Explaining the Lamb shift in classical terms

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Summary

Any realist model of an atom must explain its properties in terms of its parts: the electrons and protons. We, therefore, need a realist model of an electron and a proton. Such model must explain their properties, including their mass, radius and magnetic moment – and the anomaly therein, of course. Indeed, these properties are not to be thought of as mysterious intrinsic properties of a pointlike or dimensionless particle: the model should generate them. We think our ring current model does that rather convincingly.

In this paper, we take the next logical step. We relate these models to the four quantum numbers that define electron orbitals. In the process, we also offer the basics of a classical explanation of the Lamb shift. This should complete our realist interpretation of quantum physics.

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Introduction: the Lamb shift and proton spin flips

According to the Wikipedia article on the Lamb shift[1] (which is only useful because it *parrots* the rather fantastical mainstream explanation of this tiny split in spectral lines), we should think of the Lamb shift as a small difference (in energy) between the $^2S_{1/2}$ and $^2P_{1/2}$ orbitals in a hydrogen atom which can only be explained in terms of quantum field theory and which, therefore, basically confirms this theory.

How small? It is usually expressed as a fraction of $\alpha^5 \cdot m_e c^2 = \alpha^5 \cdot E_e$ but in *absolute* terms, it's equal to about 4.372 *millionths* of an eV. Hence, the order of magnitude (in eV energy units) is 10^{-6}. So that is *very* small, indeed. The Planck-Einstein relation tells us that corresponds to a frequency of a bit more than 1000 *mega*herz. That is *much* below the frequency of visible light (430 to 770 *tera*herz) but still corresponds to an easily detectable *radiowave* frequency.

Can we compare it with anything? We can. The order of magnitude is about the same as the energy difference between the spectral lines that are separated by the *spin* of an electron (the splitting that is referred to as the Zeeman effect) or the *fine structure* of the hydrogen spectrum. To be precise, it is one order of magnitude smaller: the Lamb shift is measured in terms of 10^{-6} eV, while the Zeeman effect or the energy difference between the *fine* lines of the spectrum is about 10 times larger.[2] The order of magnitude of the Lamb shift is, in fact, the same as that of the *hyperfine* structure, which is associated with the 1420 MHz radio *hiss* coming from outer space. This radiation comes from *spin flips* of the proton and the electron inside of the hydrogen atom.[3]

We are all very familiar with proton spin flips nowadays because of their use in magnetic resonance imagining. Indeed, I must assume that – if you have ever had one – you also *googled* and watched one or more YouTube videos explaining the physics underpinning this amazing technology. If not, I warmly recommend you do so because they are often better than Wikipedia explanations.[4]

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[1] See: https://en.wikipedia.org/wiki/Lamb_shift, accessed on 29 March 2020.

[2] The *Hyperphysics* site (http://hyperphysics.phy-astr.gsu.edu/) gives an energy difference of 4.5×10^{-5} eV between the two (fine) lines for the 2*P* level. The same site also calculates an energy difference between lines split by the Zeeman effect equal to 5.79×10^{-5} eV. These calculations are quite tricky because they depend on the *strength of the magnetic field* that is being applied to create these splits. The 5.79×10^{-5} eV energy difference, for example, is calculated for a magnetic field of 1 T (*tesla*). We mentioned the $\alpha^5 m_e c^2$ unit: it's equal to about 1×10^{-5} eV so its order of magnitude effectively seems to *connect* all of the mentioned finer divisions of the hydrogen spectrum.

[3] The reader should not confuse this with the cosmic microwave background radiation, which is understood to be a remnant from the Big Bang. The 21 cm line was discovered in the 1930s, and was confirmed to be a hydrogen spectrum line in 1951. In contrast, cosmic background radiation was accurately measured in the 1950s and 1960s only and – as mentioned – it is associated with a *temperature* (about 2.725 degrees Kelvin, to be precise). It is, therefore, *not* related to any specific spectral line. For all practical purposes, one might say the cosmic background radiation reflects the *temperature* of the Universe, which is close to but *above* zero.

[4] From the two or three we watched, we would single out the one from Doctor Klioze: https://www.youtube.com/watch?v=djAxjtN_7VE. It is almost half an hour long, but well worth spending the time!

The point is this: for the *novice* in physics, these mainstream explanations in terms of quantum field theory comes across as somewhat *bizarre*. We explain the Zeeman effect and the fine and hyperfine structure of the hydrogen spectrum in terms of the *orbital* and *spin* angular moment of the electron and – in case of the hyperfine structure – of the proton (or, more generally speaking, the *nucleus* of the atom that we are looking at). For the Lamb shift, however, we are fed a *very* different story line. It goes like this:

> Dirac's equation – for a bound electron[5] – does *not* predict this tiny energy difference. Dirac's equation must, therefore, be totally wrong. We can *only* explain this in terms of "interaction between vacuum energy fluctuations."

Let me quote Wikipedia in full here:

> "This particular difference is a one-loop effect of quantum electrodynamics, and can be interpreted as the influence of virtual photons that have been emitted and re-absorbed by the atom. In quantum electrodynamics the electromagnetic field is quantized and, like the harmonic oscillator in quantum mechanics, its lowest state is not zero. Thus, there exist small zero-point oscillations that cause the electron to execute rapid oscillatory motions."[6]

I will let you digest this for a second. […] It sounds fantastic, doesn't it? Willis Eugene Lamb Jr. got a Nobel Prize in Physics for his discovery in 1955. He had to share it with Polykarp Kusch. To be precise, Lamb got his half of the prize "for his discoveries concerning the fine structure of the hydrogen spectrum" (the Lamb shift), while Polykarp Kusch got it "for his precision determination of the magnetic moment of the electron" (the so-called anomaly in the magnetic moment).[7]

You should note that Lamb did *not* get it for the above-mentioned *explanation* which, judging from some of the later publications of Lamb, he found rather fantastical as well.[8] Likewise, Kusch had *measured* the anomaly but left the explaining of it to (other) physicists—some more famous names you probably are more acquainted with, such as Julian Schwinger and Richard Feynman. The latter, together

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[5] Dirac first developed a wave equation for a free particle (*Principles of Quantum Mechanics*, section 30), which is a particle free of any forces. Section 39 of the *Principles* then further use this theory to deal with what Dirac refers to as the electron's 'motion in a central field of force', based on which he then develops a wave equation that gives us the energy levels of the hydrogen atom (section 40). This is, basically, a modified version of Schrödinger's wave equation for the hydrogen atom. We note that Dirac consistently describes his equations as the 'equations of motion' of the electric charge. We also think all of physics can and should be expressed in terms of the equations of the motion of charges. We, therefore, like the conclusion of his *Principles* very much: "*It is to be hoped that with increasing knowledge a way will eventually be found for adapting the high-energy theories into a scheme based on equations of motion, and so unifying them with those of low-energy physics.*" We could not agree more.

[6] We quote from Wikipedia (https://en.wikipedia.org/wiki/Lamb_shift, accessed on 29 March 2020) to make sure we are *parroting* the right phrases here.

[7] See: https://www.nobelprize.org/prizes/physics/1955/summary/, accessed on 29 March 2020. We write the 'so-called' anomaly because we do not think of the anomaly as an anomaly. We think it is a perfectly normal deviation from some theoretical value. Indeed, one would always expect the measurement to be slightly different from its theoretical value. Why? Because a theoretical value is always based on mathematical idealizations that do not *really* exist. In this particular case, we should just acknowledge that zero-dimensional charges do not *really* exist: they must have *some* (spatial) dimension. Once one accepts that hypothesis, there is no longer any mystery in quantum mechanics. Moreover, because the deviation is *systematic*, one should learn from it so as to detail the model—which is exactly what we have been trying to do.

[8] See: W.E. Lamb, *Anti-photon*, Applied Physics B volume 60, pages77–84 (1995). We offer some comments on this remarkable paper – which Lamb wrote when he was over 80 years old – at the end of our paper.

with Sin-Itiro Tomonaga[9], effectively got the Nobel Prize – almost 20 years after Lamb's discovery[10] and Bethe's first work on it[11] – for *explaining* these seemingly strange measurements using even stranger theories (renormalization and quantum field theories).

Before we get into the meat of the matter – a discussion of the basics which we get from our ring current model of electrons and protons[12] – we need to make more introductory remarks on notation and energy levels, so we are all on the same page there.

Electron states, orbitals and energy levels

There are various notations of electron orbitals and states. That's, in fact, where the confusion starts: we should, perhaps, not equate an electron state with an atomic orbital. An electron state is the state of an electron and, therefore, covers notions such as its orbital and spin angular momentum. An atomic orbital will also be defined by the state of the proton which – as we all know so well since the invention of the MRI apparatus in hospitals – has two opposite *spin* states as well. Hence, *at the very least*, for an accurate description of the (hydrogen) orbitals[13], we will need to combine each *up* and *down* state of an electron with an *up* or *down* state of a proton. So let us look at these notations.

