ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ
ДУБНА

E2 - 10928

V.M.Dubovik, V.S.Zamiralov

ON POSSIBILITIES OF OBSERVATION OF μ-e TRANSITIONS AND HEAVY NEUTRAL LEPTONS

1977

E2 - 10928

V.M.Dubovik, V.S.Zamiralov*

ON POSSIBILITIES OF OBSERVATION OF μ-e TRANSITIONS AND HEAVY NEUTRAL LEPTONS

Submitted to "Nuclear Physics"

* Institute of Nuclear Physics of the Moscow State University.

Дубовик В.М., Замиралов В.С.

E2 - 10928

О возможностях наблюдения $\mu - e$ -переходов и тяжелых нейтральных лептонов

Даны оценки сечений μ-e -переходов и сечений рождения тяжелых нейтральных лептонов на e^+e^- -кольцах и электронных пучках. Указаны возможности поиска этих лептонов в $\mu^{\pm}$ и $e^{\pm}$ -пучках, а также на e^+e^- -кольцах. Обсуждены поправки к магнитному моменту мюона за счет тяжелых лептонов и некоторые другие эффекты, в том числе с возможным нарушением CP -инвариантности в лептонном секторе.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1977

Dubovik V.M., Zamiralov V.S.

E2 - 10928

On Possibilities of Observation of μ-e Transitions and Heavy Neutral Leptons

We have estimated the cross-sections of the μ-e transitions and of the production of the heavy neutral leptons by e^+e^- collisions and electron beams. A possibility is found to observe the heavy lepton at energies of SPEAR with the luminosity $\mathcal{L} = 10^{32}$ sm^{-2} sec^{-1}. With such a luminosity, it is even possible to observe a single photon of high energy from the decays $N_{1,2} \to \nu_{e,\mu}\ \gamma$ (for SPEAR with the probability $\sim 10^{-6}$ sec^{-1} for PETRA with $\sim 10^{-5}$ sec^{-1}). The weak interaction contribution to the muon magnetic moment is discussed taking into account $N_{1,2}$ and some effects due to a possible CP-violation in the leptonic sector.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1977

1. INTRODUCTION

Recently many authors have pointed out that the existence of heavy neutral leptons can yield the decay rate of $\mu \to e\gamma$ transition close to the experimental upper bound /1/. Many of them (see, e.g., ref. /2/) apply the six-lepton model with two left- and two right-handed doublets

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L ; \begin{pmatrix} N_e \\ e^- \end{pmatrix}_R , \begin{pmatrix} N_\mu \\ \mu^- \end{pmatrix}_R \qquad (1)$$

to explain possible breaking of the lepton number conservation; the weak interactions involving not $N_{e,\mu}$ themselves, but their linear combinations /2/:

$$N_1 = N_e \cos\theta' + N_\mu \sin\theta', \qquad (2)$$
$$N_2 = -N_e \sin\theta' + N_\mu \cos '.$$

In the framework of this model we consider some reactions involving leptons and slightly modify the model as to include the CP-violation into the leptonic sector.

2. ON THE e-μ TRANSITIONS

Let us estimate the e-μ transition rate in two-body and inclusive reactions. Consider first e-μ transition on nucleons (see Fig.1).

