A simple argument that small hydrogen may exist

J. Va’vra

SLAC, Stanford University, CA94309, U.S.A.
e-mail: jjv@slac.stanford.edu

Abstract – We present theoretical argument, based on virial theorem and De Broglie’s idea from 1924, why the small hydrogen may exist. It may have been created near black holes, large explosions in Universe, or, perhaps, during early stages of the Big Bang. Being neutral and stable, it could play a significant role in a formation of early galaxies. It would not be observable using usual optical spectroscopic methods. Although ideas in this paper are only speculation at present, the paper suggests two concrete experiments to test this idea: (a) a high energy physics experiment, and (b) a satellite search.

Key words: Small hydrogen atom, Deep Dirac Levels (DDL), optically invisible Universe.

1. Introduction

In 1920, Rutherford suggested that an electron and proton could be bound in a tight state [1]. He tasked his team, including Chadwick, with searching for this atom. Following Chadwick's discovery of the neutron in 1932, there was considerable debate about whether it was an elementary particle, or a hydrogen-like atom formed from an electron and a proton [2]. For instance, Heisenberg was among those who argued that Chadwick’s particle was a small hydrogen atom until 1933. Ultimately, Pauli’s argument prevailed: the neutron, with its spin of 1/2, follows Fermi-Dirac statistics, confirming it as an elementary particle. This is a well-established fact and is not the focus of this paper.

It must have been obvious to Schrödinger, Dirac and Heisenberg, that there is a peculiar solution to their equations. This solution, which corresponds to the small hydrogen, was at the end rejected [3] because the wave function is infinite at \( r = 0 \). Since nobody has observed it, the idea of the small hydrogen has died. However, its idea was revived again ~70-years later, where authors argued that the proton has a finite size, and that the electron experiences a different non-Coulomb potential at very small radius [4,5]. In fact, such non-Coulomb potentials, for example, Smith-Johnson or Nix potentials [6,7], are used in relativistic Hartree-Fock calculations for very heavy atoms where inner shell electrons are close to nucleus. Using this method, authors retained solutions for the small hydrogen which were previously rejected. However, in a follow up paper [8], it was recognized that considering such potentials does not satisfy virial theorem, and that one needs to add much stronger potential to hold the relativistic electron stable. Such potential could be the spin-orbit potential, which becomes very strong force at small distances.

Brodsky pointed out that one should not use the "1930 quantum mechanics" to solve the problem of the small hydrogen; instead, one should use the Salpeter-Bethe QED theory [9]. Spence and Vary attempted to find such electron-proton bound state using QED theory [10], which includes spin-spin, field retardation term and Coulomb potential, assuming the point-like proton. They suggested a possible existence of a bound state. Bethe and Salpeter presented a theory of the normal hydrogen atom using the Dirac equation [14]. However, they did not consider the small hydrogen.

There are two reasons why the small hydrogen idea was not investigated theoretically further: (a) nobody has found it experimentally, and (b) the correct relativistic QED theory is too complicated at small distances.

One hundred years ago, Louis De Broglie published his famous paper [11], which sparked the quantum mechanics revolution; this was before Schrödinger or Dirac equation existed, only the Bohr model was known to him. De Broglie model of normal hydrogen atom, shown in Fig.1, demonstrates that stable states occur only when the number of standing electron waves is an integer. We argue, similarly as De Broglie, that a stable "electron standing wave" in a small hydrogen atom can exist only for certain frequencies of the electron wave and that its radius is determined by the virial theorem and potential. Basic parameters of this model are shown in Table 1 for both normal and small hydrogen. Although De Broglie's model is based on old quantum mechanics, it provides a reasonable approximation for normal hydrogen, and we will assume it is also a good approximation for small hydrogen. The fact that De Broglie's model does not entirely explain the complexity of normal hydrogen is not crucial for this paper; the key argument is that it explains its stability.

Our approach is a potential-based calculation. Virial theorem is important for judging whether a bound system

---

1 Private communication with Prof. James Vary.
2 It provides approximate values of energy levels for normal hydrogen. For exact values one needs to use Dirac equation.
is stable. It can draw conclusions about the dynamics of bound states without solving differential equations. We propose to solve the problem using a simple model based on two basic physics principles: (a) Virial theorem, (b) De Broglie’s classical quantum mechanics principle stating that the only allowed atomic states are those with integral number of electron wavelengths on a given atomic orbit. These two assumptions are sufficient to judge stability of the normal hydrogen. We will assume De Broglie model is also a good approximation for small hydrogen. The fact that it does not entirely explain the complexity of normal hydrogen is not crucial for this paper; the key argument is that it explains its stability. These two assumptions are sufficient to judge stability of the normal hydrogen also.

