Photocounts and the catastrophe theory

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ABSTRACT. The electron clots formation in the interelectrode space of the vacuum detectors of the optical radiation is discussed. These clots excite the current splashes in the outer circuit of the detector, which are usually interpreted as photocounts. It is shown that the traditional photocount theory is inconsistent and, in particular, it is shown, that the causality violation is peculiar to it. By variational numerical calculations it is shown that the widespread electron cloud is unstable to the Coulomb forces and is decaying into clots. At the clots motion from the cathode to the anode the catastrophes occur and the clot sharpening happens. The catastrophes can be of the space-like (caustics) and time-like (outrunnings) types. By the numerical simulation the spherical and linear spreading of the electron cloud are investigated. The formation of the sharp electron density maximums is found. These maximums are similar to the localized charged particles and can excite the current splashes (photocounts) in the outer circuit of the detector. the reasons leading to one-electron clots are discussed.

This account as a whole is an alternative (to the world-wide accepted) approach to the photocount theory.

1 Introduction

The situation in the photocount theory can be now evaluated as satisfactory. Many experiments are done and doing, their theoretical treatment is going and there is no any contradiction between theory and experiment. However, from the logical point of view the existing photocount conceptions are far from perfect. In this paper we, appealing mainly to the physical processes in the vacuum detecting devices (such as photoelements, photomultipliers, and so on), give an attempt to analyse the contradictions of the existing photocount theory and propose a new, alternative approach to this theory, more attractive physically.

Modern photocount theory has in essence a phenomenological nature, i.e., its main equations don't follow from the basic equations of physics (such as Maxwell, Schroedinger or Dirac equations). As an example it can be mentioned, that the discrete nature of photocounts is not a consequence of the theory, but is taken as an experimental fact. Due to it some continuous values of theory, e.g., the photocount rate, are arbitrarily interpreted as corresponding to the average values describing the stochastic sequence of the discrete events (photocounts). As to the photocounts this discreteness is expressed in the fact that due to this point of view one light quantum - photon is necessary for the extracting of an electron from photocathode. Thereat the photon and electron are considered as localized particles, flying in the electromagnetic and electronic flows. It is usually considered that in the photoeffect process one particle (photon) is absorbered and the other particle (electron) is emitted.

It can be mentioned, however, that there is no any indication in QED on the existance of such localized formations in the electromagnetic and electronic flows. The absence of the localized formations in the electromagnetic radiation is especially evident in the case of the high coherent laser radiation. In the good laser source the time of coherence can be as great as one second (that is, the coherent train length is $3.10^5 km$ and it contains 10^{15} perfectly similar waves). Although the amplitude and phase of radiation are practically constant for this time interval, many photocounts occur during this time.

However, the conception of the localized photons and electrons were world-wide accepted. Especially definitely such point of view was reflected in the description of the shot noise [1,2] peculiar not only to photodetectors. Due to W.Schottky an electron as a classical point particle at an accidental time instant appears from the cathode and goes to the anode under influence of the statical electrical field initiating by this way some pulse current in the light detector circuit [3]. Both photoeffect and shot noise are widely investigated in the frames of such approach and these investigations are continuing [4-6].

However, from the currently accepted theoretical point of view this approach suffers from some inconsistency. Thus, the process of absorption of photons and generation of photoelectrons inside the cathode is considered quantum-mechanically. Specifically, it is usually assumed that a quantized plane light wave interacts with a quantized plane electron wave belonging to the valence band ; as a result, a plane electron wave is created in the conduction band. The electron wave in the conduction band is scattered by the boundary of the cathode with vacuum, and the amplitude of the electron wave propagating into the vacuum determines the probability of the generation of photoelectrons in the vicinity of the cathode. The inconsistency of the theory is that the quantum-mechanical description of the process ends here; from this point on, the evolution of the electrons is considered from the classical point of view [3], specifically, the electrons from this point onward are treated as particles, not waves.

The mentioned above inconsistency is often considered as due to the fundamental peculiarity of the quantum-mechanical measurements. The measurement (observation) of the quantum-mechanical object is usually executed by a macroscopic device (in some cases, by observer), having the properties of the classical object. Due to it there is inevitably a boundary between the object of observation and the measurement device, which divides the quantum-mechanical description (on the object side) from the classical description (on the side of the measurement device). Just due to it the electron, emitted from the cathode, is considered as a classical localized particle, that is, the mentioned above boundary is going usually along the cathode surface.

From the general point of view nothing could be said against such approach and it can't be disproved. However, the applicability of this approach is not so wide as it usually accepted. Indeed, this point of view is correct only if the resulting picture does not depend on the position of the mentioned above boundary, since this boundary is imaginary and nothing can depend on its position. Returning to the photocounts, one can ask, if the result of the theoretical treatment of the experimental results will be changed, if the imaginary boundary will be taken near the anode, but not near the cathode as usually. Therefore, such interpretation of photocounts requires an additional investigation.

It would be more consistent to treat the motion of the electrons from the cathode to the anode also quantum-mechanically and to seek the field and current created in the circuit by the electron wave. It is clear, however, that in such an approach one does not obtain photocount pulses, but rather more or less smooth solutions for the fields and currents created in the circuit, depending on time in a way similar to that of the incident light wave. The absence of short pulses in such an approach, of course, contradicts the observations, i.e., the existance of photocounts. This contradiction is especially pronounced in the case of laser light sources whose characteristic coherence times are quite large (up to seconds). Naturally, the electron flux in the photodetector should also preserve the smoothness of its amplitude over time-intervals comparable with the coherence time. However, no such feature in the phoelectric effect using laser sources has been noted. In pre-laser studies the incoherence of light from thermal and luminescent sources could mask this contradiction. Therefore the existance of photocounts, at least in the case of laser light, requires explanation.

The aim of the present paper is to present an alternative approach to the theory of photocounts, differing from that given in the literature based on the corpuscular relationship of one photon to one electron. The alternative approach is based on the idea that the electron flux emitted by the cathode under the action of, in particular, laser light, is initially, i.e., immediately after it leaves the cathode, a plane wave or something close to it (an electron cloud). However, this flux is unstable and has a tendency to decay into clots under the action of the interelectron Coulomb force. This instability can be easily understood if one recalls the widely known Wigner crystallization, i.e., the decay of an electron plasma in a solid body into clots at low densities of plasma [7,8]. Thus, the electron flux leaving the cathode, i.e., the region with high electron density, should decay near the cathode into individual clots ("electrons"), which as they accelerate in the electric field produce current splashes in the electric circuit of the detector. These splashes are recorded by the device and observed by humans as photocounts.