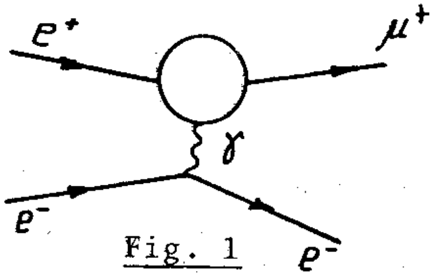

Fig. 1

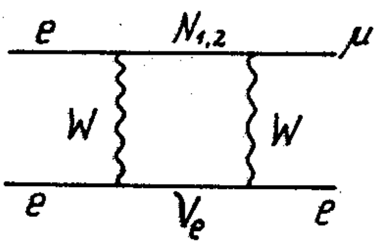

Fig. 1a

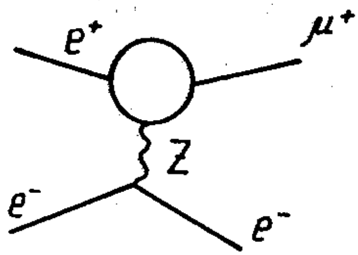

Fig. 1b

We can safely neglect the diagram with virtual photon exchange, as it was done in the case of decay /2/. This is due to the fact that diagram of Fig.1 does not contain terms $\sim q^{-4}$ as there is no transition charge and contains only terms $\sim q^{-2}$. We estimate the cross-section of $\mu^{\pm}$ production in $e^{\pm}$-beam on nucleons to be $\sim 10^{-46}$ cm^2. On heavy nuclei σ amounts to $(10^{-41} \div 10^{-42})$ cm^8. Small cross-sections of this type can become available for experiments only with the very intensive e^--beams.

Let us estimate also the e-μ transition rate on the colliding e^+e^--beams. This process is very suitable kinematically as it is a 2-body reaction and so it is enough to choose those (μe)-pairs, momenta of which lie in the plane of e^+e^--beams. Calculating cross section at energies $E_{\pm} = 15$ GeV (Project PETRA), we arrive at $\sigma \sim 10^{-47}$ cm^2, which is 12 orders of magnitude smaller than the cross-section of (μe)-pair production and practically is not accessible for any reasonable luminosity.

3. ON THE POSSIBILITIES OF $N_{1,2}$ OBSERVATION

Much more realistic is the search for neutral leptons $N_{1,2}$. Discovery of at least one of them would be a strong evidence that the μ-e transition really exists.

The most "pure" reaction seems to be $N_{1,2}$ production in the colliding e^+e^--beams. For the right-handed coupling its angular distribution is isotropic[3]. It is suitable to search for leptonic decay and, in particular, for (μ^+e^-)-pairs (Fig. 2a) and not ($\mu^+\mu^-$) or (e^+e^-) -pairs[4]; the latter being hardly observable due to huge electromagnetic background.

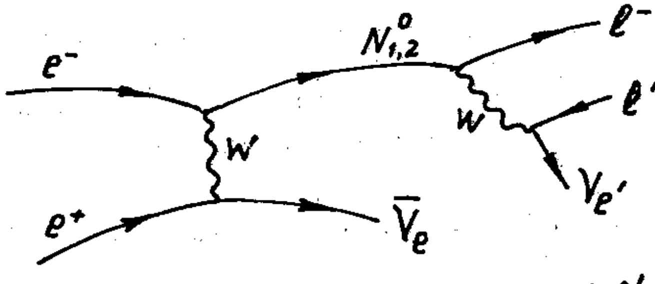

Fig. 2a $(\ell', \ell = \mu, e)$

The characteristic feature of the reaction is the distribution over the collinear angle $\theta_{coll.} = \arccos(\frac{-\vec{p}_\mu \cdot \vec{p}_e}{|\vec{p}_\mu||\vec{p}_e|})$ (Fig. 2b), completely different from the expected one in the electromagnetic production of the pairs $(\mathcal{L}^+\mathcal{L}^-)$ with the subsequent decays $\mathcal{L}^+ \to \mu^+ \nu_\mu \bar{\nu}_{\mathcal{L}}$ and $\mathcal{L}^- \to e^- \bar{\nu}_e \nu_{\mathcal{L}}$ (ref. /5/). Indeed, in the latter case the collinear angle distribution has the maximum about $\theta = 0°$ in the ultrarelativistic limit (Lorentz factor $\gamma \to \infty$), e and μ moving in the

