A light spin-0 particle solves puzzles in nuclear physics

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Abstract

A straightforward interpretation of the Feynman diagrams for the elementary particles of the standard model (SM) leads to the prediction of a light neutral spin-0 particle, which mediates a repulsive weak force between charged particles orbiting each other. Such a force acting between quarks may explain several unsolved problems in nuclear physics: proton and neutron magnetic moments that are higher than calculated; the so-called proton spin crisis, which implies that the proton's spin exceeds the sum of its theoretically and experimentally estimated components; and measurements of the proton's radius, which give conflicting results for ordinary and muonic hydrogen. Also, the force may play a key role in forming and maintaining the short-lived Hoyle state of carbon-12, which is a critical link in the chain through which stable carbon and other heavy elements are created in stars. Like the leptons and quarks, the proposed particle comes in three generations. In its lightest mass state of 12 μeV, it can be thought of as a massive, invisible "spinless photon" that may manifest its presence by triggering immediate decay of unstable atomic nuclei it happens to collide with. The predicted particle is pictured by the same Feynman diagrams that describe the heavy Higgs boson observed in CERN's Large Hadron Collider (LHC). For the latter particle, a mass of 125.62 GeV is conjectured.

Keywords: Pure QED; Dyson's argument; pure SM; spin-0 photon; light Higgs boson.

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Contents

1 The spin-0 particle of the Feynman diagrams

The term "principle of maximum simplicity" was coined by James Bjorken and Sidney Drell in 1965 [1] when they discussed the role of simplicity as a guiding rule in the development of quantum field theory (QFT).

The use of simplicity as a guiding principle has a long tradition in physics. The Ptolemaic cosmology relied on circles and spheres — maximally simple geometric objects. Isaac Newton's gravitational potential, $U = -Gm/r$, can hardly be simpler. Albert Einstein's theory of general relativity (GR) is founded on the equivalence principle, which is maximally simple because any conceivable alternative requires the introduction of at least one new physical parameter of unknown value.

In a hypothesis proposed by Kenneth Johnson, Marshal Baker, and Raymond Willey (JBW) in the early 1960s, the principle of maximum simplicity is applied to quantum electrodynamics (QED). In addition to disposing of a number of mathematical infinities, the "finite QED" or "pure QED" theory says that the bare mass of the electron is zero [2]. Thereby, it eliminates from QED a parameter of unknown value: the ratio of the electron's bare mass, m_0, to its physical mass, m. Thus, the JBW theory implies that the electron mass is of purely electromagnetic origin — dynamically generated by short-lived virtual photons surrounding the electron's massless center.

According to an argument presented by Freeman Dyson in 1951 [3], the power-series expansions used in QED are divergent. For this reason, it is often assumed that QED is internally inconsistent and cannot form a free-standing theory. Also, one may take "Dyson's argument" to mean that the JBW theory cannot hold true. However, there seems to exist an alternative power-series expansion of QED to which Dyson's argument does not apply [4]. This observation suggests that quantum electrodynamics may perfectly well constitute a self-consistent and finite, pure QED theory. Further, it suggests that the standard model, too, may form a self-consistent "pure SM" theory.

The interactions of the Higgs particle, H (which is a massive, weakly interacting spin-0 boson), and the photon, γ (which is a massless, electromagnetically interacting spin-1 boson), with the building blocks of ordinary matter (electrons and down and up quarks) are described by identical-looking Feynman diagrams [5]. Consequently, simplicity suggests that the weakly interacting Higgs may be looked upon as a kind of spinless massive photon, which generates "weak mass" in the same way as the electromagnetically interacting photon generates "electromagnetic mass".

Also, note that SM and its Feynman diagrams do not specify in how many mass states a particle may appear. Thus, it came as a surprise to physicists that the electron (that is, the electrically charged lepton) and the neutrino (the electrically neutral lepton) come in three weights. Likewise, the Feynman diagrams do not tell in how many mass states the neutral Higgs boson shows up.

Considering in parallel the second order mass contributions from the photon and Higgs to the electron (see Fig. 1),

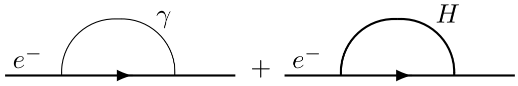

Figure 1: Photon and Higgs contributions to the electron mass.

one obtains from basic electroweak theory [6] the expression

$$m = m_0 + \delta m^{(2)}(\gamma) + \delta m^{(2)}(H) = m_0 + \frac{3\alpha}{2\pi}\left(\ln\frac{\Lambda}{m}\right)\left[1 + \frac{G_F m^2}{4\sqrt{2}\pi\alpha}\right] m, \tag{1}$$

for the renormalized mass m of the electron. In the expression, α is the fine-structure constant, G_F the Fermi coupling constant, and Λ a cut-off mass introduced to make the mathematics finite.

