CURRENT TOPICS IN HADRO-PARTICLE PHYSICS

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Current topics in particle (and nuclear) physics are discussed in some details. The contents of this talk include exotic nuclei, colorball as pomeron, neutrino masses and mixings, higgs scalar mass, superparticles, substructure of quarks and leptons, structure of the universe, future prospects.

Introduction

In this talk, I am going to discuss current topics in particle (and nuclear) physics in some details. Some parts of the contents in this talk have already been published either in the recent journals or in the proceedings of the recent international conferences, to which I will refer wherever appropriate and in which you can find the mathematical details.

1. Exotic Nuclei

A "super-hypernucleus" is a nucleus which consists of many strange quarks as well as up and down quarks. In 1979 [1], I proposed the quark-shell model of nuclei in quantum chromodynamics(QCD) [2], presented the effective two-body potential between quarks in a nucleus, pointed out the violent breakdown of isospin-invariance and an importance of U-spin invariance in superheavy nuclei, and predicted a possible creation of superhypernuclei in heavy-ion collisions at high energies, based on the natural expectation that not only the Fermi energy but also the Coulomb repulsive energy is reduced in such nuclei. A similar idea was presented independently and almost simultaneously by Chin and Kerman [3], who called super-hypernuclei "long-lived hyperstrange mulitiquark droplets". Five years later in 1984, the possible creation of such super-hypernuclear matter in bulk (on a much larger scale of both mass number and space size) in the early Universe or inside neutron stars was discussed in detail in QCD by Witten [4], who called super-hypernuclear matter "quark nuggets" while the properties of super-hypernuclei were investigated in detail in the Fermi gas model by Farhi and Jaffe [5], who called super-hypernuclei "strange matter". In a series of papers published in 1989 and 1990 [6], I reported an important part of the results of my investigation on the mass spectrum and other properties of super-hypernuclei in the quark-shell model.

In 1990, Saito et al. [7] found two abnormal events with the charge of $Z = 14$ and the mass number of $A \cong 370$ in cosmic rays and concluded that they may be explained by the hypothesis of super-hypernuclei. In order to find whether these cosmic ray events are really super-hypernuclei as suggested by the cosmic ray experimentalists, I investigated how the small charge-to-mass-number ratio of Z/A is determined when super-hypernuclei are created. In the paper published in 1991 [8], I have shown that such a small charge of $3-30$ may be realized as $Z \leq [(2/3)A]^{1/2}$ ($\cong 15.7$ for $A = 370$) if the super-hypernuclei are created spontaneously from bulk super-hypernuclear matter due to the Coulomb attraction. Therefore, the most likely explanation for the abnormal events seems to be that they are, at least, good candidates for super-hypernuclei as suggested by Saito et al. [7].

However, in the other paper published in 1993 [9], I have suggested the second most likely explanation that they may be "technibaryonic nuclei" or "technibaryon-nucleus atoms". A technibaryon is a baryon which consists of techniquarks in a bound state due to the technicolor force [10]. A technibaryonic nucleus is a nucleus which consists of nucleons and a technibaryon. A technibaryon-nucleus atom is an atom which consists of a negatively charged technibaryon and an ordinary nucleus in a bound state due to the Coulomb force. The technibaryon mass can be expected to be about 2 TeV either from scaling of the baryon mass with the color and technicolor dimensional parameters Λ_C and Λ_{TC} [11] or from my estimation of the techniquark mass to be about 0.5-0.8 TeV from the PCDC (Partially-Conserved-Dilation-Current) anomaly sum rule for quark and lepton masses [12]. The mass value of about 0.4 TeV obtained for the abnormal cosmic ray events is much smaller than the expected values for technibaryonic nuclei or technibaryon-nucleus atoms. However, this value would not be excluded since a large experimental error in determining the masses might be involved. In this respect, note that the abnormal cosmic ray event found in 1975 by Price et al. [13] may be better explained by a technibaryonic nucleus or technibaryon-nucleus atom since their later analysis might indicate the charge $Z \cong 46$ and the mass number $A \geq 1000$. Also note that the abnormal cosmic ray event found in 1993 by Ichimura et al. [14] may be better (but much less better) explained by a technibaryonic nucleus or technibaryon-nucleus atom since they reported the charge of $Z \geq 32 \pm 2$.

More recently, I have proposed the third most likely explanation for the abnormal cosmic ray events that they may be "color-balled nuclei"[15]. A color-ball is a color-singlet bound state of an arbitrary number of gluons [16] or of "chroms", C_α ($\alpha = 0, 1, 2, 3$), which are the most fundamental constituents of quarks and leptons (called "subquarks" in a generic sense) with the color quantum number and which form quarks and leptons together with a weak-isodoublet of subquarks (called "wakems"), w_i ($i = 1, 2$), in the unified composite model of all fundamental particles and forces [17]. A color-balled nucleus is a nucleus which consists of nucleons and a color-ball. The color-ball of $(C_0 C_1 C_2 C_3)$ is not only electromagnetically neutral but also weakly neutral. However, it strongly interacts with any hadrons due to the van der Waals force induced by the color-singlet state of $(C_1 C_2 C_3)$ as baryons, the color-singlet states of three quarks. Its mass may be very large as scaled by the subcolor energy scale Λ_{SC} (of the order of, say, 1 TeV) [18] and its size may be very small as scaled by $1/\Lambda_{SC}$ ($\sim$ 1/1 TeV) but it may be absolutely stable. This extremely exotic particle (which we may call "primitive hydrogen") may provide us not only the third most likely explanation for the abnormal cosmic ray events but also another candidate for the missing mass in the Universe.

Already in 1971, Bodmer [19] pointed out the possibility that super-hypernuclei (which he called "collapsed nuclei") may exist on a large scale. He even suggested then that they may explain the missing mass in the Universe. For the last one decade, "strange stars" consisting of super-hypernuclear matter have been theoretically investigated in great detail [20]. If the possible identification of the recently discovered unusual hard X-ray burster GRO J1744-28 as a strange star by Cheng, Dai, Wei, and Lu [21] is right, the existence of super-hypernuclear matter or "strange matter" has already been discovered by astrophysicists as a gigantic super-hypernucleus or "strangelet", the super-hyperstar or "strange star" in the Universe, before being discovered by high-energy experimentalists in heavy-ion collisions. I must also mention that not only the recent possible identification of the X-ray pulsar Her X-1 as a strange star claimed by Li, Dai, and Wang [22] and of the X-ray burster 4U 1820-30 proposed by Bombaci [22] but also the latest possible identification of the newly discovered millisecond X-ray pulsar SAX J 1808.4-3658 suggested by Li, Bombaci, Dey, Dey, and van den Heuvel [23] seems to be just as reasonable as that of GRO J1744-28 by Cheng et al. [21]. Very lately, NASA's Chandra X-ray Obsevatory [24] has found two stars, RXJ185635-3754 which is too small (about 11.3 km) and 3C58 which is too cold (less than 1 million degrees in Celsius), being most likely strange stars.

