ANGULAR CORRELATION BETWEEN NEUTRINO AND GAMMA QUANTUM IN L-CAPTURE

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The angular correlation between a longitudinally polarized neutrino and a circularly polarized γ-quantum released by an L-capture has been determined. For the form of the weak interaction the linear combination of S, V, T, A, P couplings has been supposed. The angular correlation was calculated for arbitrary γ-transitions and for captures forbidden in any order. As a special case the ν-γ-angular correlation by an allowed L-capture has also been given.

1. Introduction

In the recent investigations on the parity violating interactions angular correlation experiments play an important role. The reason for this is that the $\beta - \gamma$, $\nu - \gamma$ angular correlations depend rather sensitively on the polarization of the emitted elementary particles and on the type of the Fermi interaction, the form of which is of particular interest. Comparing the measurements of the polarization of electrons and those of the helicity of the neutrino we can infer the form of the weak interaction. Electron polarization measurements give unambiguously the result that the β-electrons are longitudinally polarized in backward directions in the ratio of v/c. This result suggests in the case of a left-handed neutrino (spin and momentum antiparallel) the VA in the case of a right-handed neutrino (spin and momentum parallel) the ST variants of the interaction. To decide between these alternatives the helicity of the neutrino has to be determined. From this point of view angular correlation measurements by electron capture are very suitable, since in this process only one particle (the neutrino) is emitted, thus its study is considerably easier than e.g. that of the β-decay. The wave function determining the electron before capture is exactly known; consequently, the result of calculations depends essentially only on the type of the interaction and on the helicity of the neutrino. GOLDHABER et al. [1] have shown just by means of such angular correlation measurements that the spin and the momentum of the neutrino are antiparallel, i.e. it is a left-handed particle. Their measurement strongly supports the VA variant of the interaction. The problem, however, cannot be regarded as completely solved, because the results do not give uniquely determined values for the coupling constants of the V and A interactions and for the relative sign ($V \pm A$) of them. Since angular correlation investigations may give valuable information also regarding the further development of research further theoretical investigations seem highly desirable.

Recently several papers [2], [3] have dealt with $\nu - \gamma$ angular correlation problems. These investigations, however, were confined on the one hand only to allowed transitions and on the other only to K-capture. In a previous paper [3] we generalized the calculations for K-captures forbidden in arbitrary order and for mixed γ-transitions. As is well known, under certain circumstances the probability of an L-capture may be also rather high, but in spite of this there are no calculations concerning this capture. Our aim is just to fill this gap. In the following we shall determine the $\nu - \gamma$ angular correlation for an L-capture forbidden in arbitrary order. Our results make possible not only the comparison of the neutrino theory with the experiments, but they may also serve as a theoretical basis in certain nuclear spectroscopical investigations.

2. Angular correlation formula

Let us consider the following process : A nucleus of charge Z and characterized by the quantum numbers j_1, m_1 captures one electron having been in a definite quantum state in the atomic shell. The nucleus emitting a neutrino goes over into an excited state characterized by j_2, m_2, having the nuclear charge $Z - 1$. As a next step the nucleus emitting a γ-quantum gets into the ground state with the quantum numbers j_3, m_3. Let us denote by $\mathbf{p}$ and P_ν the momentum and the polarization of the neutrino, by $\mathbf{k}$ and P_γ the momentum and the polarization of the γ-quantum, respectively. j_i, m_i ($i = 1, 2, 3$) are the angular momentum and magnetic quantum numbers of the nucleus in the states characterized above, those values for the initial electron should be j_e and m_e. Thus the following composite process has to be considered :

$$j_1, m_1; \; e \xrightarrow{\nu} j_2, \; m_2 \xrightarrow{\gamma} j_3, \; m_3.$$

We want to find the angular correlation between the directions of the emitted γ and ν particles ; i.e. we want to determine the transition probability of the above composite process as a function of the polarizations P_ν, P_γ and the angle ϑ between the vectors $\mathbf{p}$ and $\mathbf{k}$. By means of the perturbation theory the correlation in question is obtained [4] as

$$W(\vartheta, P_\nu P_\gamma) = \sum_{\substack{m_2 \\ m_2'}} E^{(\nu)}(m_2, \; m_2') E^{(\gamma)}(m_2, \; m_2'). \tag{1}$$

$E^{(\nu)}(m_2, m_2')$ and $E^{(\gamma)}(m_2, m_2')$ are the density matrices of the above two processes, which can be obtained by means of the interaction Hamiltonian :

$$E^{(\nu)}_{(m_2, m_2')} = \sum_{\substack{m_1 \\ m_e}} \langle j_2, m_2; \nu | H^{(\nu)} | j_1 m_1; n_e, j_e, m_e \rangle^* \langle j_2 m_2'; \nu | H^{(\nu)} | j_1 m_1; n_e, j_e, m_e \rangle , \tag{2}$$

$$E^{(\gamma)}_{(m_2, m_2')} = \sum_{m_3} \langle j_3 m_3; \gamma \, | \, H^{(\gamma)} \, | \, j_2 m_2 \rangle^* \langle j_3 m_3; \gamma \, | \, H^{(\gamma)} \, | \, j_2 m_2' \rangle , \tag{3}$$

where $H^{(\nu)}$ and $H^{(\gamma)}$ are interaction Hamiltonians for electron capture — neutrino emission and for gamma emission, respectively. Factors irrelevant for the correlation have been omitted. We shall determine first the density matrices $E^{(\nu)}(m_2, m_2')$ and $E^{(\gamma)}(m_2, m_2')$, from which using (1) the correlation $W(\vartheta, P_\nu, P_\gamma)$ can be obtained.

3. Electron capture

The Hamilton operator describing the electron capture — neutrino emission is given by

$$H^{(\nu)} = f \sum_i C_i (\bar{\psi}_n O_i \psi_p) \left(\bar{\psi}_\nu \tfrac{1}{2}(1 + P_\nu \gamma_5) O_i \psi_e\right) + h \cdot c. \tag{4}$$

Here ψ_n, ψ_p, ψ_ν and ψ_e are the second quantized neutron, proton, neutrino and electron field operators, respectively. Indices i refer to the five interactions S, V, T, A, P. In (4) the quantity characterizing the polarization of the neutrino may be $P_\nu = \pm 1$, depending on the spin of the neutrino being oriented in the direction of momentum or in the opposite sense. According to the measurements of GOLDHABER et al. — as we have already mentioned — it is very likely that $P_\nu = -1$, our calculations, however, will be carried out for both polarizations, thus providing the possibility of deciding the neutrino helicity on the basis of (also forbidden) L-capture experiments too. O_i $(i = 1, \ldots, 5)$ are Dirac matrices corresponding to the five interactions*

$$O_S = 1; \quad O_V = i\gamma_\mu; \quad O_T = \frac{1}{2i}(\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu); \tag{5}$$

$$O_A = i\gamma_5 \gamma_\mu; \quad O_P = i\gamma_5.$$

The matrix element of the Hamiltonian (4) for the electron capture-neutrino emission is

$$\begin{aligned} &< j_2 m_2; \nu | H^{(\nu)} | j_1 m_1; e > = \\ &= f \sum_i C_i \sum_{n=1}^{A} \int \left(\bar{\psi}_\nu \tfrac{1}{2}(1 + P_\nu \gamma_5) O_i \psi_e\right) (\Phi^\dagger_{j_2 m_2} \gamma_4 O_{in} \Phi_{j_1 m_1})\, d\tau. \end{aligned} \tag{6}$$

$\Phi_{j_1 m_1}$ and $\Phi_{j_2 m_2}$ are the state functions of the nucleus in initial and in final states, respectively. The lepton state functions are to be taken at the place of the n-th nucleon suffering the transition. The operator O_{in} acts on the variables of the n-th nucleon. Summation refers to all the nucleons, integration to the state function of the nucleus.

* We use $x_4 = ict$. The quantities $(\bar{\psi} O_i \psi)$ containing the above O_i have the same reality properties as the corresponding classical tensors. E.g. $(\bar{\psi} i \gamma_r \psi)$ $(r = 1, 2, 3)$ are hermitic, the fourth component $(\bar{\psi} i \gamma_4 \psi)$ is antihermitic, similarly for the others. In other papers frequently O_i is taken to be hermitic. In this case $O_V = \gamma_\mu$, $O_P = \gamma_5$. Then the corresponding coefficients C_V and C_P are -1 times ours. This sign difference manifests itself only in the interference terms to be calculated later.

For the determination of the matrices $E^{\nu}(m_2, m_2')$ let us chose a coordinate system with the z axis in the direction of motion of the neutrino. This choice makes the calculation easier but it does not impair its generality. Thus the wave function of the neutrino with momentum $\mathbf{p}$ is:

$$\psi_\nu = u_\nu \exp\left(\frac{i}{\hbar} pz\right). \tag{7}$$

For a neutrino polarized forward

$$\frac{1 - P_\nu \gamma_5}{2} \psi_\nu = \psi_{\nu+} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix} \exp\left(\frac{i}{\hbar} pz\right), \tag{8}$$

similarly for the backward polarized case

$$\frac{1 - P_\nu \gamma_5}{2} \psi_\nu = \psi_{\nu-} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 1 \\ 0 \\ -1 \end{pmatrix} \exp\left(\frac{i}{\hbar} pz\right). \tag{9}$$

Expanding the function $\exp\left(\frac{i}{\hbar} pz\right)$ in series of spherical functions we have

$$\exp\left(\frac{i}{\hbar} pz\right) = \sum_{l=0}^{\infty} \sqrt{4\pi(2l+1)}\, j_l\left(\frac{pr}{\hbar}\right) i^l\, Y_{l0}(\Theta). \tag{10}$$

Here $j_l\left(\frac{pr}{\hbar}\right)$ is the l-th order Bessel function.

