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High Energy Weak Interactions

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Слабые взаимодействия при высоких энергиях

В лекции рассмотрено высокоэнергетическое поведение сечений слабого взаимодействия в неперенормируемых градиентных моделях; применение партонной модели; структурные функции в глубоконеупругих реакциях с нейтрино; следствия партонной модели и масштабная инвариантность; рождение новых гипотетических частиц в нейтринных реакциях; оценка возможных сечений рождения; модели распада для новых, в частности, очарованных частиц; правила отбора; безмюонные реакции нейтрино; теоретическая интерпретация "нейтральных токов".

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The investigation of the weak interactions in the energy region actually consists now in the study of the neutrino reactions. There are of course, proposals to look for the effects of the weak interactions in the muon interactions, in the electron-positron colliding beams, but the experimental possibilities here do not achieve the desirable level of accuracy, Therefore, we concentrate our attention in the high energy neutrino reactions, which are studied intensively in IHEP (Serpukhov), CERN, FNAL and some other institutions.

I. THE STRUCTURE OF THE WEAK INTERACTIONS

First of all let us discuss the possible structure of the weak interactions. Almost all the data, excepting the muonless neutrino reactions, may be described in terms of the usual interaction of the charged currents.

$$\mathcal{L}_{int} = \frac{G}{\sqrt{2}} (j_\alpha + J_\alpha)(j_\alpha^+ + J_\alpha^+) ; \qquad (1)$$

where j_α is the leptonic current

$$j_\alpha = \bar{\mu} \gamma_\alpha (1+\gamma_5) \nu_\mu + \bar{e} \gamma_\alpha (1+\gamma_5) \nu_e ; \qquad (2)$$

and J_α is the hadronic current. To the present knowledge the study of the semileptonic decays and the neutrino reactions leads to the conclusion, that the hadronic current was described quite well in the framework of the quark model. In this case

$$J_\alpha = \cos\alpha_c \, \bar{n}\gamma_\alpha(1+\gamma_5)p + \sin\alpha_c \, \bar{\lambda}\gamma_\alpha(1+\gamma_5)p ; \qquad (3)$$

where α_c is the Cabibbo angle, $\sin\alpha_c = 0.22$ and p, n, λ are respectively: proton, neutron and λ quarks with the following quantum numbers

	p	n	λ
Q/e	2/3	-1/3	-1/3
S	0	0	-1
B	1/3	1/3	1/3
I_3	1/2	-1/2	0

The quark structure (3) immediately leads to the result, that the current belongs to the octet representation of the SU(3)-group, that is necessary for the Cabibbo scheme, which agrees with the experiment . We shall discuss later the neutrino data, which also confirm structure (3).

In the lectures we shall use the quark and the quark parton models. This models being in agrement with the experiments do not mean of course an obligatory existence of the real quarks, which have not yet been observed experimentally in spite of intense search. Maybe the agreement of the

quark model with the experiment is the consequence of some symmetry, which we do not understand now. We should also note that the quark model confronts by the difficulties in explaining the processes of the e^+e^- annihilation into hadrons and of the lepton (e, μ) production with the large momentum transfer. On the other hand, such models deserve attention, in which the quarks may exist only in the bound state and cannot under any conditions leave their "prison". After making these remarks, in what follows we shall always speak the quark lanquage.

Interaction (1) is of the unrenormalizable type, that leads to a number of the well-known difficulties. All of them are connected with the fact, that we cannot apply the perturbation theory in the unrenormalizable theories. Due to this fact, the evaluation of the higher orders of the perturbation theory becomes impossible. Let us take the neutral currents as an example to illustrate the situation.

The initial Lagrangian, of course, does not contain the term corresponding to the neutrino scattering

$$\nu_\mu + \mathcal{N} \to \nu_\mu + \mathcal{N}, \qquad \mathcal{N} = p, n ;$$
$$\bar{\nu}_\mu + \mathcal{N} \to \bar{\nu}_\mu + \mathcal{N},$$

However such a term appears in the second order (see. fig. 1), but the

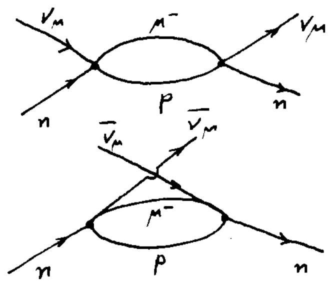

Fig. 1.

corresponding integrals diverge quadratically and we obtain for the effective interaction of the neutral currents

$$\mathcal{L}_{eff} = \frac{G^2}{2(2\pi)^2}\Lambda^2\, \bar{\nu}_\mu \gamma_\alpha(1+\gamma_5)\nu_\mu \Big[\bar{p}\gamma_\alpha(1+\gamma_5)p + \cos^2\alpha_c\, \bar{n}\gamma_\alpha(1+\gamma_5)n + \sin^2\alpha_c\, \bar{\lambda}\gamma_\alpha(1+\gamma_5)\lambda + \sin\alpha_c \cos\alpha_c \big(\bar{\lambda}\gamma_\alpha(1+\gamma_5)n + \bar{n}\gamma_\alpha(1+\gamma_5)\lambda\big)\Big]; \qquad (4)$$

where the cut-off Λ on the upper limit of the momentum intergation is introduced. This expression is meaningless, because the local theory corresponds to the limit $\Lambda \to \infty$. One may understand this expression only in two ways. If one assumes that the theory is actually nonlocal, the reversed cut-off Λ^{-1} acquires the meaning of the particle dimension, then one can make a conclusion on the value of Λ from the experiment.[1] On the other hand, if the theory is local,

the individual perturbation term has no meaning, but the perturbation series as a whole may have the one. Indeed, if we consider the structure of the factor before the neutral currents product in (4) taking into account all the perturbation theory orders, we get the series

$$\frac{G^2}{2(2\pi)^2}\Lambda^2 + a_2 G^3(\Lambda^2)^2 + \dots + a_n G^{1+n}(\Lambda^2)^n + \dots = G\sum_{n=1}^{\infty}{}' a_n (G\Lambda^2)^n. \qquad (5)$$

The local theory is meaningful only if the function F(x), being defined by the series

$$F(x) = \sum_{n=1}^{\infty} a_n x^n$$

has a finite limit for $x \to \infty$

$$\lim_{x\to\infty} F(x) = a < \infty. \qquad (6)$$

There are some arguments, based on the summation of the ladder diagrams, that the limit a may be equal to zero. However, a may be egual to some finite number. In this case the effective neutral currents arise in the first order in G, the coefficient in (4) being aG. We shall discuss later whether this possibility can correspond to the experiment.

The other important feature of the fourfermion variant of the weak interactions is the cross-sections of the neutrino reactions rising with the energy (and also of other weak processes). Namely, we obtain for the cross-section of the process, taken as an example

$$\nu_\mu + n \rightarrow \mu^- + p \tag{7}$$

the expression for the cross-section, which is proportional to the total c.m. energy squared S

$$\sigma = \frac{G^2}{\pi} S \tag{8}$$

Inasmuch as in the fourfermion variant only S and P partial waves are present in process (7), behaviour (8) contradicts the unitarity condition. According to unitariry the cross-section in the l-th partial wave cannot exceed the value

$$\sigma_l = \frac{4\pi(2l+1)}{S}$$

These considerations lead to the contradiction at the energy $S = 2\pi/G \simeq (1000\ \mathrm{GeV})^2$ (the so called "unitary" limit) and higher. In principle, this contradiction in the unrenormalization theory may be overruled, if one takes into account all the perturbative orders. In this case, on the one hand all the partial waves will be present in the amplitude. On the other hand, the cross-section itself will be represented by the series in the powers of (GS). Therefore, for $GS \geqslant 1$ one should take into account the series as a whole, that would lead to the change of behaviour (8). However, it is very

hard to obtain definitely the real form of asymptotics. One cannot exclude, for example, that the cross-section at the high energies will approach the constant of the order of magnitude $\sim G \simeq 4\ 10^{-33}\ \mathrm{cm}^2$.

