Physical Foundation

of

Pauli Exclusion Principle and Nuclear Force

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Abstract

Laws and principles in physics, each of them should have a fundamental reason why and how it works. Through reviewing the reason in ontological point of view, we can find that the singularity of black hole doesn't exist and the black hole itself is not the end of a star's life because it will be blown up eventually. Also, it is interpreted that the Pauli exclusion principle is originated in the spin-spin magnetic interaction of elementary particles such as proton, neutron, electron, etc., those of which are known as fermions. With the interpretation for the exclusion principle and a classical model of proton and neutron, we can explain how the nuclear force arises inside the nucleus, why it is in such short range and attractive, and some properties of nuclear force, which is nothing but a special case of electromagnetic interaction. In the same line of thought, new nuclear model is suggested, which is compatible to both liquid drop model and shell model.

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Introduction

As axioms in mathematics, laws and principles in physics are also supposed to be truth, those of which are mainly based on empirical facts in natural phenomena and on which physical theories are built. However, the laws and principles could be understood comprehensively with the first principle given in 4-D complex space saying that physical interactions are manifestations in real subspace in the process of searching for equilibrium states in 4-D complex space for net charge density, net mass density, and against any dynamic variation (current effect) of electric charges and/or mass. Not only identifying the origination of physical fields, such as electric field ($\vec{E}$), magnetic field ($\vec{B}$), and gravitational field ($\vec{g}$) in 4-D complex space, but we also became to know that physical interactions are not stand-alone by themselves but correlated to others. For example, gravitational interaction is attractive because physical vacuum (4-D complex space) has strong preference for the equilibrium of net charge density to the equilibrium of net mass density, which is interpreted in the comparison of strengths of coulomb interaction and gravitational interaction in phenomena. Hence, the gravitational interaction can be considered as a part of electric interaction or by-product in ontological point of view. Moreover, there should be the mass-charge interaction expected in the first principle in 4-D complex space (Kim 2017).

On the other hand, have we ever questioned about the validity of special theory of relativity? What if our nature has no light and what if physical distance is measured by sound signals or something else? Then, the science we have known could be different a lot because natural science should be based on physical facts in phenomena. In other words, the special theory of relativity is valid as long as electromagnetic interaction is involved in natural phenomena. Now, we can ask ourselves what kind of physical interaction is not related to the electromagnetic interaction in natural phenomena.

What about the Pauli exclusion principle saying that, for instance, in an atom only two electrons can be in the same quantum state, but their spins must be in antiparallel alignment? Have we ever considered why the principle should exist? Is it a just rule that we should accept blindly? The Pauli exclusion principle is applied for the electron configuration in an atom or molecule, superconductivity in solid-state physics, and even in astrophysics to explain the formations of white dwarf and neutron star (refTxt). Then, it is natural to ask what on earth makes the principle to work in atomic scale and even in such astrophysical objects. There should be a physical interaction behind the exclusion principle, which has not been identified yet. If a physical interaction is assumed for the exclusion principle, how two elementary particles (fermions) in a distance far away from each other as in white dwarf star or neutron star can interact or communicate with the other whether they are in the same quantum state or not. In another words, how such a big quantum system is possible for the Pauli exclusion principle?

Meanwhile, since physical interactions are supposed be related to the reaction of vacuum particles with the first principle in 4-D complex space, it is interesting to investigate the nuclear force that is holding nucleons in the nucleus of an atom, which is such short-range force and much stronger than gravitational or electromagnetic force that we have known. First of all, we need to investigate the range of validity for gravitational and electromagnetic interactions.

The singularity of black hole

In gravitational interaction as $F = \frac{GMm}{r^2}$, in which r is the distance between two mass objects and G is gravitational constant, let's say that the mass M is point mass at the origin and mass m is unit mass. If the distance r is getting close to the origin $(r \to 0)$, the question is whether the force F can be infinity or not. Alternatively, if the mass is not a point mass but has a finite volume and the distance r is fixed outside the volume and mass M goes to infinity $(M \to \infty)$, the similar question is whether force F can be infinity or not. In physical reality the answer is No. Not simply saying that the word 'infinity' is not possible in reality, we can find the reason that it is not possible in the 4-D complex space in which 3-D imaginary subspace is filled up with vacuum particles, each of which has electric charge and spin as in positron but negative mass (bounded). Without an external interference in 3-D real subspace (physical phenomena), vacuum particles in the imaginary subspace can be stationary with equally spaced distance among them if the spin of vacuum particles is not considered; however, according to the first principle in 4-D complex space spins of vacuum particles make them vibrate and/or rotate without pointing any specific direction.

For the mass M in real subspace, vacuum particles in imaginary subspace spontaneously rearrange themselves to get the equilibrium in net mass density or to nullify the disturbance of net mass density in which vacuum particles are getting closer to the mass object; however, there is a limit in making the equilibrium due to the finite size of volume occupied by each vacuum particle in the imaginary subspace. In gravitational force $F = \frac{GMm}{r^2}$, let's say, if mass M keeps increasing while the distance r and the mass m keep constant, there should be upper limit as shown in Fig. (1), in which gravitational force F is supposed to be increased linearly with mass M as expected in Newtonian physics and general theory of relativity, which is shown for mass $M < M_c$ in Fig. (1);

however, if mass M keeps being increased, the corresponding increment of F is getting smaller and the F gets to a limit as shown in Fig. (1).

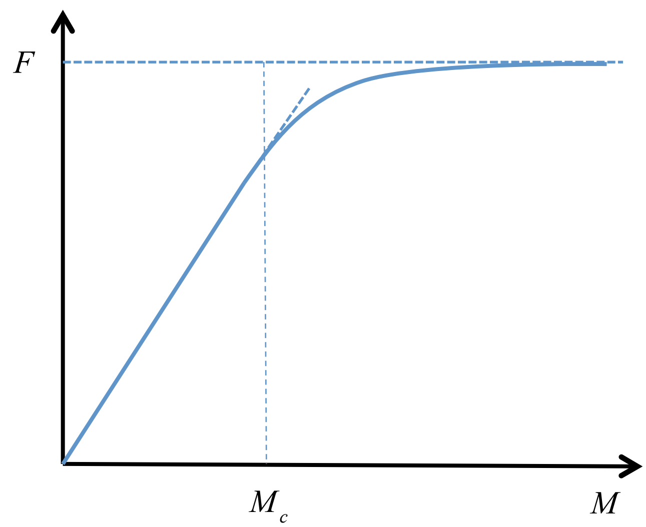

Fig. 1: the strength limit of gravitational interaction

As an extreme case, we can think a stellar object showing such strong gravitational field with the event horizon expressed as $r_s = \frac{2GM}{c^2}$, which is Schwarzschild radius for non-rotating black hole and beyond which even light cannot escape from (refTxt). Until the mass of the stellar object $M < M_c$, the radius of event horizon r_c has a linear relation to the mass M, but the increment of radius will be stopped although the mass M keeps being increased as shown in Fig. (1). Then, the stellar object will be exploded at last due to the internal pressure in vacuum space, no matter how long it takes until the explosion. Therefore, the hole (region of space and time) in the name of black hole doesn't exist and black hole is not the dead end of star's life. Even inside the event horizon, the gravitation should be finite and continuous, which means that there is no gravitational singularity and that the micro black hole in a theoretical speculation (Hawking 1977) is not possible due to the finite size of vacuum particles. By the same token, the electromagnetic interaction expressed as $F \sim \frac{1}{r^2}$ also should be finite when $r \to 0$.