The wave functions of the electron bounded in the Coulomb field are obtained from the solution of the Dirac equation:

if $j = l + \frac{1}{2}$:

$$\psi_1 = \sqrt{\frac{l+m+\frac{1}{2}}{2l+1}}\, g(r)\, Y_{l,m-\frac{1}{2}},$$

$$\psi_2 = -\sqrt{\frac{l-m+\frac{1}{2}}{2l+1}}\, g(r)\, Y_{l,m+\frac{1}{2}},$$

$$\psi_3 = -\sqrt{\frac{l-m+\frac{3}{2}}{2l+3}}\, if(r)\, Y_{l+1,m-\frac{1}{2}},$$

$$\psi_4 = -\sqrt{\frac{l+m+\frac{3}{2}}{2l+3}}\, if(r)\, Y_{l+1,m+\frac{1}{2}},$$

if $j = l - \frac{1}{2}$:

$$\psi_1 = \sqrt{\frac{l-m+\frac{1}{2}}{2l+1}}\, g(r)\, Y_{l,m-\frac{1}{2}},$$

$$\psi_2 = \sqrt{\frac{l+m+\frac{1}{2}}{2l+1}}\, g(r)\, Y_{l,m+\frac{1}{2}}, \tag{11}$$

$$\psi_3 = -\sqrt{\frac{l+m-\frac{1}{2}}{2l-1}}\, if(r)\, Y_{l-1,m-\frac{1}{2}},$$

$$\psi_4 = \sqrt{\frac{l-m-\frac{1}{2}}{2l-1}}\, if(r)\, Y_{l-1,m+\frac{1}{2}}.$$

The radial wave functions $g(r)$ and $f(r)$ for K- and L-shells are given as:

$$g_K(r) = \left(\frac{2Z}{a_0}\right)^{3/2} \sqrt{\frac{1+\varepsilon_1}{2\,\Gamma(2\gamma_1+1)}}\, e^{-\frac{1}{2}\varrho_1} \varrho_1^{\gamma_1-1}, \quad f_K(r) = -\sqrt{\frac{1-\varepsilon_1}{1+\varepsilon_1}}\, g_K(r) \tag{12a}$$

for $1S_{1/2}$ state (K-shell; $n = 1$, $l = 0$, $j = \frac{1}{2}$),

$$g_{L_\mathrm{I}}(r) = \left(\frac{2Z}{N_2 a_0}\right)^{3/2} \sqrt{\frac{2\gamma_1+1}{\Gamma(2\gamma_1+1)}} \sqrt{\frac{1+\varepsilon_2}{4N_2(N_2+1)}}\, e^{-\frac{\varrho_2}{2}} \left[N_2 \varrho_2^{\gamma_1-1} - \frac{N_2+1}{2\gamma_1+1} \varrho_2^{\gamma_1}\right]$$

for $2S_{1/2}$ state (L_I-*shell*; $n = 2$, $l = 0, j = \frac{1}{2}$),

(12b)

$$f_{L_\mathrm{I}}(r) = -\sqrt{\frac{1-\varepsilon_2}{1+\varepsilon_2}} \cdot \frac{(2\gamma_1+1)(N_2+2)-(N_2+1)\varrho_2}{(2\gamma_1+1)N_2-(N_2+1)\varrho_2}\, g_{L_\mathrm{I}}(r),$$

$$g_{L_\mathrm{II}}(r) = \left(\frac{2Z}{N_2 a_0}\right)^{3/2} \sqrt{\frac{2\gamma_1+1}{\Gamma(2\gamma_1+1)}} \cdot \sqrt{\frac{1+\varepsilon_2}{4N_2(N_2-1)}}\, e^{-\frac{\varrho_2}{2}} \left[(N_2-2)\varrho_2^{\gamma_1-1} - \frac{N_2-1}{2\gamma_1+1} \varrho_2^{\gamma_1}\right]$$

for $2P_{1/2}$ state (L_II-shell; $n = 2$; $l = 1, j = \frac{1}{2}$),

$$f_{L_\mathrm{II}}(r) = -\sqrt{\frac{1-\varepsilon_2}{1+\varepsilon_2}} \cdot \frac{(2\gamma_1+1)N_2-(N_2-1)\varrho_2}{(2\gamma_1+1)(N_2-2)-(N_2-1)\varrho_2}\, g_{L_\mathrm{II}}(r), \tag{12c}$$

$$g_{L_\mathrm{III}}(r) = \left(\frac{Z}{a_0}\right)^{3/2} \sqrt{\frac{1+\varepsilon_3}{2\Gamma(2\gamma_2+1)}}\, e^{-\frac{\varrho_3}{2}} \varrho_3^{\gamma_2-1},$$

for $2P_{3/2}$ state (L_III-shell; $n = 2, l = 1, j = \frac{3}{2}$),

$$f_{L_\mathrm{III}}(r) = -\sqrt{\frac{1-\varepsilon_3}{1+\varepsilon_3}}\, g_{L_\mathrm{III}}(r)\,. \tag{12d}$$

Here the denotations

$$\gamma_1 = \sqrt{1-(aZ)^2}; \qquad \gamma_2 = \sqrt{4-(aZ)^2};$$

$$N_1 = 1; \qquad N_2 = \sqrt{2(1+\gamma_1)}; \qquad N_3 = 2; \qquad \varrho_i = \frac{2Zr}{N_i a_0};$$

$$\varepsilon_1 = \left[1+\left(\frac{aZ}{\gamma_1}\right)^2\right]^{-1/2}; \quad \varepsilon_2 = \left[1+\left(\frac{aZ}{1+\gamma_1}\right)^2\right]^{-1/2}; \quad \varepsilon_3 = \left[1+\left(\frac{aZ}{\gamma_2}\right)^2\right]^{-1/2} \tag{13}$$

have been used. a_0 is the Bohr radius, Z is the nuclear charge.

For our purposes it is not necessary to treat the electrons relativistically; consequently we retain only the large components. The radial wave functions of the electron in the transition matrix elements are substituted — as usual — by their values on the surface of the nucleus, thus being constants they can be factored out from the integral. Using (12*a*)—(12*d*) and (13) it is easily seen that at distances of the order of a nuclear radius the large components are those terms which contain the functions $g_K(r)$, $g_{L_I}(r)$, $g_{L_{III}}(r)$, $f_{L_{II}}(r)$ for K-, L_I-, L_{III}- and L_{II}-shells, respetively. Thus we use the following wave functions for electrons :

L_I = shell: $\quad m_e = \frac{1}{2}$: $\qquad m_e = -\frac{1}{2}$:

$$\psi_e = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} g_{L_I}(r)\, Y_{00}; \qquad \psi_e = \begin{pmatrix} 0 \\ -1 \\ 0 \\ 0 \end{pmatrix} g_{L_I}(r)\, Y_{00}; \tag{14a}$$

L_{II}-shell: $\quad m_e = \frac{1}{2}$: $\qquad m_e = -\frac{1}{2}$:

$$\psi_e = \begin{pmatrix} 1 \\ 0 \\ -i \\ 0 \end{pmatrix} f_{L_{II}}(r)\, Y_{00}; \qquad \psi_e = \begin{pmatrix} 0 \\ 0 \\ 0 \\ i \end{pmatrix} f_{L_{II}}(r)\, Y_{00}; \tag{14b}$$

L_{III}-shell: $\quad m_e = \frac{3}{2}$: $\qquad m_e = -\frac{3}{2}$:

$$\psi_e = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} g_{L_{II}}(r)\, Y_{11}(\vartheta, \varphi); \qquad \psi_e = \begin{pmatrix} 0 \\ -1 \\ 0 \\ 0 \end{pmatrix} g_{L_{III}}(r)\, Y_{1,-1}(\theta, \varphi); \tag{14c}$$

$m_e = \frac{1}{2}$: $\qquad m_e = -\frac{1}{2}$:

$$\psi_e = \begin{pmatrix} \sqrt{\frac{2}{3}}\, Y_{10}(\theta\, \varphi) \\ -\frac{1}{\sqrt{3}}\, Y_{11}(\theta\, \varphi) \\ 0 \\ 0 \end{pmatrix} g_{L_{III}}(r); \qquad \psi_e = \begin{pmatrix} \frac{1}{\sqrt{3}}\, Y_{1,-1}(\theta, \varphi) \\ -\sqrt{\frac{2}{3}}\, Y_{10}(\theta, \varphi) \\ 0 \\ 0 \end{pmatrix} g_{L_{III}}(r). \tag{14d}$$

These electron and neutrino wave functions (7), (10) are to be substituted into the transition matrix element (6). The substitution gives e.g. in the case of the L_I-shell :

$$< j_2 m_2;\ \nu | H^{(\nu)} | j_1 m_1;\ e_{L_I} > \approx$$

$$\sum_{i,l} C_i \sqrt{2l+1} \left(u_\nu^\dagger \frac{1 - P_\nu \gamma_5}{2} \gamma_4 O_i\, u_e \right) \sum_{n=1}^{A} \int \Phi^\dagger_{j_2 m_2} j_l \left(\frac{p r_n}{\hbar} \right) i^{-l}\, Y_{l0}(\theta_n)\, \gamma_4\, O_{in} \Phi_{j_1 m_1} d\tau, \tag{15}$$

where u_e is the unit spinor occurring in the electron state function. In (15) constants irrelevant for the correlation (e.g. f, g_{L_1} taken on the surface of the nucleus, Y_{00}) have been omitted.