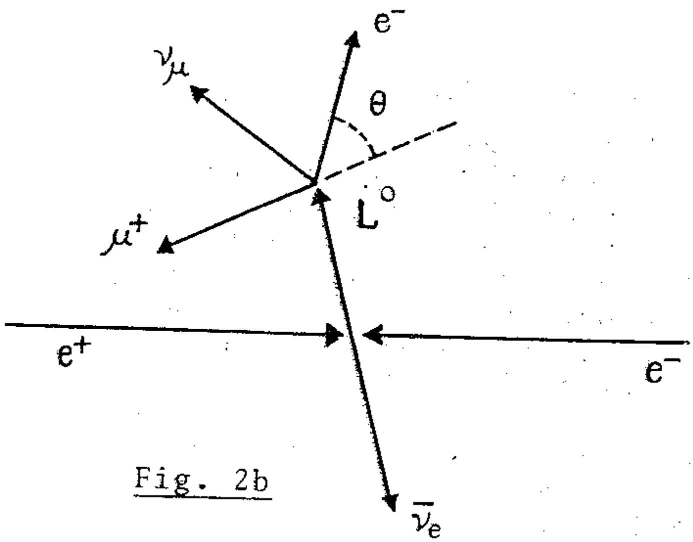

Fig. 2b

opposite directions /6/, while in the weak production of $N_{1,2}$ in the limit $(\gamma \to \infty)$ μ and e move together at $\theta = \pi$. Following /6/ we have considered the normalized distribution

$$\frac{d\Gamma}{d\cos\theta} = \frac{12}{\pi} \frac{1}{(1-\cos\theta)^2} \int_{-1}^{+1} d\cos\theta \int_{-\pi}^{+\pi} d\phi\, \mathcal{F}(\cos\theta_2, \phi), \qquad (3)$$

