

SQUEEZED STATES, UNCERTAINTY RELATIONS AND THE PAULI PRINCIPLE IN COMPOSITE AND COSMOLOGICAL MODELS

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(Dedicated to Dr. Eugene Paul Wigner, the late Professor)

Abstract

The importance of not only uncertainty relations but also the Pauli exclusion principle is emphasized in discussing various “squeezed states” existing in the universe. The contents include:

- I. Introduction
- II. Nuclear Physics in the Quark-Shell Model
- III. Hadron Physics in the Standard Quark-Gluon Model
- IV. Quark-Lepton-Gauge-Boson Physics in Composite Models
- V. Astrophysics and Space-Time Physics in Cosmological Models
- VI. Conclusion

Also, not only the possible breakdown of (or deviation from) uncertainty relations but also the superficial violation of the Pauli principle at short distances (or high energies) in composite (and string) models is discussed in some detail.

I Introduction

I have been asked by Professor Y.S. Kim, the Principal Organizer for this Conference to present a paper based on my recent research results in the field of squeezed states and uncertainty relations. Since I am a particle theorist, I have not so much to say about “squeezed states” in condensed matter physics (or science). Therefore, what I am going to do is to discuss “squeezed states” in nuclear physics (or science), hadron physics (or science), “quark-lepton-gauge-boson physics (or science)”, astrophysics (or astronomy) and “space-time (or cosmic) physics (or science)” (or cosmology). In either one of these discussions, I will try to emphasize the importance of not

only uncertainty relations but also the Pauli exclusion principle. The reason for this is that both the Heisenberg uncertainty principle and the Pauli exclusion principle are the most important principles after the particle-wave idea on which quantum mechanics is based. Also, these two principles are closely related to each other so that they may not be discussed separately. Toward the end of this talk, I will even discuss not only the possible breakdown of (or deviation from) uncertainty relations but also the superficial violation of the Pauli principle at short distances (or high energies) in composite (and string) models.

I would like to dedicate this talk to Dr. Eugene Paul Wigner, the late Professor who has developed the group theory and its application in quantum mechanics of atomic spectrum based on the uncertainty principle and the Pauli principle [1].

II Nuclear Physics in the Quark-Shell Model

In 1975, Arima and Iachello taught me that nuclear physics (or science) [2] yet needs a totally new model, their interacting boson model [3]. In 1979, I proposed another model, the quark-shell model of nuclei in quantum chromodynamics, presented the effective two-body potential between quarks in a nucleus, pointed out violent breakdown of isospin invariance and importance of U-spin invariance in superheavy nuclei and predicted possible creation of “super-hypernuclei” in heavy-ion collisions at high energies.

In this section, let me start with discussing squeezed states in nuclear physics. The nucleon density in an ordinary nucleus with the mass number A and the radius R or in ordinary nuclear matter is $\rho_N \equiv A/V = 3A/4\pi R^3 = 3/4\pi R_o^3 \cong 0.14/(\text{fermi})^3$ where $V = (4\pi/3)R^3$ since $R \cong R_o A^{1/3}$ for $R_o \cong 1.2$ fermi. A much higher nucleon density can be found in an abnormal nuclear matter such as the neutron star or the part of a compound nuclei to be formed in high-energy heavy-ion collisions. The latter of which may be produced in the near future by RHIC, which is now under construction at Brookhaven National Laboratory. It is very intriguing whether the future experiments at RHIC will observe, for the first time, the phase transition of nuclear matter from the ordinary nuclear phase to the abnormal Lee-Wick phase in which “effective” nucleon (or quark) mass inside the nucleus may be much smaller than the normal value [4], which was predicted in 1974, and also the phase transition from the ordinary nuclear phase to the quark-gluon phase in which quarks and gluons may be deconfined or liberated. However, it seems still very difficult to calculate the cross section for producing such abnormal nuclei to a very good accuracy and also to imagine the reliable signals for observing them.