The $^2S_{1/2}$ and $^2P_{1/2}$ notation is the term notation as used in the Wikipedia article on the Lamb shift. The 2*s* and 2*p* notation (often with an additional superscript to show the number of allowed electrons, so we should write $2s^2$ and $2p^6$ instead of 2*s* and 2*p*) will be more familiar to you. The $2p^6$ notation immediately triggers the obvious question: why can we have *six* electrons in this orbital? That has got to do with the *orbital* quantum number (l). We only have one state for l =0, but for l = 1 and l = 2, we have three and five respectively. The three l = 1 states are referred to as *p*-states, while the five l = 2 states are referred to as *d*-states.[14] That makes for *subshells* with six and ten electrons respectively. Any case, let us not get lost in the nitty-gritty here. Not *now*, at least.

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[9] Unlike what you might think, Tomonaga was *not* working with Schwinger, Feynman or any of the other American scientists. He apparently discovered the renormalization method independently of Julian Schwinger and calculated physical quantities such as the Lamb shift at the same time. See: https://en.wikipedia.org/wiki/Shin%27ichir%C5%8D_Tomonaga

[10] The Lamb shift was measured in the Columbia Radiation Laboratory in 1947. From W.E. Lamb's Nobel Prize Lecture, I gather the heavy lifting was actually done by one of his graduate students, Robert Curtis Retherford, whom, sadly, is only mentioned once in Lamb's Nobel Prize lecture, and who did *not* share in the Nobel Prize.

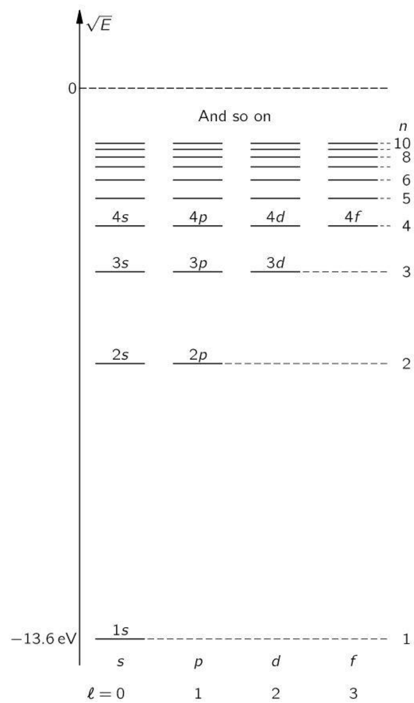
[11] For a good overview of the rather 'dirty work' that Bethe seems to have done, see: Oliver Consa, *Something is rotten in the state of QED* (https://www.researchgate.net/publication/338980602_Something_is_rotten_in_the_state_of_QED). As for the theorists getting the prize only 20 years after the experimental discovery, it should be noted this is not unusual: the Nobel Prize Committee has tended to favor new experimental results above new theories. An exception was probably made in regard to the Higgs hypothesis – as theorists received their prize (for theoretical work that was actually done in the 1960s) almost immediately after the CERN 'discovery' of the Higgs field—or Higgs particle or whatever it was they claim to have measured.

[12] See our *Alternative Theory of Everything: Classical Physics* (https://vixra.org/abs/2003.0144).

[13] We will not venture beyond a simple combination of an electron and a proton in this paper, so that's the hydrogen atom. That should not worry us: mainstream quantum mechanics hasn't much to say about more complicated atoms either.

[14] The use of *letters* instead of numbers may be confusing but it is just a fact of scientific history, which Feynman describes as follows: "The letters did once mean something—they meant "*s*harp" lines, "*p*rincipal" lines, "*d*iffuse" lines and "*f*undamental" lines of the optical spectra of atoms. But those were in the days when people did not know where the lines came from. After *f* there were no special names, so we now just continue with *g*, *h*, and so on." To add to the confusion, these letters are sometimes written as *capital* letters, as evidenced by the Wikipedia article from which we quoted: the *S* and *P* in the $^2S_{1/2}$ and $^2P_{1/2}$ term symbols effectively correspond to *s* and *p* states. The lack of standardization may be bewildering to the novice but – judging from older publications – things are a lot better already now than they were, say, 50 years ago. To decipher things then, one really needed a sort of dictionary!

The important idea here is the idea of an energy level, or an *energy state*. Photons are, effectively, absorbed and emitted when the *atom as a whole* goes from one energy state to the other. You will – or *should* – know such energy state is described by not less than *four* quantum numbers, which we will explain in very much detail later. As for now, you should just *stare* at the illustration below for a while, which we copied from Feynman's *Lectures* below. Now, think of the Lamb shift as a tiny difference between the 2*s* and 2*p* subshells, and between the 3*s*, 3*p* and 3*d* subshells, etcetera.[15]



Feynman derives the energy states above from Schrödinger's equation. To me, it shows why Schrödinger's equation can only serve as a rough approximation of the basic atomic facts. Indeed, the rather remarkable fact that an equation yields two (or more[16]) different *states* with the same energy level should lead to a much more logical conclusion: Schrödinger's equation is more or less right but is, most probably, *not sophisticated enough* (we will later make the same remark for Dirac's more sophisticated equation, however).

Of course, Feynman hastens to add the results above only applies to the hydrogen atom, where we have one electron and one proton only. When the situation gets more complicated, the various states do show different energies. For a *lithium* atom, for example, we do get different energy levels (shown below). In fact, that's, effectively, what allows us to distinguish the lithium from the hydrogen spectrum: that's why we know stars contain lithium—and how much.

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[15] See Figure 19-7 of Feynman's *Lecture* on the hydrogen atom (https://www.feynmanlectures.caltech.edu/III_19.html). There are various notations of states and electron orbitals. The $^2S_{1/2}$ and $^2P_{1/2}$ notation is the term notation as used in the Wikipedia article on the Lamb shift. The 2*s* and 2*p* notation (often with an additional superscript to show the number of allowed electrons, so we should write $2s^2$ and $2p^6$ instead of 2*s* and 2*p*.

[16] For *n* = 2, we have *two* states (2*s* and 2*p*) with the same energy, but for *n* = 3, we have three (3*s*, 3*p* and 3*d*), etcetera.

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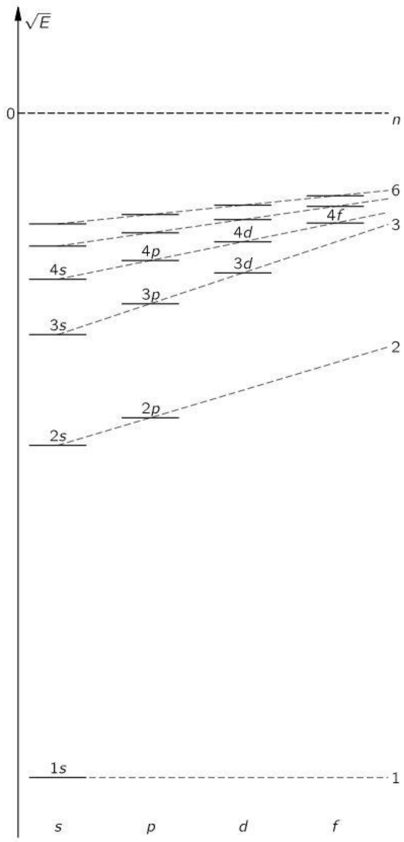


Feynman explains these differences: “The lithium nucleus has a charge of 3. The electron states will again be hydrogen-like, and the three electrons will occupy the lowest three energy levels. Two will go into 1*s* states and the third will go into an n = 2 state. But with l = 0 or l = 1? In hydrogen these states have the same energy, but in other atoms they don’t, for the following reason. Remember that a 2*s* state has some amplitude to be near the nucleus while the 2*p* state does not. That means that a 2*s* electron will feel some of the triple electric charge of the Li nucleus, but that a 2*p* electron will stay out where the field looks like the Coulomb field of a single charge. The extra attraction lowers the energy of the 2*s* state relative to the 2*p* state.” [17]

This explanation is quite sensible if we think of it in terms of *charge densities*: the orbit of an electron in the 2*s* state is closer to the nucleus that of an electron in a 2*p* state – *on average*, that is – and, hence, the electron will effectively spend more *time* nearer to the three protons in the nucleus. That sounds reasonable enough. Let’s move on and talk some more about the *constituents* of a hydrogen atom: the proton and the electron.

[17] The quote and illustration, too, come from the online edition of Feynman’s *Lectures* (III-19-6: *The Periodic Table*). The editors of this *online* edition complain we make too liberal use of it. We wonder why they make such fuss! We think our many references should make them happy rather than upset! See: https://readingfeynman.org/2020/02/20/physics-feynman-and-copyright/.