where

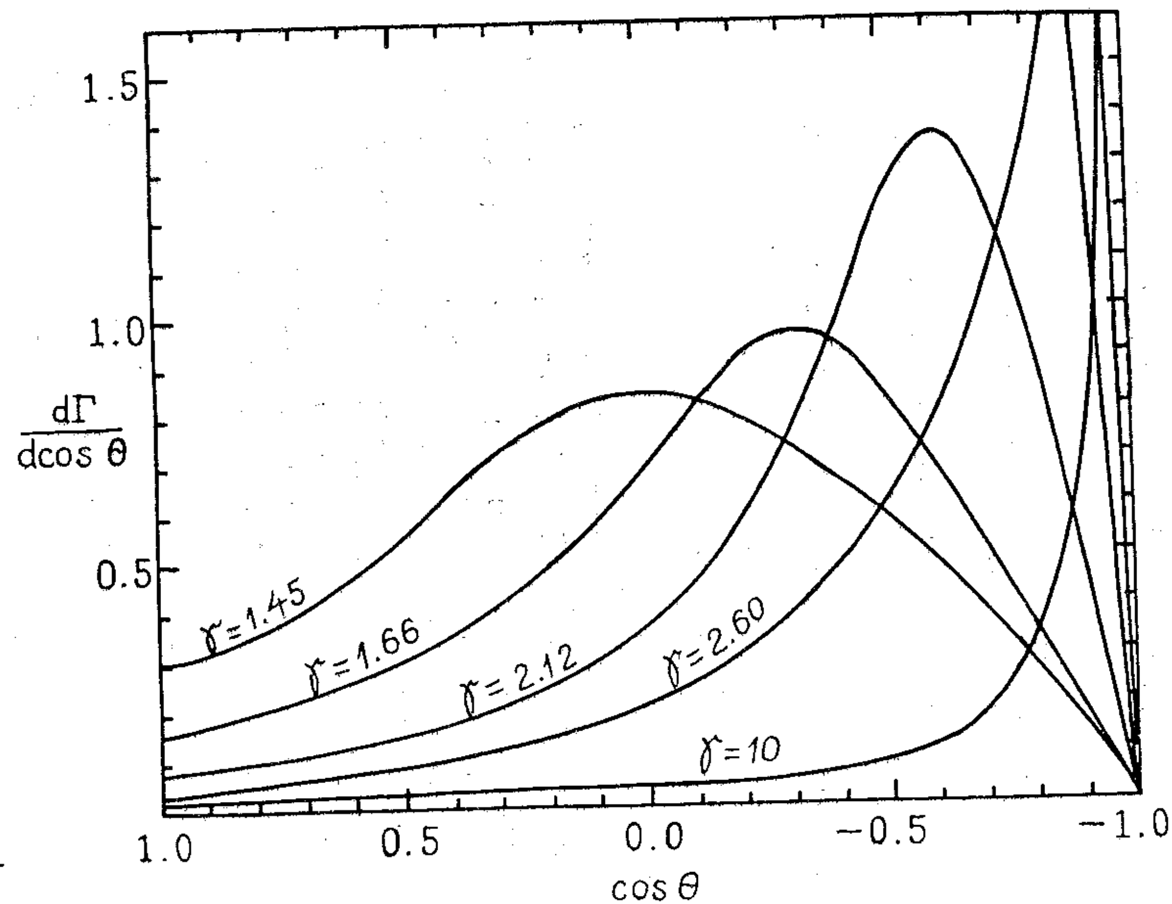

Fig. 2c

$$\mathcal{F} = (10y^2 - 13y + \frac{10}{3}) + (10y^3 - 18y^2 + 8y - 1)\,\ell n(1 - \frac{1}{y}),$$

$$y = \frac{2\gamma^2(1-\beta\cos\theta_1)(1-\beta\cos\theta_2)}{1-\cos\theta},$$

$$-\cos\theta_2 = \cos\theta\cos\theta_1 + \sin\theta\sin\theta_1\cos\phi,$$

and β, γ are the Lorentz factors for $N_{1,2}$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{E^{c.m.}_{N_{1,2}}}{M_{1,2}} = \frac{s + M^2_{1,2}}{2\sqrt{s}\,M_{1,2}}, \quad s = (2E^{c.m.}_{N_{1,2}})^2 .$$

Comparing $\frac{d\Gamma}{d\cos\theta_{coll.}}$ in our case (Fig. 2c) and $\frac{d\Gamma}{d\cos\theta_{coll.}}$ from /5/ (Fig. 1 therein) one can see that the angular distributions of $(\mu^+ e^-)$ production differ drastically. Even for $\gamma = 1.33$ (SPEAR) the distribution of $(\mu^+ e^-)$ pairs from $\mathcal{L}^+\mathcal{L}^-$ has the maximum near $\theta \simeq \pi/6$, while in our case the maximum of the γ distribution is near $\theta \simeq \pi/2$ (Fig. 2c). With increasing γ the maxima go still further shifting to the limit positions $\theta = 0$ and $\theta = \pi$, respectively.

As is seen from Fig. 3 in e^+e^- collision another process is also possible: the production of a single high-energy photon from the decay $N_{1,2} \to \nu_e \gamma$ /3/. Its width is at least α times less than the total width of the $N_{1,2}$ decay. It yields a probability at the level of $\sim 10^{-6}$ sec^{-1} at SPEAR and $\sim 10^{-5}$ at PETRA with $E_{\pm} = 15$ GeV. To observe this process it is necessary to overcome large experimental difficulties concerning background events.

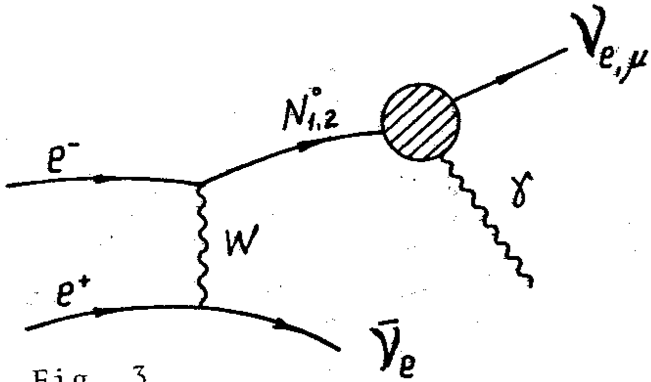

Fig. 3

One can search for heavy neutral leptons $N_{1,2}$ also in inclusive reactions on μ^--and e^- -beams (Fig. 4)

$$(e^- \text{ or } \mu^-) + N \to N_{1,2} + X \quad \longrightarrow \begin{cases} (\mu^{\pm}\ e^{\mp}) \\ \ell^- + \text{hadrons} \\ (\ell^- \ell^+) \end{cases}$$