In September, 1999, just before the BNL RHIC was about to open up a high-energy range of the order of hundred GeV/nucleon for heavy-ion-heavy-ion colliding beams, a rumor shocked the whole world [25]. It said that if a negatively charged stable strangelet were produced by RHIC experiments, it would convert ordinary matter into strange matter, eventually destroying the Earth. However, I argued that there is no danger of such a "disaster" at RHIC since the most stable configuration of strange matter must have positive electric charge thanks to the fact that the up quark is lighter than the down and strange quarks [26]. This liberation from such a horrible fear in the "disaster story" would recall us of the fact that the very existence of ordinary matter depends on the mass difference between the proton and neutron which depends on that between the up and down quarks (which further depends on that between the subquarks, w_1 and w_2)!

Concerning the observation of quark-gluon plasma (QGP) states possibly produced in high-energy heavy-ion collisions, which had been claimed strongly by the experimental groups at CERN SPS just before the RHIC was about to operate, no indication has yet been reported by the experimental groups at BNL RHIC [27]. There have been proposed several signs for the production of QGP states in heavy-ion collisions including 1) sudden change of the transverse-momentum distribution of produced particles [28], 2) sudden increase of the ratios of produced antiparticles (K^+, p^-, etc.) [29], 3) sudden suppresion of J/ψ productions, and 4) sudden broadening of the widths of produced ρ's and ω's. However, I always argue that all the proposals except for the first seem to be ambiguous since they may well indicate something else. In fact, very recently the Japanese nuclear experimental group [30] has observed a significant difference in the mass spectra below the omega meson between p+C and p+Cu interactions, indicating that the spectral shape of mesons is modified at normal nuclear-matter density.

Thus, I must conclude this Section by saying that a clear indication of exotic nuclei found in high energy experiments has not yet appeared although there are some candidates reported by cosmic-ray experimentalists and by astrophysicists. However, I must add that not only the very recent discovery of "triaxially deformed nuclei"[31] but also the latest one of the "superheavy hydrogens"[32], ^{5}H and ^{7}H, would be something exotic in low-energy nuclear physics.

2. Color-Ball as Pomeron

One of the hottest subjects in hadron-hadron, photon(gauge-boson)-hadron, and (hadronic) photon(gauge-boson)-photon(gauge-boson) scatterings at high energies is Pomeron. What is the Pomeron? It must be a kind of object which has the vacuum quantum numbers ($I^G = 0^+$ and $J^{PC} = J^{++}$) and whose t-channel exchange between hadrons universally dominates the cross section for hadron scatterings at high energies. If it is a Regge pole, its intercept is larger than unity, which leads to the increase of hadron cross sections at high energies, and its residue is rather universal to all hadrons. Is it the "soft Pomeron" whose intercept is about 1.1 or the "hard Pomeron" whose intercept is as large as 1.4? Jenkovszky, Paccanoni, and company [33] have been insisting on the uniqueness of their "extended hard Pomeron" while Donnachie, Landshoff, and company [34] have been insisting on their two-Pomeron model consisting of a conventional non-perturbative soft Pomeron with the intercept $\alpha_{\rm soft} \cong 1.08$ and a hard Pomeron with the intercept $\alpha_{\rm hard} \cong 1.40$. In addition, Nikolaev and Zollar [35] have been advocating their "running BFKL Pomeron". However, I would rather stay out of this hot debate and concentrate on the following question: What is the Pomeron made of? [16].

The simplest model is, of course, the "two-gluon-exchange model" for the Pomeron in which the Pomeron consists of two gluons and in which the Pomeron exchange can be approximated by the exchange of two gluons [36]. The second simplest model is the "BFKL Pomeron model" in which the Pomeron consists of two gluons interacting with each other and that the Pomeron exchange can be approximately described by the BFKL Pomeron equation [37] based on the DGLAP evolution equation [38]. In other words, the Pomeron is simillar to the Reggeized glueball. The third simplest picture is that the Pomeron consists of two and three gluons and that the Pomeron exchange can be better approximated by the sum of the exchanges of two and three gluons. In other words, the Pomeron is similar to the sum or mixture of the Reggeized glueballs and Reggeized odderons. Thus, we must go on and finally find the more realistic picture of the Pomeron in which the Pomeron consists of an arbitrary number of gluons and in which the Pomeron exchange is equivalent to the sum of the exchanges of any number of gluons. This "color-ball model" for the Pomeron is similar to the "color-singlet gluon cluster model" recently proposed by Meng, Rittel, Yang, and company [39]. Note also that it not only extends the now classic Nambu—Susskind hadronic string model but also revives the celebrated Freund—Harari hadron duality [which asserts that resonances in a s-channel correspond to Regge poles in a t-channel while background (or continuum) states in the s-channel to the Pomeron in the t-channel].

Thus, I have come to the main point in this Section that the Pomeron must be a "color-ball", the color-singlet complex object consisting of an arbitrary number of gluons. It seems very difficult to describe such complex objects in quantum field theory and to evaluate their effects on hadron scatterings. In fact, Meng, Rittel, Yang, and company [39] have adopted a statistical approach based on the formulation of complex systems by Bak, Tang, and Wiesenfeld [40] in describing the "color-singlet gluon clusters" with "self-organized criticality" and used an optical-geometric method in examining the space-time properties of such objects. Here, however, let me discuss how to describe "color-balls" in an ordinary particle-theoretical way.

In 1979, Nambu and, independently, Tetsuaki Matsumoto [41] showed that, if a meson can be described by the path-ordered phase factor sandwiched between a quark and an antiquark in QCD and if the gluon flux is bunched along the path when quarks are largely separated, the meson can be approximated by the Nambu—Goto massless string with quarks at their end points. It was the first field-theoretical demonstration in which the Nambu—Susskind hadronic string is realized in QCD. From their demonstration for the realization of hadronic strings, it seems natural to imagine that, if the gluon flux is not bunched but diversed along the path between quarks, it can be approximated by a "hadronic (two-dimensional) membrane" or better by "hadronic (three-dimensional) bundle". In either case, the color-ball can be approximately described by the extended Nambu—Goto action of $S_{\rm NG}^{'}$ or by the extended Polyakov action of $S_{\rm P}^{'}$. To proceed further in this way for evaluating the effects of color-balls on hadron scatterings seems very difficult, if not impossible, since it would inevitably make us be involved in some mathematical complexity.

However, in this picture of the Pomeron as a color-ball we may be able to understand the following properties of the Pomeron found in hadron scatterings at high energies without any manipulations: 1) The Pomeron cannot be taken as a simple Regge pole but be taken as a hadronic membrane or bundle, which is an extension of the Nambu—Susskind hadronic string, or a linear combination of an infinite number of Regge poles and Regge cuts, which revives the Freund—Harari hadron duality. 2) The slope of the Pomeron trajectory $\alpha'_{\rm P}$ is much smaller than that of an ordinary Regge trajectory $\alpha'_{\rm R}$ as $\alpha'_{\rm P} \cong \frac{1}{4}\alpha'_{\rm R}$ since the "membrane or bundle tension" is much larger than the string tension. 3) The Pomeron couplings are universal to any flavors of quarks (and antiquarks) and, therefore, their factorizability holds since the color-balls are not only color-blind but also flavor-insensitive. The experimental fact that the Pomeron intercept is larger than unity as $\alpha_{\rm P}(0) > 1$ seems to be very dynamical and cannot be explained intuitively even in this picture of the Pomeron.