Spin and orbital angular momentum of protons and electrons

From our previous paper, we now understand the hydrogen atom to consist of two *magnetic dipoles*: an electron and a proton. We understand both the electron and the proton to be current loops. The elementary charge q_e that is spinning around in them – which, we assume, does so at lightspeed – has the same *magnitude* but opposite sign for a proton and an electron respectively: $|+q_e| = |-q_e| = +q_e$.

The *radius* of the loop is very different, however. Making abstraction of the (small) anomalous magnetic moment – and remembering the magnetic moment is the product of the current (I) and the surface area of the loop (πa^2) – we obtain the following theoretical values for the electron and proton respectively:

Electron magnetic moment:

$$\mu_e = \pm \mathrm{I}\pi a^2 = \pm q_e f \pi a^2 = \pm q_e \frac{c}{2\pi a}\pi a^2 = \pm \frac{q_e c}{2} a = \pm \frac{q_e}{2m_e}\hbar \approx \pm 9.274 \ldots \times 10^{-24}\ \mathrm{J \cdot T^{-1}}$$

Proton magnetic moment:

$$\mu_p = \pm \mathrm{I}\pi a^2 = \pm q_e f \pi a^2 = \pm q_e \frac{c}{2\pi a}\pi a^2 = \pm \frac{q_e c}{2} a = \pm \frac{q_e c}{2}\frac{4\hbar}{m_p c}\hbar = \pm 2\frac{q_e}{m_p}\hbar \approx \pm 20.203 \ldots \times 10^{-27}\ \mathrm{J \cdot T^{-1}}$$

Needless to say, the ± sign depends on the *direction* of spin. We may already make the following brief remarks:

1. The reader should note we use the *Compton* radius of an electron in the first expression–not the Bohr radius. This triggers an obvious question: is there no *net* contribution of the *atomic* orbital—spherical (1*s*, 2*s*, etcetera) or non-spherical (e.g. *p*, *d* or *f* states)? We can only offer a rather philosophical answer to that question: we must assume some *form factor* might apply but – ultimately – the magnetic moment of an energy *state* of the hydrogen atom must come from the magnetic moments of its constituents, which are the electron and the proton—its nucleus.

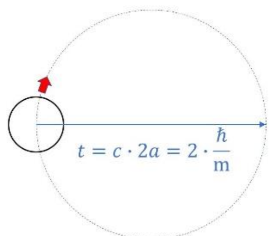
2. The equilibrium state is always the *lowest-energy* state: an excited electron will, therefore, always return from a excited state (e.g. 2*s*) by emitting one or more photons so as to get rid of the surplus energy. This rules also governs the configuration of individual spin states. *Helium* consists of *two* electrons and *two* protons and is *not* magnetic in its ground state: this is because both the electrons and protons ensure the (opposite) magnetic moments cancel out, thereby ensuring the ground state is the lowest-level energy state.[18]

3. The reader should also note the relative magnitudes: the magnetic moment of a proton is about 460

[18] Feynman (III-19-6) phrases this like this: "Both electrons can be in the same lowest state (one spin *up* and the other spin *down*). In this lowest state, the electron moves in a potential [...] like a Coulomb field. The result is a "hydrogen-like" 1*s* state with a somewhat lower energy. Both electrons occupy identical 1*s* states (*l* = 0, *m* = 0). The observed ionization energy (to remove *one* electron) is 24.6 electron volts. Since the 1s "shell" is now filled—we allow only two electrons—there is practically no tendency for an electron to be attracted from another atom. Helium is chemically inert." The value of 24.6 eV is close but not equal to 27.2 eV, which is *twice* the ionization energy of hydrogen. The difference may be explained by the fact that the two electrons are both attracted to the two protons – and very strongly so, of course – but still keep repelling each other!

times *smaller* than that of an electron.[19] Parallel or opposite spin between the proton and the electron[20] are associated with the above-mentioned omnipresent *radio hiss* we get from outer space, also known as the 21 cm hydrogen line.[21] Indeed, the wavelength of this radiation has been measured to be equal to about 21.1 cm. One can, therefore, calculate the energy of the photon that is emitted or absorbed when such *spin flip* occurs which, in turn, must be equal to the energy *difference* between the states associated with parallel and opposite spin respectively.

The magnetic moment as discussed above is associated with the *orbital* angular momentum of the charge in the ring current model of an electron (and a proton). However, the ring current model also provides a *geometric* interpretation of *spin* angular momentum: it is associated with the spin of the orbiting charge itself which – as illustrated below[22] – must have some tiny but non-zero spatial dimension itself. To be precise, we think this charge has a *physical* dimension of the order of the fine-structure constant. It is, therefore, defined as a *fraction* of the (larger) ring current radius, which is the ring current radius $a_e = \hbar/m_e c \approx 0.386$ pm or $a_p = \hbar/m_p c \approx 0.841$ fm for the electron and proton respectively.



The *spin* angular momentum of the *electron* explains the spectral lines that are associated with the *fine* structure of the hydrogen spectrum, as illustrated below.[23]

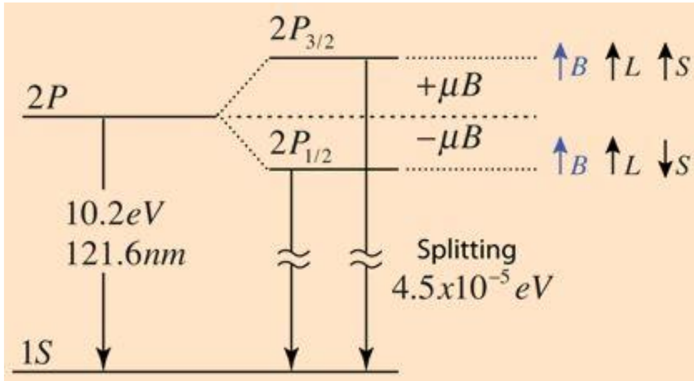
[19] The theoretical value of the magnetic moment of the proton differs by a $\sqrt{2}$ factor with the textbook value. We assume this has to do with precession. The $\sqrt{2}$ factor is not essential for our discussion here, so we are not so worried about it. However, the reader should be, and we are *very much* intrigued by it. Including the $\sqrt{2}$ factor, the ratio between the magnetic moment of the electron and the proton is close to 650. We wrote to Prof. Dr. Rudolf Pohl about it. He and his team established the 2010 precision measurement of the proton radius which inspired our proton model (after the measurement was confirmed by Jefferson Lab's PRad experiment). Prof. Pohl is also a member of the CODATA working group for fundamental constants, so he may know—even if the proton magnetic moment is *not* a fundamental constant: it is a *measured* value only. He may, therefore, not want to get involved.

[20] When combining the *up* or *down* spin of the electron with the *up* or *down* spin of the electron, one gets *four* possible states: ++, +–, –+ and ––. However, because emission and absorption of photons reflect energy *differences* between states, we get only two different spectral lines only, which are associated with parallel or opposite spin respectively.

