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AT ULTRA-LOW ENERGY POSSIBLE VIOLATION OF PAULI EXCLUSION PRINCIPLE AND ITS POSSIBLE MECHANISM AND PREDICTIONS

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Abstract

So far the universality of Pauli exclusion principle (PEP) was queried some times. First, we look out some hypothesizes of violation of PEP (VIP), and proposed violation at high energy and some tests. Next, we discuss another possibility on VIP at ultra-low energy, which is similar to superconductivity, superfluids and Bose-Einstein condensation (BEC), etc. Further, we propose a possible mechanism of VIP: Cooper pairs extend to general fermion pairs, so they transform to bosons with VIP. From this we may predict some characters of this like-boson, as in nuclei and atoms, etc. Moreover, we research some possible VIP in mathematics and physics. Based on the extensive quantum theory, its PEP may be violated.

Keywords: violation of Pauli exclusion principle; ultra-low energy; high energy; mechanism; prediction.
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I. Introduction

The Pauli exclusion principle (PEP) is a very important natural rule, and is theoretical foundation of atomic structure. It is a well-known principle in quantum mechanics, and is widely applied and may explain from the periodic table of elements to neutron stars, etc.

But, some scientists queried the universality of PEP some times. First in 1978-1980 Santilli proposed the rest of PEP, in particular, for strong interactions, and the structure of hadrons, nuclei and stars [1-3]. Further, Santilli researched inapplicable of PEP in numerous experiments [4]. Based on some experiments and theories of particles at high energy, we investigated violation of PEP at high energy begin from 1984 [5-14], and researched some possible tests of violation of PEP [6,10,11]. Then in 1987-1989 Ignatiev-Kuzmin and Greenberg-Mohapatra [15-17] proposed that PEP has a small violation for any natural substance, which contains a fraction of order β^2 of anomalous atoms and nucleons.

So far the experimental tests have proved high precisely the validity of the in usual cases. Kekez, et al., discussed an upper limit to violations of PEP [18], and searched violation of PEP in nuclear decays [19]. Thoma, et al., researched limits on small violations of PEP in the primordial nucleosynthesis [20]. Tsipenyuka, et al., discussed experimental test of the possible violation of PEP by photo-activation analysis of carbon content in pure boron [21]. Javorsek, et al., searched new experimental test of PEP using accelerator mass spectrometry [22].

Recent, the violation of PEP (VIP) aroused again attention, which poses a special word VIP. VIP Collaboration searched new experimental limit on VIP by electrons [23-25], and experimental tests of quantum mechanics on VIP and future perspectives [26]. Chakraborty, et al., discussed sufficient condition for the openness of a many-electron quantum system from the violation of a generalized PEP [27]. Abgrall, et al., researched new limits on bosonic dark matter, solar axions, PEP violation, and electron decay from the low-energy spectrum [28]. Shi, et al., searched experiments for VIP [29]. In this paper, we discuss another possibility of VIP, at ultra-low energy, and propose its possible mechanism on VIP.

2. Possible Violation of PEP at Ultra-Low Temperature

The future experiments on VIP should be combined widely with various theories of hidden and obvious violation of PEP. Author think that known experiments and theories seem to imply VIP at high energy. Some possible tests have been proposed in particle physics, nuclei at high energy and astrophysics, etc., in particular, the excited high-n atoms, the various nuclei at high energy, dineutrons in extremely neutron-rich nuclei, and gamma ray sources, black hole in high energy astrophysics, etc [6,10,11].

The most notable and realizable test is in the excited high-n atoms. For atomic electrons, if PEP is violated, the K shell will be able to accommodate more than two electrons. Rinneberg, et al., obtained high-n Rydberg atoms with the principal quantum number n=290 for in the laboratory [30]. Then they obtained again atoms with n=520. Ling, et al., observed Rydberg state with n=1000 [31,32]. In last case, its high energy level is 10^6 times as large as "normal" atom at low energy, and the effective radius is

$$a_n = n^2\hbar^2 / \mu e^2 = 5.29\times10^{-3}\,cm . \qquad (1)$$

It is already a near-macroscopic scale. According to quantum mechanics, the electron number in atom must be either two for usual orbit or infinite for ionized state. I believe that there is third possibility: For very high excited atoms, at above near-macroscopic orbit three electrons seems to be able to coexist, at least in a short time interval, which just corresponds to high energy. Moreover, in highly excited atom the effect of spin can be neglected [30], it is just that I expected the condition of the unified statistics and of the inapplicability of PEP at high energy [5]. Further, it is validated that "magic" Rydberg states with n=150 possess enough long lifetimes [33,34].

Mohapatra [35] predicted the presence of a neutral spin-3/2 hadron with mass in the 1-2 GeV range by using infinite statistics. It implies VIP at 1-2 GeV. According to the uncertainty principle we expected that usual high energy is about 2-20 GeV for particles [5]. In different regions, for instance, nuclei, multiplicity and celestial body, etc., there should be corresponding threshold values for high energy.