Cross-sections of these reactions should be comparable at high energies with the cross-sections of inclusive reactions on neutrino beams. In the framework of the model considered one can, in contrast to /4/ ,

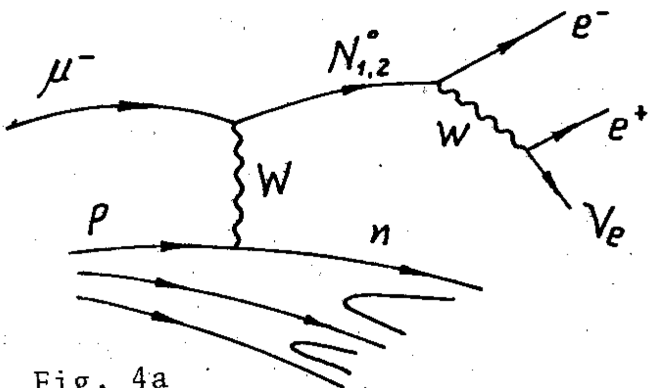

Fig. 4a

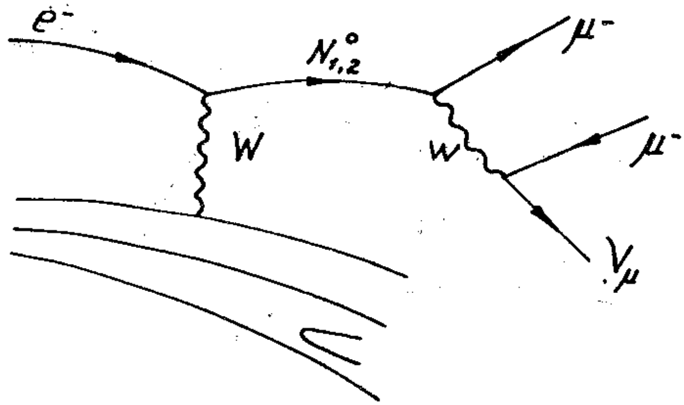

Fig. 4b

mainly concentrate on searching for (e^+e^-)-pairs in the $\mu^\pm$-beams and for $(\mu^+\mu^-)$-pairs in the e^+e^--beams. However, experimentally, it is more easy to obtain (e^+e^-)-pairs from the thin targets, therefore it is better to search for these pairs just in μ^--collisions with heavy nuclei.

We want to stress one point more. The μ^--beams are known to have predominantly the right-handed polarization while the μ^+-beams have predominantly the left-handed polarization. Such a polarization of μ-beams increases the contribution of the right-handed lepton currents into the cross-section, as was indicated in /3/, that is, just the lepton current contribution with the $N_{1,2}$ s. At the same time, conventional weak transitions with the emission of neutrino will be suppressed by the factor $(1-|\vec{P}|)$, where $\vec{P}$ is the value of longitudinal polarization of the μ-beam. Therefore, usual mechanisms of the direct production of (e^+e^-) and $(\mu^+\mu^-)$-pairs, leading to the very rare 3-lepton events[7] are suppressed additionally by kinematical factor.

4. $N_{1,2}$-EFFECTS

As was pointed out in ref.[8] weak contributions to the muon magnetic moment can be essential already when the experimental accuracy is increased by $(1\div 2)$ orders of magnitude. Those authors calculated also the contribution of heavy neutral lepton into the anomalous magnetic moment of muon a_μ in the model of Georgi-Glashow.