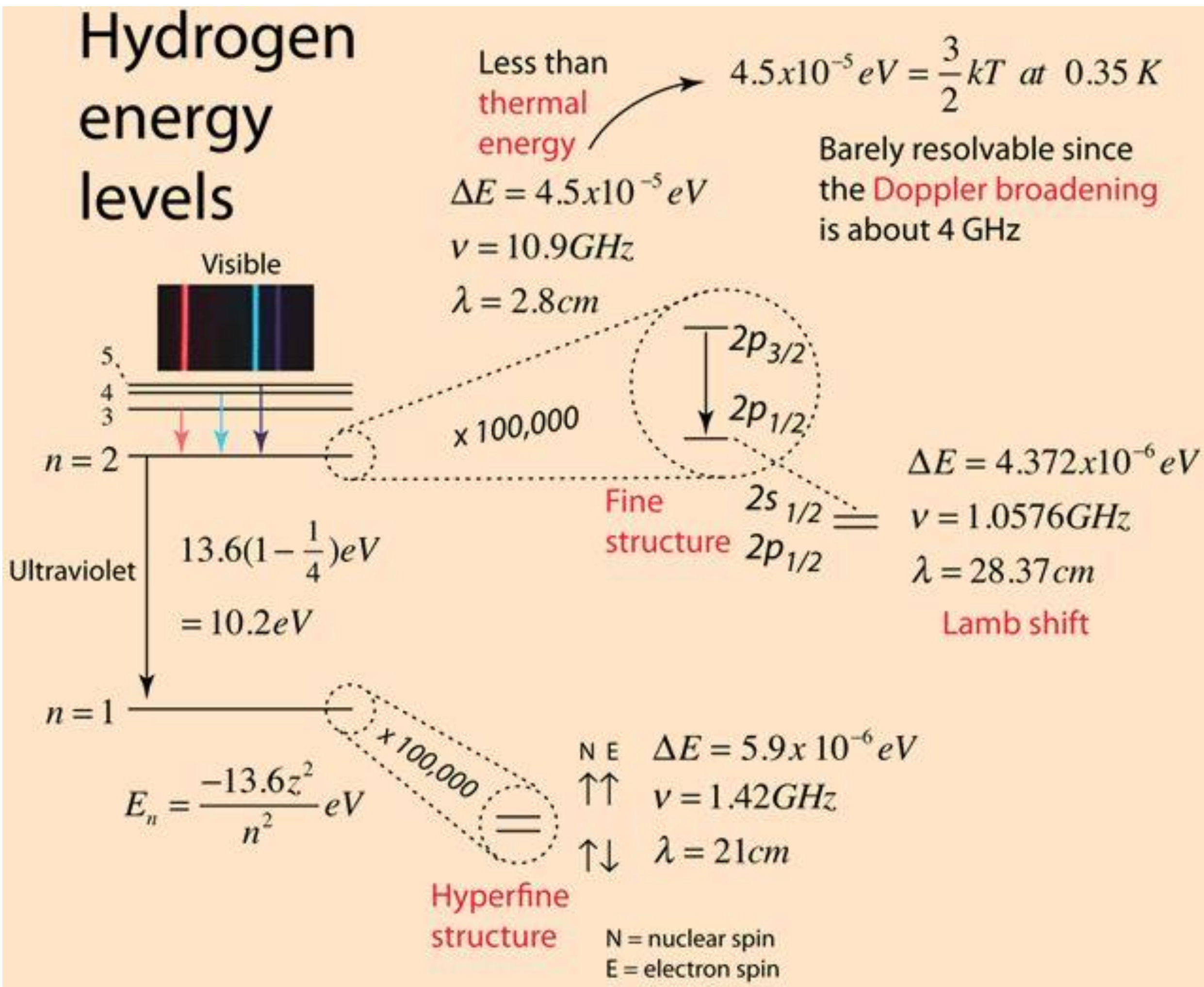
[21] The reader should not confuse this with the cosmic microwave background radiation, which is understood to be a remnant from the Big Bang.

[22] The $t = 2\hbar/m$ formula for the *cycle* time is the *clock speed* for the electron. We think the angular momentum of a proton is *four* times that of an electron, so the formula becomes $t = 4\cdot 2\hbar/m = 8\hbar/m$ for the proton. Note that the ratio of a radius of an electron and a proton is the same the ratio of their magnetic moments: about 460 to 1. This is *not* surprising, of course.

[23] Illustration from *Hyperphysics* (http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/hydfin.html).



Let us have a look at *all* of these different *types* of spectral splitting now. The *Hyperphysics* site brings all of them together in the following rather illuminating diagram.[24]



This diagram shows that the (in)famous *Lamb* shift is associated with the emission and/or absorption of

[24] See: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/h21.html.

photons with a wavelength of the same order of magnitude as the 21 cm line.[25] In fact, the ratio between the two energy differences is equal to 3/4, more or less, which is exact the same as the ratio of the energy difference between the n = *1* and n = *2* levels:

$$\frac{\Delta\mathrm{E}_{Lamb\ shift\ (n=2)}}{\Delta\mathrm{E}_{hyperfine\ (n=1)}} = \frac{h \cdot 1057.8576\ \mathrm{MHz}}{h \cdot 1420.452\ \mathrm{MHz}} \approx 0.74473 \ldots \approx \frac{3}{4} = \frac{\mathrm{E}_{n=2} - \mathrm{E}_{n=1}}{\mathrm{E}_{n=1}} = \frac{1}{1^2} - \frac{1}{2^2}$$

Of course, you will now ask: why is the ratio not *exactly* equal to 0.75? The 3/4 ratio is related to the *gross* structure of the hydrogen spectrum: we should take ratios between (electron) spin states that are comparable—both *down*, or both *up*. We will refine our calculations in the coming weeks[26] and we hope to be able to show the two ratios are *exactly* the same. We feel confident the 3/4 ratio is *not* a coincidence: the hyperfine structure at the n = 1 level and the Lamb shift at the n = 2 level must be the same!

Of course, you may have another objection: we have an energy difference in the denominator of the first ratio, but in the second ratio, the denominator is an energy level ($\mathrm{E}_{n=1}$). Yes, and no. The $\mathrm{E}_{n=1}$ level is also a difference between two energy levels: the energy of the proton without an electron (which is zero[27]), and the energy of the proton *with* an electron. We can, therefore, re-write the expression above as:

$$\frac{\Delta\mathrm{E}_{Lamb\ shift\ (n=2)}}{\Delta\mathrm{E}_{hyperfine\ (n=1)}} = \frac{h \cdot 1057.8576\ \mathrm{MHz}}{h \cdot 1420.452\ \mathrm{MHz}} \approx 0.74473 \ldots \approx \frac{3}{4} = \frac{\Delta\mathrm{E}_{1-2}}{\Delta\mathrm{E}_{0-1}} = \frac{\mathrm{E}_{n=1} - \mathrm{E}_{n=2}}{\mathrm{E}_{n=0} - \mathrm{E}_{n=1}} = \frac{1}{1^2} - \frac{1}{2^2}$$

Paraphrasing Maxwell when he found that light was nothing but an electromagnetic oscillation, we may say that, in light of this remarkable coincidence, **that the hyperfine structure at the *n* = 1 energy level and the Lamb shift at the *n* = 2 level must, essentially, be the same.**

Let us further explore this sentiment.

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[25] The Lamb shift is measured in terms of 10^{-6} eV. To be precise, the measurement for the difference in energy levels between the $^2S_{1/2}$ and $^2P_{1/2}$ orbitals is equal to 4.372×10^{-6} eV, which is associated with a wavelength of 28.37 cm. The mentioned 21.1 cm wavelength is – through the Planck-Einstein relation – associated with an energy equal to 5.9×10^{-6} eV. In contrast, the Zeeman effect or the energy difference between the *fine* lines of the spectrum is about 10 times larger. The same *Hyperphysics* site from which we took the numbers and illustration above (http://hyperphysics.phy-astr.gsu.edu/) gives an energy difference of 4.5×10^{-5} eV between the two (fine) lines for the 2*P* level. The same site also calculates an energy difference between lines split by the Zeeman effect equal to 5.79×10^{-5} eV. These calculations are quite tricky because they depend on the *strength of the magnetic field* that is being applied to create these splits. The 5.79×10^{-5} eV energy difference, for example, is calculated for a magnetic field of 1 T (*tesla*).

[26] The reader should note there are multiple high-precision measurements out there. Hence, our 1420.452 and 1057.8576 MHz values may also not be exact. In fact, we just quickly *googled* and took the first values we came across and, no, this time we are honestly not trying to kid you here! To be precise, we took the 1420.452 MHz value from https://cds.cern.ch/record/623614/files/0305205.pdf and the 1057.8576 value from https://arxiv.org/abs/hep-ph/9411356.

[27] The E = 0 reference point for calculating these *potential* energies assumes an infinite distance between the proton (or the nucleus, more generally speaking) and the electron(s). This explains the game with the signs: these energies are *negative*. In the first formula, we are dividing a negative number by a negative number, which explains why we can reverse the terms.

Was there a need for a new theory?

You tell me. I don't think so. In fact, I wonder why the theorists at the time felt there was such need. The first edition of Dirac's *Principles* was published in 1930, and it still serves as one of the better textbooks in quantum mechanics. So why would one want to invent a whole new theory instead of trying to fix *one single (wave) equation*? In fact, as mentioned above, the rather remarkable fact that an equation yields two different *states* with the same energy level should lead to a much more logical conclusion: Dirac's equation is more or less right but is, most probably, *not sophisticated enough*.

In fact, two *different* energy states with *exactly* the *same* energy? Now *that* is actually problematic, isn't it? There must be some *duplication* then somewhere, isn't it?[28] Dirac must have forgotten to incorporate some *anomaly* or some form factor relating to our mathematical idealizations. As such, we'd think Lamb's discovery should *validate* Dirac's intuitions, rather than *contradict* them, isn't it? The necessary correction that would need to be made looks rather obvious to us: when everything is said and done, we do not *really* believe electrons – or electric charge – are zero-dimensional objects, are they?

[…]

If *you* do, you should stop reading. Before you do, however, you should reflect on the fact that Dirac didn't quite believe that either, even if his theory is based on the usual assumption—which is that electrons are pointlike and, therefore, have no dimension whatsoever.[29] We think things that have no dimension whatsoever do not really *exist* or, at the very least, cannot carry charge. Once we accept this rather obvious *assumption*, all becomes perfectly explainable in terms of classical physics.