Several groups (LEPS, DIANA, CLAS and BES Collaborations) observed some multi-quark resonances at high energy [36-38]. For example, an exotic baryon Θ^+ (1540) with the quantum numbers of K^+n has been reported, in which five-quark($qqqq\overline{q}$) configurations are mixed with the standard three-quark valence configuration. These multi-quark states coexist inside a short time, which increases a possibility of VIP.

At ultra-cold there are three well-known superconductivity, superfluids and Bose-Einstein condensation (BEC) [39]. They are macroscopic quantum phenomena in essence. In ultra-low temperature two fermions can constitute a boson like the Cooper pair, and perform BEC [14]. It is the fermion degeneracy, and forms the Fermi-Dirac condensation (FDC). This is also a unification between BE and FD statistics [5]. Further, we predict that the high-T_c superfluidity should exist, which corresponds to the high-T_c superconductivity. Moreover, the new charge cluster, no matter as negative or positive charge, seems to have implied VIP.

In 1995, the condensation numbers of ^{87}Rb and ^{7}Li atoms may be high as 10^5 under this extreme condition [40]. In 1999 DeMarco and Jin cooled the potassium atomic gas with fermion characteristics to 10^{-9} K, so that the potassium atom pairs to realize quantum degeneracy to Fermi atomic gas [41]. Its quantum effects are different from Bose atomic gas, such as Fermi pressure, Pauli blocking and superfluid, etc. The interaction leads to the formation of Cooper pairs by Fermi atoms and the change of resonance interaction to realize the phase transition from the supercurrent of BCS to BEC [42-44]. At ultra-low temperature fermion pairs can VIP. Contrarily, in 1960 Girardeau proposed a gas model under the hard core boson limit, that is, Tonks-Girardeau gas, at this case the boson is confined to one-dimensional space and the repulsion is very strong. It is similar to PEP. In 2004 Paredes, et al., confirmed this case by cold atomic experiments [45]. This is a boson similar to a fermion. So boson and fermion are symmetry and unification. In this case PEP has not played a role in the ultra-cold structure, and VIP may be tested.

3. A Possible Mechanism on VIP, and Predictions

For superconductivity a well-known theory is Bardeen-Cooper-Schrieffer (BCS) theory, whose base is Cooper pairs, which interacts through phonon. Cooper pairs are extended to the electron bag model, which may possibly describe superconductivity at high temperature. Further, we propose a possible mechanism on VIP: It is similar to Cooper pairs, and can extend to general fermion pairs, which is base of VIP. Its key is that fermion pairs transform to boson, and may obtain various similar characters of bosons.

From this we may predict: 1). Existence of various fermion pairs. They are mainly proton pairs and neutron pairs, i.e., nucleon pairs. Others are atom with semi-integer spin pairs, molecule with semi-integer spin pairs, etc. It is known that the spin wave function includes a spin singlet:

$$\varphi_{n_1,n_2}^{spin} = \frac{1}{\sqrt{2}}(|\uparrow\downarrow> - |\downarrow\uparrow>). \qquad (2)$$

Since the spin singlet is an odd function of two nucleons n_1, n_2, the wave function $\varphi(r_1 - r_2)$ must be even, this is, $\varphi(r_1 - r_2) = +\varphi(r_2 - r_1)$.

The pair creation operator in a momentum space k is:

$$\hat{P}_k^+ = c_{k\uparrow}^+ c_{-k\downarrow}^+ . \qquad (3)$$

The many-body wave function of coherent state is:

$$|\psi_{BCS}> = C\exp(\sum_k \alpha_k \hat{P}_k^+)|0>. \qquad (4)$$

2). Fermion pairs condensation (FDC). For BEC, the critical temperature is:

$$T_c = \frac{2\pi\hbar^2}{k_B m}\left(\frac{n}{2.612}\right)^{2/3}. \tag{5}$$

Here the particle density is:

$$n = \frac{1}{(2\pi)^3}\int \frac{1}{e^{\beta(\varepsilon_k-\mu)}-1}dk^3 . \tag{6}$$

For fermions the particle density should be:

$$n_f = \frac{1}{(2\pi)^3}\int \frac{1}{e^{\beta(\varepsilon_k-\mu)}+1}dk^3 . \tag{7}$$

The corresponding critical temperature of FDPC is probably:

$$T_c^{FDPC} = \frac{2\pi\hbar^2}{k_B(2m_f)}\left(\frac{n_f}{2.612}\right)^{2/3}. \tag{8}$$

3). For atom if Cooper pairs exist in electron orbit, it will form a new chemical element.

