INTERACTION OF NEUTRON AS HADRON

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ABSTRACT

Neutron comprises of three quarks i.e. one up (u) quarks and two down (d) quarks. As the most abundant particle and bounded together with protons in a nucleus (both neutrons and protons in this state are referred to as hadrons), neutrons neutralize the repulsive charge of protons within the nucleus to stabilize the nucleus. This paper discusses the interaction of the baryon neutron bounded as hadron in the nucleus.

ABSTRAK

Neutron terbentuk daripada tiga quark, iaitu satu quark up (u) dan dua quark down (d) Sebagai zarah yang terbanyak dan terikat dengan proton di dalam nukleus (neutron dan proton terikat dalam keadaan ini dirujuk sebagai hadron), neutron meneutralkan daya tolakan proton-proton dalam nukleus untuk menstabilkannya. Kertas ini membincangkan interaksi antara baryon neutron yang terikat sebagai hadron di dalam nukleus

Keywords: neutron, hadron, nucleus

INTRODUCTION

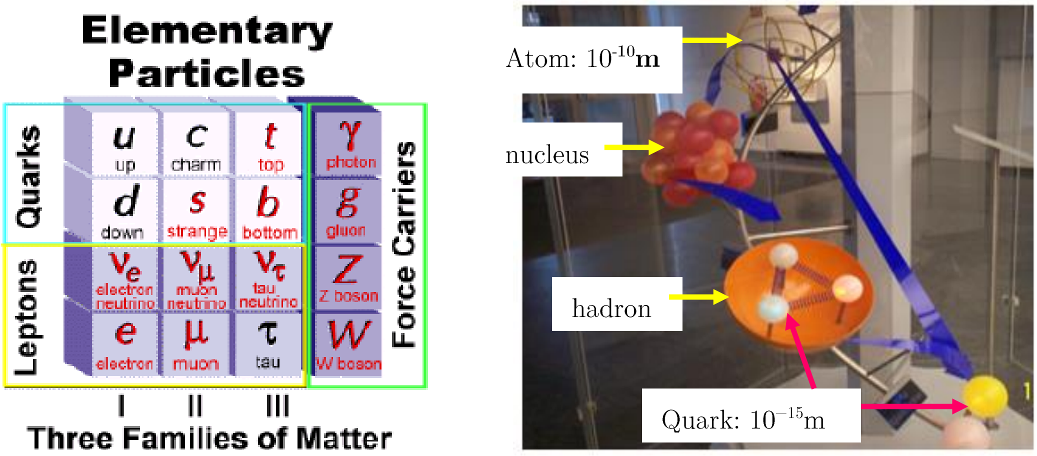
Neutron is a neutral particle with almost zero charge of neutrons $(-.04 \pm 1.1)\times10^{-21}$ e. Free neutrons outside of an atomic nucleus would decay via a weak nuclear force into a proton, an electron and anti-neutrino:

$$n \rightarrow p + e^{-} + \overline{\nu}_e \qquad \text{a)}$$

with mean life $\tau = (885.7\pm0.8)$ s [1]. Neutrons and protons are bounded together in a nuclear by strong forces via composite quarks through an exchange of meson particles [2]. These bounded neutrons and protons inside a nucleus are referred to as hadrons. Hadrons are classified into two families i.e. baryons which have three quarks and mesons with have two quarks, with neutrons and protons as family of baryons.

As a family of baryon, neutron is the heaviest of the baryon with a rest mass of 939.56536 ± 0.00008 MeV[1].Neutron comprises of three quarks i.e. one up (u) quarks and two down (d) quarks. Figure

1(a) shows standard model of quarks and leptons with force carriers mediating the exchange of quark flavors, while Figure 1(b) shows the schematic of a three quarks inside a hadron (in femto scale: 10^{-15}m). in comparison with a nucleus (in scale: 10^{-10}m).



(a) (b)

Figure 1. (a) Standard Model of Particle Physics, (b) schematic model of atom-to-quark scale at Deutches Electronen Synchrotron (DESY), Hamburg

NEUTRON IN HADRON STATE

Neutron Production Mode

Table 1 gives the properties of neutron. Bounded as hadron in a nucleus, neutrons interacts with protons to stabilizes the repulsive strong proton-proton forces within the nucleus. How do neutrons neutralize the proton-proton forces inside nucleus? Although neutrons (which comprises of quarks *udd*) and protons (which comprises of quarks *uud*) make up the atomic matter of nucleus, their detailed interaction inside the nucleus is still mysterious. Their interactions in the sea of quark-antiquarks involve the exchange of gluons, the particles that carry the strong nuclear force and hold the whole thing together [7]. In Quantum Chromodynamics, changes of one quark flavors into another involving the radiation of gluons mediating strong interactions via these force carriers which are effective at extremely close distance within the nucleus at femto scale: 10^{-15}m.