![De Broglie model](image)

**Figure 1** Schematic picture of normal hydrogen. Only frequencies giving integral number of electron wavelengths are allowed in both cases.

### Table 1 – Basic parameters for ground level (n = 1) of normal and small hydrogen:

| Variable                  | Normal hydrogen | Small hydrogen |
|---------------------------|-----------------|----------------|
| n                         | 1               | 1              |
| Radius                    | 0.529 Å         | 2.8284 Fermi   |
| De Broglie wavelength     | 3.322 Å         | 17.762 Fermi   |
| De Broglie wave frequency | ~6.6x10^15 Hz   | ~1.68x10^15 Hz |
| Electron β = v/c          | ~7.3x10^7       | ~0.9999732     |

### 2. Solutions based on the virial theorem.

De Broglie, exactly 100 years ago, wrote a paper arguing that electron motion in an atom can only be stable if the phase wave is tuned with the length of the path, according to the line integral:

\[
\int \frac{ds}{\lambda} = n \tag{1}
\]

where \( \lambda \) is the electron wavelength, \( n \) is the number of periods, and \( ds \) denotes an element of the path of a wave moving from one crest to the next. In its simplest form, the De Broglie wavelength is constrained by the radius \( r \) through the equation:

\[
\lambda = n \ 2\pi \ r \tag{2}
\]

where \( n \) is an integer, defining an integral number of wavelengths in the circumference. This provides a reasonable description of normal hydrogen. We will use the same arguments for small hydrogen.

Previously, we have suggested a simple numerical iterative method, where we step through radius in small steps until virial theorem is satisfied [12]. The procedure to find a solution is as follows:

1. The electron’s De Broglie wavelength is constrained by radius \( r \) through the equation \( \lambda = n \ 2\pi \ r \) (where \( n \) is an integer defining the integral number of wavelengths in the circumference).
2. The electron momentum is determined from the De Broglie equation \( p = h/\lambda \) (from which we get the relativistic kinetic energy \( T_{kinetic} \), \( \beta \), and \( \gamma \)).
3. The stable electron radius is determined by numerically stepping through values of \( r \) until the virial theorem is satisfied, balancing electron relativistic kinetic energy and potential energy.

Ref.[12] demonstrated that three different methods can satisfy the virial theorem for small hydrogen:

- The electron kinetic energy must balance with the expected virial kinetic energy derived from the potential:

\[
T_{kinetic} = T_{virial} \tag{3}
\]

- Lucha showed that this equation must be satisfied [13]:

\[
<p \frac{\partial}{\partial \mathbf{p}} T_{kinetic}(\mathbf{p}) - r \frac{\partial}{\partial \mathbf{r}} U(r) > = 0. \tag{4a}\]

where \( p \) is the electron relativistic momentum, \( r \) is the electron radius, and \( U(r) \) is the total potential electron feels. Since we are dealing with a periodic motion, we can drop averaging over time, rewriting the equation (4a) as follows:

\[
(\mathbf{p}c)^2/\sqrt{(\mathbf{p}c)^2 + (mc^2)^2} - r \frac{\partial}{\partial \mathbf{r}} U = 0 \tag{4b}
\]

- One can also search for a minimum in the total electron energy \( E = T_{kinetic} + U \):

\[
dE/dr = d(T_{kinetic} - \text{Abs}(U))/dr = 0 \tag{5}
\]

In this paper we will use mainly the method according to equation (3), and use equations (4) only as a cross-check. The electron kinetic energy is calculated as follows:

\[
T_{kinetic} = \sqrt{(hc/\lambda)^2 + (mc^2)^2} - mc^2 \tag{6}
\]

where \( \lambda = (2\pi \ r/n) \) is the De Broglie wavelength for electron radius \( r \), and \( n \) is the number of wavelength periods.