Pauli exclusion principle in quantum mechanics

The Pauli exclusion principle says, only two electrons in an atom can occupy the same orbital in which their spins must be antiparallel. It is a rule proposed by physicist Wolfgang Pauli in 1925 to understand electron configurations and energy levels of atoms (APS physics 2007).

It is about the spin that is one of intrinsic properties with mass, charge, and magnetic moment of elementary particles such as electron, proton, neutron, etc., which is introduced initially in quantum mechanics. The spin of elementary particles is interpreted as an intrinsic angular momentum related to the intrinsic magnetic moment. In a quantum system containing two or more identical particles, for the exchange of any two identical particles total wave function, $\psi(1,2,\ldots)$, can be antisymmetric as $\psi(1,2,\ldots)=-\psi(2,1,\ldots)$ or symmetric as $\psi(1,2,\ldots)=+\psi(2,1,\ldots)$ because the wave function in quantum mechanics is interpreted as the probability amplitude expressed as $\text{Prob.}\propto|\psi|^2$, in which the antisymmetric wave function is compatible for the Pauli exclusion principle. In particle physics there are two categories, fermions and bosons, in fundamental particles distinguished by their characters whether the Pauli exclusion principle is applied or not, in which fermions are baryons (proton, neutron, etc.), leptons (electron, neutrino, etc.), etc. and have odd half-integer-spin as $1/2$, $3/2$, … with unit $\hbar$; bosons are intermediate (force carrying) particles (photon, etc.), mesons, etc. and have integer-spin as 0, 1, 2, … with unit $\hbar$. Fermions are obeying the Pauli exclusion principle and described by Fermi-Dirac statistics; on the other hand, bosons are not obeying the Pauli exclusion principle and described by Bose-Einstein statistics (Beiser 1981, Gasiorowicz 1974, refTxt)

In two-electron quantum system, for example, the spatial wave function in quantum mechanics is symmetric if the spins of electrons are antiparallel (singlet state) to each other and antisymmetric if the spins are parallel (triplet state). Here, a fundamental question arises as what kind of physical interaction or fundamental reasoning should be behind the principle. In physics, most probable physical interaction is to make an equilibrium state or to minimize the energy in a physical system (refTxt).

As the physical interaction behind the Pauli exclusion principle, the spin-spin magnetic interaction among electrons or fermions in general is inferred in which the magnetic moment (μ_s) of electron and its spin (S) is expressed as $\mu_s \propto S$; hence, the spin-spin magnetic interaction[2] should be in a

[2] magnetic dipole-dipole interaction in a classical picture for the spin

short range as $F_s \sim r^{-4}$ if compared with electric coulomb interaction as $F_e \sim r^{-2}$, and it is repulsive for parallel spins and attractive for antiparallel spins, in which the directions of both spins are perpendicular along the line of coulomb force between two electrons or to a spherical surface made by the two electrons in dynamic motion. Then, another question arises why only two antiparallel electrons are possible in the same orbital of quantum system.

Let's think about the electron configuration in an atom. Two electrons can be in the same orbital in an atomic system; here, the orbital is the physical region corresponding to the energy level of electron, which is a restrict region not sharing with other electrons in other energy levels. In Fig. (2) two electrons with spins $S1$ and $S2$ are in the same orbital, in which the orbital is represented as a 3-D surface, which is almost exclusive region only for two electrons; the possible way to be in the same orbital with their dynamic motions is antiparallel orientation to each other with which their repulsive electric interaction $\left(F_e \sim r^{-2}\right)$ can be minimized with the attractive spin-spin magnetic interaction whenever they are in close proximity.

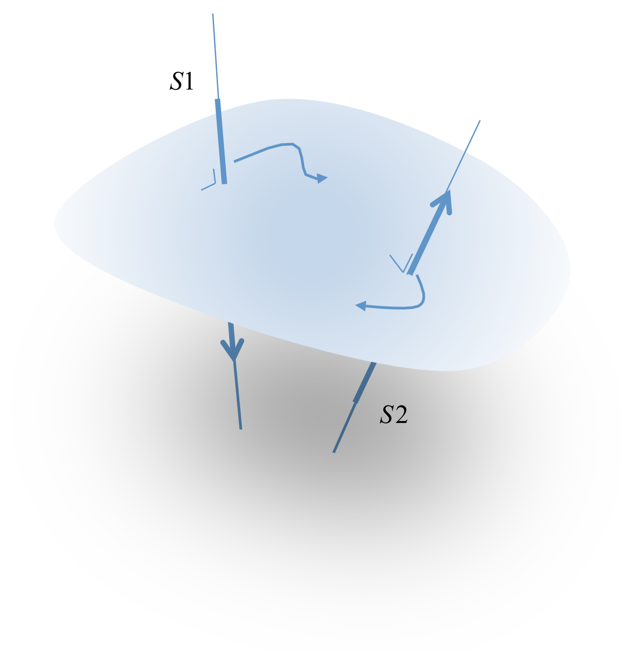

Fig. 2: spin arrangements of two electrons in the same orbital

Now, if another electron is put in the same orbital, it should confront a repulsive spin-spin interaction with one of two electrons in the orbital, which makes all three electrons unstable in the orbital. Therefore, it is inferred that the physical interaction behind the Pauli exclusion principle is the spin-spin magnetic interaction among fermions in the quantum system.

The spin of nucleons in nuclear force

Atomic nucleus consists of nucleons (protons and neutrons) and nuclear force keeps them inside the nucleus. Two nucleons, proton and neutron, have almost same masses as $m_p \sim 938\ \mathrm{MeV}/\mathrm{c}^2$ and neutron $m_n \sim 939\ \mathrm{MeV}/\mathrm{c}^2$, and the nuclear interaction in the nucleus ($r \sim 10^{-15}\mathrm{m}$) is almost independent of proton's electric charge ($q_p \sim 1.6\times10^{-19}\mathrm{C}$). Hence, it was presumed that proton and neutron are identical inherently but in different quantum states. To distinguish the states of proton and neutron, isospin quantum number I was introduced, in which proton is in state of isospin-up ($I_p = +1/2$) and neutron is isospin-down ($I_n = -1/2$) in isospin space, in which the general state of a nucleon can be described by a linear combination of eigenstates, isospin-up (proton) and isospin-down (neutron) in the group representation of $SU(2)$. In quantum mechanics, the nuclear interaction, for example, between proton and neutron in deuteron (D) is described with pi meson ($\pi^{\pm}$) exchange between the two nucleons in the nucleus, which means, proton can be changed to neutron; neutron, to proton inside the nucleus (Frauenfelder and Henley 1974, enge 1966).