The alternative approach preserves, of course, the main features of the photoelectric effect, including the Einstein law with its red limit of the photoelectric effect, since these laws operate, in fact, at the first step, when the electron wave is formed in the conduction band.

The first indications on the alternative approach were given by us in [9]. The alternative approach leads to some problems, part of which is discussed in this paper. The most important of them are: what manifestation of the electron flow instability is, if the mechanism of the electron clot sharpening exists and what its nature is, how one-electron clots can appear and, at last, what practical consequences of the alternative approach if it will occur to be correct. These problems are difficult enough. We shall show, that now the answers to these questions don't contradict to the alternative approach.

Emphasize also, that in the existing photocount theory there are some inconsistences of smaller scale. For example, some quantitative parameters of photocounts, among them the photocount rate (number of photocounts per second) violate the causality [10], that is, they don't retard in a proper manner.

At the first step we remind how the causality violation occurs. Then it will be shown by quantum-mechanical calculation that the electron cloud has a tendency to decay into clots at low densities. Then we investigate the effect of the clot sharpening based on the appearance of the temporal and space catastrophes; this research is carried out in the frames of the classical theory for the present. Later the concept of transparent and untransparent clots is introduced. In conclusion the problem of the one-electron clots is discussed.

2 The causality violation in the photocount theory

Here we discuss a small but important defect of the existing theory of photocounts - causality violation [10-14].

To show it we consider the quantity, assumed usually as a photocount rate (more exactly, the probability of photon registration in the point r in time interval $(t, t+dt)$)

$$dR(r,t) = \eta G(r,t)dt, \tag{1}$$

where $G(r,t)$ is the correlation function, defined by the equation

$$G(r,t) = Sp\left[\rho E^{(+)}(r,t)E^{(-)}(r,t)\right], \tag{2}$$

ρ is the density matrix of the electromagnetic field,

$$E^{(-)}(r,t) = i\sum_n \left(\frac{2\pi\hbar\omega_n}{V}\right)^{1/2} \alpha_n a_n e^{i(k_n r - \omega_n t)} \tag{3}$$

is the negative-frequency part of the field, and α_n is the cosine of the angle between the polarization directions of the modes and detector.

Let the field to be in a coherent state, defined by the equations

$$a_n|\psi\rangle = (Z_n/V^{1/2})|\psi\rangle; \tag{4}$$

then, taking into account Eq.3, we obtain

$$E^{(-)}(r,t)|\psi\rangle = W(r,t)|\psi\rangle \tag{5}$$

where

$$W(r,t) = iV^{-1}(2\pi\hbar)^{1/2}\sum_n \omega_n^{1/2}\alpha_n z_n e^{i(k_n r-\omega_n t)},$$

or, passing to integrals,

$$W(r,t) = \frac{2i(2\pi\hbar)^{1/2}}{(2\pi\hbar)^3}\int d^3k\ \alpha(\omega)\omega^{1/2}z(\omega)e^{i(kr-\omega t)} \tag{6}$$

is the analytical signal. In integral Eq.6 there is a factor $\exp(-i\omega t)$ with $\omega > 0$. If t is a complex variable $t = t_1$-it$_2$, then in Eq.6 there is a complementary factor $\exp(-\omega t_2)$; so $W(r,t)$ is an analytical function in the lower half plane of the complex variable t. In this case the imaginary and real parts of $W(r,t)$ are connected by

$$ImW(r,t) = \frac{1}{\pi}\int dt' \frac{ReW(r,t')}{t-t'}, \tag{7}$$

that is, by the Hilbert transformation.

According to Eqs.2 and 5 for a coherent state of the field

$$G(r,t) = W^*(r,t)W(r,t) \tag{8}$$

Thus, the photocounting rate is equal to

$$\frac{dR(r,t)}{dt} = \eta|W(r,t)|^2 = \eta\left[(ReW)^2 + (ImW)^2\right] \tag{9}$$

But according to Eqs.4 and 5 the mean value of the electric field is equal to

$$\langle\psi|E(r,t)|\psi\rangle = W^*(r,t) + W(r,t) = 2ReW(r,t). \tag{10}$$

According to Eq.5 W satisfies the homogeneous wave equation, so we can consider a plane wave, going in the positive direction of the z axis and having a sharp front,

$$W(r,t) = \theta(ct-z)F(z-ct); \tag{11}$$

here θ is the Heaviside function. In this case the mean values of the electric field $\langle\psi|E(r,t)|\psi\rangle$ and also its powers $\langle\psi|E^n(r,t)|\psi\rangle$ will also have sharp fronts; the normal ordering is used to avoid an infinite contribution of vacuum fluctuations independent of the state $|\psi\rangle$.

The signal or value of E reaches the detector at the time $t = z/c$ and is equal to zero at $t < z/c$. But the probability of photocounting Eq.9 is not equal to zero until the time $t = z/c$, that is, until the signal reaches the detector. It is due to the term $[ImW(r,t)]^2$ in Eq.9. Indeed, as can be seen from Eq.7, $ImW \neq 0$ for all t, even if $ReW(r,t) = 0$ for $t < z/c$. Let us consider an example, namely

$$W(r,t) = \theta(ct - z)\theta(l + z - ct)\sin(kz - \omega t + \varphi). \tag{12}$$

Then according to Eq.7

$$\begin{aligned} ImW(z,t) = \frac{1}{\pi}\{&\sin(\zeta+\varphi)[\,\ln|(\zeta+kl)/\zeta| + \mathrm{Cin}\,|\zeta| - \mathrm{Cin}\,|\zeta+kl|\,] \\ &- \cos(\zeta+\psi)[\,\mathrm{Si}(\zeta+kl) - \mathrm{Si}(\zeta)\,]\,\}, \quad \zeta = kz - ct, \end{aligned} \tag{13}$$

where

$$\mathrm{Cin}\,x = \int_0^x dt(1-\cos t)/t, \ \ \mathrm{Si}\,x = \int_0^x dt(sint)/t. \tag{14}$$

The field $\langle E\rangle$ and function W are not equal to zero only in the interval $ct - l < z < ct$, but ImW is not equal to zero outside this interval. Fig.1 presents the dependence $dR(\zeta = kz - \omega t)/dt$ for values $kl = \pi, 4\pi$ and $\psi = 0, \pi/2$. As can be seen in Fig.1 the photocount rate is not equal to zero outside the interval where the field is concentrated; this fictitious reading being the greater the shorter the impulse is. In the region of femtosecond impulses, that contain only some oscillations, the distortion of the true picture, due to the precursor in the photocount rate, becomes important.

