Presentation of Strong Candidates for Dark Matter

By Koshun Suto

Chudaiji Buddhist Temple, Japan

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Keywords: dark matter, dark hydrogen, ultra-low energy levels, triplet production, einstein's energy-momentum relationship, proton radius.

I. Introduction

It is well-known that the existence of Dark Matter (DM) was first pointed out by F. Zwicky in 1933.[1] Zwicky was investigating the dispersion velocity of galaxies in the Coma Cluster, but that velocity was so large that it could not be explained with classical mechanics. Therefore, Zwicky posited the existence of an unknown form of matter to explain the reason for that velocity.

Furthermore, in the latter half of the 1970s, it was discovered that DM also exists in galaxies, and since then it has been revealed by a variety of observations. As a result, the existence of DM is supported by many scientists today. This unknown form of matter is thought to have the following characteristics:

(1) It is widely present in galactic systems.
(2) It is electrically neutral.
(3) It has considerable mass.
(4) It cannot be observed optically (it does not emit light).
(5) It exhibits almost no interaction with matter.
(6) It moves at a speed far slower than light.

DM candidates can be roughly divided into two types: elementary particle candidates and astrophysical candidates. The leading elementary particle candidate is a Weakly Interacting Massive Particle (WIMP).

The Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) has investigated the distribution of DM using observation data for 50 galactic clusters photographed with the Subaru Telescope. As a result, they announced that the results agreed with a theory called Cold Dark Matter (CDM).[2]

In addition, a new theory was announced this year which posits another force dominating the world of the extremely small, and the existence of a Strongly Interacting Massive Particle (SIMP).[3]

At present, the CDM scenario is thought to have the advantage, but the fact that the candidate particle has not been discovered is regarded as a weak point.

Matter with the six characteristics given above does not exist among the elementary particles we currently know of.

The simplest model assumes one type of particle is involved in DM. However, since the 1990s various experiments have attempted to directly detect WIMPs, but no definitive signs suggesting the existence of WIMPs have been found. Therefore, some scientists have doubts about the current theory, and have begun to also consider models of DM comprised of multiple particles.[4,5]

This paper believes that DM does not necessary have to be elementary particle. Last year, the author published a paper predicting the existence of hydrogen atoms at ultra-low energy levels.[6] This paper examines whether such hydrogen atoms can be candidates for DM.

Prior to that, Sec. II explains the equations which are the departure point when deriving the equation for the ultra-low energy levels of the hydrogen atom. Sec. III actually derives the unknown energy levels from those equations. Sec. IV presents the experimental grounding demonstrating the existence of those energy levels.

II. Equation Serving as the Basis for Deriving Ultra-Low Energy Levels of the Hydrogen Atom

One of the most important relationships in the special theory of relativity is as follows:

$$\left(mc^2\right)^2 = \boldsymbol{p}^2 c^2 + \left(m_0 c^2\right)^2. \tag{1}$$

Here, $m_0 c^2$ is the rest mass energy of an object or a particle, and mc^2 is the relativistic energy. Eq. (1) can also be applied to the electron, but in that case it becomes as follows:

Author: koshun_suto129@mbr.nifty.com

$$\left(mc^2\right)^2 = \boldsymbol{p}^2c^2 + \left(m_ec^2\right)^2. \tag{2}$$

Here, m_ec^2 is the rest mass energy of an electron.

However, since Eq. (2) does not include the potential energy of the electron, this equation cannot be applied to the electron in the hydrogen atom.

Incidentally, in the classical quantum theory of Bohr, the energy eigenvalues of the hydrogen atom can be expressed with the following equation:

$$E_{\mathrm{B},n} = -\frac{1}{2}\left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{m_ee^4}{\hbar^2}\frac{1}{n^2} = -\frac{\alpha^2 m_ec^2}{2n^2}, \qquad n=1,2,\cdots. \tag{3}$$

Here, the B in E_{B} indicates the equation derived by Bohr. In this case, the total mechanical energy of the electron has a negative value.

