Protons and neutrons: what *are* they?

Summary

This article revisits the main arguments *against* an alternative explanation of nuclear processes—alternative to quark theory, that is. We will want to further expand this article in the future so as to arrive at a more comprehensive self-critique of some of the material we presented in previous papers.

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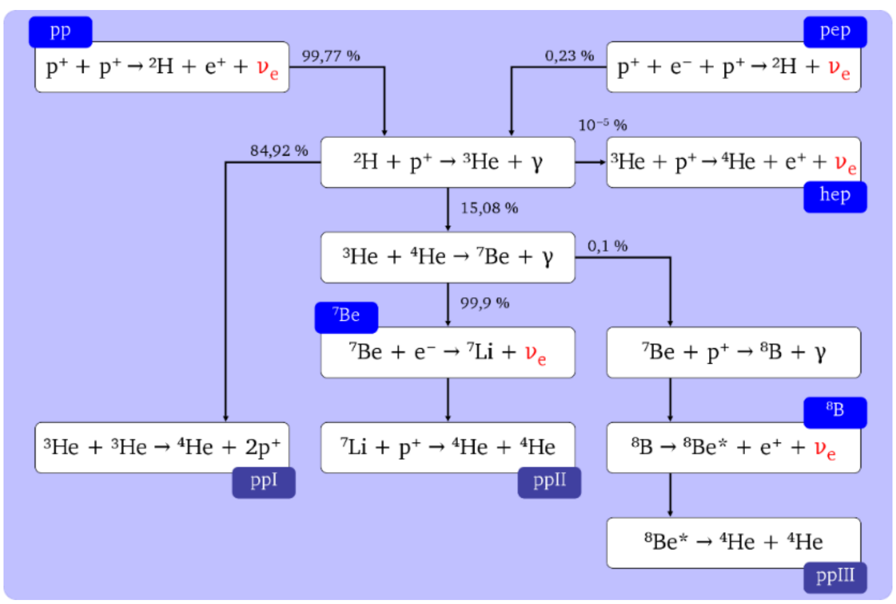
Protons and neutrons: what *are* they?

How the Sun works

Nuclear processes are intriguing. Despite all of the advances made since Schrödinger and Dirac came up with their wave equations for modeling electron behavior[1], our understanding of them is still quite poor. Let us – to get started somewhere – look at nuclear fusion processes in the Sun. Why start there? Just for fun. The Sun gives us energy. It keeps us alive: the Earth's core is hot (about 6,000 degrees Celsius[2]) – but not hot enough to keep us all warm at its surface. Neptune's core, for example, is thought to be equally hot – or hotter perhaps (7,000 °C) – but its surface temperate averages *minus* 200 degrees Celsius.

So what happens inside of the Sun? Protons – somehow – *combine* into helium: the process is referred to as nuclear fusion. The 'how' of the '*some*how' is shown below.[3] We have various pathways (see Figure 1), also referred to as pp (proton-proton) branches, or chains. The terminations of those chains are referred to as pp-I, pp-II and pp-III respectively and – in case you wonder – *hep* stands for helium-proton fusion. [I must assume you figured out *pep*: proton-electron-proton fusion.[4]]

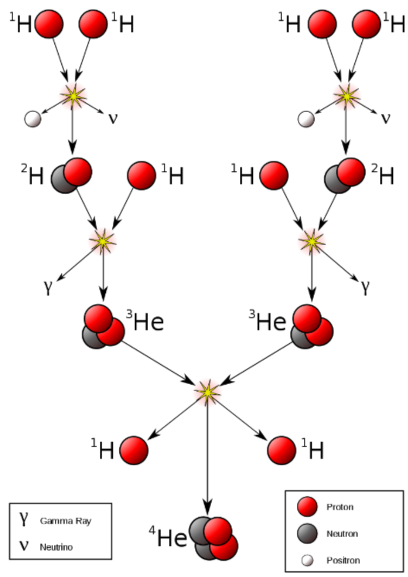
Figure 1: Nuclear reaction routes in the Sun



