a smooth variation of the current, apparently in analogy with the effect previously observed earlier by Galkin, Kan, and Lazarev [5].

No increase in R_n in the intermediate state was observed for tin samples with residual resistance 3×10^{-3}, but the variation of the resistance was likewise nonmonotonic.

It can be assumed that the described effect makes it possible to determine the fine structure of the intermediate state when superconductivity is destroyed with direct current.

[1] D. Shoenberg, Superconductivity, Cambridge University Press, 1952.

[2] S. Ya. Berkovich and G. M. Lapir, JETP 44, 1329 (1963), Soviet Phys. JETP 17, 896 (1963).

[3] C. G. Kuper, Phil. Mag. 43, 1264 (1952).

[4] Ya. S. Kan and L. B. Rabukhin, PTE No. 2, 192 (1965).

[5] Galkin, Kan, and Lazarev, JETP 20, 865 (1950)

NEUTRONIZATION OF He^4

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As is well known, at high densities, when the electron energy becomes sufficient for the inverse β process, the neutronization reaction begins in matter [1]. The first step in the investigation of the kinetics of this process was made by Frank-Kamenetskii [2]. During the time of the collapse of a star, owing to the neutronization of matter, only high-energy neutrinos will be emitted and these may be experimentally detectable. In an earlier note [3] we considered the process of collapse with neutronization of cold hydrogen. Estimates for other elements were extremely crude. An estimate under the assumption of an annual collapse of ten stars in our galaxy with masses 2 - 3 times the sun's mass yielded a high-energy neutrino flux (10 - 30 MeV) amounting to several per cent of the solar flux (the neutrino from B^8 decay, with maximum energy 14 MeV). The neutrino energy was underestimated in the cited note. Let us obtain a more accurate expression for the energy of the neutrinos produced during the course of neutronization of helium.

The production of high-energy neutrinos upon collapse of a cold star is connected with the process

$$e^- + He^4 = T + N + \nu \qquad (1)$$

The threshold energy of this process is $Q = 22.1$ MeV $= 43.4\ mc^2$. This reaction is followed by the "easier" reaction $e^- + T = 3n + \nu$. The course of the reaction (1) is made complicated by the fact that the H^4 nucleus does not exist and that the neutronization is accompanied by emission of a neutron. Nor does the H^4 nucleus apparently exist like a virtual state [4]. It is therefore natural to assume in first approximation that the matrix element depends neither on the neutrino energy nor on the neutron energy, nor on the angle between them, and the probability of the reaction is therefore assumed proportional to the phase volume.

For a given density ρ_e of electrons with energy E, the total kinetic energy of the products of the reaction (1) is $E - Q$; it is made up of the neutrino energy E_ν and the n + T kinetic energy relative to the center of inertia of this system, $E_1 = E - Q - E_\nu$. The energy motion of the T + n center of mass (of the order of 1 MeV) is neglected. In view of the fact that T and n are nonrelativistic particles, their phase volume is proportional to $(E_1)^{1/2}\, dE_1$. Thus, at a given electron energy E and for a given electron density ρ_e, the differential probability of a process with production of a neutrino in the energy interval from E_ν to $E_\nu + dE_\nu$ is of the form

$$dW = \rho_e K \cdot E_\nu^2\, (E - Q - E_\nu)^{1/2}\, dE_\nu \tag{2}$$

From this we obtain for the total probability

$$W = \rho_e K \int_0^{E-Q} E_\nu^2 (E - Q - E_\nu)^{1/2} dE_\nu = \rho_e B(E - Q)^{7/2} = \rho_e B(mc^2)^{7/2}(E' - Q')^{7/2} \tag{3}$$

where K and B are constants, E' and Q' the dimensionless energies expressed in units of mc^2, and $m = m_e$.

To determine the constant B we use the analogy between the process of interest to us and the reaction

$$\mu^- + He^4 = T + n + \nu \tag{4}$$

which was investigated experimentally 1) [5].

The experimentally obtained probability of this reaction, $W_\mu = 370 \pm 50\ \text{sec}^{-1}$, pertains to muons in the 1s state in the nuclear field. Setting up an expression analogous to (3) for the probability W_μ of a process with a μ meson,

$$W_\mu = B|\psi_\mu(0)|^2(m_e c^2)^{7/2}(E'_\mu - Q')^{7/2} \tag{5}$$

we obtain B. According to the universal weak interaction hypothesis, B should be the same for the electronic and muonic processes.

We now go from the reaction with an electron of specified energy E to the case of neutronization by a degenerate relativistic electron gas:

$$\begin{aligned} W_F &= (B/\pi^2)(h/mc)^{-3}(mc^2)^{7/2}\int_{Q'}^{E'_F}(E' - Q')^{7/2}E'^2 dE' \\ E_f &= mc^2(\rho/\mu_e 10^6)^{1/3} \end{aligned} \tag{6}$$

Substitutin the expression for B obtained from the experimental data on the muon reaction, we obtain

$$\begin{aligned} W_F &= W_\mu \frac{1}{\pi Z^3_{He}} (m_e/m_\mu)^3(e^2/hc)^{-3}\left(\frac{m_{He}+m_\mu}{m_{He}}\right)^3(E'_\mu - Q')^{-7/2} \int_Q^{E'_F}(E' - Q')^{7/2}dE' = \\ &= W_\mu 9.5(y - 1)^{9/2}[0.154y^2 + 0.056y + 0.012], \quad y = E_F/Q = (\rho/\mu_e \times 1{,}7 \times 10^{11})^{1/3} \end{aligned} \tag{7}$$

It is assumed that the next act following the process $e^- + He^4 = T + n + \nu$, namely $e^- + T = 3n + \nu$, occurs practically instantaneously, in accordance with the fact that the nucleus T is much weaker and more "friable" than He^4.