However, according to quantum mechanics, the energy eigenvalues of a hydrogen atom as obtained from the Dirac relativistic wave equation are as follows.[7]

$$E = m_ec^2\left[1 - \frac{\gamma^2}{2n^2} - \frac{\gamma^4}{2n^4}\left(\frac{n}{|k|} - \frac{3}{4}\right)\right]. \tag{4}$$

γ matches with the fine structure constant α. That is:

$$\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c} = 7.2974\times10^{-3}. \tag{5}$$

If we ignore for the third term of this equation, Eq. (4) can be written as follows.

$$E_{\mathrm{D},n} = m_ec^2 - \frac{1}{2}\left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{m_ee^4}{\hbar^2}\frac{1}{n^2} \tag{6a}$$

$$= m_ec^2 + E_n. \tag{6b}$$

Here, the D in E_{D} indicates the equation derived by Dirac. $E_{\mathrm{D},n}$ of Eq. (6) expresses the remaining amount of rest mass energy of the electron. Even if we place an electron at rest an infinite distance from its nucleus, the relativistic energy of the electron is not zero.

Taking these facts into account, the relativistic energy $E_{\mathrm{re},n}$ of the electron is defined as follows.[8]

$$E_{\mathrm{re},n} = m_ec^2 + E_n, \qquad n=1,2,\cdots. \tag{7}$$

Also, the author has derived an energy-momentum relationship applicable to the electron in a hydrogen atom by referring to the reasoning Einstein used when deriving Eq. (2).[8] That is,

$$E_{\mathrm{re},n}^2 + \boldsymbol{p}_n^2c^2 = \left(m_ec^2\right)^2. \tag{8}$$

In addition, Eq. (8) was verified in that paper.

III. Derivation of Ultra-Low Energy Levels of the Hydrogen Atom

Dirac showed that the energy in Eq. (2) has the following positive and negative values.[9]

$$E = \pm c\left(m_e^2c^2 + p^2\right)^{1/2}. \tag{9}$$

Here, the following inequality holds for the negative energy.

$$E < -m_ec^2. \tag{10}$$

If Eq. (8) is solved by following Dirac, the following solution is obtained.

$$E_{\mathrm{re},n} = \pm c\left(m_e^2c^2 - p_n^2\right)^{1/2}. \tag{11}$$

The range of values that can be assumed by $E_{\mathrm{re},n}$, obtained from this equation, is as follows.

$$m_ec^2 > E_{\mathrm{re},n} > -m_ec^2. \tag{12}$$

For this reason, it is theoretically possible for an energy level satisfying the condition $0 \ge E_{\mathrm{re},n} > -m_ec^2$ to exist.

Incidentally, according to the virial theorem, the following relation holds between K and V:

$$\langle K\rangle = -\frac{1}{2}\langle V\rangle. \tag{13}$$

Here, K is the kinetic energy of the entire system, and V is the potential energy of the entire system.

The average time of K is equal to $-1/2$ the time average of V. Also, the sum of the time average K and the time average of the total mechanical energy E of the entire system becomes 0. That is,

$$\langle K\rangle + \langle E\rangle = 0. \tag{14}$$

Next, if Eqs. (13) and (14) are combined, the result is as follows:

$$\langle E\rangle = -\langle K\rangle = \frac{1}{2}\langle V\rangle. \tag{15}$$

Taking these facts into account, the author presented the following equation as an equation indicating the relationship between the rest mass energy and potential energy of the electron in the electrostatic field of the proton.[10]

$$V(r) = -\Delta m_ec^2. \tag{16}$$

According to this equation, the potential energy corresponds to the reduction in rest mass energy of the electron in the atom. Also, the potential energy of the electron can be expressed with the following equation:

$$V(r_n) = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_n} \tag{17a}$$

$$= -\frac{\alpha\hbar c}{r_n}. \tag{17b}$$

Here, if Eq. (8) is rewritten taking into account Eq. (15), the following two equations are obtained.

$$\left(m_e c^2 - \frac{\alpha^2 m_e c^2}{2n^2}\right)^2 + p_n^2 c^2 = \left(m_e c^2\right)^2. \tag{18}$$

$$\left(m_e c^2 - \frac{\alpha\hbar c}{2r_n}\right)^2 + p_n^2 c^2 = \left(m_e c^2\right)^2. \tag{19}$$

The following p_n^2 can be found from Eq. (18).

$$p_n^2 = \frac{\alpha^2 m_e^2 c^2}{n^2}\left(1 - \frac{\alpha^2}{4n^2}\right). \tag{20}$$

