Beyond the Standard Model: Neutron Properties

S. Reucroft[1] and E. G. H. Williams[2]

ThinkIncubate, Inc., Wellesley, Mass., USA

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Abstract: We present a simple, semi-classical e-model of the neutron that gives the neutron mass, charge, spin, magnetic moment and internal charge distribution all in good agreement with measurements.

Introduction

In an earlier paper [1] we introduced the e-model of the proton. In the e-model, the proton is composed of an electron and two positrons in an orbital structure not unlike that of a simple atom. A fit to the experimentally determined internal charge distribution of the proton is used to determine the radii of the orbital particles. The effective mass of the three components is then used to calculate the proton mass. The only unknown parameter is the value of the short-distance gravitation parameter G_0. The model successfully provides the proton mass, internal charge distribution, spin and magnetic moment. In addition, the model suggests a reason for the stability of the proton (and electron) and contains an automatic, universal matter-antimatter balance.

In this paper we introduce the e-model of the neutron. We take as starting point the proton e-model and add an electron and a neutrino. Fits to the experimentally determined internal charge distribution of the neutron are used to determine the radii of the orbital charged particles. The fits to the charge distribution give one of the electrons and one of the positrons at the centre (R = 0) with the other positron and the other electron at radii R_1 = 0.28 fm (1 fm = 10^{-15} m) and R_2 = 0.9 fm, respectively. The neutrino is in orbit with radius > 4 fm. The effective mass of the five components gives the exact neutron mass.

It was demonstrated several decades ago [2] that the proton and neutron are composite objects containing point-like fundamental particles. In the Standard Model it is usually assumed that these are fractionally charged quarks that are somehow confined in a soup of virtual quarks and gluons. These assumptions are subject to interpretation and they have not been verified experimentally. In particular, neither quarks, gluons nor fractional charge have ever been detected directly in an experiment.

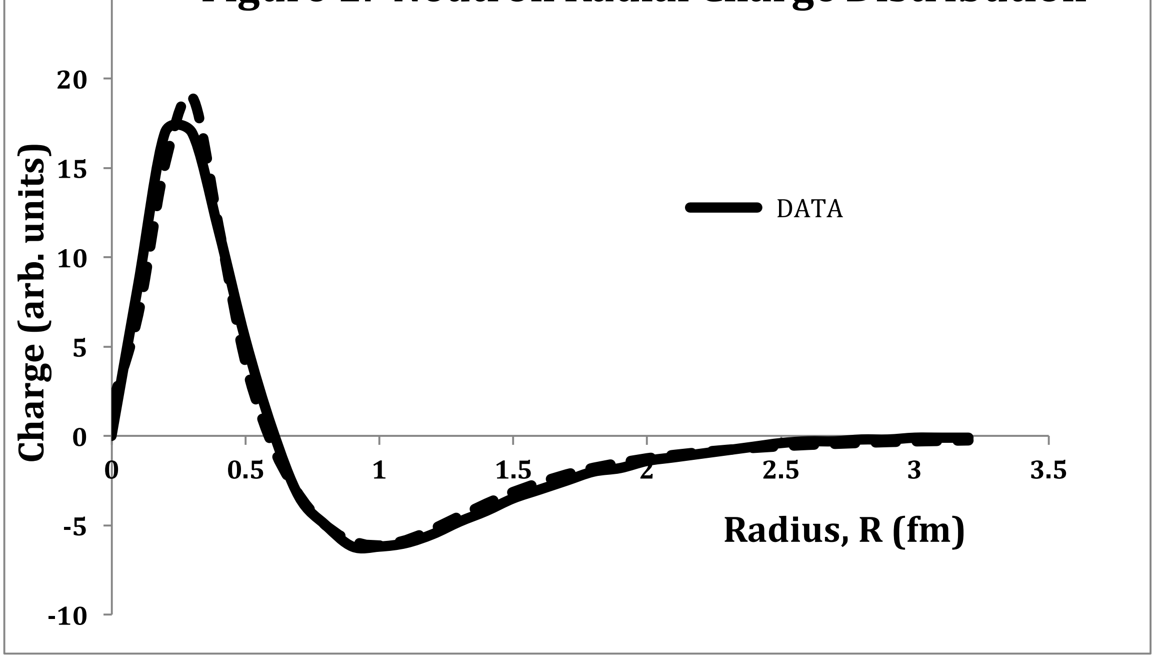
[1] reucroft@gmail.com
[2] edwardghwilliams@aol.com

In fact, the electron and positron are the only massive, charged point-like particles that are known to exist, so in the e-model we assume that the proton and neutron are composed of electrons and positrons. Of course this assumption is also subject to interpretation and it has also not yet been verified experimentally, but it has some features that are more palatable than the quark model and it does lead to some natural consequences and predictions that we present here and in the earlier paper [1].

