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Masses of W and Z Bosons

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Abstract

In this paper, it is hypothesized that within a free neutron there is a virtual "dormant" force carrier Z^0 boson with the same net charge and can get "activated" by the down quark decay and transforms itself into a virtual "dormant" force carrier W^+ boson within the newly formed proton with the same net charge and discharges the remainder, which is not a boson and has a negative charge, into an electron and an electron-antineutrino, and as the result both the charge and energy are conserved. It is demonstrated that the masses of the Z^0 and W^+ bosons are directly proportional to the total mass of the valence quarks in neutron and proton, respectively. Two expressions for the sum and the differences of Z^0 and W^+ bosons were obtained, and then the mass-energies of W and Z bosons are calculated. The calculated masses of W and Z bosons are 80.3700 GeV and 91.1842 GeV, which are in very close agreement to the reported values by the experimental results.

Keywords

Fundamental Particles, Neutron Decay, Quarks, Bosons

1. Introduction

It is well established that a free neutron is unstable and decays into a proton, an electron, and an electron anti-neutrino. According to the conservation of energy, this decay can be expressed as

$$m_n c^2 = m_p c^2 + m_e c^2 + m_{\bar{\nu}_e} c^2 + E_Q \tag{1}$$

where c is the speed of light in vacuum, m_n, m_p, m_e, and $m_{\bar{\nu}_e}$ are the rest mass of neutron, proton, electron, and electron anti-neutrino respectively, E_Q is the decay energy of this reaction and is the difference in the rest mass of the neutron and the sum of the rest masses of the products.

In the Standard Model of particle physics, all hadronic matter in the universe consists of elementary particles, of which the most abundant and stable are leptons such as up quarks, down quarks, electrons, and neutrinos. Each of these particles can exhibit either left or right chirality. The orientation of chirality has no effect on any of the fundamental forces except the weak nuclear force, which can cause left chiral particles to emit or absorb W boson force carriers with an electric charge of +1 or −1 to conserve the net electric charges in the system [1]-[3]. The current theory indicates that in the transformation of a down quark to an up quark in a neutron decay, a W boson of −1 charge is emitted. Therefore, it is the weak nuclear force responsible for the transformation of a down quark into an up quark by emitting a virtual W boson [4]. According to the conservation of energy, in a neutron decay, when a down quark decays to an up quark, an energy equivalent to the binding energy of down quark, E_d, is released. That is

$$m_d c^2 = m_u c^2 + m_e c^2 + m_{\overline{\nu}_e} c^2 + E_d \tag{2}$$

where m_d and m_u are masses of down quark and up quark, respectively. E_d is the binding energy of the decayed down quark and is defined as $E_d = m_n c^2 + m_p c^2 - m_D c^2$, where m_D is the mass of deuteron [5]. However, not all the released binding energy, E_d, exits the nucleon. That is, a portion of E_d is used to bind the newly created up quark within the proton, and the rest of this energy, E_Q, is released to the outside of the nucleon and it is mostly picked up by the newly created electron as kinetic energy [5]. Therefore, equation (2) can be expressed as the combination of the binding energy of the newly created up quark, E_u and the decay energy, E_Q, that is

$$m_d c^2 = m_u c^2 + E_u + m_e c^2 + m_{\overline{\nu}_e} c^2 + E_Q \tag{3}$$

Substituting equation (2) into the above equation and solving for the binding energy of the newly created up quark, E_u, yield $E_u = \left(m_d c^2 - m_u c^2\right) - \left(m_n c^2 - m_p c^2\right)$. Adding $m_d c^2 + m_u c^2$ to both sides of Equation (3),

$$\left(2m_d c^2 + m_u c^2\right) = \left(m_d c^2 + 2m_u c^2 + E_u\right) + \left(m_e c^2 + m_{\overline{\nu}_e} c^2 + E_Q\right) \tag{4}$$

reveals that the term on the left-hand side of the equation is the total current mass of the valence quarks in neutron, the first term on the right-hand side of the equation is the total current mass of the valence quarks in proton plus the binding energy of the newly formed up quark, and the second term on the right-hand side of the equation is what is produced outside of the nucleons in the neutron-proton decay.