Virial theorem states that for a general potential energy \( V(r) = a r^k \), the expected electron kinetic energy \( T_{virial} \) is related to potential energy as:

\[
T_{virial} = k [ \gamma/(\gamma + 1) ] U, \text{ where } \gamma = 1/\sqrt{1 - (v/c)^2} \tag{7}
\]
For example, for Coulomb potential \( (U_1 = -k/r) \), \( k = -1 \), and the kinetic virial energy is behaving as \( T_{\text{virial}} \to -(\frac{1}{2})U_1 \) as \( \gamma \to 1 \), and as \( T_{\text{virial}} \to U_1 \) as \( \gamma \to \infty \).

### 2.1 Virial theorem with Coulomb potential

Applying equation (3) to small hydrogen, one finds that the Coulomb potential \( V_{\text{Coulomb}} = -kZe^2/r \) alone cannot hold the electron in a stable deep orbit in small hydrogen, as illustrated in Fig.2, although normal hydrogen can have stable solution. This is also the case if we add the Smith-Johnson or Nix potentials, used in high-Z atom calculations. These two potentials were also used in Refs.[4,5], providing the first hint of small hydrogen existence. **We argue that a stronger potential acting at a small radius is necessary.**

### 2.2 Virial theorem with \( V_{(\text{Spin.B})} \) potential

Following Ref.[12], we assume that the following relativistic spin-orbit potential energy at small radius is a reasonable approximation (consider it as ansatz)\(^3\):

\[
V_{(\text{Spin.B})} \sim -g \mu_0 B
\]

where \( \mu_0 = 5.788 \times 10^{-9} \text{eV/Gauss} \) is the Bohr magneton, \( g = 2.0023 \), \( B \) is the self-induced magnetic field. To understand the origin of this magnetic field, we assume a simple equivalent model where the electron is at rest, and the proton is moving around it at this radius. We estimate the magnetic field value as follows\(^4\):

\[
B \sim 10^{-7} 2 \pi I/r = 10^{-7} 2 e v/r^2
\]

where \( I \) is the circular loop current due to proton’s velocity \( v \), and \( Z \) is atomic number. The magnetic field is \( B \sim 5.95 \times 10^{15} \text{ Gauss at radius of } \sim 2.84 \text{ Fermi, making the spin term in equation (8) dominant and equal to } V_{(\text{Spin.B})} \sim 69.04 \text{ MeV, while the Coulomb energy contribution to the balance is only } \sim 0.5075 \text{ MeV at the same radius.}

Although this paper uses the electron radius \( r \) in the following formulas, it should be looked at from a quantum mechanical point of view, i.e., the electron has a distribution of radii with some mean value of \( <r> \), determined by its wave function.

Figure 3 demonstrates that adding a potential \( V_{(\text{Spin.B})} \) to the Coulomb potential helps satisfy virial theorem at \( r \sim 2.84 \text{ Fermi. Table 3 shows that the mass of small hydrogen is } M(\text{pe}) = m_{\text{proton}} + \gamma m_{\text{electron}} - |U| = 938.272 \text{ MeV/c}^2, \) with a binding energy \( E_{\text{BE}} = T_{\text{Kinetic}} - |U| \sim -507.5 \text{ keV for } n = 1. \)

In normal hydrogen, where the electron is far from the proton, the spin-orbit interaction \( V_{(\text{Spin.B})} \) is a small perturbation. However, at small distances it becomes a significant force, providing stability of the bound system.

Figure 3 demonstrates that adding a potential \( V_{(\text{Spin.B})} \) to the Coulomb potential satisfies the virial theorem at \( r \sim 2.84 \text{ Fermi. Table 2 shows that the mass of small hydrogen } M(\text{pe}) = \sim 938.276 \text{ MeV and binding energy } E_{\text{BE}} \sim -507.5 \text{ keV.}

In normal hydrogen, where the electron is far from the proton, the spin-orbit interaction \( V_{(\text{Spin.B})} \) is a small perturbation. However, at small distances it becomes a significant force, providing a necessary component for the stability of the bound system.

### As a cross-check, one can also use Luch virial stability conditions following equations (4a), and (4b).

Figure 4 shows the same conclusion, i.e., the stability of small hydrogen atom, where he obtains the self-induced magnetic field of \( B \sim 4 \times 10^7 \text{ Gauss at } r \sim 2.12 \text{ Angstroms.} \)

\(^3\) The \( V_{(\text{Spin.B})} \) potential explains the hyperfine spectral structure of normal hydrogen, which is a tiny effect for electrons at large radius; at small radius, this potential represents a large force explaining stability of small hydrogen.

