considered by M. S. Marinov. We note that such T-invariant terms can obviously not lead to a shift of the atomic levels. The C-odd vertices contain a factor q^2 for both I = 1 and I = 3/2. The same takes place for I = 2. Thus, in these three cases the C-odd interaction of the electron with the nucleus has a purely contact character. The dependence of the C-odd vertices on q^2 was not considered by us for I > 2.

For a particle with spin I the number of C-odd multipoles is equal to I (for integer I) or I - 1/2 (for half-integer I). In the general case (taking into account possible parity nonconservation), the number of corresponding multipoles is given in the table.

The number of corresponding multipoles N in the third and fourth lines pertains here to integer and half-integer I, respectively. The results of the table can be easily obtained by determining the number of states in the t-channel, where the particle and antiparticle with spin I form an "atom" with total angular momentum 1.

CP	+1	-1	+1	-1
P	+1	+1	-1	-1
N	2I +1	I	I	2I
	2I +1	I - 1/2	I + 1/2	2I

The authors thank I. Ya. Pomeranchuk and B. M. Pontecorvo for useful discussions. L. B. Okun' is grateful to S. Coleman and S. Glashow for interesting discussions in Trieste.

Note added in proof. An expression for the electromagnetic current of particles with spin 1 and 3/2 with account taken of CP-noninvariant form factors is given in an article by V. Glaser and B. Jaksic, Nuovo Cimento 5, 1197 (1957). The authors are grateful to L. A. Kondratyuk for calling their attention to this paper.

[1] J. Bernstein, G. Feinberg, and T. D. Lee, Columbia Univ. Preprint, 1965.

[2] L. R. Price and F. S. Crawford, Phys. Rev. Lett. 15, 123 (1965).

[3] M. Foster and M. Good, Wisconsin Univ. Preprint, 1965.

1) The C- and CP-parity of the vertex part (unlike the current) and of the multipole are determined in this note with account of C- and P-parity of the photon.

2) The possible presence of C-even terms in the vertex parts of particles with I $\geq$ 1 was called to the attention of one of us (L. Okun') by S. Coleman and S. Glashow. M. V. Dubovik advised us that analogous questions were considered by him jointly with A. A. Cheshko.

PLASMA HEATING BY A STOCHASTIC FIELD

V. D. Shapiro
Physico-technical Institute, Ukrainian Academy of Sciences
Submitted 28 September 1965
JETP Pis'ma 2, 469-473 (15 November 1965)

The interaction between plasma particles and an electromagnetic field, with account taken of the finite correlation time of the field Fourier harmonics, was investigated in [1]. It was shown there that a finite correlation time leads to an effective transfer of energy from the field to the plasma particles, whose initial velocity is much smaller than the phase velocity of the waves ($\vec{k}\cdot\vec{v}_0 \ll \omega_k$, $\vec{k}\cdot\vec{v}_0 \ll |\omega_k - \omega_p|$). It is possible that this can explain the appearance of a large number of fast electrons in the plasma, as observed in several experiments on plasma-beam interactions [2-4]. In [1], however, the plasma acceleration was investigated only in the initial phase, when the plasma-particle velocities remain lower than the phase velocity of the wave. In the present note we treat the question of accelerating plasma particles to high energies as one particular case of interaction between a plasma and a stochastic field whose harmonics have a finite correlation time. Let us consider the case of a circularly polarized electromagnetic wave propagating along an external magnetic field. The time variation of the plasma-particle distribution function, due to the interaction with such a wave, is then given by

$$\frac{\partial f}{\partial t} = \frac{\pi e^2}{4m^2}\left\{\frac{1}{v_\perp}\frac{\partial}{\partial v_\perp}\left[v_\perp \sum_k |E_k|^2\, V(kv_z - \omega_k \mp \omega_p)(1 - kv_z/\omega_k)F\right] + \frac{\partial}{\partial v_z}\left[\sum_k |E_k|^2\, V(kv_z - \omega_k \mp \omega_p)\,\frac{kv_\perp}{\omega_k}\,F\right]\right\}. \quad (1)$$

