$B$ Non-Conservation, Cold Dark Matter and Subpreon Model

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In our model a weakly-interacting massive particle $l^e$ exists. The consideration of baryon number non-conserving processes which are assumed to originate in the subpreon physics shows an asymmetrical existence of it in the universe. Using the formalism of Griest and Seckel, it is shown that $l^e$ is a viable candidate of the cold dark matter.

§ 1. Introduction

Now we have, as simple elements of Nature, leptons, quarks, electromagnetic interactions, strong interactions based on the three colors, weak interactions due to the weak boson exchange and gravity. A main task of the present-day particle physics is to find internal relations among such simple elements and to disclose a more profound essence of Nature.

In order to connect known interactions, it is almost certain that one must introduce new interactions. If leptons and quarks are taken fundamental as in the GUT approach, it necessarily restricts properties of newly introduced interactions severely because the interactions acting among leptons and quarks are required to satisfy special properties. In the GUT approach, all interaction must be like QCD and a possible choice is only what gauge group is taken. On the other hand, if we take a composite model of leptons and quarks (namely preon models), new interactions can be taken more flexibly because properties of preons are not so restricted. This flexibility would be fruitful to clarify an essence of Nature. This point is one of virtues of preon models.

We believe that one of the key phenomena to consider physics in the preon world is the very existence of lepton and quark with their unique properties. It will be especially important to find a way by which we can explain naturally the facts that the electric charges of them are very different from each other and that quarks with abnormal charges have a color quantum number.

The author has recently proposed a preon model along this line of thought by introducing preons with charge $e/2$ as well as the preonic charge which is identified with the magnetic charge. This model has some interesting features. Among them, the following may be of fundamental importance.

1) It is an inevitable consequence that particles with an abnormal electric charge couple with other exact gauge fields. This nicely explains the existence of another exact gauge symmetry (namely QCD) besides QED and gives the reason why quarks have a color quantum number.

2) The quark charge $e/3$ is a natural consequence of the charge of preon ($= e/2$) and the number of the color ($=3$).
Our preon model has, however, serious defects from a theoretical point of view. In our preon model, the conservation of preon species requires six conservation laws, namely conservations of the electric charge, of the color, of the preonic charge, of baryon number (=B), of the lepton number (=L) and of the total preon number (=nT). Although the former three are guaranteed by gauge principles, the latter three are ad hoc. The existence of such ad hoc conservation laws shows incompleteness of the preon physics. This incompleteness directly correlates with the complexity of the matter in the preon level. In spite of the simplicity of the gauge interactions at the preon level, preon species are abundant (e.g., colorless charged preons are \( w_1, w_2 \) and \( c_0 \)) and so matter and gauge interactions do not correspond to each other.

There is another problem. If the preonic charge is identified with the magnetic charge, in order to make a \((w_1 \bar{w}_2)(=W^+)\) boson, the angular momentum carried by the photon field is required to be an integer, namely \( Z_{12} = (e_{c_0} - e_2 g_1) / 4\pi = \text{integer} \). However, the requirement from quantum field theory is that \( Z_{12} \) is a half integer. Why does Nature choose an integer \( Z_{12} \) at the preon level? It seems almost impossible to answer this question, if we stop at the preon model.

These facts show the incompleteness of the preon level physics. We attempt to solve these problems by stepping into a subpreon level and making fundamental matter simpler and more beautiful. For the accomplishment of this task, B non-conserving processes offer an important clue. Although the existence of B non-conserving processes is not confirmed by laboratory experiments (i.e., the absence of proton decay), the baryon asymmetry of the universe strongly suggests the existence of the process. Of course, we must find a way to reconcile the existence of B non-conserving process with the longevity of proton. The resolution of this problem would be one of important keys to get a true theory. B non-conserving processes which are an origin of the baryon asymmetry of the universe are expected to explain the composition of the universe. In the universe, the so-called dark matter exists, which seems to dominate in the universe. A study of B non-conserving processes will also give a clue to settle the dark matter problem. If we take a conservative viewpoint, neutrinos with the tiny mass are a candidate of the dark matter (hot dark matter). The cosmology shows, however, that hot dark matter is unfavorable and cold dark matter is relevant. This suggests the necessity of physics beyond the standard model. It will be one of the important tests for any model to explain the issue of cold dark matter.