\(^4\) For example, P.A. Tipler [22] used a similar approach to calculate the spin-orbit fine-structure splitting of spectral lines in the normal hydrogen atom, where he obtains the self-induced magnetic field of \( B \sim 4 \times 10^7 \text{ Gauss at } r \sim 2.12 \text{ Angstroms.} \)

\(^5\) The neutron mass is \( m_{\text{proton}} = 938.565413 \text{ MeV/c}^2 \), the proton mass is \( m_{\text{electron}} = 938.272088 \text{ MeV/c}^2 \), and the sum of the proton and electron masses is \( m_{\text{proton}} + m_{\text{electron}} = 938.783096461 \text{ MeV/c}^2 \).
Figure 4 Numerical solution of equation (3a) for $n = 1$. Virial theorem condition for stability occurs at $r \sim 2.838$ Fermi.

2.3 Virial theorem with $V_{\text{eff}}$ potential

Adamenko and Vysotskii [15] proved, starting from Dirac equation, that the effective potential energy of a relativistic electron in Coulomb field can be expressed as:

$$V_{\text{eff}} = \gamma V_{\text{Coulomb}} - V_{\text{Coulomb}}^2/2mc^2$$

where the Coulomb potential is: $V_{\text{Coulomb}} = -\kappa Z^2/r$ and $Z = 1$ for hydrogen.

Paillet and Meulenberg [16] used this potential and concluded that the small hydrogen may exist.

Using the iterative method described in chapter 2, I confirm their results, as demonstrated on Figure 5. Quantitative results are shown in Table 3. One can see that for large values of $n$, the binding energy approaches 511 keV.

![Figure 5](Image 5)

Figure 5 Two regions of possible bound states in $H$ for $n = 1$. Two regions of hydrogen atom stability where $T_{\text{kinetic}} = T_{\text{virial}}$, one for normal hydrogen and one for small hydrogen, calculated for potential energy $V_{\text{eff}} = \gamma V_{\text{Coulomb}} - V_{\text{Coulomb}}^2/2mc^2$ for $n = 1$.

Table 3 – Small hydrogen: $V_{\text{eff}} = \gamma V_{\text{Coulomb}} - V_{\text{Coulomb}}^2/2mc^2$

| $n$ | $T_{\text{virial}}$ [Fermi] | $V_{\text{Coulomb}}^2/2mc^2$ [MeV] | $T_{\text{kinetic}}$ [MeV] | $M(p,e)$ mass* [MeV/c^2] | $E_{\text{kin}}$** [keV] |
|-----|-----------------|-----------------|------------------|-----------------|------------------|
| 1   | 2.8284          | -69.812          | 69.302            | 938.274         | -507.5           |
| 2   | 2.8232          | -139.881         | 139.370           | 938.273         | -510.0           |
| 3   | 2.8214          | -209.949         | 209.438           | 938.272         | -510.6           |

* Mass of small hydrogen: $M(p,e) = m_{\text{proton}} + \gamma m_{\text{electron}} - |U|$

** Binding energy: $E_{\text{kin}} = T_{\text{kinetic}} - |U|$

Figure 6 shows the $V_{\text{Coulomb}}$, $V_{(\text{spin.B})}$ and $V_{\text{eff}}$ potential shapes as a function of radius close to the proton. One can see that the $V_{(\text{spin.B})}$ and $V_{\text{eff}}$ potentials are almost identical, which is not obvious from their definitions, and much stronger than the Coulomb potential in the vicinity of the proton.

![Figure 6](Image 6)

Figure 6 $V_{\text{Coulomb}}$, $V_{\text{eff}}$ and $V_{(\text{spin.B})}$ potential shapes as a function of radius close to proton.

As a cross-check, one can also use Lucha’s virial stability condition following equations (3a) and (2b). Figure 7 shows the same conclusion, i.e., the stability occurs at $r \sim 2.828$ Fermi for $n = 1$.

![Figure 7](Image 7)

Figure 7 Numerical solution of equation (3a) for $n = 1$. The virial theorem condition for stability occurs at $r \sim 2.828$ Fermi. The curve does not reach zero because of a finite binning.