2. Masses of W and Z Bosons

In the Standard Model of Particle Physics, bosons are force carrier particles. Among them are the W and Z gauge bosons that are responsible for carrying the weak nuclear force. The strength of these bosons is only effective in an exceptionally short range. A Z boson has zero charge, and it can decay into two leptons of opposite charges. On the other hand, a W boson can decay into two leptons, one charged and one neutral. A Z boson cannot decay into a pair of W bosons of opposite charges, as it violates the conservation of mass-energy [6] [7].

In a free neutron to proton decay, the current understanding is that a down quark decays into an up quark with an emission of a virtual W⁻ boson. These kinds of weak interactions require intermediate vector bosons, such as W and Z exchange particles. The intermediate vector bosons are very short lived, and the existence of these bosons and their mass nearly 85 times that of a nucleon seems to violate the laws of physics, which is explained by the uncertainty principle [8].

Let us look at this problem a bit differently. We know that dark matter cannot be seen or directly measured, and it only interacts with gravity. So, in a very loose term, dark matter is an intrinsic part of the universe and only gets "triggered" when the gravitational force is involved. What if the force carriers such the virtual photons or bosons are not "created" during the interactions as suggested in quantum field theory [9], but like dark matter, they are mathematically speaking (since these particles are virtual and not real) "dormant" intrinsic part of the particles, and they get mathematically "activated" when a correct interaction occurs? What if neutron, in virtual sense, already possess a "dormant" force carrier Z^0 boson with the same net charge and can get "activated" by the down quark decay and transforms itself into a virtual "dormant" force carrier W^+ boson within the newly formed proton with the same net charge and discharges the remainder, which is not a boson and has a negative charge, into an electron and an electron-antineutrino? If that is true, then neither conservation of charge nor conservation of energy is violated.

Let us examine this hypothesis by considering a deuteron. If a proton and a neutron possess a "dormant" virtual force carrier W^+ and Z^0 boson, respectively, then the average mass of boson, $\bar{m}_{WZ}$, per nucleon, $\bar{m}_{np}$, in a deuteron can be expressed as $\frac{\bar{m}_{WZ}}{\bar{m}_{np}} = \frac{m_Z^0 + m_W^+}{m_n + m_p}$, where m_Z^0 and m_W^+ are the masses of Z and W boson, respectively. Since there are 6 valence quarks in a deuteron (3 up and 3 down quarks), then the average mass of valence quarks, $\bar{M}_{du}$, per nucleon, $\bar{m}_{np}$, can also be expressed as $\frac{\bar{M}_{du}}{\bar{m}_{np}} = \frac{3(m_d + m_u)}{m_n + m_p}$. If these "dormant' virtual bosons" are called for "activation" by quarks, then their mass-energies are mathematically intertwined and are conjugate with the total mass-energy of the valence quarks, such that the probability of all normalized events equal unity, that is

$$\left(\frac{\bar{m}_{WZ}}{\bar{m}_{np}}\right)\left(\frac{\bar{M}_{du}}{\bar{m}_{np}}\right) = \left(\frac{m_Z^0 + m_W^+}{m_n + m_p}\right)\left(\frac{3(m_d + m_u)}{m_n + m_p}\right) = 1 \tag{5}$$

Using time-independent Schrödinger-like equation, $\left(-\frac{\hbar^2}{2\alpha\bar{m}_{np}}\nabla^2 + \bar{m}_{du}c^2\right)\psi = \frac{\hbar c}{r}\psi$ (where ∇, $\hbar$, α, $\bar{m}_{np}$, $\bar{m}_{du}c^2$, and ψ are the Laplacian operator, the reduced Planck constant, fine structure constant, the average rest mass-energy per nucleon, the average rest mass energy per quark, and a wave function respectively), the author's publication previously has shown that the sum of the masses of up and down quarks is equal to the product of fine structure constant and the average mass of nucleons, that is $m_d + m_u = \alpha \bar{m}_{np} = \frac{\alpha}{2}\left(m_n + m_p\right)$ [5]. Therefore, using this expression, Equation (5) can be simplified to

$$m_Z^0 c^2 + m_W^+ c^2 = \left(\frac{2}{3\alpha}\right)^2 \left(3\left(m_d c^2 + m_u c^2\right)\right) = \frac{2}{3\alpha}\left(m_n c^2 + m_p c^2\right) \tag{6}$$