However, in 4-D complex space, physical interactions are supposed to be with physical fields, which are manifestations in real subspace of the distribution of vacuum particles in imaginary subspace with the first principle given in the space. That means, the pi meson is not exchanged directly between proton and neutron, and also proton and neutron are not identical inherently, they have almost same masses, though. In free space, neutron is not stable and decays to proton with emitting electron and electron antineutrino in about 14 min. $\left(m_n > m_p\right)$; however, in the nucleus, neutron is stable with proton holding together. In addition, the quantum number isospin is not corresponding to any physical quantity in reality.

Without introducing Quantum Chromodynamics (QCD) (refTxt); however, with a classical picture for the spin of elementary particles, such as electron, proton, neutron, etc., as shown in Fig. (3), in which proton is described like a spinning ball with its positive charge distributed on the surface while neutron has a positive charge at the center with the same amount negative charge distributed on the surface, the nuclear force in the nucleus can be understood why it is apparently charge independent and why it is so strong and attractive in such short range.

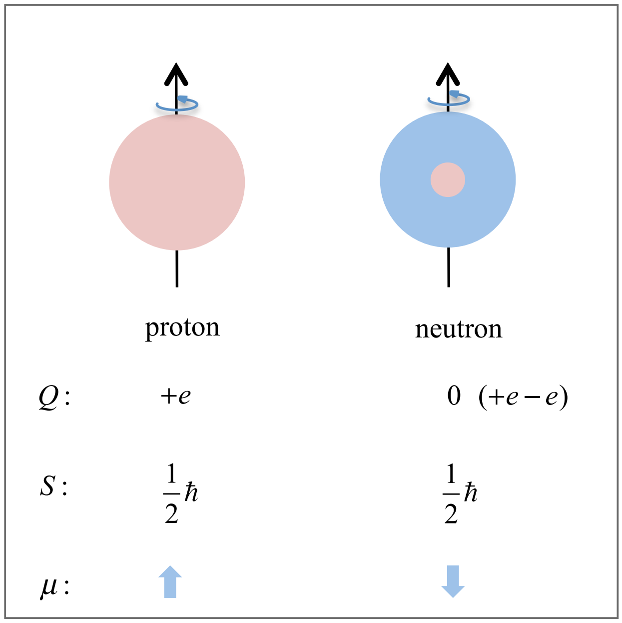

Fig. 3: classical picture of proton and neutron

The magnetic moment of proton is known as $\mu_p \sim 2.79\ \mu_N$ and neutron as $\mu_n \sim -1.91\ \mu_N$, in which nuclear magneton $\mu_N = \frac{e\hbar}{2m_p}$. Let's think, two tiny bar magnets of which the magnetic dipole moments are m_1 and m_2; then, magnetic diploe-dipole interaction is expressed as

$$H = -\frac{\mu_0}{4\pi r^3}\left[3\left(\vec{m}_1 \cdot \hat{r}\right)\left(\left(\vec{m}_2 \cdot \hat{r}\right) - \vec{m}_1 \cdot \vec{m}_2\right)\right] \tag{1}$$

in which r is distance between two magnets $\left(r > 0\right)$. Depending on magnet arrangements the interaction H can be negative to make the bar magnets hold steady each other as shown in case (b): $H_b = -\frac{\mu_0}{4\pi r^3}\left(2m_1 m_2\right)$ and case (c): $H_c = -\frac{\mu_0}{4\pi r^3}\left(m_1 m_2\right)$ in Fig. (4), in which the binding force $F_{m-m} \sim -\frac{1}{r^4}$ being compared with coulomb interaction $F_c \sim \pm\frac{1}{r^2}$ (Foundations of Electromagnetic Theory 1979, Wiki, refTxt).

Even though the case (b) indicates much stronger binding than the case (c) since $\left|H_b\right| > \left|H_c\right|$, the case (c), which is antiparallel, is more stable because the magnetic fields exposed in space is minimized.

Deuteron has one proton and one neutron in $r \sim 10^{-15}$ m (fm). If the spin-spin magnetic interaction of proton and neutron is considered inside the nucleus as $F_{m_p m_n} \sim -\frac{1}{r^4}$, which is attractive as in the case (c) in Fig. (4) and such short range compared to a coulomb force $F_c \sim \pm\frac{1}{r^2}$ inside the nucleus, it should be a crucial part of the binding force of deuteron.

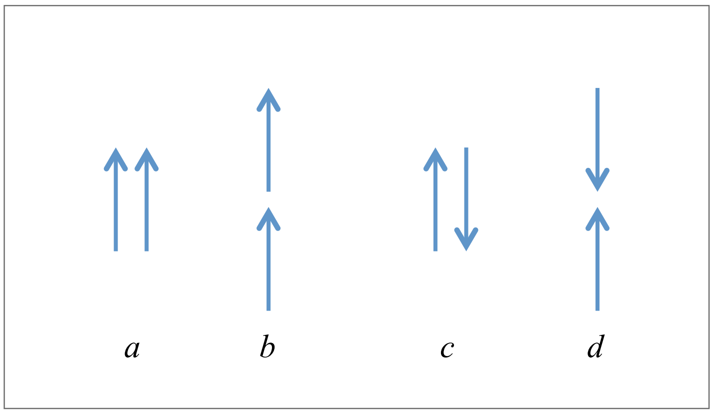

Fig. 4: arrangements of two bar magnets

In addition, the coulomb interaction is also expected between two nucleons due to the electric polarization induced on two nucleons when they are paired; first, it is attractive when they get close to each other; however, it can be repulsive when they are too close. Although the spin-spin interaction is a tensor force as shown in Eqn. (1), to make it simple let's assume that the pairing of two antiparallel magnetic moments is fixed as in the case (c) in Fig. (4), in which magnetic field energy in space is minimized inside the deuteron.