A little later, in 1979, Chin and Kerman, and independently myself predicted another type of abnormal nuclei (called super-hypernuclei or “strange quark matter”) consisting of almost equal numbers of up, down and strange quarks, based on the natural expectation that they may enjoy suppression of not only the Fermi energy but also the Coulomb repulsive energy in nuclei [5]. Furthermore, the possible creation of such abnormal matter in bulk (called “quark nuggets”) in the early universe or inside the neutron star had been discussed in detail by Witten, and the properties of “strange matter” had been investigated in detail in the Fermi-gas model by Farhi and Jaffe. Recently, Saito *et al.* found in cosmic rays two abnormal events with the charge of $Z = 14$ and the mass number of $A \cong 370$ and emphasized the possibility that they are super-hypernuclei [6]. In order to determine whether or not these cosmic rays are really super-hypernuclei as claimed by the cosmic-ray experimentalists, I have investigated how the small charge-to-mass-

number ratio of Z/A is determined for super-hypernuclei when created and concluded that such a small charge of $3 \sim 30$ may be realized as $Z \leq \sqrt{2/3}A^{1/2}$ ($\cong 15.7$ for $A = 370$) if the nuclei are created spontaneously from bulk strange quark matter due to the Coulomb attraction [7]. The second most likely interpretation of the Saito events is that they are “technibaryonic nuclei” or “technibaryon-nucleus atoms” [8].

In concluding this section, I wish to advocate my proposal for measuring not only the weak mixing angle but also the quark density in nuclei by observing the effect that the electron energy spectrum in nuclear β -decays is affected by the weak neutral current interaction in nuclei to the order of several eV [9]. Also, I wish to advocate my proposal for studying the quark structure of nuclei in inelastic virtual Compton scattering of photons from nuclei for lepton-pair production, $\gamma + A \rightarrow \gamma^* + \text{anything}$ and $\gamma^* \rightarrow e^+ + e^-$ [10].

III Hadron Physics in the Quark-Gluon Model

In this section, let me discuss squeezed states in hadron physics. The quark density in an ordinary hadron with the quark number N_q and the radius R_h or in ordinary hadronic matter is $\rho_q \cong N_q/V_h = 3N_q/4\pi R_h^3 \cong 9/4\pi r_p^3 \cong 1.35 \sim 2.61/(\text{fermi})^3$ where $V_h = (4\pi/3)R_h^3$ and r_p is the proton charge radius of the order of 0.81 fermi or the proton “quark radius” of the order of 0.65 fermi [11]. A much higher quark density can be found in an abnormal hadron or abnormal hadronic matter such as the dense quark-gluon plasma or the part of a compound hadron to be formed in super high-energy hadron collisions. The so-called Centauro events with extremely high multiplicities of produced hadrons ($n_h = 100 \pm 20$) and with unusually high average transverse momenta ($\langle p_T \rangle = 0.35 \pm 0.10$ GeV/c) but without any γ 's observed in the cosmic ray experiments by the Brasil-Japan Emulsion Chamber Collaboration in 1977 may be indications of such abnormal hadrons although no candidates for such exotic hadrons have yet been observed in any accelerator experiments [12]. However, my personal prejudice is that such unusual events may not be taken as indications of such exotic hadrons but be explained either by coherent effects of many nucleons in projectile and target heavy ions or by incoherent effects of individual nucleons since the charged multiplicity in hadron-hadron collisions at very high energies may become much larger than usually expected. In fact, in 1982 I demonstrated that the average charged multiplicity ($\langle n_{ch} \rangle$) and transverse momentum ($\langle p_T \rangle$) of produced particles in hadron-hadron collisions at very high energies (\sqrt{s}) have a simple relation of $\langle n_{ch} \rangle^2 \langle p_T \rangle / \sqrt{s} = \text{constant}$ ($= 0.70 \pm 0.05$) in the generalized Fermi-Landau statistical and hydrodynamical model. The relation is satisfied remarkably well by the experimental data up to the SPS p - \bar{p} Collider energies and will soon be tested by Tevatron Collider experiments. From the relation, I have predicted that the average charged multiplicity will become as large as $\langle n_{ch} \rangle = 47 \pm 2$ at $\sqrt{s} = 1.8$ TeV [13].