We have introduced here the notation

$$F = (1 - kv_z/\omega_k)\frac{\partial f}{\partial v_\perp} + \frac{kv_\perp}{\omega_k}\frac{\partial f}{\partial v_z};$$

$V_k(\omega)$ is the Fourier transform of the field-amplitude correlation function:

$$V_k(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\omega t}\, U_k(t)dt, \quad \overline{E_k(t)E_k(t')} = |E_k(t)|^2 U_k(t - t'), \quad U_k(-t) = U_k(t). \quad (2)$$

We shall assume henceforth that the correlation function is of the form $U_k(t) = \exp(-t/\tau_k)$, $t > 0$. Then

$$V(\omega) = \frac{1}{\pi}\,\frac{\tau_k}{\omega^2\tau_k^2 + 1}.$$

We assume that within the plasma relaxation time (see Eq. (8) below) the level $|E_k|^2$ is not changed by external pumping, and that there is excited in the plasma a sufficiently narrow packet of oscillations, all of whose harmonics have approximately the same phase velocity $v_{ph} \simeq u_0$.

Equation (1) can be considerably simplified by going over to the independent variables $w = v_\perp^2 + v_z^2 - 2v_z u_0$ and $v_\parallel = v_z$. As a result we obtain in lieu of (1) [1)]

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial v_\parallel}\left[D\frac{\partial f}{\partial v_\parallel}\right]. \quad (3)$$

In this equation

$$D = \frac{e^2}{4m^2}\sum_k |E_k|^2\,\frac{\tau_k}{(kv_\parallel - \omega_k \mp \omega_p)^2\tau_k^2 + 1}\,\frac{v_\perp^2(w, v_\parallel)}{u_0^2}$$

is the coefficient of particle diffusion along the lines w = const. In the course of time the diffusion equalizes the propagation function along these lines, so that a distribution for which $\partial f^{\infty}/\partial v_{\parallel} = 0$ is established as $t \to \infty$. The form of the distribution function f^{∞} can be determined by using the relation

$$\int_{v_1}^{v_2} \frac{\partial f}{\partial t}\, dv_{\parallel} = 0, \tag{4}$$

which follows from (2) and in which the integration is along the line $w = \text{const}$. v_1 and v_2 are the points on this line at which the diffusion coefficient vanishes, i.e., in the case $v_{\perp} = 0$, considered by us we have $v_1 = u_0 - \sqrt{u_0^2 + w}$ and $v_2 = u_0 + \sqrt{u_0^2 + w}$. From (4) we obtain

$$f^{\infty} = \frac{1}{v_2 - v_1}\int_{v_1}^{v_2} f^0 dv_{\parallel}. \tag{5}$$

Assuming that the initial distribution f^0 of the plasma particles is Maxwellian, we obtain

$$f^{\infty} = N\left(\frac{m}{2\pi T_0}\right)^{1/2} \frac{1}{2\pi u_0} \sqrt{\frac{1}{v_{\perp}^2 + (v_z - u_0)^2}} \left\{\exp\left[-\frac{m}{2T_0}\left(\sqrt{v_{\perp}^2 + (v_z - u_0)^2} - u_0\right)^2\right]\right.$$

$$\left. - \exp\left[-\frac{m}{2T_0}\left(\sqrt{v_{\perp}^2 + (v_z - u_0)^2} + u_0\right)^2\right]\right\} \simeq N\left(\frac{m}{2\pi T_0}\right)^{1/2} \tag{6}$$

$$\times \frac{1}{2\pi u_0^2} \exp\left[-\frac{m}{8T_0u_0^2} - \left(v_{\perp}^2 + (v_z - u_0)^2 - u_0^2\right)\right].$$

In deriving the last relation we used the fact that the initial plasma temperature is $T_0 \ll mu_0^2$.