[1] The solutions to Schrödinger's wave equation model electron orbitals around a one-proton nucleus (read: a hydrogen atom), while Dirac's equation models an electron in free space.
[2] That's not quite comparable to the core of the Sun, where temperatures are thought to be at least a *thousand* times that – probably up to 15 million degrees Celsius – so as to enable nuclear fusion processes. At the same time, the Sun's surface temperatures – however you'd want to define the Sun's surface – are in the same range: a few thousand degrees Celsius.
[3] Source: Dorottya Szam - file:Proton proton cycle.png, CC BY-SA 2.5, from Wikipedia Commons.
[4] The other symbols in the chart are pretty obvious. Be, for example, denotes *beryllium* and B stands for *boron*. Note that the pp-II chain reaction is often referred to as lithium burning – a process which is characteristic of so-called *brown dwarfs*..

The percentages shouldn't worry us: they'll depend on the Star – age, mass, etcetera – that we're looking at: Hans Bethe deserved his 1967 Nobel Prize[5] for a good reason so these percentages make sense as part of a generally consistent picture of what's going on inside of our Sun. Let us try to follow the main pp-I route – if only because it involves the least steps. Three steps, to be precise – as shown below.

Figure 2: The pp-I route



The more particular presentation of the pp-I route above invites us to also keep track of the electrons. At these temperatures, atoms are *ionized* which, in this case (simple hydrogen and helium atoms), means our atoms are just nuclei with fairly free electrons somewhere 'out there'. Physicists refer to this situation as *plasma*, which – in Greek – means 'something molded' and, therefore, fairly undefined. However, we must keep track of the electrons too, so ^{1}H and p^+ are not the same. We may write:

$$^1\text{H} \leftrightarrow p^+ + e^-$$

1. Two ^{1}H atoms combine into *deuterium* (^{2}H). Deuterium consists of a proton, a neutron and an electron, somewhere. The process involves the emission of a positron (e^+) in 99.77% of the cases.[6] In the remaining 0.23% of cases, they do so by absorbing an electron (e^-): that's the *pep* route, but that's not the one we're following here.

An interesting question: what happens to the positron? It should annihilate with a nearby electron. In fact, the so-called Q-value of this reaction is 1.44 MeV and assumes such annihilation.[7] The question thus becomes: where do we get the electron from? The answer is: we only need one electron for the

[5] Bethe's work was worthy of several Nobel prizes but – when everything is said and done – he got his for his work on the theory of stellar nucleosynthesis, which underpins most of what we're writing here.
[6] We'd need to define what a 'case' actually means in this context – in time and in space – but, for the time being, let's just go along with this story.
[7] The Q values (energy emission or absorption during a nuclear reaction) are taken from Encyclopædia Britannica.

deuterium, so one of the electrons from the two ^{1}H atoms can effectively go up in smoke – sorry, highly energetic gamma rays – when greeting the positron.

2. In the next step, deuterium (^{2}H) will combine with another hydrogen atom to form a proper helium-3 atom (^{3}He).[8] The ^{3}He atom has two protons and one neutron, so it needs two electrons to be electrically neutral. We get one from the deuterium and the other from the hydrogen atom that also gives its proton to the new ^{3}He atom. Again, no problem with the electron balance here: electric charge is being conserved. The Q-value here is 5.49 MeV and, as shown in Figure 1 and Figure 2, the energy goes out as electromagnetic radiation (photons): highly energetic gamma rays, basically.[9]

3. The ^{3}He atom that is formed in this way meets with another ^{3}He atom to yield stable helium-4 (^{4}He), which is helium as we know it.[10] The by-product of two helium-3 atoms merging into a single helium-4 atom is two ^{1}H atoms, which feed back into the first step. The electron balance is fine again: we had four electrons from the two ^{3}He atoms, and only two of them are needed for our ^{4}He atom – so the two ^{1}H atoms are fine.

The helium-4 then combines with helium-3 to produce heavier elements (beryllium, lithium-7, and boron) and these are then fused into still-heavier elements. That's a story you know[11] and it all sounds logical and great.

The most intriguing process here is the transformation of a proton into a neutron. Let's have a look at that.