Tables 2 and 3 show that both potential choices yield almost the same results for the small hydrogen. They also show that small hydrogen is stable, based on the argument that $M(p,e)$ mass is smaller than sum of masses proton and electron. Notice also that binding energy $E_{\text{kin}}$ values are close to $E_{\text{kin}}$ values presented in Refs.[8],[9], obtained using the relativistic Schrödinger and Dirac equations, i.e., using completely different calculations. Another interesting conclusion is that the mass of the small hydrogen $M(p,e)$ is slightly smaller than the mass of a neutron.

The small hydrogen cannot be formed spontaneously since the electron can obtain only $\sim 507.5$ keV at a radius of 2.84 Fermi from the available static Coulomb potential energy. This means that energy must be supplied to the electron externally to form the small hydrogen (in this respect, this is similar to the electron capture on a proton $p + e^- \rightarrow n + v_e$, which requires external energy of at least 782.33 keV).

The small hydrogen will remain in the $n = 1$ state, as any excitation to higher $n$ requires too much energy, which is not available in typical collisions in Universe. The small hydrogen
will appear optically "dark" to an observer. Figure 8 shows strengths of various potentials considered in this paper.  

Figure 8 Relative strengths of various potential energies considered in this paper.

2.4 Interactions of small hydrogen

In gas medium its dE/dx deposit will be \( \sim 10^7 \)-times smaller than that of a typical charged particle because the small hydrogen will interact via a slight electric dipole [17]. It will not be ionized by collisions with light nuclei or with collisions with another small hydrogen at velocities typical in the Universe, such as, for example, the Bullet Cluster galaxy collision assuming velocity of 4500 km/sec, which corresponds to a kinetic energy of small hydrogen of only \( \sim 105 \) keV. One will be able to recognize an existence of small hydrogen only through gravitational effect.

However, at thermal velocities, small hydrogen can be captured by positively charged nuclei since the Coulomb barrier in this case is significantly smaller than when two positively charged nuclei collide. At energies slightly higher than \( \sim 0.511 \) MeV it could be ionized, and at very high energies it can initiate hadronic shower just like a neutron.

3. Accelerator test to find small hydrogen

A free thermal electron, when approaching a thermal proton, is captured on the highest level of the normal hydrogen first and subsequently gains a total energy of \( \sim 13.6 \) eV from the available electrostatic potential energy. It then latches onto the ground level with the correct De Broglie wavelength, where the electron has a radius \( r \sim 0.529 \) Å and a De Broglie wavelength \( \lambda \sim 3.222 \) Å, which corresponds to an electron kinetic energy of \( E_{\text{kinetic}} \sim 13.6 \) eV. If there is a large mismatch in relative energies (or velocities), the electron and proton will not form normal hydrogen. I will use the same argument for formation of small hydrogen. Table 3 tells us that the electron radius is approximately 2.8\( \times 10^{-15} \) cm, its De Broglie wavelength is approximately 17.762 Å, its frequency is about 1.688\( \times 10^{12} \) Hz, electron kinetic energy \( E_{\text{kinetic}} \) is approximately 69.302 MeV, \( \beta = v/c \sim 0.999973212 \) and \( \gamma \sim 136.620 \). For this condition, the electron may latch to the small hydrogen orbit if the proton has the same velocity as the electron; this corresponds to proton kinetic energy of 128.189 GeV. Electrons and protons are going in the same direction, as shown on Figure 9. The required beam kinetic energies are shown in Table 4. The idea is to tune electron energy around a value of 69.302 MeV and observe a peak in detector rates.

Table 4 - Electron and proton kinetic energies needed to form small hydrogen in flight: (both particles have the same \( \beta = v/c = 0.99997322 \)):

| Potential | Electron kinetic energy [MeV] | Proton kinetic energy [GeV] |
|-----------|-----------------------------|-----------------------------|
| \( V_{\text{eff}} \) | 69.301 | 128.189 |

Figure 9 Schematic concept to prove that the small hydrogen exists. Proton beam is brought tangentially to electron beam so that both beams travel parallel to each other for some distance. If the small hydrogen is formed, it will emit a 508.6 keV gamma in the two-particle rest frame, while electrons are deflected by a magnet.