We estimate here the weak correction a_μ^w taking into account the exchange by ν_μ and both leptons $N_{1,2}$ (Fig. 5). Up to terms of the order $(M_{1,2}/M_w)^2$ we have:

$$a_\mu^w = \frac{G_F \mu^2}{8\pi^2\sqrt{2}} \frac{10}{3} \times 2 \simeq 7 \cdot 10^{-9} , \quad . \tag{4}$$

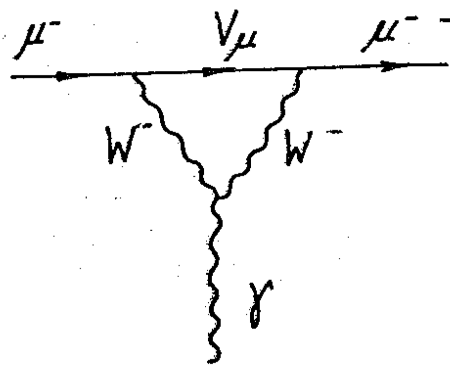

Fig. 5a

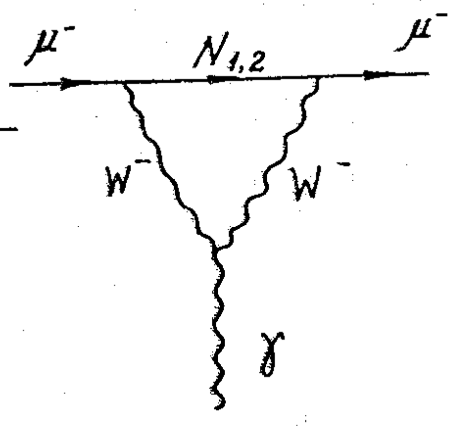

Fig. 5b

which is twice as large as the contribution with the ν_μ -exchange only (Fig.5a) and should be compared with the contribution due to the strong interactions equal to $(60\pm 10)\times 10^{-9}$ [9].

The six-lepton model allows one to introduce CP-violation effects. To recognize this fact, we must write a more general form of the left-handed current allowing $\nu_e - N_e$, $\nu_\mu - N_\mu$ and $N_e - N_\mu$ mixing. The full weak charged leptonic current has in this case generally speaking 10 complex coefficients. The phase factors of lepton wave functions cannot make all of them real. So, one arrives at CP-violating $\mathcal{L}_w$. For the sake of simplicity let us take here only usual left-handed charged currents $(\bar{\nu}_e e^-)$ and $(\bar{\nu}_\mu \mu^-)$ (and their conjugates) and introduce the CP-violation with the help of angle ϕ for the right-handed currents only :

$$N_1 = \alpha N_\mu - \beta N_e, \quad N_2 = \alpha^* N_e + \beta^* N_\mu$$
$$\alpha = \cos\theta'\cos\phi + i\sin\theta'\sin\phi, \quad \beta = \sin\theta'\cos\phi + i\cos\theta'\sin\phi. \tag{5}$$

So all previous parametrizations with the only angle of the Cabibbo type in the lepton sector [2] should be generalized at least to that of (5). The results quoted in [4] appear to depend on more than one parameter and one cannot hope to extract, e.g., θ' of (5) immediately from measurements of $(\mu \to e\gamma)$, (3e) transitions even with the given masses of heavy neutral leptons. An insight of this situation can be given by example of muonium-antimuonium transition. Diagram (Fig.6a) describing this transition is analogous to that of $K^\circ - \bar{K}^\circ$ -transition [10] and can be written with the help of the effective Lagrangian