We will show why and how in the next sections but, before we continue, we should warn the professional or academic physicist: our tone or language is rather light—somewhat sarcastic at times, perhaps. This is not meant to offend anyone. We just thought that – in light of Dr. Consa's rather skeptical assessment of the *state* of current physics[30] – we might as well have some fun while exploring (the) matter—*literally*. We promise we will do our best to sound more serious in the next version of this paper.[31]

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[28] The academic physicist will probably object to our sarcastic or even caustic language but we thought that – in light of Dr. Consa's rather skeptical assessment of the *state* of current physics (https://vixra.org/abs/2002.0011) – we might as well have some fun with it.

[29] It is always worth quoting Dirac's summary of why an electron has the radius it has: "*The variables give rise to some rather unexpected phenomena concerning the motion of the electron. These have been fully worked out by Schrödinger. It is found that an electron which seems to us to be moving slowly, must actually have a very high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light. This is a prediction which cannot be directly verified by experiment, since the frequency of the oscillatory motion is so high and its amplitude is so small. But one must believe in this consequence of the theory, since other consequences of the theory which are inseparably bound up with this one, such as the law of scattering of light by an electron, are confirmed by experiment.*" (Paul A.M. Dirac, Theory of Electrons and Positrons, Nobel Lecture, December 12, 1933)

[30] Oliver Consa, *Something is rotten in the state of QED*, 1 February 2020 (https://vixra.org/ab0s/2002.0011).

[31] No guarantee here, though!

The four quantum numbers for electron orbitals

To make sense of whatever it is that we are trying to make sense of here, we should make sure we are on the same page in regard to notation and the basics of the ring current electron model that we are using here.[32] We already talked about notations. Let us be more precise on this now.

The $^2S_{1/2}$ and $^2P_{1/2}$ notation for the orbitals is the *term symbol* notation.[33] The numbers in the super- and subscript (2 and 1/2) and the *letter* symbol (S and P) correspond to the quantum numbers *S*, *L* and *J* respectively, like this:

$$^{2S+1}L_J$$

These symbols are a bit confusing, so let us try to clarify:

1. *S* is the spin quantum number: it is plus or minus 1/2 (*up* or *down*). It is the simplest of all quantum numbers but also the most confusing, because no one will ever tell you what it actually *is*.[34] The superscript in the $^2S_{1/2}$ and $^2P_{1/2}$ is, therefore, largely meaningless in this context: it basically denotes we have *two* states for each energy level: spin *up* versus spin *down*. In other words, it tells you we can have *two* electrons in these orbitals. As such, no value added here.

2. *L* is the (total) *orbital* quantum number. If it is zero, then the orbital is a *spherically symmetric solution* to Schrödinger's equation. If it is 1, 2,… , *n*, then it's a non-spherical solution. Physicists will often be vague about the unit for *S* (and rightly so, as we will explain later[35]) but for *L* you can be sure: it's expressed in units of $\hbar$, so that's the regular unit for angular momentum. This number is the most logical one because it is reflected in the Planck-Einstein law:

$$\mathrm{E} = n \cdot \hbar\omega = \frac{h}{2\pi} 2\pi f = h \cdot f \Leftrightarrow \frac{\mathrm{E}}{f} = \mathrm{E} \cdot \mathrm{T} = n \cdot h$$

Think of T as the *cycle time* – the time that is needed for one rotation of the elementary charge that generates the magnetic moment – or the *clock speed* of the particle that we are looking at here which, in this case, is an *atom* rather than an electron or a proton. The energy level is, therefore, just a *fraction* of the energy of the electron. To be precise, for *n* = 1, we get the *Rydberg* energy E_R. Indeed, combining the Planck-Einstein relation and the classical Bohr model of a hydrogen atom – which relates the Bohr

[32] We effectively assume our reader is familiar with the electron ring current model that we are constantly referring to in this paper. The basics of this model are very simple: an electron has a magnetic moment and we, therefore, assume the electron is a perpetual ring current. The current consists of an elementary charge spinning around at lightspeed. The radius of its motion is the Compton radius of an electron, which we directly derive from Einstein's mass-energy equivalence relation, the Planck-Einstein relation and the tangential velocity formula:

$$\left.\begin{array}{c} \left.\begin{array}{c} \mathrm{E} = \mathrm{m}c^2 \\ \mathrm{E} = \hbar\omega \end{array}\right\} \Rightarrow \mathrm{m}c^2 = \hbar\omega \\ c = a\omega \Leftrightarrow a = \dfrac{c}{\omega} \Leftrightarrow \omega = \dfrac{c}{a} \end{array}\right\} \Rightarrow \mathrm{m}a^2\omega^2 = \hbar\omega \Longrightarrow \mathrm{m}\frac{c^2}{\omega^2}\omega^2 = \hbar\frac{c}{a} \Leftrightarrow a = \frac{\hbar}{\mathrm{m}c}$$

For more detail, see: https://vixra.org/abs/2003.0094 or other previous publications (https://vixra.org/author/jean_louis_van_belle).

[33] At least, that's what the Wikipedia article from which we took the quotes is claiming. The 2*S* + 1 variable often seems to be substituted by the principal quantum number, which is the general energy level (*n*).

[34] For an explanation of spin, see my recent blog post: https://ideez.org/2020/03/22/whats-the-spin-of-spin-1-2-particles/.

[35] The *spin* angular momentum should also be expressed in units of $\hbar$ (preferably in units of $\hbar/2$, actually) but the contribution of the spin angular momentum is only a very tiny fraction of such units. In fact, all of the angular momentum of an electron comes from the orbital angular momentum of the charge inside, *which must include the angular momentum that we associate with the spin of the Zitterbewegung charge*.

and Compton radius through the fine-structure constant ($r_C = \alpha \cdot r_B$) and which associates a classical velocity $v = \alpha \cdot c$ with the motion of the electron[36] – we get:

$$h = \mathrm{E}_R \cdot \mathrm{T} = \mathrm{E}_R \cdot \frac{2\pi r_\mathrm{B}}{v} = \mathrm{E}_R \cdot \frac{\frac{h}{\alpha \mathrm{m}c}}{\alpha c} \Leftrightarrow \mathrm{E}_R = \alpha^2 \mathrm{m}c^2 = \frac{\mathrm{q_e}^4 \mathrm{m}}{8\varepsilon_0{}^2 \mathrm{h}^2} \approx 13.6\ \mathrm{eV}$$

L is also referred to as a *subshell* number. It is then related to a so-called *principal* quantum number which describes the *principal* energy level, which is usually denoted by *n*. The subshell number *l* will always be less than the number of energy states. To be precise, we can write: l = 0, 1, 2,… $n - 1$ for n = 1, 2, 3,… *n*, and the energy of the n^{th} level is equal to:

$$\mathrm{E}_n = -\frac{1}{n^2} \cdot \alpha^2 \mathrm{m}c^2 = -\frac{1}{n^2} \cdot \frac{\mathrm{q_e}^4 \mathrm{m}}{8\varepsilon_0{}^2 \mathrm{h}^2} \approx -\frac{1}{n^2} \cdot 13.6\ \mathrm{eV}$$

This simple formula can be derived straight from the Bohr model or – if one prefers a more sophisticated approach – from solving Schrödinger's equation.[37]

A quick remark: is an electron spin-1 or spin-1/2? The equations above suggest it's spin-1, right? Right. The spin-1/2 property is not an easy one to interpret. We've explained that elsewhere, so we will skip the question here.[38]

3. *J* is supposed to be the sum of both: $J = L + S$. Many authors use lower-case letters (*j*, *l* and *s*), which we also prefer because *L* denotes angular momentum *tout court* in classical physics. This is quite confusing because, in addition to this, physicists will usually also use *letters* rather than numbers for the *value* of *L*, and the first letter is an *s* or an *S*, to denote – you guessed it – *s*pherical states.[39] Hence, the same symbol *S* or *s* means two very different things depending on the context: (1) the spin number (*up* or *down*) and (2) the spherical solution to Schrödinger's (or Dirac's) equation, which corresponds to an $L = l = 0$ *energy state*. For the $^2S_{1/2}$ orbital, we get $J = 1/2$ because $L = 0$ and $S = +1/2$. We are, therefore, talking a spin-*up* electron.

In contrast, a *P*- or *p*-state corresponds to a *non*-spherical solution, so *L* is equal to $l = 1$ or – using letters – *p* or *P*. Hence, to get a *J* that is (also) equal to 1/2, the spin *S* must be down ($S = -1/2$) in order for the $J = L + S = 1 = 1/2$ to make sense ($1 - 1/2 = +1/2$).