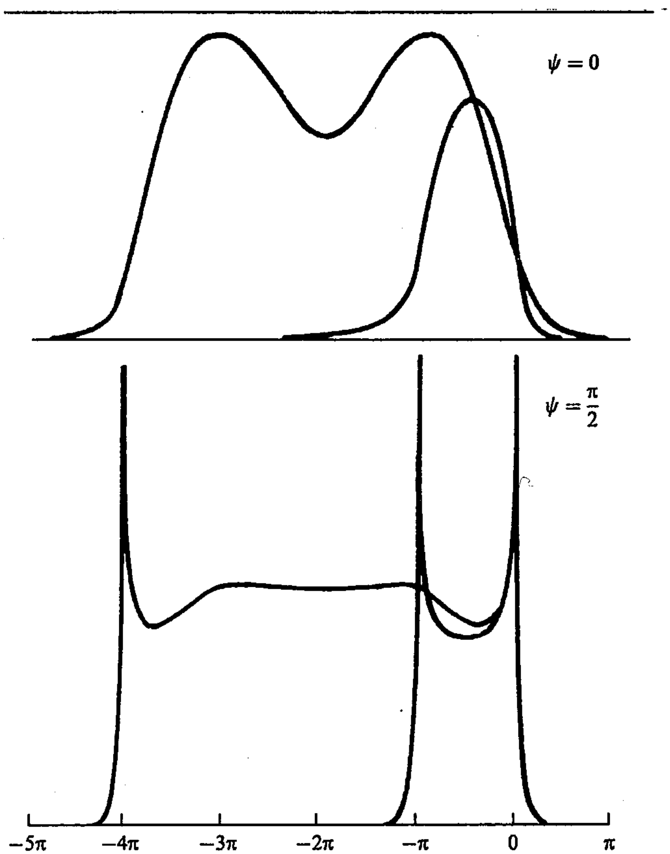

Figure 1. Photon counting rate as a function of $\zeta = kz - \omega t$ for different pulse length:1) $kl = \pi$, and 2) $kl = 4\pi$. a) Pulse with no jump at $\zeta = 0 (\varphi = 0)$, b) pulse with a jump at $\zeta = 0 (\varphi = \pi/2)$. A nonzero photocount rate for $\zeta > 0$ represents a nonphysical precursor that violates causality.

It is necessary to notice that parallel to Eq.7 there is an analogous relation connecting the real part of W with its imaginary part. Hence, the localization of one part of W makes the other part distributed in the whole space. Consequently in the coherent state the usual correlation functions cannot be taken as localized. Only the electric field $\langle E \rangle = 2ReW$ and functions of this field can be localized.

Equation 7 and its conjugate similar to the Kramers-Kronig relations. But the meaning of these relations is opposite. The Kramers-

Kronig relations give restrictions for the spectral properties of the dielectric constant $\epsilon(\omega)$ due to the causality. Equation 7 and its inversion give causality violation due to artificial restrictions in the spectrum of $E^{(+)}$ and $E^{(-)}$.

Causality violation in Eq.2 requires changing the determination of the correlation functions and in particular the photocount rate.

One can sometimes meet the statement, that the causality violation is quantitatively small and, hence, does not play great role. But this statement is not true. First, the quantitative criterion cannot be applied to such a concept as causality. There are only two possibilities: either causality is violated and the theory is not correct, or causality is not violated and the theory has some base to be correct. Second, there were attempts to correct the theory of photocounts. These attempts were partly successful [13,15], but they lead to correlation functions and, in particular, to the photocount rate, depending on the photo detector properties, while in the nature of these functions and the photocount rate to describe the properties of the fields only and to be independent of the photo detector properties. In essence, the independence of the field characteristics on the photo detector properties is an additional to causality requirement. To satisfy these two requirements is not easy.

3 The electron cloud instability at small densities

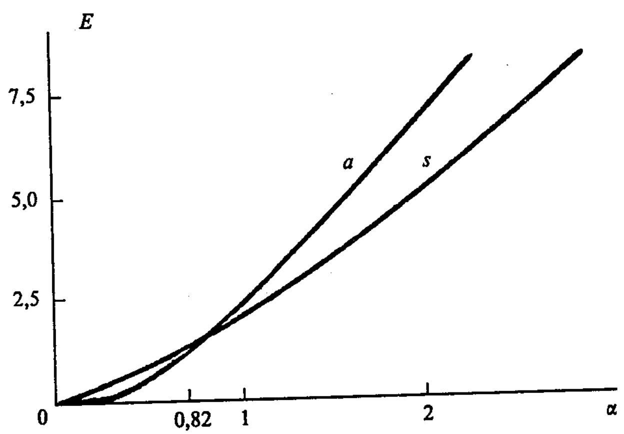

Figure 2. The energy E (in atomic units) of the symmetric (s) and asymmetric (a) state as a function of the parameter a of the quadratic potential well.

In order to illustrate the decay of the electron cloud into clots at low electron densities, let us consider a simple example: two electrons located in a quadratic potential well and interacting with each other according to the Coulomb law. Such electron system can be described by the Hamiltonian

$$H = -\frac{1}{2}\Delta_1 - \frac{1}{2}\Delta_2 + \alpha(\rho_1^2 + \rho_2^2) - \frac{1}{\rho_{12}},$$

where α is a parameter of a quadratic potential well; the greater α, the narrower the potential well is. By varying the parameter α, it is possible to control the electron density of the system and determine that instant at which the electron cloud begins to decay into clots. Calculations of stationary wave functions and the corresponding energies were carried out using baseless variational method [16,17]. Figure 2 shows the dependence of the energies of the symmetric (not decaying into clots) and asymmetric (decaying into two clots) states on the parameter α, i.e., on the magnitude of the forces holding electrons together. As can be seen, at values of a less than 0.82, the asymmetric state becomes energetically favoured. The decay of the electron cloud into clots is seen in Fig.3, which shows the charge density of the asymmetric state along the z axis. When the forces holding the electrons together are large, the Coulomb repulsion does not play a large role and symmetric state is favoured. With decrease of the attractive forces (i.e., the parameter α) the relative importance of the Coulomb energy grows, and beginning with the value $\alpha = 0.82$, the asymmetric state, which decays into two clots, becomes favoured.

