[3] D. A. Glaser, Phys. Rev. **91**, 762 (1953). Nuovo cimento **11**, Suppl. No. 2, 361 (1954). Bertanza, Martelli, and Tallini, Nuovo cimento **5**, 940 (1957).

[4] F. Seitz, Phys. Fluids **1**, 2 (1958). Yu. Kagan, DAN SSSR **119**, 247 (1958), Soviet Phys. Doklady **3**, 295 (1958).

Translated by J. G. Adashko
264

POSSIBILITY OF OBSERVING NEUTRAL CURRENTS IN NEUTRINO EXPERIMENTS

S. S. GERSHTEĬN, NGUYEN VAN HIEU, and R. A. ÉRAMZHYAN[1)]

Joint Institute for Nuclear Research

Submitted to JETP editor July 31, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 1554-1556 (October, 1962)

A weak interaction scheme, which contains along with the product of the charged currents [1,2] also the product of neutral currents, was proposed and discussed by several authors [3-6]. Schemes of this type, for example the Bludman scheme, have the same degree of beauty as the Feynman–Gell-Mann scheme, and do not lead to the appearance of experimentally unobservable decays of the type $\mu \to 3e$, $K \to \pi + 2e(2\nu)$, etc, since they contain "symmetrical" neutral currents of the type $(\nu\nu)$ and (ee), and do not contain "asymmetrical" ones such as (μe) and $(K\pi)$ (see [6]). The experimental detection of neutral currents in weak interactions is very important both from the point of view of checking the correctness of the weak-interaction scheme, and from the point of view of applications to astrophysical phenomena (inasmuch as the existence of neutral currents can lead to very effective mechanisms of emission of $\nu\bar{\nu}$ pairs by stars [6]). However, experiments proposed for the observation of neutral currents on the basis of effects of parity non-conservation and scattering of electrons by nuclei [4] or in electron-electron scattering [5] are quite difficult.

We wish to remark that possibly a more realistic method of observing neutral currents are neutrino experiments. The existence in the weak-interaction Lagrangian of terms in the form

$$L' = \frac{G}{\sqrt{2}}(\bar{\nu}\,\hat{O}\,\nu)(\bar{N}\,\hat{O}\tau_3 N), \qquad \hat{O} = \gamma_\mu(1+\gamma_5), \tag{1}$$

which was proposed in the papers of Bludman [3] and Zel'dovich [4], should lead, in the case of the scattering of high-energy neutrinos by nuclei, to the appearance of lepton-free stars due to the interaction

$$\nu + N \to \nu + N. \tag{2}$$

At neutrino energies near 1 BeV, the cross section of this process should be on the order of 10^{-38} cm^2 and consequently this process can undoubtedly be noted in the presently performed neutrino experiments at high energies.

On the other hand, apparently, there is a possibility of verifying the existence of interaction (2) in experiments with low-energy anti-neutrinos (from a reactor). Indeed, interaction (2) should lead to the excitation of the nuclear levels

$$\bar{\nu} + Z \to \bar{\nu} + Z^*, \tag{3}$$

which can be detected by the characteristic radiation $Z^* \to Z + \gamma$. The differential cross section for the scattering of a neutrino by an angle θ with excitation of a nucleus, in the case of interaction (1), has the form

$$d\sigma/d\Omega = (2\pi)^{-2}G^2\left[a_0(1+\cos\theta) + b_0\left(1-\tfrac{1}{3}\cos\theta\right)\right](E_\nu - \Delta E)^2, \tag{4}$$

where

$$a_0 = \left|\int d\tau \left\langle Z^*\left|\sum_A \tau_3 e^{i\mathbf{kr}}\right|Z\right\rangle\right|^2,$$
$$b_0 = \left|\int d\tau \left\langle Z^*\left|\sum_A \tau_3 \sigma e^{i\mathbf{kr}}\right|Z\right\rangle\right|^2, \tag{5}$$

ΔE is the excitation energy of the nucleus, E_ν is the anti-neutrino energy. From formulas (5) we see that for the antineutrino in reactor experiments the vector variant does not make a contribution to the cross section, since $a_0 = 0$ owing to the orthogonality of the wave functions Z and Z*. The total excitation cross section is

$$\sigma = \frac{G^2}{\pi} b_0 (E_\nu - \Delta E)^2. \tag{6}$$

The value of the cross section (6) is of the same order as the cross section of the process $\bar{\nu} + p \to e^+ + n$ in the experiments of Reines and Cowan [7].