4). For nuclei if nucleon pairs exist, it will form new nucleus, or it is known α-particle (He cluster) model of nuclei, and corresponds to four electron creation operators for the same k point,

$$\hat{P}_k^+\hat{P}_k^+ = (\hat{P}_k^+)^2 = c_{k\uparrow}^+ c_{-k\downarrow}^+ c_{k\uparrow}^+ c_{-k\downarrow}^+ = 0 . \tag{9}$$

It corresponds to the even-even nuclei (whose basic state has spin J=0), and relates magic number, and stable magic nucleus and double magic nuclei with spin J=0 in the nuclear shell model.

And 3) and 4) relate atom and nucleus at ultra-cold. In nuclei the strong interactions exist between nucleons, so $(p\uparrow p\downarrow),(n\uparrow n\downarrow)$ is formed easier, and become the similar boson and the simplest α-particle model and general more stable even-even nuclei. In a certain extent nuclei are FDPC. Further, it is namely neutron star.

5). Different energy levels of the same structure exist in atoms and nuclei, etc. For example, for He nucleus the energy level of $(p\uparrow p\downarrow),(n\uparrow n\downarrow)$ is the lowest than $(p\uparrow p\uparrow),(n\uparrow n\downarrow)$ and so on. For water molecule the energy level of $H\uparrow OH\downarrow$ is the lowest.

6). Probably, the fermion laser exists.

4. Possible Violation of PEP in Mathematics and Physics

We suggested that particles at high energy possess a new statistics unifying BE and FD statistics [5], for example, a possible unified distribution is:

$$y_{\Gamma} = \frac{\beta^{\alpha}}{\Gamma(\alpha)} x^{\alpha-1} e^{-\beta x} . \qquad (10)$$

This agrees quantitatively with scaling, the multiplicity and its distribution, and large transverse momentum, etc., which are independent of the types of particles.

In fact, the parastatistics, the fractional statistics [46], anyon, and the fractional quantum Hall effect, etc., have some contradictions with the standard theory in which two types of different particles and their properties are distinguished from the spin-statistics stringently. Even in the nonabelian gauge field theory there is the ghost particle whose spin is zero, but which agrees with anticommutation relation. They correlate to various theories relevant to possible VIP, including some obvious and hidden ones [9,10].

Some experiments and theories implied VIP at high energy [5,6], etc. This is related with the nonlinear theory [8]. Haldane discussed the fractional statistics in arbitrary dimensions has a generalization of PEP [47]. It is applied to the vortex-like quasiparticles of the fractional quantum Hall effect, and gives the same result as that based on the braid-group. It is also used to classify spinons in gapless spin-1/2 antiferromagnetic chains as semions. Greenberg and Mishra demonstrated that parastatistics can be quantized using path integrals by calculating the generating functionals for time-ordered products of both free and interacting parabose and parafermi fields in terms of path integrals, and gave a convenient form of the commutation relations for the Green components of the parabose and parafermi operators in both the canonical and path integral formalisms [48]. Moreover, the ghost field, anyon, some abnormal phenomena, spin, polarization and collisions, etc., are correlated closely with possible VIP and unified quantum statistics.

5. Extensive Quantum Theory and Corresponding VIP

Feynman pointed out: "There are certain situations in which the peculiarities of quantum mechanics can come out in a special way on large scale." In a special situation "quantum mechanics will produce its own characteristic effects on a large or 'macroscopic' scale" [49]. The Titius-Bode (TB) law describes approximately the average distances between the Sun and various planets in the solar system. The law has implied a quantized phenomenon in the solar system. We developed the TB law to a new form [50,51]:

$$r_n = an^2 . \qquad (11)$$

From this we derived a similar theory with the Bohr atom model, and obtained the quantum constants $H = (aGM_O)^{1/2}$ of the solar system and corresponding Schrödinger equation. Some exoplanets and ten satellite galaxies of Galaxy, etc. agree with the same form. Further, we proposed the extensive quantum theory and its three laws: 1. Extensive quantum is its element in any system. 2. Its theory has similar quantum formulations with different quantum constants H. 3. Evolutions of systems may be continuous, but stable states are quantized [52]. Its mathematical base is fractal. Using the geometric average method, three different values of the quantum constants of man, cell and macromolecule may be derived for biological, chemical and physical discrete systems with different scales. Using this theory we researched superconductivity, superfluidity, BEC, and various macroscopic quantum phenomena. Alexandrov researched an extensive theory from weak to strong coupling superconductivity [53].

We searched that the extensive quantum theory is applied to various macroscopic quantum phenomena [54,55], and proposed the extensive quantum biology and its application in DNA [56-58]. We researched the extensive quantum social sciences [59-61], in which the social entangled states and exclusion exist, and the cooper pair corresponds to husband and wife. In a word, the extensive quantum theory agrees with symmetry, and it has corresponding PEP, but this can be violated under some conditions.

6. Conclusion

Through the experiments provides high precisely tests on PEP in usual cases, but we may research some possible violations of PEP (VIP) under some special conditions, for example, high energy and/or ultra-low energy, etc. Further, we should investigate possible mechanism on VIP, which relates usually nonlinear theory and so on.

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