Expanding and rearranging Eq. (19), it is possible to obtain the following quadratic equation for r_n :

$$p_n^2 r_n^2 - \alpha\hbar m_e c r_n + \frac{\alpha^2 \hbar^2}{4} = 0. \tag{21}$$

If the value of Eq. (20) is substituted here for p_n^2, the following solution is obtained:

$$r_n = \frac{\alpha\hbar m_e c \pm \left(\alpha^2 \hbar^2 m_e^2 c^2 - p_n^2 \alpha^2 \hbar^2\right)^{1/2}}{2p_n^2} \tag{22a}$$

$$= \left[r_e \pm r_e\left(1 - \frac{\alpha^2}{2n^2}\right)\right]\frac{n^2}{2\alpha^2}\left(1 - \frac{\alpha^2}{4n^2}\right)^{-1}. \tag{22b}$$

Here, r_e is the classical electron radius as following:

$$r_e = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{m_e c^2}. \tag{23}$$

Here if r_n^+ is taken to be the larger of the two solutions obtained from Eq. (22), and r_n^- the smaller, then r_n^+ and r_n^- are as follows:

$$r_n^+ = \frac{n^2}{\alpha^2}r_e = n^2 a_B, \qquad n = 1,2,\cdots. \tag{24}$$

$$r_n^- = \frac{r_e}{4}\left(\frac{n^2}{n^2 - \alpha^2/4}\right), \qquad n = 1,2,\cdots. \tag{25}$$

Here, a_B is the Bohr radius. In Eq. (25) the radius approaches $r_e/4$ with $n \to \infty$. Therefore this paper predicts that $r_e/4$ will be the radius of the atomic nucleus (the proton).

Next, the energy is found when the radius is r_n^+ and r_n^-. Here, E_n in Eq. (3) can be written as follows if Eq. (15) and Eq. (17a) are taken into consideration.

$$E_n = -\frac{1}{2}\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_n}. \tag{26}$$

Here, if E_n^+ is taken to be the energy obtained by substituting r_n^+ for r_n in Eq. (26), and similarly E_n^- is taken to be the energy obtained by substituting r_n^- for r_n, then E_n^+ and E_n^- are as follows:

$$E_n^+ = E_{B,n} = -\frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1,2,\cdots. \tag{27}$$

$$E_n^- = -2m_e c^2 + \frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1,2,\cdots. \tag{28}$$

If these energies are described on an absolute scale using $E_{re,n}$ defined in Eq. (7), the values are as follows:

$$E_{re,n}^+ = m_e c^2 - \frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1,2,\cdots. \tag{29}$$

$$E_{re,n}^- = -m_e c^2 + \frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1,2,\cdots. \tag{30}$$

If the above is indicated graphically, the result is as follows (see Fig. 1).

IV. Phenomena which Demonstrate the Existence of Ultra-Low Energy Levels

If it is assumed that the energy of an incident γ-ray is 1.022 MeV ($2m_e c^2$), then due to the effects of the Coulomb potential of atomic nucleus, the γ-ray may suddenly disappear and produce an electron-positron pair (electron-pair creation). The electron and positron pair, which absorbed all of the energy of the γ-ray, are produced, classically speaking, near $r_e/2$ from the center of the atomic nucleus.

If an electron exists at the E_n^- energy levels, then the energy E necessary for the electron to be excited and emitted outside of the shell is as follows due to Eq. (28):

$$E = 2m_e c^2 - \frac{\alpha^2 m_e c^2}{2n^2} \approx 2m_e c^2 = 1.022\,\text{MeV}. \tag{31}$$

Now, how can hydrogen atoms in this energy state be verified? Simply put, it can be predicted that if such an atom is irradiated with a 1.022MeV photon, then a single electron will be emitted to the outside of the shell. However, this sort of phenomenon has not been

discovered. Actually, the $r=r_e/2$ point is a location where energetically $E_{re}=0$ and an electron-positron pair is created due to the vacuum absorbing the energy of this photon. Since the photon energy is consumed at that time, the photon cannot arrive at an electron in the E_n^- state. Therefore this paper looks at triplet production.