Both difficulties are closely connected with each other the rising cross-sections and the unremovable higher order divergences. Really the divergences in the higher orders appear due to diagrams, contain the amplitudes, which rapidly rise with the increase of the corresponding variables. Therefore the integration of such rising functions leads to divergences.

The theory with the intermediate charged vector boson W is unrenormalizable as well as the fourfermion one. The corresponding interaction is

$$\mathcal{L}_{int} = g_W \{ (j_\alpha + J_\alpha) W^\alpha + h.c. \} ; \tag{9}$$

where $g_W^2 / M_W^2 = G/\sqrt{2}$. Here we obtain instead of increasing asymptotics for process (7) the constant one, but, for example, the cross-section of the process

$$\nu_\mu + \bar{\nu}_\mu \rightarrow W^+ + W^- ; \tag{10}$$

increases linearly in the same way as (8). The higher orders evidently contain the unremovable divergences.

In spite of some success, achieved in study of the unrenormalizable theories, nobody did really succeed in evaluating higher order corrections, or in obtaining the high energy cross-section asymptotics for the real weak interaction theory (fourfermion or with W-boson) without additional assumptions. There are only some model calculations (see, for example[2]). Therefore, the interest in the renormalizable theories of weak interactions is in full size justified. Such theories are free of the difficulties being discussed, and remain under intensive study during the last several years. This is very interesting region of the theory of the weak (and the electromagnetic) interactions. We shall not discuss these theories in detail, because there are excellent papers and reviews on the item[3]. We try to make clear only the main ideas and discuss the form of interaction, which is obtained here. The main goal to achive while constructing the renormalizable theory is to exclude the rapidly rising amplitudes. This automatically reduces the divergences in the higher orders. Let us take as an example process (10). In the theory with interaction (9) the diagram of fig. 2.

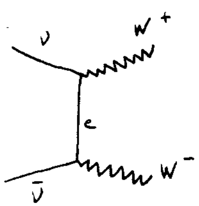

Fig. 2a.

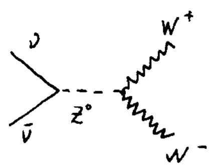

Fig. 2b.

leads to the rising amplitude. However, if one introduces in addition to the charged intermediate bosons W^+ the neutral one Z° , the interaction constants being suitably chosen, the rising part of diagram 2b cancels the same part of diagram 2a. For the process $e^+e^- \to W^+W^-$ it is necessary to take into account also the photon exchange.

These guidening considerations may be realized in the theory, where charged vector boson W^+ , neutral Z° and photons exist.
The cancelation to be performed in the proper way requires a symmetry between them. Such an approach is a ground stone in the Salam-Weinberg model[3]. Now we will consider the type of weak interaction to which this approach leads. It is noticing that cancelation of increasing parts of the amplitude may be achieved by introducing heavy leptons, as it was done in the Georgy-Glashow model[4]. We will not treat this model here.

In the Salam-Weinberg model there is introduced a doublet of left-hand particles for leptons (e.g., for e, ν_e)

$$\psi_L = \frac{1+\gamma_5}{2} \begin{pmatrix} \nu_e \\ e \end{pmatrix} ; \qquad (11)$$

and a singlet which is a right-hand electron

$$\psi_R = \frac{1-\gamma_5}{2} e . \qquad (12)$$

As was mentioned four vector particles are needed. They will be chosen in the following way: triplet

$$\vec{W}_\mu = (W_\mu^+, W_\mu^-, Z_\mu \cos\theta + A_\mu \sin\theta); \tag{13}$$

and singlet

$$B_\mu = -Z_\mu \sin\theta + A_\mu \cos\theta . \tag{14}$$

It is quite natural that neutal particles mix up, as they do not differ in quantum numbers. Lepton interaction with the vector boson may be presented in the form

$$\mathcal{L}_{int} = \bar{\Psi}_L \gamma^\mu (g \vec{\tau} \vec{W}_\mu - g' B_\mu) \Psi_L - g'' \bar{\Psi}_R \gamma^\mu \Psi_R B_\mu . \tag{15}$$

First of all we are to obtain electromagnetic interaction for electron. From (13), (14), (15) we obtain that the expression

$$\bar{e}_L \gamma^\mu e_L A_\mu (-g \sin\theta - g' \cos\theta) - \bar{e}_R \gamma^\mu e_R A_\mu g'' \cos\theta ;$$

should be equal to

$$e (\bar{e}_L \gamma^\mu e_L + \bar{e}_R \gamma^\mu e_R) A_\mu \quad ;$$

whereof

$$g \sin\theta + g' \cos\theta = g'' \cos\theta = -e . \tag{16}$$

Neutrino should not have any electromagnetic interaction. Thus we have

$$g \sin\theta - g' \cos\theta = 0 , \qquad \frac{g'}{g} = tg\,\theta . \tag{17}$$

From (16) we will have

$$g'' = 2g' , \qquad e = -2g\sin\theta = -\frac{2gg'}{\sqrt{g^2+g'^2}} . \tag{18}$$

Having considered the part related to $W^\pm$ we will find that g_W defined in (9) is

$$g_W = \frac{g}{\sqrt{2}} .$$

Whereof and from (9) we can determine the mass M_W

$$M_W = \sqrt{\frac{g^2\sqrt{2}}{2G}} = \frac{1}{2\sqrt{2}\,|\sin\theta|} \sqrt{\frac{e^2\sqrt{2}}{G}} = \frac{37\ \text{Gev}}{|\sin\theta|} . \tag{19}$$

The mass of neutral Z-particle can also be easily determined, if we consider mixing up of W_3 and B particles.

$$M_Z = \frac{73\ \text{Gev}}{|\sin 2\theta|} = \frac{M_W}{|\cos\theta|} .$$

As the result we come to the Lagrangian of weak interaction

$$\frac{g}{\sqrt{2}} \left(\bar{e} \gamma^\mu (1+\gamma_5) \nu_e W_\mu + h.c. \right) + \frac{g}{2\cos\theta} \bar{\nu}_e \gamma^\mu (1+\gamma_5) \nu_e Z_\mu^0 +$$

$$+ \frac{g}{2\cos\theta} \bar{e} \gamma^\mu \left[(1+\gamma_5)(\sin^2\theta - \cos^2\theta) + (1-\gamma_5) 2 \sin^2\theta \right] e Z_\mu^0 +$$

$$+ (e, \nu_e \rightarrow \mu, \nu_\mu) \quad ;$$

in its turn it effectively leads to the following effective Lagrangian of ν_μ interaction with electrons[x)]

$$\mathcal{L}_{int} = \frac{G}{\sqrt{2}} \bar{\nu}_\mu \gamma_\alpha (1+\gamma_5) \nu_\mu \; \bar{e} \gamma^\alpha \left[(1+\gamma_5)(-\tfrac{1}{2} + \sin^2\theta) + (1-\gamma_5)\sin^2\theta \right] e . \qquad (20)$$

As is easily seen we obtain the following cross sections for ν_μ and $\bar{\nu}_\mu$ scattering on electrons.

$$\sigma_{\nu_\mu e} = \frac{2G^2}{\pi} m_e E \left[(\sin^2\theta - \tfrac{1}{2})^2 + \tfrac{1}{3}\sin^4\theta \right] ; \qquad (21)$$

$$\sigma_{\bar{\nu}_\mu e} = \frac{2G^2}{\pi} m_e E \left[\tfrac{1}{3}(\sin^2\theta - \tfrac{1}{2})^2 + \sin^4\theta \right] .$$

The experimental data available for the present moment /5/

$$0.03 \cdot 10^{-41} \frac{E}{Gev} \, cm^2 \leq \sigma_{\bar{\nu}_\mu e} \leq 0.29 \cdot 10^{-41} \frac{E}{Gev} \, cm^2 ;$$

$$\sigma_{\nu_\mu e} \leq 0.3 \cdot 10^{-41} \frac{E}{Gev} \, cm^2 , \qquad (22)$$

x) Here and after we will consider $s \ll M_W^2, M_Z^2$, that is valid for the now existing accelerators, if the masses are of the order of (19).

put limitations on $\sin^2\theta$

$$0.1 \leq \sin^2\theta \leq 0.45 .$$

Further investigation of these processes is of great interest to check the scheme of weak interactions. As will be discussed below, not only the theories of the Salam-Weinberg type may lead to such processes.