First of all, the coulomb interaction between two nucleons can be expressed as $U_c(r) \sim -\frac{a}{(r-\Delta_n)} + \frac{b}{(r-\Delta_p)}$ with positive constants a and b, in which $|a-b| \sim [\text{fm}]$; $\Delta_n \sim \Delta_1 + \Delta_2$ and $\Delta_p \sim \Delta_2$ in Fig. (5) representing the displacements of the negative charge distribution of neutron and the positive charge distribution of proton when proton gets close to neutron, which can be expressed with a series expansion[3] as

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[3] $\frac{1}{1-x} = 1 + x + x^2 + x^3 + \ \ldots \ (-1 < x < 1)$.

$$U_c(r) \sim -\frac{a}{r}\sum_{n=0}^{\infty}\left(\frac{\Delta_n}{r}\right)^n + \frac{b}{r}\sum_{n=0}^{\infty}\left(\frac{\Delta_p}{r}\right)^n \tag{2}$$

If the distance between two nucleons is in the scale of angstrom[4] $(\text{Å} \sim 10^{-10}\,\text{m})$, $U_c(r) \sim 0$, which means that nuclear force doesn't appear even in atomic scale distance since $\Delta_n \sim 10^{-15}\,\text{m} = 1$ fm; however, when two nucleons get closer inside the nucleus, the factor $\left(\frac{\Delta}{r}\right)$ in Eqn. (2) is significantly getting bigger since $\Delta \propto \frac{1}{r^2}$ in the respect of electric polarization.

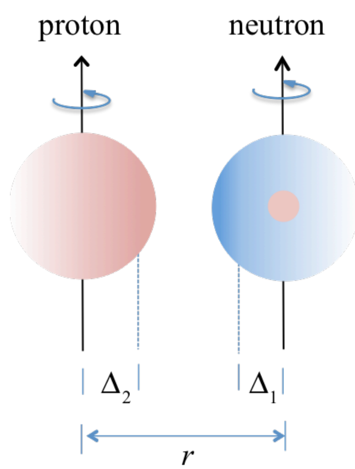

Fig. 5: electrical polarizations of neutron and proton

The force between proton and neutron in deuteron appears only inside the deuteron and stronger than the Coulomb interaction expressed as $U(r) \sim -\frac{1}{r}$.

Although the spin-spin magnetic interaction is supposed to be crucial for binding nucleons together, which makes proton-neutron pairs in the nucleus, if we use the point-like-dipole approximation for the magnetic dipole-dipole interaction energy,

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[4] size of Hydrogen atom: $r_H \sim 0.37 \times 10^{-10}\,\text{m}$

in which $H_{p-n} = -\frac{\mu_0}{4\pi r^3}\left(m_p m_n\right) \sim -\frac{0.085}{r^3\left[\text{fm}\right]^3}\left[\text{MeV}\right]$ as shown in Eqn. (1), it seems that the spin-spin magnetic interaction energy H_{p-n} is much smaller than coulomb interaction energy $U_c = -\frac{e^2}{4\pi\varepsilon_0 r} \sim -\frac{1.44}{r\left[\text{fm}\right]}\left[\text{MeV}\right]$ inside the deuteron in which the distance between two nucleons can be supposed as $1.6 < d_{p-n} < 2.6\ \left[\text{fm}\right]$ from the known facts; the size of deuteron $r_d \sim 2.13$ fm, size of proton $r_p \sim 0.84$ fm, and size of neutron $r_n \sim 0.8$ fm (refTxt).

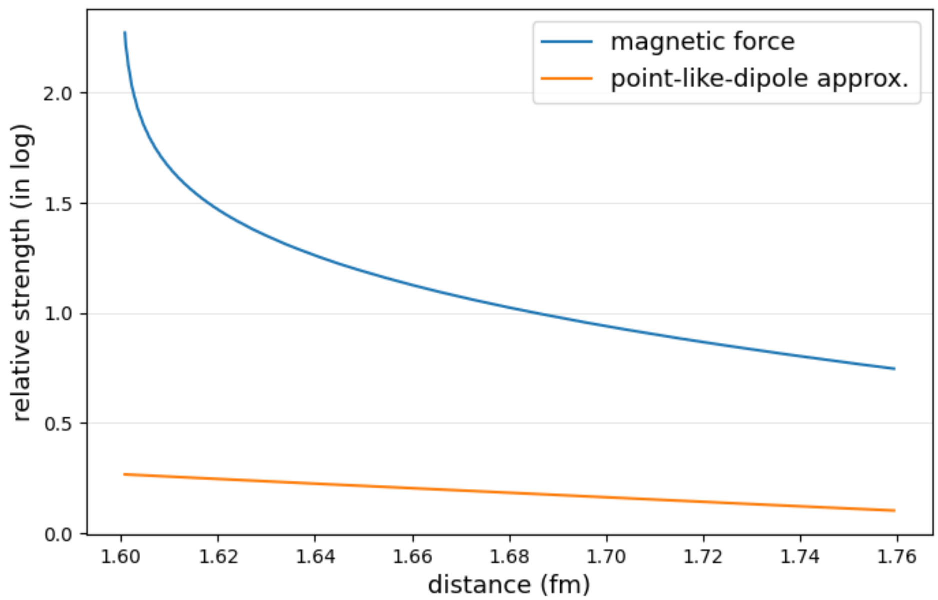

Fig. 6: spin-spin magnetic interaction: from Bito-Savart law and dipole approximation

Hence, the interaction potential in deuteron can be supposed to be mainly come from coulomb interaction; however, the point-like-dipole approximation cannot be used to estimate the magnetic dipole-dipole interaction energy between two nucleons in $\left[\text{fm}\right]$ order distance, especially in the classical picture of nucleons shown in Fig. (3). Let's say, there are two identical current loops with radius $r_{loop} = 0.8$ fm, and they are getting close to each other with antiparallel magnetic dipole alignment as in the case (c) in Fig. (4). The magnetic force between two loops can be estimated from Bito-Savart law and by using the point-like-dipole approximation as $F_d = \frac{-3m^2}{r^4}$, in which $m = IS$ $(S = \pi r_I^2)$ and r is the distance between two loops (Foundations of

Electromagnetic Theory 1979) (refTxt). Then, the difference of magnetic forces, those of which are calculated from Bito-Savart law and approximated by the point-like-dipole approximation, is getting bigger if the distance r gets close to $2 \cdot r_{loop}$, as we can expect, and significant if the distance $r \sim 2 \cdot r_{loop}$ as shown in Fig. (6). Then, the binding mechanism in deuteron can be understood as following: If the distance between two nucleons (proton and neutron) is far away or more than in atomic scale, there is no even electric interaction between two nucleons since neutron is still electrically neutral; hence, the nuclear interaction seems to be charge independent. If the distance is much less than in atomic scale or in femtometre scale ($1.0\ \text{fm} = 10^{-15}\text{m}$), the positive charge of proton makes neutron polarized electrically and then proton itself get polarized by the polarized neutron; electric attractive force appears between two nucleons and it gets bigger when two nucleons are getting close to each other. In addition, the magnetic dipole-dipole interaction between two nucleons appears but the intensity of magnetic force is still smaller than the electric force. However, if they get closer and closer to each other, the magnetic force gets dominant to the electric force and makes them hold together with the antiparallel spin alignment. It is magnetic force in the end although the electrical polarization initiates the binding process in deuteron. In addition, neutrons are supposed to be necessary to make protons keep staying in atomic nuclei. By the same token, the stable binding state of two protons or two neutrons cannot be expected due to the repulsive electric interaction between two electrically polarized nucleons, p-p or n-n.