The proton-neutron *Verwandlung*

In the first step of the pp-I chain, one of the protons, *somehow*, becomes a neutron. We know these processes: electron capture, or positron emission. There are three mechanisms here:

1. Electron capture by a proton: $p^{+} + e^{-} \rightarrow n^{0} + \nu^{0}$
2. Positron emission by a proton (neutrino absorption): $\nu^{0} + p^{+} \rightarrow n^{0} + e^{+}$
3. Positron emission by a proton (photon absorption): $\gamma + p^{+} \rightarrow n^{0} + e^{+} + \nu^{0}$

So how does this work – *exactly*? The mass/energy difference between a neutron and a proton is about 1.3 MeV.[12] This mass difference, combined with the fact that neutrons spontaneously decay into

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[8] Helium-3 is a stable isotope of helium. It's rare on Earth but relatively abundant in stars because of this fusion process, of course.

[9] The Greek letter for gamma (γ) may, conveniently, refer to a photon, generally speaking, or, more specifically, to high-energy gamma ray photons.

[10] 99.999863% of the helium we find here on Earth is helium-4.

[11] This is how it's told on a NASA site (https://helios.gsfc.nasa.gov/nucleo.html): "Our Sun is currently burning, or fusing, hydrogen to helium. This is the process that occurs during most of a star's lifetime. After the hydrogen in the star's core is exhausted, the star can burn helium to form progressively heavier elements, carbon and oxygen and so on, until iron and nickel are formed. Up to this point the process releases energy. The formation of elements heavier than iron and nickel requires the input of energy. Supernova explosions result when the cores of massive stars have exhausted their fuel supplies and burned everything into iron and nickel. The nuclei with mass heavier than nickel are thought to be formed during these explosions."

[12] To be somewhat more precise, the neutron's energy is about 939,565,420 eV. The proton energy is about 938,272,088 eV. The difference is about 1,293,332 eV.

protons but – conversely – there is no such thing as spontaneous proton decay[13], makes it very tempting to think a neutron might, somehow, combine a proton and an electron. The mass of an electron is 0.511 MeV, so that's only 40%, but its kinetic energy and other energies could make up for a lot of the remainder.

What other energies? Some kind of binding energy between the proton and the electron, perhaps? The idea is not as crazy as it sounds – especially when we combine it with another crazy idea: neutrinos as a carrier of the strong force. Look at the neutron decay reaction, which is just the opposite of proton electron capture:

$$n^0 \rightarrow p^+ + e^- + \nu^0$$

All reactions involve one or more neutrinos carrying some energy to ensure Nature's energy conservation law is respected. Hence, I like to think of the neutrino as providing the *nickel-and-dime* in interactions involving the strong force. Of course, skeptics will cry wolf here and object: neutron decay involves the *weak* force – not the strong force, right? Yes – so we must add the next crazy idea: the weak force is not a force. A force holds things together. So when we're talking about the weak force, we're actually talking about why and how the strong force *breaks down*. That crazy theory involves a discussion on harmonic and not-so-harmonic oscillations (resonance) and how they may or may not be related to the stability and instability of what we generally refer to as particles, even if we shouldn't refer to instable particles as particles because… Well… Because they are not stable.

The idea is quite simple, really: if photons carry electromagnetic energy, then neutrinos might be carrying the 'strong' energy. The idea of electromagnetic energy is pretty meaningless without the idea of the electric charge and, hence, the idea of 'strong' energy should also imply the idea of a 'strong' charge. However, the two proton-neutron *Verwandlung* reactions involving positron emission do *not* involve any electron. Let us write them down again:

1. Neutrino absorption: $\nu + p^+ \rightarrow n^0 + e^+$
2. Photon absorption: $\gamma + p^+ \rightarrow n^0 + e^+ + \nu^0$

That's where pair production comes in. You probably best know the reaction involving photon absorption. In fact, pair production is a fairly dominant mode of interaction with matter for photons with very high energy (MeV scale and higher), and this mode was discovered in a relatively early stage of the development of quantum physics (Blackett and Occhialini, 1933).[14] Dirac duly noted that in the preface to the fourth and last edition of his seminal 'Principles of Quantum Mechanics', in which he recognized the significance of electron-positron pair creation and annihilation:

> "In present-day high-energy physics, the creation and annihilation of charged particles is a frequent occurrence. A quantum electrodynamics which demands conservation of the number of charged particles is, therefore, out of touch with physical reality. So I have replaced it by a quantum electrodynamics which includes creation and annihilation of electron-positron pairs."