Ignoring other contributions to m, and relying on the fact that $m_0 = 0$ in pure QED, one immediately gets from Eq. (1) the ratio

$$\frac{\delta m^{(2)}(H)}{\delta m^{(2)}(\gamma)} = \frac{G_F m^2}{4\sqrt{2}\pi\alpha} \tag{2}$$

between the two contributions to the mass of the electron.

Since the Higgs–lepton diagrams exactly parallel the photon–lepton diagrams, one may expect that the ratio between the Higgs and photon contributions to the electron mass should remain the same as in Eq. (2) when higher-order self-mass diagrams are included in the calculations. That is, $\delta m(H)/\delta m(\gamma) = \delta m^{(2)}(H)/\delta m^{(2)}(\gamma)$ is expected to hold true.

Because Higgs and other corrections to the mass of the electron are small in comparison with the photon's contribution to it, one may set $\delta m(\gamma)$ equal to m, and obtain as a good approximation

$$\delta m(H) = \frac{G_F m^2}{4\sqrt{2}\pi\alpha} m. \tag{3}$$

Finally, resorting once again to the principle of maximum simplicity, one may conjecture that the mass of the Higgs particle itself equals its contribution to the electron mass; that is, m_H may replace $\delta m(H)$ in Eq. (3). (Note, however, that the relation $m_H = \delta m(H)$ was first suggested by a study of the muon–electron mass ratio [7].)

Using the values $1/\alpha = 137.035\ 999$ and (after restoring $\hbar$ and c, which are customarily set equal to 1) $G_F/(\hbar c)^3 = 1.166\ 36 \times 10^{-5}\ \mathrm{GeV}^{-2}$ [8, p. 1587], one obtains from Eq. (3) the relation

$$m_H = \frac{m^2}{11\ 118.8\ \mathrm{GeV}^2} m \tag{4}$$

between the mass m of the electron and the mass m_H of the light Higgs particle.

For the mass of a Higgs particle emitted by an ordinary electron (which possesses a mass of $m_e = 0.510\ 9989$ MeV) and the heavier muon ($m_\mu = 105.658\ 37$ MeV) and tauon ($m_\tau = 1777$ MeV), respectively, one obtains from Eq. (4)

$$\begin{aligned} m_{H_e} &= 12.0006\ \mu\mathrm{eV}, \\ m_{H_\mu} &= 106.085\ \mathrm{eV}, \\ m_{H_\tau} &= 0.505\ \mathrm{MeV}. \end{aligned} \tag{5}$$

The self-energy, 12.0006 μeV, of the electron-type Higgs corresponds to the energy of a photon of frequency 2.9017 GHz.

The Higgs particle is unstable, and in its light version it may annihilate into a pair of photons through a virtual charged-lepton loop (H_e via an e^+e^- pair, H_μ via a $\mu^+\mu^-$ pair, and H_τ via a $\tau^+\tau^-$ pair) or a down or up-quark loop (a $d\bar{d}$ or $u\bar{u}$ pair).

Direct evidence for the existence of a light Higgs boson comes from the E821 muon $(g-2)$ experiment at Brookhaven [9], which yielded the value [8, p. 1588]

$$a_\mu^{\mathrm{exp}} = 0.001\ 165\ 920\ 91(63) \tag{6}$$

for the muon's anomalous magnetic moment a_μ (equal to $g_\mu - 2$ divided by 2).

In the same manner as Eq. (2) is obtained from basic electroweak theory, one may derive the ratio

$$\frac{a_\mu(H)^{(2)}}{a_\mu(\gamma)^{(2)}} = \frac{3G_F m_\mu^2 \alpha}{4\sqrt{2}\pi}, \tag{7}$$

which holds if the particle (H_μ) appearing in the one-loop (second-order) Higgs correction to a_μ is considerably lighter than the muon. Using the known value, $a_\mu(\gamma)^{(2)} = \alpha/2\pi$, one obtains from Eq. (7) the second-order Higgs contribution,

$$a_\mu(H_\mu) = \frac{3G_F m_\mu^2}{8\sqrt{2}\pi^2} = 0.000\ 000\ 003\ 50 \quad (m_{H_\mu} \ll m_\mu), \tag{8}$$

to the value of a_μ.