For a neutron-proton decay, there is a remainder in the process of transformation of a "dormant" virtual Z^0 boson in neutron into a "dormant" virtual W^+ boson in proton that gets discharged immediately into an electron, electron antineutrino, and a decay energy. Since the sum of the mass-energies of the two "dormant" bosons from Equation (6) is proportional to the sum of the mass-energies of all valence quarks in nucleons (neutron-proton), then the difference between the mass-energies of these two "dormant" bosons must also be proportional to the remainder energies of the products in the neutron-proton decay, that is

$$m_X^- c^2 = m_Z^0 c^2 - m_W^+ c^2 = \left(\frac{2}{3\alpha}\right)^2 \left(m_e c^2 + m_{\bar{\nu}_e} c^2 + E_Q\right) = \left(\frac{2}{3\alpha}\right)^2 \left(m_n c^2 - m_p c^2\right) \tag{7}$$

where $m_X^- c^2$ is the difference in mass-energies of W and Z bosons and it is not a boson itself.

3. Results

To find the mass-energies of the W and Z boson, we simply add and subtract Equations (6) and (7) respectively, that is

$m_W^+ c^2 = \frac{1}{2}\left(\frac{2}{3\alpha}\right)^2 \left[3\left(m_d c^2 + m_u c^2\right) - \left(m_e c^2 + m_{\bar{\nu}_e} c^2 + E_Q\right)\right]$, and

$m_Z^0 c^2 = \frac{1}{2}\left(\frac{2}{3\alpha}\right)^2 \left[3\left(m_d c^2 + m_u c^2\right) + \left(m_e c^2 + m_{\bar{\nu}_e} c^2 + E_Q\right)\right]$.

To better understand this, let us consider each terms in the parenthesis of Equation (4) as a function of the corresponding bosons, that is

$2m_d c^2 + m_u c^2 = \left(\frac{3\alpha}{2}\right)^2 m_Z^0 c^2 + \frac{1}{2}E_u$, $m_d c^2 + 2m_u c^2 + E_u = \left(\frac{3\alpha}{2}\right)^2 m_W^+ c^2 + \frac{1}{2}E_u$,

and $m_e c^2 + m_{\bar{\nu}_e} c^2 + E_Q = \left(\frac{3\alpha}{2}\right)^2 m_X^- c^2$. or

$$\begin{pmatrix} m_W^+ c^2 \\ m_Z^0 c^2 \\ m_X^- c^2 \end{pmatrix} = \left(\frac{2}{3\alpha}\right)^2 \begin{pmatrix} 1 & 2 & \frac{1}{2} \\ 2 & 1 & -\frac{1}{2} \\ 1 & -1 & -1 \end{pmatrix} \begin{pmatrix} m_d c^2 \\ m_u c^2 \\ E_u \end{pmatrix} \tag{8}$$

Equation (8) clearly indicates that the masses of W^+ and Z^0 bosons are directly proportional to the total current mass of the valence quarks in a proton and a neutron, respectively. Also, it shows that $m_Z^0 c^2 = m_W^+ c^2 + m_X^- c^2$, where both the energy and the charge are conserved. It appears that no W^- boson is involved in this process, but rather a Z boson is the force career collectively for the valence quarks in neutron, transforming into a W⁺ boson that carries the valence quarks in proton and the remainder, X⁻, discharges into an electron. That is, inside nucleons, these virtual force carriers are mathematically "dormant" and stable, but they cannot survive without quarks and decay immediately as they exit nucleons. So, in the absence of protons, if the conservation of charge is met, instead of X⁻ discharge, an emission of a W⁻ boson will occur, where the W⁻ boson is immediately decays into an electron. That is because both X⁻ and W⁻ have enough energy for the creation of an electron to occur.

Equation (8) can also be expressed in terms of the masses of nucleons, that is

$$\begin{pmatrix} m_W^+ \\ m_Z^0 \end{pmatrix} = \frac{1}{2}\left(\frac{2}{3\alpha}\right)^2 \begin{pmatrix} \left(1+\frac{3\alpha}{2}\right) & -\left(1-\frac{3\alpha}{2}\right) \\ -\left(1-\frac{3\alpha}{2}\right) & \left(1+\frac{3\alpha}{2}\right) \end{pmatrix} \begin{pmatrix} m_p \\ m_n \end{pmatrix} \tag{9}$$

These equations link quarks, bosons, and nucleons together. **Table 1** gives the numerical values of these bosons.

Table 1. Calculated values of W and Z bosons.