The basic neutrino experiments are performed with nucleon targets. Therefore we will consider now the type of interactions of leptonic currents with quarks we come to using the Salam-Weinberg model. In full analogy with the leptonic case we first of all should define the left-hand doublet.

$$\psi_L = \frac{1+\gamma_5}{2} \begin{pmatrix} p \\ n' \end{pmatrix} , \qquad n' = \cos\alpha_c \, n + \sin\alpha_c \, \lambda ; \qquad (23)$$

and right-hand singlets

$$p_R = \frac{1-\gamma_5}{2} p , \qquad n'_R = \frac{1-\gamma_5}{2} n' , \qquad \lambda'_R = \frac{1-\gamma_5}{2} \lambda' ,$$
$$\lambda' = -\sin\alpha_c \, n + \cos\alpha_c \, \lambda \qquad (24)$$

and

$$\lambda'_L = \frac{1+\gamma_5}{2} \lambda' .$$

Then the interaction will take the following form:

$$\mathcal{L}_{int} = \bar{\psi}_L \gamma^\alpha (g \vec{\tau} \vec{W}_\alpha - g' B_\alpha) \psi_L - g'' \bar{p}_R \gamma^\alpha p_R B_\alpha -$$
$$- g''' \bar{n}'_R \gamma^\alpha n'_R B_\alpha - g^{IV} (\bar{\lambda}'_R \gamma^\alpha \lambda'_R + \bar{\lambda}'_L \gamma^\alpha \lambda'_L) B_\alpha .$$

The requirement that electromagnetic interaction should have the proper form

$$\mathcal{L}_{e.m} = e A_\alpha \left(\bar{p}\gamma^\alpha p \cdot \frac{2}{3} - \bar{n}'\gamma^\alpha n' \frac{1}{3} - \bar{\lambda}'\gamma^\alpha \lambda' \frac{1}{3} \right);$$

results in the following ratio among the constants

$$g' = -\frac{g}{3} tg\theta, \quad g'' = -\frac{4g}{3} tg\theta, \quad g''' = g^{IV} = \frac{2g}{3} tg\theta.$$

Having these ratio at our disposal and bearing in mind the earlier obtained results on the values for the masses of W and Z we will obtain the following effective electromagnetic weak interaction with currents containing neutrinos

$$\begin{aligned} \mathcal{L}_{int} = & \frac{G}{\sqrt{2}} \bar{\nu}_\mu \gamma^\alpha (1+\gamma_5) \mu \left[\bar{p}\gamma_\alpha(1+\gamma_5) n \cos\alpha_c + \bar{p}\gamma_\alpha(1+\gamma_5)\lambda \sin\alpha_c \right] + h.c. + \\ & + \frac{G}{\sqrt{2}} \bar{\nu}_\mu \gamma^\alpha (1+\gamma_5)\nu_\mu \Big\{ \bar{p}\gamma_\alpha(1+\gamma_5) p \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta\right) + \bar{p}\gamma_\alpha(1+\gamma_5) p \left(-\frac{2}{3}\sin^2\theta\right) \\ & + \bar{n}\gamma_\alpha(1+\gamma_5) n \left(-\frac{\cos^2\alpha_c}{2} + \frac{1}{3}\sin^2\theta \right) + \bar{n}\gamma_\alpha(1-\gamma_5) n \frac{1}{3}\sin^2\theta + \\ & -+ \bar{\lambda}\gamma_\alpha(1+\gamma_5)\lambda \frac{\sin^2\alpha_c}{2} + \bar{\lambda}\gamma_\alpha \lambda \frac{2}{3}\sin^2\theta - \frac{\cos\alpha_c \sin\alpha_c}{2} \left(\bar{n}\gamma_\alpha(1+\gamma_5)\lambda + \bar{\lambda}\gamma_\alpha(1+\gamma_5) n \right) \Big\} + \\ & + (\mu, \nu_\mu \to e, \nu_e). \end{aligned} \tag{25}$$

As we see, the charged part of interaction is obtained in the form required, while, in the part with the neutral currents there is a term, that changes the strangeness. Existence of such terms decisevely contradicts the experiment, in particular, a very low probability level of decays with leptonic pair emission[6] :

$$K^+ \to \pi^+ e^+ e^- \qquad \frac{\Gamma}{\Gamma_t} \simeq (2.3 \pm 0.7)\cdot 10^{-7};$$

$$K^+ \to \pi^+ \nu\bar{\nu} \qquad \frac{\Gamma}{\Gamma_t} \leq 0.56 \cdot 10^{-6};$$

$$K_L \to \mu^+ \mu^- \qquad \frac{\Gamma}{\Gamma_t} \simeq \left(12^{+8}_{-4}\right)\cdot 10^{-9};$$

and small value for $\Delta m = m_{K_L} - m_{K_S}$. It should be noted that a similar contradiction exists in effective neutral current (4), that can arise in the fourfermion version due to corrections of higher order.

The currents with $|\Delta S| = 1$ should be excluded. To know the way of doing it, let us pay attention to the reasons that cause their arising. The reason in that n and λ enter the interaction nonsymetrically. In case the neutral currents occur always combination $\bar{n}n + \bar{\lambda}\lambda$, the Cabibbo transformation

$$n \to n\cos\alpha + \lambda\sin\alpha ,$$

$$\lambda \to -n\sin\alpha + \lambda\cos\alpha ;$$

would never lead to crossed terms.