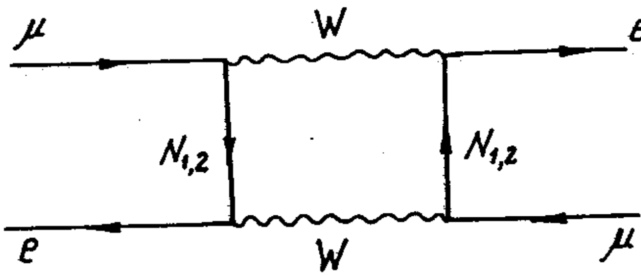

Fig. 6a

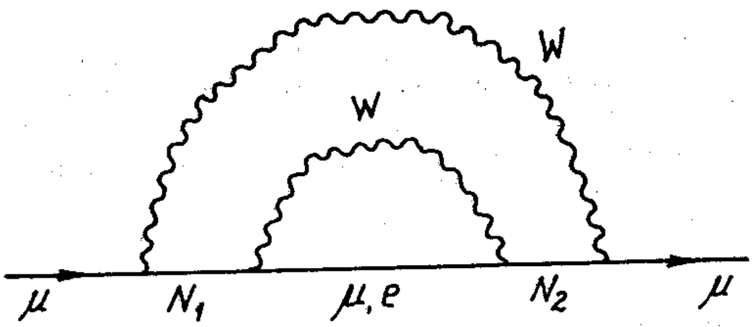

Fig. 6b

$$\mathcal{L}_{eff} = g_{eff}\,[\bar{e}(1-\gamma_5)\gamma_\mu\,\mu][\bar{\mu}(1-\gamma_5)\gamma^\lambda e],$$

$$g_{eff} = \frac{G_F^2}{16\pi^2}(\alpha\beta^*)^2\,(M_1^2-M_2^2)\begin{pmatrix}\ell n\dfrac{M_1^2}{M_2^2}\\ 1\end{pmatrix} \text{for } \begin{matrix} M_1 = M_2 \\ M_1 \ll M_2\end{matrix} \quad (6)$$

which contains two angle parameters and goes back to the usual form given for example in ref.[6] at $\phi = 0$.

If $\phi \neq 0$ then electric dipole moments D_ℓ's of μ and e differ from zero. The main effect is determined by the diagram (Fig. 6b), to which one should attach photon line in all possible ways. Following [11], one can estimate D_ℓ:

$$D_\ell \sim e \frac{\alpha G_F}{2\pi} m_\ell \sin 2\phi \cos 2\theta' . \qquad (7)$$

5. CONCLUDING REMARK

Thus, it is seen that the possibility of the intensive μ-e transition and attempts to explain it in the framework of the six-lepton model concern many phenomenological and theoretical questions. In this situation the crucial point is whether heavy neutral leptons really exist.

The authors are grateful to Z.R.Babaev, G.V.Micelmacher and S.T.Petcov for fruitful discussions and the participants of the Seminar of LNP, JINR for useful remarks.

REFERENCES

1. Korenchenko S.M. et al. Ya.F., 1971, 13, p.341; SIN Physics Reports, 1976, no. 1, p.9.
2. Bilenky S.M., Petcov S.T., Pontecorvo B.M. JINR, E2-10374, Dubna, 1977; Cheng T.P., Li L.-F. Phys.Rev.Lett., 1977, 38, p.391; Marciano M.J., Sanda A.I. Rock.Univ. N.Y., Rep, NCOO, 1977.

3. Bjorken J., Llewellyn C.H. Phys.Rev., 1973, D7, p.887.
4. Barger V., Nanopoulos D.V. Univ. of Wisconsin, preprint COO-573, 1977.
5. Park I.Y., Yildiz A. Phys.Rev., 1976, D14, p.2941.
6. Fujikawa K. Univ.Tokyo, 1977, Zns-Rep-286.
7. Barish B.C. et al. Phys.Rev.Lett., 1977, 38, pp.577,1037.
8. Fujikawa K., Lee B.W., Sanda A.I. Phys. Rev., 1972, D6, p.2923.
9. Calmet J. et al. Rev.Mod.Phys., 1977, 49, p.21.
10. Glashow S., Iliopoulos J., Maiani L. Phys.Rev., 1970, D2, p.1285.
11. Pais A., Primack J.R. Phys. Rev., 1973, D8, p.3063.

Received by Publishing Department
on September 26, 1977.