Previously we discussed these problems in a short note, where the dark matter problem was studied only in a very crude approximation. Although it expresses a qualitative feature of our model correctly, its quantitative results are far from the real situation. In this paper we shall investigate the dark matter problem in detail, using a more realistic formalism of Griest and Seckel. Below it will be shown that the cosmological mass density problem and some related problems can be resolved naturally. Namely our model can give a viable candidate of cold dark matter.

This paper is organized as follows. In the next section, for completeness, B non-conserving processes based on subpreon model are reviewed. In § 3, whether our model can explain the dark matter problem is investigated. Some related problems are also studied. Section 4 is devoted to discussion.
§ 2. Baryon number non-conservation and subpreon model

We study baryon number non-conserving processes (or more generally speaking, preon number non-conserving processes) which is assumed to originate in the subpreon physics through considering a phenomenological preon number non-conserving Lagrangian expressed in terms of preons.\(^5\) In general a preon number non-conserving phenomenological Lagrangian is written as

\[
L \sim (w_1 \cdots w_l)(c_0 \cdots c_0)(c_1 c_2 c_3 \cdots c_1 c_2 c_3)(h \cdots h) \times K + \text{h.c.,} \tag{1}
\]

where \(K\) is a preon number conserving term and the color conservation is imposed. Hereafter we omit \(K\)-term for simplicity. The conservations of the electric charge \((Q)\), preonic charge \((Q_p)\) and color are guaranteed by gauge symmetries. Hence we assume that these are also conserved in a subpreon world. Consequently the following relations are obtained, since \(Q_{w_1} = -Q_{w_2} = -Q_{c_0} = 3Q_{c_i}\), \(Q_h = 0\) and \(Q_{p} = -2Q_{p}^{w}\)

\[
\begin{align*}
-2Q_{p}^{c}, \\
\end{align*}
\]

\(n - m - l + p = 0, \quad n + m + l + 3p - 2q = 0 \quad \text{and} \quad n + m + l + 3p + q \text{= even}, \tag{2}
\]

where the last relation is required from the fact that \(L\) is a scalar. If the preonic charge is identified with the magnetic charge, the conservation of the color magnetic charge is also required, which results in \(n + m + l + 3p + q = 3 \times \text{integer}\) because all preons carry the same color magnetic charge and the color magnetic charge is a \(\mathbb{Z}(3)\) charge. This relation is automatically satisfied by Eq. (2).

In the subpreon level, the conservations of \(B, L\) and \(n_T\) may be all violated. In this case we must study all cases allowed by Eq. (2). However, we take a conjecture that interactions with more conservation laws are stronger than those with less conservation laws. If we adopt this conjecture, the dominant preon number non-conserving processes satisfy two conservation laws besides \(Q, Q_p\) and color conservations. We take \(n_T\) as one of them, since the conservation of \(n_T\) has a more general character than that of individual preon species. In this case, the following is imposed further,

\[
n + m + l + 3p + q = 0. \tag{3}
\]

From Eqs. (2) and (3), we obtain that \(n = -2p, m = -(l + p)\) and \(q = 0\). If we fix \(l\) and \(p\), then \(\Delta B/\Delta L = p/l\) is obtained. The values of \(p\) and \(l\) reflect physics at the subpreon level. We take the case \(l = p\) for the following reason.

As discussed in the previous paper,\(^1\) if we identify the preonic charge with the magnetic charge, the abnormal charge of \(c_i\) is naturally understood using the color number 3. It is \(\pm e/6\). In our model there is no reason to take only \(+ e/6\). Both the cases should reproduce the real world. This is realized by the simultaneous change of the sign of the charge of \(c_0\) which results in \(Q_{c_0} + \sum Q_{c_i} = 0\). This condition is not
guaranteed in the preon level. This should be done in the subpreon physics. (This condition will be simply satisfied if \( c_0 \) and \( c_i \) have common charged constituents.) If this condition is not an accident but a necessity from the subpreon physics, the charge of \( c_0 \) should be compensated by that of \( c_i \) also in preon number non-conserving Lagrangian since it originates in the subpreon physics. This results in \( l = p \), which implies the \((B-L)\) conservation.