Together with the rest of the standard model's theoretically estimated contributions to a_μ, 0.001 165 917 78(61) [9], the contribution from $a_\mu(H_\mu)$ in Eq. (8) gives

$$a_\mu^{\rm th} = 0.001\ 165\ 921\ 28(61) \tag{9}$$

for the theoretical a_μ value. The difference between the experimental and theoretical values is, with uncertainties added in quadrature, $-0.000\ 000\ 000\ 37(88)$, which indicates good agreement between the theoretically predicted and experimentally measured values.

The general expression for $a_\mu(H_\mu)$ [10] shows that its value is negligibly small if the Higgs particle H_μ is much heavier than the muon. In this case, the difference between the experimental and theoretical values is $+0.000\ 000\ 003\ 13(88)$, which indicates a mismatch between the two values. Consequently, the Brookhaven experiment convincingly demonstrates that the Higgs particle contributing to a_μ is lighter than the muon; that is, $m_{H_\mu} < m_\mu = 105.66$ MeV.

The anomalous magnetic moment of the electron, a_e, has been experimentally determined with a precision about 2000 times higher than that of a_μ. The value obtained is [11]

$$a_e^{\rm exp} = 0.001\ 159\ 652\ 180\ 73(28). \tag{10}$$

However, the H_e contribution to the electron anomalous moment,

$$a_e(H_e) = \frac{3G_F m_e^2}{8\sqrt{2}\pi^2} = 0.000\ 000\ 000\ 000\ 08 \quad (m_{H_e} \ll m_e), \tag{11}$$

is $(m_\mu/m_e)^2$, or about 40 000 times smaller than $a_\mu(H_\mu)$. Therefore, in spite of the high precision achieved in the electron $(g - 2)$ experiment, the result is not precise enough to provide any information about the value of m_{H_e}.

2 Manifestations in nuclear physics

A comparison between the Higgs and photon Feynman diagrams suggests that the Higgs-mediated force between two charged particles is repulsive, independent of the signs of the charges (whereas the photon-mediated electromagnetic force is attractive or repulsive depending on whether the charges are of opposite or equal sign, respectively).

The fact that no repulsive static force attributable to the Higgs has been observed means that the Higgs-mediated force is of purely dynamic nature, possibly resembling the photon-mediated magnetic force.

In nuclear physics, there are a number of puzzling observations, which might be explained by the existence of a very light Higgs particle that produces a force of sufficiently long range to affect the behavior of the constituent particles (the down and up quarks) of the nucleons.

2.1 The proton's missing spin

The proton's spin is the sum of the orbital and spin angular momenta of its constituent particles (quarks and gluons). However, experiments indicate a gap between the proton's spin angular momentum of $\frac{1}{2}\hbar$ and the sum of its component particles' theoretically estimated orbital angular momenta and observed spin angular momenta [12]. A Higgs force affecting the dynamics of the quarks might explain the discrepancy.

Asymptotic freedom implies that the strong force, which glues quarks together, vanishes for $r \ll r_p$, where r is the distance between the quarks and r_p the proton radius. Fig. 2 shows the quarks of the proton positioned on a common line with the down quark of fractional charge $-\frac{1}{3}e$ at the center.

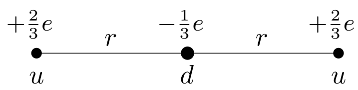

Figure 2: The proton's three quarks.

The electric force between one of the up quarks and the down quark in Fig. 2 is attractive and proportional to $-(+\frac{2}{3}e)(-\frac{1}{3}e)r^{-2} = +\frac{2}{9}e^2r^{-2}$, where e is the unit charge. The corresponding force between the two up quarks is repulsive and proportional to $-(+\frac{2}{3}e)^2(2r)^{-2} = -\frac{1}{9}e^2r^{-2}$. The positive sum, $+\frac{2}{9}e^2r^{-2} - \frac{1}{9}e^2r^{-2} = +\frac{1}{9}e^2r^{-2}$, implies that there is a net inward force acting on the quarks even when r is small and the strong force negligible. Consequently, the three quarks tend to stick closely together at the center of the proton, which means that their orbital angular momenta are small.

The situation changes radically if a repulsive Higgs force outweighs the attractive electromagnetic force and causes the quarks to move in orbits as wide as allowed by the strong force (which, like the force of a rubber band, increases with increasing r). Therefore, if virtual lightweight Higgs particles are present, the angular momenta of the quarks might be considerably larger than they would be if the Higgs particles are absent.

Consequently, the existence of light scalar Higgs bosons provides a simple explanation for the proton's missing-spin mystery within the framework of SM.

