Now, if we consider the whole system as enclosed in a large volume, a unit cube for example, we can change the variables describing the U-field by the Fourier transformation

$$\left.\begin{aligned} U &= i\hbar c \sum_k \sqrt{\frac{2\pi}{E_k}} (\cancel{a_k^*} - b_k^*) e^{i(\vec{k}\,\vec{r})} \\ \tilde{U} &= -i\hbar c \sum_k \sqrt{\frac{2\pi}{E_k}} (a_k^* - b_k) e^{-i(\vec{k}\,\vec{r})} \end{aligned}\right\} \quad (10)$$

a_k

where the suffix k stands for the vector $\vec{k}$, the components of which are each zero or integer multiplied by 2π, and $E_k = \hbar c\sqrt{k^2+\kappa^2}$. The new variables a_k, a_k^*, b_k and b_k^* satisfy the commutation relations

$$a_k a_l^* \cancel{\times} a_l^* a_k = \delta_{kl}, \quad b_k b_l^* - b_l b_k^* = \delta_{kl}, \quad (11)$$

any other two commuting with each other. Thus, $N_k^+ = a_k^* a_k$ has eigenvalues $0, 1, 2, \ldots$ and denotes the number of heavy quanta with the

$+e$

charge $\cancel{\mp} e$, the momentum $\hbar k$ and the energy E_k, whereas $N_k^- = b_k^* b_k$ denotes the number of those with the charge $-e$, the momentum $-\hbar k$ and the energy E_k, the Hamiltonian for the U-field (4) being reduced to the simple form

$$H_U = \sum_k (N_k^+ + N_k^- + 1) E_k. \quad (12)$$

Next, when n heavy particles are present, the variables $\vec{r}_i, \vec{p}_i, (\vec{\alpha}_i, \beta_i)$ $(\tau_1^{(i)}, \tau_2^{(i)}, \tau_3^{(i)})$ denoting the coordinates, momenta, Dirac matrices and isotopic spin matrices for i-th particle with $i = 1, 2, \ldots, n$ can be used instead of $\Psi, \tilde{\Psi}$, so that the Hamiltonian (7) taken an alternative form

$\tilde{\Psi}$

$$\bar{H}_M = \sum_i \left\{ c\vec{\alpha}_i \vec{p}_i + \beta_i \left(\frac{1+\tau_3^{(i)}}{2} M_N c^2 + \frac{1-\tau_3^{(i)}}{2} M_P c^2 \right) \right\}. \quad (13)$$

The interaction term (8) becomes accordingly

$$\bar{H}' = g \sum_i \{ Q_i^* \tilde{U}(\vec{r}_i) + Q_i U(\vec{r}_i) \} \beta_i,$$

or
$$= -i\hbar g c \sum_i \sum_k \sqrt{\frac{2\pi}{E_k}} \{ (a_k^* - b_k) e^{-i(\vec{k}\,\vec{r})} Q_i^* - (a_k - b_k^*) e^{i(\vec{k}\,\vec{r})} Q_i \} \beta_i \quad (14)$$

where
$$Q_i = \frac{\tau_1^{(i)} + i\tau_2^{(i)}}{2}, \quad Q_i^* = \frac{\tau_1^{(i)} - i\tau_2^{(i)}}{2}.$$

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(14) involves the operators causing the transition of the heavy particle between the neutron and the proton states with the simultaneous emission or absorption of the heavy quantum and can be considered as perturbation in actual calculations.