The β Decay and the QCD Gas Atmospheric Density

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Abstract: β decay is one of the most fundamental and thoroughly studied nuclear decay[1]. Surprisingly, the β decay rate constants were found to have periodic time variability[2],[3]. However, others argued that there is no evidence for such cyclic deviation from the exponential first order kinetics decay law[4]. Here we first propose that the β decay is a pseudo first order exchange reaction triggered by a $u\tilde{d}d\widetilde{u}$ tetraquark boson, and second develop a QCD gas theory assuming that the proposed tetraquark bosons fill space and form a reactive, polarizable, and compressible gas. In analogy to the atmospheric gas density, the proposed QCD gas density drops with elevation from the sun surface. Accordingly, we propose that the β decay rate variability is due to the pseudo first order exchange reaction kinetics and the QCD gas atmospheric density drop. Our main result is a formula for calculating the mass of the QCD gas based on the observed β decay rate variability.

Contents

1. The β Decay and the $u\tilde{d}d\tilde{u}$ Boson Principal Role

In 1930 Wolfgang Pauli postulated the neutrino as a desperate remedy to the energy crisis of the time – the continues energy spectrum of electron emitted in the negative β decay[5]. Pauli assumed that nuclear β decay emits a neutrino together with the electron such that the sum of energies is constant since sensitive measurements of the energy and momentum of the β decay electrons and the recoiling nuclei in cloud chambers indicated that substantial quantities of energy and momentum were missing.

$$n \rightarrow p^{+} + e^{-} + \tilde{\nu}_e \qquad Eq. 1$$

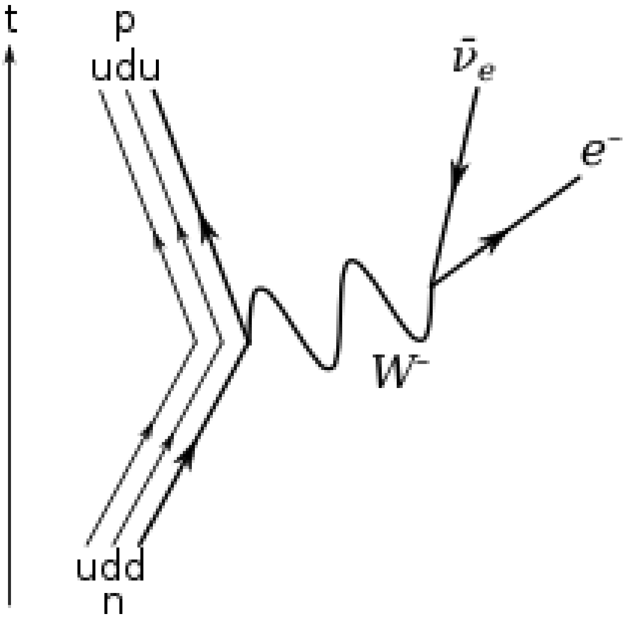
In 1932 Enrico Fermi provided a theoretical framework for the β decay[6] but it took another 25 years before the neutrino was detected indirectly. In 1957 Reines and Cowan made the first observation of the free antineutrino $\tilde{\nu}_e$ through the positive β decay utilizing the flux of $\tilde{\nu}_e$ from a nuclear reactor.

$$\tilde{\nu}_e + p^{+} \rightarrow e^{+} + n \qquad Eq. 2$$

Reines and Cowan measured the ϒ rays of the positron-electron annihilation (Eq. 3) for the positive β decay not the $\tilde{\nu}_e$ flux directly of Eq. 1.

$$e^{+} + e^{-} \rightarrow 2\,\Upsilon \qquad Eq. 3$$

Pauli and Fermi were unaware in the 1930s of the sub nucleon quark particles discovered in 1964 by Murray Gell-Mann[7] and George Zweig. The modern description of the β decay via the charged weak force boson W^- using Feynman diagrams is -



Accordingly, a down quark is replaced by an up quark and the weak force charged short lived W^- boson is emitted transforming the neutron (udd) to a proton (udu). Next, the W^- boson decays into an electron e^- and an electron antineutrino $\tilde{\nu_e}$ or to a $d\ and\ \tilde{u}$ meson.