I have discussed so far the squeezed states of nuclear matter and hadronic matter which are squeezed by the external force or pressure caused by heavy-ion collisions and hadron-hadron collisions. However, some hadronic matter can be squeezed by itself at low temperatures (or low energies) due to the very strong attractive force between constituents of hadronic matter, the quarks. It may be called “self-squeezing”. For example, the very heavy top quark (t) and the antiquark must have a very strong attractive force due to an exchange of the Higgs scalar (H) in the standard model of Glashow-Salam-Weinberg for electroweak interactions. Therefore, suppose

that the vacuum consists of quark-antiquark and lepton-antilepton pairs as in our unified model of the Nambu-Jona-Lasinio type for all elementary-particle forces [14], we can expect that a top quark and an anti-top quark be self-squeezed to form a scalar bound state of $t\bar{t}$ [14]. This is called “top(-antitop) condensation”. According to Nambu, this is a kind of “bootstrap”, the original form of which was advocated by Chew in hadron physics in the middle of 1960’s, since the Higgs scalar is taken as a bound state of $t\bar{t}$ or a condensate of $t\bar{t}$ in our picture. In 1980, I predicted, from the sum rules for quark and lepton masses previously derived in our unified model of 1977 [14], the top-quark and Higgs scalar masses to be $m_t \cong \sqrt{8/3}m_W \cong 131$ GeV and $m_H \cong 2m_t \cong 261$ GeV. Much later, Nambu, Miransky *et al.* and Bardeen *et al.* made similar predictions for m_t and m_H in their models of the Nambu-Jona-Lasinio type which are similar to our unified model [14]. In 1990, I derived a similar sum rule for quark and lepton masses in a model-independent way [15].

IV Quark-Lepton-Gauge-Boson Physics in Composite Models

In this section, let me discuss squeezed states in quark-lepton-gauge-boson physics. Since Pati and Salam, and independently ourselves proposed composite models of quarks and leptons in the middle of 1970’s [16], hundreds of particle theorists have extensively investigated these models in great detail for the last two decades [17]. For the last decade, thousands of high-energy particle experimentalists have been seriously searching for a possible evidence for the substructure and excited states of not only quarks and leptons but also gauge bosons [18] although they have not yet found any clear evidence [19].

In our unified composite model of quarks and leptons [16], not only quarks and leptons but also gauge bosons as well as Higgs scalars are composite states of subquarks (or preons), the more fundamental and probably most fundamental constituents of matter. All these fundamental particles in quark-lepton-gauge-boson physics may be taken as self-squeezed composite states of the quark-leptonic matter. Since our composite model of quarks and leptons is a simple analogy of the celebrated quark-gluon model of hadrons by Gell-Mann, Zweig and Nambu, it leads us to a lot of easy analogous ideas in quark-lepton-gauge-boson physics. One of the most eminent examples is the principle of “triplicity”, which asserts that a certain physical quantity such as the weak current can be taken equally well as a composite operator of hadrons, or of quarks, or of subquarks [20]:

$$\begin{aligned}
J_\mu &\cong \bar{\nu}_e \gamma_\mu (1 - \gamma_5) e + \bar{\nu}_\mu \gamma_\mu (1 - \gamma_5) \mu + \bar{\nu}_\tau \gamma_\mu (1 - \gamma_5) \tau \\
&\quad + \frac{G^\beta}{G^\mu} \bar{p} \gamma_\mu (1 - \frac{g_A^\beta}{g_V^\beta} \gamma_5) n + \frac{G^\Lambda}{G^\mu} \bar{p} \gamma_\mu (1 - \frac{g_A^\Lambda}{g_V^\Lambda} \gamma_5) \Lambda + \dots \\
&\cong \bar{\nu}_e \gamma_\mu (1 - \gamma_5) e + \bar{\nu}_r \gamma_\mu (1 - \gamma_5) \mu + \bar{\nu}_\tau \gamma_\mu (1 - \gamma_5) \tau \\
&\quad + V_{ud} \bar{u}_i \gamma_\mu (1 - \gamma_5) d_i + V_{us} \bar{u}_i \gamma_\mu (1 - \gamma_5) s_i + \dots \\
&\cong \bar{w}_1 \gamma_\mu (1 - \gamma_5) w_2,
\end{aligned}$$

where w_1 and w_2 are an iso-doublet of spinor subquarks with charges $\pm 1/2$ (called “wakems”).

