# On the Interaction of Elementary Particles. III.

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## §1. Introduction and Summary.

In two previous papers,[1] the interaction of elementary particles was discussed by introducing a new field of force. On quantizing this field, we obtained new quanta obeying Bose statistics, each with the elementary charge either positive or negative and the mass $m_u$ intermediate between those of the electron and the proton, ~~obeying the Bose statistics.~~ which $m_u$ is connected with the range $\left(\frac{1}{\kappa}\right)$ of the nuclear force by the relation $\frac{1}{\kappa} = \frac{\hbar}{m_u c}$. This field was described by two four vector functions complex conjugate to each other in I, whereas it was ~~des~~ described by two scalar functions in II. These formulations were adopted for the sake of simplicity, but neither of them was ample enough for the derivation of complete expressions for the interaction of the heavy particles and their anomalous magnetic moments.

In this paper, we begin with the construction of the linear equations for the new field, which can be considered as a generalization of Maxwell's equations for the electromagnetic field. The field is thus described by two four vectors and two six vectors, which are complex conjugate to each other respectively. (§2.) It is interesting that this system of equations

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1) Yukawa, Proc. Phys.-Math. Soc. Japan 17, 48, 1935; Yukawa and Sakata, ibid. 19, 1084, 1937. These papers will be referred to as I and II respectively. See also Yukawa, ibid. 19, 712, 1937.

written in spinor form reduces to a special case of Dirac's wave equations for the particle with the spin larger than 1/2.[2] Meanwhile, it came to our notice that our formulation ~~I~~ was equivalent to a method of linearization of wave equations for the electron, which had been developed by Proca[3] as an extension of the scalar theory of Pauli and Weisskopf.[4] Very recently, Kemmer and Bhabha[5] also discussed the nature of nuclear force, anomalous magnetic moment of the heavy particle[6] and cosmic ray by using Proca's scheme.

The new field equations can be derived from the Lagrangian, so that the canonical variables and the Hamiltonian can be determined in the usual way. Then, we can go over into the quanum theory by constructing the commutation relations and the equations of motion for these variables. (§2.) We can decompose the field variables into Fourier components, each of which consists, in turn, of three components, indicating that the quanta accompanying this field have each spin 1. (§3.)

In the presence of the electromagnetic field, the Lagrangian for the U-field is transformed in the usual manner, corresponding to the fact that the U-quantum has the elementary charge either positive or negative. It follows further that the quanta have each the magnetic moment of the magnitude $e\hbar/2m_U c$ in nonrelativistic approximation. (§4.) Thus, the origin

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2) Dirac, Proc. Roy. Soc. (A) 155, 447, 1936. See also Sakata and Yukawa, Proc. Phys.-Math. Soc. Japan 19, 91, 1937. Detailed discussions of the formal problems will be made elsewhere.
3) Proca, Jour. d. Phys. 7, 347, 1936. See further Durandin and Erschow, Sow. Phys. 12, 466, 1937.
4) Pauli and Weisskopf, Helv. Phys. 7, 709, 1934.
5) Kemmer, Nature 141, 116, 1938; Bhabha, ibid. 141, 117, 1938.
6) The problem of magnetic moment of the heavy particle was discussed ~~by~~ also by Taketani, Kagaku 7, 532, 1937, and by Fröhlich and Heitler, Nature 141, 37, 1938.

of the anomalous magnetic moments of the neutron and the proton can be attributed to the virtual presence of the heavy quanta in the intermediate states. (§5.) The order of magnitude of the additional moment thus obtained is in fair agreement with the experiment.

Finally, the possible forms of the interaction between the U-field and the heavy particle is considered and the force between the neutron and the proton is ~~was~~ deduced. It is found that the combination of the exchange forces of Majorana and Heisenberg types, which agrees with the result of the current theory both in sign and magnitude, ~~magnitude and sign~~, can be obtained by choosing the constant ~~s~~ suitably. (§6. & §7.) It should be noticed that the results from the current theory force is not strictly central, so that considerable departures are expected in some cases.