From the above arguments, we obtain for the simplest \( B \) nonconserving Lagrangian,

\[
L \sim f w_1 \omega_2 w_2 \omega_2 c_0 c_{[1} c_{2} c_{3]} + h.c.,
\]

where \( f \) is a dimensionful coupling constant determined by an energy scale of the subpreon physics. It is not difficult to construct a subpreon model which gives rise to the process \((4)\). Let us introduce subpreons \( \alpha \) which is a pure charge \(-e/2, \beta_i (i = 1 \sim 3)\) with charge \(+e/6\) which is 3 under \( SU(3)c \) and \( b \) with a preonic charge which is electrically neutral and a singlet under \( SU(3)c \). (In the case that the preonic charge is identified with the magnetic charge, \( b \) carries also the color magnetic charge.) If \( w_1 = (\alpha b), w_2 = (\alpha b), c_i = (\beta_i b) \) and \( c_0 = (\bar{\beta}_1 \bar{\beta}_2 \bar{\beta}_3 b) \), process \((4)\) takes place through the rearrangement of subpreons. Or, if we assume the existence of a boson \( X(= bbb) \) with a mass of the order of an energy scale typical to the subpreon physics, process \((4)\) occurs via an \( X \) exchange since \( X \) can decay into \( w_1 \omega_1 \omega_2 \omega_2 \) and \( c_0 c_{[1} c_{2} c_{3]} \). In this model \( B \) and \( L \) are meaningful only in the preon level because it is meaningless to assign \( B = 1/3 \) to \( \beta_i \) in the subpreon level. In the case that the preonic charge is identified with the magnetic charge, the Dirac condition requires for the \( \alpha \) and \( b \) system that \((e_1 g_b - e_2 g_b)/4\pi = e/2 \times g_b/4\pi = \pm 1/2\), where \( g_b \) is the magnetic charge of \( b \). Hence we obtain \( g_b = \pm 4\pi/e \), which implies that \( w_1 (w_2) \) carries charge \( e/2 (e - e)/2 \) and magnetic charge \( 4\pi/e (g_b \) is taken to be \( 4\pi/e \)). Therefore we have, for the \( w_1 \) and \( \bar{w}_2 \) system (i.e., \( W^+\)-boson), \((e_1 g_b - e_2 g_b)/4\pi = 1\). Thus we can derive the condition which is assumed in the preon physics.\(^5\)

Even if process \((4)\) is introduced, \( l^s (= w_1 w_2) \) is stable. However, process \((4)\) causes a proton decay as follows.\(^5\)

\[
P \rightarrow e^+ l_s^s l_s^s l_s^s l_s^s.
\]

This is easily seen from the fact that \( L \) in Eq. \((4)\) is expressed as \( UYYY(U = (w c_0) \) and \( Y = (w \bar{c}_i) \)). As shown later, the cosmological mass density problem requires the mass of \( l^s > (M_P - M_e)/4 \). Hence proton cannot decay due to a negative \( Q\)-value.

In the case that Sakharov's conditions\(^3\) are satisfied (note that \( CP\)-violation is a natural consequence of our model\(^1\)), Eq. \((4)\) gives a net composition of the universe as follows.\(^4\)

\[
\frac{1}{3} \omega_1 \omega_2 \omega_2 \omega_2 \omega_2 c_{[1} c_{2} c_{3]} ,
\]

\(^*\) Although Sakharov's conditions can be satisfied in our model, we cannot clarify at the present stage a concrete mechanism through which the baryon asymmetry of the universe is produced. The fact that interactions are strong even at a short distance in our model may bring about a problem in the explanation of the baryon asymmetry. For a discussion on this point, however, it is necessary to know a detailed dynamics in the preon and the subpreon world.
which results at a sufficiently low temperature in the following composition of the universe,\(^5\)

\[
a(P + e^-) + (1 - a)(N + \nu) + 4\bar{l}_s^e + \bar{\nu} - \nu \, \text{pairs} + l^e_s - l_s^e \, \text{pairs},
\]

where \(a\) is a parameter determined by the \(N/P\) ratio in the universe.