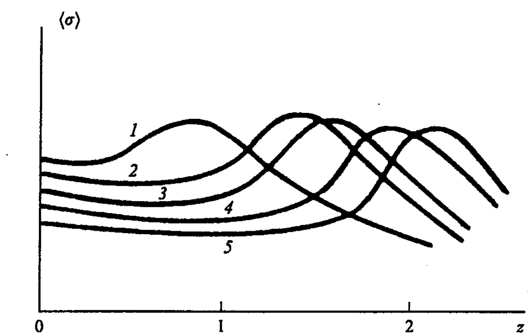

Figure 3. Charge distribution along the z axis in the asymmetric state at different values of the parameter a: 1) 0.4, 2) 0.25, 3) 0.2, 4) 0.15, 5) 0.1.

4 Catastrophes of the nonuniform electron flow

As it will be shown below the catastrophes, identical to described by the catastrophes theory [18,19,20], can occur in the uniform electron flow. In the alternative approach these catastrophes are of interest, since in some their points the electron density can become infinitely great. Hence, the catastrophes give us the natural mechanism of the electron clots sharpening.

The catastrophes can be of two types: space and temporal. Space catastrophes are well known from the ray optics - they are caustics and focuses [21]. In the ray optics approximation the light intensity on caustics and in focuses is infinitely great. The same situation is in the electron flow.

The temporal catastrophes are outrunnings of some parts of the electron flow by other parts of the same flow. In temporal catastrophes the electron density becomes also infinite.

a. The temporal catastrophes - outrunnings. To obtain some idea about the growth of the electron density at the outrunning, two examples (spherical and linear) of the electron cloud expansion under the influence of the Coulomb forces were studied. The spherical case is very convenient, since the corresponding motion equation can be integrated in the time interval from the beginning of the expansion up to the outrunning. Thus, the electron density behavior can be investigated in the analytical form.

a.Spherical expansion of the electron cloud. Let the distribution of the electron density $\sigma(r)$ there is at the initial instant and the cloud is at rest at that moment, that is, the velocities are equal to zero in all points of the cloud. Then the electrical field $E(R)$ on the sphere of radius R equals

$$E(R) = Q(R)/R^2, \tag{1}$$

where $Q(R)$ is the full charge in the sphere,

$$Q(R) = 4\pi \int_0^R dr\, r^2 \sigma(r). \tag{2}$$

Emphasize, that $Q(R)$ is constant up to the beginning of the outrunning, in other words

$$Q(R) = Q(R_0), \tag{3}$$

if R_0 is the initial value of R. Thus the motion equation of the charges on the sphere of radius R is

$$m\ddot{R} = eQ(R_0)/R^2 \tag{4}$$

We suppose below, that at $t = 0$ the charge distribution is gaussian

$$\sigma(r) = \frac{Q_0}{\pi^{3/2} r_0^3}\, e^{-r^2/r_0^2}, \tag{5}$$

where Q_0 is the entire charge of the distribution. Then the solution of this equation is

$$\left[\left(\rho(\rho-\rho_0)\right)^{1/2} + \rho_0 \ln \frac{(\rho-\rho_0)^{1/2} + \rho^{1/2}}{\rho_0^{1/2}} \right] \left(\rho_0 Q_0 / 2Q(R_0)\right)^{1/2} = \tau \tag{6}$$

where

$$\rho = R/r_0, \quad \rho_0 = R_0/r_0, \quad \tau = t/t_0 \tag{7}$$

and

$$t_0 = \left(\frac{m}{e} \frac{r_0^3}{Q_0} \right)^{1/2} \tag{8}$$

Let us study the time dependence of the electron density. Emphasize, that up to the beginning of the outrunning the full charge in the spherical layer of width $d < R$ is constant

$$\sigma(R)\, R^2\, dR = \sigma(R_0)\, R_0^2\, dR_0$$

Hence, we have

$$\sigma(R) = \sigma(R_0)\, \frac{R_0^2}{R^2}\, \frac{dR_0}{dR}. \tag{9}$$

One can see from this equation, that the electron density becomes infinite if the derivative dR_0/dR turns into infinity, or, that is the same, the derivative dR/dR_0 turns to zero.

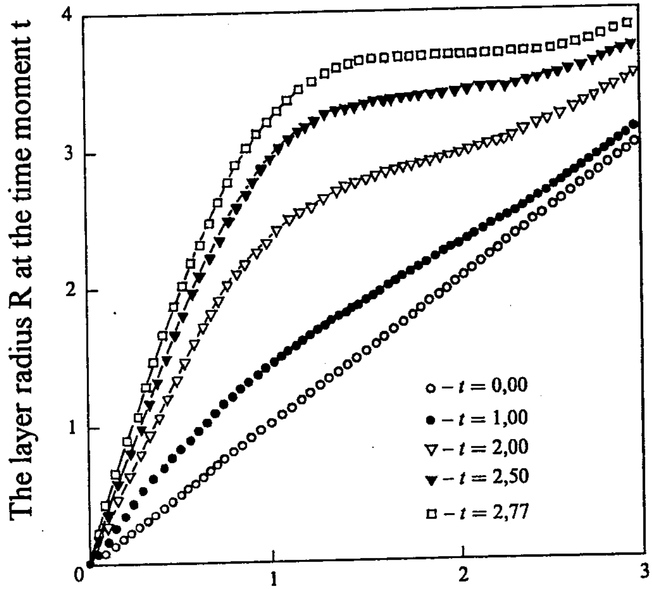

Figure 4. The spherical spreading of the electron cloud under the influence of its Coulomb field. At the beginning of the outrunning of some layers by others the R-derivative over R_0 at fixed t turns to zero at the bend point.