In concluding this Section, I wish to emphasize the importance of not only further theoretical works but also future experimental investigations on the real picture of the Pomeron by checking various things including the ever increasing total, elastic, and diffractive cross sections, the universality and factorizability such as the now classic relations of $\sigma(\bar{\rm p}{\rm p}) \cong \sigma({\rm pp})$, $\sigma(\pi{\rm p}) \cong \frac{2}{3}\sigma({\rm pp})$, and $\sigma(\gamma\gamma \to {\rm hadrons}) \cong \sigma(\gamma{\rm p} \to {\rm hadrons})^2/\sigma({\rm pp})$ [42], and the triple-Pomeron and Pomeron-Reggeon-Reggeon vertices based on the Brandt—Preparata and Mueller diagrams [43] in hadron-hadron, photon(gauge-boson)-hadron, and (hadronic) photon(gauge-boson)-photon(gauge-boson) scatterings at high energies [44]. After all, they will eventually clarify one of the most fundamental subjects in hadron physics, the origin of finite and non-vanishing hadron sizes. Here, I must add the following one comment: Recently, Achasov and Shestakov have pointed to the strong violation of the putative factorized Pomeron exchange model in the reactions of $\gamma\gamma \to VV'$ in the high energy region where the model works fairly well in all other cases [45]. However, I suspect that the $\gamma\gamma \to \rho^0\rho^0$ reaction cross section would reach the magnitude expected on the basis of the factorization model only at still higher energies since I have found that the $\gamma\gamma \to \rho^+\rho^-$ cross section is very well fitted by the magnitude expected from the PCAC low-energy theorem for $\gamma\gamma \to 2\pi^+2\pi^-$ [46].

3. Neutrino Masses and Mixings

In 1998, the Super-Kamiokande Collaboration [47] found the ratio of up-going to down-going atmospheric muon neutrinos much less than unity and they claimed it as an evidence for the non-vanishing mass for the muon and/or tau neutrinos in the analysis based on the neutrino oscillation [48] due to the neutrino mixing among three generations of neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$. Very lately, the neutrino oscillation has been almost confirmed not only by the K2K Collaboration [49] for the long-base-line neutrino oscillation experiment by neutrino beams from KEK to Super-Kamiokande but also by the SNO Collaboration [50] for the solar neutrinos at the Sudbury Neutrino Observatory. It may be taken as one of the most important discoveries in particle physics since it would indicate not only the non-vanishing mass of neutrinos (which has been searched for a long time mostly in the beta decays but in vain so far) but also the breakdown of lepton number conservation [51] (which has been searched for mostly in the decays such as $\mu \to e\gamma$). Note that neither the non-vanishing mass of neutrinos nor the non-zero mixing of neutrinos would indicate by itself anything beyond the standard model for electroweak interactions [52] since both of them can be perfectly accommodated in the standard model. However, one may feel rather uneasy in accepting the Super-Kamiokande report [47], which says, "The data are consistent with two-flavor $\nu_\mu \leftrightarrow \nu_\tau$ oscillations with $\sin^2 2\theta \geq 0.88$ and $\Delta m^2 = (2-5) \times 10^{-3}{\rm eV}^2$ at 90% confidence level". In 1999, I found a simple model of neutrino masses and mixings whose predictions are consistent not only with such a large mixing and such a small mass-squared difference between ν_μ and ν_τ suggested by the Super-Kamiokande data but also with a small mixing and a large mass-squared difference between ν_e and ν_μ suggested by the LSND data [53] but not with the solar neutrino deficit [54]. For the details of the model, see [55]. In view of the latest KamLAND experimental result [54] with a large mixing and a small mass-squared difference between ν_e and ν_μ, which disagrees with the LSND data [53], we must find another model of neutrino masses and mixings whose predictions are consistent not only with the Super-Kamiokande data [47] for ν_μ and ν_τ but also with the KamLAND data [54] for ν_e and ν_μ.

The non-vanishing small masses for neutrinos have no contradiction with the standard model since fermion masses are all free parameters proportional to Yukawa coupling constants for interactions between the Higgs scalar and fermions in the model. In other words, the possible extreme smallness of the ratio (of the order of 10^{-6}) of a neutrino mass (m_ν of the order of, say, 1 eV) to the electron mass ($m_e \cong 0.5$ MeV) is no more natural in the standard model than the smallness of that of the electron mass to the top quark mass ($m_t \cong 180$ GeV). After all, the standard model would not tell us anything about fermion masses in the tree approximation. Historically, many attempts have been made to explain the small mass ratios of fermions such as m_e/m_μ ($\cong 1/200$) by taking a smaller mass as a radiative self-mass (caused by a larger mass) which is finite and calculable in the standard model [56]. Although it may be possible to derive such a small mass ratio as one of the order of 10^{-6} from this picture of radiative corrections (even in the second order), we would not try it here as it seems difficult. On the other hand, the popular see-saw mechanism for producing the non-vanishing small Majorana masses for neutrinos [57] in grand unified theories is easy, provided that neutrinos are not Dirac particles but Majorana ones. However, it suggests the mass ratios of $m_{\nu_e} : m_{\nu_\mu} : m_{\nu_\tau} = m_e^2 : m_\mu^2 : m_\tau^2$, which do not seem to explain the Super-Kamiokande and KamLAND data. Also, the "see-saw-like mechanism"[58] in supersymmetric grand unified theories suggests the mass ratios of $m_{\nu_e} : m_{\nu_\mu} : m_{\nu_\tau} = m_e : m_\mu : m_\tau$, which do not seem to explain those data either. In the composite models of quarks and leptons [17], not only the smallness of neutrino masses but also that of quark and charged-lepton masses compared to the compositeness energy-scale (of the order of, say, 1 TeV) has tempted us to assume that quarks and leptons (at least of the first and second generations) are taken as almost Nambu—Goldstone (NG) fermions due to spontaneous breakdown of approximate supersymmetry [59]. In the unified supersymmetric composite model, we have derived the square-root mass sum rules of $m_{\nu_e}^{1/2} - m_e^{1/2} = m_u^{1/2} - m_d^{1/2}$ and $m_e^{1/2} - m_\mu^{1/2} = m_d^{1/2} - m_s^{1/2}$ [60], both of which are very well satisfied with experimental data. Furthermore, by assuming that quarks and leptons of the first, second, and third generations are almost NG, quasi NG [61], and ordinary composite fermions, respectively, we have derived the simple mass relations of $m_\tau = (m_\mu^3/m_e)^{1/2}$ and $m_t = (m_d m_c^3 m_b/m_u m_s^3)^{1/2}$ [62], both of which are well satisfied with the experimental data. However, we have not yet succeeded in deriving any relations among neutrino masses.