It is generally assumed that in triplet production, in which 2 electrons and 1 positron are created, electron-pair creation occurs not near the atomic nucleus, but near the electron in the outer shell orbital. A total of three particles are created in this case: one outer shell electron forming the atom, and a positron and electron created through pair production. However, in this model, (1.022MeV- E_n^+) should be sufficient as the necessary photon energy. If an energy of 2.044MeV ($4m_ec^2$), is needed for triplet production, then the recoiled electron should be regarded as being at an ultra-low energy level. Thus this theory changes the existing interpretation of triplet production by taking into account the law of conservation of energy.

Now, consider the case where an incident γ-ray has the energy corresponding to the mass of 4 electrons (2.044 MeV). If this is discussed classically, the γ-ray can create an electron and positron near $r=r_e/2$ (see Fig.2).

Even if 1.022 MeV of energy is consumed in this pair creation, the γ-ray still has the energy of corresponding to the mass of 2 electrons (1.022MeV). If the γ-ray gives energy to an electron in the orbital near the proton, the electron will be excited and appear in free space. As a result, 2 electrons and 1 positron will appear in free space.

This paper points out that one of the two electrons which appears is an electron in the E_n^- state. A hydrogen atom in the E_n^- state will henceforth be called a "dark hydrogen atom" in this paper, and indicated as $_DH$ (where the D stands for "dark"). Also, the E_n^- in Eq. (28) will be indicated as $_DE_n$, and E_n^+ will be returned to the original symbol E_n. In addition, the $E_{re,n}^-$ in Eq. (30) will be expressed as $_DE_{re,n}$, and $E_{re,n}^+$ will be returned to the original symbol $E_{re,n}$.

Furthermore, the hydrogen molecule produced from $_DH$ will be called "dark hydrogen molecule", and indicated as $_DH_2$. In this paper, $_DH$ and $_DH_2$ will be grouped together and called either hydrogen at ultra-low energy levels, or "dark hydrogen". In the next section, this paper will examine whether dark hydrogen can be a DM candidate.

V. Discussion

This section examines whether $_DH$ and $_DH_2$ have the six characteristics indicated in the introduction.

(1) Hydrogen atoms are the most common atoms in the universe. Therefore, if dark hydrogen exists, it is natural to assume that it is present universally throughout space. Also, it is clear that it is electrically neutral. Therefore characteristics (1) and (2) are satisfied.

(2) The relativistic energy E_{re} of the electron forming H is about $\approx m_ec^2$ (however, $E_{re} < m_ec^2$). In contrast, the relativistic energy E_{re} of the electron forming $_DH$ is about $\approx -m_ec^2$ (however, $E_{re} > -m_ec^2$).

Also, as is clear from Eq. (30), $E_{re} < 0$ in the case of the $_DH$ electron, and therefore the mass of the electron forming $_DH$ has a negative value. $_DH$ is about $2m_ec^2$ lighter than H. However, $_DH$ has a far smaller radius than H. Now, if the classical radii of $_DH$ and H are compared, the results are as follows:

$$\frac{r_1^-}{r_1^+} = \frac{\alpha^2}{4-\alpha^2} \tag{32a}$$

$$= 1.331{\times}10^{-5}. \tag{32b}$$

Therefore, dark hydrogen can achieve a state of far higher density than ordinary hydrogen. It is likely it will be observed as matter with high mass. Therefore, characteristic (3) can be regarded as satisfied.

(3) In atoms and molecules, electrons occupy orbitals starting from states with low energy. However, as shown by Eq. (14), there is a lower limit on the potential energy of an electron in a hydrogen atom. That is,

$$0 > V(r) > -m_ec^2. \tag{33}$$

When an electron in a hydrogen atom makes a transition from E_n^+ to E_n^-, the electron must have the energy of a photon emitted to the outside of the shell. However, the energy necessary for this transition does not remain at the electron if Eq. (33) is taken into consideration. Therefore, a transition from E_n^+ to E_n^- does not occur. In contrast, the transition from E_n^- to E_n^+ is regarded as possible. If a dark electron absorbs $2m_ec^2$ of energy from the outside, the electron in $_DH$ is excited, and it transitions to an orbital within the hydrogen atom, or is omitted outside of the shell [This satisfies characteristic (4)].