Mass of neutron [10]	m_n	939.56542194 MeV/c²
Mass of proton [10]	m_p	938.27208943 MeV/c²
Mass of W boson	$m_W^+ c^2 = \frac{1}{2}\left(\frac{2}{3\alpha}\right)^2 \left[\left(1+\frac{3\alpha}{2}\right)m_p - \left(1-\frac{3\alpha}{2}\right)m_n\right]$	80.37993173 GeV/c²
Mass of Z boson	$m_Z^0 c^2 = \frac{1}{2}\left(\frac{2}{3\alpha}\right)^2 \left[\left(1+\frac{3\alpha}{2}\right)m_n - \left(1-\frac{3\alpha}{2}\right)m_p\right]$	91.17429471 GeV/c²
Weak mixing angle	$\sin^2\theta_W$	0.222768415

4. Discussion

Force carriers such as W and Z bosons within the nucleons are mathematically complementarity with the valence quarks and are "dormant" and stable until activated in a process like a decay (**Figure 1**). The presence of quarks causes the creation of these virtual "dormant" bosons and in the absence of these quarks (such as the decay of a down quark), these "dormant" virtual bosons become "activated" and decay immediately. Therefore, one can think of these force carrier particles as mathematically intrinsic (as they are not real and hence cannot be truly intrinsic) part of quarks that follow the quarks like a shadow following an object. And just as the removal of an object causes the shadow to disappear, the removal of a quark by any means causes a rapid decay of the virtual boson.

We can obtain a mathematical expression from the interactions of W and Z bosons within deuteron with the quarks. Within a free Neutron, there exist three valence quarks of which one is up and two are down, as well as a virtual "dormant"

Z^0 boson of a mass that is much greater than a neutron itself, which cannot be directly measured, but the effect of it can be detected when the neutron decays into a proton. The mass of the "dormant" Z^0 boson is directly proportional to the mass of the valence quarks in neutron. During the decay of a free neutron, the Z^0 boson acts as force carrier (like a pipe) to direct the three down, down, and up quarks into the decay process. As one of the down quarks decays, the Z boson also transforms itself into a W^+ boson force carrier to carry the down, up, and up quarks in place. Leaving the remainder to be discharged into an electron and an electron-antineutrino (**Figure 2**).

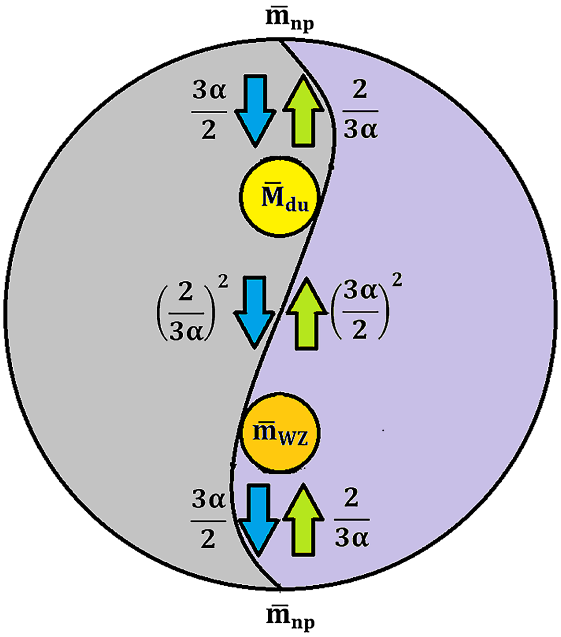

Figure 1. Force carriers such as W and Z bosons within the nucleons mathematically play a yin-yang with the valence quarks and are "dormant" and stable until "activated" in a process like a decay.