Not only the CKM quark-mixing matrix elements (V_{ij} for $i = u, c, t$ and $j = d, s, b$) [63] but also the possible lepton-mixing matrix elements (U_{ij} for $i = \nu_e, \nu_\mu, \nu_\tau$ and $j = e, \mu, \tau$) [64] are all free parameters to be determined by Yukawa coupling constants for interactions between the Higgs scalar and fermions in the standard model. In other words, the possible almost maximal mixing between ν_μ and ν_τ ($\sin 2\theta_{\mu\tau} \cong 1$) is no more natural than the small mixing between d and s ($\sin\theta_C \cong 0.2$). After all, the standard model would not tell us anything about quark and lepton mixings in the tree approximation. Historically, many attempts have been made to explain the small Cabibbo mixing (and especially the "folklore relation" of $\sin\theta_C \cong (m_d/m_s)^{1/2}$ [65]) based on rather arbitrary assumptions. Neither grand unified theories nor supersymmetric grand unified theories would help us in explaining or predicting the quark and lepton mixing matrix elements. In composite models of quarks and leptons[17], the quark and lepton mixings are naturally taken as mixings between dynamically different composite states of the same subquarks in different generations [66]. Not only the unitarity of the quark and lepton mixing matrices ($VV^+ = V^+V = 1$ and $UU^+ = U^+U = 1$) has been demonstrated by using the algebra of subqark currents[67] but also the possible momentum transfer dependence of the mixing matrix elements has been predicted. Furthermore, we have derived many relations such as $V_{us} = -V_{cd}^*, V_{cb} = -V_{ts}^*, V_{cb}(= -V_{ts}^*) \cong (m_s/m_b)V_{us}, V_{ub} \cong (m_s/m_c)V_{us}V_{cb}$, and $V_{td} \cong V_{us}V_{cb}$, all of which agree well with the experimental data, and have succeeded in determining all the CKM matrix elements by a single parameter (say, the Cabibbo element). However, we have not yet succeeded in predicting any lepton mixing matrix elements but may only suppose that the larger the mass difference between leptons, the smaller the mixings as in the case of quark mixings. If this is the case, it would contradict the Super-Kamiokande data indicating the small mass-squared difference and the almost maximal mixing between ν_μ and ν_τ! Thus, we are forced to find a new mechanism for the non-vanishing small neutrino masses and the almost maximal mixing for at least between two generations of neutrinos.

The extremely small mass difference and almost maximal mixing between two neutral particles reminds us of these between K^0 and $\bar{K^0}$, which was first pointed out by Gell-Mann and Pais in 1955[68]. They have asserted that K^0 and $\bar{K^0}$, which are eigen-states of strangeness when produced in strong interaction reactions conserving strangeness, should be transformed into either $K_1 = (K^0 + \bar{K^0})/\sqrt{2}$ or $K_2 = (K^0 - \bar{K^0})/\sqrt{2}$, both of which are eigen-states of CP, before disappearing in weak decays conserving CP quantum numbers to a good accurcy. In fact, it was one of the strongest motivations for Pontecorvo to consider the possibility of neutrino oscillation [48]. It is now well known that the transition of $K^0 \leftrightarrow \bar{K}^0$ occurs due to the double exchange of W^+ and W^- between the $(d\bar{s})$ and $(\bar{d}s)$ states and generates an extremely small difference of $m_{K_L} - m_{K_S}$ ($\cong 3 \times 10^{-6}$ eV) between K_S ($\cong K_1$) and K_L ($\cong K_2$) mass eigen-states.

In analogy to this picture of $K^0 - \bar{K}^0$ mixing, suppose that the three neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$ have transitions of $\nu_e \leftrightarrow \nu_\mu, \nu_e \leftrightarrow \nu_\tau$, and $\nu_\mu \leftrightarrow \nu_\tau$ due to some unknown mechanism. Also, suppose that there exists a symmetry under the exchange of ν_μ and ν_τ. Then, the neutrino mass matrix has the form of

$$\begin{pmatrix} m' & M & M \\ M & m & \mu \\ M & \mu & m \end{pmatrix}$$

where μ and M are unknown parameters for the transition matrix elements. This matrix can be diagonalized by the neutrino-mixing matrix U of

$$\begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta/\sqrt{2} & \cos\theta/\sqrt{2} & -1/\sqrt{2} \\ \sin\theta/\sqrt{2} & \cos\theta/\sqrt{2} & 1/\sqrt{2} \end{pmatrix}$$

into $diagonal[(m+\mu+m')/2 + \Delta/2, (m+\mu+m')/2 - \Delta/2, m-\mu]$ where $\Delta = \sqrt{(-m-\mu+m')^2 + 8M^2}$ for $\tan 2\theta = \sqrt{8}M/(-m-\mu+m')$.

The model has turned out to produce the "maximal mixing mechanism" both for the $\nu_\mu - \nu_\tau$ sector and for the $\nu_e - \nu_\mu$ sector if $\theta \cong \cong \pm\pi/4$ (or $|-m-\mu+m'|/\sqrt{8}M \ll 1$). What is left is to explain why the neutrino mass matrix must have the structure. The original smallness of neutrino masses cannot be explained in the standard model, in grand unified theories, or even in supersymmetric grand unified theories, but can be attributed to the degeneracy of the spinor and scalar subquarks of which neutrinos consist in supersymmetric composite models [59—62]. However, it seems difficult to explain the smallness of the parameters of m, m', μ, and M and the ratio of $|-m-\mu+m'|/\sqrt{8}M$ at this stage of particle theories as it is to explain that of the quark and charged-lepton masses of lower generations such as m_e, m_μ, m_d, etc., and their ratios such as $m_e/m_\mu, m_d/m_s$, etc. Again, subquark models of quarks and leptons [17] provide us at least with a theoretical ground, on which we can imagine that they are small since they are transitions between dynamically different composite states. How to explain the smallness more quantitatively in composite models is a subject for future investigations. Note that the neutrino mass matrix in this model is essentially the same as the one in the Ma model [69].

4. Higgs Scalar Mass

The Higgs scalar which has been introduced as the origin of particle masses in the standard model [52] is the last member still missing among the fundamental particles since the DONUT Collaboration [70] established the existence of the tau neutrino in 1999. In November, 2000, just before the LEPII was about to be shut down for constructing the LHC at CERN, the ALEPH and L3 Collaborations [71] announced the excess of candidates for $e^+e^- \to Z^* \to HZ$ with the Higgs mass near 114 GeV and 114.5 GeV, respectively. Although other two groups at LEPII, the OPAL and DELPHI Collaborations [72], reported no evidence for H, the possible Higgs mass of about 114 GeV became a hottest issue in particle physics around the end of the last century [73]. By combining all the information from precision measurements with the results from these direct search experiments at LEPII, Degrassi [74] has recently concluded that the probability for the Higgs mass being less than 116 GeV is 35% and that the upper bound is around 210—230 GeV at 95% confidence level.