It is also likely that dark hydrogen satisfies characteristic (5) and (6). For the above reasons, this paper has determined that $_DH$ and $_DH_2$ can be DM candidates.

VI. Conclusion

This paper has shown it as possible to demonstrate the existence of $_DH$ by changing the interpretation of the phenomenon of triplet production. Also, the characteristics of $_DH$ and $_DH_2$ match with the six characteristics indicated in the introduction.

Thus, this paper presents hydrogen with ultra-low energy levels as a strong candidate for DM. If the energy levels of $_D$H is described at the level of classical quantum theory, the result is as follows.

$$_D E_n = -2m_e c^2 + \frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1, 2, \cdots. \qquad (34)$$

$$_D E_{re,n} = -m_e c^2 + \frac{\alpha^2 m_e c^2}{2n^2}, \qquad n = 1, 2, \cdots. \qquad (35)$$

This paper predicts that, in addition to such dark hydrogen, diverse types of atoms and various types of molecules comprised of diverse types of atoms, can also be candidates for Dark Matter.

VII. ACKNOWLEDGMENTS

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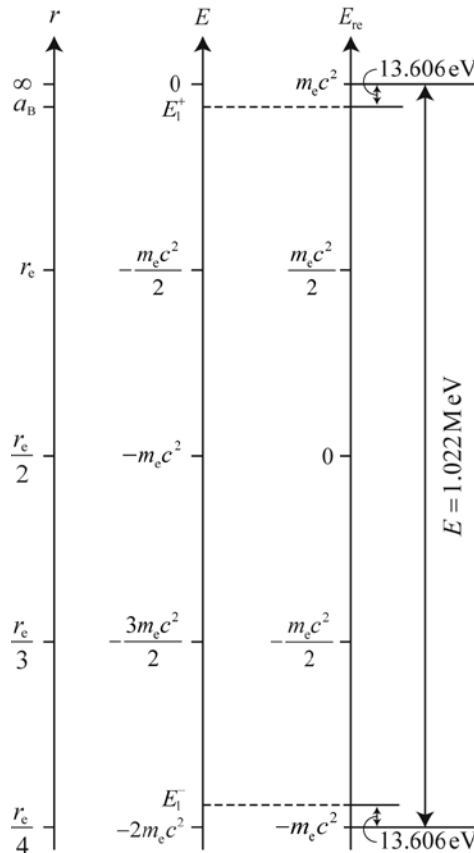10. K. Suto, Phys. Ess, 22, 135 (2009).

Figure Captions

Fig. 1

Fig.1 : The energy levels of the hydrogen atom predicted by classical quantum theory E_n^+ ($E_{re,n}^+$) and the new energy levels whose existence has been indicated by this paper E_n^- ($E_{re,n}^-$). Also, *r* is physical quantity with meaning within the scope of classical discussions. The region of physical vacuum where pair production is possible in the hydrogen atom is $r_e/2 \geq r > r_e/4$.
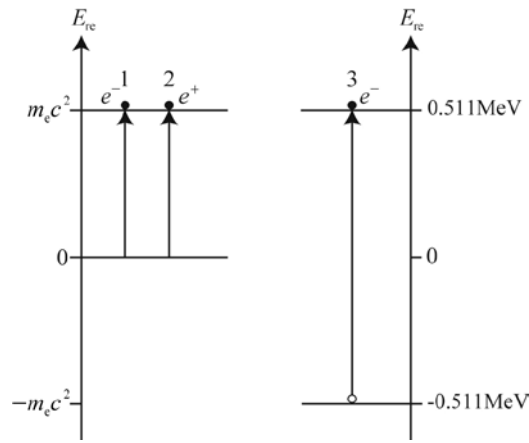
Fig. 2a   *Fig. 2b*

Fig. 2 : Interpretation of this paper regarding triplet production. From the perspective of this paper, this *γ*-ray will give 1.022 MeV of energy to the virtual particles at $r=r_e/2$, and an electron-positron pair will be created (Fig. 2a). When this *γ*-ray approaches closer to the atomic nuclear, and the electron in the orbital around the proton absorbs this energy, the electron will be excited and appear in free space (Fig. 2b). This paper points out that one of the two electrons which appears is an electron in the E_n^- state.