It means that in Lagrangian there should be a symmetry of $n \rightleftarrows \lambda$. It is achieved by introducing the famous forth quark p' with the charge 2/3 and by adding to combinations (23), (24)

$$\Psi'_L = \frac{1+\gamma_5}{2}\begin{pmatrix} p' \\ \lambda' \end{pmatrix}, \quad p'_R = \frac{1-\gamma_5}{2} p' .$$

Then the electromagnetic interaction takes the form

$$\mathcal{L}_{e.m.} = eA_\mu\left[\frac{2}{3}\left(\bar{p}\gamma^\mu p + \bar{p}'\gamma^\mu p'\right) - \frac{1}{3}\left(\bar{n}\gamma^\mu n + \bar{\lambda}\gamma^\mu\lambda\right)\right];$$

and the effective weak interaction does not contain neutral $\Delta S \neq 0$ currents owing to symmetry between λ and n

$$\begin{aligned}\mathcal{L}_{int} = {} & \frac{G}{\sqrt{2}}\bar{\nu}_\mu\gamma^\alpha(1+\gamma_5)\mu\left[\bar{p}\gamma_\alpha(1+\gamma_5)n\cos\alpha_c + \bar{p}\gamma_\alpha(1+\gamma_5)\lambda\sin\alpha_c - \right.\\ & \left. - \bar{p}'\gamma_\alpha(1+\gamma_5)n\sin\alpha_c + \bar{p}'\gamma_\alpha(1+\gamma_5)\lambda\cos\alpha_c\right] + h.c.\\ & + \frac{G}{\sqrt{2}}\bar{\nu}_\mu\gamma^\alpha(1+\gamma_5)\nu_\mu\left\{\left[\bar{p}\gamma^\alpha(1+\gamma_5)p + \bar{p}'\gamma^\alpha(1+\gamma_5)p'\right]\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta\right) + \right.\\ & + \left[\bar{p}\gamma_\alpha(1-\gamma_5)p + \bar{p}'\gamma_\alpha(1-\gamma_5)p'\right]\left(-\frac{2}{3}\sin^2\theta\right) + \\ & + \left[\bar{n}\gamma_\alpha(1+\gamma_5)n + \bar{\lambda}\gamma_\alpha(1+\gamma_5)\lambda\right]\left(-\frac{1}{2} + \frac{1}{3}\sin^2\theta\right) + \\ & + \left[\bar{n}\gamma_\alpha(1-\gamma_5)n + \bar{\lambda}\gamma_\alpha(1-\gamma_5)\lambda\right]\left(\frac{1}{3}\sin^2\theta\right) + (\mu,\nu_\mu \to e,\nu_e).\end{aligned} \qquad (26)$$

Note that if a similar operation is performed in the fourfermion model, neutral currents with $\Delta S \neq 0$ will be excluded from the Lagrangian, and instead of (4) we will have

$$\mathcal{L}_{int} = 2G\bar{\nu}_\mu\gamma^\alpha(1+\gamma_5)\nu_\mu\left[\bar{p}\gamma_\alpha(1+\gamma_5)p + \bar{p}'\gamma_\alpha(1+\gamma_5)p' + \bar{n}\gamma_\alpha(1+\gamma_5)n + \bar{\lambda}\gamma_\alpha(1+\gamma_5)\lambda\right]. \qquad (27)$$

Interaction (27) (as well as (26)) results in neutral neutrino reactions

$$\begin{aligned}\nu_\mu + \mathcal{N} &\to \nu_\mu + X(\Delta S=0);\\ \bar{\nu}_\mu + \mathcal{N} &\to \bar{\nu}_\mu + X(\Delta S=0).\end{aligned} \qquad (28)$$

Here we should note that reaction (28) may be caused not only by the aforementioned reasons but by some other ones. First of all a possibility of phenomenological introduction of neutral currents has been discussed since long ago. In this case a great variety is possible and these versions do not require an introduction of p'. The idea of subscribing reactions (28) to the electromagnetic interaction of neutrino with the matter is very interesting as well. It means that neutrino has an electromagnetic radius[7,8] and it results to appearance of vertex of neutrino interaction with electromagnetic field

$$\frac{e\langle r^2\rangle}{6}q^2\,\bar{\nu}_\mu\gamma^\alpha(1+\gamma_5)\nu_\mu A_\alpha .$$

In our consideration of effective neutrino interaction with matter we come to a Lagrangian

$$\mathcal{L}_{int} = \frac{e^2\langle r^2\rangle}{6}\bar{\nu}_\mu\gamma^\alpha(1+\gamma_5)\nu_\mu\left[\frac{2}{3}\bar{p}\gamma_\alpha p - \frac{1}{3}\bar{n}\gamma_\alpha n - \frac{1}{3}\bar{\lambda}\gamma_\alpha\lambda - \bar{e}\gamma_\alpha e\right]. \qquad (29)$$

The experimental consequences of the assumption will be treated below alongside with the consequences of other possibilities. Here we will briefly deal with the possible values for the magnitude $\langle r^2\rangle$. As is seen from (29), in order neutral reaction (28) should have a probability comparable with the usual one, it is necessary that

$$\langle r^2 \rangle \simeq \frac{G}{e^2} . \qquad (30)$$

If in the fourfermion version we estimate $\langle r^2 \rangle$ from the simplest diagram presented in fig. 3.

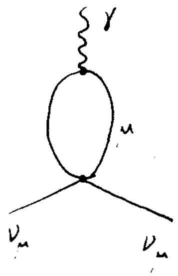

Fig. 3.

then we will obtain a divergent result

$$\langle r_\nu^2 \rangle = \frac{G}{2\sqrt{2}\,\pi^2} \log \frac{\Lambda^2}{m^2} \qquad (31)$$

The question is what sense is to be attached to the diverging logarithm. If the effective cut off takes place owing to weak interactions, i.e., $\Lambda^2 \simeq G^{-1}$, then the obtained value for the radius is too small. In ref.[8] it is pointed out that a reasonable value for the radius (30) is obtained in the cut off due to the electromagnetic interactions. In any case, if the experimental data confirm (29) we will have arguments to explain a large value for neutrino radius.

Note that in this case we will not have to introduce the fourth quark p', as the electromagnetic interaction conserves strangeness.

Let us come back to the problem on the forth quark. In the case it does exist, symmetry of strong interactions will then not be described with a broken SU(3) symmetry but with the broken SU(4) symmetry. Here the composition of multiplets widens and new charmed particles arise. These particles were thoroughly considered in rewiews[9] therefore we will not take this problem in detail here. Here we will present only quark composition of some of charmed particles as we will need it further on. Vector and pseudoscalar particles are not any longer a representation $8+1$ of SU(3) group, but are in representation $15+1$ of SU(4) group. 7 extra particles arising here are the following (C quantum number, charm)

$$\left.\begin{array}{l} D^+ = (\bar{n}\,p') \\ D^0 = (\bar{p}\,p') \end{array}\right\} I = \frac{1}{2},\ S = 0,\ C = 1; \qquad (32)$$

$$F^+ = (\bar{\lambda}\,p') \quad I = 0,\ S = +1,\ C = 1.$$

There are also antiparticles $\bar{D}$ and $\bar{F}$ as well as the state $(\bar{p}'p')$. There are reasons to interpret this state as newly discovered $\psi(3100)$ particle[10]. Such an identification allows us to estimate the masses of D and F mesons. For preudoscalar and vector particles the obtained values are 2 - 2.3 GeV.

The forth quark leads to a widening of the multiplet of the barions with the spin 1/2 from 8 upto 20. Here is a simplest example of new particles.

$$\left.\begin{aligned} C_1^{++} &= (p'pp) \\ C_1^{+} &= \left(p' \frac{pn+np}{\sqrt{2}}\right) \\ C_1^{0} &= (p'nn) \end{aligned}\right\} I=1,\ S=0,\ C=1\ ; \qquad (33)$$

$$C_0^{+} = \left(p' \frac{pn-np}{\sqrt{2}}\right) \qquad I=0,\ S=0,\ C=1.$$

The estimations for the masses of charmed barions are less definite and vary within the limits from 2 up to 5 GeV.

