong 5 \cdot 10^{19}$ at/cm^3, and their complete number is equal to $n = n_0 \cdot V$. Matrix elements are $|r|^2 \cong 2 \cdot 10^{-19}$ cm^2 [8]. Then, due to (14), at number of photons in the signal mode equal $N \cong 10^{-8}$, the output mode field increases up to the maximum value in time $\tau_0 \cong 10^{-8}$ sec. As above maximum value of the output mode field becomes approximately equal to field in the pumping mode. In the pumping mode it can, for example, be one hundred photons. Hence, the energy amplification factor of the signal can reach considerable values. Certainly, the embodying of such sensitivities will require serious experimental gains and theoretical account of quantum nature of detecting signal.

The estimation shows, that the number of parasitic photons in the signal mode of the frequency ω which has arisen, for example, due to nonresonant Rayleigh scattering or due to nonresonant Raman effect is at least two order less than an above mentioned value.

Thus it is shown, that the detection of optical signals is possible by laser means, when there are no reasons for appearance of photocounts. As could be seen, similar devices are rather sensitive.

5 Conclusion

In this paper it is given the physical explanation to photocounts, i.e. splashes of a current originating in detectors of optical radiation at reception of weak coherent signals. This explanation is based on Coulomb instability of electronic flows in the detector. This instability can be in other cases also, for example, in the form of Schottky noises.

The laser method of detection of optical signals, at which the photocounts should be absent, is offered. In other words, the laser method of optical detection allows to put down Schottky noises.

The most amazing peculiarity of the laser method of detection of optical signals is that the physical process laying in its basis, is not connected in any way with the energy absorption on the order of $\hbar\omega$ and consequently such detectors are capable to react to the energy portion of much smaller magnitude. If this ability of laser detectors will be implemented practically, it will drastically change the conventional picture of quantum mechanical measurements.

The explanation of photocounts, developed in this paper and in [8], allows to look from new positions at old controversies about observations of electrons as localized particles. Observation of separate electrons is always the observation at small values of electronic density. Thus at selection of separate electrons from large multielectronic systems always there is enough time for decay corresponding electronic clouds to one-electron clots, which then are observed as separate electrons.

Author is thankful to A.M.Prokhorov for influential discussions. Author is thankful to G.Lochak for many discussions on physics and science philosophy.

This paper is supported by the grant RFBR 98-02-16671.

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(Manuscrit reçu le 20 juin 2000)