Charge

The distribution of charge inside the neutron has been obtained from its electric and magnetic form factors [3, 4]. A recent particle physics planning report gives the status as of five or so years ago based on a compilation of all available data [5]. As seen in figure 1 (solid curve), the charge is zero at the neutron centre (R = 0), rises to a positive maximum at ~ 0.3 fm, falls and passes through zero at ~ 0.6 fm, rises to a negative maximum at ~ 1 fm and falls slowly to zero by 4 fm. More than 95% of the neutron charge is within a radius of ~ 2 fm. The experimental uncertainty at the positive peak is ~ 15% and at the negative peak it is ~ 20%.

Figure 1: Neutron Radial Charge Distribution



Following the proton e-model study, we have used Breit-Wigner line shapes and obtained an excellent description of the total neutron charge distribution. The χ^2 fit was started at the proton values [1] with an electron added at a radius of 1 fm. After several iterations, the dashed curve in figure 1 shows the resulting sum of the 4 Breit-Wigners with best fit parameters:

	Radius (fm)	Width (fm)
positron	0	1.7 ± 0.3
electron	0	1.2 ± 0.1
positron	0.28 ± 0.01	0.37 ± 0.03
electron	0.90 ± 0.03	1.2 ± 0.2

We did not constrain the charge to be zero at R = 0 in the fit.

This supports the basic idea that the neutron is composed of two positrons plus two electrons. For calculation purposes, in the following we assume the radii given in this table. The reality is perhaps more complex. As is the case with the e-model of the proton [1], it is not clear what is the significance, if any, of obtaining good fits using Breit-Wigner line shapes rather than Gaussians. In any case, the fitted values of the radii are the same whether Gaussians or Breit-Wigners are used.

Mass and Gravity

In order to derive an expression for the mass of the neutron, we use the following notation: electron and positron at $R = R_0 = 0$, positron at $R = R_1 = 0.28$ fm and electron at $R = R_2 = 0.9$ fm. In addition there is a neutrino of energy E_ν at radius R_ν.

The quantum conditions for the positron and electron are: $\gamma_1 m_e v_1 R_1 = \hbar$ and $\gamma_2 m_e v_2 R_2 = \hbar$; and for the neutrino: $E_\nu R_\nu = \hbar c$; where $\gamma_{1,2}$ are the relativistic factors ($1/\sqrt{1 - v_{1,2}^2/c^2}$) and $\hbar$ is the reduced Planck constant ($h/2\pi$). Note that these quantum conditions have nothing to do with angular momentum. In a semi-classical sense, they are saying that the de Broglie wavelength ($\lambda = h/p = h/\gamma m v$) has to equal the circumference of the orbit.

If the total internal vector momentum is zero, the effective mass of the two positrons. two electrons and a neutrino is given by:

$$m_n = 2m_e + \gamma_1 m_e + \gamma_2 m_e + \frac{E_\nu}{c^2} = 2m_e + \frac{\hbar}{v_1 R_1} + \frac{\hbar}{v_2 R_2} + \frac{E_\nu}{c^2}.$$

With R_1 = 0.28 fm and R_2 = 0.9 fm, the neutrino term contributes ~ 1.5% to the neutron mass. This formula gives the exact neutron mass when E_ν = 14.6 MeV and R_ν = 13.6 fm. The experimental uncertainties in R_1 and R_2 given in the table above can be used to calculate the lower limits of $E_\nu \sim 0$ MeV and $R_\nu \sim 4$ fm. Also, with these values of R_1 and R_2, $\gamma_1 = 1380$ and $\gamma_2 = 430$ and the approximation $v_1 = v_2 = c$ is good to better than 1 part in 10^5.

The approximate equation of motion of the outer electron may be used to estimate the gravitation parameter G_0:

$$\frac{\gamma_2 m_e v_2^2}{R_2} = \frac{G_0 \gamma_1 \gamma_2 m_e^2}{R_2^2}.$$

And this gives:

$$G_0 = \frac{R_2 v_2^2}{\gamma_1 m_e} = \frac{\hbar^2}{\gamma_1 \gamma_2^2 m_e^3 R_2}.$$

With the values given above, $G_0 = 6.4 \times 10^{28}$ Nm^2/kg^2 with an experimental uncertainty of ~ 10%.