[…]

Wait a minute here! Yes. You should stop me here: we shouldn't be distinguishing between spin up or spin down electrons here, should we? The Lamb shift does *not* refer to that, does it? It doesn't measure the energy difference between a spin-*up* and a spin-*down* state of an electron, does it? You are right. It's

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[36] See Chapter VII of our manuscript (https://vixra.org/abs/1901.0105)

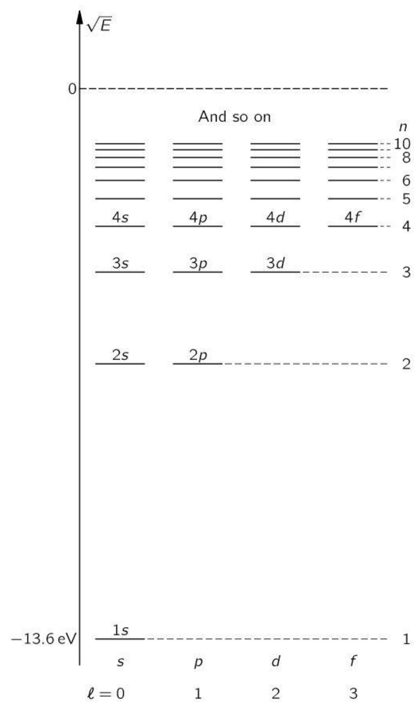
[37] See formula 19.51 in Feynman's *Lecture* on the hydrogen atom (https://www.feynmanlectures.caltech.edu/III_19.html). Note that we added the *minus* sign to account for the fact that we are measuring the (potential) energy with reference to an infinite distance from the nucleus. We should have added the minus sign in the formula for the Rydberg energy as well but we did not want to confuse the reader too much there.

[38] We deal with the question here: https://ideez.org/2020/03/22/whats-the-spin-of-spin-1-2-particles/.

[39] See the footnote above on the history – according to Feynman, at least! – of the meaning of these letters. The *S* apparently means *sharp* rather than *spherical!* And *p* means principal, which is a term which is now reserved for *n!* All quite confusing, but things are much more obvious now than they were, say, 50 years ago!

got nothing to do with the electron: we think the Lamb shift results from the two possible directions of the proton spin!

Now that we are here, you should also note something else. If $l = 1$, then the principal quantum number must be equal to $n = 2$ and the energy level must be *one fourth* of the Rydberg energy. To make sure we're on the same page, I copied the illustration from Feynman's *Lectures* once more below: the Lamb shift is a tiny difference between the 2*s* and 2*p* subshells, and then between the 3*s*, 3*p* and 3*d* subshells, of course, etcetera.[40]



This is an important point: the Lamb shift is a tiny difference between the *excited* state of the *s*-orbital and the *p*-orbital[41], or between the *excited* state of a 2*p*-orbital (which is the 3*p*-orbital) and the 3*d*-orbital, so that fixes the 1/4 problem.[42] Don't trust Wikipedia to bring *too* much clarity here! 😊

4. Finally, we have a fourth quantum number, but that's one that's *not* reflected in this so-called *term* symbol notation[43]: the ***magnetic* quantum number** *m* or m_z. We will come back to that in the next section.

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[40] See Figure 19-7 of Feynman's *Lecture* on the hydrogen atom (https://www.feynmanlectures.caltech.edu/III_19.html). We still thank the editors of the *online* version of Feynman's *Lectures* despite their complaints we make too liberal use of it. We wonder why they make such a fuss! See: https://readingfeynman.org/2020/02/20/physics-feynman-and-copyright/.

[41] For a short but good overview of how the Lamb shift is actually being measured, and how it compares to the fine and hyperfine structure, we refer the reader to the *Hypherphysics* page on it (http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/lamb.html#c2), which we found much more readable than the Wikipedia article.

[42] Note the use of the square root (√E) in Feynman's graph. It is just a bit of a logarithmic scale to ensure better visualization.

[43] The reference to a term is apparently based on the Rydberg–Ritz combination principle, which tells us that the *difference* in energy between the various orbitals should be equal to the difference of the following two *terms*:

$$\Delta \mathrm{E} = \left(\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right) \cdot \mathrm{E}_R$$

The point is this: this very short introduction to the quantum numbers describing electron orbitals is incomplete but should be sufficient for you to understand that one shouldn't be surprised that the $^2S_{1/2}$ and $^2P_{1/2}$ energy states are *different*. **Instead of being surprised about a difference, *we should wonder why these two energy states are so nearly together!***

Our tentative answer is this: they differ in the spin of the proton. That sounds very revolutionary, of course, but we think we will be able to demonstrate that convincingly by relating the above-mentioned quantum numbers to our ring current model.

The four quantum numbers and the ring current model of an electron

Any realist electron model must explain the properties of an electron as used in mainstream quantum physics, including its mass, radius, magnetic moment – and the anomaly in them, of course. Indeed, in a *realist* interpretation of quantum mechanics, these properties are not to be considered as mysterious intrinsic properties of a pointlike electron: the model should generate them. We think we have done that rather convincingly in previous papers.[44]

The challenge here is different: we here need to relate the model to the four quantum numbers that define electron orbitals. How can we do that?

In order to facilitate the discussion (common language facilitates communication), we prefer to stick somewhat closer to the basics as presented in Feynman's derivation of the structure of the elementary atom (^1H) based on Schrödinger's equation[45]:

1. We have discrete energy states or energy levels, and the principal quantum number (n) refers to the energy of the nth energy level. It is used in the formula for the allowed energy levels, which is equal to $E_n = -E_R/n^2$ (E_R is the Rydberg energy).[46] It is often conveniently referred to as a shell[47]. The principal quantum number is always a simple natural number: n = 1, 2, 3, etc.

When discussing a free electron – which has one energy state only – there is no need for this number.[48] However, in the context of electron orbitals, it is a very essential number. One should note that an electron may move from one spherical state to another: the higher energy states are referred to as excited states and the electron will emit or absorb a photon when moving from one energy state to the other.

This, however, only concerns the *main* spectral lines which derive from the *principal* quantum number n, which gives us the n^{th} energy level: $E_n = -E_R/n^2$. From this, the reader can easily derive the formula above.

[44] See the references above.

[45] See: Feynman's *Lectures on Physics*, Vol. III, Chapter 19. The reader should note we will also use Feynman's notation (n, l, and m_z). As mentioned, the use of s for the spin quantum number is somewhat confusing because s is also used to refer to the *s*pherical solution(s) to Schrödinger's equation.

[46] Note that the energy is negative and *lowest* for n = 1. The energy concept used is the potential energy, and we assume the electron has zero (potential) energy when it is *not* in an electron orbital.

[47] See: https://en.wikipedia.org/wiki/Quantum_number#Magnetic_quantum_number.

[48] Its energy (potential and kinetic) depends on the reference frame, obviously, but we are not concerned with other reference frames now.

It is very important to note the Lamb shift compares excited and non-excited electron orbitals! Once again, the question is not so much: what is the difference between these energies, but *what makes them so nearly equal?*

2. The orbital angular momentum (l) is expressed in units of $\hbar$. It may also be zero. In fact, $l = 0$ is associated with spherically symmetric solutions: these states have no angular dependence.[49] They are referred to as an *s*-state – *s* for *s*pherical. As mentioned above, this injects some unnecessary confusion because the same symbol is used for the much more general concept of *s*pin. We will, effectively, also use it to designate the spin of the *Zitterbewegung* charge in our electron model.

The non-spherical solutions for Schrödinger's equation are associated with proper multiples of $\hbar$. If $l = 1$, for example, then we have a number of *p*-states, which are defined by the magnetic quantum number (m_z) as a function of l (see the next section). For $l = 2$, we have *d*-states. When $l = 3, 4, 5,\ldots$ we get *f*, *g*, *h*,… states.[50]

The orbital angular momentum of an electron in an electron orbital should be distinguished from the orbital angular momentum as discussed in the context of an electron model (ring current, *Zitterbewegung*, or Kerr-Newman). We, therefore, find the oft-used term *subshell* for this number very convenient.