Figure 10 Schematic concept to prove that the small hydrogen exists. Proton beam is brought tangentially to electron beam so that both beams travel parallel to each other for some distance. If the small hydrogen is formed, it will emit a 508.6 keV gamma in the two-particle rest frame, while electrons are deflected by a magnet.

If the small hydrogen atom is formed, a \( \sim 508.6 \) keV gamma is created in the two-particle rest frame. In the lab frame, the photon energy is very sensitive to the choice of angle due to the Doppler effect. The angle is angle between the direction of motion and gamma detector position:

\[
E_{\text{observed}} = E_{\text{source}} / [\gamma (1 - \beta \cos \phi)]
\]  

(11)

Figure 10 shows this dependency on the angle \( \phi \), based on equation (11). The gamma detector should be

---

\( ^6 \) Yukawa potential can be considered if one assumes that exchanging virtual photon develops a small mass in nuclear field.
positioned at $\phi \sim 6.9^\circ$ to measure $E_{\text{observed}} / E_{\text{Source}} \sim 1$. Energy of gammas produced at $\phi = 0^\circ$ will be boosted from 0.5086 MeV to 138.9 MeV. Therefore detector, shown on Figure 9, would detect gamma in the electromagnetic calorimeter and the small hydrogen will create a large collinear hadronic shower in the hadronic calorimeter, both well separated in space. The idea is to tune beam energies and observe a peak at expected electron and proton energies.

This result would be a direct proof of small hydrogen existence. This measurement is a high energy physics equivalent to what were the 1920’s bench-top experiments.

At present, the only places where such experiment is feasible are Brookhaven National Lab (BNL), Fermilab or CERN (protons of $\sim 128.2$ GeV already exist at the CERN SPS and a $\sim 69.3$ MeV electron accelerator may not be that difficult to construct).

4. The 511keV signal from the Galaxy center

The first gamma-ray line originating from outside the solar system that was ever detected is the 511 keV emission from the center of our Galaxy. The accepted explanation of this signal is the annihilation of electrons and positrons. However, despite 30 years of intense theoretical and observational investigation, the main sources of positrons have not been identified. Ref. [17] has proposed an alternative explanation: the observed signal is due to atomic transitions to “small hydrogen atom.”

5. Collapse of very large stars

De Broglie’s hydrogen model says that electron wave is undergoing periodic orbital motion and it does not radiate provided the shell radius is an integral multiple of waves; the orbit need not be circular nor even planar, it can be a vibration in 3D. For example, for a choice of potential according to Table 3, $r_{\text{stable}} \sim 2.828$ Fermi, and proton is surrounded by “standing electron wave” with the De Broglie wavelength of 17.762 Fermi and oscillating with very high frequency of $\sim 1.688 \times 10^{22}$ Hz. That is a very high number, but applying the same idea to the normal hydrogen, the frequency of electron wave is $\sim 6.6 \times 10^{13}$ Hz, still a very large number. In this picture, the small hydrogen is just a different hydrogen atom with electron oscillating at higher frequency.

One could ask a question if the small hydrogen could be formed in plasma oscillation, which is a coherent oscillation of electrons relative to relatively stable nucleons. We make an ansatz that if the electron plasma frequency reaches values, required by the De Broglie’s model, the small hydrogen could be formed. To reach plasma frequency of $\sim 10^{22}$ Hz, the required electron plasma density is $n_e \sim 10^{25}/\text{cm}^3$. We calculate oscillation frequency as:

$$f_e \sim \left(\frac{e^2 n_e}{\varepsilon_0 m_e}\right)^{1/2} / 2\pi \quad (12)$$

where $e$ is the electric charge, $n_e$ is electron density, $\varepsilon_0$ permittivity of vacuum and $m_e$ is the electron mass [18]. Table 5 shows examples of plasma parameters for various plasma densities.