The dependence R on R_0 was calculated numerically and the result of the calculation is given in Fig.4. One can see that in the point, where dR/dR_0 at the first time turns to zero, this dependence has a bend and, hence, it can be taken in the form

$$R = B + \epsilon\,(R_0 - A)^3 + ..., \tag{10}$$

where A and B are some constants. Then R_0 is a function of R

$$R_0 = A + [(R - B)/\epsilon]^{1/3} \tag{11}$$

The derivative dR/dR_0 near this point has the form

$$R = 3\epsilon(R_0 - A)^2 = 3\epsilon^{1/2}(R - B)^{2/3} \tag{12}$$

Thus, the electron density near the point, where it turns to infinity has the following dependence on R

$$\sigma(R) = \frac{1}{3}\,\sigma(A)\,\epsilon^{-1/2}(A/B)^2(R - B)^{-2/3} \tag{13}$$

Fig.4 shows, how R depends (due to (4)) on R_0 at some time instants. In the initial instant R and R_0 are the same. Then, after the beginning of the cloud expansion the charges on the slope of the distribution receive the greatest velocities and, as a consequence, the greatest shifts. Due to it the fore-running layers outrun the subsequent layers. So the shifts at $R_0 \cong 1.5$ are significantly greater than the shifts at $R_0 \cong 2.0$. In the instant $t = 2.77$ values R, corresponding to $1.5 < R_0 < 2.0$, become approximately equal and it is the beginning of the outrunning and turning of the electron density into the infinity. Fig.5 shows the formation of the electron density maximum near $R \cong 3.65$ and its sharpening with time. One can see that at $t = 2.77$ the electron density at the maximum is four orders greater than in center of the distribution.

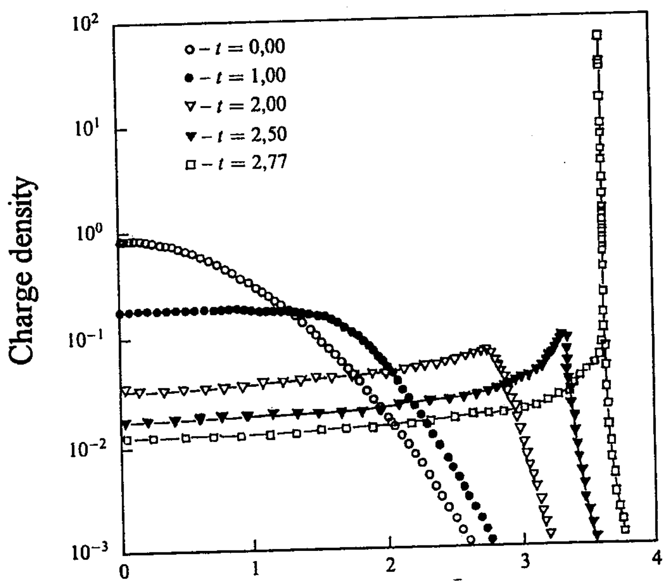

Figure 5. The electron density maximum formation and its sharpening with time at the spherical spreading of the electron cloud. The electron density at the maximum is four orders greater than in the center of the distribution.

Fig.6 shows the electrical field dependence on R. One can see, that in the vicinity of the point, where the electron density turns into the infinity, there is a jump of the field, as it has to be near the charged layer. Fig.7 shows the dependence of the inner charge of the sphere on its radius R. As one can see in this figure, in the vicinity of the charged layer not less than 20% of the full charge is concentrated.

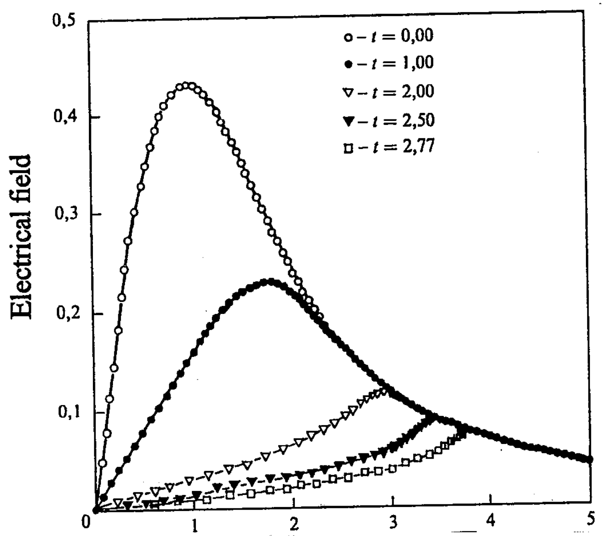

Figure 6. The electrical field jump near the electron density maximum.

b.Linear expansion of the electron cloud. Let the charge distribution is kept in the vicinity of the z-axis by the outside forces. The linear density has the distribution $\sigma(z)$, which will be supposed symmetrical to the origin. The initial velocities we let to be zero as before. The motion equations of the charge element have the form

$$\frac{dz(z_0,t)}{dt} = V(z_0,t), \quad \frac{dV(z_0,t)}{dt} = a(z_0,t) \tag{14}$$

where z is the coordinate of the charge, initially situated at z_0, V is its velocity

$$a(z_0,t) = \frac{e}{m} E(z_0,t) \tag{15}$$

is the acceleration and E is the field influencing it.

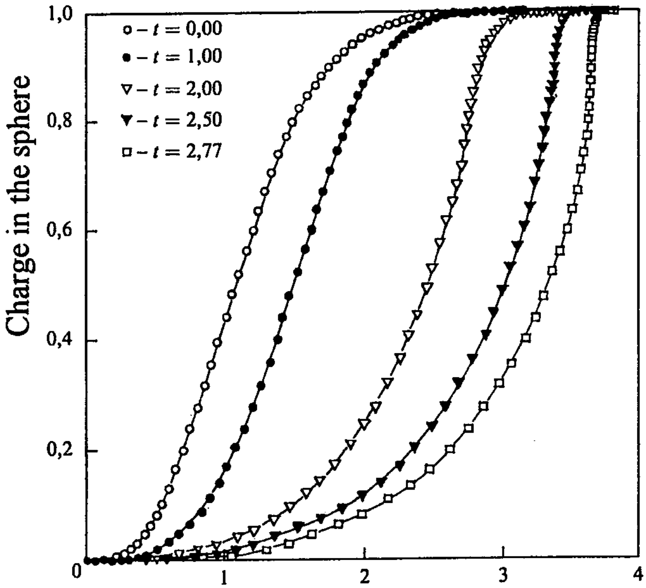

Figure 7. The dependence of the entire charge in the sphere on its radius.

In the crosssection the distribution is supposed a uniform in the circle of the radius r. In other words the distribution is in the cylinder with the radius r and the axis, coinciding with the z-axis. The supposition, that the distribution is infinitely thin, leads to the divergent fields.