In composite models of the Nambu—Jona—Lasinio type [75], the Higgs scalar appears as a composite state of fermion-antifermion pairs with the mass twice as much as the fermion mass. Our unified subquark model of the Nambu—Jona—Lasinio type [76] has predicted the following two sum rules: $m_W = [3(m_{w_1}^2 + m_{w_2}^2)]^{1/2}$ and $m_{\rm H} = 2[(m_{w_1}^4 + m_{w_2}^4)/(m_{w_1}^2 + m_{w_2}^2)]^{1/2}$, where m_{w_1} and m_{w_2} are the masses of wakems (the weak-isospin-doublet of spinor subquarks) while m_W and $m_{\rm H}$ are the charged weak boson and physical Higgs scalar masses in the standard model, respectively. By combining these sum rules, the following relation has been obtained for $m_{w_1} = m_{w_2} \equiv m_w$: $m_w : m_W : m_{\rm H} = 1 : \sqrt{3} : 2$. From this relation, the wakem and Higgs scalar masses have been predicted as $m_w = m_W/\sqrt{3} = (46.430 \pm 0.032)$ GeV and $m_{\rm H} = 2m_W/\sqrt{3} = (92.860 \pm 0.065)$ GeV for $m_W = (80.419 \pm 0.056)$ GeV [77]. More precisely, from the two sum rules, the Higgs scalar mass can be bounded as $(92.860 \pm 0.065)\,{\rm GeV} = 2m_W/\sqrt{3} \le m_{\rm H} \le 2\sqrt{6}m_W/3 = (131.32 \pm 0.009)$ GeV. Note that the lower bound corresponds to the case of $m_{w_1} = m_{w_2}$ while the upper one to that of $m_{w_1}/m_{w_2} = 0\, or\, \infty$. Therefore, it seems more likely that the physical Higgs scalar mass will be found close to the lower bound, i.e.

$m_{\mathrm{H}} \cong 93$ GeV. The reliability of this prediction may be enhanced by the following independent observation. Suppose that the subquark dynamics is described by QSCD [18]. Then, the masses of W and H are scaled by Λ_{sc}, the energy scale of QSCD, while the masses of the corresponding hadrons, ρ and σ, are scaled by Λ_s, the scale of QCD. If this is the case, the Higgs scalar mass can be estimated as $m_{\mathrm{H}} \cong (m_\sigma/m_\rho)m_W \cong (\sim 900\,\mathrm{MeV}/\sim 77\,0\ \mathrm{MeV})(80.419 \pm 0.056)$ GeV ~ 94 GeV, which amazingly produces a similar prediction, $m_{\mathrm{H}} \sim 93$ GeV.

Also, our unified quark-lepton model of the Nambu—Jona—Lasinio type [76] has predicted the following two sum rules: $m_W = (3\langle m_{q,l}^2\rangle)^{1/2}$ and $m_{\mathrm{H}} = 2(\sum m_{q,l}^4/\sum m_{q,l}^2)^{1/2}$ where $m_{q,l}$'s are the quark and lepton masses and $\langle\rangle$ denotes the average value for all the quarks and leptons. Note that the second sum rule is essentially the same as the Nambu relation [78] $m_\xi : m_\psi : m_\eta = 0 : 1 : 2$ or $m_\xi^2 + m_\eta^2 = 4m_\psi^2$, where ξ, η, and ψ are the Nambu—Goldstone boson, the physical scalar, and the consistent fermion, respectively, and that they are the consequences of Nambu's supersymmetry and, therefore, less model-dependent. If there exist only three generations of quarks and leptons, these sum rules completely determine the top quark and Higgs scalar masses [79] as $m_t \cong (2\sqrt{6}/3)m_W = (131.32 \pm 0.009)$ GeV and $m_{\mathrm{H}} \cong 2m_t \cong (4\sqrt{6}/3)m_W = (262.65 \pm 0.18)$ GeV.

Triplicity or trinity of hadrons, quarks, and subquarks [80] tells us that these sum rules can be further extended to the approximate sum rules of $m_W \cong (3\langle m_{B,l}^2\rangle)^{1/2}$ and $m_{\mathrm{H}} \cong 2(\sum m_{B,i}^4/\sum m_{B,l}^2)^{1/2}$, where $m_{B,l}$'s are the "canonical baryon" and lepton masses and $\langle\rangle$ denotes the average value for all the canonical baryons and leptons. The "canonical baryon" means either one of p, n, and other ground-state baryons of spin 1/2 and weak-isospin 1/2 consisting of a quark heavier than the u and d quarks and a scalar and isoscalar diquark made of u and d quarks. These sum rules can be derived, in the same way as for those in the unified quark-lepton model, in the "unified baryon-lepton model" of the Nambu—Jona—Lasinio type which is written in terms of the canonical baryons and leptons as fundamental fermions. If there exist only three generations of quarks and leptons, these sum rules completely determine the masses of the canonical topped baryon, T, and the Higgs scalar as $m_T \cong 2m_W = (160.84 \pm 0.11)$ GeV and $m_{\mathrm{H}} \cong 2m_T \cong 4m_W = (321.68 \pm 0.22)$ GeV. Note that the predicted value for the canonical topped baryon mass is by 22% percent larger than that for the top quark mass and that the predicted values for the Higgs scalar mass in these models are in the ratio $1 : \sqrt{8} : \sqrt{12}$. In particular, the latter may indicate that the unified quark-lepton model of the Nambu—Jona—Lasinio type and the unified baryon-lepton model are poor approximations for describing the Higgs scalar.

If the Higgs scalar mass of around 114 GeV suggested by the ALEPH and L3 Collaborations [71] were real, it would perfectly agree with the predicted value in the subquark model of the Nambu—Jona—Lasinio type which is bounded between 93 and 131 GeV. If, instead, future experiments at Tevatron II, LHC, NLC (or JLC), or TESLA find it between 131 and 263 GeV, which is the predicted value in the unified quark-lepton model of the Nambu—Jona—Lasinio type, the Higgs scalar may be taken as a mixture of the composite state of subquark-antisubquark pairs and that of quark (or lepton)-antiquark (or antilepton) pairs (mostly top-quark-anti-top-quark pair). Furthermore, if they find it between 263 and 322 GeV, which is the predicted value in the unified baryon-lepton model of the Nambu—Jona—Lasinio type, the Higgs scalar may be taken as a mixture of the composite state of mostly top-quark-anti-top-quark pairs and that of mostly topped-baryon-anti-topped-baryon pairs. The answer will be given by future high-energy experiments.

5. Superparticles

In supersymmetric theories [81], every fundamental particle such as a quark, lepton, photon, W boson, Z boson, gluon, and Higgs scalar is assumed to accompany its superpartner such as a scalar quark, scalar lepton, photino, wino, zino, gluino, and Higgsino. In 1999, the DAMA Collaboration [82] reported the possible discovery of a weakly interacting massive object (WIMP) although it has not been confirmed by the other experimental groups. Also, in 2001, the Muon (g-2) Collaboration [83] reported the possible discrepancy between their new experimental value of the muon g-2 and the current theoretical one from the standard model. Although both of these once-claimed anomalies had often beeen taken as the first indications of the superparticles, it seemed to me too early to decide what would cause them since it could be anything even if they had been real.