The problem of the interaction of the heavy quanta with the light particles, i.e. the electrons and the neutrinos, are not ~~will be~~ considered in detail in this ~~the next~~ paper. ~~In this paper,~~ Only the probability of the annihilation of a heavy quantum by emitting a positive or negative electron and a neutrino or an antineutrino simultaneously, which was pointed out by Bhabha[7], is calculated and its bearing on the problem of the hard component of the cosmic ray is discussed ~~briefly~~. (§8.)

Among various many phenomena processes, connected related due to the

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7) Bhabha, loc. cit.

those perpendicular to $\vec{e}_{1k}$ and to each other, forming a right handed system. By inserting (15) into the field equations (13), we obtain the equations of motion for the new variables $u_{jk}$, $u^{+}_{jk}$ etc.

$$\left.\begin{aligned} \dot{u}_{jk} &= 4\pi\kappa^2c^2\,\tilde{u}^{+}_{jk} + 4\pi k^2c^2\,\delta_{j1}\,\tilde{u}^{+}_{1k}, \\ \dot{\tilde{u}}^{+}_{jk} &= \frac{-k^2-\kappa^2}{4\pi\kappa^2}\,u_{jk} + \frac{k^2}{4\pi\kappa^2}\,\delta_{j1}\,u_{1k}, \quad \text{etc.} \end{aligned}\right\} \tag{16}$$

and similar equations for $v_{jk}$, $v^{+}_{jk}$, etc. These equations show that each variable has the time factor either $e^{-ik_0ct}$ or $e^{ik_0ct}$ with $k_0 = +\sqrt{k^2+\kappa^2}$, so that we can denote the variables with the time factor $e^{-ik_0ct}$ by $u_{jk}$, $\tilde{u}^{+}_{jk}$, while those with the time factor $e^{ik_0ct}$ by $\tilde{v}_{jk}$, $v^{+}_{jk}$. The commutation relations (9) are transformed into the form

$$\left.\begin{aligned} u_{jk}u^{+}_{lk'} - u^{+}_{lk'}u_{jk} &= \frac{i\hbar}{2}\,\delta_{jl}\,\delta(\vec{k},\vec{k}'), \\ u_{jk}u_{lk'} - u_{lk'}u_{jk} &= 0, \qquad \text{etc.} \end{aligned}\right\} \tag{17}$$

and similar relations for v's, u's and v's being commutative with one another.

Correspondingly, the Hamiltonian (11) becomes

$$\bar{H}_U = \sum_k\sum_j\Big\{4\pi c^2(\kappa^2+k^2\delta_{j1})(\tilde{u}^{+}_{jk}+v^{+}_{jk})(u^{+}_{jk}+\tilde{v}^{+}_{jk}) + \frac{1}{4\pi\kappa^2}(k_0^2-k^2\delta_{j1})(\tilde{u}_{jk}+v_{jk})(u_{jk}+\tilde{v}_{jk})\Big\} \tag{18}$$

Now, we obtain the relations

$$-ik_0c\,u^{+}_{jk} = \frac{k_0^2-k^2\delta_{j1}}{4\pi\kappa^2}\,\tilde{u}_{jk}, \quad \text{etc.} \tag{16'}$$

from (16) at once and consequently, (17) takes the form

$$u_{jk}\tilde{u}_{lk'} - \tilde{u}_{lk'}u_{jk} = \frac{2\pi\kappa^2k_0\hbar c}{k_0^2-k^2\delta_{j1}}\,\delta_{jl}\,\delta(\vec{k},\vec{k}'). \tag{17'}$$