II. NEUTRINO REACTION DYNAMICS

Neutrino reactions on nucleons result in production of some hadronic state. Quasielastic reactions at high energies comprise now a small fraction of cross section. Therefore the very first thing studied in neutrino reactions is inclusive characteristics: total cross sections and distributions in variables independent of the details of hadronic state. Nevertheless these data turn out to carry a very usefull and profound information. Before treating the models, that describe neutrino reactions, we will remind you, of the cross section for neutrino reaction on a point particle (e.g.,on electron). As an example we will choose interaction of ν_μ with some particle b

$$\mathcal{L}_{int} = \xi \frac{G}{\sqrt{2}} \bar{\nu}_\mu \gamma^\alpha (1+\gamma_5) \nu_\mu \, \bar{b} \gamma_\alpha (1 \pm \gamma_5) b \, . \qquad (34)$$

Here one should bear in mind that in transition from ν_μ to $\bar{\nu}_\mu$ the left-hand particle is replaced with the right-hand one, i.e., $1+\gamma_5$ effectively transforms into $1-\gamma_5$. As is easily seen the expression for cross sections depends on either the signs in the first and second brackets coinside or not. The values belonging to the first case will be designted as "even" and those belonging to the second one as odd. Then if the momenta are prescribed to the particles as indicated in fig. 4.

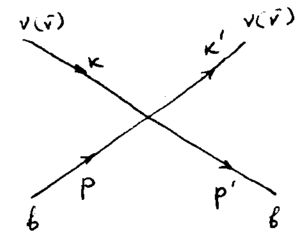

Fig. 4.

the differential cross section in the c.m.s. will take the form $(s=(p+k)^2)$

$$\left(\frac{d\sigma}{d\cos\theta}\right)_{even} = \xi^2 \frac{G^2}{2\pi} s \quad ;$$

$$\left(\frac{d\sigma}{d\cos\theta}\right)_{odd} = \xi^2 \frac{G^2}{2\pi} s \frac{(pk')^2}{(pk)^2} .$$

It is convenient to introduce instead of $\cos\theta$ an invariant variable

$$y = \frac{(pq)}{(pk)} = \frac{(p, k-k')}{(pk)} = 1 - \frac{(pk')}{(pk)} .$$

In the c.m.s.

$$y = \frac{1}{2}(1+\cos\theta).$$

Thus the expressions for the cross sections are written in the following way

$$\left(\frac{d\sigma}{dy}\right)_{even} = \xi^2 \frac{G^2}{\pi} s ;$$

$$\left(\frac{d\sigma}{dy}\right)_{odd} = \xi^2 \frac{G^2}{\pi} s (1-y)^2 ; \qquad (35)$$

and y changes from 0 up to 1. As y is an invariant variable, we do not need to care about the reference system. These formulae in particular give expressions (21) for cross sections of scattering on electron in the Salam-Weinberg model.

Let us consider a so-called quark parton model /12/ so as to proceed to the description of neutrino reactions on nucleons. It is known that in the quark model /12/ nucleons are of the following composition

$$P = (ppn) ; \qquad N = (nnp) .$$

Besides we may assume in P and N there are some $\bar{p}p$, $\bar{n}n$, and $\bar{\lambda}\lambda$ pairs (and $\bar{p}'p'$ if they exist). It is assumed that in the reference system, where nucleon momentum tends to infinity, $p\to\infty$ the transverse components of quark momentum inside nucleon may be neglected, and the longitudinal momentum is distributed among partons with density $q(x)$, where $p_q = xp$. Then in each nucleon there will be several distributions

$$P: \quad p_1(x), \; n_1(x), \; \bar{p}_1(x), \; \bar{n}_1(x), \; \lambda_1(x), \; \bar{\lambda}_1(x) ;$$

$$N: \quad p_2(x), \; n_2(x), \; \bar{p}_2(x), \; \bar{n}_2(x), \; \lambda_2(x), \; \bar{\lambda}_2(x) . \qquad (36)$$

Note, as during transition from proton to neutron p is replaced with n , then

$$
\begin{aligned}
&p_1(x) = n_2(x) = d(x), \quad \bar{p}_1(x) = \bar{n}_2(x) = \bar{d}(x), \\
&n_1(x) = p_2(x) = u(x), \quad \bar{p}_2(x) = \bar{n}_1(x) = \bar{u}(x), \\
&\lambda_1(x) = \lambda_2(x) = s(x), \\
&\bar{\lambda}_1(x) = \bar{\lambda}_2(x) = \bar{s}(x).
\end{aligned}
\tag{37}
$$

As the result we have 6 distribution functions at our disposal, besides in the parton model it is assumed that;

1) Reactions on separate quarks proceed uncoherently;

2) The quarks are point ones (formula (35) may be used).

3) Effective masses of quarks are small and the quarks may be treated as "almost free".

Then the neutrino reactions will follow the scheme in fig. 5.

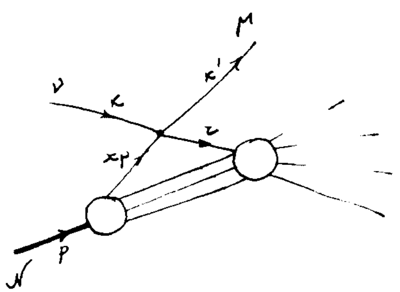

Fig. 5.

In order to clarify, in what way the variable x is connected with the kinematic variables we should consider the energy-momentum conservation in the leptonic vertex

$$
\begin{aligned}
xp + k &= z + k', \\
xp + q &= z, \\
q &= k - k'.
\end{aligned}
$$

Having calculated the invariant mass squared, we will obtain

$$(xp + q)^2 = z^2,$$

$$(xp)^2 + 2x(pq) + q^2 = z^2$$

As $(xp)^2 \simeq z^2 \simeq m_q^2$ (according to assumption 3) then

$$x = -\frac{q^2}{2(pq)}, \quad 0 < x < 1. \tag{38}$$

Let us now use the expression for cross sections (35) and calculate the distributions $d^2\sigma/dx\,dy$ for various processes. Here we must bear in mind (we mean the charged currents $\sin\alpha_c$ being neglected), that according to (1)-(3) the following reactions take place

$$\nu_\mu + n \to \mu^- + p,$$

$$\nu_\mu + \bar{p} \to \mu^- + \bar{n}$$

$$\bar{\nu}_\mu + p \to \mu^+ + n\,,$$
$$\bar{\nu}_\mu + \bar{n} \to \mu^+ + \bar{p}\,. \tag{39}$$

With account of the charge symmetry (37) we will obtain the cross section for different processes in the lab.system. Here it is worth noticing that the variables x and y have the following form in the lab. system

$$x = \frac{2E_\nu E_\mu \sin^2\frac{\theta}{2}}{M E_h}\,,$$
$$y = \frac{E_h}{E_\nu} \tag{40}$$

where E_ν, E_μ, E_h are neutrino, muon and summed hadron energies respectively, and Θ is scattering angle.

1) $\nu_\mu + P \to \mu^- + X$

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu 2x \left(u(x) + (1-y)^2 \bar{d}(x)\right);$$

2) $\nu_\mu + N \to \mu^- + X$

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu 2x \left(d(x) + (1-y)^2 \bar{u}(x)\right);$$

3) $\bar{\nu}_\mu + P \to \mu^+ + X$

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu 2x \left(d(x)(1-y)^2 + \bar{u}(x)\right);$$

4) $\bar{\nu}_\mu + N \to \mu^+ + X$ (41)

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu 2x \left(u(x)(1-y)^2 + \bar{d}(x)\right).$$

As a rule the experiments are performed with matter, e.g., iron, where the number of protons and neutrons is approximately equal. Then the averaged cross section for nucleon $\mathcal{N}$ will be

1) $\nu_\mu + \mathcal{N} \to \mu^- + X^-$

$$\frac{d\sigma}{dx\,dy} = \frac{G^2}{\pi} E_\nu M x \left[(u(x) + d(x)) + (1-y)^2 (\bar{u}(x) + \bar{d}(x))\right];$$

2) $\bar{\nu}_\mu + \mathcal{N} \to \mu^+ + X$ (42)

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu x \left[(u(x) + d(x))(1-y)^2 + (\bar{u}(x) + \bar{d}(x))\right].$$