\section{3. \(l_s^e\) as a cold dark matter candidate

In our model\(^1\) the lowest mass particle among new fermions and \(U\) - and \(Y\) -bosons is stable. We take that it is \(l_s^e\).\(^1,7\) Since \(l_s^e\) interacts only weakly (hereafter we suppress the generation suffix \(e\)), it behaves as cold dark matter in the universe.\(^5\) In this section we study the cosmological mass density assuming that \(l_s\) is dark matter. Assuming that the cosmological mass density \((\rho)\) is dominated by baryonic matter \((\rho_b)\) and \(\bar{T}_s(l_s)\) \((\rho_{\bar{T}_s} \text{ and } \rho_{l_s})\), we obtain the following relation\(^5\) for the present-day mass densities in units of the critical mass density \((\rho_C = 3H_0^2/8\pi G, \Omega = \rho/\rho_C, \Omega_b = \rho_b/\rho_C)\),

\[
\Omega = \Omega_{l_s} + \Omega_{\bar{T}_s} + \Omega_b,
\]

where \(\Omega_{l_s} - \Omega_{\bar{T}_s} = 4\Omega_b M/M_N\), where \(M(M_N)\) is the mass of \(l_s^e\) (nucleon). If we take \(\Omega = 1\) which is the prediction of the inflationary universe theory, the upper bound of \(M\) is obtained independently of the annihilation cross section of \(\bar{T}_s - l_s\),

\[
M < M_b((1 - \Omega_b)/\Omega_b)/4.
\]

According to the analyses of the nucleosynthesis,\(^8\) \(0.04 < \Omega_b h^2 < 0.14\), where the present-day Hubble constant \(H_0\) is expressed as \(H_0 = 50 \, \text{h} \, \text{km/s/Mpc}\). The direct observation shows that \(1 \leq h \leq 2\). However, the age of the galaxy seems to show that the age of the universe is larger than 10 Gyr, which implies \(H_0 < 70 \, \text{km/s/Mpc}\) if we take \(\Omega \approx 1\). Hence we take \(1 \leq h \leq 1.4\) in this paper. In this case \(\Omega_b > 0.04/1.4^2 = 0.02\). Therefore we obtain for \(\Omega = 1\),

\[
M < 11.5 \, \text{GeV}.
\]

\(\bar{T}_s\) and \(l_s\) can annihilate via \(U\) - and \(Y\)-boson exchanges as follows,\(^1,7\)

\[
\bar{T}_s + l_s \rightarrow \bar{\nu}_e + \nu_e \, \text{via } U^0 \, \text{exchange},
\]

\[
\rightarrow e^+ + e^- \, \text{via } U^+ \, \text{exchange},
\]

\[
\rightarrow \bar{u} + u \, \text{via } Y^{-2/3} \, \text{exchange}
\]

and

\[
\rightarrow \bar{d} + d \, \text{via } Y^{1/3} \, \text{exchange},
\]

where: \(U^0 = (w_2 \bar{\epsilon}_0), \, U^+ = (w_1 \bar{\epsilon}_0), \, Y^{-2/3} = (w_2 \bar{\epsilon}_i), \, \text{and } Y^{1/3} = (w_1 \bar{\epsilon}_i)\). There exist two species of colorless diagonal bosons with weak isospin=0 (denoted as \(D\)'s), which are a linear combination of \((\bar{w}_1 w_1 + \bar{w}_2 w_2), \bar{\epsilon}_0 c_0\) and \((\bar{\epsilon}_1 c_1 + \bar{\epsilon}_2 c_2 + \bar{\epsilon}_3 c_3)\). In addition, a boson constructed from \(\bar{h}\) and \(h\) exists \((N = (\bar{h} h))\). These bosons can contribute to \(\bar{T}_s l_s \rightarrow \bar{f} f(f \text{ is lepton or quark})\). However these bosons also affect neutral currents of the lepton and quark in the tree level. The remarkable success of the standard
model implies that the masses of these bosons are much larger than the $W$-boson mass. Hence we neglect the contributions of these bosons (i.e., $D$'s and $N$). If we take $SU(6)_{we}$, we obtain for $\bar{T}_s - l_s$ annihilation cross sections at a low energy limit,

$$ (\sigma \cdot v_{rel}) = (G_F M^2 / \pi) N_A, $$

where $v_{rel}$ is a relative velocity and

$$ N_A = (M_w / M_{l_s})^4 + (M_w / M_{\bar{T}_s})^4 + 3 [(M_w / M_{\bar{T}_s} - 2 \omega)^4 + (M_w / M_{\bar{T}_s} - 2 \omega)^4]. $$