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[13] None of the experiments (think of the Super-Kamiokande detector here) found any evidence of proton decay so far.

[14] Blackett and Occhialini discovered pair production by taking photographs of electrons and positrons created from cosmic rays in a Wilson cloud chamber and matter. It was this discovery that got Patrick Blackett his 1948 l Nobel Prize in Physics, although he is also to be credited with many other advances in science.

It should be noted that Dirac does not doubt the charge conservation law here: he only says that any law demanding the conservation of *the number of charged particles* is no longer relevant. That's clear enough. We can imagine some interaction between the highly energetic photon and the proton creating an electron-positron pair: the electron then, somehow, combines with the proton to form a neutron. The electron remains, and a neutrino provides the necessary *nickel-and-dime* to ensure energy conservation. Highly speculative, but plausible enough – for me, at least. But what about this reaction involving the absorption of a neutrino?

The discovery was made in 1951 by Cowan and Reines: they showed that bombarding protons with neutrinos also leads to the creation of neutrons and positrons.[15] What about energy conservation here? The energy of a neutron and a positron add up to a bit more than 940 MeV: the energy difference with a proton is about 1.8 MeV. Can the incoming neutrino have such energy? The answer is positive: neutrinos can have any energy. In fact, we may usefully remind ourselves that Wolfgang Pauli postulated the existence of neutrinos in 1930 to account for rather large variations in the measured energy of the electron coming out of beta decay processes. Hence, the order of magnitude may surprise but remains reasonable.

It is a most intriguing thing. In fact, the incoming neutrino is thought of as an anti-neutrino, which – because of the very contested answers to the question of what anti-neutrinos actually are[16] – makes the whole thing even more mysterious.

We will let the matter rest for a while – literally. 😊 The only idea I wanted to introduce was this: perhaps we should think of a neutron as a *composite* particle – but not in the way mainstream physicists tell us we should do: quarks, color charges and gluons don't make much sense to me. Thinking of a neutron as a combination of two stable elementary particles – a proton and an electron – does.

In order to further develop this idea, we need to develop some other ideas. These ideas are triggered by the same questions as those who led to the quark hypothesis: what keeps nucleons together? We must assume it is some kind of 'strong' force. A force acts on a charge. Hence, we need to develop the idea of a strong charge. Let's do that now.

The idea of a strong charge

We have to be brief here, as we developed these idea somewhere elsewhere[17] and so we don't want to be too long here. I'll just mention the general line of reasoning and the grand results. We first assume Yukawa's formula for the 'strong' potential is essentially correct:

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[15] Clyde Cowan died in 1974 at the young age of 54. Frederick Reines lived long enough to finally be honored with the Nobel Prize for his work on neutrino physics: he got the Prize in 1995. He died three years later, aged 80.

[16] See: https://www.symmetrymagazine.org/article/is-the-neutrino-its-own-antiparticle. In order to prove the distinction between anti-neutrinos and neutrinos is useful, one would have to prove they annihilate each other. That has not been done yet.

[17] See my *Neutrinos as the Photons of the Strong Force* post on viXra.org (1 Oct 2019, http://vixra.org/abs/1909.0026).

$$\mathrm{U}(r) = -\frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\frac{e^{-r/a}}{r}$$

The g_N factor here is the rather infamous nucleon charge, which we'll now refer to as the strong charge. It's quite similar to the q_e factor in the formula for the electrostatic potential V(r):

$$\mathrm{V}(r) = -\frac{\mathrm{q_e^2}}{4\pi\varepsilon_0}\frac{1}{r}$$

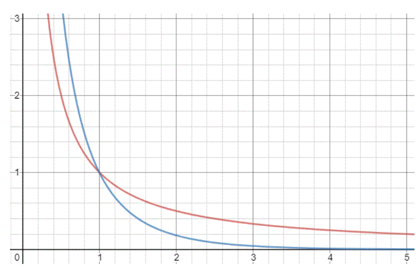
The two formulas differ because of (1) the *nature* of the charge and (2) the $e^{-r/a}$ function:

1. The different *nature* of the electric and charge is evidenced not only by a different symbol for the charge (g_N versus q_e) but also by the υ_0 factor in Yukawa's formula.[18] This new *upsilon* factor has the same role as the electric constant (ε_0) factor in Yukawa's formula. It's a *physical* proportionality constant. Of course, because we have the luxury of defining the unit for this new *nucleon* charge g_N, we can equate the *numerical* value of υ_0 to 1. However, it should have some physical dimension – just like ε_0, whose *physical* dimension is equal to $C^2/N{\cdot}m^2$. So what's the equivalent of the *coulomb* unit for the strong force? Let's call it the l Let's call it the *Dirac*, for the time being. Why? Because he doesn't have a unit yet.[19] To ensure we're all completely confused now, we'll abbreviate it as Y. Why? No good reason. The symbol hasn't been used yet – and it's a nice reference to Yukawa, of course – so let's just use it and get on with our story. We write:

$$[\upsilon_0] = Y^2/N{\cdot}m^2$$

2. The $e^{-r/a}$ function is there because the strong force is supposed to be very strong at very close range only – as compared to the electrostatic force, that is. Figure 3 illustrates the idea.[20]

Figure 3: The Yukawa versus the Coulomb potential



Now, we can use the *range parameter a* as a natural distance unit (what we are saying here is that we are going to measure r in units of a) in an attempt to get rid of it, but that doesn't help us all that much. On the contrary: we'd actually like to find some value for a, right? Right. What can we do? At some

[18] You will *not* find this factor in textbooks. We put it there because it was essentially lacking.

[19] It is said that Dirac's colleagues at Cambridge did actually define a 'dirac' unit as 'one word per hour' (see: https://en.wikipedia.org/wiki/Paul_Dirac) but – jokes apart – I am not aware of any other form of recognition of this genius.

[20] You may wonder: what about the 4π factor? Don't worry about that: the 1/4π factor is common to both formulas and, in any case, it is just the 4π factor in the formulas for the surface *area* ($4\pi r^2$) and the *volume* ($4\pi r^3$) of a sphere. Gauss' Law can be expressed in integral or differential form and these spherical surface area and volume formulas pop up when you go from one to the other. Hence, you shouldn't think of this 4π factor as something weird.

distance *r*, the strong and electrostatic force should be equally strong. We can easily calculate the force from the potential, so we get this condition:

$$\mathrm{F} = -\frac{\mathrm{dU}}{\mathrm{d}r} = -\frac{\mathrm{dV}}{\mathrm{d}r}$$

Let us think about the minus signs here. The forces should be opposite, right? Right, but the formula should take care of that. We should keep our wits with us here, so let us remind ourselves of whatever is that we are trying to do here. We are thinking of two nucleons here, and two nucleons – whatever they are – carry an electric charge (q_e) as well as what we vaguely referred to as a nucleon charge (g_N) – or a *strong* charge. Think of two protons: the electric charge pushes them away from each other, but the strong charge pulls them together. At some in-between point, the two forces are equal but opposite. So we should find some value for a force – expressed in *newton*. The force unit (*newton*) doesn't depend on the *nature* of the charge, even if we know the force *acts* on a charge. A unit charge, to be precise. So…

Well… We have two *different* unit charges here: q_e versus g_N. What does that mean? Let us go through the calculations and see where we get. The Coulomb force is easy to calculate:

$$\mathrm{F_C} = -\frac{\mathrm{dV}}{\mathrm{d}r} = -\frac{\mathrm{d}\left(-\frac{\mathrm{q_e^2}}{4\pi\varepsilon_0}\frac{1}{r}\right)}{\mathrm{d}r} = \frac{\mathrm{q_e^2}}{4\pi\varepsilon_0}\frac{\mathrm{d}\left(\frac{1}{r}\right)}{\mathrm{d}r} = -\frac{\mathrm{q_e^2}}{4\pi\varepsilon_0}\frac{1}{r^2}$$