For the matrix element we use the usual denotation

$$\sum_{n=1}^{A} \int \Phi^{\dagger}_{j_2 m_2} j_l \left(\frac{p r_n}{\hbar}\right) i^{-l} Y_{l0}(\theta_n) \gamma_4 O_{in} \Phi_{j_1 m_1} d\tau = \langle j_2 m_2 | j_l i^{-l} Y_{l0} \gamma_4 O_i | j_1 m_1 \rangle, \quad (16)$$

from which

$$\langle j_2 m_2;\ \nu | H^{(\nu)} | j_1 m_1;\ e_{L_1} \rangle \approx$$
$$\sum_{i,l} C_i \sqrt{2l+1} \left(u_\nu^{\dagger} \frac{1-P_\nu \gamma_5}{2} \gamma_4 O_i\, u_e \right) \langle j_2 m_2 | j_l i^{-l} Y_{l0} \gamma_4 O_i | j_1 m_1 \rangle. \quad (17)$$

The matrix element $\langle j_2 m_2 | j_l i^{-l} \gamma_4 Y_{l0} O_i | j_1, m_1 \rangle$ can be decomposed using the Wigner-Eckart theorem to the product of a reduced matrix element independent of the magnetic quantum numbers and a certain Clebsch-Gordan coefficient. The nucleons are treated in non-relativistic approximation. The small components of the wave function will not be taken equal to zero, but terms in the transition matrix elements containing second and higher powers in v/c are neglected.

Let us treat e.g. in detail the vector interaction. In this case $O_V = i\gamma_\mu$. The space-like components ($\mu = 1, 2, 3$) are $\varrho_1 \sigma$; the fourth component ($\mu = 4$) is i. The matrix element of $H_V^{(\nu)}$ according to (17) is :

$$\langle j_2 m_2;\ \nu | H_V^{(\nu)} | j_1 m_1;\ e_{L_1} \rangle \approx$$
$$\sum_l \sqrt{(2l+1)} \left(u_\nu^{\dagger} \frac{1-P_\nu \gamma_5}{2} i \gamma_4 \gamma_\mu u_e \right) \langle j_2 m_2 | j_l i^{-l} Y_{l0} i \gamma_4 \gamma_\mu | j_1 m_1 \rangle =$$
$$= \sum_l \sqrt{2l+1} \left(u_\nu^{\dagger} \frac{1-P_\nu \gamma_5}{2} \varrho_1 \sigma u_e \right) \langle j_2 m_2 | j_l i^{-l} Y_{l0} \varrho_1 \sigma | j_1 m_1 \rangle - \quad (18)$$
$$- \sum_l \sqrt{2l+1} \left(u_\nu^{\dagger} \frac{1-P_\nu \gamma_5}{2} u_e \right) \langle j_2 m_2 | j_l i^{-l} Y_{l0} | j_1 m_1 \rangle.$$

The first sum on the right side is the "relativistic", the second is the "ordinary" transition matrix element. A given order "relativistic" term is v/c times the corresponding "ordinary" element. (v is the mean velocity of nucleons.) Let us treat first the "ordinary" matrix element. The leptonic matrix elements from (8), (9) and (14a) are*

* $u_e(+)$ denotes the spinor corresponding to $m_e = +\frac{1}{2}$, $u_e(-)$ that corresponding to $m_e = -\frac{1}{2}$.

$$\left(u_\nu^\dagger \frac{1-\gamma_5}{2} u_e(+)\right) = \frac{1}{\sqrt{2}}; \qquad \left(u_\nu^\dagger \frac{1-\gamma_5}{2} u_e(-)\right) = 0; \tag{19}$$
$$\left(u_\nu^\dagger \frac{1+\gamma_5}{2} u_e(+)\right) = 0; \qquad \left(u_\nu^\dagger \frac{1+\gamma_5}{2} u_e(-)\right) = -\frac{1}{\sqrt{2}}.$$

The nuclear matrix elements, using the Wigner-Eckart theorem, can be written

$$< j_2 m_2 | j_l i^{-1} Y_{l0} | j_1 m_1 > = (-1)^l (j_1 l m_1 0 | j_2 m_2) < j_2 || l || j_1 > \delta(\pi_2, (-1)^l \pi_1), \tag{20}$$

where $< j_2 || l || j_1 >$ is the reduced matrix element independent of the magnetic quantum numbers; π_1 and π_2 are the parities of the initial and final states, respectively. In the following we use the denotation $\pi(l)$ for $\delta(\pi_2, (-1)^l \pi_1)$. The reduced matrix elements $< j_2 || l || j_1 >$ are real, the condition for which is that the tensor operator Ω_{kq} occurring in the nuclear matrix element should satisfy

$$T \Omega_{kq}^\dagger = (-1)^{k-q} \Omega_{k,-q} T, \tag{21}$$

when time is reversed [4]. T is the operator of time reversal. It can be seen very easily that $i^l Y_{l0}$ satisfies condition (21).

From (17) and (20) we get

$$< j_2 m_2; \nu | H_V^{(\nu)} | j_1 m_1; e_{L_1} >_0 \sim \sum_l \sqrt{2l+1} (j_1 l m_1 0 | j_2 m_2) (-1)^l < j_2 || l || j_1 > \pi(l). \tag{22}$$

Substituting this into (2) we obtain

$$E_{V_0}^{(\nu)}(m_2, m_2') \sim \sum_{m_1} \sum_{l,l'} \sqrt{(2l+1)(2l'+1)} < j_2 || l || j_1 > < j_2 || l' || j_1 > \cdot$$
$$(-1)^{l+l'} \pi(l) \pi(l') (j_1 l m_1 0 | j_2 m_2) (j_1 l' m_1 0 | j_2 m_2'). \tag{23}$$

From (23) it is easily seen that for a given m_1 $m_2 = m_2'$, if not, $E_{V_0}^{(\nu)}(m_2, m_2') = 0$. The first Clebsch-Gordan coefficient namely differs from zero only if $m_2 = m_1$ the second if $m_2' = m_1$. Thus

$$E_{V_0}^{(\nu)}(m_2, m_2') \approx \sum_{m_1} (\ldots) \delta(m_2, m_2').$$

Let us treat now the "relativistic" matrix element. We use for the vector σ its spherical components

$$\sigma_1 = -\frac{1}{\sqrt{2}}(\sigma_x + i\sigma_y); \quad \sigma_0 = \sigma_z; \quad \sigma_{-1} = \frac{1}{\sqrt{2}}(\sigma_x - i\,\sigma_y). \tag{24}$$

The scalar product (σ, σ) is then

$$(\boldsymbol{\sigma}, \boldsymbol{\sigma}) = \sum_{\mu=-1}^{1} (-1)^{\mu} \sigma_{\mu} \sigma_{-\mu}. \tag{25}$$

The matrix element now contains the operator

$$(-1)^{\mu} i^{-l} Y_{l0} \sigma_{-\mu}.$$

This is the adjunged operator to $i^l\, Y_{l0}\, \sigma_\mu$. Let us introduce the tensor operator Ω_{Ll}^{M} as follows:

$$\Omega_{Ll}^{M} = \sum_{m' + \mu' = M} (l\,1\,m'\,\mu' \,|\, L\,M)\, i^l\, Y_{l\,m'}\, \sigma_{\mu'}, \tag{26}$$

from which

$$i^l\, Y_{lm}\, \sigma_\mu = \sum_{L,M} (l\,1\,m\,\mu | L\,M)\, \Omega_{Ll}^{M}. \tag{27}$$

(18), (25), (27) and the Wigner-Eckart theorem gives

$$\begin{aligned} &< j_2\, m_2 | j_l\, (-1)^{\mu}\, i^{-l}\, Y_{l0}\, \sigma_{-\mu}\, \varrho_1 | j_1\, m_1 > = \\ &= \sum_L (-1)^{\mu+L+1} (l10\mu | L\mu)\, (j_1\, Lm_1 - \mu | j_2\, m_2) < j_2 \,||\, lL\varrho_1 \,||\, j_1 > \pi\,(l+1)\,. \end{aligned} \tag{28}$$

One can easily obtain the lepton matrix elements also in this case and from (27), (18), (28) we get

$$\begin{aligned} E_{\gamma 2}^{(\nu)}(m_2, m_2') \approx & \sum_{m_1} \sum_{l,l'} \sum_{L,L'} \sqrt{(2l+1)\,(2l'+1)}\,(-)^{l+l'} \langle j_2 || lL\,\varrho_1 || j_1 \rangle \langle j_2 || l'L'\,\varrho_1 || j_1 \rangle \\ & \cdot \pi\,(l+1)\, \pi\,(l'+1)\, \{ (l100 \,|\, L0)\, (l'100 \,|\, L'0)\, (j_1 Lm_1 0 \,|\, j_2\, m_2)\, (j_1 L'\, m_1 0 \,|\, j_2\, m_2') + \\ & + 2P_{\nu}^{l+l'+L+L'}\, (l10-1 | L-1)\, (l'10-1 \,|\, L'-1)\, (j_1\, Lm_1 - P_\nu \,|\, j_2\, m_2) \cdot \\ & \cdot (j_1\, L'm_1 - P_\nu \,|\, j_2\, m_2') \}\,. \end{aligned} \tag{29}$$

We can conclude again that for a given m_1 $m_2 = m_2'$ i.e.

$$E_{\gamma 2}^{(\nu)}(m_2, m_2') \approx \sum_{m_1} (\ldots)\, \delta\,(m_2, m_2')\,.$$

The reduced matrix elements $< j_2 \,||\, lL\varrho_1 \,||\, j_1' >$ in (29) are also real. This will indeed be the case if $\Omega_{L l_{\varrho_1}}^{M\dagger}$ satisfies (21). Using $\sigma_\mu^* = -(-1)^{\mu}\, T^{-1} \sigma_{-\mu}\, T$

and $\varrho_1^* = T^{-1}\varrho_1 T$, the condition can be easily verified. (* denotes complex conjugate.)