The β decay equations in terms of the quarks and charged W^- boson decay channels are –

$$udd\ (n) \rightarrow \ \ udu\ (p^+) + \ w^- \qquad Eq.4$$

$$w^- \rightarrow \ d\tilde{u} \qquad Eq.5a$$

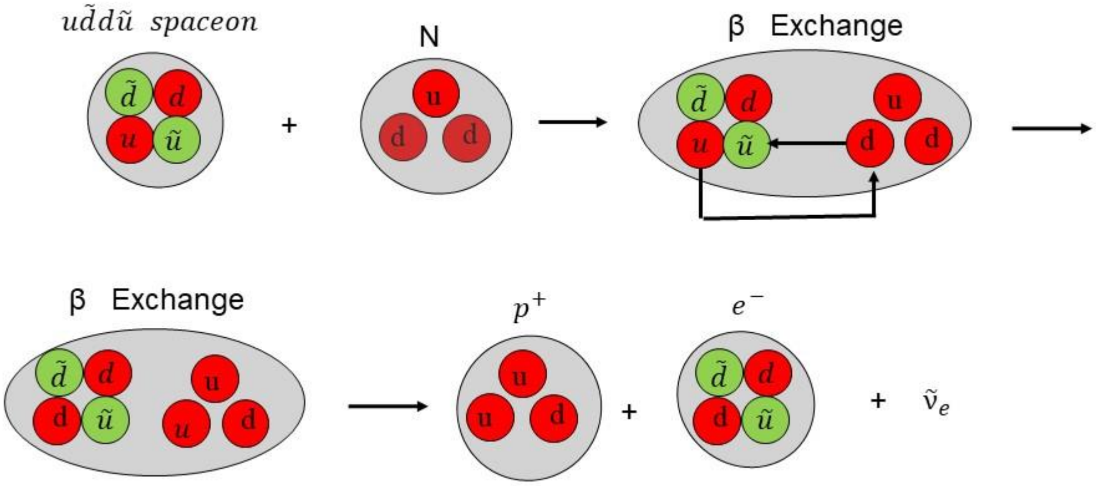
$$w^- \rightarrow \ \ e^- + \tilde{\nu}_e \qquad Eq.5b$$

The first issue with the β decay equation is that it is not balanced in terms of quarks. A down quark is annihilated and an up quark and a w^- boson are created (Eq. 4). Then, two different flavor quark and antiquark, $d\ and\ \tilde{u}$, meson is created by the w^- charged boson decay (Eq. 5a), or alternatively, the w^- decays to two leptons, $e^- + \tilde{\nu}_e$, (Eq. 5b) that are assumed to be created without their anti-fermion pairs. The second issue with the β decay equation is that neutrons of stable atoms do not decay hinting that the β decay is not a simple first order kinetic reaction. The third issue is the observed periodic time variability of the β decay rates[8].

In this paper we first propose an alternative pseudo first order exchange reaction kinetics for the β decay triggered by a $u\tilde{d}d\tilde{u}$ tetraquark boson. The proposed β decay pseudo first order exchange reaction equation is:

$$udd\ (n)\ + u\tilde{d}d\tilde{u}\ (boson) \rightarrow\ \ udu\ (p^{+}) + \ d\tilde{u}\,d\tilde{d} \qquad\qquad Eq.6$$

Eq. 6 describes a second order reaction, but since we assume that the $u\tilde{d}d\tilde{u}$ bosons fill space and are in a huge excess over neutrons, it behaves like a pseudo first order kinetic reaction. Eq. 6 is balanced in terms of quarks that appear on the left-hand-side and the right-hand-side. The first principal role of the $u\tilde{d}d\tilde{u}$ boson is to trigger the β decay reaction by capturing a down quark from the neutron by its antiup quark ($\tilde{u}$) and then providing an up-quark replacement (u) via an exchange reaction as illustrated below. The proposed pseudo first order exchange reaction explains why neutrons in the atoms are stable and do not decay to protons if the approach of the $u\tilde{d}d\tilde{u}$ boson is blocked. Hence, the size of the $u\tilde{d}d\tilde{u}$ boson should be bigger than the typical distance between the quarks inside the incompressible nucleus liquid-drop, about $0.7 * 10^{-15}$ meters, same order as the estimated size of the virtual QCD Instanton[9], and should be smaller than the neutron radii, which is about $1.25 * 10^{-15}$ meters, to confine quarks as described further below.