6. Substructure of Quarks and Leptons

Since this main subject in this talk had been reviewed so many times in great details by myself for the last more than two decades [17], I shall discuss it very briefly by concentrating on the comparison between many predictions in our unified composite model of all the fundamental particles and forces and the recent experimental observations.

In 1996, the CDF Collaboration at Tevatron [84] released their data on the inclusive jet differential cross section for jet transverse energies, E_T, from 15 to 440 GeV with the significant excess over current predictions based on perturvative QCD calculations for $E_T > 200$ GeV, which may indicate the presence of quark substructure at the compositeness energy scale, Λ_C, of the order of 1.6 TeV. It could be taken as an exciting and intriguing historical discovery of the substructure of quarks (and leptons), which had been long predicted, or as the first evidence for the composite model of quarks (and leptons), which had been long proposed since the middle of 1970's [85]. It might dramatically change not only the so-called "common sense " in physics or science but also that in philosophy, which often states that quarks (and leptons) are the smallest and most fundamental forms (or particles) of matter in "mother nature". Note that such a relatively low energy scale for Λ_C of the order of 1 TeV had been anticipated rather theoretically [86] or by precise comparison between currently available experimental data and calculations in the composite model of quarks (and leptons) [87]. In 1997, the H1 and ZEUS Collaborations at HERA [88] reported their data on the deep inelastic e^+p scattering with a significant excess of events over the expectation of the standard model of electroweak and strong interactions for high momentum-transfer squared $Q^2 > 15000\,\text{GeV}^2$, which might indicate a sign for new physics beyond the standard model. Although neither one of these indications has been confirmed by the other experiments and the significance of the HERA anomaly has decreased with higher statistics, not only the possible substructure of quarks and leptons as well as Higgs scalars and gauge bosons but also the possible existence of leptoquarks have been extensively re-investigated [89]. As it stands now, I must conclude that both the CDF and HERA anomalies are still there and wish to emphasize that the explanation of the latter anomaly either by the leptoquark with the mass between 280 and 440 GeV or by the excited electron with the mass between 300 and 370 GeV [90] is still very viable.

As for the recent progress in the ultimate program for explaining or predicting all the properties (such as quantum numbers, masses, mixings, and coupling constants) of not only quarks and leptons but also gauge bosons and Higgs scalars in the unified composite model of all the fundamental particles and forces, I have too many things to cover in this Section. I shall present only a shortest summary of the present status in the following.

The minimal supersymmetric composite model of quarks and leptons consists of an isodoublet of spinor subquarks with charges $\pm 1/2$, w_1 and w_2 (called "wakems" standing for **we**ak and **e**lectro**m**agnetic) [76], and a Pati—Salam color-quartet of scalar subquarks with charges $+1/2$ and -1/6, C_0 and C_i ($i = 1,2,3$) (called "chroms" standing for colors) [85]. The spinor and scalar subquarks with the same charge $+1/2$, w_1 and C_0, may form a fundamental multiplet of $N = 1$ supersymmetry[59]. Also, all the six subquarks, $w_i (i = 1,2)$ and $C_\alpha (\alpha = 0,1,2,3)$, may have "subcolors", the additional degrees of freedom[18], and belong to a fundamental representation of subcolor symmetry. Although the subcolor symmetry is unknown, a simplest and most likely candidate for it is SU(4). Therefore, for simplicity, all the subquarks are assumed to be quartet in subcolor SU(4). Also although the confining force is unknown, a simplest and most likely candidate for it is the one described by quantum subchromodynamics(QCSD), the Yang—Mills gauge theory of subcolor SU(4) [18]. Note that the subquark charges satisfy not only the Nishijima—Gell—Mann rule of $Q = I_w + (B - L)/2$ but also the "anomaly-free condition" of $\sum Q_w = \sum Q_C = 0$.

In the minimal supersymmetric composite model, we expect that there exist at least 36 (= 6 × 6) composite states of a subquark and an antisubquark which are subcolor-singlet. They include 1) 16 (= 4 × 2 × 2) spinor states corresponding to one generation of quarks and leptons, and their antiparticles of $\nu = \bar{C}_0 w_1, l = \bar{C}_0 w_2, u_i = \bar{C}_i w_1, di = \bar{C}_i w_2$, and their Hermitian conjugates ($i = 1,2,3$), 2) 4 (= 2 × 2) vector states corresponding to the photon and weak bosons of $W^+ = \bar{w}_2 w_1; \gamma, Z = \bar{w}_1 w_1, \bar{w}_2 w_2, \bar{C}_0 C_0, \bar{C}_i C_i; W^- = \bar{w}_1 w_2$ or 4 (= 2 × 2) scalar states corresponding to the Higgs scalars of $\phi_{ij} = [(\bar{w}_1 w_1)(\bar{w}_2 w_1)/(\bar{w}_1 w_2)(\bar{w}_2 w_2)](i,j = 1,2)$ and 3) 16 (= 4 × 4) vector states corresponding to a) the gluons, "leptogluon", and "barygluon" of $G_a = \bar{C}_i (\lambda_a/2)_{ij} C_j; G_0 = \bar{C}_0 C_0; G_9 = \bar{C}_i C_i (i,j = 1,2,3)$, where λ_a ($a = 1,2,3,...,8$) is the Gell-Mann's matrix of $SU(3)_c$, and b) the "vector leptoquarks" of $X_i = \bar{C}_0 C_i$ and the Hermitian conjugates ($i = 1,2,3$), or 16 (= 4 × 4) scalar states corresponding to the "scalar gluons", "scalar leptogluon", "scalar barygluon", and "scalar leptoquarks" of $\Phi_{\alpha,\beta} = \bar{C}_\alpha C_\beta$ ($\alpha, \beta = 0,1,2,3$). Quarks and leptons with the same quantum numbers but in different generations can be taken as dynamically different composite states of the same constituents. In addition to these “meson-like composite states” of a subquark and an antisubquark, there may also exist “baryon-like composite states” of 4 subquarks which are subcolor-singlet.

In the unified subquark model of quarks and leptons [67], it is an elementary exercise to derive the Georgi—Glashow relations [91], $\sin^2\theta_w = \sum I_3^2/\sum Q^2 = 3/8$ and $f^2/g^2 = \sum I_3^2/\sum(\lambda_a/2)^2 = 1$ for the weak-mixing angle (θ_w), the gluon and weak-boson coupling constants (f and g), the third component of the isospin (I_3), the charge (Q), and the color-spin ($\lambda_a/2$) of subquarks, without depending on the assumption of the grand unification of strong and electroweak interactions. The experimental value [77] is $\sin^2\theta_w(M_Z) = 0.23117(16)$. The disagreement between the value of $3/8$ predicted in the subquark model and the experimental value might be excused by insisting that the predicted value is viable as the running value renormalized *a la* Georgi, Quinn, and Weinberg [92] at extremely high energies (as high as 10^{15} GeV), given the “desert hypothesis”.

