Neutrons magnetic Mass

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Abstract:

In Quantum Physics the Spin of an elementary particle is defined to be an „intrinsic, inherent" property. The same to the magnetic moment (μ) due to the spin of charged particles - like Electron (m_e) and Proton (m_p). So the intrinsic spin (S=1/2h-bar) of the electron entails a magnetic moment because of charge (e). However, a magnetic moment of a charged particle can also be generated by a circular motion (due to spin) of an electric charge (e), forming a current. Hence the „orbital motion of charge" around a „mass-nucleus" generates a magnetic moment by Ampère's law. This concept leads to an alternative way calculating the neutrino mass (m_v) while discussing the beta decay of a neutron into fragments: proton, electron, neutrino and binding Energy. The change of neutrons magnetic moment during the decay process based on energy and spin and charge conservation allows to calculate the restmass of the neutrino: m_v = 0.10(20)eV.

Introduction

In short: The fact that the charged particle (m_p) is lighter than the neutral one (m_n) about (m_n-m_p=1,29333235<u>89</u>MeV or mn/mp=1.00137841<u>93</u>1) remained mysterious up to now. The difference between the neutron mass (m_n) and proton (m_p) mass is an open question in Physics [1].

As shown by Cottingham [1], the magnetic mass is determined by the spin averaged forward Compton scattering amplitude. However, the Cottingham formula [1] did not explain the size of the observed mass differences with such a high accuracy (m_{QED}=0,7(3)MeV) [1] needed to come up with neutrino restmass estimation.

In this paper we start with the magnetic moment definition based on Ampère's law. From Ampère's law pure neutral restmass without charge can not generate a magnetic moment. Thus the neutron mass must have an internal dynamic charge-action from a positive and negative parts (a least from quarks [1]) to come up with a magnetic moment not zero.

Elementary particles like electron, electron-neutrino and fundamental particles like proton, and neutron obey the wave-particle behaviour as nature's fundamental fact today shown by Comptons famous equation [2]:

1. $$h \cdot c/\lambda = m \cdot c^2$$

Here Compton introduced the wavelength (λ=c/f) instead of frequency (f). The **Compton wavelength** [2] **(** λ **)** is a quantum mechanical **wave like parameter** of a massive quantum entity defined by mass (m) velocity of light (c) and Planck constant (h) and Einsteins famous E=m*c²..

1.1 $$\lambda = h/(m \cdot c)$$

„The wavelength (λ) was introduced by Arthur Compton in his explanation of the scattering of photons by electrons (Compton scattering)." [3]

Remark:
Compton-Einstein: wave (λ) of a particle-mass (m)
Compton-Einstein: wave (λ) of a particle-radius (r_{GN}) [4]

1.2 $\lambda = 4\pi \cdot r_{GN}$

Let us (instead of lambda) introduce an equivalent **particle like parameter** r_{GN} [4] by the following hypothesis only to switch from wave picture into a particle picture (r_{GN}) assuming the particle ist not point-like which allows to apply Ampère's Law (I*pi*r_{GN}^2) easily.

Hint: $_G$ indicates a (missing) General Relativity [4] theoretical fundament concerning the derivation of mass from theory and $_N$ formally indicates an intrinsic Quantum Number which respects the quantisation of mass of elementary and fundamental particles from a GR point of view.

So r_{GN} is nothing new from the Einstein-Compton point of view but new is the interpretation due to r_{GN} [4].

The intrinsic spin (S=1/2*$\hbar$) due to r_{GN}-interpretation can be written:

1.3 $S = c \cdot m \cdot r_{GN}$

Magnetic Moments and Ampère's Law
In atomic physics, the Bohr magneton [5] μ_B=e*h/(4π*m) in [As*Js/kg] is a „natural unit“ expressing the magnetic moment in Si-units [J/T] with (T=1kg/s/(A*s)) caused by either its spin-orbital or spin-angular momentum of a fundamental particle and mass (m). The Magnetic Moment (μ) [5] while using Ampère's law [5] and 1.3 reads [3,4,5,6]: in units [A*m²] = [J/T]

1.4 $\mu = 1/2\ g_s \cdot e \cdot c \cdot r_{GN}$

The Intrinsic Magnetic Moment [5] from textbook $\mu = 1/2\ g_s \cdot e \cdot c \cdot (1/m) \cdot S$ depends on the Landé Factor gs, the charge (e=1.602176634E-19C), velocity of light (c=2.99792458E8m/s) and instead of particle parameter (r_{GN}) we have the Compton Wavelength (λ) or as shown the Rest-Mass (m) of the particle under investigation. Planck constant (h=6.62607015E-34Js) is needed if we use the intrinsic Spin (S) for basic discussion and calculation. Thus 1.3 and 1.4 in one gives (textbook formula μ above [5]).

Result:.
The two formulae (1.3 and 1.4) above show an important energy based effect: (magnetic Energie is equivalent to magnetic-mass energy)

If in (1.3) the mass (m) increases so (r_{GN}) decreases because the spin remains constant. If in (1.4) (r_{GN}) decreases then the magnetic moment (μ) decreases.