Table 1. Properties of neutron[1]

Parameter	Properties
Charge	$q = (-0.4 \pm 1.1) \times 10^{21} e$
Spin	$1/2$
Rest mass	$m_n = (939.56536 \pm 0.00008)\,\mathrm{MeV}$
$m_n - m_p$	$(1.2933317 \pm 0.0000005)\,\mathrm{MeV}$
Magnetic moment	$\mu = -1.913\mu_N$

Family	Baryons with 3 quarks: u d d
Decay mode	$n \rightarrow p + e^{-} + \bar{\nu}_e$
Decay length	$c\tau = 2.655 \times 10^{8} km$
Mean life	$\tau = 885.7 \pm 0.8s$
Electric dipole moment (EDM)	$d <$ 0.63~10^{-25}ecm

In high energy physics experiments, free neutrons may be produced from these reactions:

(i) In leading neutron production through one-pion exchanged in electron-proton collision at 30GeV-920GeV respectively, where the leading neutrons moved in straight trajectory as incoming protons [2][3].

(ii) As decay product of Λ^0 as in Figure 1, where neutrons being produced through $\Lambda \rightarrow n\pi^0$ reaction, in the ZEUS detector at DESY, Hamburg [2]

(iii) As a byproduct of proton proton interaction with structural material and rest gas mass in the electron-proton collider DESY, causing the reaction $\pi^{+} \rightarrow \mu^{+}$ to produce neutron n^0 via a photon γ emission. This interaction of μ^{+} occurs with bound state nucleons N (refer Figure 2)

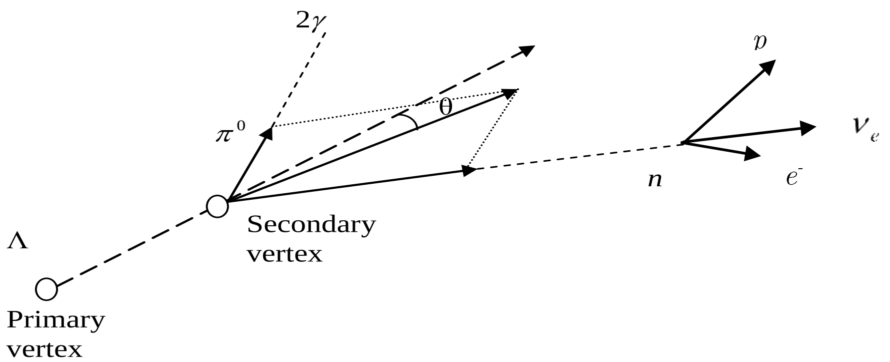


Figure 1. Neutron moves in a straight path, in decay channel $\Lambda \rightarrow n\pi^0$ (35.8% yield) where the two decay products moved along its original trajectories in two undetectable tracks, with $\pi^0 \rightarrow 2\gamma$ (98.8%)[2]t

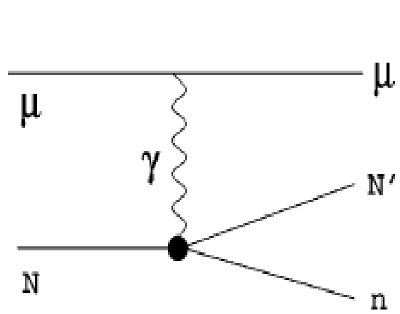


Figure 2. Fayman diagram of a neutron production from cosmic-ray muons

In fission process of fissile material such as ^{235}U, new neutrons are produced when a the fissile nucleus such as ^{235}U absorbed a neutron and causes the nucleus to break into two fragments to release energy 200MeV of kinetic energy, two new neutrons with kinetic energy of 2MeV:

$$^{235}U + {}^{0}n\,(thermal) \rightarrow fission\;\; products\; + {}^{0}n(\,fast) + 200MeV \qquad \text{i)}$$

In fusion reaction, two atoms ^{2}H and ^{3}H were merged together using immense energy to produce helium and neutron:

$$^{2}H + {}^{3}H \rightarrow {}^{4}_{2}He\,(3.5MeV) + {}^{0}n\,(14.1MeV) \qquad \text{ii)}$$

In either case, the hadrons inside the nucleus were triggered externally to produce fee neutrons. These triggers were able to overcome strong nuclear forces to cause the target atoms to rearrange itself into new atoms, which involved rearrangement of the hadrons within the nucleus.