2.2 The nucleon's magnetic moment

The theoretically predicted values for the magnetic moments of the proton, neutron, and other hadrons tend to be considerably smaller than the experimentally observed values [13].

The same effect that explains the "proton spin crisis" — why the sum of the quarks' theoretically calculated spatial angular momenta, the experimentally determined quark spin angular momenta, and the estimated net glue polarization is less than the proton's spin — should explain why the magnetic moments of hadrons are larger than theoretical considerations suggest they should be.

2.3 The proton radius

Another problem in nuclear physics is that measurements of the proton radius using muonic hydrogen (where the electron that orbits the proton is replaced by a muon) and ordinary hydrogen yield nonmatching results: $r_p = 0.841\,84(67)$ fm and $0.8768(69)$ fm, respectively [14].

The straightforward explanation for the difference, 0.035(7) fm, is that the light muon-type Higgs, whose existence the Brookhaven muon $g-2$ experiment convincingly demonstrates (see Sec. 1), causes a repulsive force between the quarks of the proton and the muon orbiting it.

The “Bohr radius” of the hydrogen atom is $a_0 = 52\ 918$ fm, and of an the corresponding radius is smaller by a factor of m_μ/m_e. That is, $a = a_0/206.768 = 256$ fm for muonic hydrogen atoms.

For the repulsive force to be of sufficiently long range, the force-mediating gauge particle must be light. The maximum lifetime of a virtual particle is determined by the Heisenberg uncertainty relation $\Delta t \Delta E = \hbar$. Using the value for m_{H_μ} given in Eq. (5), one obtains a lifetime of $\Delta t = \hbar/m_{H_\mu}c^2 = 6.582 \times 10^{-16}$ eV s/106.086 eV $= 6.2 \times 10^{-18}$ s. The distance, which a particle with speed near c may travel in this time, should give an indication of the maximum reach of the force it mediates. For H_μ, it is $c\Delta t = 2.998 \times 10^8$ m s$^{-1} \times 6.2 \times 10^{-18}$ s $= 1.86$ nm, which is considerably larger than the radius a of the atom of muonic hydrogen.

For the heaviest (H_τ) of the three light spinless particles, one similarly obtains $c\Delta t = 390$ fm, which means that the force it mediates is of sufficient reach for it to play a crucial role in atomic nuclei (compare with the value 0.8768(69) fm of the proton radius).

2.4 The Hoyle state

In a normal star — such as the sun — four hydrogen nuclei, ${}^1_1$H, fuse into a helium nucleus, or alpha particle, ${}^4_2$He. When the star exhausts its hydrogen fuel, it expands to a red giant, in which two alpha particles combine to form an unstable ${}^8_4$Be isotope (the stable isotope of beryllium is ${}^9_4$Be). Fusion of a ${}^8_4$Be and a ${}^4_2$He nucleus, in turn, produces a stable ${}^{12}_6$C nucleus.

Because of the short lifetimes of the various beryllium-8 states — about or below 10^{-16} s — a beryllium and a helium nucleus will in general not fuse directly into a ground-state carbon nucleus. Instead, creation of carbon in red giants proceeds through an intermediate, short-lived excited state of carbon-12 — the so-called Hoyle state.

A recently performed *ab initio* lattice calculation [15] of the ground and Hoyle states of carbon-12 shows that there is a bent-arm configuration associated with the Hoyle state, while a compact triangular configuration is associated with the ground state. See Fig. 3.

Figure 3: Compact triangular and bent-arm configurations of carbon-12.

Figure 3 suggests that a repulsive dynamic force of longer range than the attractive strong force may be active when the three alpha particles rapidly (within beryllium-8’s lifetime of about or less than 10^{-16} s) form an elongated Hoyle state instead of a more compact state.

The strong force attempts to gather the alpha particles in a compact configuration. This process is counteracted by the repulsive electrostatic force between the positively charged alpha particles. However, the action of these two well-known, essentially static forces cannot explain the details of the Hoyle state, which is found to be of a highly dynamic nature; for instance, evidence is found for a “low-lying spin-2 excitation of the Hoyle state” [15].

Consequently, the assumption of an additional, dynamically generated repulsive force is needed to account for the properties of the Hoyle state.

3 'Spinless photon'-triggered radioactive decay

A number of observations indicate that the decay rates of various radionuclides exhibit seasonal variations [16, 17]. It has been suggested that the influence could arise from some flavor of solar neutrinos, or through objects called "neutrellos," which behave in some ways like neutrinos [18]. An obvious candidate for the neutrello particle is a light, massive 'spinless photon' described by the same Feynman diagrams that describe the heavy Higgs boson. Thus, the neutrello should be identical to the H_e particle of Eq. (4).