In our model the dark matter exists asymmetrically. Griest and Seckel have studied in detail the mass density of cold dark matter in an asymmetrical case. We analyse the cosmological mass density using their results. In our model the net number of $\bar{T}_s$ and $l_s$ is not so large compared with that of baryon ($n_{\bar{T}_s} - n_{l_s} = 4 n_b$, where $n$ is the number density.) Therefore, taking $a \ll Y_f$ in Eq. (15) of their paper, we use the following for the $Q$ value of the minority component (namely $\Omega_s$),

$$ \Omega_s = (4 M / M_N) \Omega_0 \exp [-4 (M / M_N) (\Omega_b / \Omega_s)] / (1 - \exp [-4 (M / M_N) (\Omega_b / \Omega_s)]), $$

where $\Omega_0$ is a value of $\Omega_{00}$ in a symmetrical case. Taking $M / T_f \approx 20$ where $T_f$ is a freezeout temperature, we obtain

$$ \Omega_s \approx 35 / (\sqrt{(M / \text{GeV})^3 N_a h^2}) \times (16 g^*(T_f))^{1/2}, $$

where $g^*(T)$ is the usual effective number of relativistic degrees of freedom at temperature $T$. $g^*$ changes drastically at the QCD confinement temperature $T_c$. At $T < T_c$, gluons, quarks, photons and leptons are treated as free particles. At $T < T_s$, photons, leptons and low mass ($m < T_c$) hadrons mainly contribute to $g^*$. If $T_c = 0.2$ GeV, we obtain for $g^* 57/4$ for $m_u < T < m_\pi$, 69/4 for $m_\pi < T < T_c$, 247/4 for $T_c < T < m_\pi$, and 289/4 for $m_\pi < T < m_c$, where we take $m_u = m_d = 0$ and $m_s = 0.15$ GeV. Hence we can take in a first approximation, considering a relevant value of $T_f < 11.5/20 \sim 0.6$ GeV, that $g^* = 16$ for $T < T_c$ and $= 64$ for $T > T_c$. However, this step function is not realistic. In this paper we take $g^* = 16$ for $T < 0.175$ GeV and $g^* = 64$ for $T > 0.225$ GeV and interpolate linearly between 0.175 and 0.225 GeV. $Q_s$ depends severely on the masses of $U$ and $Y$. As discussed previously a naive guess suggests that $M_u < M_{l_s} \sim M_w < M_Y$. The flavor changing neutral current problem suggests $M_Y \gg 1$ TeV. In this paper we take $M_U = M_w$ and $M_{U'} < M_w$ and neglect $Y$ exchanges. Hence we use,

$$ N_A = N_A^\text{eff} = (M_w / M_{U'})^4 + 1. $$

(a) Qualitative features of our model

Equation (14) shows that, for a small $M$, $\Omega_s \sim \Omega_0$ and, for a large $M$, $\Omega_s \sim 0$. Since both $U'$ and $W$ belong to the same multiplet in $SU(6)_{we}$ and both are colorless, they are expected to have the same mass in a first approximation. For a qualitative discussion, it is sufficient to take

$$ M_{U'} = M_w, \quad g^* = 16, \quad h = 1, $$

and
\[ \Omega = 2\Omega_b + 4\Omega_b M/M_N + \Omega_b. \]  

In this case we have that \( \Omega_{\text{min}} \sim 16\Omega_b^{2/3} + \Omega_b \). Hence,

\[ \Omega_{\text{CDM}}/\Omega_b = (\Omega - \Omega_b)/\Omega_b > (\Omega_{\text{min}} - \Omega_b)/\Omega_b \sim 16\Omega_b^{-1/3} > 16\Omega_b^{2/3}. \]  

If we take \( \Omega = O(1) \), then \( \Omega_{\text{CDM}} \gg \Omega_b \), which implies that the universe is dominated by the dark matter and \( \Omega_b \ll 1 \). These fit nicely to the real situation. Thus our model can naturally explain the peculiar features of the universe.

(b) Quantitative analysis

Using Eq. (14) and the assumed values of \( g^* \), we perform a full analysis of \( \Omega \). If \( M_{U^0} < M_Z/2 \), the process \( Z \to U^0 U^0 \) occurs. Since \( r = \Gamma(Z \to U^0 U^0)/\Gamma(Z \to \nu e\nu_e) = (1 - 4/y)^1/2(y^2 + 16y - 48/y - 68)/8 \) \( (y = M_L^2/M_{U^0}^2) \), in the case \( M_{U^0} = 40 \text{ GeV} \) (45 GeV),

\[ h = 1.0 \quad \Omega_{B^*} = 0.04 \]
\[ M_{U^0} = 75 \text{ GeV} \]
\[ 65 \text{ GeV} \]
\[ 55 \text{ GeV} \]
\[ 45 \text{ GeV} \]

