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Coherent Understanding of New Phenomena of Weak Interactions - Weak Charge of Cs, Muon g-2 and WIMP-CDM

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Abstract

Now it is sure that the weak interaction phenomena are rich beyond the standard model. This is typically shown by the positive excess of $Q_W(Cs)$ of the order of 1% and the recent discovery of positive excess of the muon (g-2) as well as the existence of WIMP-CDM. These are discussed based on the preon model. The muon (g-2) naturally receives a positive extra contribution through a new diagram with properties similar to the (W, ν) loop.

§ 1. Introcuction

The standard model (SM) is very successful in describing low energy phenomena. It predicts the existence of W and Z bosons with unique properties, which have been confirmed experimentally as a whole. It is sure that the SM reflects some essential features of Nature, including the gauge boson nature at low energies of the W(Z). However, it is also sure that the SM cannot give a natural explanation to several important facts, such as the baryon asymmetry of the universe (BAU), the existence of cold dark matter (CDM) and neutrino oscillations. Furthermore, the SM suffers from a naturalness problem due to the existence of fundamental Higgs fields.

As a candidate of physics beyond the SM, supersymmetric (SUSY) extensions of the SM, including SUSY GUTs, have been studied by many physicists. However, SUSY models have encounterd serious problems. For example, the proton decay has not been observed even at the Superkamiokande.[1] Now, we know that $\tau_p(p \to e^+ \pi^0) > 4.4 \times 10^{33}$yr and $\tau_p(p \to \nu K^+) > 1.9 \times 10^{33}$yr. In these models, such a longevity of the proton is very difficult to explain in a simple and natural way.[2] Of course, because of the existence of the BAU, baryon number non-conserving processes must exist. The model required by Nature would be that in which the puzzling facts, the BAU and the stability of proton, are reconciled. The existence of stable weakly-interacting-massive-particles (WIMP) relies on a rather ad hoc assumption, the conservation of R

parity, and is not a necessary consequence of the model. The prediction of what particles exist stably is one of the fundamental properties of a model and therefore should be a necessary consequence of it. The Higgs boson (usually called h) should be light. In the foreseeable future, this will be fully tested. However, even the present lower limit on the h mass, if combined with other constraints, gives rise to a severe problem, namely, the appearance of color and charge breaking vacua, at least in the most desirable case, MSSM with low $\tan\beta$.[3] Moreover, we believe the facts of fundamental importance such as color and charge conservation should be a necessary consequence of the model itself, and must not be parameter-dependent. The principal content of a model is expressed by the conservation laws it possesses, and the quality of the model is determined by the manner the conservation laws are guaranteed. In the SM the observed CP violations can be accommodated through the Kobayashi-Maskawa mechanism, though the fundamental origin of CP violations remains an open problem. In SUSY models the situation becomes worse: the origin of CP violations is still unsettled, and even the success of the Kobayashi-Maskawa mechanisn is a mystery because many other sources of CP violation exist in SUSY models. The author strongly feels that SUSY models do not succeed in explaining, with simplicity and naturalness, the principal features of Nature, although, of course, in order to draw a definite conclusion on the validity of SUSY models, it is necessary to -

make clear whether superpartners of mass below 1 TeV exist or not.

If the WIMP-CDM is the case, it implies weak interaction phenomena are rich beyond the SM. Recently results of very precise experiments at low energies have been reported, which strongly support this ststement. They are the weak charge of Cs[4] and g-2 of muon[5]. In the discovery of a true particle model, it is of fundamental importance to explain the whole of weak interaction phenomena in a natural and unified way, and so it is one of key points to the validity of model whether it gives a coherent understanding of the whole weak interaction phenomena.