In the simplest quark model, we assume, that antiquarks may be neglected as compared with quarks. Then x-distributions for neutrino and antineutrino are identical and for the ratio of the total cross sections for $\bar{\nu}_\mu$ and ν_μ we will obtain

$$\frac{\sigma(\bar{\nu}_\mu)}{\sigma(\nu_\mu)} = \frac{\int_0^1 dy(1-y)^2}{\int_0^1 dy} = \frac{1}{3}. \qquad (43)$$

The experimental value for this ratio is /13/

$$\frac{\sigma(\bar{\nu}_\mu)}{\sigma(\nu_\mu)} = 0.36 \pm 0.05 \qquad (44)$$

As we see the agreement with the experiment is good. Hence we really may neglect $\bar{q}(x)$ as compared with $q(x)$, A study on y-distribution in neutrino reactions points to the same fact. From experiment we obtain $(1-y)^2$ for $\bar{\nu}_\mu$ and 1 for ν_μ within the error bars /13/. Definition of quark charge from comparison of the data on neutrino reactions and deep inelastic electroproduction also supports the simplest quark model. The ratio

$$(Q_p)^2 + (Q_n)^2 = \frac{4}{9} + \frac{1}{9} = \frac{5}{9};$$

is in a good agreement with the available data. Then all the data provide a surprisingly nice agreement*). Note, that

*) We will speak on some deviations at superhigh energies later on.

from the data we get limitations on the fraction of antiquarks in nucleon

$$\frac{\int_0^1 x(\bar{u}(x) + \bar{d}(x))dx}{\int_0^1 x(u(x) + d(x))dx} < 0.05. \qquad (45)$$

Let us now treat more general expressions for cross sections of neutrino deep inelastic processes. Summing over all the hadronic states brings us to the expression, corresponding to fig. 6.

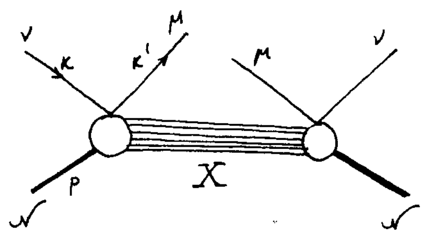

Fig. 6.

Here the cross sections turn out to be equal to

$$\frac{d^2\sigma^{\nu,\bar{\nu}}}{dx\,dy} = \frac{G^2}{2\pi} y\left[K_\alpha K'_\beta + K_\beta K'_\alpha - g_{\alpha\beta}(KK') \pm i\varepsilon_{\alpha\beta\mu\nu} K^\mu K'^\nu\right] \cdot \qquad (46)$$

$$\cdot W_{\alpha\beta}^{\nu,\bar{\nu}};$$

where the hadronic part

$$W_{\alpha\beta}^{\nu,\bar\nu} = \frac{1}{8\pi}\sum_{spin}' \int d^4x\, e^{iqx} \langle p | [\, J_\alpha^\mp(x),\, J_\beta^\pm(0)] | p\rangle \,; \tag{47}$$

depends on momenta p and $q = k - k'$ and therefore may be decomposed in invariant functions in the following way

$$W_{\alpha\beta}^{\nu\bar\nu}(q,p) = \left(-g_{\alpha\beta} + \frac{q_\alpha q_\beta}{q^2}\right) W_1^{\nu,\bar\nu} + \left(p_\alpha - \frac{(pq)q_\alpha}{q^2}\right)\left(p_\beta - \frac{(pq)q_\beta}{q^2}\right) W_2^{\nu,\bar\nu} -$$

$$- \frac{i}{2}\varepsilon_{\alpha\beta\sigma\rho}\, p^\sigma q^\rho\, W_3^{\nu,\bar\nu} + q_\alpha q_\beta W_4^{\nu,\bar\nu} + \tag{48}$$

$$+ (p_\alpha q_\beta + q_\alpha p_\beta) W_5^{\nu,\bar\nu} + i(p_\alpha q_\beta - q_\alpha p_\beta) W_6^{\nu,\bar\nu}.$$

Taking into account, that multiplication of a leptonic bracket by q_α brings us to 0 muon mass neglected, we will obtain

$$W_{\alpha\beta}^{\nu,\bar\nu} = -g_{\alpha\beta} W_1^{\nu,\bar\nu} + p_\alpha p_\beta W_2^{\nu,\bar\nu} - \frac{i}{2}\varepsilon_{\alpha\beta\sigma\rho}\, p^\sigma q^\rho W_3^{\nu,\bar\nu}; \tag{49}$$

then the final expression for the cross section is

$$\frac{d^2\sigma^{\nu,\bar\nu}}{dxdy} = \frac{G^2 s'}{2\pi}\left\{ y^2 x W_1^{\nu,\bar\nu}(\nu,q^2) + (1-y)\nu W_2^{\nu,\bar\nu}(\nu,q^2) \mp x\left(y - \frac{y^2}{2}\right)\nu W_3^{\nu,\bar\nu}(\nu,q^2)\right\}; \tag{50}$$

where $\nu = (pq)$.

Formfactors $W_1, \nu W_2, \nu W_3$ are dependent on momenta p and q and it means that on two invariant variables ν and q^2 as well. These three functions are dimensionless, therefore under assumption on scale invariance they may depend on the ratio of q^2 and ν only, i.e., on $x = -q^2/2\nu$. Then (50) may be rewritten in the form

$$\frac{d^2\sigma}{dxdy} = \frac{G^2 s'}{2\pi}\left\{ y^2 x F_1(x) + (1-y) F_2(x) \mp x\left(y - \frac{y^2}{2}\right) F_3(x)\right\}. \tag{51}$$

For a point particle we have (see (35))

$$F_1 = \frac{F_2}{2x} = -\frac{F_3}{2} = \delta(1-x).$$

For a simple quark model the ratio between F_i is the same, and, e.g., for the proton (see (4))

$$F_1^\nu = \frac{F_2^\nu}{2x} = -\frac{F_3^\nu}{2} = u(x). \tag{52}$$

For the quark-parton model with account of antiquarks (for protons too)

$$F_1 = \frac{F_2}{2x} = u(x) + \bar d(x)\,; \tag{53a}$$

$$F_3 = -2(u(x) - \bar{d}(x)) . \tag{53b}$$

Ratio (53a) is called the Callan-Gross relation and it follows from the fact that partons have spin 1/2.

Indeed the general analysis with account of possible deviations from the scale invariance should be performed with the help of representation (50). However the consequences of the parton model, or it is just the same, of scale invariance and the Callan-Gross relation are in a good agreement with experiment, thus our further reasonings will be in this particular language.