Another example is scaling mass parameters of hadrons, quarks and subquarks. It asserts that the current mass of light quarks be scaled to those of subquarks which can be as small as 45 GeV and that the “electrostrong” gauge theory for hadrons may appear as an effective theory in QCD as the electroweak gauge theory for quarks with the scaling relations of $m_H/m_W = m_\sigma/m_\rho$, which predicts $m_H \cong 94$ GeV [21].

The principle of triplicity tells us that the Higgs scalars can be taken equally well as composites (or condensates) of subquark-antibsubquark pairs or of quark-antiquark (or lepton-antilepton) pairs as in our unified model of the Nambu-Jona-Lasinio type as π 's and σ as those of nucleon-antinucleon pairs as in the original form of Nambu-Jona-Lasinio model [14]. In this picture of subquark-antibsubquark condensation, we have derived the mass formula for composite quarks and leptons from a partially conserved induced supercurrent hypothesis. In supersymmetric composite models [22], it leads to a simple sum rule for quark and lepton masses of [23]

$$m_e^{1/2} = m_d^{1/2} - m_u^{1/2}$$

if the first generation of quarks and leptons can be taken as almost Nambu-Goldstone fermions [24]. We have found that not only this square-root mass sum rule but also another similar sum rule of $m_\mu^{1/2} - m_e^{1/2} = m_s^{1/2} - m_d^{1/2}$ are satisfied remarkably well by the experimental values. Furthermore, if the first and second generations of quarks and leptons can be taken as almost and quasi Nambu-Goldstone fermions, respectively, we can derive not only a simple relation among lepton masses of $m_\tau \cong (m_\mu^3/m_e)^{1/2}$ [25] but also a simple relation among quark masses $m_t \cong (m_d m_c^3 m_b^2 / m_u m_s^3)^{1/2}$ [26]. These relations predict $m_\tau \cong 1520$ MeV and $m_t \cong 177$ GeV, which should be compared to the experimental values of $m_\tau = 1777.1 \pm_{0.5}^{0.4}$ MeV and $m_t = 176 \pm 8 \pm 10$ GeV or $199 \pm_{21}^{19} \pm 22$ GeV [27], respectively.

In 1991, I suggested that the existing mass spectrum of quarks and leptons can be explained by solving a set of sum rules for quark and lepton masses [28]. Today, I am pleased to announce that it can be explained completely by solving a set of not only the previously derived sum rules for quark and lepton masses but also these newly derived relations among quark and lepton masses. As an illustration, given a set of the sum rules and relations of

$$m_e^{1/2} = m_d^{1/2} - m_u^{1/2}, m_\mu^{1/2} - m_e^{1/2} = m_s^{1/2} - m_d^{1/2}, m_e m_\tau^2 = m_\mu^3, m_u m_s^3 m_t^2 = m_d m_c^3 m_b^2,$$

I have obtained the solution of

$$\begin{pmatrix} m_e & m_\mu & m_\tau \\ m_u & m_c & m_t \\ m_d & m_s & m_b \end{pmatrix} = \begin{pmatrix} 0.511 \text{ MeV} & 105.7 \text{ MeV} & 1520 \text{ MeV} \\ \text{(input)} & \text{(input)} & (1777.1 \pm_{0.5}^{0.4} \text{ MeV}) \\ 4.5 \pm 1.4 \text{ MeV} & 1350 \pm 50 \text{ MeV} & 183 \pm 78 \text{ GeV} \\ \text{(input)} & \text{(input)} & (176 \pm 8 \pm 10 \text{ or } 199 \pm_{21}^{19} \pm 22 \text{ GeV}) \\ 8.0 \pm 1.9 \text{ MeV} & 154 \pm 8 \text{ MeV} & 5.3 \pm 0.1 \text{ GeV} \\ (7.9 \pm 2.4 \text{ MeV}) & (155 \pm 50 \text{ MeV}) & \text{(input)} \end{pmatrix}$$

where the values indicated in the parentheses denote the experimental, to which my predicted values should be compared. As another illustration, given another set of the sum rules and relations of