The neutrellos or 'spin-0 photons' (H_e) interact weakly with electrons in much the same manner as ordinary spin-1 photons interact electromagnetically with them.

There is, however, a significant difference between the "Higgs photon" and an ordinary photon. A Higgs photon ejected by an electron strips the electron of a small part of its mass, while a captured H_e adds the same amount of mass to the electron. Therefore, since the electron's mass is a conserved quantity, real electrons cannot absorb Higgs radiation permanently, only delay and refract it. Since the same observation should apply to quarks, it means that the neutrello is a kind of invisible photon that is conserved in its interactions with stable matter in the earth.

Consequently, to the neutrello, the earth is like a giant, perfectly transparent glass ball with density increasing toward its center.

In the same way as fast neutrons are slowed down in the moderator of a nuclear reactor, hot neutrellos are cooled through their elastic collisions with matter (quarks and electrons). As a result, the neutrello radiation trapped in the earth will tend to acquire an average temperature of somewhere between the upper crust's temperature of about 20 °C (equal to 293.15 K) and the conjectured 6000 K of the core of the earth.

An estimate using the results obtained for a heavy Higgs boson [19, p. 97] suggests that the lifetime of H_e is on the order of ten hours for a particle at rest, or

$$\tau_{H_e} \approx 10 \text{ h}. \tag{12}$$

The energy kT (where $k = 8.6173 \times 10^{-5}$ eV K^{-1} is the Boltzmann constant) that corresponds to room temperature (20 °C or $T = 293.15$ K) is 0.0253 eV. This energy is $0.0253/12 \times 10^{-6} =$ 21 000 times the particle's rest energy. Since its lifetime is prolonged by the same factor of 21 000, the H_e will most probably escape into space before it decays.

It is hypothesized that a neutrello that is scattered by a down quark in an unstable isotope may, if it carries the proper amount of energy, trigger the isotope's beta decay. Similarly, neutrello–electron scattering may cause electron capture ($p + e^- \to n + \nu_e$).

Neutrellos are created in the sun through the process $\nu_e\gamma \to \nu_e H_e$. Since the neutrello may decay into a pair of photons ($H_e \to \gamma\gamma$) via an e^+e^- pair, the process resembles the reaction $\nu_e\gamma \to \nu_e\gamma\gamma$, for which the cross section

$$\sigma(\nu_e\gamma \to \nu_e\gamma\gamma) = \frac{262}{127\ 575} \frac{G_F^2 a^2 \alpha^3}{\pi^4} \left(\frac{\omega}{m_e}\right)^8 \omega^2 \tag{13}$$

has been obtained [20]. In Eq. (13), ω is the photon energy and $a = 1 - \frac{1}{2}(1 - 4\sin^2\theta_W) \approx 0.95$. A similar — but simpler — calculation should yield the corresponding cross section for H_e production through neutrino collisions with photons.

Neutrinos created in the sun's core interact with photons everywhere within the sun and produce neutrellos of various energies. Part of the neutrellos radiating out into space from the sun's upper atmosphere will hit the earth and be trapped in it. (The sun's transparent atmosphere consists of the *chromosphere* about 10 000 km thick with temperature T rising from about 4000 K to about 50 000 K and the *corona* with T reaching about 2 million K at a height of some 75 000 km [21].)

Because of the low mass of the neutrello, its moderation is a comparatively slow process (see Appendix A). Therefore, the neutrellos that have achieved thermal equilibrium — along with those neutrellos that are being cooled — together form a broad, continuous energy spectrum. Consequently, they are potentially able to affect the decay rates of a large number of radionuclides.

At a certain depth in the earth's crust, the moderated neutrellos should arrive in equal numbers from all directions; that is, from a solid angle of $\Omega = 4\pi$ (measured in steradians) or 720°, which is the maximum solid angle. Here, their effect on decay rates should reach its maximum.

On the earth's surface, where $\Omega = 2\pi$ should hold (moderated neutrellos only coming from below), the effect is expected to be about half as large as deep in the crust. At heights (h) of 990 km and 3260 km above the ground, the corresponding solid angles are π and $\pi/2$, respectively, which implies that the corresponding increase in decay rate should be about one half and one fourth of the increase observed on the ground. See Fig. 4.