The subshell number l will always be less than the number of energy states. To be precise, we can write: $l = 0, 1, 2,\ldots n - 1$. Hence, if we have one energy state only, then we have only state: $l = 0$. Hence, this number is also *not* very relevant in the context of a free electron. However, the concept of angular momentum is very relevant as part of the discussions on the anomalous magnetic moment, of course![51]

We urge the reader to think about the units here once more: the angular momentum of a free electron is expressed in *full* units of $\hbar$, not in *half* units.[52]

3. The magnetic quantum number (m_z) corresponds to the orientation of the shape of the subshell. It is defined by the following formula:

$$-l \leq m_z \leq +l$$

The magnetic quantum number is related to the weird 720-degree symmetry of the wavefunction which, in turn, results from mainstream academics not using the *plus* or *minus* sign of the imaginary unit to distinguish between the *direction* of spin. We are tempted to write a bit more about this – we actually promised to do so in the previous section – but we will feel it will likely confuse the reader even more, so we refer to our previous writings on that[53] and note we don't really need the concept in the context of this discussion (a *physical* explanation of the Lamb shift). The bottom line is this: in our

[49] Feynman solves Schrödinger's equation using polar (spherical) coordinates. Hence, the coordinates are expressed in terms of the distance from the proton (r), a polar angle (θ) and an azimuthal angle (φ). The spherical symmetric solutions only depend on the distance from the proton (r).

[50] Feynman's dictionary of quantum numbers (III-19-3, Table 19-1) is very useful.

[51] For our classical explanation of the anomalous magnetic moment, which is not an anomaly at all, see: https://vixra.org/abs/2003.0094.

[52] The reader will ask the obvious question here: the electron is a spin-1/2 particle, right? Yes, and no. We refer the reader to our explanation of the *meaning* of the concept of spin (https://ideez.org/2020/03/22/whats-the-spin-of-spin-1-2-particles/).

[53] See: *Euler's wavefunction and the double-life of –1*, 30 October 2018 (https://vixra.org/abs/1810.0339).

physical interpretation of the electron as a ring current, we only have use for the concepts of *orbital* and *spin* angular momentum. As a result, the *principal*, *orbital*, *magnetic* and *spin* numbers may be summarized in two quantum numbers only: one that has to do with the *orbital* angular momentum around the center of the electron and one that has got to do with the *spin* of the *Zitterbewegung* charge around its own axis.

4. The fourth and last quantum number is usually that what is referred to as the spin *tout court*. It explains why we can have two electrons in any configuration—say, the $2p^6$ configuration for the neon atom. It also explains the finer structure of the hydrogen spectral lines.

The term 'spin' is a very simple but, at the same time, also a very confusing term because so many things are spinning here. Indeed, besides the electron that is spinning inside an atom, and the pointlike *Zitterbewegung* charge that is spinning inside the electron, we will now also want to think of the *Zitterbewegung* charge spinning around its own axis.

In how many directions can it spin around its own axis? Quantum-mechanics tells us that, here also, the spin will be either *up* or *down* and, in light of the geometry of the situation, we will, of course, also want to define the up or down here in terms of the orientation of the plane of the ring current.

The electron (and the proton) as a four-state system

If we assume the *zbw* charge has spin of its own – which it probably should have in light of the above-mentioned quantum number logic – then we can think of the magnetic moment of an electron consisting of the addition of the magnetic moment generated by the spinning *zbw* charge and the magnetic moment generated by the ring current.[54] The next question, then is, this: how should we *add* the two numbers? Following considerations may be relevant here:

1. The spin around its own axis has a different symmetry axis and the formula for the angular mass of a sphere or spherical shell involves different form factors than the disk-like structure that we associate with the electron as a whole: instead of $I = (1/2)\cdot m\cdot r^2$, we should use the $I = (3/5)\cdot m\cdot r^2$ or $I = (2/3)\cdot m\cdot r^2$ formulas.

2. Apart from deciding on a form factor, we should also decide on this: what is *r* here? What is the *radius* of the *Zitterbewegung* charge that we think is *zittering* around at lightspeed? The *anomaly* of the magnetic moment of an electron suggests *r* is of the order of the classical electron radius, so that's a *fraction* (of the order of the fine-structure constant α, to be precise) of its *Compton* radius.

However, we noted this radius is a rather strange thing: the anomaly for the muon is about the same and, hence, the size of this *zbw* charge seems to be in the same relation with the (Compton) radius of a muon: *it shrinks along with it*.[55] Hence, we should probably *not* think of the *zbw* charge as some immutable *hard core* charge. Perhaps we should think in terms of some fractal structure here.

[54] Wikipedia offers a confusing but – as far as we can see – also quite consistent explanation for the addition of spin and orbital angular momenta. See: https://en.wikipedia.org/wiki/Vector_model_of_the_atom.

[55] The anomalous magnetic moment of the muon is about the same when expressed as a *ratio* between the measurement and the theoretical value. Hence, our calculations of the size of the *zbw* charge are also *relative*. They must be, because the classical electron radius is actually *larger* than the radius of the muon.

[…]

After reading the two points above, you should conclude this: we don't know much, do we? So what *can* we say then?

3. I think one conclusion – or *hypothesis*, I should say – should be fairly easy to agree with: the contribution of the *spin* angular momentum to the magnetic moment of the electron must be *very* small. Why? The radius of the *zbw* charge is much smaller, and the *spin* velocity can (also) not exceed the speed of light, can it? In short, the contribution of spin to the measured magnetic moment of the electron will only be of the same order as the ratio between the classical electron radius and the Compton radius, which is equal to $\alpha \approx 0.0073$, which is less than 1%. We will denote the magnetic moment resulting from the *orbital* angular momentum as $\boldsymbol{l}_e$ (we hope this is not too confusing as a notation[56]), and the magnetic moment resulting from the *spin* angular momentum as $\boldsymbol{s}_e$, then we get the following matrix[57]:

***zbw* spin vs. ring current**	**clockwise (up)[58]**	**counterclockwise (down)**
up	$\boldsymbol{l}_e + \boldsymbol{s}_e \approx \boldsymbol{l}_e$	$-\boldsymbol{l}_e + \boldsymbol{s}_e \approx -\boldsymbol{l}_e$
down	$\boldsymbol{l}_e - \boldsymbol{s}_e \approx \boldsymbol{l}_e$	$-\boldsymbol{l}_e - \boldsymbol{s}_e \approx -\boldsymbol{l}_e$

Note that we assume that $\boldsymbol{s}_e$ will be a (small) fraction of $\boldsymbol{l}_e$, which we may write as $\boldsymbol{s}_e = \varepsilon \boldsymbol{l}_e$. This shows that the magnetic moment of an electron in a magnetic field may take any of *four* values—two of which would be centered around $\boldsymbol{l}_e$, and two of which would be centered around $-\boldsymbol{l}_e$. The $\boldsymbol{l}_e$ and $-\boldsymbol{l}_e$ values correspond to the main *up* or *down* states of the electron. However, a finer measurement would, perhaps, reveal a very fine *split* of these two main states. As such, we should think of the orbital electron as a four-state system rather than a two-state system.

4. The angular momentum of the electron can then, of course, *couple* with the angular momentum of the proton, which must also – upon detailed examination – come in *four* rather than two *states*. Hence, we can use the same table but, because a proton is much more massive and also because its angular momentum may or may not be different[59], the *spin* angular momentum may or may not be a *different* fraction of the orbital or total angular momentum. If we denote it by χ, we may write $\boldsymbol{s}_p = \chi \boldsymbol{l}_p$. We get the following matrix:

[56] We previously reserved the *l* and *s* symbols for the *orbital* and *spin* angular momentum. Hence, it is not very logical to now use them for the magnetic moment, although the magnetic moment is – of course – related to it through the g-factor. However, we did not want to multiply the number of symbols as there are quite a lot already.

[57] Wikipedia offers a confusing but – as far as we can see – also quite consistent explanation for the addition of spin and orbital angular momenta. See: https://en.wikipedia.org/wiki/Vector_model_of_the_atom. We, therefore, think we can also add the vectors that are associated with the magnetic moments, but we

[58] What is clockwise or counterclockwise depends on your reference frame, but that is the same for defining up or down. If we look from the opposite direction, both up and down as well as clockwise as well counterclockwise will swap their definition. Hence, the reference frame doesn't matter here. The same reasoning applies to the definition of what's up or down in regard to the plane of the circulation of the *zbw* charge.