$$\begin{aligned}
\sum_{q,l} m_{q,l}^4 / \sum_{q,l} m_{q,l}^2 &= \frac{1}{4} m_H^2, \quad \sum_{q,l} m_{q,l}^2 / \sum_{q,l} 1 = \frac{1}{3} m_W^2, \\
m_e^{1/2} &= m_d^{1/2} - m_u^{1/2}, \quad m_\mu^{1/2} - m_e^{1/2} = m_s^{1/2} - m_d^{1/2}, \quad m_\tau^{1/2} = m_b^{1/2} - m_c^{1/2}, \\
m_e m_\tau^2 &= m_\mu^3, \quad m_u m_s^3 m_t^2 = m_d m_c^3 m_b^2, \\
(m_\mu/m_e)^{1/2} &= (m_c/m_u)^{1/2} - (m_s/m_d)^{1/2}, \quad (m_\tau/m_\mu)^{1/2} = (m_t/m_c)^{1/2} - (m_b/m_s)^{1/2},
\end{aligned}$$

I have obtained the other solution of $m_H (\cong \sqrt{32/3} m_W) \cong 261$ GeV and

$$\left(\begin{array}{ccc} m_e & m_\mu & m_\tau \\ m_u & m_c & m_t \\ m_d & m_s & m_b \end{array} \right) = \left(\begin{array}{ccc} 0.49 \text{ MeV} & 101 \text{ MeV} & 1454 \text{ MeV} \\ (0.511 \text{ MeV}) & (105.7 \text{ MeV}) & (1777.1 \pm_{0.5}^{0.4} \text{ MeV}) \\ 3.3 \text{ MeV} & 1204 \text{ MeV} & 131 \text{ GeV} \\ (4.5 \pm 1.4 \text{ MeV}) & (1350 \pm 50 \text{ MeV}) & (176 \pm 8 \pm 10 \text{ or } 199 \pm_{21}^{19} \pm 22 \text{ GeV}) \\ 6.3 \text{ MeV} & 140.8 \text{ MeV} & 5.3 \pm 0.1 \text{ GeV} \\ (7.9 \pm 2.4 \text{ MeV}) & (155 \pm 50 \text{ MeV}) & (\text{input}) \end{array} \right)$$

for $m_W = 80$ GeV.

In 1977, I suggested that the CKM quark mixing matrix (V_{mn}) can be defined by the matrix element between the \underline{m} th up-like quark (U_M) with charge $2/3$ and the \underline{n} th down-like quark (d_n) with the charge $-1/3$ as $\langle u_m | \bar{w}_1 \gamma_\mu w_2 | d_n \rangle = V_{mn} \bar{u}_m \gamma_\mu d_n$ and that the Cabbibo angle (and all the CKM mixing angles) may vary as a function of momentum transfer between quarks [29], which should be observed in the future high energy experiments such as for decays of $b \rightarrow c$ at B factories (or $t \rightarrow b$) and for scatterings of $\nu + u \rightarrow l + s$ and $\nu + u \rightarrow l + d$ (or $e + u \rightarrow \nu + d$ and $e + u \rightarrow \nu + s$ at HERA). In 1981, we predicted that the Cabbibo angle becomes larger as momentum transfer between quarks grows up in a simple subquark model [30]. Furthermore, in 1992, I pointed out that given the us element of the CKM quark mixing matrix (V_{us}), all the other elements can be successfully explained or predicted by using the five relations derived in a composite model of quarks [31]. In fact, given a set of the relations of

$$V_{us} \cong -V_{cd}^*, V_{cb} \cong -V_{ts}^*, |V_{cb}| \cong (m_s/m_b) |V_{us}|, |V_{ub}| \cong (m_s/m_c) |V_{us} V_{cb}|, |V_{td}| \cong |V_{us} V_{cb}|,$$

I have obtained the solution of

$$\left(\begin{array}{ccc} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{array} \right) = \left(\begin{array}{ccc} 0.975 & 0.218 \sim 0.224 & 0.0017 \\ (0.9747 \sim 0.9759) & (\text{input}) & (0.002 \sim 0.005) \\ 0.218 \sim 0.224 & 0.975 & 0.021 \\ (0.218 \sim 0.224) & (0.9738 \sim 0.9752) & (0.032 \sim 0.048) \\ 0.0046 & 0.021 & 0.9996 \\ (0.001 \sim 0.015) & (0.030 \sim 0.048) & (0.9988 \sim 0.9995) \end{array} \right)$$

To sum up, I wish to emphasize that not only the mass spectrum of quarks and leptons but also the CKM quark mixing matrix can be explained successfully in the unified composite model of quarks and leptons and that "elementary-particle" physics of quarks and leptons in the last quarter century will no doubt proceed by one step forward to "subphysics", the elementary-particle physics of subquarks.