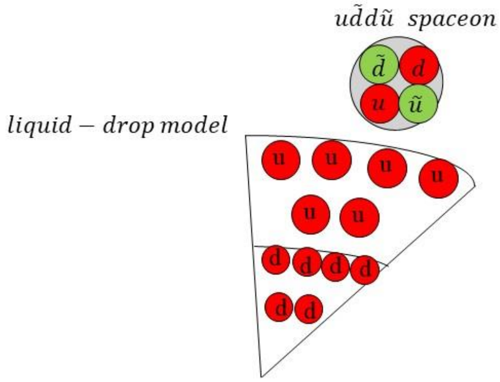


Eq. 7 completes the description of the proposed pseudo first order β decay and is also informative since the remnant tetraquark composite $d\widetilde{u}\ d\tilde{d}$ of Eq. 6 decays into an electron and antineutrino -

$$d\widetilde{u}\, d\tilde{d} \quad \rightarrow \quad e^- + \tilde{\nu}_e \qquad\qquad\qquad Eq.7$$

We suggest that the remnant tetraquark composite, $d\tilde{u}d\tilde{d}$, is the underlying quark structure of the electron, which may not be an elementary and not a point like particle[10]. The antineutrino particle that is observed only indirectly may be an excitation of the proposed QCD gas like solid state phonons.

Based on the proposed pseudo first order β decay exchange reaction kinetics we assume that in stable nuclei, the up quarks are closer to the surface of Gamow's incompressible nucleus liquid-drop model[11] where the down quarks may be kept inaccessible in the inner part of the liquid drop. Hence, the quark exchange reaction triggered by the $u\tilde{d}d\tilde{u}$ boson antiup quark capturing a down quark from the nucleus is blocked in stable atom nuclei as illustrated below.

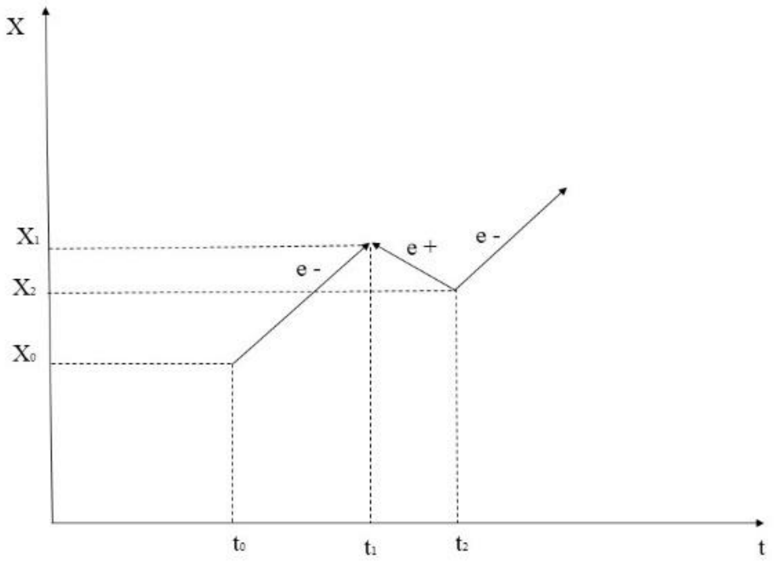


The pseudo first order β decay exchange reaction kinetic (Eq. 6) explains the stability of neutrons inside atoms, provides a quark balance and hints that the electron may be a composite non-elementary particle made of quarks. Eq. 6 reveals the first principal role of the $u\tilde{d}d\tilde{u}$ boson and the quark exchange reactions used further below to explain electron and quark dynamics.