![Graph](a)

\[ h = 1.0 \quad \Omega_{B^*} = 0.05 \]
\[ M_{U^0} = 65 \text{ GeV} \]
\[ 55 \text{ GeV} \]
\[ 45 \text{ GeV} \]

![Graph](b)

\[ h = 1.0 \quad \Omega_{B^*} = 0.06 \]
\[ M_{U^0} = 50 \text{ GeV} \]
\[ 45 \text{ GeV} \]

![Graph](c)

Fig. 1. Plots of \( \Omega \) versus \( M_{L_S} \) for \( h = 1 \) for various values of \( \Omega_b h^2 \) and \( M_{U^0} \). (a) for \( \Omega_b h^2 = 0.04 \), (b) for \( \Omega_b h^2 = 0.05 \) and (c) for \( \Omega_b h^2 = 0.06 \).
According to recent experiments,\textsuperscript{11} there is no evidence that \( \Gamma_T \) is larger than that in the three generation standard model. Hence we take \( M_{\nu s} \approx 45 \) GeV. \( \mathcal{Q} \) is a function of \( M(=M_{\nu s}), Q_b, M_{\nu s} \) and \( h \). In Fig. 1 we plot \( \mathcal{Q} \) versus \( M \) for \( h=1 \) for various values of \( M_{\nu s} \) and \( \Omega_b h^2 \). \( \mathcal{Q} \) for other values of \( h \) is that multiplied by \( (h/s)^{0.7} \).

Table I. Values of \( M_{\nu s} \) (in units of GeV) for \( \mathcal{Q}=1 \) for various values of \( h \) (\( H_0=50 \) km/s/Mpc), \( M_{\nu s} \) and \( \Omega_b h^2 \). Values of \( \Omega_b h^2 \) are also given in parentheses, where zero implies \( \Omega_b h^2<10^{-5} \). (a) for \( h=1 \), (b) for \( h=1.2 \) and (c) for \( h=1.4 \).

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by $h^{-2}$, if we fix $Q_{bh^2}$, $M_{u_0}$ and $M$. As $h$ gets larger, $M_{u_0}$ smaller and $Q_{bh} h^2$ smaller, $\Omega$ becomes smaller. Taking $h=1.4$, $M_{u_0}=45$ GeV and $Q_{b} h^2=0.04$, we obtain $\Omega_{\text{min}} \sim 0.35$ at $M=3.6$ GeV. If $\Omega$ turns out to be <0.35, our model will be excluded. If $\Omega = 1$ as required by the inflationary universe, the values of $M$ are determined as shown in the Table, where the values of $\Omega_{ls}$ are also given. In the previous papers we mentioned that the condition of $\Omega = 1$ requires $M_{u_0} < 40$ GeV in the case $h=1$. This is due to a crude approximation (Eq. (17)). The better analysis in this paper shows that a solution of $M$ for $\Omega = 1$ exists for $h=1$ if $M_{u_0} \leq 75$ GeV. The existence of a solution for $\Omega = 1$ requires $Q_{b} \leq 0.07$ for all values of $h$. $M$ has two solutions for $\Omega = 1$ except for a special case. In many cases $\Omega_{ls} \sim 0$ at a larger value of $M$, namely the universe is dominated by $\Omega_{ls}$. If $H_0 \leq 40$ km/s/Mpc, there is no solution for $\Omega = 1$.

Hence, if the age of the universe is larger than 17 Gyr, our model encounters a serious difficulty. If we take $M_{u_0} = M_{w}$, a solution for $\Omega = 1$ exists for any values of $M_{u_0}$ in the case of $h=1.4$. Even if $M_{u_0}$ is restricted to the value $<M_{u^*}$, the solution exists for $M_{u_0} < 125$ GeV (if $M_{u^*} \rightarrow \infty$, $M_{u_0} \leq 105$ GeV). For a smaller $H_0$, whether a solution for $\Omega = 1$ exists or not depends considerably on the value of $T_s$. If $T_c = 0.4$ GeV, the solution does not exist for $M_{u_0} > 58$ GeV for $Q_{bh^2} = 0.04$ and for $M_{u_0} > 50$ GeV for $Q_{bh^2} = 0.05$ in the case $h=1$. However, it seems reasonable to take $T_c \sim 0.2$ GeV.