V Astrophysics and Space-Time Physics in Cosmological Models

In this section, let me discuss squeezed states of matter in the universe. A simplest example of self-squeezed states of matter in the universe is a star. A planetary system, a nebula, a galaxy, a cluster of galaxies and a cluster of the clusters of galaxies are also self-squeezed states in a sense. Since I have no time (or space) to discuss either one of these examples one by one, I only point out the importance of searching for “super-hypernuclear stars”, which are self-squeezed states of super-hypernuclei (or strange quark matter) predicted by Chin and Kerman and by myself [5]. It has been especially advocated later by Witten.

More fascinating, however, is to imagine that the universe itself is a self-squeezed state of matter. No question, it was a self-squeezed state of matter right after the big bang. One can imagine that it had also been a self-squeezed state of matter even before the big bang. In order to discuss possible physics before the big bang, if any, we may not be able to use any more Einstein’s theory of general relativity on gravitation. Instead, we must adopt “pregeometry”, the more fundamental theory, first suggested by Sakharov in 1967 [32] and first demonstrated by us in 1977 [33], in which gravity is taken as a quantum effect of matter fields and in which Einstein’s theory of general relativity for gravity appears as an approximate and effective theory at long distances (or low energies). In 1983, we could even suggest the pregeometric origin of the big bang in the following way [34]. Pregeometry has changed the notion of the space-time metric completely since the space-time metric can be taken as a kind of composite object of the fundamental matters. Therefore, we can even imagine that at high temperature the space-time metric would dissociate into its constituents just as ordinary objects do. Then, the metric would vanish although the fundamental matters still remain in the mathematical manifold of the space-time. Namely, the pregeometric phase is the phase of the space-time in which metric $g^{\mu\nu}(g_{\mu\nu})$ vanishes (diverges) and, therefore, the distance of $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$ diverges. There, the space-time still exists as a mathematical manifold for the presence of the fundamental matters. Such an extraordinary phase may be realized in such regions as that beyond the space-time singularity, i.e., before the big bang and that far inside a black hole where the temperature is extremely high (as high as the Planck mass). In a simple model of pregeometry, Akama and I have demonstrated that although the pregeometric phase is stable at very high temperature the geometric phase where the metric is finite and non-vanishing will turn out to be stable as the temperature goes down. This remarkable possibility of phase transitions of the space-time between the geometric and pregeometric phase will exhibit a characteristic feature of pregeometry, if it is found. It seems very attractive to interpret the origin of the big bang of our universe as such a local and spontaneous phase transition of the space-time from the pregeometric phase to the geometric one in the overcooled space-time manifold which had been present in the “pre-big-bang” era for some reason.

This interpretation of the big bang also suggests that there may exist thousands of universes created and expanding in the space-time manifold as our universe. It even predicts that such different universes may collide with each other. Furthermore, even in our universe there may exist “pregeometric holes”, the local spots in the pregeometric phase with an extremely high temperature where the space-time metric disappears, liberating enormous latent heat, and/or “space-time discontinuities”, the local plains where the metric (and, therefore, the light velocity or the Newtonian gravitational constant) discretely changes due to the phase difference of two

adjacent space-times (or two colliding universes). I have been strongly urging astronomical and cosmological experimentalists to search for these pregeometric holes and space-time discontinuities, which are much more exotic than black holes. It would be fascinating if the recently observed “Great Wall” of galaxies (much older than the Chinese Great Wall) be caused by such space-time discontinuity.

The most fascinating among my suggestions on squeezed states is that in a model of the extended n -dimensional Einstein-Hilbert action for space-time and matter the space-time (or universe), when contracted (or squeezed), may transit into a new one of higher or lower dimensions at the minimum action near the Planck scale [35]. Since I suggested this in 1987, many authors have discussed this “incredible” possibility and concluded that it is possible [36].