2. Electron dynamics by Exchange Reactions

Feynman described a non-local electron exchange reaction with a virtual electron-positron vacuum fluctuation[12]:

$$e^{-} + [e^{+} - e^{-}]_{pair} \xrightarrow{electron\,exchange} [e^{-} - e^{+}]_{pair} + e^{-} \qquad Eq.\,8$$



The virtual electron-positron fluctuation is spontaneously created by the vacuum in a point (x_2, t_2) and the positron moves backward in time to position (x_1, t_1) as shown above. It seems that the electron jumps in space from x1 to x2, however, it should be noted that it is not the first electron. It is a second electron released from its pair positron in the second position. Thus, electrons do not move continuously along classical paths, they are annihilated in a first position and created by the vacuum's random fluctuations in another position.

Alternatively, we propose here that the electron-positron pairs are not virtual random vacuum fluctuations but are part of the QCD gas. Taking a hint from the proposed pseudo first order β decay kinetics (Eq. 6) we re-write the electron exchange reaction of Eq. 8 in terms of the $u\tilde{d}d\tilde{u}$ boson –

$$d\tilde{u}\,d\tilde{d}(e^-*) + u\tilde{d}d\tilde{u}\,(boson) \xrightarrow{e^-} u\tilde{d}d\tilde{u}\,(boson\,*) + d\tilde{u}\,d\tilde{d}(e^-) \quad Eq.\ 9$$

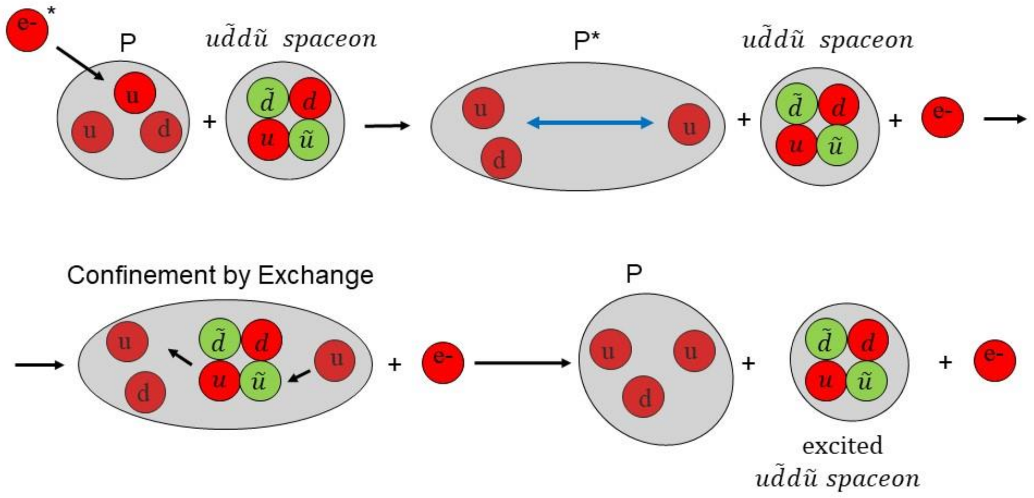
The $u\tilde{d}d\tilde{u}$ boson role here is to enable the electron exchange reaction assuming that the QCD gas is comprised of $u\tilde{d}d\tilde{u}$ bosons. The quark exchange reaction may be non-local chain reaction. The $u\tilde{d}d\widetilde{u}$ chargeless boson may be seen as the remnant of the condensed deep bound peculiar positronium state discovered by Crater and Wong[13].

The electron exchange reactions with the QCD gas (Eq. 9) depends on the QCD gas polarization determined by the applied fields such that electrons can heat up or cool down by the exchange reactions. The difference in the momentum of the incoming and outgoing electron can be positive or negative or zero in case the electron velocity remains constant.