The electrical field on the axis of the cylinder equals

$$E = 2\pi\rho[1 - l/(l^2 + r^2)^{1/2}]dz, \tag{16}$$

where r is the disk radius, ρ is the charge density, l is the distance from the field point on the cylinder axis to the center of the disk, and dz is the disk thickness. Summing such fields over all distances l, we receive the field on the cylinder axis in the point z

$$E(z) = 2\pi \left[\int_{-\infty}^{z} dz'\rho(z') \left(1 - \frac{z - z'}{[(z - z')^2 + r^2]^{1/2}}\right) - \int_{z}^{+\infty} dz''\rho(z'') \left(1 - \frac{z'' - z}{[(z'' - z)^2 + r^2]^{1/2}}\right)\right]. \tag{17}$$

Below we shall use the full charge, which is on the left side from the point z. It equals

$$Q(z) = \pi r^2 \int_{-\infty}^{z} dz'\, \rho(z'), \quad Q(z = +\infty) = Q_0 \tag{18}$$

Then, using the equation

$$dQ = \pi r^2 \rho(z) dz \tag{19}$$

we receive

$$E(z) = \frac{2}{r^2} \left\{ \int_0^Q dQ' \left[1 - \frac{z(Q) - z(Q')}{[\, r^2 + (\, z(Q) - z(Q')\,)^2\,]^{1/2}} \right] \right.$$

$$\left. - \int_Q^{Q_0} dQ'' \left[1 - \frac{z(Q'') - z(Q)}{[\, r^2 + (\, z(Q'') - z(Q)\,)^2\,]^{1/2}} \right] \right\}. \tag{20}$$

The equations (14) and (15) now can be written in the form

$$\frac{dz(Q,t)}{dt} = V(Q,t), \quad \frac{dV(Q,t)}{dt} = a(Q,t), \tag{21}$$

$$a(Q,t) = \frac{2e}{mr^2} \int_0^{Q_0} dQ'\, W(Q,Q'), \tag{22}$$

where

$$W(Q,Q') = 1 - \frac{z(Q) - z(Q')}{[\, r^2 + (\, z(Q) - z(Q')\,)^2\,]^{1/2}} \qquad (Q' < Q) \tag{23}$$

and

$$W(Q,Q') = \frac{z(Q') - z(Q)}{[\, r^2 + (\, z(Q) - z(Q')\,)^2\,]^{1/2}} - 1 \qquad (Q' > Q). \tag{24}$$

The dependence z on Q is defined by equation (18).

Before the beginning of the outrunning the charge between two crosssections is constant. Therefore we have the equation

$$\rho(z,t)\,dz|_t = \rho(z_0,0)\,dz_0|_{t=0}$$

or

$$\rho(z,t) = \rho(z_0,0)\left(\frac{dz}{dz_0}\right)^{-1}_{t=const}. \tag{25}$$

Hence, the electron density can turn into the infinity, if the derivative $(dz/dz_0)_{t=const}$ turns to zero.

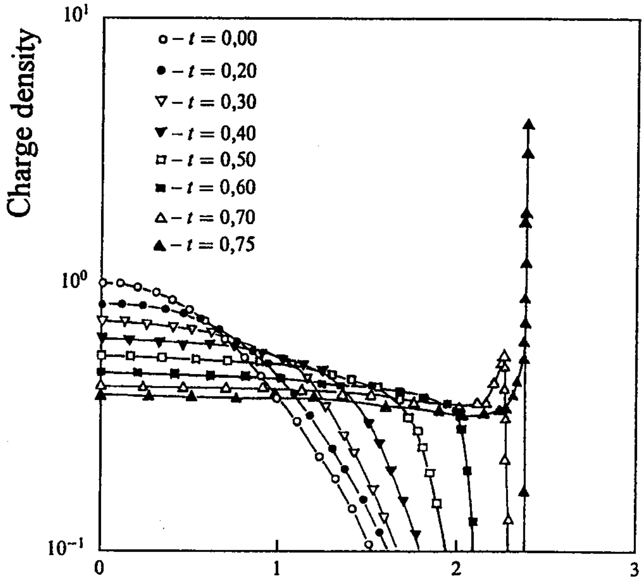

Figure 8. The electron density maximum formation at the linear spreading.

Results of the numerical calculations are given in Fig.8. As in the spherical case the infinite maximum of the electron density distribution is forming. However, now we have an opportunity to study the dependence of the maximum formation on the cross section diameter. The corresponding picture is given in Fig.9. One can see that the smaller the cross-section dimension the faster the formation of the distribution maximum occurs. This circumstance makes more important the process of the electron cloud focusing, which we concern in the following section.

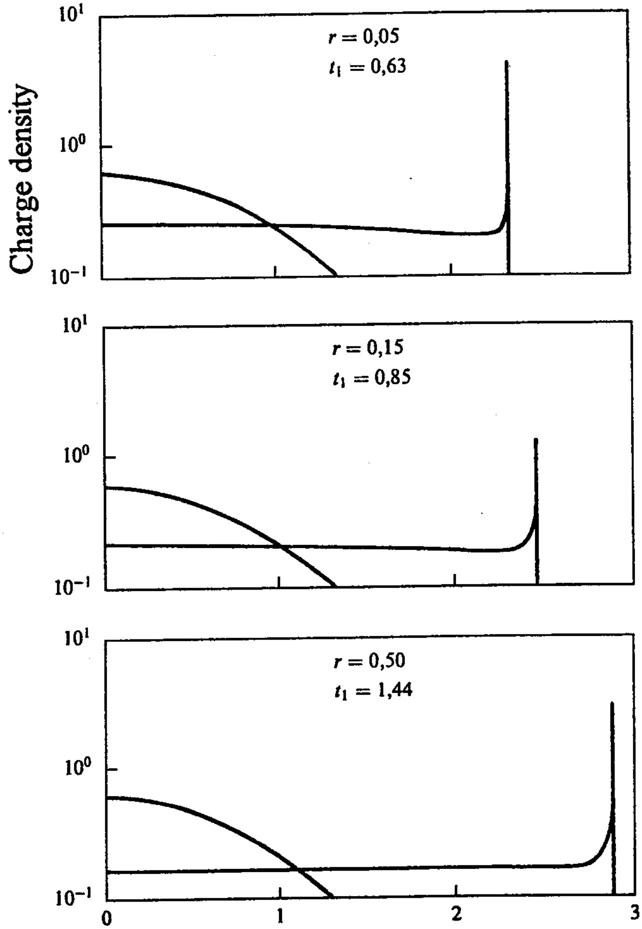

Figure 9. The electron density maximum formation at different dimensions of the distribution cross-section.