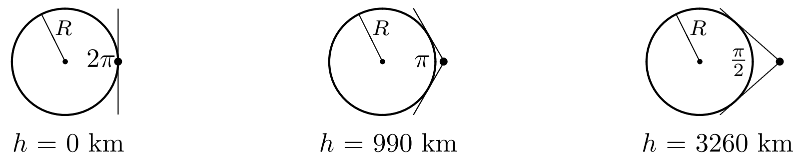

Figure 4: Earth seen from a height h above the ground.

Consequently, radioactive samples placed on board a satellite in a highly (or even moderately) elliptical orbit might exhibit the effect. Also, by lowering radioactive samples together with the required measurement equipment sufficiently deep into the ground, it might be possible to demonstrate the effect. If water a few kilometers of depth is sufficient to reflect an appreciable part of the neutrellos traversing it, an increased decay rate might also be observable in deep ocean trenches.

In the unlikely case where the spontaneous decay of a radioisotope is extremely rare and the observed decay events are caused entirely by collisions with solar neutrellos, there should be a 6.7% seasonal variation due to the 3.3% sun–earth distance variation between 147 million km in early July and some 152 million km in the beginning of January ((152 - 147)/150 = 1/30 = 0.033, or 3.3%).

4 The lithium problem

In the hot interior of stars, lithium is burned to helium through fusion with a proton (${}^{7}_{3}\mathrm{Li} + p \rightarrow {}^{8}_{4}\mathrm{Be}$ + 17.3 MeV) followed by fission of the resulting beryllium nucleus (${}^{8}_{4}\mathrm{Be} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He}$ + 92 keV). Proton–lithium fusion requires a temperature of approximately 2×10^{6} K, which is less than the 2.5×10^{6} K necessary for hydrogen fusion. Only protons possessing energies much higher than their average energy are able to overcome the Coulomb barrier and fuse with lithium nuclei.

With a lifetime of about 7×10^{-17} s, the beryllium-8 nucleus almost instantly splits into two helium nuclei (or alpha particles), each one carrying about 8.6 MeV of kinetic energy.

The amount of lithium-7 believed to have been created in the primordial nucleosynthesis matches the amount observed in the Small Magellanic Cloud [22].

However, in the atmospheres of old, so-called galactic halo stars, there is about one fourth as much lithium-7 as predicted [22].

A possible explanation for this mismatch between theory and observation is supplied by the lightweight Higgs particle or neutrello, which suggests a mechanism through which solar neutrinos may cause lithium depletion. That is, in a collision with a proton, a high-energy neutrello may heat the proton to a temperature that enables it to fuse with a lithium-7 nucleus.

An experiment performed in 1932 demonstrated that, for a proton to be able to overcome (or tunnel through) the Coulomb barrier and fuse with a lithium-7 nucleus, it requires an energy of about 0.1 MeV [23]. This energy is several hundred times higher than the energy $E = kT = 170$ eV corresponding to the temperature $T = 2 \times 10^6$ K. (The average kinetic energy of a *thermal neutron* [24] is $\frac{3}{2}kT$, its most probable kinetic energy is $\frac{1}{2}kT$, and its most probable speed $v = (2kT/m)^{1/2}$; that is, a thermal particle with kinetic energy $\frac{1}{2}mv^2 = kT$ moves with the most probable speed.)

Solar neutrinos created in boron decay, ${}^8_5\mathrm{B} \to {}^8_4\mathrm{Be}^* + e^+ + \nu_e$, acquire energies approaching 14 MeV [19, p. 452]. In the $\nu_e\gamma \to \nu_e H_e$ process, the neutrino may give over most of its energy to the neutrello it creates from a photon. For simplicity, assume that the neutrello gets an energy of 9.38 MeV, which is one percent of the proton's rest energy. According to Eq. (A.5), it means that $\Delta E/E = 0.02$. In other words, the proton may acquire two percent of the neutrello's energy, or 0.19 MeV, which is more than it needs to fuse with a lithium nucleus. It follows that a single neutrello with an initial energy about or above 10 MeV may heat dozens of protons to 0.1 MeV.

Some of the neutrellos created in the corona will immediately escape from the sun. Therefore, one may assume that a small part of the neutrellos that hit the surface of the earth are energetic enough to cause lithium burning. It should be a straightforward task to experimentally check the validity of this assumption.

Naturally occurring lithium contains 92.4% lithium-7 and 7.6% lithium-6. If lithium chloride (LiCl) is dissolved in water (H_2O), sooner or later a hydrogen-1 nucleus (that is, a proton) heated in a collision with a neutrello should fuse with a lithium-7 nucleus and transform it into a beryllium-8 nucleus, which within less than a femtosecond splits into two alpha particles moving away from each other at high speeds. The resulting "bright scintillation" [23] should be easily detected.