The full density matrix $E_V^{(\nu)}(m_2, m_2')$ according to (2) and (18) besides the above matrices $E_{V_0}^{(\nu)}$, $E_{V_R}^{(\nu)}$ contains in addition the interference terms of the "ordinary" and "relativistic" matrix elements too:

$$E_V^{(\nu)}(m_2, m_2') = E_{V0}^{(\nu)}(m_2, m_2') + E_{V_R}^{(\nu)}(m_2, m_2') + E_{V_I}^{(\nu)}(m_2, m_2') \,. \tag{30}$$

$E_{V_I}^{(\nu)}$ can be calculated similarly, it is:

$$\begin{aligned} E_{V_I}^{(\nu)}(m_2, m_2') \approx -2 \sum_{m_1} \sum_{ll'} \sum_{L'} \sqrt{(2l+1)(2l'+1)}\,(-1)^{l+l'} \langle j_2 \| l \| j_1 \rangle \cdot \\ \cdot \langle j_2 \| l' L' \varrho_1 \| j_1 \rangle \pi(l)\, \pi(l'+1)\, (l' 100 \mid L'0)\, (j_1 L' m_1 0 \mid j_2 m_2')\, (j_1 l m_1 0 \mid j_2 m_2) \,. \end{aligned} \tag{31}$$

It can be seen from (31) that similarly to the former two expressions

$$E_V^{(\nu)}(m_2, m_2') \approx \sum (\ldots)\, \delta(m_2, m_2') \,.$$

Other members of the full density matrix $E_V^{(\nu)}(m_2, m_2')$ can be computed on similar lines. We give here only the result of the straightforward calculation

$$\begin{aligned} E^{(\nu)}(m_2, m_2')_{L_I} \approx \sum_{m_1} \sum_{ll'} \sqrt{(2l+1)(2l'+1)}\,(-1)^{l+l'} \{ e_1 (ll' m_1 m_2 m_2')\, a_I(ll' P_\nu) + \\ + \sum_{LL'} e_2 (ll' LL' m_1 m_2 m_2', P_\nu)\, b_I(ll' LL', P_\nu) + \\ + \sum_{L'} e_3 (ll' L' m_1 m_2 m_2')\, c_I(ll' L', P_\nu) \}, \end{aligned} \tag{32}$$

where e_1, e_2, e_3 and a_I, b_I, c_I are

$$e_1 (ll' m_1 m_2 m_2') = (j_1 l m_1 0 \mid j_2 m_2)\, (j_1 l' m_1 0 \mid j_2 m_2)\, \delta(m_2, m_2') \,, \tag{33}$$

$$\begin{aligned} e_2 (ll' LL' m_1 m_2 m_2', P_\nu) = \\ = \{ (l 100 \mid L0)\, (l 100 \mid L'0)\, (j_1 L m_1 0 \mid j_2 m_2)\, (j_1 L' m_1 0 \mid j_2 m_2) + \\ + 2P_\nu^{l+l'+L+L'} (l 10 -1 \mid L -1)\, (l' 10 -1 \mid L' -1)\, (j_1 L m_1 - P_\nu \mid j_2 m_2) \cdot \\ (j_1 L' m_1 - P_\nu \mid j_2 m_2) \}\, \delta(m_2, m_2') \,, \end{aligned} \tag{34}$$

$$\begin{aligned} e_3 (ll' L' m_1 m_2 m_2') = \\ = (l' 100 \mid L'0)\, (j_1 L' m_1 0 \mid j_2 m_2)\, (j_1 l m_1 0 \mid j_2 m_2)\, \delta(m_2, m_2') \,, \end{aligned} \tag{35}$$

$$a_{\rm I}(ll', P_\nu) = C_S^2 M_S(l) M_S(l') + C_V^2 M_{V_O}(l) M_{V_O}(l') + C_A^2 M_{A_E}(l) M_{A_E}(l') + C_P^2 M_P(l) M_P(l') - 2C_A C_P M_{A_E}(l) M_P(l') + 2P_\nu [C_S C_P M_S(l) M_P(l') + C_V C_A M_{V_O} M_{A_E}(l') - C_S C_A M_S(l) M_{A_E}(l') - C_V C_P M_{V_O}(l) M_P(l')], \quad (36)$$

$$\begin{aligned} b_{\rm I}(ll'LL', P_\nu) = {} & C_V^2 M_{V_E}(lL) M_{V_E}(l'L') + C_T^2 M_{T_O}(lL) M_{T_O}(l'L') + \\ & + C_T^2 M_{T_E}(lL) M_{T_E}(l'L') + C_A^2 M_{A_O}(lL) M_{A_O}(l'L') - \\ & - 2C_V C_T M_{V_E}(lL) M_{T_E}(l'L') + 2P_\nu [- C_T^2 M_{T_O}(lL) M_{T_E}(l'L') + \\ & + C_V C_T M_{V_E}(lL) M_{T_O}(l'L') + C_V C_A M_{V_E}(lL) M_{A_O}(l'L')], \end{aligned} \quad (37)$$

$$\begin{aligned} C_{\rm I}(ll'L', P_\nu) = 2\{ & -C_V^2 M_{V_O}(l) M_{V_E}(l'L') - C_A^2 M_{A_E}(l) M_{A_O} l'L') - \\ & - C_S C_T M_S(l) M_{T_E}(l'L') + C_V C_T M_{V_O}(l) M_{T_E}(l'L') + \\ & + C_T C_P M_P(l) M_{T_O}(l'L') + C_A C_P M_P(l) M_{A_O}(l'L') + \\ & + P_\nu [C_S C_T M_S(l) M_{T_O}(l'L') + C_S C_A M_S(l) M_{A_O}(l'L') - \\ & - C_V C_T M_{V_O}(l) M_{T_O}(l'L') - C_V C_A M_{V_O}(l) M_{A_O}(l'L') - \\ & - C_V C_A M_{A_E}(l) M_{V_E}(l'L') + C_V C_P M_P(l) M_{V_E}(l'L') - \\ & - C_T C_P M_P(l) M_{T_E}(l'L')]\}. \end{aligned}$$

M_l occurring in the expressions $a_{\rm I}$, $b_{\rm I}$, $c_{\rm I}$ denotes the product of the reduced matrix element and the corresponding parity symbol $\pi(l)$. The exact relations are given in Table 1.

Table I

$M_S(l) = < j_2 \| l\varrho_3 \| j_1 > \pi(l)$;	
$M_{V_O}(l) = < j_2 \| l \| j_1 > \pi(l)$;	$M_{V_E}(lL) = < j_2 \| lL\varrho_1 \| j_1 > \pi(l+1)$;
$M_{T_O}(lL) = < j_2 \| lL\varrho_3 \| j_1 > \pi(l)$;	$M_{T_E}(lL) = < j_2 \| lLi\varrho_2 \| j_1 > \pi(l+1)$;
$M_{A_O}(lL) = < j_2 \| lL \| j_1 > \pi(l)$;	$M_{A_E}(l) = < j_2 \| l\varrho_1 \| j_1 > \pi(l+1)$;
	$M_P(l) = < j_2 \| li\varrho_2 \| j_1 > \pi(l+1)$.

In (32) all the interference terms have been taken into account except the terms SV and TA. These terms as we know from β-decay experiments do not appear.

From (32)—(38) it is seen that the density matrix $E_{L_{\rm I}}^{(\nu)}$ for $L_{\rm I}$-capture is the same as for K-capture. This can be seen directly from the comparison of the state functions ψ_e too. The transition probabilities for $L_{\rm I}$- and K-capture differ only in terms containing the energy and the radial wave functions of the electrons. These factors being unimportant for the correlation had formerly been neglected. The density matrices describing the γ-transition being the same for both captures, the $\nu - \gamma$-angular correlation for the K- and L_I-capture are also the same [3].

The determination of the density matrices $E^{(\nu)}(m_2, m_2')_{L_{II}}$, $E^{(\nu)}(m_2, m_2')_{L_{III}}$ for L_{II}- and L_{III}-captures using the electron wave functions (14b)—(14d) is similar to our former calculations. We quote only the results :

$$E^{(\nu)}(m_2, m_2')_{L_{II}} \approx \sum_{m_1} \sum_{l,l'} \sqrt{(2l+1)(2l'+1)}\,(-1)^{l+l'} \{e_1(ll'm_1m_2m_2')\,a_{II}(ll', P_\nu) + \\ + \sum_{LL'} e_2(ll'LL'm_1m_2m_2', P_\nu)\,b_{II}(ll'LL', P_\nu) + \\ + \sum_{L'} e_3(ll'L'm_1m_2m_2')\,c_{II}(ll'L', P_V)\}, \tag{39}$$

where c_1, c_2 and c_3 are equal to (33), (34) and (35); a_{II}, b_{II}, c_{II} are expressions containing the reduced matrix elements :

$$a_{II}(ll', P_\nu) = C_S^2 M_S(l) M_S(l') + C_V^2 M_{V_0}(l') M_{V_0}(l) + C_A^2 M_{A_E}(l) M_{A_E}(l') + \\ + C_P^2 M_P(l) M_P(l') + 2C_A C_P M_{A_E}(l) M_P(l) + 2P_\nu [C_S C_A M_S(l) M_{A_E}(l') + \\ + C_S C_P M_S(l) M_P(l') + C_V C_A M_{V_0}(l) M_{A_E}(l') + C_V C_P M_{V_0}(l) M_P(l')], \tag{40}$$