One of the ways to go beyond the SM is, along the line of the atomic view, to consider that leptons, quarks and weak bosons are composites of more fundamental matter, namely to assume a full preon model. Recently we have developed a full preon model by introducing preons with charge e/2 and a preonic charge which is identified with the magnetic charge.[6)-11)] All preons also carry a common color magnetic charge, which is a source of the color magnetic field. Preonic charge is responsible for binding preons. Bound states of preons are conjectured to behave as strings at long distance due to the formation of a magnetic flux tube through the Meissner effect. Through the well-known mechanism,[12)] W bosons behave as gauge bosons at low energies, energies much lower than the mass scale typical of preon dynamics, $\Lambda_P \sim$ 1000 TeV. (In the ortho-para mixing model for family mixing,[9,10)]

we have that the charm quark mass $\sim A^2/\Lambda_P$ with $A \sim 10^{-3}\Lambda_P$ which implies $\Lambda_P \sim 1000$ TeV.) At energy of $O(M_Z)$, corrections to the gauge theory of W(Z) are expected to be the order of $(M_Z/\Lambda_P)^2 \sim 10^{-8}$, because a string amplitude (F) can be expanded at low energy in powers of the Regge slope $\alpha' \sim \Lambda_P^{-2}$, $F = F_0 + \alpha' F_1 + \cdots$ and the second term represents a dominant non-gauge-theory effect. The universality of coupling constants is expected to hold with excellent accuracy at low energy. The identification of preons with dyons leads to the conclusion that preons cannot be the most elementary particles. In our model preons are constructed from subpreons. Ad hoc quantum numbers, B and L, the conservations of which are not guaranteed by any gauge principle, are defined when preons are constructed from subpreons. Subpreons are free from such ad hoc quantum numbers, and their conservations are guaranteed by the gauge principle. The baryon number non-conserving processes originate in the subpreon physics.[8]

The model has some interesting features, such as the explanation of charge quantization and color-charge relations,[6] the natural existence of CP violation,[10),7)] and the understanding of quark masses, CKM matrices and CP violation effects in weak interactions.[9,10] A nearly maximal ν_{mu} - ν_{tau} mixing is realized in a simple way.[13] While CP violation effects are necessarily tiny at long distances as shown by the very small Jarlskog parameter, they become comparable to those of CP conserving interactions at short distances due to the running of the coupling

constants. The remarkable features of the model are that there exists naturally a stable WIMP (called l_s), which behaves as CDM in the universe, and that the proton becomes stable despite the existence of baryon number non-conserving processes.[8] In our model the existence of CDM and the stablity of the proton are directly related.

This model predicts many new particles. In this paper we shall show that new processes generated by new particles naturally explain new weak interaction phenomena.

§ 2. Weak charge of Cs and muon g-2

In our model, vector bosons belong to $\underline{35}$ under $SU(6)_{wc}$.[7] Among them, those expected to be relatively light constitute an octet[7] under $SU(3)_{w_1 w_2 c_0}$ that is a subgroup of $SU(6)_{wc}$. The octet contains W(Z), an isodoublet (U^+, U^0) and their antiparticles, and an isoscalar D_1. The structures of octet bosons are as follows: $W^+ = (w_1 \overline{w}_2)$, $W_3 = (w_1 \overline{w}_1 - w_2 \overline{w}_2)/\sqrt{2}$, $U^+ = (w_1 \overline{c}_0)$, $U^0 = (w_2 \overline{c}_0)$, and $D_1 = (w_1 \overline{w}_1 + w_2 \overline{w}_2 - 2 c_0 \overline{c}_0)/\sqrt{6}$. Leptons and quarks, together with the CDM particle l_s and other fermions, belong to $\underline{15}$ under $SU(6)_{wc}$. Leptons and l_s constitute an anti-triplet under $SU(3)_{w_1 w_2 c_0}$. The fermion l_s is completely neutral under the SM gauge group. They have the following structure: $\nu = ([w_1, c_0]h)$, $e = ([w_2, c_0]h)$ and $l_s = ([w_1, w_2]h)$, where $[p_j, p_k] = (p_j p_k - p_k p_j)/\sqrt{2}$. Among predicted new particles, first class particles participate in processes only in pairs. The fermion l_s and bosons U belong to the first class. The first and second family l_s's have almost equal masses. From

the cosmological argument, they are required to lie around 10 GeV.[8]

In our model there exists a symmetry which holds better than $SU(6)_{wc}$ and $SU(3)_{w1w2c0}$. It is a symmetry between w_2 and c_0 (we call it K symmetry).[10] This is because w_2 and c_0 have the same color, electric charge as well as magnetic charge. K symmetry, of course, is not an exact symmetry due to various symmetry breaking effects such as the mass difference between w_2 and c_0 and possible subpreonic effects. The K symmetry connects l_s and U^+ with ν and W^+ as follows:

$$l_s \longleftrightarrow \nu \quad \text{and} \quad U^+ \longleftrightarrow W^+.$$

In the K symmetry limit, l_s is nearly massless and the U^+ mass is equal to the W mass. Under the K transformation, e transforms into -e and so we have that the ratio of the coupling constant of $We\nu$ to that of Uel_s equals to -1.