This is just Coulomb's Law, of course! The calculation of this new nucleon force (think of it as a 'strong' nucle*ar* force) is somewhat more complicated because of the $e^{-r/a}$ factor[21]:

$$\mathrm{F_N} = -\frac{\mathrm{dU}}{\mathrm{d}r} = -\frac{\mathrm{d}\left(-\frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\frac{e^{-\frac{r}{a}}}{r}\right)}{\mathrm{d}r} = \frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\frac{\mathrm{d}\left(\frac{e^{-\frac{r}{a}}}{r}\right)}{\mathrm{d}r}$$

$$= \frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\cdot\frac{\frac{\mathrm{d}\left(e^{-\frac{r}{a}}\right)}{\mathrm{d}r}\cdot r - e^{-\frac{r}{a}}\cdot\frac{\mathrm{d}r}{\mathrm{d}r}}{r^2} = \frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\cdot\frac{-\frac{r}{a}\cdot e^{-\frac{r}{a}} - e^{-\frac{r}{a}}}{r^2} = -\frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\cdot\frac{(\frac{r}{a}+1)\cdot e^{-\frac{r}{a}}}{r^2}$$

The condition for F_C and F_N to be equal is:

$$\frac{\mathrm{q_e^2}}{4\pi\varepsilon_0}\frac{1}{r^2} = \frac{\mathrm{g_N^2}}{4\pi\upsilon_0}\cdot\frac{\left(\frac{r}{a}+1\right)\cdot e^{-\frac{r}{a}}}{r^2} \Leftrightarrow \frac{\mathrm{q_e^2}}{\mathrm{g_N^2}} = \frac{\varepsilon_0}{\upsilon_0}\cdot\left(\frac{r}{a}+1\right)\cdot e^{-\frac{r}{a}}$$

What can we do with this? Our range parameter can be anything, right? So how can we determine its value? The answer is: we can't. However, we can follow another line of reasoning here. We can *define* it as a natural distance unit. What natural distance unit? Well… As we can choose whatever natural distance unit we would want to choose, let us *define* it as the distance where the two forces are effectively equal to each other. Hence, the force condition can now be re-written as:

$$F_C = F_N \Leftrightarrow a = r$$

[21] We need to take the derivative of a quotient of two functions here, so you will want to check that rule.

Is this tautological? It is and it isn't. What's happening here is that we define some new weird force here – the nuclear force – by its range parameter. That's not a philosophical exercise because we actually do have a pretty good idea about the size of a nucleus from scattering experiments. To be precise, if you open a textbook[22], you'll read that the range to be used in Yukawa's potential formula is about 2 fm, which is about the size of deuteron, i.e. the nucleus of deuterium, which consists of a proton and a neutron bound together. To be *very* precise, the charge radius of deuteron is about 2.1 fm.

That all makes sense, intuitively, so we won't dwell on it here. Just note that we *know* the actual range of the force that holds protons together: within that range, protons stay together and, beyond it, they pull each other apart. So let us see where we get with this. If $r = a$, the equality of forces condition becomes:

$$\frac{\mathrm{q_e^2}}{\mathrm{g_N^2}} = \frac{\varepsilon_0}{\upsilon_0} \cdot \left(\frac{a}{a} + 1\right) \cdot e^{-\frac{a}{a}} = \frac{2}{e} \cdot \frac{\varepsilon_0}{\upsilon_0} \approx 3.26 \times 10^{-12} \frac{\mathrm{C^2}}{\mathrm{Y^2}}$$

Is this a sensible value? We can't say much about this because of the weird physical dimension of the ratio: what's the square of the *coulomb/dirac*? Let us, therefore, do something else. We can re-write ε_0 in terms of the fine-structure constant[23] and some other

$$\frac{\mathrm{q_e^2}}{\mathrm{g_N^2}} = \frac{2}{e} \cdot \frac{\varepsilon_0}{\upsilon_0} \Leftrightarrow \mathrm{g_N^2} = \frac{e \cdot \upsilon_0}{2 \cdot \varepsilon_0} \cdot \mathrm{q_e^2} = \frac{e \cdot \upsilon_0 \cdot 2\alpha hc}{2 \cdot \mathrm{q_e^2}} \cdot \mathrm{q_e^2} = e \cdot \alpha \cdot h \cdot c \cdot \upsilon_0$$