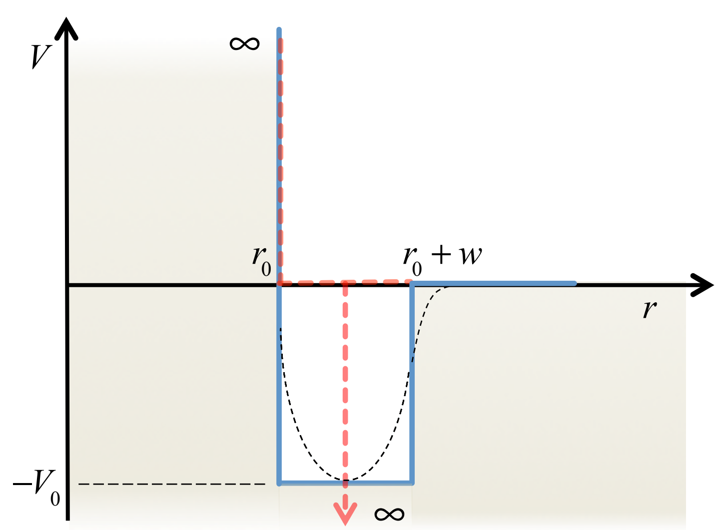

Fig. 7: spherical well potential and δ - function potential for deuteron

Now, to describe the binding status of deuteron that is the most simple nucleus but important to understand general mechanism of nuclear binding, let's think a spherical well potential as shown in Fig. (7) with width w and a rigid core at r_0 since nucleons are not point particles. If the potential well for deuteron is such narrow, it might be the reason that deuteron has no exciting state.

For deuteron system the radial part of Schrödinger equation is expressed as following:

$$\frac{d^2R}{dr^2}+\frac{2}{r}\frac{dR}{dr}+\left[\frac{2m}{\hbar^2}\left(E-V\right)-\frac{l\left(l+1\right)}{r^2}\right]R=0 \tag{3}$$

in which l is zero or positive integer for possible centrifugal potential[5]. To make it simple, let's $l=0$. Then, for $r_0<r\le r_0+\mathrm{w}$ if we set $U(r)=rR(r)$ and $k^2=\frac{2m}{\hbar^2}\left(E+V_0\right)$, in which $m=\frac{m_p m_n}{m_p+m_n}\sim\frac{m_p}{2}$ and r is distance between two nucleons, the Eqn. (3) is $\frac{d^2U}{dr^2}+k^2U=0$ and $U=A\sin\left[k\left(r-r_0\right)\right]$ since $U(r_0)=0$ at $r=r_0$. Similarly, for the region $\left(r\ge r_0+\mathrm{w}\right)$, $\frac{d^2U}{dr^2}-\kappa^2U=0$ and $U=Ce^{-\kappa r}$, in which $\kappa^2=-\frac{2mE}{\hbar^2}$. From the boundary condition at $r=r_0+\mathrm{w}$, which are $A\sin(k\mathrm{w})=Ce^{-\kappa(r_0+\mathrm{w})}$ and $kA\cos(k\mathrm{w})=-\kappa Ce^{-\kappa(r_0+\mathrm{w})}$, we can have a constrained condition as $k\cot(k\mathrm{w})=-\kappa$, in which $k=\sqrt{\frac{2mV_0}{\hbar^2}-\kappa^2}$. For example, for the bound state of deuteron with binding energy $E_b\sim 2.2$ MeV, if the width $w\sim 1$ fm in Fig. (7), the well potential energy should be at least $V_0\sim 122$ MeV; If $w\sim 0.5$ fm, $V_0\sim 450$ MeV.

Since both nucleons in deuteron are supposed to be almost attached to each other without much kinetic displacement $\left(\Delta r<<1\right)$, alternatively we can think a delta potential $\mathrm{V}\left(r\right)=-D\cdot\delta\left(r-r_c\right)$ with a rigid core at $r=r_0$ which is shown in Fig. (7) with dotted red lines, in which D is a positive constant and $r_c=r_0+\frac{w}{2}$; then, the radial part of Schrödinger equation for deuteron system is

[5] It has been known that the ground state is mixed with $l=0$ (~96%) and $l=2$ (~4%).

$$\frac{d^2R}{dr^2}+\frac{2}{r}\frac{dR}{dr}+\left[\frac{2m}{\hbar^2}\left(E+D\delta\left(r-r_c\right)\right)-\frac{l\left(l+1\right)}{r^2}\right]R=0 \tag{4}$$

where $R(r_0)=0$ at the rigid core surface. For a simple case, let's say, $l=0$ and set $U\equiv rR$, $\kappa=\frac{\sqrt{2m|E|}}{\hbar}$ since $E<0$ for the bound state of deuteron; then, Eqn. (4) is expressed as

$$\frac{d^2U}{dr^2}-\kappa^2\left[1-\frac{D}{|E|}\delta\left(r-r_c\right)\right]U=0 \tag{5}$$

with solutions for region $r\geq r_c$, $U_A=Ae^{-\kappa r}$ and for region $r_0\leq r\leq r_c$, $U_B=B\left(e^{+\kappa r}-e^{+\kappa r_0}\right)$. The coefficient $A\sim\left(e^{+\kappa r_c}-e^{+\kappa r_0}\right)$ and $B\sim e^{-\kappa r_c}$ since $U_A(r_c)=U_B(r_c)$ at $r=r_c$. Now, let's integrate both sides in Eqn. (5) including the delta function potential region at $r=r_c$ as following:

$\left.\frac{dU}{dr}\right|_{r_c-\varepsilon}^{r_c+\varepsilon}-\kappa^2\int_{r_c-\varepsilon}^{r_c+\varepsilon}U(r)\,dr+\frac{\kappa^2D}{|E|}U(r_c)=0$ and makes $\varepsilon\to 0$, then, we can find a conditional relation as $D=\sqrt{\frac{\hbar^2|E|}{2m}}\left(2+\frac{e^{-\frac{\kappa w}{2}}}{1-e^{-\frac{\kappa w}{2}}}\right)$ with only one bound state of deuteron, in which $|E|\sim 2.2$ MeV. If $r_0\sim r_p+r_n\sim 1.6$ fm as the core radius in Fig. (7), $D\sim 98\left[\text{MeV}\cdot\text{fm}\right]$ for $w\sim 1.0$ fm, and $D\sim 180\left[\text{MeV}\cdot\text{fm}\right]$ for $w\sim 0.5$ fm.