By way of an example we have considered the excitation of the Li^7 nucleus. The ground state of Li^7 has the characteristics $J = 3/2^-$, $T = 1/2$; the first excited level has $J = 1/2^-$ and $T = 1/2$; the excitation energy is $\Delta E = 480$ keV. In the calculation of b_0 the wave functions of the ground and excited states were obtained by mixing the configurations with the pair potential in the form of a Rosenfeld exchange variant with parameters $\xi = -2.1$ MeV, L/K = 6, and K = 0.9[9], which yields as a result $b_0 = 2.56$. The cross section (6) should be averaged over the neutrino spectrum $\rho_\nu(E)$ from the reactor. Assuming as a lower estimate[2)] $\rho_\nu(E) \approx \rho_e(E)$ and taking $\rho_e(E)$ as given by Carter et al[8], we obtain

$$\sigma'(\mathrm{Li}^7) \geqslant \int_{\Delta E}^{\infty} \rho_e(E)\,\sigma(E)\,dE \approx 2\cdot 10^{-42}\,\mathrm{cm}^2. \quad (7)$$

(For the reaction $\bar{\nu} + p \to e^+ + n$, the cross section for neutrinos from a reactor is 6.7×10^{-43} cm^2.) It must be noted that the excited nuclei during the process (3) will, generally speaking, be polarized in the direction of motion of the antineutrino, so that the succeeding gamma radiation will also have definite polarization properties. In principle, this fact could be used to separate the process (3) from the background.

We note that the interaction (1) which we use follows from the Bludman scheme, which presupposes the identity of the muon and the electron neutrino. It is not difficult to generalize the Bludman scheme to include the case $\nu_\mu \neq \nu_e$. In this case the interaction constant in the product of the neutral currents (1) turns out to be equal to G/2, and the cross sections given above are decreased to one-quarter. At the same time, the process $\nu_e + e \to \nu_e + e$ arises, which is forbidden by the Bludman scheme (see also [5]), but unlike the Feynman–Gell-Mann scheme it should be characterized by a constant $G/\sqrt{2}$ (and not G). Analogously, the process $\nu_\mu + e \to \nu_\mu + e$ should have a constant $-G/2$. From this point of view, it is quite interesting to study experimentally the scattering $\nu + e \to \nu + e$ both on reactor neutrinos and on neutrinos from the decay $\pi \to \mu + \nu$.

In conclusion, the authors are deeply grateful to V. V. Belashov, B. M. Pontecorvo, and R. M. Sulyaev for a valuable discussion.

[1)]Staff member of the Institute of Nuclear Physics, Moscow State University.

[2)]It follows from [8] that in the region $E_\nu \gtrsim 1$ MeV the value of $\rho_\nu(E)$ can exceed $\rho_e(E)$ by about 1.5 times.

[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

[2] R. C. G. Sudarshan and R. E. Marshak, Proc. Padua-Venice Conf. on Elementary Particles, 1957.

[3] S. Bludman, Nuovo cimento 9, 433 (1958).

[4] Ya. B. Zel'dovich, JETP 36, 1952 (1959), Soviet Phys. JETP 9, 1389 (1959).

Translated by J. G. Adashko
265

LIMITATION ON THE RATE OF DECREASE OF AMPLITUDES FOR VARIOUS PROCESSES

V. N. GRIBOV and I. Ya. POMERANCHUK

Submitted to JETP editor August 9, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) 43, 1556-1559 (October, 1962)

It has become clear recently that the asymptotic behavior of the amplitudes A(s, t) for the transition of two particles into two particles at high energies and at fixed momentum transfer t is governed by the singularities of the partial wave amplitudes $f_l(t)$ as a function of the angular momentum l in the channel where t is the energy.[1-5] If the singularity of $f_l(t)$ farthest to the right is a Regge pole at $l = l(t)$ then the invariant amplitude behaves like $s^{l(t)}$. In the case of elastic processes for small t such a pole is the vacuum pole, which for t = 0 has $l(0) = 1$. As the momentum transfer $\sqrt{-t}$ increases $l(t)$ can become negative. And so the impression is created that for sufficiently large negative t the amplitude may decrease arbitrarily fast with increasing s.