Inclusive reactions where the final hadronic state has a strangeness are very important for check of weak interaction structure. The following neutrino reactions with changing strangeness may take place on quarks

$$\begin{aligned} &\bar{\nu}_\mu + p \to \mu^+ + \lambda , \\ &\bar{\nu}_\mu + \bar{\lambda} \to \mu^+ + \bar{p} , \\ &\nu_\mu + \bar{p} \to \mu^- + \bar{\lambda} , \\ &\nu_\mu + \lambda \to \mu^- + p . \end{aligned} \tag{54}$$

And by no means the selection rule $\Delta S = \Delta Q$ is realized here. Therefore in antineutrino and neutrino reactions the states with $S = -1$ and $S = +1$ respectively may occur. Following the method presented above from (35) and (37) we will obtain

$$\begin{aligned} &1)\ \bar{\nu}_\mu + P \to \mu^+ + (S = -1) , \\ &\frac{d^2\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} M E_\nu 2x\left[d(x)(1-y)^2 + \bar{s}(x)\right] ; \\ &2)\ \bar{\nu}_\mu + N \to \mu^+ + (S = -1) , \\ &\frac{d^2\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} M E_\nu 2x\left[u(x)(1-y)^2 + \bar{s}(x)\right] ; \\ &3)\ \nu_\mu + P \to \mu^- + (S = +1) , \\ &\frac{d^2\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} M E_\nu 2x\left[\bar{d}(x)(1-y)^2 + s(x)\right] ; \\ &4)\ \nu_\mu + N \to \mu^- + (S = +1) , \\ &\frac{d^2\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} M E_\nu 2x\left[\bar{u}(x)(1-y)^2 + s(x)\right] . \end{aligned} \tag{55}$$

For the reaction going with matter we have

$$\begin{aligned} &1)\ \bar{\nu}_\mu + \mathcal{N} \to \mu^+ + (S = -1) , \\ &\frac{d^2\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} M E_\nu x\left[(u(x) + d(x))(1-y)^2 + 2\bar{s}(x)\right] ; \\ &2)\ \nu_\mu + \mathcal{N} \to \mu^- + (S = +1) , \end{aligned} \tag{56a}$$

$$\frac{d\sigma}{dx\,dy} = \sin^2\alpha_c \frac{G^2}{\pi} ME_\nu x \left[(\bar{d}(x) + \bar{u}(x))(1-y)^2 + 2s(x)\right]; \quad (56b)$$

As we see in the simple quark model only the first reaction takes place and the ratio of its cross section to the cross section of a nonstrange reaction is

$$\frac{\sigma(\bar{\nu}_\mu + N \to (s=-1))}{\sigma(\bar{\nu}_\mu + N \to (s=0))} = \sin^2\alpha_c = 0.05. \qquad (57)$$

It is of great importance to study y dependence in this reaction, as the dependence $(1-y)^2$ was obtained under assumption on a precise $V-A$ variant in $\bar{\lambda}p$ current, though we do not have any experimental data at present confirming this fact. The second reaction is also of interest, as the small quantities are directly measured here. The probability for such a process should be very small. Indeed if we assume $s(x) \simeq \bar{u}(x) \simeq \bar{d}(x)$ and use the estimation (45)

$$\frac{\sigma(\nu_\mu + N \to (s=+1))}{\sigma(\nu_\mu + N \to (s=0))} < \sin^2\alpha_c\, 0.05 = 2.5\cdot 10^{-3}. \qquad (58)$$

Note that in ν_μ reactions we mean a more probable pair production of strange particles with a total zero strangeness.

Let us now discuss muonless processes. For the Weinberg-Salam model from (26) in the framework of the simple quark model we will obtain

1) $\nu_\mu + p \to \nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} ME_\nu 2x \left\{ d(x)\left[\left(\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta\right)^2 + (1-y)^2 \tfrac{4}{9}\sin^4\theta\right] + u(x)\left[\left(\tfrac{1}{2} - \tfrac{1}{3}\sin^2\theta\right)^2 + (1-y)^2\tfrac{1}{9}\sin^4\theta\right]\right\};$$

2) $\nu_\mu + N \to \nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} ME_\nu 2x \left\{ u(x)\left[\left(\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta\right)^2 + (1-y)^2 \tfrac{4}{9}\sin^4\theta\right] + d(x)\left[\left(\tfrac{1}{2} - \tfrac{1}{3}\sin^2\theta\right)^2 + (1-y)^2\tfrac{1}{9}\sin^4\theta\right]\right\}; \qquad (59)$$

3) $\bar{\nu}_\mu + p \to \bar{\nu}_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} ME_\nu 2x \left\{ d(x)\left[(1-y)^2\left(\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta\right)^2 + \tfrac{4}{9}\sin^4\theta\right] + u(x)\left[(1-y)^2\left(\tfrac{1}{2} - \tfrac{1}{3}\sin^2\theta\right)^2 + \tfrac{1}{9}\sin^4\theta\right]\right\};$$

4) $\bar{\nu}_\mu + N \to \bar{\nu}_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} ME_\nu 2x \left\{ u(x)\left[(1-y)^2\left(\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta\right)^2 + \tfrac{4}{9}\sin^4\theta\right] + d(x)\left[(1-y)^2\left(\tfrac{1}{2} - \tfrac{1}{3}\sin^2\theta\right)^2 + \tfrac{1}{9}\sin^4\theta\right]\right\};$$

For matter we obtain

1) $\nu_\mu + N \to \nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu x\{d(x) + u(x)\}\left[\frac{1}{2} - \sin^2\theta + \frac{5}{9}\sin^4\theta + (1-y)^2\frac{5}{9}\sin^4\theta\right];$$

$$\tag{60}$$

2) $\bar\nu_\mu + N \to \bar\nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{G^2}{\pi} M E_\nu x\left(d(x) + u(x)\right)\left[\left(\frac{1}{2} - \sin^2\theta + \frac{5}{9}\sin^4\theta\right)(1-y)^2 + \frac{5}{9}\sin^4\theta\right].$$

Having compared it with usual cross section (42) and integrated it over x and y we obtain the values that can experimentally be measured.

$$R(\nu) = \frac{\sigma(\nu_\mu + N \to \nu_\mu + X)}{\sigma(\nu_\mu + N \to \mu^- + X)} = \frac{1}{2} - \sin^2\theta + \frac{20}{27}\sin^4\theta\ ;$$

$$\tag{61}$$

$$R(\bar\nu) = \frac{\sigma(\bar\nu_\mu + N \to \bar\nu_\mu + X)}{\sigma(\bar\nu_\mu + N \to \mu^+ + X)} = \frac{1}{2} - \sin^2\theta + \frac{20}{9}\sin^4\theta.$$

Let us in addition to the Salam-Weinberg model consider other possibilities. First of all the possibility of explaining the muon less processes due to a large electromagnetic radius. From (29) (37) we obtain (the cross sections for neutrino and antineutrino are obviously equal)

1) $\nu_\mu + p \to \nu_\mu + X$, $\bar\nu_\mu + p \to \bar\nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{2}{\pi}\left(\frac{e^2\langle r^2\rangle}{6}\right)^2 M E_\nu 2x\left(\frac{4}{9}d(x) + \frac{1}{9}u(x)\right)\frac{1+(1-y)^2}{4}\ ;$$

2) $\nu_\mu + N \to \nu_\mu + X$, $\bar\nu_\mu + N \to \bar\nu_\mu + X$,

$$\frac{d^2\sigma}{dx\,dy} = \frac{2}{\pi}\left(\frac{e^2\langle r^2\rangle}{6}\right)^2 M E_\nu 2x\left(\frac{4}{9}u(x) + \frac{1}{9}d(x)\right)\frac{1+(1-y)^2}{4}. \tag{62}$$

In the matter we will obtain

$$\nu_\mu(\bar\nu_\mu) + N \to \nu_\mu(\bar\nu_\mu) + X$$

$$\frac{d^2\sigma}{dx\,dy} = \frac{1}{2\pi}\left(\frac{e^2\langle r^2\rangle}{6}\right)^2 M E_\nu x\left(u(x) + d(x)\right)\frac{5}{9}\left(1 + (1-y)^2\right). \tag{63}$$

For the ratio of cross sections (61) we will obtain

$$R(\nu) = \left(\frac{e^2\langle r^2\rangle}{6G}\right)^2\frac{10}{27},$$

$$R(\bar\nu) = \left(\frac{e^2\langle r^2\rangle}{6G}\right)^2\frac{10}{9}, \qquad R(\bar\nu) = 3R(\nu). \tag{64}$$