Now, let's find the co-relation of the delta function potential and the well potential shown in Fig. (7). If the well potential is squeezed from both sides, the kinetic energy inside the well potential increases as $K\sim\frac{1}{w}$, which means that $V_0\sim\frac{1}{w}$ for the only one bound state of deuteron with $E_b=2.2$ MeV. With the co-relation if we compare the results from the well potential and from the delta function potential, in which two nucleons in the nucleus supposedly hold on together at $r_c=r_0+\frac{w}{2}$ in Fig. (7), it is consistent as $D\sim wV_0\left(w\right)$, at least in order of magnitude. In addition, it suggests that two nucleons are binding together at $r\sim 2.1$ fm and vibrating next to each other in a short distance $w\sim 1.0$ fm due to the attractive magnetic force as shown in Fig. (6) and the possible coulomb repulsive force if the distance between them is too close, in which as shown with dotted black line in Fig. (7) the potential function can be described as $V(r) = -V_0 + \frac{1}{2} m\omega^2 \left(r - r_c\right)^2$, in which ω is the frequency of vibration. The kinematic vibrating energy can be estimated as $K \sim \frac{3p_x^2}{2m} \sim 94$ MeV if $\Delta r \sim 1$ fm, in which $p_x = p_y = p_z$; $\Delta x \sim \frac{\Delta r}{\sqrt{3}}$; $p_x \geq \frac{\hbar}{2\left(\Delta x\right)}$.

On the other hand, a fundamental question arises as why there is no electromagnetic radiation from the oscillation of two nucleons in which one is charged (proton) and the other is polarized (neutron) as the one aroused in classical picture of hydrogen atom: why the electron in hydrogen atom doesn't collapse into the positive core because any charged particle being accelerated should emit electromagnetic radiation in classical electromagnetics, which means that the electron in hydrogen atom should have electromagnetic radiation; its kinetic energy gets smaller; then, it should be collapsed into the core.

According to the interpretation of physical reality in 4-D complex space, quantum mechanics is the representation of statistical intrinsic nature in natural phenomena (Kim 1997), in which physical fields, such as electromagnetic and gravitational fields, are realizations of the distribution of vacuum particles those of which are reacting with the first principle in the space.

Now, a possible explanation for the hydrogen atom in classical picture is as following: In a stationary quantum state, let's say, an electron is being occupied in an orbital, which corresponds to a restricted region in the space occupied by the electron in its periodic and dynamic motion, for example, the electron in ground state of hydrogen atom; a disturbance of electromagnetic field in the orbit made by the electron is supposed to be restored by the electron itself right away before the process of electromagnetic radiation takes place, which means that the disturbance of electromagnetic field is not propagating outward but confined in the orbit. Similarly, the disturbance of electromagnetic field made by the oscillation of two nucleons should be restored by itself.

If nucleons such as proton and neutron are considered as the classical pictures as shown in Fig. (3) and Fig. (5), the nuclear force in the nucleus is nothing but a special case of electromagnetic interaction in the short range of femtometre scale $\left(1 \text{ fm} = 10^{-15} \text{m}\right)$. Moreover, the function of neutrons in the nucleus is important to make the nucleus stable or to keep protons inside the nucleus, which suggests that NP (neutron and proton) magnetic pairing should be the most important feature in the nucleus.

NP magnetic pairing model of the nucleus

There have been several nuclear models in nuclear physics, none of which is comprehensive explaining all the properties of nucleus in general, such as constant (interior) nuclear mass density, saturation of nuclear binding energy, equal numbers of neutrons and protons for stable nuclei, the magic atomic numbers for exceptionally stable nuclei, etc.

Liquid drop model can explain the facts that the nucleus is closely packed; thus, the nuclear mass density or nucleon number density is approximately constant, which means that the radius of typical nucleus $R = R_0 A^{1/3}$, in which $R_0 = 1.2$ fm and A is mass number, and the binding energy per nucleon increases sharply for nuclei with small mass numbers as shown in Fig. (9) and keeps increasing until the mass number 56 ($^{56}\mathrm{Fe}$: the most stable nucleus); however, it diminish slowly after the mass number 56 and close to $E_b / A \sim 8$ MeV. On the other hand, Fermi–Gas model and shell model assume that the kinetic motion of individual nucleon is independent of others in a common potential made by others and the energy levels in the nucleus are filled out as in the electron energy levels in an atom. The shell-model assumes that most of nucleons are paired to make zero spin and zero magnetic moment and closed-energy levels are related with the stability of nucleus and the magic atomic numbers of nuclei (enge 1966, Frauenfelder and Henley 1974, refTxt). Anyhow, like the wave-particle duality of light, shell model is not compatible apparently with liquid drop model because if each of molecules in an incompressible liquid drop is compared to each nucleon in the nucleus, it cannot move independently; however, which is assumed in shell model.

Since the paring of proton and neutron in the nucleus is supposed to be essential, which is minimizing magnetic field energy exposed inside the nucleus. Alternatively, we can suggest a nuclear model comprising both liquid drop model and shell-model. Nucleons in the ground state of a nucleus are supposed to be connected to others due to the dominant magnetic interaction without much kinematic displacement. For some stable nuclei, the possible nucleus structures are shown with diagrams in Fig. (8), in which diagrams are constructed based on experimental data for nucleus spins and magnetic moments (Stone, refTxt).

Let's start with deuteron (1H2), which has only one ground state: both spins are parallel ($s = 1$) which means that the paring of nucleons is as in Fig. (4c), the magnetic moment of deuteron $m_{\mathrm{D}} \sim m_{\mathrm{p}} - m_{\mathrm{n}}$, and binding energy $E_b \sim 2.2$ MeV. Tritium (1H3), in which 3 conjoined nucleons should be as in Fig. (4b), has spin $\frac{1}{2}$ and magnetic moment $\mu = 2.9789$ (nm)[6] which is comparable to $\mu_p = 2.793$ (nm). Similarly, Helium (2He3) has spin $\frac{1}{2}$ and magnetic moment $\mu = -2.127$ (nm), which is comparable to $\mu_n = -1.913$ (nm). Now, let's see, Helium (2He4), which has two protons and two neutrons (even-even), has spin 0 and magnetic moment $\mu = 0$. On the other hand, Lithium (3Li6), which has three protons and three neutrons (odd-odd), has spin 1 and magnetic moment $\mu = 0.822$ (nm), which is comparable to the magnetic moment of deuteron, $\mu_d = 0.857$.