We now show that in the relativistic theory the partial wave amplitudes $f_l(t)$ for any t have singularities when $\mathrm{Re}\, l \geq -1$, consequently, that the amplitude A(s, t) cannot decrease faster than 1/s for any value of t. This conclusion is valid for the amplitudes of any two-particle processes. The reason for the existence of these singularities is due to the fact that the relativistic amplitude has three Mandelstam spectral functions, which give rise to the appearance of singularities near negative integer l. These singularities are, apparently, poles that accumulate at these points, i.e., the points themselves become essential singular points.

To prove these assertions we consider the expression for the partial wave amplitude:[2]

$$f_l(t) = \frac{2}{\pi}\int_{z_0}^{\infty} Q_l(z)\,A_1(s, t)\,dz,$$

$$z_0 = 1 + 8\mu^2/(t - 4\mu^2), \quad z = 1 + 2s/(t - 4\mu^2); \quad (1)$$

for simplicity we consider the case of identical particles of mass μ. If $\mathrm{Re}\, l > l_0$, where l_0 is determined by the maximum number of subtractions, then, as was shown in[6], the quantity $\Phi_l(t) = f_l(t)(t - 4\mu^2)^{-l}$ satisfied as a function of t a dispersion relation of the form

$$\Phi_l(t) = \frac{1}{\pi}\int_{4\mu^2}^{\infty} \frac{\mathrm{Im}\,\Phi_l(t')\,dt'}{t' - t} + \frac{1}{\pi}\int_{-\infty}^{0} \frac{\Delta\Phi_l(t')}{t' - t}\,dt', \quad (2)$$

where

ERRATA

Vol	No	Author	page	Correction
15	6	Turov	1098	The article contains an erroneous statement that weak ferromagnetism cannot exist in any cubic crystal (with collinear or weakly noncollinear antiferromagnetic structure. This was found to be true only for crystal classes T and T_h, and for others weak ferromagnetism will appear in antiferromagnets with magnetic structure type $3^+ 4^-$, and only due to invariants of third and higher orders in the antiferromagnetism vector L. Consequently a line (14) should be added to the table on p. 1100: $$14 \mid 207\text{-}230 \mid \text{Cubic} \mid 3^+, 4^- \mid M_x L_x (L_y^2 - L_z^2) + M_y L_y (L_z^2 - L_x^2) + M_z L_z (L_x^2 - L_y^2) \mid \text{VI}$$ The Cartesian axes are directed here parallel to the fourfold symmetry axes. The tensors $g^{(1)}$ and $g^{(2)}$ for this (sixth) group of weakly ferromagnetic structures will be identically equal and isotropic: $$g_{\alpha\beta}^{(1)} = g_{\alpha\beta}^{(2)} = g\delta_{\alpha\beta}$$
16	1	Valuev	172	At the end of the article there are incorrect expressions pertaining to $K\mu_3$ decay. The correct formula can be easily obtained from the main formula of the article by putting $g_S = g_T = 0$. The tangent of the angle between the $\mid m \mid^2$ curve and the $\cos\theta$ axis will be $\approx \beta_e$ if $g_{V2}/g_{V1} = -0.5$ and ≈ 0 if $g_{V2}/g_{V1} = 4.5$ and $\beta_e \sim 1$, so that in fact the difference in the angle correlations between these cases is even somewhat stronger than indicated in the article.
16	1	Zhdanov et al	246	The horizontal parts of curves 2 and 3 in Fig. 2 should be drawn with solid lines (they correspond to the asymptotic calculated values of the ionization losses, i.e., to the region in which the theory describes the relation between g/g_0 and the particle energy exactly).
16	1	Deutsch	478 & 481	When account is taken of thermoelectric processes it is necessary to add in the first curly bracket of (24) the term $$A = 3v_0^2 H_y c(\alpha_{xz} - \alpha_{zx})/2$$ and in Eq. (31) the term A/9.
16	1	Nguyen	920 Eqs. (4), (6), (7), & (8)	The combinations $V^1 \pm V^2$, $A^1 \pm A^2$, and $I^1 \pm I^2$ should be divided by $\sqrt{2}$.
16	1	Gershtein et al	1097 Eq. (1)	Reads $G/\sqrt{2}$, should read G/2
16	5	Gurevich		An error has crept into Eq. (30). The right half of this formula is actually equal to $$\varepsilon_E \frac{\delta_{kz}}{2\pi E}\left[F_0(\varepsilon) + 2\varepsilon \frac{d}{d\varepsilon} F_0(\varepsilon)\right].$$