Hence, if we introduce the new variables

$$\left.\begin{aligned} N_{jk} &= \frac{(k_0^2-k^2\delta_{j1})}{2\pi\kappa^2k_0\hbar c}\,\tilde{u}_{jk}u_{jk} \\ M_{jk} &= \frac{(k_0^2-k^2\delta_{j1})}{2\pi\kappa^2k_0\hbar c}\,\tilde{v}_{jk}v_{jk} \end{aligned}\right\} \tag{19}$$

which are all commutative with one another and each has the eigenvalues 0, 1, 2, ...., the Hamiltonian (18) reduces to

$$\bar{H}_U = \sum_k\sum_j k_0\hbar c\,(N_{jk}+M_{jk}+1). \tag{20}$$

The variable $N_{jk}$ denotes the number of the heavy quanta with the positive charge in the state of energy $E_k = k_0\hbar c = \hbar c\sqrt{k^2+\kappa^2}$ and momentum $\hbar ck$, whereas

From these equations, we obtain at once the quadratic equations

$$\left.\begin{aligned} \frac{1}{c^2}\frac{\partial^2 U}{\partial t^2} - \Delta U + \varkappa^2 U &= 4\pi g_1\Big(\varkappa M - \frac{1}{\varkappa}\,\mathrm{grad\,div}\,M \\ &\quad - \frac{1}{\varkappa}\,\mathrm{grad}\,\frac{1}{c}\frac{\partial M_0}{\partial t}\Big) + 4\pi g_2\Big(\frac{1}{c}\frac{\partial T}{\partial t} - \mathrm{curl}\,S\Big) \\ \frac{1}{c^2}\frac{\partial^2 \tilde{U}^\dagger}{\partial t^2} - \Delta \tilde{U}^\dagger + \varkappa^2 \tilde{U}^\dagger &= \frac{g_1}{\varkappa c}\Big(\mathrm{grad}\,M_0 + \frac{1}{c}\frac{\partial M}{\partial t}\Big) \\ &\quad - g_2\Big(T + \frac{1}{\varkappa^2}\,\mathrm{curl\,curl}\,\frac{1}{c}\frac{\partial T}{\partial t} - \frac{1}{\varkappa^2 c}\,\mathrm{curl}\,\frac{1}{c}\frac{\partial S}{\partial t}\Big) \end{aligned}\right\} \qquad (49)$$

The complete Hamiltonian for the system consisting of the U-field and the heavy particle is

$$\bar{H} = \iiint (H_U + H' + H_M)\,dv \qquad (50)$$

with $H_U$, $H'$ given by (47) and

$$H_M = \tilde{\Psi}\Big\{\cancel{-i\hbar}\,c\,\vec{\alpha}\,\overrightarrow{\mathrm{grad}} + \beta\Big(\frac{1+\tau_3}{2}M_N c^2 + \frac{1-\tau_3}{2}M_P c^2\Big)\Big\}\Psi, \qquad (51)$$

if we ignore the electromagnetic interaction between the heavy quantum and the proton, where $\vec{p} = -i\hbar\,\mathrm{grad}$

§7. Deduction of the Force between the Neutron and the Proton.

The interaction between the neutron and the proton, which is caused by virtual emission and absorption of the heavy quanta, can be calculated from the Hamiltonian (50) by straightforward application of the perturbation theory as in II. Namely, we first transform the variables for the U-field and for the heavy particle into the normal coordinates, ~~as in §2,~~ then express the perturbation energy in terms of these coordinates and finally, after performing rather complicated integrations, we obtain the required formulae. An alternative method, which is similar to that given in I, however, leads to the same results more quickly, so that only this method will be mentioned in the following.

$$+ \overline{H}_M = \sum_j \left\{ c\rho_1^{(j)} (\vec{\sigma}^{(j)} \vec{p}_j) + \rho_3^{(j)} \left( \frac{1+\tau_3^{(j)}}{2} M_N c^2 + \frac{1-\tau_3^{(j)}}{2} M_P c^2 \right) \right\}$$