It's a beautiful formula. We have the product of two pure numbers (Euler's number and the fine-structure constant), two physical constants (Planck's constant and the speed of light) and then a physical proportionality constant whose numerical value is one. In fact, although it has no physical dimension, we should think of the fine-structure constant as a physical constant too, so we have one mathematical constant (e) and three physical constants (α, h and c). And then we also have that nuclear factor υ_0: our nuclear constant – or whatever you'd want to call it.

Hence, the physical dimension of this product combines that of (physical) action (h), velocity (c) and υ_0. Crazy? The dimensions come out alright, so that's somewhat encouraging:

$$[\mathrm{g_N}^2] = [e\alpha hc\upsilon_0] = (\mathrm{N{\cdot}m{\cdot}s}){\cdot}(\mathrm{m/s}){\cdot}(\mathrm{Y^2/N{\cdot}m^2}) = \mathrm{Y^2}$$

We can now calculate the value of the nuclear charge as the square root of this:

$$\mathrm{g_N} = \sqrt{e \cdot \alpha \cdot h \cdot c \cdot \upsilon_0} = 6.27723 \ldots \times 10^{-14}\ \mathrm{Y}\ (dirac)$$

As you can see, our *dirac* is a big unit: the elementary nuclear charge – our nucleon, that is – carries only a fraction equal to $6.27723\ldots \times 10^{-14}$ of it. That's not something to worry about. The Coulomb is a huge unit too: the elementary charge – the electron – carries only 1.6×10^{-14} of it.

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22 See, for example, Aitchison and Hey's *Gauge Theories in Particle Physics* (2013).

23 You may or may not have come across the $\varepsilon_0 = \mathrm{q_e}^2/2\alpha hc$ formula. If you did, you probably saw it like this:

$$\alpha = \frac{\mathrm{q_e^2}}{4\pi\varepsilon_0 \hbar c} = \frac{\mathrm{q_e^2}}{2\varepsilon_0 hc} \Leftrightarrow \varepsilon_0 = \frac{\mathrm{q_e^2}}{2\alpha hc}$$

For an explanation of what the fine-structure constant might actually *mean*, see my paper on the meaning of the fine-structure constant (http://vixra.org/abs/1812.0273).

What can we do with this? Lots of stuff. We can use the mentioned experimental value for the range parameter ($a \approx 2.1$ fm) and actually *calculate* a value for the strong force at this range. Try it. It's easy math. You should get some humongous but not necessarily nonsensical value. However, we're not writing this for mere entertainment. At some point, we'll want to get back to the main story line.

What was it again? I am not sure. We were freewheeling about the nature of protons and neutrons, and so we'll just continue with that.

Size matters

Our excursion in Fantasyland served only one purpose: the idea of a strong charge makes sense, and we're *not* thinking color charge here. No hocus-pocus. We think of protons as particles that *carry* or – how to phrase it – *combine* electric as well as strong charge. The electric charge pushes them away but – within very close range – the attractive force between the strong charge keeps them together.

What's the electric charge in a proton? It's just the unit charge, so it must be a positron, right? Maybe. Maybe not. We don't exclude the existence of quarks – weird particles mixing partial electric as well as strong charge (mainstream physicists would refer to it as *color* charge but – again – I think the concept of color charge mystifies more than as it explains so I won't use it).