3. Quark Dynamics by Exchange Reactions

The strong force quark confinement is explained by the Yukawa potential[14]. A quark confinement mechanism is proposed here based on quark exchange reactions with the QCD gas. We assume that the QCD gas fills space with high density such that whenever a gap between quarks in a hadron is created, for example by an accelerated electron that hits a quark, the $u\tilde{d}d\widetilde{u}$ boson will enter the gap performing a quark exchange reaction with the excited hadron that will carry away part of the impact energy and momentum and will decrease the distance between the quarks.

$$uu^{*}d\,(proton\,*) + \,u\tilde{d}d\widetilde{u}\,(spaceon) \rightarrow \,uud\,(proton) + \,u^{*}\tilde{d}d\widetilde{u}\,(spceon\,*) \qquad Eq.10$$

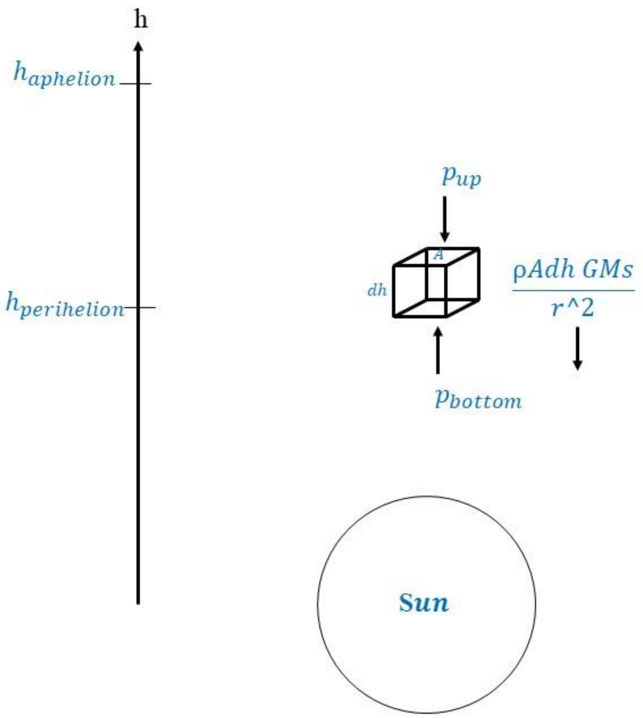


The quark exchange reactions may repeat with additional $u\tilde{d}d\tilde{u}$ bosons of the QCD gas until the gap is closed. The quark exchange reactions (Eq. 11) can heat up or cool down matter particles according to the polarizability state of the QCD gas.

4. QCD Gas Atmospheric Density

The QCD gas atmospheric density provides an alternative explanation for the observed variability of the β decay rates[15],[16]. Boltzmann's gas kinetic theory[17] is based on non-reactive collisions between inert atoms and molecules that collide and reach thermodynamic equilibrium. The QCD gas kinetic theory describes a reactive gas that performs rapid quark exchange reactions with matter particles and can accelerate, deaccelerate, or conserve the velocity of matter particles. Both gas theories are driven by the underlying particle dynamics, quark exchange reactions with the QCD gas and atoms and molecules collisions with Boltzmann's kinetic theory[18].

Both gas particles have mass and hence are affected by gravity. The atmospheric density formula describes the drop in the atmospheric density as a function of elevation above sea level due to gravity. In analogy, we propose that the QCD gas in the solar system has a similar atmospheric density that drops as a function of elevation from the sun surface as shown below.



The force balance on an infitisimal box of volume Adh taking into account the sun gravitational force acting on the QCD gas in the box is illustrated above and described by Eq. 11a -

$$p_{up}A - p_{bottom}A = \frac{\rho AdhGM_s}{r^2} \qquad Eq.11a$$

The QCD gas density ρ is related to the gas pressure using the ideal gas equation -

$$\rho = \frac{m_{QCD\_gas}n}{V} = \frac{m_{QCD\_gas}p}{k_BT} \qquad Eq.11b$$

A differential equation for the pressure as a function of the elevation interval dh is obtained by dividing Eq. 11a by the surface area A and substituting $dp = p_{up} - p_{bottom}$ -

$$\frac{dp}{p} = -\frac{m_{QCD\_gas} G M_s}{r^2 k_B T} dh \qquad Eq.11c$$

The solution of Eq. 11c is -

$$p(h) = p(h_0) e^{\frac{-m_{QCD\,gas} G\, M_{sun}(h-h_0)}{{h_0}^2 k_b\, T}} \qquad Eq.11d$$