We consider two heavy particles with the coordinates $\vec{r}_j$ , the momenta $\vec{p}_j$ , the spin matrices $(\rho_1^{(j)}, \rho_2^{(j)}, \rho_3^{(j)})$, $\vec{\sigma}^{(j)}$ and the isotopic spin matrices $\tau_1^{(j)}, \tau_2^{(j)}, \tau_3^{(j)}$, where j = 1 and 2 denote the first and the second particles respectively. Further, we assume $\vec{M}$, $M_0$, $\vec{T}$, $\vec{S}$ etc. to have the simplest forms (38), (39) etc. In this case, the Hamiltonian (50) can be written alternatively in form

$$\overline{H} = \overline{H}_U + \overline{H}' + \overline{H}_M \qquad (52)$$

$$Q_1 \tilde{Q}_2 + Q_2 \tilde{Q}_1 + \cdots + \cdots$$

with $\overline{H}_U$ as given by (47) and

$$\begin{aligned} \overline{H}' = \sum_j \Big[ & \frac{4\pi g_1 c}{\kappa} \{ \operatorname{div} U^\dagger(\vec{r}_j) \tilde{Q}_j + \operatorname{div} \tilde{U}^\dagger(\vec{r}_j) Q_j \} - \frac{g_1}{\kappa} \{ \tilde{U}(\vec{r}_j) \rho_1^{(j)} \sigma^{(j)} \tilde{Q}_j \\ & + U(\vec{r}_j) \rho_1^{(j)} \sigma^{(j)} Q_j \} - 4\pi g_2 c \{ U^\dagger(\vec{r}_j) \rho_2^{(j)} \sigma^{(j)} \tilde{Q}_j + \tilde{U}^\dagger(\vec{r}_j) \rho_2^{(j)} \sigma^{(j)} Q_j \} \\ & + \frac{g_2}{\kappa^2} \{ \operatorname{curl} U(\vec{r}_j) \cdot \rho_3^{(j)} \sigma^{(j)} \tilde{Q}_j + \operatorname{curl} \tilde{U}(\vec{r}_j) \cdot \rho_3^{(j)} \sigma^{(j)} Q_j \} + \cancel{\frac{4\pi}{\kappa^2} (g_1^2 \tilde{Q}_j Q_j + g_2^2 \tilde{Q}_j Q_j} \\ & + \frac{4\pi}{\kappa^2} (\tilde{Q}_1 Q_2 + \tilde{Q}_2 Q_1) \{ g_1^2 + g_2^2 \rho_3^{(1)} \rho_3^{(2)} (\sigma^{(1)} \sigma^{(2)}) \} \Big] + \end{aligned} \qquad (53)$$

where $\frac{(\tilde{Q}_1 Q_2 + \tilde{Q}_2 Q_1)}{2}$ $\tilde{Q}_j = \frac{\tau_1^{(j)} - i\tau_2^{(j)}}{2}$ $\qquad Q_j = \frac{\tau_1^{(j)} + i\tau_2^{(j)}}{2}$.

When the heavy particles are in the states each with the kinetic energy small compared with the proper energy $Mc^2$, $\rho_1^{(j)} \vec{\sigma}^{(j)}$, $\rho_2^{(j)} \vec{\sigma}^{(j)}$ are negligible in comparison with 1 and $\rho_3^{(j)} \vec{\sigma}^{(j)} \simeq \vec{\sigma}^{(j)}$. Moreover, when the difference of energies of the heavy particles is small compared with $m_U c^2$, the ~~tin~~ terms in (53), which involve time derivatives can be neglected, so that we obtain

$$\begin{aligned} \overline{H}' = \sum_j \Big[ & \frac{4\pi g_1 c}{\kappa} \{ \operatorname{div} U^\dagger(\vec{r}_j) \cdot \tilde{Q}_j + \operatorname{div} \tilde{U}^\dagger(\vec{r}_j) \cdot Q_j \\ & - \frac{g_2}{\kappa^2} \{ \tilde{Q}_j (\vec{\sigma}^{(j)} \operatorname{curl} U(\vec{r}_j)) + Q_j (\vec{\sigma}^{(j)} \operatorname{curl} \tilde{U}(\vec{r}_j)) \} \\ & + \cdots \end{aligned} \qquad (54)$$