From a possibility of neutral currents to arise from the higher orders of fourfermion interaction there follows a consequence (see (27))

$$R(\nu) = R(\bar\nu) \tag{65}$$

as in this case a pure $V-A$ variant is valid. The available experimental data are:

1) CERN Bubble chamber Gargamell /14/,/13/

$$R(\nu) = 0.22 \pm 0.03$$

$$R(\bar\nu) = 0.43 \pm 0.12 \tag{66}$$

2) FNAL, colaboration Harward, Persilvania, Visconsin

$$R(\nu) = 0.12 \pm 0.04 ,$$
$$R(\bar{\nu}) = 0.32 \pm 0.08 . \qquad (67)$$

There are also some preliminary data, but their processing is still in progress. Data (66) agree with the Salam Weinberg model, i.e., with (61) when

$$\sin^2\theta \simeq 0.35 . \qquad (68)$$

Data (67) agree with (61) much worse, but they are in a good agreement with (64), when

$$\langle z^2 \rangle \simeq \frac{3G}{e^2} = 1.4 \cdot 10^{-31} cm^2 . \qquad (69)$$

Note that from simple estimation of ref./8/ we get $\langle z^2 \rangle = \frac{6G}{\sqrt{2}e^2}$. Ratio (65) does not agree with the data, therefore we can consider the possibility of explaining neutral processes due to higher orders of fourfermion theory to be excluded. It is worth noticing that when we have the value (69) we obtain the following cross sections for muonic neutrino and antineutrino scattering on electron

$$\sigma(\nu_\mu e) = \sigma(\bar{\nu}_\mu e) = \frac{G^2}{3\pi} m_e E_\nu = 0.28 \cdot 10^{-41} \frac{E}{GeV} cm^2 ; \qquad (70)$$

it lies within the limits of the experimental data (22). Note that at $\sin\theta = 0.35$ in the Salam-Weinberg model according to (21) we obtain

$$\sigma(\nu_\mu e) = 0.1 \cdot 10^{-41} \frac{E}{GeV} cm^2 ;$$

$$\sigma(\bar{\nu}_\mu e) = 0.22 \cdot 10^{-41} \frac{E}{GeV} cm^2 . \qquad (71)$$

Thus the available experimental data allow us to interpret them both in the framework of the Salam Weinberg model (or its modifications) and under assumption on the electromagnetic nature of muonless processes. Let us enumerate the main features, that will help us in our future experiments to distinguish these possibilities. Main prediction of the model with the electromagnetic radius is

$$\sigma(\nu_\mu N \to \nu_\mu X) = \sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X) ,$$
$$R(\bar{\nu}) = 3R(\nu) ; \qquad (72)$$

$$\sigma(\nu_\mu e) = \sigma(\bar{\nu}_\mu e) ; \qquad (73)$$

here all the data are described with one parameter $\langle z^2 \rangle$. Generally speaking ratios (72) and (73) are not fulfilled in the Salam-Weinberg model. Ratio (72) is valid only at $\sin\theta = 0.5$ but then (see (21))

$$\sigma(\nu_\mu e) = \frac{1}{3} \sigma(\bar{\nu}_\mu e) . \qquad (74)$$

Besides these mechanisms differ in y-distributions, as is seen from the corresponding formulae. Hence any clarification of the experimental data in the near future will be considerably helpful in understanding the situation in this branch.

III. ON POSSIBILITIES OF SEARCHING FOR CHARMED PARTICLES IN NEUTRINO REACTIONS

Neutrino reactions are a very convenient tool in the search for hypothetic charmed particles. Indeed in neutrino interactions charm is not conserved and according to(26) the following reactions may take place (on quarks)

$$\begin{aligned} &\nu_\mu + n \to \mu^- + p', \\ &\nu_\mu + \lambda \to \mu^- + p', \\ &\bar\nu_\mu + \bar n \to \mu^+ + \bar p', \\ &\bar\nu_\mu + \bar\lambda \to \mu^+ + \bar p'. \end{aligned} \tag{75}$$

As $n(x) \gg \lambda(x) \simeq \bar n(x) \simeq \bar\lambda(x)$ then such reactions may intensively proceed only in the neutrino beam and be suppressed by the factor of $\sin^2\alpha_c \simeq 0.05$. Here are some examples of some concrete reactions (see (32), (33))

$$\begin{aligned} &\nu_\mu + P \to \mu^- + C_1^{++}; \\ &\nu_\mu + N \to \mu^- + C_{1,0}^{+}, \\ &\nu_\mu + P \to \mu^- + D^+ + P. \end{aligned} \tag{76}$$

It is of interest to note, that the last experiments at FNAL (joint experiment of HPW/16/) carry such an indication of possible production of new particles. These indications are first of all deviations from the predictions of scale invariance and parton model when neutrino and antineutrino energies $>$ 30 GeV, as well as observation of muonic pair production in neutrino and antineutrino interactions. These effects may be explained by production of new particles with

the decay channel probability with muon in the final state of about 10% and the mass within the interval from 2 up to 4 GeV. As the effect of violating the scale invariance is most distinct in antineutrino interactions the mechanism (76) cannot be used for its explanation. However in the same quark language the process (not suppressed by $\sin^2\alpha_c$)

$$\nu_\mu \to \mu^- + p'\bar\lambda ,$$

$$\bar\nu_\mu \to \mu^+ + \bar p'\lambda ;$$

my occur.

And if the systems $(p'\bar\lambda)$ or $(\bar p'\lambda)$ have interacted with the target strongly then the process may become real. Besides if we use the idea of vector dominance then we can present the process as the one following scheme fig. 7.

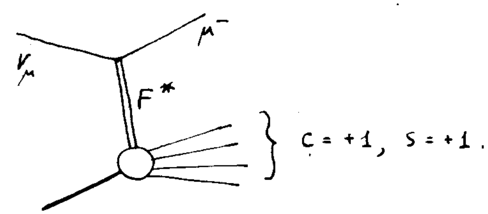

Fig. 7.

In refs./17/ there are presented the estimations that show that it is just the mechanism that may explain the aforementioned FNAL data. Indeed the cross section for such a process is equal for neutrino and antineutrino, therefore the effect manifests itself more strongly in antineutrino interactions. Besides the data are peculiar for a more distinct effect at small momentum transfer q^2. It is also very natural for this machanism, as the state with the mass 2 GeV is exchanged, while the energy here is of order of 100 GeV. Therefore a study on the quasidiffraction processes similar to the one discussed is of high interest. As another example we will point out the process of diffraction production of $\Psi(\approx 100)$ particle in neutral neutrino processes, that may follow the scheme in fig. 8.

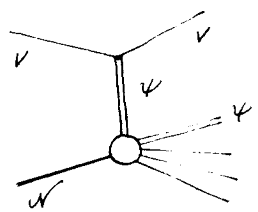

Fig. 8.

If the interpretation of $\psi \equiv (\bar{p}'p')$ is true and the neutral weak current has form (26) then the vector part of $\bar{p}'p'$ current has a multiplier

$$\frac{1}{2} - \frac{3}{4}\sin^2\theta ;$$

that is very small at $\sin^2\theta = 0.35$. On the other hand, in the case of electromagnetic origin of neutral currents, there is not such a smallness and production of ψ in neutral reactions, especially in antineutrino ones, should be considerable. Here it should be noted that the data

from ref. /16/ on muonic parts can hardly be subscribed to the production of ψ as invariant mass distribution of $\mu^+\mu^-$ is smooth.

In conlusion we would like to note that neutrino reactions are of continuously increasing importance in the field of elementary particle physics. In partucular the solution of the problem on validity of gauge theories may be achieved in the neutrino experiments only.

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