The elastic scattering of electron and quark takes place at the tree level through the Z and D_1 boson exchanges. Hence the weak charge of Cs atom has an extra contribution $(Q_W(Cs)^D)$due to the D_1 exchange. As discussed in the previous paper,[14] it is expressed as

$$Q_W(Cs)^D = a_e{}^D\{(2Z+N)v_u{}^D + (Z+2N)v_d{}^D\} \frac{M_Z{}^2}{M_D{}^2}, \tag{1}$$

where, with $s_W(c_W)$ the sine (cosine) of the Weinberg angle, $a_e{}^D$ is the axial coupling of electron in the unit of $e/(4s_Wc_W)$ in the eeD_1 vertex$(= 1/\sqrt{3-4s_W{}^2})$, $v_u{}^D$ the vector coupling of u quark

$(=(1-8s_W^2/3)/\sqrt{3-4s_W^2})$, v_d^D that of d quark$(=(1-2s_W^2/3)/\sqrt{3-4s_W^2})$, and Z(N) the number of the proton (neutron) in the ^{133}Cs nucleus. The contribution of e-d interaction via the Z exchange to Q_W is negative due to the isotriplet nature of the Z boson and exceeds that of e-u interaction that is positive, and so Q_W is negative. In the exchange of D_1 boson which is an isoscalar partner of W(Z) in the vector boson octet, both the contributions of e-u interaction and of e-d one are positive, and so $Q_W(Cs)^D$ is necessarily positive. In the case of $M_D \sim 1$ TeV, $Q_W(Cs)^D$ is $\sim$ 1.0 for $s_W^2=0.23$, Z=55 and N=78. Thus we can explain the reported discrepncy of $Q_W(Cs)$ between the SM and experiments[4] both in the sign and in the magnitude. This is a non-trivial success of our model.

In our model the muon anomalous magnetic moment, $a_{mu}=(g-2)/2$, receives contributions from the processes of pure QED, of QED with hadronic vacuum polarisation and of the octet gauge boson exchange. The diagrams at the one loop level which contribute to the last are shown in Figure. They are the (W, ν), (Z, μ),

Figure

(charged U, l_S) and (D_1, μ) loops, whose contributions to a_{mu} are denoted as a_{mu}^W, a_{mu}^Z, a_{mu}^U, and a_{mu}^D, respectively. Thus, in our model, a_{mu} has extra contributions, a_{mu}^U and a_{mu}^D, besides those in the SM. Since the mass of D_1 is ~ 1 Tev, a_{mu}^D can be safely neglected. The reported deviation of a_{mu}, Δa_{mu}, is attributed to a_{mu}^U in our model. Unfotunately our model has not been

developed enough to calculate reliably the loop diagrams. However, invoking the K symmetry inherent in our model, we can make a qualitative and semi-quantitative discussion.

Through the K symmetry, a_{mu}^{U} is directly related to a_{mu}^{W} and both are the same in the limit of the exact K symmetry, that is, a_{mu}^{U} is postive and its absolute value is $(G_F m_{mu}^2/6\pi^2\sqrt{2}) \times 5/2 \sim 39 \times 10^{-10}$ since $\kappa_U = \kappa_W = 1$,[15] where G_F is the muon decay constant and m_{mu} the muon mass. The K symmetry is not exact and therefore the mass of U^+ (M_U) is not equal to the mass of W (M_W). According to the LEP 2 experiments, M_U is larger than 104 GeV due to the absence of the event $e^+e^- \rightarrow U^+U^- \rightarrow$ charged lepton pair+ missing energy.[11] Hence, we obtain

$$a_{mu}^{U} = a_{mu}^{W} \times (M_W/M_U)^2. \qquad (2)$$

In Eq.(2), l_S is assumed to be massless. Since it is sufficiently light, this may not be unreasonable. If we take seriously Eq.(2), we have