In concluding this section, I wish to announce my latest work on squeezed states of matter in the universe entitled, “The Meaning of Dirac’s Large Number Hypothesis” [37]. Dirac’s large number hypothesis (LNH) [38] states that the Eddington large numbers [39] $N_1(\equiv \alpha/Gm_em_p \cong 10^{39})$, $N_2(\equiv m_e/\alpha H \cong 10^{40})$ and $N_3(\equiv 4\pi\rho/3m_p H^3 \cong 10^{80})$ are not independent but related with each other. By reconsidering the meaning of the LNH, I have shown that not only the “dynamical” LNH relation of $N_3 \sim N_1 N_2$ [40] but also the “geometrical” LNH relation of $N_3 \sim (N_2)^2$ holds so that the LNH may not be taken as a hypothesis but become the large number rule (LNR).

VI Conclusion

In the previous sections, I have discussed not only various squeezed states existing in the universe and various squeezed states which might be existing or may be produced in the universe, but also even a squeezed state of the universe (or space-time), itself. In this last section, I have originally planned to emphasize the importance of uncertainty relations and the Pauli principle in discussing these squeezed states in the nature. However, since I have no time (or space) to do that, which seems to be rather trivial, I will instead emphasize how closely these two principles, the Heisenberg uncertainty principle and the Pauli exclusion principle, are related with each other and discuss how they may be violated in the nature.

The close relation between the two principles seems to be self-explained in the following chain diagram:

$$\Delta x \cdot \Delta p \gtrsim \hbar \rightarrow [p, q] = -i\hbar \rightarrow [\varphi(x), \varphi(y)] = i\Delta(x - y) \text{ and } \{\psi(x), \bar{\psi}(y)\} = i(i \not{\partial}_x + m)\Delta(x - y).$$

The possible breakdown of (or deviation from) uncertainty relations at extremely short distances (or high energies) has already been suggested and extensively discussed in superstring models [41] by Amati, Ciafaloni and Veneziano [42]. They have suggested the extended uncertainty relation (EUR or ACV relation) of

$$\Delta x > \frac{\hbar}{\Delta p} + \alpha' \Delta p,$$

where α' is the Regge slope of superstrings which is the order of $(Planckmass)^{-2}$. This realizes not only the old conjecture by Landau and Weiskopf who suggested the existence of natural cutoff at a short distance (or high energy) of the Planck scale but also our hypothesis in the unified composite model for all elementary-particle forces including gravity [43].

Also, the possible simple violation of the Pauli principle has already been investigated not only theoretically but also experimentally [44]. Recently, we have discussed superficial violation of the Pauli principle due to the possible substructure of electrons in composite models of quarks and leptons, and estimated the ratio of the Pauli forbidden atomic transition to the allowed one to be of order $10^{-50} - 10^{-44}$ for heavy atoms if the size of the electron is of order 10^{-17} cm [45]. We have also emphasized that such superficial violation of the Pauli principle must exist, no matter how small it is, if the electron has any substructure at all. It seems even natural since it is a simple extension of the familiar effects at the various levels of atoms, nuclei, and hadrons: For example, the hydrogen atom which consists of the proton and the electron obeys Bose statistics in ordinary situations. However, when two hydrogen atoms overlap each other, the bosonic property of each hydrogen atom becomes meaningless and, instead, the fermionic property of the constituent protons and electrons becomes effective. Suppose also two helium nuclei are overlapping each other. Then, the genuine bosonic statistics of each helium nucleus is meaningless and only the fermionic statistics of the constituent nucleons is valid. Furthermore, when two protons overlap each other, the fermionic property of protons will be lost and that of constituent quarks will be effective.