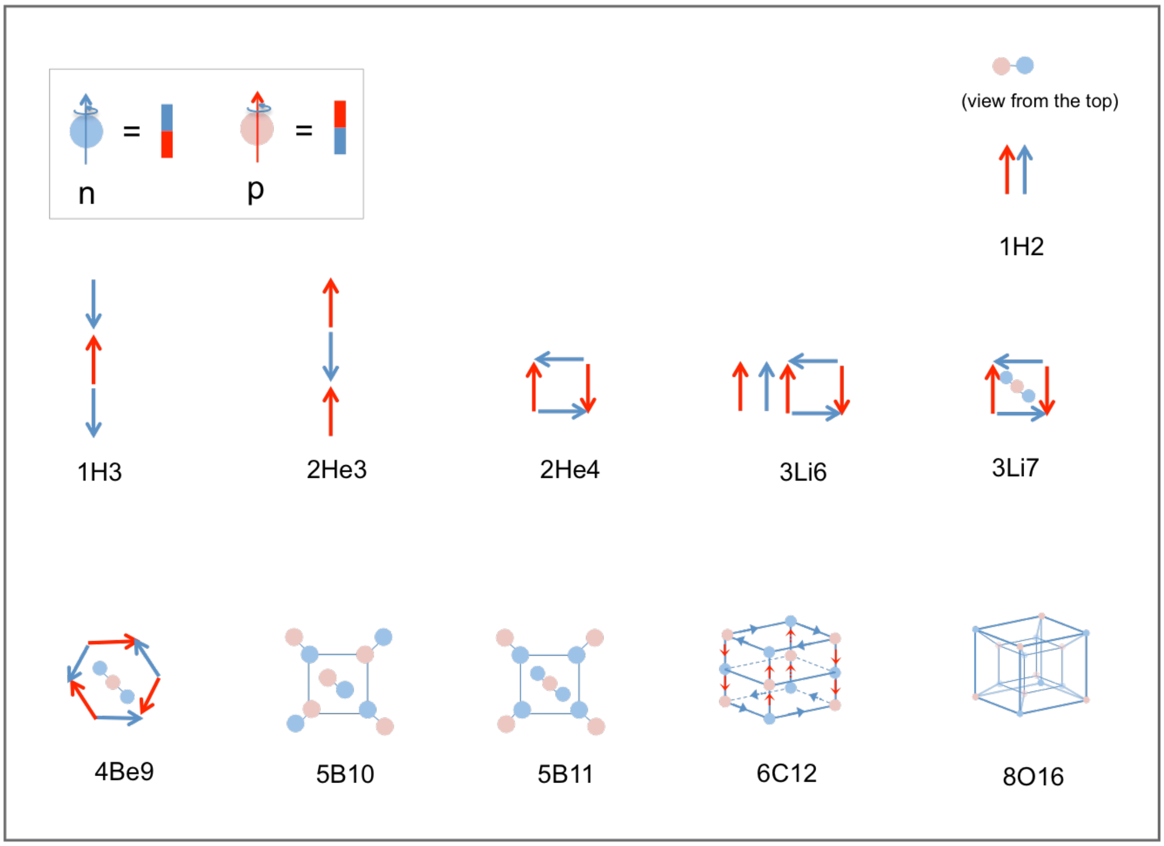

Fig. 8: nucleus magnetic structures

In case of Lithium (3Li7), its magnetic moment, $\mu = 3.25$ (nm), seems to be bigger than the expectation in diagram (3LI7); however, it should be dependent on its spatial geometry. The magnetic moment of Beryllium (4Be9), which has spin $\frac{3}{2}$ and $\mu = -1.178$ (nm), is comparable to

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[6] nm $= \dfrac{e\hbar}{2m_p}$ (nuclear magneton)

$\mu \sim 2\mu_n - \mu_p$ as shown in diagram (4Be9). In the diagram (5B10) showing Boron, which has spin 3 and magnetic moment $\mu = 1.80$ (nm), each pair of proton and neutron adds spin 1 as in deuteron (1H2) except one in center that is pointing to the other direction. On the other hand, Boron (5B11) has spin $\frac{3}{2}$ and magnetic moment $\mu = 2.69$ (nm), which can be understood with the diagram (5B11); each pair of proton and neutron contributes nucleus spin with 1 and -1 alternatively and three nucleons at the center makes nucleus spin $\frac{3}{2}$ and its magnetic moment, which is comparable to the case of Tritium (1H3).

Now, carbon nucleus (6C12), which has spin 2 and magnetic moment $\mu = 0$ (nm), has 3-D geometry as shown in diagram (6C12) in which nucleons in the middle layer make the nucleus spin 2 and the magnetic moment should be zero because of the geometrical symmetry. It is like constructing a magnetic circuit with tiny magnets, those of which are two kinds (p and n) and nearest neighbors of each magnet should be the other kind due to the repulsive electric interaction.

Let's think about nitrogen nucleus (7N14) that has spin 1 and magnetic moment $\mu \sim 0.4$ (nm). What if one pair of proton and neutron as in deuteron (1H2) is put at the center of the middle layer of carbon nucleus (6C12) with pointing opposite direction to the spin 2 of carbon nucleus. For next stable nucleus oxygen (8O16), which has spin 0 and magnetic moment $\mu \sim 0$ (nm), we can think two cubic structures in which one is embedded in the other as shown in Fig. (6).

Now, let's review the nuclear binding energy with the model shown in Fig. (8). The binding energy per nucleon of tritium nucleus (1H3) or helium nucleus (2He3) is bigger than Deuteron (1H2) because of the binding geometries: the strength of magnetic interaction of line-up arrangement in Fig. (4b) is about twice bigger than antiparallel arrangement in Fig. (4c), which is the case of (1H3) and (2He3) to (1H2) in Fig. (8). In addition, the binding energy per nucleon (BEN) of tritium nucleus (1H3) is bigger than helium (2He3) due to the electric repulsive interaction between two protons in helium (2He3). The BEN of helium nucleus (2He4) is much bigger than lithium nuclei such as (3Li6) and (3Li7) in Fig. (9). The nucleons in helium nucleus (2He4) are arranged in a closed loop as shown in Fig. (8), and it makes the high binding energy of helium nucleus (2He4); therefore, BEN of helium nucleus (2He4) is bigger than lithium, beryllium, and boron isotopes (Stone).

In Fig. (8), the arrangement of nucleons in carbon nucleus (6C12) makes a closed geometry in 3-D as well as the binding geometry in oxygen nucleus (8O16), and the number of magnetic connecting nodes (~nearest neighbors) for each nucleon of helium (2He4)) is 2; carbon (6C12), 3;

and oxygen (8O16), 4. Since the more magnetic connections each nucleon has, the stronger nuclear binding is expected because it can reduce any excess magnetic fields without connecting to other nucleons. Therefore, the BEN of oxygen nucleus is supposed to be bigger than carbon nucleus as shown in Fig. (8) and Fig. (9).