$$a_{mu}^{U} = 21 \times 10^{-10} \quad \text{for } M=110 \text{ GeV},$$

$$= 18 \times 10^{-10} \quad \text{for } M=120 \text{ GeV},$$

and

$$= 15 \times 10^{-10} \quad \text{for } M=130 \text{ GeV}. \qquad (3)$$

Eq.(3) shows that, although the sign of Δa_{mu} is correctly given and its magnitude agrees roughly with the data, a_{mu}^{U} is slightly lower than the reported value for Δa_{mu}, $43 \pm 16 \times 10^{-10}$.[5] The theoretical value has some uncertainties such as that of the hadronic vaccum polarization contributions.[16] However, these will not alter the theoretical value largely. In a near future, more

precise 0.4 ppm data on positive and negative muon will be available. An answer to the validity of our model will be given by these experiments. In our model, muon is an extended object. In principle, this fact gives an effect to a_{mu}. However, its radius is very small, $\Lambda_p^{-1} \sim (1000\ \mathrm{TeV})^{-1}$, so that its contribution to a_{mu} is expected to be negligibly small, of the order of $(m_{mu}/\Lambda_p)^2 \sim 10^{-14}$.[17]

The fact that Δa_{mu} is of the order of a_{mu}^W suugests the existence of new particles (X) which interact with a strength of normal weak interactions but do not have a vertex X-f-f′ with a normal weak interaction strength (f anf f′ are leptons and/or quarks). Thus the hypothesis of WIMP as CDM particle is strongly supported. In order for a model to be viable, a natural existence of WIMP-CDM is indispensable. In our model the lightest of first class particles, l_s, is stable and its interactions are mainly governed by neutral and charged U boson exchanges. Therefore it is naturally a required WIMP.[8,10] One of the unique points of our model is that l_s and anti-l_s exist asymmetrically in the Universe and so a number density of minority component natully becomes extremely small. Hence, on the contrary to the neuralino dark matter model, it is no problem that any signal due to WIMP annihilations has not been observed, even from the galactic center.[18] (The observed Sgr A* spectrum at radio wavelengths might be due to WIMP annihilations at the galactic center.[19] If this is the case, it implies that the ratio of the number density

of l_S to that of anti-l_S is $\sim 10^{-7}$, which is realized easily in our model. This point will be discussed elsewhere.)

A direct detection of l_S as CDM particle can be performed through a detection of the recoil nucleus generated by l_S-nucleus scattering, $l_S A \rightarrow l_S A$ which occurs via the D_1 exchange. In this case the detection rate is governed by its cross section ($\sigma(l_S A \rightarrow l_S A)$). Instead of $\sigma(l_S A \rightarrow l_S A)$, usually the cross section per nucleon $\sigma(l_S N \rightarrow l_S N)$ is used. We predict that,[14]

$$\sigma(l_S N \rightarrow l_S N) \sim \pi [\alpha/(2M_Z^2 s_W^2)]^2 [Q_W(Cs)^D/133]^2 M_{red}^2, \qquad (4)$$

where $M_{red} = M_N m/(M_N + m)$ ($M_N(m)$ is the nucleon(l_S) mass). Eq.(4) is nealy a constant since $M_{red} \sim M_N$ due to the fact that m is sufficiently larger than M_N. For $Q_W(Cs)^D \sim 1.0$ (namely, $M_D \sim 1$ TeV), $\sigma(l_S N \rightarrow l_S N) \sim 2.0 \times 10^{-43} cm^2$ for $m \sim 10$ GeV. The ongoing and future direct detection experiments will be able to confirm or exclude our model.

§ 3 Remarks

The observed deviation Δa_{mu} can be also explained in SUSY models if $\tan\beta$ is taken to be large.[16] However, there exist serious problems. These models cannot predict the sign of the deviation. Even if it were observed to be negative, it could be also accommodated in the models. Since the lifetime of proton is proportional to $\tan^{-4}\beta$ at large $\tan\beta$, a large $\tan\beta$ is disastrous to explain the longevity of proton. It seems to be extremely difficult to construct a model that can escape this problem without destroying the essencial features of GUTs, e.g., the charge

quantisation and the unity of coupling constants. The large positive excess of $Q_W(Cs)$ of the order of 1% implies the necessity of the extension of the SM at the tree level. Despite the existence of many new particles and many free parameters, the SUSY SM could not explain the excess of $Q_W(Cs)$ without introducing further new particles just to explain the excess. Considering these points, a coherent understanding of the real world in our model may be noteworthy.