$$b_{II}(ll'LL', P_\nu) = C_V^2 M_{V_E}(lL) M_{V_E}(l'L') + \\ + C_T^2 M_{T_0}(lL) M_{T_0}(l'L') + C_T^2 M_{T_E}(lL) M_{T_E}(l'L') + \\ + C_A^2 M_{A_0}(lL) M_{A_0}(l'L') + 2C_V C_T M_{V_E}(lL) M_{T_E}('L') + \\ + 2P_\nu [-C_V C_T M_{V_E}(lL) M_{T_0}(l'L') + C_V C_A M_{V_E}(lL) M_{A_0}(l'L') - \\ - C_T^2 M_{T_0}(lL) M_{T_E}(l'L')], \tag{41}$$

$$c_{II}(ll'L', P_\nu) = 2\{-C_V^2 M_{V_0}(l) M_{V_E}(l'L') - C_A^2 M_{A_E}(l) M_{A_0}(l'L') - \\ - C_S C_T M_S(l) M_{T_E}(l'L') - C_V C_T M_{V_0}(l) M_{T_E}(l'L') + \\ + C_T C_P M_P(l) M_{T_0}(l'L') - C_A C_P M_P(l) M_{A_0}(l'L') + \\ + P_\nu [C_S C_T M_S(l) M_{T_0}(l'L') - C_S C_A M_S(l) M_{A_0}(l'L') + \\ + C_V C_T M_{V_0}(l) M_{T_0}(l'L') - C_V C_A M_{V_0}(l) M_{A_0}(l'L') - \\ - C_V C_A M_{A_E}(l) M_{V_E}(l'L') - C_V C_P M_P(l) M_{V_E}(l'L') - \\ - C_T C_P M_P(l) M_{T_E}(l'L')]\}. \tag{42}$$

The M_i are given in Table 1. (39) is very similar to (32) only the expressions a, b, c are different. The electron energy and the radial wave functions are here also different, but being unimportant factors they have been omitted.

$$E^{(\nu)}(m_2, m_2')_{L_{III}} \approx \sum_{m_1} \sum_{ll'} \sum_{JJ'} 3\,(2l+1)\,(2l'+1)\,[(2J+1)\,(2J'+1)]^{-1/2}\,(-1)^{\Delta} \cdot \\ \cdot \{d_1(ll'JJ'm_1\,m_2\,m_2'\,P_\nu)\,a_{III}(ll'JJ', P_\nu) + \sum_{LL'} d_2(ll'JJ'LL'm_1\,m_2\,m_2', P_\nu) \cdot \\ \cdot b_{III}(ll'JJ'LL', P_\nu) + \sum_{L'} d_3(ll'JJ'L'm_1\,m_2\,m_2', P_\nu)\,c_{III}(ll'JJ'L', P_\nu)\}, \tag{43}$$

where

$$\Delta = l + l' + \delta(J, l-1) + \delta(J', l'-1)\,, \tag{44}$$

$$\begin{aligned}
&d_1(ll'JJ'm_1 m_2 m_2', P_\nu) = \\
&= (l100 \mid J0)(l'100 \mid J'0)\{\tfrac{2}{3}(l100 \mid J0)(l'100 \mid J'0)(j_1 Jm_1 0 \mid j_2 m_2)\cdot \\
&\cdot(j_1 J'm_1 0 \mid j_2 m_2) + (l101 \mid J1)(l'101 \mid J'1)(j_1 Jm_1 P_\nu \mid j_2 m_2)\cdot \\
&\cdot(j_1 J'm_1 P_\nu \mid j_2 m_2) + \tfrac{1}{3}(l10-1 \mid J-1)(l'10-1 \mid J'-1)\cdot \\
&\cdot(j_1 Jm_1 - P_\nu \mid j_2 m_2)(j_1 J'm_1 - P_\nu \mid j_2 m_2)\}\,\delta(m_2, m_2')\,,
\end{aligned} \tag{45}$$

$$\begin{aligned}
&d_2(ll'JJ'LL'm_1 m_2 m_2', P_\nu) = \\
&= (l100 \mid J0)(l'100 \mid J'0)P_\nu^{J+J'+L+L'}\{(l101 \mid J1)(l'101 \mid J'1)\cdot \\
&\cdot(J110 \mid L1)(J'110 \mid L'1)(j_1 Lm_1 P_\nu \mid j_2 m_2)(j_1 L'm_1 P_\nu \mid j_2 m_2) + \\
&+ 2(l10-1 \mid J-1)(l'10-1 \mid J'-1)(J1-1-1 \mid L-2)\cdot \\
&\cdot(J'1-1-1 \mid L'-2)(j_1 Lm_1 - 2P_\nu \mid j_2 m_2)(j_1 L'm_1 - 2P_V \mid j_2 m_2) + \\
&+ \tfrac{2}{3}(j_1 Lm_1 0 \mid j_2 m_2)(j_1 L'm_1 0 \mid j_2 m_2)[(l101 \mid J1)(J11-1 \mid L0) - \\
&- (l100 \mid J0)(J100 \mid L0)][(l'101 \mid J'1)(J'11-1 \mid L'0) - (l'100 \mid J'0)\cdot \\
&\cdot(J'100 \mid L'0) + \tfrac{1}{3}(j_1 Lm_1 - P_\nu \mid j_2 m_2)(j_1 L'm_1 - P_\nu \mid j_2 m_2)\cdot \\
&\cdot[2(l100 \mid J0)(J10-1 \mid L-1) - (l10-1 \mid J-1)(J1-10 \mid L-1)]\cdot \\
&\cdot[2(l'100 \mid J'0)(J'10-1 \mid L'-1) - (l'10-1 \mid J'-1)(J'1-10 \mid L'-1)]\}\cdot \\
&\cdot\delta(m_2, m_2')\,,
\end{aligned} \tag{46}$$

$$\begin{aligned}
&d_3(ll'JJ'L'm_1 m_2 m_2', P_\nu) = (l100 \mid J0)(l'100 \mid J'0)P_\nu^{l'+L'}\{(l101 \mid J1)\cdot \\
&\cdot(l'101 \mid J'1)(J'110 \mid L'1)(j_1 Jm_1 P_\nu \mid j_2 m_2)(j_1 L'm_1 P_\nu \mid j_2 m_2) - \\
&- \tfrac{2}{3}(l100 \mid J0)[(l'101 \mid J'1)(J'11-1 \mid L'0) - (l'100 \mid J'0)(J'100 \mid L'0)]\cdot \\
&\cdot(j_1 Jm_1 0 \mid j_2 m_2)(j_1 L'm_1 0 \mid j_2 m_2) - \tfrac{1}{3}(l10-1 \mid J-1)[2(l'100 \mid J'0)\cdot \\
&\cdot(J'10-1 \mid L'-1) - (l'10-1 \mid J'-1)(J'1-10 \mid L'-1)]\cdot \\
&\cdot(j_1 Jm_1 - P_\nu \mid j_2 m_2)(j_1 L'm_1 - P_\nu \mid j_2 m_2)\}\,\delta(m_2, m_2)\,,
\end{aligned} \tag{47}$$

$$\begin{aligned}
&a_{III}(ll'JJ', P_\nu) = C_S^2 M_S(lJ) M_S(l'J') + C_V^2 M_{V_0}(lJ) M_{V_0}(l'J') + \\
&+ C_A^2 M_{A_R}(lJ) M_{A_R}(l'J') + C_P^2 M_P(lJ) M_P(l'J') - 2C_P C_A M_P(lJ) M_{A_R}(l'J') + \\
&+ 2P_\nu[-C_S C_A M_S(lJ) M_{A_R}(l'J') + C_S C_P M_S(lJ) M_P(l'J') + \\
&+ C_V C_A M_{V_0}(lJ) M_{A_R}(l'J') - C_V C_P M_{V_0}(lJ) M_P(l'J')],
\end{aligned} \tag{48}$$

$$
\begin{aligned}
b_{\mathrm{III}}(ll'JJ'LL',P_\nu) = {} & C_V^2 M_{V_E}(lJL)\, M_{V_E}(l'J'L') + C_T^2 M_{T_O}(lJL)\, M_{T_O}(l'J'L') + \\
& + C_T^2 M_{T_E}(lJL)\, M_{T_E}(l'J'L') + C_A^2 M_{A_O}(lJL)\, M_{A_O}(l'J'L') - \\
& - 2C_V C_T M_{V_E}(lJL)\, M_{T_E}(l'J'L') + 2P_\nu [C_V C_T M_{V_E}(lJL)\, M_{T_O}(l'J'L') + \\
& + C_V C_A M_{V_E}(lJL)\, M_{A_O}(l'J'L') - C_T^2 M_{T_O}(lJL)\, M_{T_E}(l'J'L')],
\end{aligned}
\tag{49}
$$

$$
\begin{aligned}
c_{\mathrm{III}}(ll'JJ'L',P_\nu) = 2\{ & -C_S C_T M_S(lJ)\, M_{T_E}(l'J'L') + C_V C_T M_{V_O}(lJ)\, M_{T_E}(l'J'L') + \\
& + C_T C_P M_P(lJ)\, M_{T_O}(l'J'L') + C_A C_P M_P(lJ)\, M_{A_O}(l'J'L') - \\
& - C_V^2 M_{V_O}(lJ)\, M_{V_E}(l'J'L') - C_A^2 M_{A_E}(lJ)\, M_{A_O}(l'J'L') + \\
& + P_\nu [C_S C_T M_S(lJ)\, M_{T_O}(l'J'L') + C_S C_A M_S(lJ)\, M_{A_O}(l'J'L') - \\
& - C_V C_T M_{V_O}(lJ)\, M_{T_O}(l'J'L') - C_V C_A M_{V_O}(lJ)\, M_{A_O}(l'J'L') - \\
& - C_V C_A M_{A_E}(lJ)\, M_{V_E}(l'J'L') + C_V C_P M_P(lJ)\, M_{V_E}(l'J'L') - \\
& - C_T C_P M_P(lJ)\, M_{T_E}(l'J'L')]\}.
\end{aligned}
\tag{50}
$$