Table 5 – Densities, temperature and plasma frequencies for different types of plasma examples:

| Type                          | Electron density [cm$^{-3}$] | Electron frequency [Hz] | Plasma temperature [keV] |
|-------------------------------|-----------------------------|--------------------------|--------------------------|
| The Sun’s core                | $-10^{27}$                  | $-10^{21}$               | 2.3                      |
| Larger star                   | $-10^{23}$                  | $-10^{20}$               | 2                        |
| Supernova explosion which may produce the neutron star at center | $-10^{40}$ | $-10^{39}$ | 8000-9000 |
| Laser fusion [18,19]          | $-6 \times 10^{30}$         | $-2 \times 10^{17}$      | 2.3                      |
| Tokamak fusion                | $-10^{14}$                  | $-2.8 \times 10^{11}$    | 10-20                    |
| Sparkling tests [20]          | $< -10^{11}$                | $< -3 \times 10^{12}$    | 10                       |

It seems presently impossible to reach high enough density in typical lab conditions on the Earth to create the small hydrogen, the laser fusion being the highest, but still not enough. However, it maybe possible to reach it in a collapse of very large stars capable of producing neutron stars, which are formed if the inner core of the star collapses to extremely high mass densities, exceeding $\sim 10^{14}$ g/cm$^3$ [23]. Electrons are forced to combine with protons through inverse beta decay (electron capture), forming neutrons and neutrinos ($p + e^- \rightarrow n + \nu_e$), forming a neutron star. To make it energetically possible, one must supply an external energy of at least 782.33 keV to the electron in the form of gravitational pressure.

The theory of Supernova collapse is very complicated [24]. Here we offer a simplenminded approach. Surrounding the collapsing core, there are layers where densities and pressures are extremely high but not yet at the level of neutron star densities. In these regions, the matter is compressed to such an extent that the small hydrogen may be formed. To form it, the mass density would have to reach values close to $\sim 1.25 \times 10^{13}$ g/cm$^3$ and an electron density of $3.5 \times 10^{36}$ el/cm$^3$. At that electron density, the plasma frequency can reach a value of $\sim 1.68 \times 10^{22}$ Hz, which is the frequency of the electron wave in small hydrogen. To calculate electron density, we have assumed that this region of the collapsing star is dominated by iron; this is oversimplified for calculation purposes as for densities higher than $\sim 10^{11}$ g/cm$^3$ neutrons start “dropping” out of nuclei [24]. Figure 11 shows schematically plasma frequency, as calculated using equation (12), as a function of mass and electron density in a collapsing star. This idea is bordering on speculation at present. More through calculation by Supernova theorists is needed.

---

7 At the end it is a balance between formation and destruction.

8 Density in sparking tests [20] is likely to be higher than quoted in the table because of the pinch effect, which explains rather high X-ray energies observed.
Figure 11 Plasma frequency as a function of mass and electron density during the collapse of a large star. Plot shows density region where the neutron star is formed, and somewhat lower density where the plasma frequency reaches a value where small hydrogen could be formed.

The main point of this idea is that if Supernovas are capable of producing small hydrogen, and assuming that it is stable, the Universe is full of particles which will appear as if they are neutrons. This is an opportunity for experimental tests in regions where one cannot have a contamination from real neutrons produced by the Sun - see next chapter.

If supernovas produce small hydrogen, longer a galaxy exists more of small hydrogen would be produced due to long-term supernova activity.

6. Neutron capture signal in Integral satellite

Figure 12 shows the analysis of low energy spectra, including the nuclear capture signals, by the Integral satellite, which cannot detect thermal neutrons coming from the Sun in its location. The only possible explanation is that neutron capture peaks are caused by cosmic ray proton interactions with the satellites structure, producing neutrons, which then capture and produce multi-MeV Gammas. Quoting Ref.[21], the only puzzling conclusion is this: “Thermal neutron capture is responsible for numerous and strong lines at several MeV; their unexpected presence poses a difficult challenge for our physical understanding of instrumental backgrounds and for Monte Carlo codes.”

Figure 12 The evidence for the thermal neutron capture signals detected by the Integral satellite [21].

The presence of the thermal small hydrogen in outer space, and its capture on nuclei, could explain these so far unexplained capture signals - see previous chapter.

We suggest searching for the thermal small hydrogen in the outer space far away from the Sun and Earth. The satellite should have small mass in supporting structure to minimize neutron production by cosmic protons. The detector could be like the one the Integral satellite used.