The decay mode of free neutron into a proton (half life ~$10^{34 years}$ [8]), an electron and an antineutrino as in Equation (1) bounded quarks *uud* in a proton are more stable as compared to bounded quarks *udd* in a neutron, with[1]:

$$m_n - m_p = (1.2933317 \pm 0.0000005)\mathrm{MeV} \qquad \text{iii)}$$

From Table 1 and Equation 1, the difference in neutron and proton rest mass indicates that:

$$m_n - m_p = m_{e^-} + m_{\bar{v}_e} = 1.2933317\,\mathrm{MeV} \qquad \text{iv)}$$

Given that the rest mass of an electron[1]:

$$m_{e^-} = (0.51099892 \pm 0.00000004)MeV \qquad \text{v)}$$

Thus from rest mass of a antineutrino,

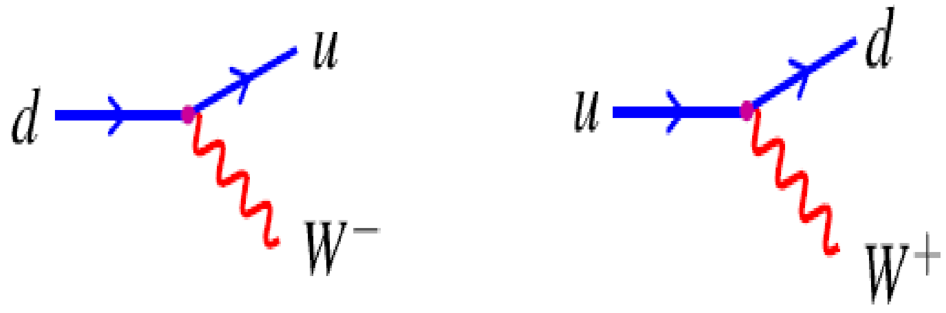
$$m_{\bar{v}_e} = 1.2933317\,\mathrm{MeV} - m_{e^-} \qquad \text{vi)}$$

$$m_{\bar{v}_e} = 1.2933317\,\mathrm{MeV} - 0.51099892MeV = 0.78233278\mathrm{MeV} \qquad \text{vii)}$$

Hadronic Interaction

Although neutron is neutral overall, it has a spin of $1/2$. In nuclear research reactor physics experiments, neutron spin effects have studied using cold neutrons in magnetic field in [5][10] using Larmor Precession. This shows that neutron path could be influenced by a magnetic field, indicating that it has a net charge albeit a small $q = (-0.4 \pm 1.1) \times 10^{21} e$ and detectable in cold/ultracold environment.

Figure 3(a) shows a Feynman diagram of changing of flavor of quark *d* to quark *u* via an emission of weak boson W^-, while Figure 3 (b) of that of quark *u* to quark *d* via an emission of weak boson W^+. These indicate that the neutron with quarks *udd* and neutrons with quarks *uud* have the possibility to change flavors between them via exchanges of bosons $W^{\pm}$ to stabilize strong forces within a nucleus. Figure 4 shows a strong neutron-proton coupling



(a) (b)

Figure 3. (a) Changing of quark *d* to quark *u* via an emission of weak boson W^- (b) Changing of quark *u* to quark *d* via an emission of weak boson W^+ [9].

Figure 4 shows strong coupling between neutron and proton via exchange of mesons $\pi^{\pm}$ with the emission of photon γ. This may be one of the mechanism whereby the neutrons neutralize the repulsive strong force of protons inside a nucleus.