If the stability of nucleus is not matter, any kind of shapes or geometries can be made with those of tiny magnets such as protons and neutrons because the magnetic force between proton and neutron is in such short range as shown in Fig. (6). By the same token, the binding of nucleons in the nucleus depends on only nearest neighbors due to the short range of magnetic force; and the number of nearest neighbors is getting constant with the mass number increases, which can explain the fact that the binding energy per nucleon $\left(E_b/A\right)$ among stable nuclei is getting close to a constant $\left(\sim 8\ \mathrm{MeV}\right)$ as mass number A increases as shown in Fig. (9), which is also explained in liquid drop model.

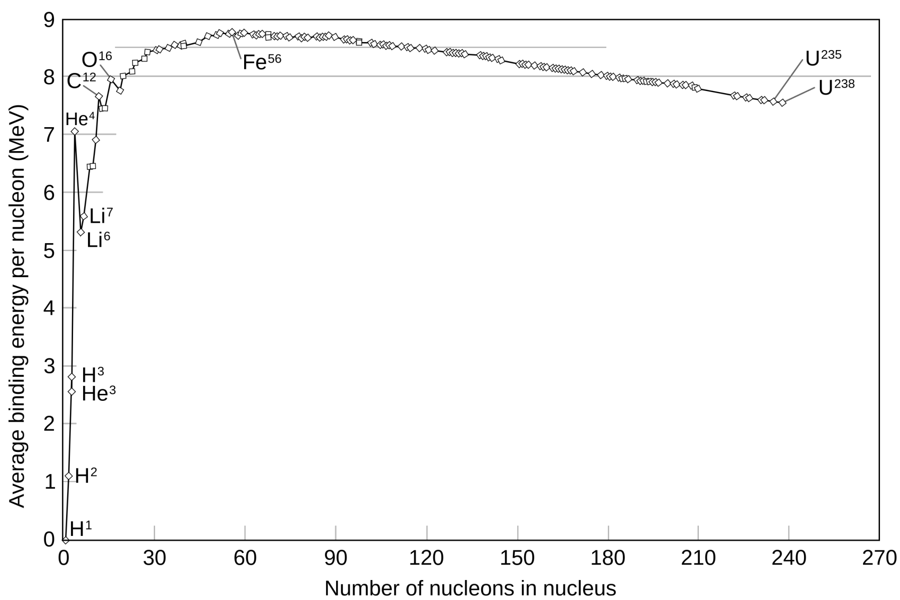

Fig. 9: average binding energy per nucleon[7]

In fact, the slope in Fig. (9) after mass number 56 (Fe) is slightly negative. That is because more neutrons are needed to reduce the coulomb repulsive interaction among protons in the nucleus, which makes nuclear binding energy itself decreasing. If the binding geometry in the nucleus, which is made by magnetic force, is closed as deuteron (1H2), carbon (6C12), or oxygen (8O16) as

[7] Wikipedia

shown in Fig. (8), the magnetic field exposed inside the nucleus is minimized, which makes the nuclear binding energy enhanced. Also, those closed binding geometries are corresponded to a physical shell not an abstract one as in the shell model in which the stability of the nucleus depends on numbers of protons and neutrons (even-even, odd-odd, even-odd, etc.) that is related to the closed shell in energy levels.

Summary and Discussion

According to the first principle in 4-D complex space, the strength of physical interactions such as electromagnetic or gravitational interaction has an upper limit as shown in Fig. (1), which means that the so-called black hole, which has been a famous topic in astrophysics and physical cosmology, doesn't exist in nature and also it is not the end-of-life cycle of a star because it should be exploded eventually. If the singularity of black hole doesn't exist, do we still need to investigate gravitational interaction in a microscopic scale?

The Pauli exclusion principle is important in modern physics; nevertheless, it is not well known about the fundamental reasoning why it exists and how it works. However, the fundamental reasoning for the principle is interpreted as the spin-spin magnetic interaction, which is intrinsic magnetic interaction among elementary particles (fermions). Then, with the spin-spin magnetic interaction among nucleons nuclear force is investigated, in which the classical picture of nucleons (proton and neutron) is used as shown in Fig. (3).

Neutron can be electrically polarized for the positive charge of proton inside the nucleus, which initiates the attractive interaction between proton and neutron; however, the spin–spin magnetic interaction of proton and neutron (magnetic pairing) is dominant in the end and crucial for the binding states of nucleons in the nucleus, which is a special case of electromagnetic interactions. Nuclear binding structure is explained with neutron-proton magnetic pairing method, which is compatible to both liquid drop model and shell model.

The Pauli exclusion principle can be understood; only two electrons, of which the spins are antiparallel to each other as shown in Fig. (2), can occupy in the same orbital in quantum states in atomic scale or solid state. However, it is questionable whether the Pauli exclusion principle can be applied for degenerate electrons in white dwarf star or degenerated neutrons in neutron star because the system is too big for the electrons or neutrons to interact or communicate with remote ones. Instead, we'd better say that there is a repulsive interaction among them (degenerate electrons or neutrons), which makes an extra pressure against the gravitational collapse in white dwarf star or neutron star in astrophysics.

In fractality, the basic algorithm in drawing for morphological structures is identical in small scales or big scales, which reminds us; the fundamental principle of nature should be unique regardless in microscopic scale, macroscopic scale, or even in cosmological scale.

Works Cited

APS physics. *APS NEWS.* 01 2007. https://www.aps.org/publications/apsnews/200701/history.cfm.

Beiser, Arthur. *Perspectives of Modern Physics.* McGraw-Hill, Inc., 1981.

enge, harald. *introduction to nuclear physics.* Addison-Wesley Publishing Company. Inc., 1966.

Frauenfelder, Hans, and Ernest M. Henley. *Subatomic Physics.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1974.

Gasiorowicz, Stephen. *Quantum Physics.* John Wiley & Sons, Inc., 1974.

Hawking, S. W. "The Quantum Mechanics of Black Holes." *Scientific American*, January 1977.

Kim, Kiyoung. "Paradigm Shift in Physics." *viXra e-prints.* vixra.org. 02 2017. http://vixra.org/pdf/1702.0179v1.pdf.

—. "The Wave Function in Quantum Mechanics." *arXiv e-prints.* 01 1997. arXiv:quant-ph/9701023.

refTxt. *any college textbook related.*

Reitz, John R., Frederick J. Milford, and Robert W. Christy. *Foundations of Electromagnetic Theory.* Addison-Wesley Publishing Company, Inc., 1979.

Stone, N. J. "Table of Nuclear Magnetic Dipole and Electric Quadrupole Moments."

Wiki. "Magnetic dipole-dipole interaction." *WIKIPEDIA The Free Encyclopedia.* https://en.wjkipedia.org/wiki/Magnetic _dipole-dipole_interaction.