M_i as in Table 1 denotes the product of the reduced matrix element and the corresponding parity symbol. The reduced matrix elements occurring here are different from the elements treated before. Matrix elements for the L_{III}-shell contain a spherical function of type $Y_{1,-1}$, Y_{10} or Y_{11}, these are to be taken at the place of the nucleon suffering transition. These are thus not constants as Y_{00} was before, this making here some small difference. Let us treat e.g. the transition matrix element of scalar interaction from the electronic state $j_e = {}^3/_2$, $m_e = {}^3/_2$ to the neutrino state having the polarization $P_\nu = +1$. The leptonic matrix element from (8) and (14c) is

$$
(\psi_\nu^\dagger \varrho_3 \psi_{e(^3/_2)}) = \frac{1}{\sqrt{2}} Y_{11}\, g_{L\mathrm{III}}\, e^{-\frac{i}{\hbar} pz}.
$$

Taking into account the series (10) for the l-th term of the matrix element (after omitting irrelevant constant factors) we obtain

$$
\langle j_2 m_2; \nu | H_S^{(\nu)}(l) | j_1 m_1; e_{L\mathrm{III}} \rangle \approx \sqrt{4\pi(2l+1)} \langle j_2 m_2 | j_l\!\left(\frac{pr}{\hbar}\right) i^{-l}\, Y_{l0} Y_{11}\, \varrho_3 | j_1 m_1 \rangle . \tag{51}
$$

Y_{l0} and Y_{11} are to be taken at the place of the interacting n-th nucleon. Using the identity

$$
Y_{lm}(\theta\varphi)\, Y_{l'm'}(\theta\varphi) = \sum_{JN} \left[\frac{(2l+1)(2l'+1)}{4\pi(2J+1)} \right]^{1/2} (ll'00|JN)\,(ll'mm'|JN)\, Y_{JN}(\Theta\varphi),
$$

we obtain

$$<j_2 m_2;\, \nu\, |\, H_S^{(\nu)}(l)\, |\, j_1 m_1; e_{L\,III}> \approx -i\,(2l+1)\,\sqrt{3}\sum_J (2J+1)^{-1/2}\,(-l)^l\,(l100\,|\,J0)\cdot$$

$$\cdot\,(l101\,|\,J1) <j_2 \quad j_l\left(\frac{pr}{\hbar}\right) i^{l+1}\, Y_{J1}\,\varrho_3\,|\,j_1 m_1>. \tag{53}$$

In the sum for J there are only two terms different from zero, because $(l100|l0) = 0$ if $J = l$. In the $J = l + 1$-th term the nuclear matrix element contains $i^{l+1} Y_{l+1,1}$ which results (c.f. 21) real reduced matrix element. $i^{l+1} Y_{l-1,1}$ occurring in the term $J = l - 1$ can be written as $i^{l-1}\ Y_{l-1,1}\ i^2 = -\ i^{l-1}\ Y_{l-1,1}$. Therefore the $J = l - 1$-th term after factoring out (-1) gives a real reduced matrix element of similar structure. We multiply, consequently, the right side of (53) by $(-1)^{\delta(J,l-1)}$. Thus using the Wigner-Eckart theorem we obtain

$$<j_2 m_2;\nu\,|\,H_S^{(\nu)}(l)\,|\,j_1 m_1; e_{L\,III}> \approx$$

$$\approx i\sqrt{3}\,(2l+1)\sum_J (2J+1)^{-1/2}\,(-1)^{l+\delta(J,l-1)}\,(l\,100\,|\,J0)\,(l\,101\,|\,J1)\cdot \tag{54}$$

$$\cdot\,(j_1 J m_1 1\,|\,j_2 m_2) <j_2\,||\,J l \varrho_3\,||\,j_1> \pi(J).$$

It is to be seen from (53) and (54) that the parity symbol occurring in M^l contains J and not l, namely in the nuclear matrix element occurs Y_{Jm} the parity of which is be to considered here.

4. The $\nu - \gamma$ angular correlation

We have determined in Part 3 the density matrix $E^{(\nu)}(m_2, m_2')$ describing electron capture — neutrino emission for L-capture. The density matrix describing γ-emission is known from our previous paper [3]:

$$E^{(\gamma)}(m_2, m_2') = (-1)^{2j_2+j_3+1+m_2}\sum_{k,\lambda,\lambda'}(-1)^{\lambda-\lambda'+k}\sqrt{(2\lambda+1)(2\lambda'+1)}<j_3\,||\,\lambda\,||\,j_2>\cdot$$

$$\cdot <j_3\,||\,\lambda'\,||\,j_2> P_\gamma^k\ (\lambda\lambda' 1 -1\,|\,k0)\ W(j_2 j_2 \lambda\lambda';\, k j_3)\ (j_2 j_2 - m_2 m_2'\,|\,k\, m_2' - m_2)\cdot$$

$$\cdot\, D^k_{m_2'-m_2,0}(k). \tag{55}$$

The angular correlation is given by (1).

It is to be seen from (32), (39), (43) and (55) that that part of $\sum_{m_2 m_2'} E^{(\nu)}(m_2, m_2')\, E^{(\gamma)}(m_2, m_2')$ which contains m_2 and m_2' is

$$\sum_{m_2 m_2'}\sum_{m_1}(-1)^{m_2}(j_1\, L m_1 - n P_\nu\,|\,j_2\, m_2)\,(j_1\, L' m_1 - n P_\nu\,|\,j_2\, m_2)\cdot$$

$$\cdot\,(j_2 j_2 - m_2 m_2'\,|\,k\, m_2' - m_2)\, D^k_{m_2'-m_2,0}\ (k)\ \delta(m_2, m_2'), \tag{56}$$

where n is an integer. Using $\delta(m_2 m_2')$ one can easily sum for m_2', it remains

$$\sum_{m_1 m_2}' (-1)^{m_2} (j_1 L m_1 - n P_\nu \mid j_2 m_2)(j_1 L' m_1 - n P_\nu \mid j_2 m_2)(j_2 j_2 - m_2 m_2 \mid k0). \tag{57}$$

One can easily sum here by means of the Racah theorem. According to that

$$\sum_{\beta\varepsilon\delta} (ab\, a\beta \mid e\, \varepsilon)(ed\, \varepsilon\delta \mid c\gamma)(bd\, \beta\delta \mid f\varphi) =$$
$$= \sqrt{(2e+1)(2f+1)}\, (af\, a\varphi \mid c\gamma)\, W(abcd\,;\, ef), \tag{58}$$

where $W(abcd;ef)$ is the so-called Racah coefficient, the values of which are tabulated. We apply the theorem for

$$a = L, \quad b = j_2, \quad c = L', \quad d = j_2, \quad e = j_1, \quad f = k$$
$$\alpha = nP_\nu, \quad \beta = m_2, \quad \gamma = nP_\nu, \quad \delta = -m_2, \quad \varepsilon = m_1, \quad \varphi = 0. \tag{59}$$

We use, moreover, the well-known formula

$$(ab\, \alpha\beta \mid c - \gamma) = (-1)^{3b-c+\gamma-\beta} \sqrt{\frac{2c+1}{2b+1}}\, (ca\, \gamma\alpha \mid b - \beta) =$$
$$= (-1)^{a+2b-\beta+\gamma} \sqrt{\frac{2c+1}{2b+1}}\, (ac\, \alpha\gamma \mid b - \beta) = \tag{60}$$
$$= (-1)^{a+b+c+2\gamma} (ab - \alpha - \beta \mid c\, \gamma)$$

for the Clebsch-Gordan coefficients. Using (58), (59) and (60) we obtain

$$\sum_{m_1, m_2} (-1)^{m_2} (j_1 L m_1 - nP_\nu \mid j_2 m_2)(j_1 L' m_1 - nP_\nu \mid j_2 m_2)(j_2 j_2 - m_2 m_2 \mid k0) =$$
$$= (-1)^{k-j_1+nP_\nu} (2j_2+1)(LL'\, nP_\nu, -nP_\nu \mid k0)\, W(LL' j_2 j_2\,;\, kj_1). \tag{61}$$

In expressions (32), (39) and (43) occur the values $n = 0, 1, -1, 2$.