Conclusions

The paper uses a simple iterative model based on virial theorem and De Broglie’s idea from 1924. It concludes that the small hydrogen may exist. To form the small hydrogen atom, electron’s energy must be supplied externally, which is a process like the electron capture on proton $p + e^- \rightarrow n + \nu_e$, which also requires external energy, i.e., small hydrogen cannot be formed spontaneously. This would explain the stability of our world. It can be formed only at high energy, in vicinity of large black holes or collapse of large stars, which are also producing neutron stars, and perhaps, during the Big Bang. If it was produced during the Big Bang, it would be produced sooner than the normal hydrogen; small hydrogen may have provided a seed to early galaxies.

A question if the small hydrogen is the dark matter or produced during the Big Bang would require more study requiring a rigorous scrutiny against observational data, ensuring consistency with the Big Bang nucleosynthesis (BBN) and cosmic microwave background (CMB) constraints, matching large-scale structure formation patterns, Bullet Galaxy collision, etc.

This paper suggests two methods to find it, one is a high energy experiment and the other is a search for intergalactic neutron-like signal. If these tests are successful, the real theory of small hydrogen can be developed.

REFERENCES

[1] R. Reeves, “A force of Nature”, page 114, Atlas books, New York - London, 2008.
[2] A. Pais, “Inward bound”, page 397, Clarendon press - Oxford, 1986.
[3] L. I. Schiff, “Quantum Mechanics”, (equation 53.16, page 470), 3rd ed., McGraw-Hill Publishing Company, New York (1968).
[4] J. Maly and J. Va'vra, “Electron Transitions on Deep Dirac Levels I”, Fusion Technology, Vol. 24, November 1993.
[5] J. Maly and J. Va'vra, “Electron Transitions on Deep Dirac Levels II”, Fusion Technology, Vol. 27, January 1995.
[6] F. C. Smith and W. R. Johnson, “Relativistic Self-Consistent Fields with Exchange”, Phys. Rev. 160, 136–142 (1967).
[7] B. W. Bush, J.R. Nix, Ann. of Phys., 227, 97 (1993).
[8] J. Va'vra, ArXiv:1304.0833v4, Feb. 7, 2018.
[9] E.E. Salpeter and H. Bethe, “A relativistic Equation for Bound-State Problems”, Physical Review, Vol.84, No.6, 1951.
[10] J.R. Spence and J.P. Vary, “Electron-proton resonances at low energy from a relativistic two-body wave equation”, Physics Letters B 271 (1991) 27-31.
[11] Luis de Broglie, Phil. Mag. 47 (1924) p.446.
[12] J. Va'vra, "A simple argument that small hydrogen may exist," Physics Letters B 794 (2019) 130-134.
[13] W. Lucha, “Relativistic virial theorem,” Modern Physics Letters A, Vol 5, No.30 (1990) 2473.
[14] Bethe and E.E. Salpeter, “Quantum Mechanics of one- and two-electron atoms” Handbuch der Phys. 35, 88 (1957).
[15] S. V. Adamenko and V. I. Vysotskii, “Mechanism of synthesis of superheavy nuclei via the process of controlled electron-nuclear collapse,” Foundations of Physics Letters, Vol. 17, No. 3, June 2004.
[16] J.L. Paillet and A. Meulenberg, “Advance on Electron Deep Orbits of the Hydrogen Atom”, J. Condensed Matter Nucl. Sci. 24 (2017) 258–277.
[17] J. Va’vra, “A new way to explain the 511 keV signal from the centre of the galaxy and some dark matter experiments,” ArXiv:1304.0833v3 [astro-ph.IM], June 9, 2013.
[18] P. Gibbon, Proceedings of the CAS-CERN Accelerator School: Plasma Wake Acceleration, Geneva, Switzerland, 23 Nov. 2014.
[19] Laser tests at NIF LANL, https://en.wikipedia.org/wiki/National_Ignition_Facility [20] J. Va’vra, J. Maly, P.M. Va’vra, “Soft X-ray production in spark discharges in hydrogen, nitrogen, air, argon, and xenon gases,” Nucl. Instr. Meth., A 418 (1998) 405
[21] G. Weidenspointner et al., Astronomy and Astrophysics 411, L113L11 (2003).
[22] A. Mezzacappa, “Ascertaining the core collapse Supernova mechanism”, Annual Reviews Nucl. Part. Sci., 2005, 55:467–515.
[23] I. Vidana, ”A short walk through the physics of neutron stars”, arXiv:1805.00837v1 [nucl-th] May 2, 2018.