Correspondingly, the equations (49) reduce to

$$\left. \begin{aligned} \left( \frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \Delta + \kappa^2 \right) U(\vec{r}) &= 4\pi g_2 \sum_j (\vec{\sigma}^{(j)} \times \operatorname{grad}) \delta(\vec{r}, \vec{r}_j) \\ \left( \frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \Delta + \kappa^2 \right) \tilde{U}^\dagger(\vec{r}) &= \frac{g_1}{\kappa c} \sum_j \operatorname{grad} \delta(\vec{r}, \vec{r}_j) \end{aligned} \right\} \qquad (55)$$

Now, the particular solutions of (55) corresponding to the presence of the heavy parti~~y~~cles at $\vec{r}_1$ and $\vec{r}_2$ are

$$\left.\begin{aligned} U(\vec{r}) &= g_2 \sum_j \tilde{Q}_j (\vec{\sigma}^{(j)} \times \mathrm{grad}) \frac{e^{-\varkappa|\vec{r}-\vec{r}_j|}}{|\vec{r}-\vec{r}_j|}, \\ \tilde{U}^+(\vec{r}) &= \frac{g_1}{4\pi\varkappa c} \sum_j \tilde{Q}_j \,\mathrm{grad}\, \frac{e^{-\varkappa|\vec{r}-\vec{r}_j|}}{|\vec{r}-\vec{r}_j|}. \end{aligned}\right\} \tag{56}$$

Inserting these expressions in (54) and omitting the infinite terms, which contribute only to the self energy of the heavy particles, ~~we~~ we obtain the interaction energy

$$\begin{aligned} H_{12} = {} & \frac{2g_1^2}{\varkappa^2}(Q_1\tilde{Q}_2 + \tilde{Q}_1 Q_2)\,\Delta \frac{e^{-\varkappa r}}{r} + \frac{4\pi g_1^2}{\varkappa^2}(Q_1\tilde{Q}_2 + \tilde{Q}_1 Q_2)\,\delta(\vec{r}) \\ & - \frac{2g_2^2}{\varkappa^2}(Q_1\tilde{Q}_2 + \tilde{Q}_1 Q_2)(\vec{\sigma}^{(1)} \times \mathrm{grad})(\vec{\sigma}^{(2)} \times \mathrm{grad})\frac{e^{-\varkappa r}}{r} + \frac{4\pi g_2^2}{\varkappa^2}(Q_1\tilde{Q}_2 + \tilde{Q}_1 Q_2)(\vec{\sigma}^{(1)}\vec{\sigma}^{(2)})\,\delta(\vec{r}) \end{aligned} \tag{57}$$

where $\vec{r} = \vec{r}_1 - \vec{r}_2$. By using the relation

$$\Delta \frac{e^{-\varkappa r}}{r} = \varkappa^2 \frac{e^{-\varkappa r}}{r} - 4\pi\,\delta(\vec{r}), \tag{58}$$

(57) can ~~be~~ easily be transformed into the form, if we omit the terms involving the $\delta$-functions,

$$\begin{aligned} H_{12} &= (\tau_1^{(1)}\tau_1^{(2)} + \tau_2^{(1)}\tau_2^{(2)})\left\{g_1^2 + g_2^2(\vec{\sigma}^{(1)}\vec{\sigma}^{(2)}) - g_2^2\frac{(\vec{\sigma}^{(1)}\mathrm{grad})(\vec{\sigma}^{(2)}\mathrm{grad})}{\varkappa^2}\right\}\frac{e^{-\varkappa r}}{r} \end{aligned}$$