(c) Monochromatic neutrinos from the SUN and related problems

If $\bar{T}_s$ and $I_s$ are captured by the SUN in a sufficient amount, $\nu_e$ with $E_\nu = M$ will be detected in the proton decay detectors. The flux of the neutrino is determined mainly by the capture rate of the minority component (i.e., $I_s$) and by the branching ratio of $\bar{T}_s l_s \rightarrow \bar{\nu}_e \nu_e$ ($=BR$), as far as $M$ is larger than evaporation mass ($\sim 3.3$ GeV). In our model $BR$ is expected to be large ($\sim 1$). Certainly, even if we take a condition of $\Omega = 1$, the case $M > 3.3$ GeV exists (e.g., $M = 3.9$ and 5.6 GeV for $h=1$, $Q_{bh^2} = 0.04$ and $M_{u_0} = 60$ GeV) as shown in the Table. However, the capture rate is proportional to $\rho_{ls} \times$ (cross section of elastic scattering of $I_s$ off nuclei). The elastic scattering of $I_s$ ($\bar{T}_s$)-Nucleus occurs via $Y$-, $D$- and $N$-bosons. As mentioned previously, $M_T$ is expected to be extremely large and $M_0 (M_0)$ to be sufficiently larger than $M_D$. If $M_D \sim 5 M_Z$, $\sigma_{\nu N}$ is very small compared with that in heavy Dirac neutrino $\nu_D (\sigma_{\nu NN})$ because $\sigma_{\nu NN} / \sigma_{\nu NN} \sim (M_Z / M_0)^4 \sim 1/625$ (we assume a $(V-A)$ for the coupling of $D$). In this case, for the monochromatic electron neutrino flux from the SUN ($\phi$), we obtain that $R = (\phi$ in the $I_s$ case)/$\phi$ in the symmetric $\nu_D$ case) $< 1/625 \times 1/0.07 \sim 0.02$, where we use $BR$ of $\nu_D \sim 0.07$. Therefore, although the absence of the signal in the proton decay detector experiments is fatal to the symmetric $\nu_D$ case, our model passes easily this constraint. In the case $h=1$, $Q_{bh^2} = 0.04$, $M_{u_0} = 60$ GeV and $M = 3.9$ GeV, we have $R \sim 0.006$. Hence the predicted flux is smaller by more than one order of the magnitude than the experimental upper limit. In the case $M = 5.6$ GeV, the predicted flux is negligibly small almost independently of the masses of $D$, $N$ and $Y$, since $\Omega_{ls} < 1$. An anti-proton flux due to occasional annihilations $\bar{T}_s I_s \rightarrow \bar{q}q$ in the galactic halo may not be large enough to detect due to the same reason in the neutrino flux.

The direct detection of the recoil nucleus produced through dark matter-nucleus scattering on the earth will be useful to confirm the existence of the cold dark matter and to clarify its property. Since $I_s$ has a rather small mass ($< 12$ GeV), the detection
scheme of superheated superconducting colloids proposed by Druiker and Stodolsky\textsuperscript{14} may be necessary, which is expected to detect or rule out GeV mass dark matter candidates. Whether the direct detection of $\nu_s$ in this scheme is really possible or not depends, of course, on the masses of $D$, $N$- and $Y$-bosons. If one of them (e.g., $D$) has a smaller mass than $\sim 1$ TeV, the direct detection will be possible because, according to the study of Druiker, Freese and Spergel,\textsuperscript{15} the count rates are expected to be $\sim 1$ count/day or larger for a 1-kg detector.

§ 4. Discussion

Stepping into the subpreon level, we have understood the existence of $B$ and $L$ non-conserving processes. The essential ingredient of the idea is to consider that quantum numbers such as $B$ and $L$, whose coservations are not guaranteed by the gauge principle, are possible to be defined when preons are constructed from sub-preons. This makes the subpreons free from such ad hoc quantum numbers and so the subpreon world on a higher level from the viewpoint of the gauge principle.

This progress settles some problems which necessarily exist at the preon level. At the preon level, matter is in a very complicated situation as shown typically by the copious existence of charged and colorless preons, $w_1$, $w_2$ and $c_0$, in spite of the rather simplicity of gauge interactions and so we cannot specify all preons in terms of the physical properties with respect to gauge interactions alone. This unfavorable point as a fundamental property of Nature is removed in the subpreon physics once we recognize a simple pattern of charged and colored particles, namely $(\beta_1, \beta_2, \beta_3, a)$. This implies that the subpreon world approaches a profound essence of Nature. The simple grouping $(\beta_1, \beta_2, \beta_3, a)$ strongly suggests that QED and QCD will be connected on a higher level in the subpreon world.