Using the relations for free fall

$$\rho = 1/6\pi G(t_0 - t)^2 = (8 \times 10^5)/(t_0 - t)^2; \qquad dt = 4.5 \times 10^2 \rho^{-3/2} d\rho$$

we obtain an approximate equation for the neutronization kinetics (x is the fraction of the non-decaying He^4)

$$dx/d\rho = - 3 \times 10^5 (x/\rho^{3/2} Q'^2)(\rho x/2 \times 10^6)^{2/3} [(1/Q')(\rho x/2 \times 10^6)^{1/3} - 1]^{9/2}$$

Integration of this equation from $\rho = 0$, $x = 1$ yields $\rho = \rho_t = 1.7 \times 10^{11}$, $x = 1$ (threshold); $\rho = 7.5\rho_t$, $x = 0.86$; $\rho = 15\rho_t$, $x = 0.5$; $\rho = 60\rho_t$, $x = 0.16$. Neutronization of the bulk of the He^4 mass in the free-fall regime occurs at a Fermi energy double the threshold value, i.e., 45 MeV. This means that neutrinos with energies up to 35 MeV are produced in the process $e^- + T = 3n + \nu$. Their registration probability is 10 - 20 times greater than that of the threshold neutrinos from B^8 decay expected to be observed in the spectrum of the sun; these neutrinos can differ from the solar neutrinos, if the detector registers the neutrino energy and, albeit roughly, their direction [6].

The emission of a neutrino with energy up to 35 MeV from a collapsing star occurs at a density on the order of $10^{12} - 10^{13}$ g/cm^3. This density must be compared with the critical value [7, 9]

$$\rho_g = 1.8 \times 10^{16} (M/M_\odot)^{-2}$$

at which gravitational self-closure takes place. It is clear that at masses less than 50 sun masses, i.e., for the overwhelming majority of stars, the high-energy neutrinos produced by neutronization have time to leave the star without becoming noticeably weakened by the gravitational field. At the same time, the density $\rho \sim 3 \times 10^{12}$ g/cm^3 is still appreciably smaller than nuclear density, so that the analysis made above, without account of nuclear interaction, is perfectly justified. Concerning emission of thermal neutrinos following collapse see [7] and [10].

[1] L. B. Landau and E. M. Lifshitz, Statisticheskaya fizika (Statistical Physics), Nauka, 1964.

[2] D. A. Frank-Kamenetskii, JETP 42, 875 (1962), Soviet Phys. JETP 15, 607 (1962).

[3] Ya. B. Zel'dovich and O. Kh. Guseinov, DAN SSSR 162, no. 4, 1965.

[4] Baz', Gol'danskii, and Zel'dovich, UFN 85, 415 (1965), Soviet Phys. Uspekhi 8 (1965).

[5] L. Foldy and Walecka, Congres Int. Phys. Nucl., Paris, 1964, II, p. 1168.

[6] F. Reines and R. M. Woods, Jr., Phys. Rev. Lett. 14, 20 (1965).

[7] Ya. B. Zel'dovich, Astr. tsirk. (Astron. Circular) No. 50, I - VII, 1963.

[8] F. Hoyle and W. Fowler, Relativistic Astrophysics, Preprint, 1963.

[9] Ya. B. Zel'dovich and I. D. Novikov, UFN 84, 377 (1964), Soviet Phys. Uspekhi 7, 763

(1965).
[10] Ya. B. Zel'dovich and I. D. Novikov, UFN 86, No. 3 (1965).

1) The average number of neutrons in one event of the reaction $\mu^- + He^4$ is approximately 1.2, from which it follows that the reactions $\mu^- + He^4 = D + 2n + \nu$ and $\mu^- + He^4 = p + 3n + \nu$ constitute less than half of all the cases.

MIRROR REFLECTION SYMMETRY IN THE CASE OF THE SU(3) GROUP

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Not all the concepts used in the theory of representations of the SU(2) group find their generalization in the theory of representations of group SU(3). Among these concepts are the symmetry of mirror reflection, which in the case of SU(2) group was developed in [1-4] 1). In the present note we indicate the possibility of introducing this concept into the theory of group SU(3) representations, and the practical utility of the corresponding symmetry properties for the calculation of the Clebsch-Gordan coefficients.

If we use the system of phases chosen in [5], then the analog of symmetry of mirror reflection in the theory of the group SU(3) can be the relation

$$\varphi(\{N\}II_zY) = (-1)^{I_z + (1/2)Y}\varphi\left(\{N\}\bar{I}I_zY\right) \tag{1}$$

with

$$I \to \bar{I} \equiv - I - 1 \tag{2}$$

Here φ is the basis function of the irreducible representation $\{N\} = (pq)$. I is the isospin quantum number, I_z and Y are the quantum numbers of the projection of the isospin and they hypercharge, respectively.

It is seen from (1) that the substitution (2) denotes a transition from the representation $D^{\{N\}}_{II_zY,\ I'I'_zY'}$ to the equivalent representation $D^{\{N\}}_{\bar{I}I_zY,\bar{I}'I'_zY'}$, obtained from the former by adding the phase factor equal to minus unity raised to the power $I + (1/2)Y + I' + (1/2)Y'$. Equation (1) leads to the relation

$$\varphi(\{N^*\},\ \nu) = \varphi^*(\{N\},\ \bar{\nu}) \tag{3}$$

where

$$\nu = II_zY, \qquad \text{and} \qquad \bar{\nu} = II_zY$$

$$(\bar{I} = - 1,\ \bar{I}_z = - I_z,\ \bar{Y} = - Y) \tag{4}$$