Naturally, lithium burning induced by solar neutrellos can only occur in the daytime. Consequently, if there are diurnal variations in the observed scintillation rate, it might indicate that part of the events are caused by neutrellos.

Because only newly created neutrellos may carry enough energy to cause lithium burning, they convey instant information about the rate of production of solar neutrinos. Therefore, if neutrello-induced proton–lithium fusion occurs frequently enough to be readily detected, it might provide a valuable tool for monitoring processes in the core of the sun.

5 Conjectured mass of the heavy Higgs boson

Equation (4), which yields the masses of the light Higgs particle, may contain a clue to the value of the mass of the heavy Higgs boson. For a hypothetical spin-$\frac{1}{2}$ particle lacking electromagnetic mass, the equation, when written

$$M_H = \frac{M^2}{11\ 118.8\ \mathrm{GeV}^2} M, \tag{14}$$

suggests that the Higgs mass (M_H) should equal the Higgs-generated mass (M) of the neutral particle. That is, $M = M_H = 105.45$ GeV should hold.

However, the standard model's neutral particle of purely weak origin is not a spin-$\frac{1}{2}$ fermion, but the spin-1 boson called Z or Z^0 with mass $M_Z = 91.19$ GeV. Also, the heavy Higgs mass has a value that differs from 105.45 GeV, since measurements at CERN shows it to be about 125 GeV.

Therefore, Eq. (14) cannot be applied as such to the spin-1 Z boson. Still, it is interesting that the mass $M = 105.45$ GeV obtained from the equation is of the right order of magnitude, and even seems to represent some kind of midpoint value between the masses $M_Z = 91.19$ GeV and $M_H \approx 125$ GeV. Assuming that there exists a simple relation between the three mass values, numerical considerations suggest that

$$M_H - M = \sqrt{2}(M - M_Z), \tag{15}$$

which yields $M_H = 125.62$ GeV for the the Higgs mass.

6 Conclusions

By applying the principle of maximum simplicity to the standard model, one arrives at a kind of "pure SM" based on the finite-QED or pure-QED hypothesis of Johnson, Baker, and Willey. A straightforward interpretation of the Feynman graphs further suggests that the mass-generating so-called Higgs mechanism, in addition to producing the weak masses of the Z and W bosons, gives small weak contributions to the electromagnetically generated masses of the electron and the heavier muon and tauon.

It appears that the existence of the light Higgs particle that generates the fermionic weak mass components can explain several observations in nuclear physics that would otherwise require introduction of some sort of "new physics" of unknown nature.

A Moderation of neutral particles

In his textbook on nuclear reactor physics [25], Raymond Murray states: "Elastic scattering of a neutron with a nucleus results in a discrete loss of neutron energy of an amount varying from zero to the maximum allowable by the laws of conservation of momentum and energy. The largest possible loss is now derived for the case of a target nucleus with mass A times as large as the neutron mass, which will be taken as m."

The maximum fractional loss is suffered by a neutron that reverses its direction, and is in the textbook found to be $4A/(1 + A)^2$, or $4/A = 4m/M$ for a nucleus of mass $M \gg m$ (or $A = M/m \gg 1$). That is,

$$\Delta T/T = 4m/M \quad (M \gg m), \tag{A.1}$$

where T is the kinetic energy of the neutron.

Eq. (A.1) applies as well to H_μ and H_τ, which, when moderated in the earth, move with non-relativistic velocities. However, it does not apply to the light H_e, which in practice moves with the velocity of light, c. For a free particle of mass m, the relation [6]

$$E^2 = (pc)^2 + (mc^2)^2 \tag{A.2}$$

connects the momentum p to its energy E. Conservation of momentum in the particle's head-on collision with a nucleus of mass M means that

$$p = -(p - \Delta p) + M(v - v_0) \tag{A.3}$$

holds true. For $m \ll M$ (compare with a light ping-pong ball hitting a heavy solid iron ball), the loss of momentum, Δp, of the light particle may be ignored. Thus, if the nucleus is at rest ($v_0 = 0$) initially, $(Mvc)^2 = (2pc)^2 = 4(E^2 - m^2c^4)$, and

$$\Delta E = \frac{1}{2}Mv^2 = 2(E^2 - m^2c^4)/Mc^2. \tag{A.4}$$

For a nonrelativistic particle ($v \ll c$), one obtains $E^2 = m^2c^4 + m^2c^2v^2$ from the generally valid relation $E^2 = m^2c^4(1 - v^2/c^2)^{-1}$. Insertion of E^2 in Eq. (A.4) gives $\Delta E = (4m/M) \times \frac{1}{2}mv^2$, and the fractional decrease in the particle's kinetic energy T (equal to $\frac{1}{2}mv^2$) becomes $\Delta T/T = 4m/M$ in agreement with Eq. (A.1).