It follows from the form of the obtained distribution function that even when $T_0 \ll mu_0^2$ the interaction with the electromagnetic field produces in the plasma a large number of fast electrons with energy up to $2mu_0^2$. Thus, for example, the number of particles with velocities in the interval $|v_{\perp} - u_0| \lesssim \Delta v$, $|v_z - u_0| \lesssim \Delta v$, $\Delta v \lesssim \sqrt{T_0/m}$ is determined by the relation

$$\begin{aligned} \Delta N &\simeq N(m/2\pi T_0)^{1/2} \cdot (\Delta v)^2/u_0 \sim N\sqrt{T_0/mu_0^2}\,, \\ \Delta N &- 10^{-1}N \qquad \text{for } T_0 \sim 10^{-2}mu_0^2. \end{aligned} \tag{7}$$

It must be noted that if the particles accelerated by the stochastic fields were to be uniformly distributed in velocity space, then the number of high-energy particles would be insignificant. In fact, owing to the existence of the invariant $w = \text{const}$, the accelerated particles with velocities $v \lesssim \sqrt{T_0/m}$ at $t = 0$ will fill in the course of time a rather narrow region in velocity space (a spherical layer of radius u_0 and thickness $\sim\sqrt{T_0/m}$). The number of particles accelerated to high energies is therefore quite appreciable.

The duration t_0 of the establishment of the velocity distribution function (5) can be estimated, using (2), as being the time in which the particles diffuse through a distance $\Delta v_{\parallel} \sim u_0$:

$$t_0 \sim \frac{(\Delta v_{\parallel})^2}{D} \sim \tau \frac{16\pi N m u_0^2}{\sum_k |E_k|^2 \frac{\omega_0^2}{(\omega_k \mp \omega_p)^2}}, \tag{8}$$

i.e., $t_0 > \tau$ within the limits of applicability of the present theory.

The author is grateful to Ya. B. Fainberg for valuable advice, and to B. B. Kadomtsev for a discussion of the work.

[1] F. G. Bass, Ya. B. Fainberg, and V. D. Shapiro, JETP 49, 329 (1965), Soviet Phys. JETP 22, 230 (1966).

[2] I. F. Kharchenko, Ya. B. Fainberg, R. M. Nikolaev, E. A. Kornilov, E. I. Lutsenko, and I. S. Pedenko, Nuclear Fusion (Supplement) 3 (1962); A. K. Berezin, Ya. B. Fainberg, L. I. Bolotin, and T. P. Berezina, Atomnaya energiya 14, 243 (1963).

[3] E. K. Zavoiskii, Atomnaya energiya 14, 143 (1963).

[4] I. Alezeef, R. V. Neigligh, and W. F. Peed, Phys. Rev. 136 A, 689 (1964).

[5] A. A. Andronov and V. Yu. Trakhtengerts, JETP 45, 1009 (1963), Soviet Phys. 18, 698 (1964).

1) The possibility of reducing the quasilinear equation for f to one-dimensional form in the case of cyclotron instability was indicated earlier in [5].

EFFECT OF HARD RADIATION ON THE OPTICAL CENTERS OF TR^{3+} IONS IN CRYSTALS

Yu. K. Voron'ko, A. A. Kaminskii, and V. V. Osiko
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 29 September 1965
JETP Pis'ma 2, 473-478 (15 November 1965)

We have observed a new effect produced by hard radiation in crystals with TR^{3+} impurity, consisting in a change of the structure and of the optical properties of the TR^{3+} centers.

It is well known that crystals containing trivalent rare-earth impurities (TR^{3+}) become colored under the influence of hard radiation such as γ rays, neutrons, deuterons, or fast electrons. However, the accompanying absorption (and sometimes luminescence) is connected either with the formation of proper color centers, or with a transition of the TR^{3+} to a divalent state [1-4].

The investigations were carried out with the crystals CaF_2:Nd^{3+} (0.3 wt.%), CaF_2:Er^{3+} (0.3 wt.%), and CaF_2:Eu^{3+} (0.3 wt.%, type I), synthesized by the procedure described in [5]. Figure 1a shows the absorption spectrum of the CaF_2:Nd^{3+} (0.3 wt.%) obtained at 77°K with a DFS-12 diffraction spectrometer. The spectrum corresponds to the transition $^4I_{9/2} \rightarrow {}^4F_{3/2}$. The letters L on the figure denote the lines belonging to tetragonal-symmetry centers, while M and N denote lines belonging to the two types of rhombic centers [6]. Figure 1b shows the