The CKM quark-mixing matrix V is given by the expectation value of the subquark current between the up and down composite quark states as $V_{ud} \sim < u|\bar{w}_1 w_2|d >$,... [66]. By using the algebra of subquark currents [67], the unitarity of the quark-mixing matrix, $VV^\dagger = V^\dagger V = 1$, has been demonstrated although the superficial non-unitarity of V as a possible evidence for the substructure of quarks has also been discussed by myself [93]. In the first-order perturbation of isospin breaking, we have derived the relations $V_{us} = -V_{cd}^*, V_{cb} = -V_{ts}^*$,..., which agree well with the experimental values of $V_{us} = 0.219 \sim 0.226$ and $V_{cd} = 0.219 \sim 0.225$ [77], and some other relations such as $V_{cb}(= V_{ts}) \cong (m_s/m_b)V_{us} \cong 0.021$, which roughly agree with the latest experimental value of $V_{cb} = 0.037 \sim 0.043$ [77]. In the second-order perturbation, the relations $V_{ub} \cong (m_s/m_c)V_{us}V_{cb} \cong 0.0017$ and $V_{td} \cong V_{us}V_{cb} \cong 0.0046$ have been predicted. The former relation agrees remarkably well with the latest experimental data $V_{ub} \cong 0.002 \sim 0.005$ [77]. The predictions for V_{ts} and V_{td} also agree fairly well with the experimental estimates from the assumed unitarity of V, $V_{ts} \cong 0.035 \sim 0.043$ and $V_{td} \cong 0.004 \sim 0.014$ [77]. To sum up, we have succeeded in predicting all the magnitudes of the CKM matrix elements except for a single element, say, V_{us}.

In the remaining part of this Section, I shall present the more recent progress in predicting all the quark and lepton masses. By taking the first generation of quarks and leptons as almost Nambu—Goldstone fermions [59] due to spontaneous breakdown of the approximate supersymmetry between a wakem and a chrom, and the second generation of them as quasi Nambu—Goldstone fermions [61], the superpartners of the Nambu—Goldstone bosons due to spontaneous breakdown of the approximate global symmetry, we have not only explained the hierarchy of quark and lepton masses, $m_e << m_\mu << m_\tau, m_u << m_c << m_t, m_d << m_s << m_b$, but also obtained the square-root sum rule for quark and lepton masses [60], $m_e^{1/2} = m_d^{1/2} - m_u^{1/2}$ and $m_\mu^{1/2} - m_e^{1/2} = m_s^{1/2} - m_d^{1/2}$, and the simple relations among quark and lepton masses [62], $m_e m_\tau^2 = m_\mu^3$ and $m_u m_s^3 m_t^2 = m_d m_c^3 m_b^2$, all of which are remarkably well satisfied by the experimental values and estimates. By solving a set of these two sum rules and two relations [94], we can obtain the following predictions:

$$\begin{pmatrix} m_e & m_\mu & m_\tau \\ m_u & m_c & m_t \\ m_d & m_s & m_b \end{pmatrix} = \begin{pmatrix} 0.511\,\mathrm{MeV}_{(\mathrm{input})} & 105.7\,\mathrm{MeV}_{(\mathrm{input})} & 1520\,\mathrm{MeV}_{(1777.03+0.30/-0.26\,\mathrm{MeV})} \\ 4.5 \pm 1.4\,\mathrm{MeV}_{(\mathrm{input})} & 1350 \pm 50\,\mathrm{MeV}_{(\mathrm{input})} & 183 \pm 78\,\mathrm{GeV}_{(176.1\pm5.1\pm5.3\,\mathrm{GeV})} \\ 8.0 \pm 1.9\,\mathrm{MeV}_{(7.9\pm2.4\,\mathrm{MeV})} & 154 \pm 8\,\mathrm{MeV}_{(155\pm50\,\mathrm{MeV})} & 5.3 \pm 0.1\,\mathrm{GeV}_{(\mathrm{input})} \end{pmatrix}$$

where the “inputs” and the values indicated in the parentheses denote either the experimental data [77] or the phenomenological estimates[95], to which our predicted values should be compared. Furthermore, if we solve a set of these two sum rules and these two relations, and the other two sum rules for m_W and m_{H} mentioned in Section 4, we can predict not only four quark and/or lepton masses such as m_d, m_s, m_t, and m_τ as above but also the Higgs scalar and weak boson masses as $m_{\mathrm{H}} \cong 2m_t = 366 \pm 156$ GeV and $m_W \cong \sqrt{3/8}m_t = 112 \pm 24$ GeV, which should be compared to the experimental value of $m_W = 80.419 \pm 0.056$ GeV [77]. To sum up, we have succeeded in explaining and predicting most of the properties (masses and mixing angles) of quarks and leptons in the unified supersymmetric composite model.

What is left for future theoretical investigations is to try to complete the ambitious program for explaining all the quark and lepton masses by deriving more sum rules and/or relations among them and by solving a complete set of the sum rules and relations. To this end, my private concern is to see whether one can take the remarkable agreement between my prediction of $m_t = (m_d m_c^3 m_b^2 / m_u m_s^3)^{1/2} \cong 180$ GeV and the experimental data as an evidence for the unified supersymmetric composite model. Very recently, I have been more puzzled by the "new Nambu's empirical quark-mass formula " of $M = 2^n M_0$ with his assignment of $n = 0, 1, 5, 8, 10, 15$ for u, d, s, c, b, t [96], which makes my relation of $m_u m_s^3 m_t^2 = m_d m_c^3 m_b^2$ exactly hold. Even more recently, I have been even more puzzled by the relations of $m_u m_b \cong m_s^2$ and $m_d m_t \cong m_c^2$ suggested by Davidson, Schwartz, and Wali(DSW) [97], which can coexist with my relation and which are exactly satisfied by the Nambu's assignment. If we add the DSW relations to a set of our two sum rules, our two relations, and our sum rule for m_W and if we solve a set of these seven equations by taking the experimental values of $m_e = 0.511\,\mathrm{MeV}, m_\mu = 105.7$ MeV , and $m_W = 80.4$ GeV as inputs, we can find the quark and lepton mass matrix of

$$\begin{pmatrix} m_e & m_\mu & m_\tau \\ m_u & m_c & m_t \\ m_d & m_s & m_b \end{pmatrix} = \begin{pmatrix} 0.511\,\mathrm{MeV}_{(\mathrm{input})} & 105.7\,\mathrm{MeV}_{(\mathrm{input})} & 1520\,\mathrm{MeV}_{(1777.03+0.30/-0.26\,\mathrm{MeV})} \\ 3.8\,\mathrm{MeV}_{(4.5\pm1.4\,\mathrm{MeV})} & 970\,\mathrm{MeV}_{(1350\pm50\,\mathrm{MeV})} & 131.3\pm0.2\,\mathrm{GeV}_{(176.1\pm5.1\pm5.3\,\mathrm{GeV})} \\ 7.2\,\mathrm{MeV}_{(8.0\pm1.9\,\mathrm{Mev})} & 150\,\mathrm{MeV}_{(155\pm50\,\mathrm{MeV})} & 5.9\,\mathrm{GeV}_{(5.3\pm0.1\,\mathrm{GeV})} \end{pmatrix}$$

where an agreement between the calculated values and the experimental data or the phenomenological estimates looks reasonable. This result may be taken as one of the most elaborated "modern developments in elementary particle physics".

