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Short Note

Note on the Magnetic Moment of the Nucleon.

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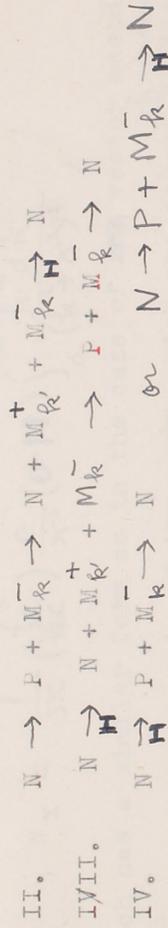
In the present formalism of the meson theory, the anomalous magnetic moment of the nucleon is ascribed to the ^{virtual} ~~virtual~~ ^{those} existence of mesons around it, which are described by the vector field.¹⁾ Recent trend of the theory indicates, however, the coexistence of mesons, which can be described by the pseudoscalar field and contribute to the nuclear force as much as the vector mesons. Thus we can expect that the pseudoscalar mesons are also responsible for the anomalous magnetic moment of the nucleon. But a closer investigation is needed in order to make this point clear, since the pseudoscalar mesons have no intrinsic magnetic moments in contrast to the vector mesons.²⁾

Now we consider a neutron with the spin vector in the magnetic field. The energy of the neutron changes on account of the interaction of the virtual mesons and protons in the intermediate states with the magnetic \not{p} field. There are four types of relevant processes:

I. $N \rightarrow P + M \vec{k} \rightarrow P + M \vec{k}' \rightarrow N$

- 1) Fröhlich, Heitler and Kemmer, Proc. Roy. Soc. A 166(1938), 154; Yukawa, Sakata and Taketani, Proc. Phys.-Math. Soc. Japan 26(1938), 319.
- 2) Similar calculations were performed independently by Yamasaki and Uma (Proc. Phys.-Math. Soc. Japan, in press). The authors are indebted to Dr. Kobayasi for the communication of their results before publication.

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where P , $M_{\vec{k}}$ and $M_{\vec{k}}$ denote a proton, a meson with the negative charge and the momentum \vec{k} and a meson with the positive charge and the momentum \vec{k}' respectively. The energy change due to the process I, for instance, is given by the well known formula

$$W_I = \sum_{\vec{k}, \vec{k}'} \frac{H_{0\vec{k}'} H_{\vec{k}'\vec{k}} H_{\vec{k}\vec{k}_0}}{(E_{\vec{k}'} + \epsilon_{\vec{k}'} - Mc^2)(E_{\vec{k}} + \epsilon_{\vec{k}} - Mc^2)} \quad (1)$$

where $H_{\vec{k}_0}$, $H_{\vec{k}'\vec{k}}$ and $H_{0\vec{k}'}$ denote the matrix elements of the interaction energy corresponding to the transitions between the initial state (0), the first intermediate state (\vec{k}), the second intermediate state (\vec{k}') and the final state (0), which is identical with the initial state, respectively. $E_{\vec{k}}$, $\epsilon_{\vec{k}}$ denote the energies of the proton and the meson, both having the momentum of magnitude $|\vec{k}|$. The first summation $\sum_{\vec{k}, \vec{k}'}$ in (1), which should be performed over all possible values of the momenta \vec{k} , \vec{k}' of the mesons in the intermediate states, can be transformed into the integration with respect to \vec{k} and \vec{k}' . It reduces to the integral with respect to \vec{k} alone, since the conservation of momentum requires $\vec{k} = \vec{k}'$. The second summation refers to possible orientation of the spin of the proton, the summation with respect to the spin of the meson being, of course, unnecessary in this case.

By using the expressions for the Hamiltonian in the pseudoscalar theory, which were obtained by Tanikawa and Yukawa³⁾, we arrive at a result

3) Tanikawa and Yukawa, Proc. Phys.-Math. Soc. Japan 23(1941), 445.

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$$W_I = \frac{1}{3\pi} \left(\frac{f_2^2}{\hbar c} \right) \frac{e}{x^2} (\sigma \cdot H) \int_0^\infty \frac{k^4 dk}{(k^2 + \kappa^2)^2}, \quad (2)$$

which has a similar form as in the case of ~~the~~ vector mesons, although only those magnetic moments of ~~the~~ mesons which are caused by the orbital motion of pseudoscalar mesons contribute to the energy change in our case. The upper limit of the integration in (2) should be replaced by a finite value k_0 instead of extending to infinity in order to avoid the well known divergence difficulty.

The energy changes W_{II}, W_{III} due to the processes II and III can be calculated in a similar manner and we obtain the result

$$W_{II} + W_{III} = W_I.$$

On the other hand, the energy change W_{IV} due to the process IV originated by the simultaneous interaction of the meson with the nucleon and the electromagnetic field is found to be 0, so that the resultant energy change W takes the form,

$$W = W_I + W_{II} + W_{III} + W_{IV} \approx 2W_I = -\mu H \quad (3)$$

with

$$\mu = -\frac{2}{3\pi} \left(\frac{f_2^2}{\hbar c} \right) \frac{e\hbar}{\mu c} \sigma f(x_0), \quad (4)$$

where $x_0 = k_0/\kappa$ and

$$f(x_0) = \int_0^{x_0} \frac{x^4 dx}{(1+x^2)^2}.$$

Thus μ is the additional magnetic moment of the neutron due to the virtual existence of pseudoscalar mesons.

This result can be compared with the corresponding moment

$$\mu' = -\frac{4}{3\pi} \left(\frac{g_2^2}{\hbar c} \right) \frac{e\hbar}{\mu c} \sigma f(x_0) \quad (5)$$

in the case of the vector mesons. If we take, for example, the constant characterizing the dipole interaction between the nucleon and the pseudoscalar meson equal to that between the nucleon and the vector meson g_2 , we find

f_2

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that the contribution of the pseudoscalar meson is just one half of that of the vector meson. Further discussions on the bearing of this conclusion to other problems of the meson theory ^(are) ~~made~~ (made by Yamasaki and Uma⁴) on the basis of the single force hypothesis, which was put forward by Kobayasi.⁵)

In conclusion, the authors wishes to express their cordial thanks to Prof. Yukawa for his continual guidance and also to Dr. Sakata, Dr. Kobayasi and Mr. Tanikawa for valuable discussions. Their thanks are also due to the Japan Society for Promotion of Scientific Research for ^(f) financial aid.

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4) Yamasaki and Uma, loc. cit.

5) Kobayasi, Proc. Phys.-Math. Soc. Japan 23(1941), 891.