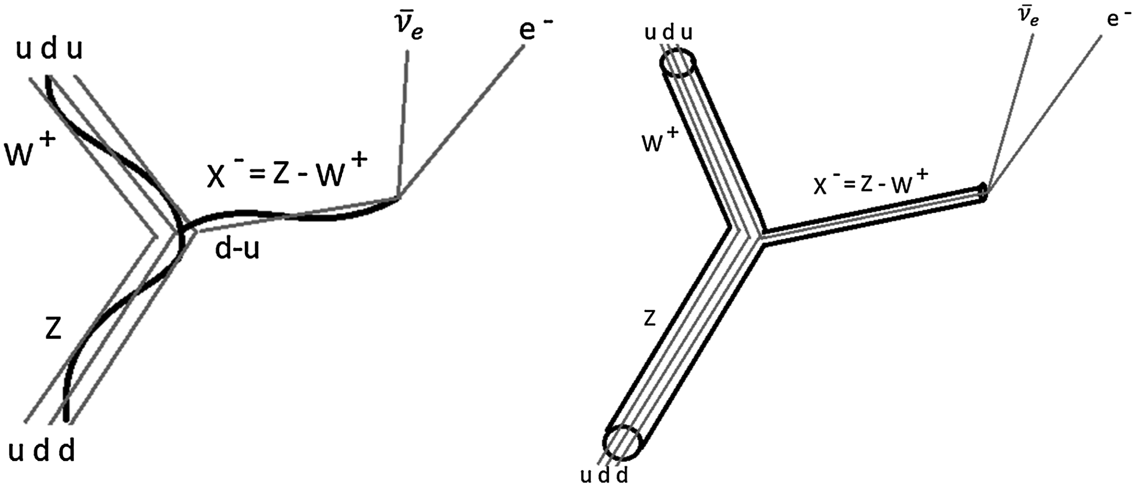

Figure 2. During the decay of a free neutron, the Z boson acts as force carrier (like a pipe) to direct the three down, down, and up quarks into the decay process. As one of the down quark decays, the Z boson, also transforms itself into a W^+ boson force carrier to carry the down, up, and up quarks in place, leaving the remainder to decay into an electron and an electron-antineutrino.

The mass-energies of a W and Z boson can be calculated from the interactions of W and Z bosons with quarks, as well as their remainder. The values calculated in this paper are 80.3799 GeV and 91.1743 GeV versus 80.3692 GeV and 91.1880 GeV reported by Particle Data Group (difference of 0.013%, and 0.015%), respectively [11]. This gives a weak mixing angle $\sin^2\theta_W = 0.22276$ compared to 0.22305 reported by the National Institute of Standards and Technology (difference of 0.126%) [12].

The author's publication has previously shown that the reduced mass of quarks, μ, is nearly identical to the binding energy of up quark, E_u, (1.43985520 MeV versus 1.44223281 MeV) [5], and the small shift of 0.002378 MeV from E_u to μ might be due to some internal structures during the decay process that need further investigation. Replacing E_u with μ does not change the masses of up and down quarks stated in the author's previous publication [5]. However, this replacement in equation (8) changes the values of W and Z bosons (and consequently the value of weak mixing angle) by a small amount to be identical to the reported values. That is for W and Z bosons, the calculated masses become 80.3700 GeV and 91.1842 GeV versus the world average of 80.3692 GeV and 91.1880 GeV reported by Particle Data Group (difference of 0.001% and 0.004% respectively) [11]. Similarly, the value of weak mixing angle becomes $\sin^2\theta_W = 0.22313$ compared to 0.22305 reported by National Institute of Standards and Technology (difference of 0.036%) [12]. These values are listed in **Table 2**.

Table 2. Calculated values of W and Z bosons using the reduced mass of quarks.

Mass of down quark [5]	m_d	4.7935916300 MeV/c^2
Mass of up quark [5]	m_u	2.0580263093 MeV/c^2
Reduced mass of quarks	$\mu = \dfrac{m_d c^2 m_u c^2}{m_d c^2 + m_u c^2}$	1.4398551960 MeV/c^2
Mass of W boson	$m_W^{+} c^2 = \left(\dfrac{2}{3\alpha}\right)^2 \left[m_d c^2 + 2m_u c^2 + \dfrac{1}{2}\mu\right]$	80.369969065 GeV/c^2
Mass of Z boson	$m_Z^{0} c^2 = \left(\dfrac{2}{3\alpha}\right)^2 \left[2m_d c^2 + m_u c^2 - \dfrac{1}{2}\mu\right]$	91.1841759996 GeV/c^2
Weak mixing angle	$\sin^2\theta_W$	0.22312947101

5. Conclusion

Although the Standard Model of Particle Physics predicts the values of W and Z bosons, it does not give a simple solution to find these masses [13]. Here, we formulate a simple approach that relates to the masses of quarks and bosons. We found that when the binding energy of an up quark is used in the calculations, the W and Z bosons have masses of 80.37993173 MeV and 91.27429471 MeV, respectively. On the other hand, when the binding energy of an up quark is replaced by the reduced mass of quarks, these values become identical to the values reported by the Particle Data Group (80.3700 GeV and 91.1842 GeV, respectively).

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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