7. Structure of the Universe

Since I have recently reviewed this subject in detail at the Third Bolyai—Gauss—Lobachevski Conference on Non-Euclidean Geometry in Modern Physics, Tirgu—Mures, Romania, 2002 [98], I shall discuss it very briefly by summarizing the recent results.

In 1998 [99], I pointed out that the Universe has fractal substructures such as clusters of galaxies, galaxies, clusters of stellar systems, and stellar systems due to the scaling properties in these gravitational subsystems with respect to the numbers and masses of constituents, and the size-scales and time-scales of substructures. I also suggested a clue to explain both the "less-large-number hypothetical relations" of $N_G \sim N_S (\sim N_C)$ [100] where N_G and N_S (N_C) are the "total number of galaxies" in the Universe and the average total number of stars in a galaxy (the average total number of comets, whose sizes are of the order of 10 km, in a stellar system), respectively, and the "even-less-large-number hypothetical relations" $n_1 \sim n_2 \sim n_3$ [101] for $n_1 = R_U/D_G, n_2 = D_G/R_G$, and $n_3 = R_G/D_S$ where R_U (R_G) is the "radius of the Universe" (the average radius of an ordinary galaxy) and D_G (D_S) is the average distance between two neighboring galaxies (that between two neighboring stars).

In 1999 [102], I discussed the "kappa-Lambda problem" in the Friedmann cosmology in the Einstein theory of gravity consisting of whether the space-time in the Universe is closed, flat, or open, i.e. $\kappa = +1, 0$, or -1, and whether the "cosmological constant" in the Einstein field equations vanishes or not, i.e. $\Lambda = 0$ or $\neq 0$, in the light of the recent observations by the Supernova Cosmology Project and by the High-Z Supernova Search Team [103] indicating $\kappa = 0$ or -1 and $\Lambda \neq 0$. I presented possible answers to these fundamental questions. In particular, I suggested that $\kappa = 0$ or -1 since the space-time would have collapsed in the early Universe due to the "Casimir effect" if it had been closed at the beginning and since a transition of the flat or open Universe to the closed one has never occurred because of its extreme difficulty. I also sugested that $\Lambda \neq 0$ since the "cosmological constant" would have appeared due to the vacuum fluctuations of matter and, therefore, might not be a constant but have varied from the past to the present in the Universe. I pointed out that our Universe is simulated by a simple model in which $\kappa = 0$ and $(\Omega_M, \Omega_\Lambda, A) = (0, 1, 1), (1/3, 2/3, 1/3)$, or $(1/3, 2/3, 1/2)$ for the early inflationary, old radiation-dominated, or present matter-dominated Universe, respectively, where Ω_M, Ω_Λ, and A are the pressureless-matter-density, scaled "cosmological constant", and "acceleration parameter". The model suggests that there must be another "phase transition" in which Ω_Λ changed from 1 to 2/3 in between the early inflationary era and the radiation-dominated era.

The Supernova Cosmology Project[103] has also found that $0.8\Omega_M - 0.6\Omega_\Lambda = -0.2 \pm 0.1$ for $\Omega_M < 1.5$, with which the simple model of $\Omega_M = 1/3$ and $\Omega_\Lambda = 2/3$ (and therefore $0.8\Omega_M - 0.6\Omega_\Lambda = -0.1$) certainly agrees. However, whether the predicted value of $A = 1/2$ in the simple model would agree with the future observation is non-trivial and subject to a careful test. It is more desirable to observe the time dependence of Λ and the sudden change of Ω_Λ in between the early inflationary era and the old radiation-dominated era in our Universe, which are crucial predictions in this picture of the Universe.

In 2000 [104], I derived a simple relation between the time-dependent fine-structure and gravitational constants of $(d\alpha/dt)/\alpha^2 \sim (dG/dt)/G$ from the hypothesis that both of these fundamental constants are related to the more fundamental length scale of nature as in the unified pregauge and pregeometric theory of all fundamental forces. From the latest observation of $(d\alpha/dt)/\alpha = (2.25 \pm 0.56) \times 10^{-15}/yr$ for $\langle z \rangle = 2.0$ by Webb et al. [105], it leads to the prediction of $(dG/dt)/G = (0.181 \pm 0.045) \times 10^{-12}/yr$, which is not only consistent with the most precise limit of $(dG/dt)/G = (-0.6 \pm 2.0) \times 10^{-12}/yr$ by Thorsett [106] but also feasible for future experimental tests.

8. Conclusion and Future Prospects

I have discussed current topics in particle (and nuclear) physics, ranging from nuclear, hadron, and particle physics to cosmology. As for future prospects of particle physics, I have recently presented many discussions at various conferences [107]. Instead of repeating these discussions, I wish to present a few comments in the following:

As emphasized in Section 1, the stability of nuclei and, therefore, that of matter depends on the small mass difference between the proton and neutron or that between the up and down quarks (due to the mass difference between the w_1 and w_2 subquarks). As emphasized in Section 2, the origin of the finite and non-vanishing size of hadrons may be closely related to the Pomeron. It must also be related to the energy scale of QCD, $\Lambda_c (\cong 100\,\mathrm{MeV})$, which may eventually be related to the small but non-vanishing up and down quark masses. As discussed in Sections 3 and 6, the non-vanishing but extremely small neutrino masses may be due to the combination of spontaneous breakdown of supersymmetry between the w_1 and C_0 subquarks, which are equal-mass (and maybe massless), and breaking of iso-spin symmetry between the w_1 and w_2 subquarks, which is caused by the mass difference between them. Recently, the observations of CP violation in the neutral B meson system have been reported both by the BABAR and Belle Collaborations [108]. I suppose that the CP violation, which may be described phenomenologically in the standard model of quarks, must also be originated from subquarks in quantum subchromodynamics. Imagine that everything comes out of subquarks!

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СУЧАСНІ ПРОБЛЕМИ ФІЗИКИ ЧАСТИНОК

Х. Теразава

Резюме

Детально обговорюються сучасні проблеми фізики частинок та ядерної фізики, а саме: екзотичні ядра, кольорова куля як померон, маси нейтрино та змішування, маса скаляра Хіггса, суперчастинки, субструктура кварків та лептонів, структура Всесвіту та нові перспективи.

СОВРЕМЕННЫЕ ПРОБЛЕМЫ ФИЗИКИ ЧАСТИЦ

Х. Теразава

Резюме

Детально обсуждаются современные проблемы физики частиц и ядерной физики, а именно: экзотические ядра, цветной шар как померон, массы нейтрино и смешивания, масса скаляра Хиггса, суперчастицы, субструктура кварков и лептонов, структура Вселенной и новые перспективы.