A sizable $a_{m_U}{}^U$ implies not so heavy charged U boson (say, $M_U < 160$ GeV), which leads to some excess of the cross section of $e^+e^- \to \gamma$ +missing energy over that in the SM.[20] According to the analysis by C. Matteuzzi et al.,[21] the lower bound on M_U from this process is rather low at the present stage, $M_U > 87$ GeV.

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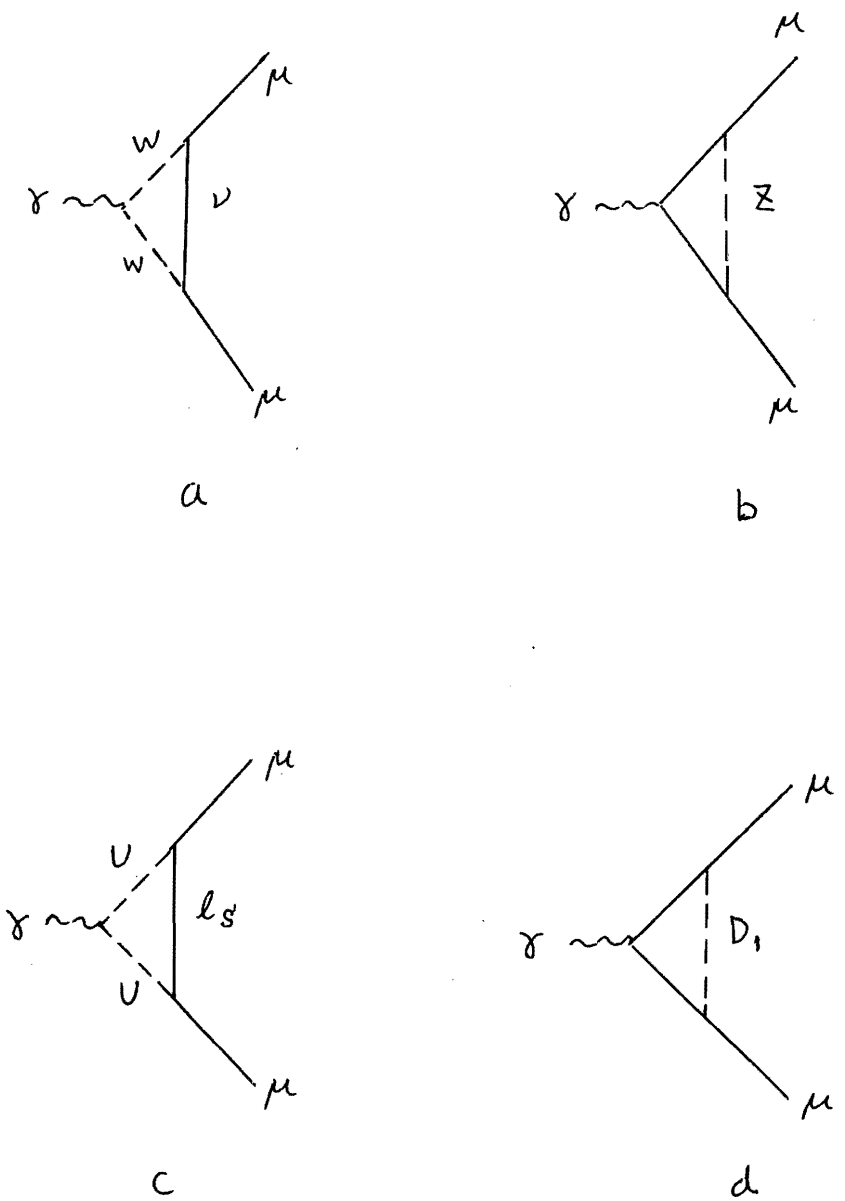

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One loop octet gauge boson exchange diagrams contributing to the muon anomalous magnetic moment.