Space catastrophes - focusing. Space catastrophes, connected with focusing, are well known, for example, from the ray optics [21]. Therefore, below we give only some qualitative considerations of the electron clot sharpening due to the focusing.

As a rule, the electron cloud motion takes place in the focusing electrical field of the cathode-anode space. The own Coulomb electrical field of the cloud can also be focusing in some cases. The catastrophes of two types - caustics and focuses - can occur as a result of focusing. In focuses the electron density grows as $1/R^2$ (if the wave nature of the electron field can be neglected), and in the vicinity of caustics it grows as $1/R$. However, the focuses are not the catastrophes of the general position. In other words, only in exceptional cases the curvature radii are equal to each other, that is necessary for the existance of the spherical wave front and formation of the focuses. However, the difference between them is not great, so that in the vicinity of caustics the electron density will grow apparently as $1/R^n$, where n is between one and two.

At the approaching of the electron cloud to the caustic region and, correspondingly, with the growing of the electron density all processes influenced by the Coulomb field will be intensified, in particular, the outrunning process. It can be seen especially well in Fig.9. Therefore, there is a great probability that the outrunning will occur also in the vicinity of caustics. Then the electron density will grow with the law close to $1/R^2$, i.e., the electron clot in this case will become untransparent (see following section).

5 The transparent and untransparent electron clots

As was shown above, the catastrophes, forming in the electron flow, give the electron density growth in some points up to infinity. The charged clots in the vicinity of such points have some properties of the pointlike particles. Such clots can be of two types: transparent and untransparent. The untransparent clots are especially similar to the pointlike particles, since they are more stable. Correspondingly they are more important for our investigation. We consider, for example, spherically symmetrical clots.

Let us clarify, how the electron density in the clot must depend on the distance from its center the potential to be infinite. In this case outer clots incident on that under consideration will not penetrate into its center, i.e., the clot will be untransparent.

Let the electron density distribution in the clot is

$$\sigma(r) = G/r^n \tag{1}$$

The full charge $Q(R)$ in the center of the clot (in a sphere of a small radius R) must be finite

$$Q(R) = 4\pi \int_0^R dr\, r^2\, \sigma(r) = 4\pi G \int_0^R dr\, r^{2-n} = \frac{4\pi G}{3-n}\, r^{3-n}\Big|_0^R ; \tag{2}$$

it is possible if

$$n < 3$$

The charge $Q(R)$ in this case equals

$$Q(R) = \frac{4\pi G}{3-n}\, R^{3-n}. \tag{3}$$

The electrical field equals

$$E(R) = Q(R)/R^2 = \frac{4\pi G}{3-n}\, R^{1-n} \tag{4}$$

Correspondingly, for potential the following expression can be obtained

$$\begin{aligned} U(R) &= \int_R dR'\, E(R') \\ &= \frac{4\pi G}{3-n} \int_R dR'\, R'^{(1-n)} = \frac{4\pi G}{(2-n)(3-n)} R'^{(2-n)}\Big|_R \end{aligned} \tag{5}$$

The potential behavior at the upper limit is not important, since far from the singularity (1) the electron density can decrease faster then in (1). The potential behavior at the clot center is more important. Its value is going to infinity if

$$n > 2.$$

Thus, the electron clot is untransparent if its density distribution is obeyed to the law (1) with

$$2 < n < 3$$

Practically n can be only close to 2, since the subsequent growth of the density is stoppening by the Coulomb forces.

6 The one-electron clots

One of the most important and difficult problems of the alternative approach is the necessity to explain the formation mainly one-electron clots. It is considered usually that one point-like electron, emitted from the cathode, corresponds to one photocount. However, we did not find experiments confirming such point of view. We did not find also the evidence that the current splashes, corresponding to photocounts, are identical to each other. Nevertheless, this point of view is apparently correct. Therefore, developing an alternative approach it is necessary to indicate the reasons, due to which the observation of the one-electron clots is preferrable.

The above research of two electron system in a quadratic potential well showed that at small electron density the cloud decays into two clots. We suppose that this circumstance is not occasional: the three electron cloud will decay into three clots, the four electron cloud - into four clots, and the n electron cloud - into n clots.

Qualitatively this statement can be founded in the following manner. Emphasize the absence of the selfinfluence, that is influence of the Coulomb field of an electron onto it itself, in the Hamiltonian, taking into account the Coulomb interaction,

$$H = \sum_n \frac{1}{2m} p_n^2 + \sum_{n,l} \frac{e^2}{r_{nl}} \tag{1}$$

here the first term is the kinetic energy of electrons and the summation is over all electrons, the second term is the Coulomb energy of the electron system and summation is over all electron couples. The absence of the selfinfluence means that if a narrow wave-packet, containing one electron, is formed, its Coulomb field will not influence its diffusion; such wave-packet will diffuse as a noncharged wave-packet, that is, relatively slow.

In multielectron systems, such as the electron cloud under investigation, all electron wave-packets are on principle multielectron due to the well-known symmetry properties of the electron wave-function. However, among such multielectron configurations there are "equivalent " to one-electron configurations. Indeed, let the function $\psi(r)$ describes a narrow electron wave-packet, e.g., gaussian (All spins let be oriented equivalently and neglect the spin-spin and spin-orbit interactions). Then the wave-function

$$\psi(r_1, r_2) = 2^{-1/2}[\psi(r_1)\psi(r_2 - a) - \psi(r_2)\psi(r_1 - a)] \tag{2}$$

having the necessary symmetry, describes the two-electron system, concentrated in two wave-packets - one is in the origin, and the other is in the point with radius-vector a.