A field theoretical formulation of such an effect is unfamiliar. Suppose that the electron consists of a fermion w and a boson C as in the minimal composite model of quarks and leptons [17]. Then, the local field of the composite electron ψ (of mass m and energy E) can be constructed in the Haag-Nishijima-Zimmermann formalism [46] as

$$\psi(x) = \lim_{\substack{\xi^2 < 0 \\ \xi \rightarrow 0}} \frac{w(x + \xi)C(x - \xi)}{[(2\pi)^3(E/m)\langle 0 | w(x + \xi)C(x - \xi) | \psi \rangle]^{1/2}}.$$

However, in the local limit of $\xi \rightarrow 0$ no such effect as a violation of the Pauli principle due to the compositeness of electrons can be expected. To find such an effect, let us consider the bilocal field of a composite electron,

$$\psi(x, \xi) = Nw(x + \xi)C(x - \xi),$$

where ξ represents the finite nonvanishing size of order $r_0 [= (\xi^2)^{1/2}]$ and N is an appropriate normalization factor. The anticommutator of the fields, given by

$$N^{-2}\{\psi(x, \xi), \psi(y, \eta)\} = \{w(x + \xi), w(y + \eta)\}C(x - \xi)C(y - \eta) + w(y + \eta)w(x + \xi)[C(y - \eta), C(x - \xi)],$$

clearly indicates the superficial violation of not only the Pauli principle but also causality, since neither $\{w(x + \xi), w(y + \eta)\}$ nor $[C(y - \eta), C(x - \xi)]$ vanishes for $(x - y)^2 < 0$ [although the former vanishes for $(x - y + \xi - \eta)^2 < 0$ while the latter does for $(x - y - \xi + \eta)^2 < 0$].

This demonstration may illustrate what we mean by the superficial violation. Namely, neither the Pauli principle nor causality is violated at the level of constituent fields of w and C since w and C perfectly obey Fermi and Bose statistics, respectively. Also, the anticommutator of w 's and the commutator of C 's perfectly respect causality. However, due to the possible substructure of electrons, the composite electron field may exhibit the situation in which its statistics looks neither purely fermionic nor purely bosonic when two electrons are located close to and are overlapped with each other at a distance of the order of their size r_0 .

The recent experiment of Ejiri *et al.* [47] using a NaI detector in Osaka University may be able to set an upper bound of order 3×10^{-16} on the ratio for $Z = 53$, which is the atomic number of I . This corresponds to an upper bound of 1×10^{-17} cm on the electron size r_0 . If this is the case, it also corresponds to a lower bound of 2 TeV on the inverse size of electrons, $1/r_0$ which is 1 order of magnitude larger than the known lower bounds of order 100 GeV on the compositeness scale of electrons, Λ , obtained by e^+e^- collider experiments [48].

In the rest of my talk, let me talk about the future prospects of these two principles. One possible movement is to take the uncertainty principle not as a fundamental principle but a consequence of a more basic idea. Along this line of thinking, let me remind you of the latest work by Hall, who has shown that the sum of the information gains corresponding to measurements of position and momentum is bounded as

$$I(X | \varepsilon) + I(P | \varepsilon) \leq \log_2(\Delta X)_\varepsilon(\Delta P)_\varepsilon/h$$

for a quantum ensemble with position and momentum uncertainties ΔX and ΔP [49]. In any case, we may need to investigate seriously extended uncertainty relations such as the ACV relation in superstring models and generalized nonlocal commutation relations such as ours in composite models discussed in Section V (, and also perhaps quantum group).

Another possible movement is to take the Pauli principle not as a fundamental principle but a consequence of the more basic idea. To this end, we may need to reconsider generalized Bose-Einstein and Fermi-Pauli statistics such as parabose and parafermi statistics (, and also q-bose and q-fermi statistics [50]).

More interesting seems to investigate “prequantum theory (or mechanics)” in which the familiar quantum theory (or mechanics) may appear as an approximate and effective theory. Along this line, we may need to reconsider Bohm’s theory with hidden variables and Einstein’s argument against Bohr’s probability-statistical interpretation in quantum mechanics.

In concluding my talk, I wish to emphasize that both subphysics and pregeometry are at least promising “theories of everything” and working frameworks or machineries for “prephysics”, a new line of physics (or philosophy but not metaphysics) in which some basic hypotheses (or principles) taken as sacred ones in ordinary physics such as the four dimensionality of space-time [35], the number of subquarks [51], the invariance under gauge transformation [52], that under general coordinate transformation [53], the microscopic causality, the principle of superposition (or particle-wave idea in more general) and so on are to be reasoned. Therefore, I wish to conclude this talk simply by modifying the original Wheeler’s word into the following: Never more than today does one have the incentive to explore prephysics (or “new physics”) [54].

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