or

$$\begin{aligned} &= (\tau_1^{(1)}\tau_1^{(2)} + \tau_2^{(1)}\tau_2^{(2)})\Big[g_1^2 + g_2^2\left\{(\vec{\sigma}^{(1)}\vec{\sigma}^{(2)}) - \frac{(\vec{\sigma}^{(1)}\vec{r})(\vec{\sigma}^{(2)}\vec{r})}{r^2}\right\} \\ &\quad + g_2^2\left\{(\vec{\sigma}^{(1)}\vec{\sigma}^{(2)}) - \frac{3(\vec{\sigma}^{(1)}\vec{r})(\vec{\sigma}^{(2)}\vec{r})}{r^2}\right\}\left(\frac{1}{\varkappa r} - \frac{1}{\varkappa^2 r^2}\right)\Big]\frac{e^{-\varkappa r}}{r}. \end{aligned} \tag{59}$$

As well known, this is a combination of exchange forces of Majorana and Heisenberg types between the neutron and the proton.[13] ~~Similar~~ It should be noticed, however, that the force thus obtained is not strictly central, so that we can speak of S state, P state only in the first approximation.

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13) Similar formula was obtained by Kemmer (loc. cit.), which had three arbitrary constants A, B, C instead of $g_1$ and $g_2$.

if we consider the whole system to be in the unit cube,



or

$$dw_0 = \frac{m_u c}{32\pi^2\hbar^4}\sum|V|^2 d\Omega \qquad (63)$$

where E is the total energy of the final state which is equal to $m_u c^2$ in this case and V is the matrix element of the energy of interaction of the U-field with the light particle corresponding to the above transition. $\sum$ means the summation with respect to the spins of the electron and the neutrino.

Now, if we assume the interaction in this case has the same form as that between the U-field and the heavy particle, we can use the formula for $\bar{H}'$ given by (47) with the modification that the constants $g_1$ and $g_2$ are replaced by ~~other~~ smaller constants, $g_1'$ and $g_2'$ say, and the wave functions, spin matrices etc. for the heavy particle by the corresponding quantities for the light particle. Since the heavy quantum is at rest initially, the derivatives of U, $U^+$ etc. vanish, ~~can be ignored,~~ so that the energy of interaction becomes simply

$$\bar{H}' = -\frac{g_1'}{\kappa}\iiint \tilde{U}\tilde{\psi}\rho_1\sigma\varphi\, dv - 4\pi g_2' c\iiint U^+\tilde{\psi}\rho_2\vec{\sigma}\varphi\, dv \qquad (64)$$

where $\psi, \varphi$ are the wave functions for the electron and the neutrino respectively. Thus, when the heavy quantum initially at rest is polarized in the direction $\vec{e}$, the matrix element takes the form

$$V = -\sqrt{\frac{24\pi\hbar c}{\kappa}}\left\{g_1'(\tilde{u}\rho_1\vec{\sigma}\vec{e}v) + i g_2'(\tilde{u}\rho_2\vec{\sigma}\vec{e}v)\right\}, \qquad (65)$$

where u, v are the constant spinors representing the amplitudes of the wave functions of the electron and the neutrino respectively. By inserting (65) in (63), the ~~The~~ summation with respect to the spin and the integration with respect to the direction of emission can easily be performed and we obtain the total probabilty per unit time of annihilation

$$w_0 = \frac{2g_1'^2 + g_2'^2}{6\hbar c}\frac{m_u c^2}{\hbar}. \qquad (66)$$

$\rho_2 =$
$(g_1' + g_2')\rho_1 = (g_1'\rho_1 + i g_2'\rho_2)$

The corresponding probability, when the heavy quantum is moving with the velocity v and energy E, is