Due to the $B$ non-conserving process a proton decay can occur in general and the generation of the $B$ asymmetry of the universe takes place (for the latter the natural existence of the $CP$ violation in our model is also important). However, the proton decay does not really occur due to a negative $Q$-value (i.e., 4 times the mass of $l_s$ > the proton mass). In many models it is a very difficult problem to reconcile the existence of the asymmetry of the universe and the longevity of the proton. The existence of the simple solution to this problem may be one of virtues of our model.

Since $l_s$ is the stable weakly-interacting massive particle, it exists in a considerable amount in the present-day universe. Taking it as cold dark matter, we can naturally explain the fact that $\Omega_{\text{DM}} \sim O(10) \times \Omega_b$. Our model has a solution to $\Omega = 1$ over a wide range of the mass of $U^0$, i.e., $\leq 125$ GeV, without a contradiction with the experiments on the neutrino flux from the Sun. (Our success is not trivial. Note that symmetric heavy Dirac neutrinos, sneutrinos and Majorana neutrinos are already excluded as a dark matter candidate by the experiments on the neutrino flux from the SUN.\textsuperscript{13}) Survivors are not many.) The cosmological parameters are restricted severely. If we take $\Omega = 1$, $H_0 > 40$ km/s/Mpc and $\Omega_b \leq 0.07$. Fortunately, these are within observed limits. The mass of $l_s$ is probably smaller than 11.5 GeV. $e^+ - e^-$ annihilation experiments with a high luminosity may be able to detect $l_s$ through $e^+e^- \rightarrow l_sl\gamma$. It will be a pleasure if $U^0$ (or $U^+$) has a rather small mass ($< M_W$) and
future experiments at LEP can confirm the existence of $U^0$ (or $U^+$). As for a
detection of $l_s$ as cold dark matter, the detector of the Druker-Stodolsky type\textsuperscript{14} may
be useful.

In our model the lowest mass particle (LMP) among the new fermions and $U$- and
$Y$-bosons is stable. We have always taken that it is $l_s$. Although this choice is
certainly the most attractive one from a theoretical point of view, it is undoubtedly an
assumption. The cosmology gives a powerful argument that only this choice is
viable. In order that LMP behaves as dark matter, it must interact only weakly.
Among the first class particles, there exist two candidates, namely $l_s$ and $U^0$. If $U^0$
is stable, Eq. (4) implies that the composition of the universe is $P + e^- + 4 \bar{\nu} + 4 \bar{U}^0$.
Hence, as for the cosmological mass density, it may appear that these two cases give
similar predictions. However, there is an essential difference. While $l_s$ is a weak
isospin singlet, $U^0$ belongs to a weak isospin doublet. $U^0$ couples to $Z$ and so
$Z \to U^0 U^0$ occurs if $M_{U^0} < M_{Z}/2$. As discussed previously, recent experiments strongly
suggest $M_{U^0} > 45$ GeV. Hence, $\Omega > 4 \Omega_0 M_{U^0}/M_N > 200 \Omega_0 > 4$. Thus we cannot adopt
the stable $U^0$ as dark matter. In addition, the stable $U^0$ case brings about a serious
trouble in the CDM detection experiments on the earth. $U^0$ can scatter through a $Z$
exchange coherently off nuclei. Hence the stable $U^0$ with such a large mass should
be detected in the Ge detectors. Recent experiments exclude this case.\textsuperscript{16} The origin
of troubles in the $U^0$ case is that it belongs to a weak isospin doublet. Heavy Dirac
neutrino as CDM also encounters a serious difficulty in a similar manner to the case
of $U^0$, even if, taking asymmetrical $\nu_D$, one passes the constraint from the neutrino
flux from the Sun. In the $l_s$ case, such a trouble does not occur due to its neutrality
under the weak isospin. The new particle required from the CDM problem must not
couple to $Z$ in a similar way to leptons and quarks. This strongly suggests that the
required particle is not relative of leptons and quarks but very exotic, such as the
photino or our $l_s$.

Acknowledgements

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References

11) M. Yasue, a private communication.