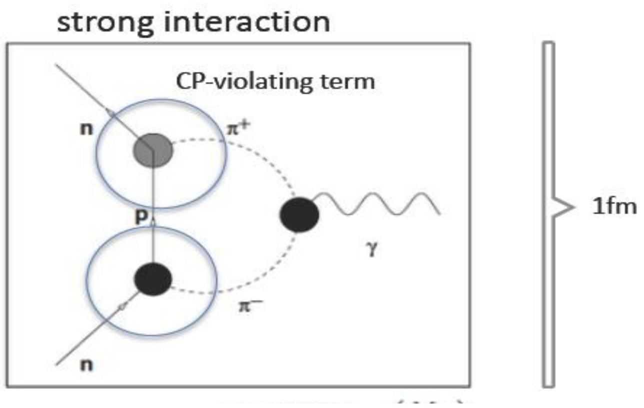


Figure 4. Coupling between neutron and proton via an exchange of meson $\pi^{\pm}$ with the emission of γ [5].

Figure 5 shows the changing flavors of *s* quark to *d* involving the $W^{\pm}$ boson with the emission of a photon γ. In this figure, the *s* quark changes flavor to *d* quark via an intermediate *t* quark. Such changes of flavor is observed the decay channel $\Lambda \rightarrow n\pi^0$ as shown in Figure 1. Table 2 shows the components of decay channel $\Lambda \rightarrow n\pi^0$. Here the baryon Λ (*uds*) decays into s n (*udd*) and π^0 ($u\bar{d}$), with *s* quark in baryon Λ changes its flavor into *d* (or *u*). Such decay channel was observed in the ZEUS detector at DESY Hamburg[2].

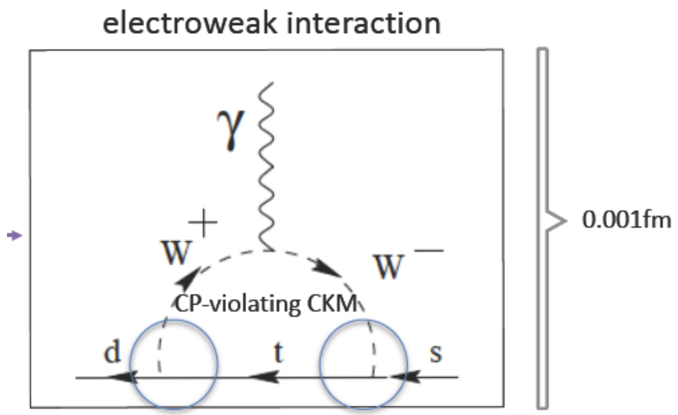


Figure 5. The changing flavors of *s* quark to *d* involving the $W^{\pm}$ boson with the emission of a photon γ [5].

Table 2. Components of $\Lambda \rightarrow n\pi^0$ channel [2]

Decay scheme	$\Lambda \rightarrow n\pi^0$		
particle	Λ	n	π^0
Quark components	*uds*	*udd*	$\frac{\bar{u}u + \bar{d}d}{\sqrt{2}} \approx u\bar{d}$
Strangeness	-1	0	0
$I(J^P)$	$0\left(\frac{1}{2}^+\right)$	$\frac{1}{2}\left(\frac{1}{2}^+\right)$	
$I^G(J^{PC})$			$1^-(0^{-+})$

C : charge conjugation, *P*: Parity, *G*: parity on whole multiplet

CONCLUSION

The interaction of neutron as hadron, bounded in a nucleus is still mysterious. As hadron, neutrons neutralize the strong repulsive force from protons within the nucleus to from form stable nuclides. At femto scale, the protons and neutrons within the nucleus interact with each other through the exchange of intermediary particles such as mesons and exchange of bosons $W^{\pm}$.

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REFERENCES

1. Particle Data Group, *Review of Particle Physics 2006*, Institute of Physics Publishing

2. Faridah Mohamad Idris; Long-live neutral hadrons in the calorimeter of the ZEUS detector, PhD thesis, University of Malaya 2011

3. P. Fagerstorm; Leading Neutron Production in Deep Inelastic Scattering at HERA, Ph.D. Thesis, University of Toronto

4. N. Tuning, Proton structure functions at HERA; Ph.D. Thesis, NIKHEF Amsterdam; 12 Sept 200**1**

5. Stephan Paul, The neutron and the Universe: History of a Relationship, TU-München

6. Brad Filippone, Fundamental Neutron Physics, NIST Summer School June 26, 2009

7. http://faculty.washington.edu/dparno/neutronspin.html

8. http://hyperphysics.phy-astr.gsu.edu/hbase/Particles/proton.html

9. Mark Thomson, Particle Physics - Handout 12:The CKM Matrix and CP Violation, Michaelmas Term 2009

10. Roger Pynn, Neutron Spin Echo, Los Alamos National Laboratory and University of California at Santa Barbara