(67)

$$\bar{H}' = -\iiint\left\{\frac{g_1'}{\kappa}\tilde{U}\tilde{\psi}\rho_1\sigma\varphi + 4\pi g_2' c\, U^+\tilde{\psi}\rho_2\sigma\varphi\right\}dv$$

owing to the change of time scale under Lorentz transformation. The mean life time and the ~~t~~ mean free path of the heavy quantum with the energy E can be determined from (67) by using the relations

$$\tau = \frac{1}{w}, \qquad \lambda = v\tau \tag{68}$$

If we take $g_1' = g_2' = g' = 4 \times 10^{-17}$, a value which was determined from the probability of $\beta$-disintegration in §4, I, and $m_u = 100\ m$;[17] we obtain

$$w = 2 \times 10^{8}\ \frac{mc^2}{E}, \tag{69}$$

so that ~~the numerical values for~~ of $\tau$ and $\lambda$ ~~take~~ becomes are ~~can be~~ determined for several values of energy become as shown in Table 1.

Table 1.

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|---|---|---|---|---|---|---|---|
| Kinetic energy | $E - m_u c^2$ | 0 | $10^9$ | $10^{10}$ | $10^{11}$ | $10^{12}$ | eV |
| Mean life time | $\tau$ | 1/200 | $10^{-5}$ | $10^{-4}$ | $10^{-3}$ | $10^{-2}$ | sec. |
| Mean free path | $\lambda$ | — | 3 ~~10~~ | 30 | $3 \times 10^2$ | $3 \times 10^3$ | km |

Thus, even the heavy quantum with the energy $10^{12}$ eV can travel only a distance smaller ~~compared with~~ than the radius of the earth before it changes into an electron and a neutrino. The bearing of this conclusion on the interpreta- of the hard component of cosmic ray was already discussed above.

On the other hand, there are many processes, which are connected with the creation of the heavy quanta, such as the creation of a pair of positive and negative quanta by $\gamma$-rays of energy larger than $2m_u c^2$, the emission of one or more heavy quanta by nuclear disintegration caused by high energy radiations of various sorts, etc. Among them, the creation of pair by $\gamma$-ray has the

The ~~exact value~~ mass of ~~$m_\nu$ is not~~ the new particle in the cosmic ray, which is considered to be identified with the heavy quantum in our theory, is not yet determined accurately.

17) Very recently, a value 120 m was obtained by Ruhlig and Crane, Phys. Rev. 53, 266, which is in close agreement with the value 130 m of Street and Stevenson, but is smaller than those of Nishina, Takeuchi and Ichimiya and of Corson and Brode.

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1) Serber, Bull. Amer. Phys. Soc. 12, Nr. 6, p. 5, 1937.
2) Kemmer, Nature 141, 116, 1938.
3) Bhabha, ibid. 141, 117, 1938.
4) Proca, Journ. d. Phys. 7, 347, 1936.
5) Dirac, Proc. Roy. Soc.
6) Fröhlich and Heitler, Nature 141, 37, 1938.
7) Durandin and Erschow, ~~Phys. Zeits. d. Sowj.~~ Sow. Phys. 12, 466, 1937.
8) Bhabha, Proc. Roy. Soc. ,1938
9) Ruhlig and Crane, Phys. Rev. 53, 266, 1938,
120 ± 30 m

O neutral Quanta

The problem of the interaction of the heavy quanta with the light particles, i.e. the electrons and the neutrinos, ~~will~~, which is responsible for the β disintegration, will ~~not~~ be considered in detail in the subsequent paper. ~~However,~~ only ~~The process~~ annihilation of ~~the~~ a heavy quantum by emitting an, in this paper, ~~possibility~~ of the ~~elect~~ positive or negative electron and a neutrino or an anti-neutrino, which was pointed out by Bhabha, is calculated ~~will~~ also, as this process ~~has~~ its bearing ~~as of importance~~ is very important ~~in relation to the nature~~ on the problem of the hard component of the cosmic ray, ~~and is~~ discussed in ~~constitution~~ ~~some detail in this~~