Thus from the energy point of view if the magnetic moment decreases then magnetic-mass energy increases (and vice versa) to keep total energy constant.

Data from 2020

We „use“ r_G instead of r_{GN} now.

Of course the magnetic moment should be based on the quark model [1] on the level of the constituent quarks. The theoretical result is not completed. up to 2021[6].Thus our simplified discussion is helpful as a common (Fermi) and alternative way while using high accurate data from Codata 2020 now.

Free **Proton:**
Magnetic moment: **μ_p (+**1.41060679<u>36</u>(60)E-26J/T**)**
g_{sp} (5.58569468<u>93</u>(16)) defined relative to the proton mass
Restmass: m_p (**1.67**2621923<u>69</u>(51)E-27kg)
- S-radius from (1.3): **r_{Gp}**(S)=(1.051544551<u>67</u>E-16m)
- μ-radius from (1.4): **r_{Gp}**(M)=(1.051544551<u>67</u>E-16m)

Neutron:
Magnetic moment: **μ_n (-**9.66236<u>51</u>(23)E-27J/T**)**
g_{snp} (3.826085<u>45</u>(90)) defined relative to the proton (not neutron) mass
Restmass: m_n (**1.67**4927498<u>04</u>E-27kg)
- S-radius from (1.3): r_{Gn}(S)=**1.05**0097077<u>59</u>E-16m
- μ-radius (1.4): r_{Gnp}(M)=**1.05**1544551<u>67</u>eE-16m

Free **Electron**
Magnetic moment: **μ_e (-**9.28476470<u>43</u>(28)E-24J/T**)**
g_{se} (2.002319304362<u>56</u>(35)) defined relative to the electron mass
Restmass: m_e (9.10938370<u>15</u>(28)E-31kg)
- S-radius from (1.3): r_{Ge}(S)=1.93079633<u>98</u>E-13m
- μ-radius from (1.4): r_{Ge}(M)=1.93079633<u>98</u>E-13m

The electron „**magnetic mass**“ is equal to the total restmass if r_G(S) is equal r_G(M) Not so for the neutron.

Why a mismatch for the neutron?

The electron and proton go confirm with this 1.4 see (table 1). Not so the neutron. The reason is g_{snp} =3.826085<u>45</u>(90) (gyromagnetic ratio Codata) is here related to the proton mass and not to the neutron mass as should be if we want to apply 1.3 and 1.4 (or textbook formula). Therefore we have to define $g_{sn}=g_{snp}*m_n/m_p=3.83135940$ then 1.4 works for the neutron as well and magnetic mass equals restmass for a charged particle.

Overview: (2020-Codata (m), (μ), (g), from 1.3 $r_{Gx}(S)$, from 1.4 $r_{Gx}(M)$)

2020	Restmass (m) In kg	Magnetic Moment (μ) In J/T	Landé Factor (g)	rGx(S) in m rGx(M) in m
Electron	9.1093837015(28)E-31	-9.2847647043(28)E-24	2.00231930436256 (35)	1.9307963398E-13 1.9307963398E-13
Muon	1.883531627(42)E-28	-4.49044830(10)E-26	2.0023318418(13)	9.3379715299E-16 9.3379715**376**E-16
Tauon	3.16754E-27	No value	No value	5.5526890611E-17
Proton	**1.67**262192369(51)E-27	1.41060679736(60)E-26	5.5856946893(16)	**1.05**15445516E-16 **1.05**15445516E-16
Neutron **mn/mp**	**1.67**492749804(95)E-27 1.00137841931	-9.6623651(23)E-27	3.82608545(90)	**1.05**00970776E-16 **1.05**15445516E-16

Table 1 **Magnetic Moments and Neutrons Mass.** The mass of the Neutron is that of the experimental mass m_n=1.67492749804E-27kg. So we get from the Spin (1.3) the corresponding $r_{Gn}(S)$=1.050097707759E-16m corresponding to m_n and from the magnetic moment μ_n (1.4): $r_{Gnp}(M)$=1.05**154455167**E-16m*(m_p/m_n)=$r_{Gn}(S)$=**1.05**00970776E-16m.

We know that the neutron decays into a proton, electron and neutrino in accordance with Fermi's 1934 theory of beta decay. So the inverse beta decay allows to re-build a neutron from proton, electron, neutrino and binding energy.

In short:
From Magnetic Moment (1.4) we have $r_{Gnp}(M)$ leading to magnetic mass $m_{np}(M)$ when introduced into (1.3):

- $m_{np}(M)$= **1.67**26219238 6E-27kg from $r_{Gnp}(M)$ using (1.3) > $m_p < m_n$
- m_p =**1.67**262192369(51)E-27kg from experiment equal to $m_p(M)$
- m_n =**1.67**492749804(95)E-27kg from experiment not equal to $m_n(M)$

The magnetic mass equivalent of the neutron is equal to restmass m_n:
$m_{np}(M)*(m_n/m_p)$=**1.67**492749804(95)E-27kg=m_n

The change of neutron magnetic moment during the beta-decay must have to do with the binding energy released taken from magnetic energy changed during and after emission of the proton, electron, electron neutrino.