As a final result for the $\nu - \gamma$ angular correlation we obtain

$$W_{L_{\rm I}}(\vartheta, P_\nu, P_\gamma) = \sum_k A_k^{(\nu, L_{\rm I})} A_k^{(\gamma)} P_k(\cos\vartheta), \tag{62a}$$

$$W_{L_{\rm II}}(\vartheta, P_\nu, P_\gamma) = \sum_k A_k^{(\nu, L_{\rm II})} A_k^{(\gamma)} P_k(\cos\vartheta), \tag{62b}$$

$$W_{L_{\rm III}}(\vartheta, P_\nu, P_\gamma) = \sum_k A_k^{(\nu, L_{\rm III})} A_k^{(\gamma)} P_k(\cos\vartheta), \tag{62c}$$

where

$$A_k^{(\gamma)} = (-1)^{j_3+1} \sum_{\lambda\lambda'} \sqrt{(2\lambda+1)(2\lambda'+1)} < j_3 \| \lambda \| j_2 > < j_3 \| \lambda' \| j_2 > (-1)^{\lambda-\lambda'} P_\gamma^k \cdot \cdot (\lambda\lambda' 1 -1 | k0)\, W(j_2 j_2 \lambda\lambda';\, kj_3), \tag{63}$$

$$A_k^{(\nu,L_{\rm I})} = (-1)^{j_1} \sum_{ll'} \sqrt{(2l+1)(2l'+1)}\, (-1)^{l+l'} \{ a_k(ll')\, a_{\rm I}(ll', P_\nu) + + \sum_{LL'} \beta_k(ll'LL', P_\nu)\; b_{\rm I}\;(ll'LL', P_\nu) + \sum_{L'} \gamma_k(ll'L')\, c_{\rm I}(ll'L', P_\nu) \}, \tag{64a}$$

$$A_k^{(\nu,L_{\rm II})} = (-1)^{j_1} \sum_{ll'} \sqrt{(2l+1)(2l'+1)}\, (1-1)^{l+l'} \{ a_k(ll')\, a_{\rm II}(ll', P_\nu) + + \sum_{LL'} \beta_k(ll'LL', P_\nu)\, b_{\rm II}(ll'LL', P_\nu) + \sum_{L'} \gamma_k(ll'L')\, c_{\rm II}(ll'L', P_\nu) \}, \tag{64b}$$

$$A_k^{(\nu,L_{\rm III})} = (-1)^{j_1} \sum_{ll'} \sum_{JJ'} 3\,(2l+1)\,(2l'+1)\, [(2J+1)(2J'+1)]^{-1/2}\, (-1)^{\Delta} \cdot \cdot \{ \sigma_k(ll'JJ', P_\nu)\, a_{\rm III}(ll'JJ', P_\nu) + \sum_{LL'} \tau_k(ll'JJ'LL', P_\nu)\, b_{\rm III}(ll'JJ'LL', P_\nu) + + \sum_{L'} \varrho_k(ll'JJ'L', P_\nu)\, c_{\rm III}(ll'JJ'L', P_\nu) \}, \tag{64c}$$

$$a_k(ll') = (ll'00 \mid k0)\; W(j_2 j_2\, ll';\, kj_1), \tag{65a}$$

$$\beta_k(ll'LL', P_\nu) = [(l100|L0)\,(l'100|L'0)\,(LL'00|k0) - 2P_\nu^{l+l'+k}\,(l10-1|L-1) \cdot \cdot (l'10-1|L'-1)\,(LL'1-1|k0)]\; W(j_2 j_2\, LL';\, kj_1), \tag{65b}$$

$$\gamma_k(ll'L') = (l'100 \mid L'0)\,(lL'00 \mid k0)\; W(j_2 j_2\, lL';\, kj_1), \tag{65c}$$

$$\sigma_k(ll'JJ', P_\nu) = (l100 \mid J0)\,(l'100 \mid J'0)\, \{ \tfrac{2}{3}\,(l100|J0)\,(l'100 \mid J'0)\,(JJ'00 \mid k0) - - [(l101|J1)\,(l'101|J'1)\,(-1)^{J+J'+k} + \tfrac{1}{3}(l10-1 \mid J-1) \cdot \cdot (l'10-1|J'-1)]\,(JJ'1-1|k0) \}\, P_\nu^{J+J'+k}\; W(j_2 j_2\, JJ';\, kj_1), \tag{65d}$$

$$\tau_k(ll'JJ'LL', P_\nu) = (l100|J0)\,(l'100/J'0)\, \{ \tfrac{2}{3} [(l101|J1)\,(J11-1|L0) - - (l100|J0)\,(J100|L0)]\; [(l'101|J'1)\,(J'1-1|L'0) - (l'100|J'0) \cdot \cdot (J'100|L'0)]\,(LL'00|k0) - \Big[\tfrac{1}{3}\Big(2\,(l100|J0)\,(J10-1|L-1) - - (l10-1|J-1)\,(J1-10|L-1)\Big)\Big(2\,(l'100|J'0)\,(J'10-1|L'-1) - - (l'10-1|J'-1)\,(J'1-10|L'-1)\Big) + + (-1)^{L+L'+k} (l101|J1)(l'101|J'1)(J110|L1)(J'110|L'1)]\,(LL'1-1|k0) + + 2\,(l10-1|J-1)\,(l'10-1|J'-1)\,(J1-1-1|L-2) \cdot \cdot (J'1-1-1|L'-2)\,(LL'2-2|k0) \}\, P_\nu^{J+J'+k}\; W(j_2 j_2\, LL';\, kj_1), \tag{65e}$$

$$\varrho_k(ll'JJ'L', P_\nu) = (l100 \mid J0)\,(l'100 \mid J'0)\,\{-\tfrac{2}{3}(l100 \mid J0)\,((l'101 \mid J'1)\cdot$$
$$\cdot(J'11-1 \mid L'0) - (l'100 \mid J'0)\,(J'100 \mid L'0))\,(JL'00 \mid k0) +$$
$$[\tfrac{1}{3}(l10-1 \mid J-1)\,(2\,(l'100 \mid J'0)\,(J'10-1 \mid L'-1) - \qquad (65f)$$
$$-(l'10-1 \mid J'-1)\,(J'1-10 \mid L'-1)) - (l101 \mid J1)\,(l'101 \mid J'1)\cdot$$
$$\cdot(J'110 \mid L'1)\,(-1)^{J+L'+k}]\,(JL'1-1 \mid k0)\}\,P_\nu^{J+J'+k+1}\,W(j_2 j_2 jJL'; kj_1)\cdot$$

5. Allowed L-capture

We now specialize our general results for allowed L-captures. For allowed transitions only $l = 0$-th order "ordinary" matrix elements are different from zero. In the general expressions $(62a)-(62c)$ only expressions $A_k^{(\nu,t)}(t = L_{\rm I}, L_{\rm II}, L_{\rm III})$ will be modified as follows:

$$A_k^{(\nu,L_{\rm I})} = (-1)^{j_1}\,[\alpha_k(00)\,a_{\rm I}(00) + \beta_k(0011, P_\nu)\,b_{\rm I}(0011) + \\ + \gamma_k(001, P_\nu)\,c_{\rm I}(001)]\,, \qquad (66a)$$

$$A_k^{(\nu,L_{\rm II})} = (-1)^{j_1}\,[\alpha_k(00)\,a_{\rm II}(00) + \beta_k(0011, P_\nu)\,b_{\rm II}(0011) + \\ + \gamma_k(001)\,c_{\rm II}(001, P_\nu)]\,, \qquad (66b)$$

$$A^{(\nu,L_{\rm III})} = (-1)^{j_1}[\sigma_k(0011, P_\nu)\,a_{\rm III}(0011) + \sum_{LL'}\tau_k(0011LL', P_\nu)\cdot \\ \cdot\, b_{\rm III}(0011LL') + \sum_{L'}\varrho_k(0011L', P_\nu)\,c_{\rm III}(0011L', P_\nu)]\,, \qquad (66c)$$

where

$$\alpha_k(00) = W(j_2 j_2 00; kj_1)\,, \qquad (67a)$$

$$\beta_k(0011, P_\nu) = [(1100 \mid k0) - 2P_\nu^k(111-1 \mid k0)]\,W(j_2 j_2 11; kj_1), \qquad (67b)$$

$$\gamma_k(001) = W(j_2 j_2 01; kj_1)\,, \qquad (67c)$$

$$\sigma_k(0011, P_\nu) = \{\tfrac{2}{3}(1100 \mid k0) - [(-1)^k + \tfrac{1}{3}](111-1 \mid k0)\}\cdot \\ \cdot P_\nu^k\,W(j_2 j_2 11; kj_1) \qquad (67d)$$

$$\tau_k(0011LL', P_\nu) = \{\tfrac{2}{3}[(111-1 \mid L0) - (1100 \mid L0)]\,[(111-1 \mid L'0) -$$
$$-(1100 \mid L'0)]\,(LL'00 \mid k0) - [\tfrac{1}{3}(110-1 \mid L-1)\cdot$$
$$\cdot(110-1 \mid L'-1)\,(2-(-1)^L)\,(2-(-1)^{L'}) + \qquad (67e)$$
$$+(-1)^{L+L'+k}(1110 \mid L1)\,(1110 \mid L'1)]\,(LL'1-1 \mid k0) +$$
$$+2\,(11-1-1 \mid L-2)\,(11-1-1 \mid L'-2)\cdot$$
$$\cdot(LL'2-2 \mid k0)\}\,P_\nu^k\,W(j_2 j_2 LL'; kj_1)\,,$$