The approximate equation of motion of the neutrino may also be used to give another formula for G_0:

$$\frac{E_\nu}{R_\nu} = \frac{G_0 m_n E_\nu}{R_\nu^2 c^2} \text{ or } G_0 = \frac{R_\nu c^2}{m_n},$$

and this gives $G_0 = 7.3 \times 10^{29}$ Nm^2/kg^2. Given the large uncertainties, this is in good agreement with the value obtained from the electron orbit.

Spin

None of the components of the neutron have orbital angular momentum, so the spin of the proton is obtained by adding together the five component spins. We make the assumption that there are three with spin up and two with spin down. The spin of the proton is then, by definition, exactly equal to the spin of one of the components.

Magnetic Moment

In the e-model, the magnetic moment of the neutron (μ_n) may be written as the sum of three terms. These are the mass-scaled magnetic moment (μ_e) of one of the electrons or positrons and the current loop of the orbital positron and electron. We assume that everything else cancels. These terms are:

$$\pm \mu_e \frac{m_e}{m_n}, \quad \frac{ecR_1}{2}, \quad \frac{-ecR_2}{2}.$$

where we have made the approximation $v_1 = v_2 = c$.

The numerical values for these three terms are: 5.05 x 10^{-27} J/T, (6.7 ± 0.2) x 10^{-27} J/T and (21.6 ± 0.7) x 10^{-27} J/T. With the first two terms positive and the third term negative, the resultant magnetic moment of the neutron is –(9.85 ± 0.73) x 10^{-27} J/T = -(1.94 ± 0.14) nuclear magnetons. This is in good agreement with the measured value of -1.91 nuclear magnetons [6].

Schwarzschild Radius

The Schwarzschild radius of an object of mass *m* is given by:

$$R_S = \frac{2Gm}{c^2},$$

where *G* is the gravitation parameter and *c* the speed of light *in vacuo*.

For the value of G_0 given here for the interior of the neutron[3], the value of R_S = 2.4 fm.

Most, but not all of the neutron charge is contained within this radius and the neutrino is perhaps completely outside. In the previous paper [1] it was shown that the electron and the proton are totally contained within their Schwarzschild radii. Could this be a clue regarding the stability of the electron and proton while the neutron is an unstable particle?

Conclusions and Predictions

In this paper we introduce the e-model of the neutron. There are no quarks nor gluons in the model and the gravitation parameter is assumed to be much larger than the macroscopic value, therefore this description of the neutron takes us beyond the Standard Model.

The neutron internal charge distribution supports the basic hypothesis of the model that the neutron is composed of two electrons and two positrons that are contained in a sphere of radius ~ 3 fm with a neutrino outside this. One of the electrons and one of the positrons are assumed to be at the centre with the other positron and the other electron at radii R_1 = 0.28 fm and R_2 = 0.9 fm, respectively. The whole system is held together by gravitational forces with a gravitation parameter G_0 that is approximately forty orders of magnitude larger than the macroscopic value. All of the measured neutron properties are consistent with the calculated quantities provided by this model.

[3] We are making the assumption that *G* is dominated by its short distance value G_0 .

There is no acceptable quantum theory that governs this situation and so our calculations are made within a simple, semi-classical framework. Many of the calculations are also necessarily approximate.

Even though some arbitrary assumptions have to be made, it is remarkable that such a simple model can calculate the neutron mass and magnetic moment, charge and spin that are all in excellent agreement with measured values [6]. It is even more remarkable that a similar e-model of the proton gives all of the proton properties [1].

We are not suggesting that this is an exact description of the neutron. It is, at best, a non-rigorous approximation that might lead us in the right direction. The results of the calculations indicate that we might be on the right track.

Two other interesting features of the e-model are a natural matter-antimatter symmetry in the universe and a hint of a *rationale* for the stability of the electron and the proton while the neutron is unstable.

Finally we make some predictions that can be tested experimentally These have been discussed elsewhere [1, 7]. Two of them are worth repeating here:

- The gravitation parameter has to drop from ~ 10^{29} Nm^2/kg^2 to ~ 10^{-11} Nm^2/kg^2 as distances increase from ~ 10^{-15} m to ~ 10^{-2} m. This should be detectable;
- It should be possible to produce single protons and single antiprotons in e^+e^- collisions via the reactions $e^+e^- \to pe^-$ and $e^+e^- \to \bar{p}e^+$. An e^+e^-experiment below the $p\bar{p}$ threshold (at 1.85 GeV, say) ought to produce detectable ~ 700 MeV/c protons and antiprotons.

Acknowledgements

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