Conclusion:

„Magnetic Binding“ Energy from 1.3 combined with 1.4:
m_n-$\mathbf{m_{np}}$**(M)**-m_e=**782.333<u>311</u>**keV=B_E (compared with 0.7(3) MeV from [1])

Here B_E is **without neutrino mass** before decay. The charge-less neutrino due to conservation of charge can not have a magnetic moment! So no magnetic mass appears for the neutrino - simply restmass.

„Total Binding“ Energy from Codata values:
m_n-$\mathbf{m_p}$-m_e=**782.333<u>410</u>**keV=$B_{E\nu}$ (compared with 0.7(3) MeV from [1])

Here $B_{E\nu}$ is **including anti-neutrino restmass** short before decay. Thus neutrino must have at least simply restmass not zero.

B_E<$B_{E\nu}$: The difference leads to the (positive) electron anti-neutrino restmass BE-BEv=-m_p(S)+m_{np}(M)=-0.099eV.

Anti-electron neutrinos restmass is non magnetic based and postive.
$m_{\nu a}$=m_{np}(M)-m_p=**0.<u>10</u>(20)eV**

(Cosmological observations suggest that the mass of neutrinos could be 0.1 eV or lighter. [8])

Remark:
g_{snp}=3.826085<u>45</u>(90) and μ_n=-9.66236<u>51</u>(23)E-27J/T error-limits giving the maximum absolut error-bars (+444.15 and - 443.95)eV. From this we get the „mean error“ (0.20)eV „estimation“ (between the absolute error-bars while assuming the absolute errors both are gaussian shape).

The Spin (S), charge, velocity of light and energy all must be invariant during the process. Mass (m), radius (r_G), and magnetic moment (µ) must not be constant. This is easily seen from 1.3 and 1.4 and table 1.

1.3 $$S = c \cdot m \cdot r_{GN}$$

1.4 $$\mu = 1/2\ g_s \cdot e \cdot c \cdot r_{GN}$$

Notice: N formally respects quantisation of radius r_{GN} due to a quantum number N. The same to the particles restmass m(N) [4].

Beyond the SM:
The neutron releases a proton and electron and the electron releases an electron-neutrinos restmass to become a stable electron mass after the decay process is possible.

Literature

(1) J. Gasser, H. Leutwyler, A. Rusetsky On the mass difference between proton and neutron Physics Letters B Volume 814, 2021,.

(2) The Dirac Electron: Spin, Zitterbewegung, the Compton Wavelength, and the Kinetic Foundation of Rest Mass, Herausgeber: Kiyoshi Nishikawa, Jean Maruani, Erkki J. Brändas, Print ISBN: 978-94-007-5296-2 or ISBN: 978-94-007-5297-9Gerardo Delgado-Barrio, Piotr Piecuch,
Verlag: Springer Netherlands

(3) Compton scattering:
https://en.wikipedia.org/wiki/Compton_wavelength

(4) Derivation of Radius (Particle restmass (r_{GN}) behaves like a wave!)
https://www.researchsquare.com/article/rs-524770/v3
Only if a GR-theory is able to derive r_{GN} exclusively. Thus we will have a theoretical answer for the open question: „Why does the Compton Wavelength exist from a theoretical point of view already proved by Compton scattering experiment?“

(5) Magneton
https://en.wikipedia.org/wiki/Bohr_magneton
Intrinsic Magnetic Moment
https://de.wikipedia.org/wiki/Land%C3%A9-Faktor
mu_s(xM) = g_s *q/(2m(xM))*S leads to
m(pM)=**1.67**262192370E-27kg Codata: m_p=**1.67**262192369(51)E-27kg
m(eM)=**9.10**938837015E-31kg Codata: m_e=**9.10**938837015(28)E-31kg
m(npM)=**1.67**262192387E-27kg Codata:m_n=**1.67**492749804(95)E-27kg

(6) Constituent quarks and magnetic moment
https://de.wikipedia.org/wiki/Proton
Große Deutsche Enzyklopädie
„Damit ein Elementarteilchen ein intrinsisches magnetisches Moment hat, muss es sowohl Spin als auch elektrische Ladung haben. Das Neutron hat einen Spin von 1/2 ħ, aber keine Nettoladung. Die Existenz des magnetischen Moments des Neutrons war rätselhaft und widersetzte sich einer korrekten Erklärung, bis in den 1960er Jahren das Quarkmodell für Partikel entwickelt wurde. Das Neutron besteht aus drei Quarks, und die magnetischen Momente dieser Elementarteilchen verbinden sich, um dem Neutron sein magnetisches Moment zu verleihen.“

(7) More accuracy
Double-trap measurement of the proton magnetic moment at 0.3 parts per billion precision Schneider et al., Science 358, 1081–1084 (2017)

(8) https://www.nature.com/articles/d41586-019-02786-z