One can be convinced of the absence of the Coulomb interaction inside the wave-packets at the least if the distance a between the wave-packets is much greater of their width. Indeed, the Coulomb energy average value in the state, described by the wave-function $\psi(r_1, r_2)$, equals

$$\begin{aligned}\langle U_{Coulomb}\rangle = e^2 \iint dr_1 dr_2 |\psi(r_1,r_2)|^2/|r_1-r_2| = \\ = \frac{1}{2}\, e^2 \iint dr_1 dr_2 \left[\, |\psi(r_1)|^2|\psi(r_2-a)|^2 + |\psi(r_2)|^2|\psi(r_1-a)|^2 \right. \\ - \psi^*(r_1)\psi(r_1-a)\psi(r_2)\psi^*(r_2-a) \\ \left. -\psi(r_1)\psi^*(r_1-a)\psi^*(r_2)\psi(r_2-a)\,\right]/|r_1-r_2|.\end{aligned} \tag{3}$$

The first two terms correspond to the Coulomb energy of two electrons, placed correspondingly at the origin and at the point with radius-vector a. Approximately this part of the Coulomb energy equals

$$\langle U_{Coulomb}\rangle' = e^2/|a| \tag{4}$$

since the factor $1/|r_1 - r_2|$ can be taken a constant in the frames of distributions $|\psi(r_1)|^2$ and $|\psi(r_2-a)|^2$. The two other terms are so called the integrals of the overlapping; in our case they can be only very small, since there are the combinations

$$\psi^*(r_1)\psi(r_1-a), \quad \psi(r_2)\psi^*(r_2-a)$$

and complex conjugated to them, which are enavitably small, if the width of the gaussian wave-packet is much smaller than the distance a between them. If $\psi^*(r_1)$ is near the distribution maximum, then $\psi(r_1 - a)$ will have a very small value and so on ...

Thus, although both electrons with equal probabilities can be found in every wave-packet, the Coulomb interaction between them inside the wave-packet is absent. The situation is equivalent to that, when one electron is in the first wave-packet, and the other is in the second wave-packet. This consideration can be easily generalized to multielectron systems. It is enough for it to use the $n \times n$ Slater determinant instead of function (2). The considerations given here are similar to those which permit to consider atoms without taking into account all other electrons (for example, the electrons of other atoms).

Hence, if at the initial instant the real multielectron wave-packet (not such as (2)) was created, it will decay rapidly under the influence of the interpacket Coulomb forces, seeking to form finally one-electron wave-packet, similar to (2). This one-electron wave-packet after its formation will relatively slow diffuse as the noncharged packets are diffusing in the free space. Therefore the one-electron wave-packets have an advantage over the multielectron ones in their time of life and due to it their observation is more probable.

7 Conclusion

The considerations of this paper don't exhaust the problem and they don't give the evidence of the alternative approach correctness. The reader can find questions for which there are no answers in this paper. However, it is wonderful, how many arguments can be given for this approach. The major argument in favour of the alternative approach is that the electron clot is forming naturally, but not as a result of the mysterious and miraculous transformation of the wave into the particle. Therefore we decided to publish these cosiderations to attract attention of experimenters and theorists to them.

The qualitative picture of the photocount appearance at the detecting of the laser radiation can be described in the following manner. The electron system of the metallic or semiconductor cathode has a high density and is uniformly (if we neglect fluctuations) distributed over the cathode volume. Under influence of the coherent (laser) radiation, this system, being as before uniform, becomes excited so that the electron cloud exit into the free space gets possible. In the outer space the electron density of the cloud is very small and the disintegration of the cloud into the particular clots (may be, one-electron) becomes preferrable. However, these clots are very widespread so that the distance between them is of the order of their width. During the clot acceleration in the electrical field between the cathode and anode the focusing (the space catastrophe) of the clot occurs and it leads to the increasing of its density. The outrunning effect (the temporal catastrophe) also occurs in the cloud due to its Coulomb field and the cloud become more dense in the longitudinal direction and their width becomes significantly smaller than the distance between them. Formed very dense clot is very similar to the localized particle. Moving in the cathode-anode space this clot is inducing the sharp and intensive current splash in the outer circuit of the photodetector; this splash will be accepted by the observer as a photocount.

Emphasize, that the possibility of the including of the catastrophe theory with its topological methods to the problem of the clots sharpening indicates on the not occasional nature of this effect. Therefore, it is interesting to develop the catastrophe theory for the $3N$-dimension configuration space of the N-electron wavefunction.

The developing approach to the photocount theory on the one hand gives the physical base for the usual statistical interpretation of the quantum-mechanical values, on the other hand delivers the theory from the immanent character of this statisticalness, that is, makes it not obligatory, but only peculiar to many physical cases. In this respect the alternative approach returns us to the old discussions on the localization and delocalization of particles (it is especially important to remind the book of L.DeBroglie [22]). It may be that the new insight to these problems will become possible.

The alternative approach shows also that the situations can exist when the statistical character of the effect is absent, and such situations are of great interest.

Thus, the statistics of the current splashes in the photodetector, which is usually identified with the photon statistics, reflects the statistical nature of the process of the electron cloud decay into clots and only partially, through the statistics, the properties of the light which have given rise to the effect. This is the main consequence of the alternative approach.

From the experimental viewpoint the most interesting consequence of the alternative approach is the possibility of a regime in which the photocathode operates without current splashes or, in other words, without photocounts. This possibility is a particular case of the mentioned above situations without statistical character of quantum-mechanical effect. It can be manifested in a very strong fields, in which the electron cloud has no enough time to decay into clots. In this case the spectral composition of the photocurrent is substantially changed: the high frequency components due to the individual clots disappear, and only the low-frequency components due to the variation of the amplitude of the optical signal remain. As a rule, the amplifiers which follow the photodetector have a depressed sensitivity in the low-frequency region. It is necessary to correct this low sensitivity in the regime with the absence of current splashes; otherwise, the disappearance of current splashes will manifest itself as a decrease in the efficiency of the photocathode. In experimental studies there have been hints of such phenomena in strong fields.

Thus, the alternative approach can qualitatively explain the main phenomena of the physics of photocounts. However, a more detailed verification of these features requires additional study.

What conclusions can be arrived at from the alternative approach for the practice of photodetecting devices? The most general reason of the electron cloud instability is the strong quasidegeneration of the electronic systems in such devices. Indeed, the energy levels of the translational electron motion are very close to each other and their number is very great. Due to it the electronic system becomes very pliant to any disturbing influences. For comparison remind that the same electronic system is very stable in the atomic conditions - for a change of its state in atom a great energy of one quantum is necessary.

Therefore it is natural to refuse the systems with great degree of degeneration. In this sense the atomic systems become attractive, where the electron cloud is strongly stabilized by the Coulomb field of a nucleus. On this way it is necessary to apply in the first place to such a well-known devices as optical amplifiers. These amplifiers are studied well at present and it was concluded that they can't be good detectors of the weak radiation, since the active medium of the amplifiers spontaneously radiates with a relatively high intensity.

However, the possibilities of the atomic systems as detectors did not apparently exhausted entirely. In this respect the atomic systems with two degenerate levels are attractive, provided the multiphoton process occurs there [23].

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