For the massless photon, and for a light particle with energy $E \gg mc^2$, the relation $E = pc$ holds true. In this case, $p = -p + Mv$ gives $\Delta E = \frac{1}{2}(Mv)^2/M = 2p^2/M = 2E^2/Mc^2$, and

$$\Delta E/E = 2E/Mc^2. \tag{A.5}$$

Thus, assuming that the nucleus has a mass of 50 GeV (the hydrogen nucleus has a mass of $m_p = 938$ MeV ≈ 1 GeV), Eq. (A.1) gives for the fractional loss in kinetic energy of the H_τ and H_μ (which do not interact with the electrons of the atomic shell) $4 \times 0.505 \times 10^6/50 \times 10^9 = 4 \times 10^{-5}$ and $4 \times 106/50 \times 10^9 = 8.5 \times 10^{-9}$, respectively.

Similarly, Eq. (A.5) yields for the fractional loss in kinetic energy of electron-type Higgs particles of energy 0.025 eV (compare with $kT = 0.0253$ eV at room temperature) a maximum fractional energy loss of $\Delta E/E = 2 \times 0.025/50 \times 10^9 = 10^{-12}$. Vary rarely, the H_e should reverse its direction of motion. Therefore the temperature of a high-energy H_e should decrease at a rather slow rate. How fast its energy decreases depends on the mean free path of the particle.

References

[1] J. D. Bjorken and S. D. Drell, *Relativistic Quantum Fields* (McGraw-Hill, New York, 1965) pp. 94–96.

[2] K. Johnson, M. Baker, and R. Willey, *Phys. Rev.* **136** (1964) B1111.

[3] F. J. Dyson *Phys. Rev.* **85** (1952) 631.

[4] S. Sundman, *Nucl. Phys. B* **656** (2003) 344.

[5] M. Veltman, *Diagrammatica: The Path to Feynman Diagrams* (Cambridge University Press, 1994), pp. 270–271.

[6] J. D. Bjorken and S. D. Drell, *Relativistic Quantum Mechanics* (McGraw-Hill, New York, 1964).

[7] S. Sundman, *Int. J. Mod. Phys. E* **22** (2013) 1350002, [physicsideas.com/Article.pdf].

[8] CODATA recommended values of the physical constants: 2010, *Rev. Mod. Phys.* **84** (2012) 1527.

[9] M. Passera, W. J. Marciano, and A. Sirlin, *Phys. Rev. D* **78** (2008) 013009.

[10] T. Kinoshita and W. J. Marciano, in *Quantum Electrodynamics*, ed. T. Kinoshita (World Scientific, Singapore, 1990), p. 463.

[11] D. Hanneke, S. Fogwell, and G. Gabrielse, *Phys. Rev. Lett.* **100** (2008) 120801.

[12] J. T. Londergan, *Int. J. Mod. Phys. E* **18** (2009) 1135.

[13] W. Greiner, S. Schramm, and E. Stein, *Quantum Chromodynamics*, 2nd ed. (Springer, 2002), pp. 150–151.

[14] R. Pohl *et al.*, *Nature* **466** (2010) 213.

[15] E. Epelbaum *et al.*, *Phys. Rev. Lett.* **109** (2012) 252501.

[16] J. Jenkins *et al.*, *Astroparticle Physics* **37** (2012) 81.

[17] J. Jenkins, *Jere Jenkins's articles on arXiv*, arxiv.org/a/jenkins_j_1.atom.

[18] E. Fischbach, J.H. Jenkins, and P.H. Sturrock, arxiv.org/abs/1106.1470 (2011).

[19] P. D. B. Collins, A. D. Martin, and E. J. Squires, *Particle Physics and Cosmology* (John Wiley & Sons, 1989).

[20] D. A. Dicus and W. W. Repko, cds.cern.ch/record/321504/files/9703210.pdf (1997).

[21] *A Dictonary of Science*, 6th ed. (Oxford University Press, 2009).

[22] J. C. Howk, N. Lehner, B. D. Fields, and G. J. Matthews, *Nature* **489** (2012) 121.

[23] J. D. Cockcroft and E. T. S. Walton, *Nature* **129** (1932) 649.

[24] *The Penguin Dictionary of Physics*, 3rd ed. (Market House Books, 2000).

[25] R. L. Murray, *Nuclear Reactor Physics* (Macmillan, 1959).