Table 2

k	0	1	2	3
$\alpha_k(00)$	$W(j_2 j_2 00;\ 0\, j_1)$	0	0	0
$\beta_k(0011)$	$-\sqrt{3}\, W(j_2 j_2 11;\ 0\, j_1)$	$-\sqrt{2}\, P_\nu W(j_2 j_2 11;\ 1\, j_1)$	0	0
$\gamma_k(001)$	0	$W(j_2 j_2 01;\ 1\, j_1)$	0	0
$\sigma_k(0011)$	$-\frac{2}{\sqrt{3}}\, W(j_2 j_2 11;\ 0 j_1)$	$\frac{\sqrt{2}}{3}\, P_\nu W(j_2 j_2 11;\ 1\, j_1)$	0	0
$\tau_k(001100)$	$\frac{8}{9}\, W(j_2 j_2 00;\ 0\, j_1)$	0	0	0
$\tau_k(001101)$	0	$\frac{4}{3\sqrt{6}}\, P_\nu W(j_2 j_2 01;\ 1\, j_1)$	0	0
$\tau_k(001102)$	0	0	$-\frac{2}{9}\sqrt{2}\, W(j_2 j_2 02;\ 2\, j_1)$	0
$\tau_k(001110)$	0	$\frac{4}{3\sqrt{6}}\, P_\nu W(j_2 j_2 10;\ 1\, j_1)$	0	0
$\tau_k(001111)$	$-\frac{7}{3\sqrt{3}}\, W(j_2 j_2 11; 0 j_1)$	$-\frac{P_\nu}{\sqrt{2}}\, W(j_2 j_2 11;\ 1\, j_1)$	$-\frac{4}{3\sqrt{6}}\, W(j_2 j_2 11;\ 2\, j_1)$	0
$\tau_k(001112)$	0	$-\frac{7}{3\sqrt{30}}\, P_\nu W(j_2 j_2 12;\ 1\, j_1)$	0	$-\frac{4\, P_\nu}{3\sqrt{5}}\, W(j_2 j_2 12;\ 3\, j_1)$
$\tau_k(001120)$	0	0	$-\frac{2}{9}\sqrt{2}\, W(j_2 j_2 20;\ 2\, j_1)$	0
$\tau_k(001121)$	0	$-\frac{7\, P_\nu}{3\sqrt{30}}\, W(j_2 j_2 21;\ 1\, j_1)$	0	$-\frac{4\, P_\nu}{3\sqrt{5}}\, W(j_2 j_2 21;\ 3\, j_1)$
$\tau_k(001122)$	$\frac{5}{9}\sqrt{5}\, W(j_2 j_2 22;\ 0 j_1)$	$\frac{11\, P_\nu}{3\sqrt{10}}\, W(j_2 j_2 22;\ 1\, j_1)$	$\frac{28}{9\sqrt{14}}\, W(j_2 j_2\ 22;\ 2\, j_1$	$\frac{8\, P_\nu}{3\sqrt{10}}\, W(j_2 j_2 22;\ 3\, j_1)$
$\varrho_k(00110)$	0	$-\frac{4}{3\sqrt{3}}\, W(j_2 j_2 10;\ 1\, j_1)$	0	0
$\varrho_k(00111)$	$\frac{2}{3\sqrt{6}}\, P_\nu W(j_2 j_2 11;\ 0 j_1)$	$W(j_2 j_2 11;\ 1\, j_1)$	$-\frac{2}{3\sqrt{3}}\, P_\nu W(j_2 j_2 11;\ 2\, j_1)$	0
$\varrho_k(00112)$	0	$-\frac{5}{3\sqrt{15}}\, W(j_2 j_2 12;\ 1\, j_1)$	$\frac{2}{3}\, P\, W_\nu(j_2 j_2 12;\ 2\, j_1)$	0

$$\varrho_k(0011L', P_\nu) = \{-\tfrac{2}{3}[(111-1 \mid L'0) - (1100 \mid L'0)](1L'00 \mid k0) +$$
$$+ [\tfrac{1}{3}(110-1 \mid L'-1)(2-(-1)^{L'}) - \tag{67f}$$
$$-(1110 \mid L'1)(-1)^{1+L'+k}](1L'1-1 \mid k0)\} P_\nu^{k+1} W(j_2 j_2 1L'; kj_1).$$

$$a_{\rm I}(00) = C_S^2 M_S^2(0) + C_V^2 M_{V_0}^2(0), \tag{68a}$$

$$b_{\rm I}(0011) = C_T^2 M_{T_0}^2(01) + C_A^2 M_{A_0}^2(01), \tag{68b}$$

$$c_{\rm I}(001, P_\nu) = 2P_\nu [C_S C_T M_S(0) M_{T_0}(01) + C_S C_A M_S(0) M_{A_0}(01) -$$
$$- C_V C_T M_{V_0}(0) M_{T_0}(01) - C_V C_A M_{V_0}(0) M_{A_0}(01)], \tag{68c}$$

$$a_{\rm II}(00) = a_{\rm I}(00), \tag{69a}$$

$$b_{\rm II}(0011) = b_{\rm I}(0011), \tag{69b}$$

$$c_{\rm II}(001, P_\nu) = 2P_\nu [C_S C_T M_S(0) M_{T_0}(01) - C_S C_A M_S(0) M_{A_0}(01) +$$
$$+ C_V C_T M_{V_0}(0) M_{T_0}(01) - C_V C_A M_{V_0}(0) M_{A_0}(01)], \tag{69c}$$

$$a_{\rm III}(0011) = C_S^2 M_S^2(01) + C_V^2 M_{V_0}^2(01), \tag{70a}$$

$$b_{\rm III}(0011\,LL') = C_T^2 M_{T_0}(01L) M_{T_0}(01L') + C_A^2 M_{A_0}(01L) M_{A_0}(01L'), \tag{70b}$$

$$c_{\rm III}(0011L', P_\nu) = 2P_\nu [C_S C_T M_S(01) M_{T_0}(01L') + C_S C_A M_S(01) M_{A_0}(01L') -$$
$$- C_V C_T M_{V_0}(01) M_{T_0}(01L') - C_V C_A M_{V_0}(01) M_{A_0}(01L')]. \tag{70c}$$

From formulae (67a)—(67f) it can be seen what values of k may occur and from tables the Clebsch-Gordan coefficients α_k, β_k, .. can be determined. The results of the straightforward calculations are tabulated in Table 2.

For allowed L-captures k equals at most 3. The coefficients α_k, β_k .. for k more than three all vanish. The correlation term with $k = 0$ is independent of the angle ϑ between the neutrino and γ-quantum. Thus if $k = 0$ there is no correlation. Table 2 shows that for allowed $L_{\rm I}$- and $L_{\rm II}$-captures in the case of pure Fermi (S, V) transitions there is no $\nu - \gamma$ correlation, naturally there is no correlation for K-captures but there is for Gamow-Teller (A, T) transitions having the form $1 + K \cos\vartheta$ (K is some constant depending on the nuclear state and on the multipolarity of the γ-transition). The situation is different for $L_{\rm III}$-captures, here also for Fermi transitions arises a correlation $(\alpha_1(0\,011) \neq 0)$ of form $1 + K_1 \cos\vartheta$.

6. Discussion

From the general expressions (62a)—(65f) it is to be seen that — just as in K-captures — $A_k^{(\nu,t)}$ and $A_k^{(\gamma)}$ depend on P_ν and P_γ only if k is odd. This is trivial for (55). In the case of $A_k^{(\nu,t)}$ let us consider e.g. the term of (64a) containing a_k. This depends on P_ν through $a_I(l\,l', P_\nu)$. From (65a) it follows that a_k is different from zero only if $l + l' + k =$ an even number, namely $(ll'00 \mid k0) = 0$ if $l + l' + k$ is odd. Let us suppose first that k is even. Then $l + l'$ is also even. There are two cases : (i) both l and l' are even and (ii) both l and l' are odd. In (36) each term in the brackets beside P_ν contains a factor $\pi(l)$ and $\pi(l' + 1)$, thus these terms vanish if l and l' are both even or odd. Therefore the term of (64a) containing a_k does not depend on P_ν if k is even. Let us consider now the case when k is odd. Then a_k is different from zero if $l + l' =$ an odd number. We have again two possibilities : (i) l is even, l' is odd and (ii) l is odd, l' is even. In this case those terms of $a_I(l\,l', P_\nu)$ are different from zero which contain the product of $\pi(l)\,\pi(l' + 1)$; these are just proportional to P_ν. This can be seen similarly also for terms β_k, γ_k . . . etc. Thus $A_k^{(\nu,t)}\,A_k^{(\gamma)}$ is proportional to $P_\nu\,P_\gamma$ if k is odd. Therefore if we do not measure the polarization of the γ-quantum (i.e. we sum for P_γ) the angular correlation does not depend on the neutrino polarization P_ν. The $\nu - \gamma$ angular correlation measurements with circularly polarized γ-quanta on the other hand make possible the determination of P_ν.

Finally we should like to mention one more problem. The universal Fermi interaction proposed by FEYNMAN and GELL-MANN, SUDARSHAN and MARSHAK as well as by SAKURAI [7] is — using the usual terminology ot the β-decay — a VA-interaction. According to the theory both the combinations $V + A$ and $V - A$ are possible. The relative sign has to be determined by means of experiments. Therefore measurements have to be carried out involving interference terms. It is very likely from the measurements of TELEGDI et al. [8] of the electron distribution in polarized neutron decay that $V - A$ is the correct combination. As it is to be seen from our general expressions also the $\nu - \gamma$ angular correlation formulae contain interference terms, thus experiments of the above type are suitable for the clearing up of this problem as well.

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УГЛОВАЯ КОРРЕЛЯЦИЯ НЕЙТРИНО И ГАММА-КВАНТА ПРИ *L*-ЗАХВАТЕ ЭЛЕКТРОНА

К. НАДЬ

Резюме

Автором определена угловая корреляция между нейтрино и гамма-квантом, испускаемыми при *L*-захвате в случае циркулярно поляризованного гамма-кванта и продольно поляризованного нейтрино. β взаимодействие, описывающее захват электрона было взято нами как линеарная комбинация взаимодействий *S*, *V*, *T*, *A* и *P*. Корреляция вычислена для запрещенного в произвольном порядке захвата электрона и для любого гамма-перехода. Как частный случай дана корреляция $\nu-\gamma$, относящаяся к разрешенному *L*-захвату.