Letter to the Editor of the Physical Review.

On the Theory of the New Particle in Cosmic Ray.

As already suggested by several authors[1], the existence of the new particle in cosmic ray, if confirmed, will be a strong support to the theory which had been proposed by one of the present writers[2] and recently by Stueckelberg. Thus it will not be useless to give here a brief account of further consequences of the theory and their bearings on cosmic ray and nuclear phenomena.

The aim of the theory was to remove the wellknown difficulty in the so-called "β-hypothesis of the nuclear force", in a natural way, by introducing a new field, which was responsible for the short range exchange force between the neutron and the proton, as well as for the β-disintegration. We could arrive at consistent results by assuming the interaction of the new field with the heavy particle to be much larger than that with the light particle. As one of the simplest possible forms, the field was considered to be described by two scalar potentials U and $\tilde{U}$ conjugate complex to each other, which satisfy the wave equations

$$\left(\Delta - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \kappa^2\right) U = -4\pi g \tilde{\Psi} Q \Psi, \qquad (1)$$

$$\left(\Delta - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \kappa^2\right) \tilde{U} = -4\pi g \tilde{\Psi} Q^* \Psi, \qquad (2)$$

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1) Oppenheimer and Serber, Phys. Rev. 51, 1113, 1937; Yukawa, Proc. Phys.-Math. Soc. Japan 19, 712, 1937; Stueckelberg, Phys. Rev. 52, 41, 1937. It should be noticed that the criticism of Oppenheimer and Serber is not well founded, since many of the difficulties in the current theory do not appear in our theory, as will be shown in the following paragraphs.

2) Yukawa, Proc. Phys.-Math. Soc. Japan 17, 48, 1935.

where Ψ and $\tilde{\Psi}$ are the wave functions for the heavy particle and Q and Q* are operators which transform the neutron into the proton and vice versa respectively. g and $\varkappa$ are two new constants. The interaction between the neutron and the proton at a distance r due to the intervention of U-field was shown to be an exchange force of Heisenberg type with the potential $g^2 \frac{e^{-\varkappa r}}{r}$. The force of Majorana type can be derived by assuming, for instance, the potentials to be tensors and the terms in the right hand sides of (1) and (2) to contain the spin of the heavy particle. Further, we can obtain short range force between like particles as higher order term with the attractive potential $-\frac{g^4}{\hbar c} \frac{iH_0^{(1)}(2i\varkappa r)}{r}$, which is the same order of magnitude as the unlike particle force.[3)]

4π

Similarly, in the presence of the light particle, the right hand sides of (1) and (2) should be added by terms corresponding to the transition of it from electron to neutrino state and vice versa respectively. In this case, however, the constant g should be replaced by another constant g' which is ~~very small~~ much smaller. Thus we obtained a theory of β-disintegration essentially equivalent to that of Fermi. The well-known modification due to Konopinski and Uhlenbeck can also be adopted in this theory, if we assume the source terms to contain derivatives of the wave functions for the light particle.

An important and inevitable consequence of the above theory was

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3) $H_0^{(1)}$ denotes Hankel function and the potential decreases as $e^{-2\varkappa r}/r^{\frac{3}{2}}$ for large r. It should be noticed, however, that the like particle force becomes only about 1/10 of the unlike particle force, if we take $\varkappa = 5 \times 10^{12}\ cm^{-1}$ and $g^2/\hbar c = 1/10$. Thus, it may be necessary to consider neutral heavy quanta, if we accept the current assumption of approximate equality of two forces. (happen to)

that the new field should be accompanied by quanta satisfying Bose statistics with the elementary charge either +e or -e and the mass m_U about 200 times as large as that of the electron, if we take the range of the nuclear force $1/\kappa$ to be 2×10^{-13} cm, for instance.[4] It is possible, further, to decompose the quadratic equations of the type (1) or (2) into linear equations, which can be considered as a generalization of Maxwell's equations.

If we take the electromagnetic field into account, the equations are altered in the usual manner and it follows that the quanta have spin 1, so that the anomalous magnetic moment of the heavy particle can be interpreted in the following way. Namely, if we assume the self energy of the heavy particle due to the U-field to be responsible for the whole mass M of the heavy particle, its "radius" becomes about g^2/Mc^2 and the additional magnetic moment comes out to be about

$$-\mu + \sqrt{\frac{2g^2}{\pi\hbar c}}\,\frac{e\hbar}{2m_U c} \cong -\mu + 2.5 \times \frac{e\hbar}{2Mc}$$

for the neutron or the proton, which is in good agreement with the observed value $\mp 2 \times \frac{e\hbar}{2Mc}$.

Next, we want to refer briefly to the problem of the passage of high energy heavy quanta through matter. In addition to the energy loss due to the ionization, the heavy quanta can be captured by the nuclei with subsequent emission of heavy particles, heavy quanta or γ-rays. The process, in which a heavy quantum of kinetic energy E is captured

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4) According to the preliminary result of the experiment of Nishina, Takeuchi and Ichimiya, the mass of the new particle in the cosmic ray is the order of 1/10 of the protonic mass in fair accord with the theory.

and a heavy particle is emitted, was dealed with in a manner analogous to the ordinary photoelectric effect. ~~It was found~~ We find that the absorption coefficient in lead due to this process alone is about 0.02 cm^{-1} for E of the order of 10^8 eV and 4 cm^{-1} for E about 10^7 eV. It increases rapidly as E decreases, so that the heavy quanta slowed down by ionization will soon be absorbed ~~by~~ into matter. These results are, at least, not in contradiction with known properties of hard component of the cosmic ray.

In this way, the above theory seems to be very promising for consistent interpretation of the nuclear phenomena as well as of the cosmic ray, although it can not be avoided for the time being that the mathematical scheme becomes more and more complicated, as we want to fit the theory better to the experiment. Detailed account of the whole subject will be given in later issues of the Proc. Phys.-Math. Soc. Japan.

In conclusion, the authors wish to express their cordial thanks to Dr. Y. Nishina for valuable discussions.

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