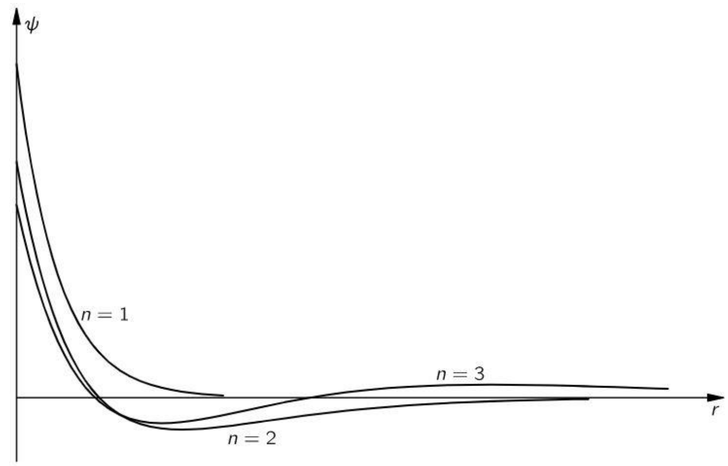
Let's suppose a proton, somehow, combines a positron with a strong charge, and that its strong charge explains why two protons will just sit on top of each other, despite this humongous repulsive electrostatic force between them. Right on top of each other? I guess so. As far as we know, protons (and neutrons) do appear to be stacked together like hard spheres of a constant size – just like marbles, really.[24]

Now, *electrons* don't just go and sit on top of protons. Why not? Despite all mainstream quantum-mechanical *mumbo-jumbo*, we don't have any *real* explanation here (with *real*, I just mean something we can sort of *understand* intuitively). Here we have a conundrum: electrons are not supposed to be affected by strong forces (or strong *charges*) but – at the same time – we need something like a strong force to explain why electrons don't just go and crash into the nucleus to sit on top of some proton.[25]

It is really confusing to think about this. First, the spherical solutions to Schrödinger's wave equation for a hydrogen atom do actually assume that – if we think of an electron as some pointlike charge – the probability to find it at the very center of the atom would be very high. In fact, the graph below[26] shows the probability – for the spherical solutions (*s*-states) – is actually *highest* there.

[24] See: The Particles and Forces of the Standard Model, p. 3, in: Ian J.R. Aitchison and Anthony J.G. Hey, Gauge Theories in Particle Physics: A Practical Introduction, 2013.
[25] If you think neutrons might play some role, think about a simple hydrogen atom: it's just a proton and an electron.
[26] Source: *Feynman's Lectures*, III-19-2 (Fig. 19-2).

Figure 4: Wavefunction for electron *s*-states (l = 0)[27]



That is very confusing: should we think of the pointlike charge actually passing and/or *going through* the nucleus instead of orbiting around it?

Here we need to talk about size. The charge radius of protons and neutrons is about 0.80 to 0.85×10^{-15} meter. That's a lot *smaller* than the radius of an electron. What radius – because we have two, right? Right. We actually have *three* radii, and they are related by the fine-structure constant (α):

1. The classical electron radius (aka *Thomson* radius): $r_e = e^2/mc^2 = \alpha \cdot r_C \approx 2.818\times10^{-15}$ m
2. The Compton (scattering) radius: $r_C = \hbar/mc \approx 0.386\times10^{-12}$ m
3. The Bohr radius, which is the size of a hydrogen atom: $r_B = r_C/\alpha \approx 0.53\times10^{-10}$ m

The charge radius of protons and neutrons is about 0.80 to 0.85×10^{-15} meter[28], so that's about 1/3 of the smallest of the *trio* above. Hence, if a proton would – somehow – be some weird positron, and if a neutron would consist of a proton and an electron, then why are they so much *smaller* that their supposed constituents? What makes them *shrink*, so to speak? The strong force? That doesn't make much sense, does it?

The size issue makes one think again. Electron capture by a proton? If size matters, we should probably think of it as proton capture by an electron – because, taking the Compton radius, the electron is like 500 times *bigger* than the proton. On the other hand, the proton's mass is almost 2,000 times that of the electron. It all is and remains a big mystery.

Jean Louis Van Belle, 7 January 2020

[27] The quantum number l is the orbital angular momentum. The *s*-states have no angular dependency. Note that the wavefunction is actually *real*-valued, i.e. *not* complex-valued. The probability is, as usual, the (absolute) square of the function value $\psi(r)$.
[28] It seems experiments have finally settled the question of the *exact* size of a proton: see https://www.quantamagazine.org/physicists-finally-nail-the-protons-size-and-hope-dies-20190911/.