[59] For our proton model, we refer to one of our recent papers (https://vixra.org/abs/2003.0144).

zbw spin vs. ring current	clockwise (up)[60]	counterclockwise (down)
up	$\boldsymbol{l}_{\mathbf{p}} + \boldsymbol{s}_{\mathbf{p}} \approx \boldsymbol{l}_{\mathbf{p}}$	$-\boldsymbol{l}_{\mathbf{p}} + \boldsymbol{s}_{\mathbf{p}} \approx -\boldsymbol{l}_{\mathbf{p}}$
down	$\boldsymbol{l}_{\mathbf{p}} - \boldsymbol{s}_{\mathbf{p}} \approx \boldsymbol{l}_{\mathbf{p}}$	$-\boldsymbol{l}_{\mathbf{p}} - \boldsymbol{s}_{\mathbf{e}} \approx -\boldsymbol{l}_{\mathbf{p}}$

The magnetic moment of a proton is *much* smaller than that of an electron: the magnetic moment of an electron is of the order of -9.28×10^{-26} J/T, while the magnetic moment of a proton is of the order of 1.41×10^{-24} J/T. To be precise, the magnetic moment of an electron is about 658 times larger than that of a proton.[61]

Combining the four possible values for the electron with the four possible values for the electron, we get $4 \times 4 = 16$ different values centered around $2 \times 2 = 4$ *main* values ($\pm \boldsymbol{l}_{\mathbf{e}} \pm \boldsymbol{l}_{\mathbf{p}}$) which, in turn, are centered around $+\boldsymbol{l}_{\mathbf{e}}$ and $-\boldsymbol{l}_{\mathbf{e}}$ because of the relatively large value of the magnetic moment of the electron as compared to that of the proton. We think these 16 values should offer sufficient *degrees of freedom*[62] to analyze whatever fine, finer or finest structure we get from experiments analyzing the full width and depth of the hydrogen spectrum. We, therefore, see no need to think of "interactions between vacuum energy fluctuations", "one-, two- or n^{th} loop effects", influences of "virtual photons", "zero-point oscillations" or whatever other metaphysical concepts that have been invented since World War II.[63]

5. In fact, it is total *overkill*, isn't it? We do not need 16 values: *four*, in some combination with the sub-shell number, will do. That's easy enough: *because the magnetic moment of a proton is so small in comparison with that of an electron, there may be no need to distinguish between the proton's orbital and spin angular momentum!* Hence, we may reduce the *four* spin states of the proton to *two* only—for practical (read: *measurement*) purposes, and that solves the matter then!

[60] What is clockwise or counterclockwise depends on your reference frame, but that is the same for defining up or down. If we look from the opposite direction, both up and down as well as clockwise as well counterclockwise will swap their definition. Hence, the reference frame doesn't matter here. The same reasoning applies to the definition of what's up or down in regard to the plane of the circulation of the *zbw* charge.
[61] We use the CODATA values for the calculation here.
[62] We have not less than 4×4 combinations here but the so-called selection rules (see: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/hydazi.html#c3) probably imply some combinations are not possible. Because of lack of time (we are not academics so we do have another day job), we have not managed to refine our research here.
[63] A fellow amateur physicist refers to mainstream physics as "cargo-cult science". We must admit we think that expression reflects the current situation rather well—with the emphasis on *cargo* and on *cult*, of course! The funny thing is that it is a term which was, apparently, coined by Richard Feynman himself! See: http://calteches.library.caltech.edu/51/2/CargoCult.htm.

How to test the ring current electron model?

The reader may have hoped that we would already have done all of the necessary calculations to definitely *prove* the point(s) that we have made above. However, as amateur physicists we are not in a position to do what would amount to full-blown PhD research—and it would probably require a team rather than a single individual relating everything to everything. We are confident such calculations are possible and will look out for research in this regard. In fact, we obviously hope that someone will beat us in this regard.[64]

There is also, of course, an obvious *experiment* which could test the hypothesis—and the ring current model of an electron as a whole. Indeed, it is now assumed that an electron – when doing a Stern-Gerlach experiment – should appear to be in two states: its magnetic moment will be either *up* (+1) or *down* (–1). However, a finer measurement should reveal a secondary *split* of these two states because of the *spin* angular momentum. We am not aware of any measurements having been made here, but that should not surprise us: ***actual Stern-Gerlach experiments are never done with electrons*.**

What? Yes. This is an inconvenient truth which most amateur physicists are blissfully unaware of: while a lot of quantum theory hinges on the assumption that an electron has *two* spin states only (*up* versus *down*), *actual* Stern-Gerlach experiments are always done with electrically neutral particles, such as potassium atoms[65] or, in the original experiment, silver atoms. Why? Because any electric charge in the magnetic field in the Stern-Gerlach apparatus would be subject to a Lorentz force which would be much larger than the force resulting from the magnetic moment.

In light of the importance of the assumption that electrons have two spin states – *up* or *down* – we find this simple fact actually rather shocking. The obvious question here is: is there *no one* trying to work around that?

The answer is: yes. *Some* people are really *trying* to do something here. H. Batelaan, T. J. Gay, and J. J. Schwendiman, for example, wrote a rather intriguing *letter* to the *Physical Review* journal in 1997, explaining in very much detail how the Stern-Gerlach experiment could be modified to also split an electron beam based on the magnetic moment being up or down.[66]

However, we are not aware of any follow-up to this, which we find very strange because the proposal of Batelaan, Gay and Schwendiman is based on a much older proposal of the French physicist Léon

[64] We thank one reader in particular – with a much stronger background in both physics as well as math than us – for sending us an encouraging message in this regard. While saying he had expected us to do the calculations, he also included some very classical calculations from a publication we were not aware of but which seems to be extremely promising: Dr. Randell Mills, *The Grand Unified Theory of Classical Physics* (https://brilliantlightpower.com/GUT/GUT-CP-2020-Ed-Volume1-Web.pdf). See pp. 152-153 in particular. These suggest we are on the right track with this. 😊

[65] See, for example, the MIT's lab experiment for students: http://web.mit.edu/8.13/www/JLExperiments/JLExp18.pdf.

[66] The proposition is based on the geometry of the so-called Penning trap, which keeps charged particles in place so as to accurately measure their magnetic moment. See: Physical Review Letters, H. Batelaan, T. J. Gay, and J. J. Schwendiman, *Stern-Gerlach Effect for Electron Beams*, Vol. 79, 8 Dec 1997, number 23 (https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1031&context=physicsgay).

Brillouin—a proposal which goes back to 1928![67] Hence, one would think this – rather than another US$600 m accelerator project – should be a top priority![68]

A good experiment here would probably decisively settle more than one ongoing discussion! Indeed, as far as we are concerned, this would be *a very testable prediction of the ring current electron model*: would or would we not get a finer splitting of the two main spots where the electron should hit the detector after going through the magnetic field of a (modified) Stern-Gerlach apparatus—one that *can* deal with the *electric* force on a charged particle?

We are willing to take a bet on this: we think there is such finer split. Why?

First, because of the Lamb shift itself—which is *real*, obviously. However, we don't believe it can be explained by "interaction between vacuum energy fluctuations". Why not? Because vacuums are vacuums. Hence, there's nothing to fluctuate, not in first loops and not in higher orders either!

Second, historical experience suggests the idea of elementary particles having some fractal structure is not a bad idea: the gross hydrogen spectrum hid a finer spectrum. The Lamb shift suggests we can go one level deeper.

Thirdly, because W.E. Lamb himself published a rather remarkable paper at rather old age – he was over 80 years old – in which he suggests a lot of mainstream theories, concepts and explanations are plain nonsense.[69] If W.E. Lamb had doubts about the concept of the photon *tout court*, he should surely have had a lot of doubts about the concept of *virtual* photons being constantly emitted and re-absorbed in some kind weird of *mediation* of the force keeping electrons in a bound state. We, therefore, think our simpler theory is better.

In fact, the actual *value* of the Lamb shift may be used to help solve the questions on the form factor and symmetry axis we started off with—very much in the same way as we used the *actual* value of the anomalous magnetic moment to infer the effective radius and velocity of the *zbw* charge.[70] Indeed, it should be clear from this paper that the Lamb shift and the anomaly in the magnetic moment and radius of an electron are just two aspects of one and the same reality.

Jean Louis Van Belle, 1 April 2020

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[67] Batelaan, Gay and Schwendiman include the following reference: L. Brillouin, Proc. Natl. Acad. Sci. U.S.A. 14, 755, 1928. We *googled* and a scanned copy is available here: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1085707/. We plan to study it carefully in the coming weeks/months. Though his name is much less well known, Brillouin was, without any doubt, a genius of the stature of Einstein. He studied with Arnold Sommerfeld and was, therefore, abreast of Sommerfeld's discovery of the fine-structure constant. He was also in touch with Albert Einstein, as evidenced by what is now referred to as the Einstein–Brillouin–Keller method for calculating the eigenvalues of a quantum-mechanical system.

[68] We mention the US$600m amount because it is an example in Dr. Consa's article ((https://vixra.org/ab0s/2002.0011).

[69] We thank Dr. Oliver Consa for alerting us to this article. The reference is this: W.E. Lamb, *Anti-photon*, Applied Physics B volume 60, pages77–84(1995). We found this open-access version: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.393.688&rep=rep1&type=pdf. The reader will find defensive papers *written by other authors* which carry the same title but actually downplay or understate the importance of this paper. The article posted on arxiv.org by Jacques Moret-Bailly is an example of such regretful practice.

[70] See our geometrical explanation of the anomaly in *An Explanation of the Electron and Its Wavefunction* (https://vixra.org/abs/2003.0094).