And the QCD gas density similarly -

$$\rho(h) = \rho(h_0) e^{\frac{-m_{QCD\,gas} G\, M_{sun}(h-h_0)}{{h_0}^2 k_b\, T}} \qquad Eq.11e$$

Where $m_{QCD\,gas}$ is the mass of the QCD gas tetraquark; M_{sun} is the sun mass; G is the gravitation constant; k_B is Boltzmann constant; and T is the QCD gas temperature

According to the assumption that the nuclear β decay is a pseudo first order kinetic reaction (see Eq. 6), the β decay rate depends on the QCD gas density inversely

$$t_{1/2} = \frac{1}{k_\beta\, \rho[u\tilde{d}d\tilde{u}](h)} \qquad Eq.12$$

We propose to measure the β decay half-life time, $t_{1/2}$, in summertime and wintertime at the aphelion and perihelion of earth's elliptical trajectory around the sun[19].

The QCD gas density, $\rho[u\tilde{d}d\tilde{u}](h)$, at the aphelion is

$$\rho(h_{aphelion}) = \rho(h_{perihelion}) e^{\frac{-m_{QCD\,gas} G\, M_{sun}(h_{aphelion} - h_{perihelion})}{{h_{perihelion}}^2 k_b\, T}} \qquad Eq.13$$

Where $h_{aphelion}$ and $h_{aphelion}$ are earth's perihelion and aphelion trajectory distances from the sun surface. Thus, the ratio of the β decay half-life times at the two elevations is –

$$\frac{t_{\frac{1}{2}}(perihelion)}{t_{\frac{1}{2}}(aphelion)} = e^{\frac{-m_{QCD\,gas} G M_{sun}(h_{aphelion} - h_{perihelion})}{{h_{perihelion}}^2 k_b\, T}} \qquad Eq.14$$

If we assume that the mass of the QCD gas tetraquark, $m_{QCD\ gas}$, is about 1.0^{-31} kg (similar to electron mass) and that the QCD gas temperature is about 2.7 Kelvin, we get that the β decay half-life time ratio according to Eq. 14 is 0.9211. Due to the inverse relation on the QCD gas density, the β decay half-life time is longer at the aphelion -

$$\frac{t_{\frac{1}{2}}(perihelion)}{t_{\frac{1}{2}}(aphelion)} = e^{\frac{-1.0^{-31} * 1.989^{30} *(152093251- 147098925)*1000}{2.1637^{18} *1.38^{-23}*2.7}} = 0.9211 \qquad Eq. 15$$

Hence, the mass of the QCD gas tetraquark can be calculated from the β decay rates measured at two extreme points during the year, the earth trajectory aphelion and perihelion -

$$m_{QCD\ gas} = \frac{- k_b T\, {h_{perihelion}}^2 \ln(\frac{t_{\frac{1}{2},periheilion}}{t_{\frac{1}{2},apheilion}})}{M_{sun}(h_{aphelion} - h_{perihelion})} \qquad Eq. 16$$

It should be noted that the observed periodic time variability of the β decay rates was suggested to be due to the sun's neutrino flux[20],[21]. Pumee argued that the evidence does not suggest that radioactive decay is triggered by neutrinos and that there are no cyclic deviations from the exponential (first order kinetics) decay law[22]. We note here that the β decay reaction does not depend on incoming neutrino flux (Eq. 1) and alternatively we propose that the observed β decay variability is due to the β decay pseudo first order exchange reaction kinetics and to the QCD gas density drop. We further propose to determine the QCD gas mass using the observed β decay rates (Eq. 16).

5. Summary

We propose a QCD gas theory based on quark exchange reactions providing alternative mechanisms for the β decay and for electron and quark dynamics. The prediction that the pseudo first order β decay rates will increase with elevation from the sun surface due to the QCD gas density drop provides an alternative explanation for the observed β decay rates variability. Our main result is a formula for determining the mass of the QCD gas using the observed β decay rate variability (Eq. 16).

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