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Novel Consequences of Coexistence of Matter and Antimatter in Nature

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Abstract

In the present letter we discuss novel possible applications and implications of the formation of exotic atomic and molecular structures composed of particles and antiparticles. Particularly, we argue that huge amount of energy could be produced as a result of matter-antimatter cold fusion. Crucial questions raised concerning the fate of particles and antiparticles produced by the big bang are addressed. Assumptions of possible existence of two kinds of gravity and masses of different signs are proposed.

Keywords

Matter-Antimatter Annihilation Energy, Cold Fusion, Big Bang Theory, Antigravity, Antiuniverse, Theory of Multiverses, Matter-Antimatter Chemistry

1. Introduction

Possible formation of exotic atoms composed of particles and antiparticles, (e.g. positronium, protonium true muonium ant pionium) was confirmed by many authors, (for a review see Abdel-Raouf 2019 [1]). The coexistence of antihydrogen with hydrogen, deuterium and tritium was mathematically proved by Abdel-Raouf and Ladik [2] based on the theory of four-body system (see [3], [4] and [5]). A computational code was developed for performing quite elaborate calculations for four-body systems using Ritz' variational method, (for a review, see Abdel-Raouf [6]). The code was employed by Abdel-Raouf *et al.* [7] in order to confirm the existence of exotic four-body molecules. Quite accurate calculations of the binding energy of positronium molecule (Ps_2) were presented by El-Gogary *et al.* [8], (for experimental confirmation, see Cassidy and Mils [9]). In the present letter we shed light on the calculation of the binding energies of positronium with protonium, true muonium, pionium, antiproton-deuteron and

antiproton-triton exotic molecules. Section 2 is devoted to short presentation of the variational treatment of four-body systems. The results are displayed in Section 3. Section 4 contains the discussion of our results and novel implications of the coexistence of matter and antimatter in nature. The letter ends with a list of references presented in the text.

2. Variational Treatment of Four-Body Systems

The total Hamiltonian of the four-body system presented in Figure 1 is given by:

$$H = -\frac{\hbar^2}{2m_1}\nabla_1^2 - \frac{\hbar^2}{2m_3}\nabla_3^2 - \frac{\hbar^2}{2m_2}\nabla_2^2 - \frac{\hbar^2}{2m_4}\nabla_4^2 + Z^2e^2\left(\frac{1}{r_{13}} + \frac{1}{r_{24}} - \frac{1}{r_{12}} - \frac{1}{r_{14}} - \frac{1}{r_{23}} - \frac{1}{r_{34}}\right) \quad (1)$$

where $m_i^{\pm}$ is the mass of the i^{th} particle, r_{ij} is the internal distance between the i and j particles and $Ze^{\pm}$ is the charge of the ± particle.

The calculation of the binding energy using Rayleigh-Ritz' variational method is carried out by diagonalizing the Hamiltonian (1) in the Hilbert space $\{|\chi_i\rangle\}_{i=1}^{\infty}$, spanned by the Hylleraas type functions

$$|\chi_i\rangle = A(1\leftrightarrow 3, 2\leftrightarrow 4)\left\{s_1^{mi}s_2^{ni}\exp\left\{-\alpha_i(s_1+s_2)t_1^{ki}t_2^{\ell i}\cosh\left[\beta_i(t_1-t_2)uve^{-\gamma iv}\right]\right\}\right\} \quad (2)$$

with the following set of parameters:

$$\begin{aligned} &s_i = (r_{i3}+r_{i4})/r_{34}; i=1,2 \\ &t_i = (r_{i3}-r_{i4})/r_{34}; i=1,2 \\ &s_3 = (r_{13}+r_{23})/r_{12}, s_4 = (r_{14}+r_{24})/r_{12}, \\ &t_3 = (r_{13}-r_{23})/r_{12}, t_4 = (r_{14}-r_{24})/r_{12}, \\ &u = r_{12}/r_{34}, v = r_{34}. \end{aligned} \quad (3)$$

The calculations have been carried out using the first 50 components of the Hylleraas vectors for the following four-body systems:

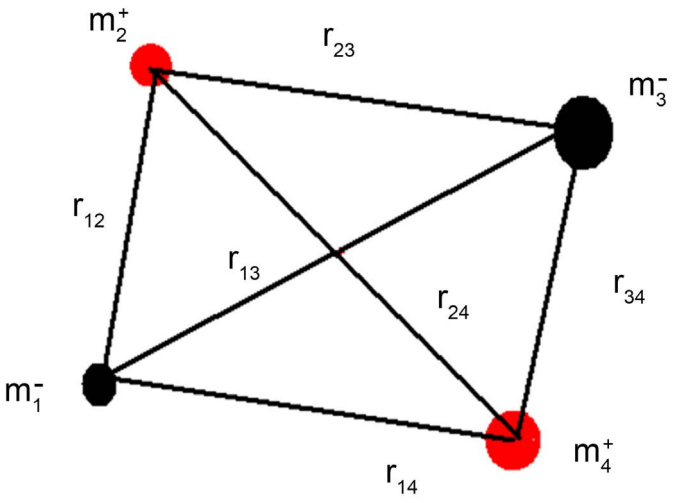

Figure 1. Schematic representation of a four-body system.

1) e^-e^+- e^-e^+
2) e^-e^+- $\mu^-\mu^+$
3) e^-e^+- p^-p^+
4) e^-e^+- $\pi^-\pi^+$
5) e^-e^+- p^-d^+
6) e-e^+- p^-t^+

The bound state of any of these systems is said to be confirmed if and only if the variational binding energy supports the coexistence of the lowest threshold of this system, *i.e.* if the system is stable against all possible corresponding dissociation channels.

Let us proceed by defining the following quantities:

$$\sigma = m_i^- / m_j^+ ,$$

where $i = 1, 2$ and $j = 3, 4$, *i.e.* σ is the mass ration between negatively and positively charged particles,

$E_{thr} = (E_{12} + E_{34})$), is total energy of the lowest threshold channel (or the dissociation energy) of the four-bodies, composed of the two separate exotic atoms ($m_1^- - m_2^+$) and ($m_3^- - m_4^+$).

$W(\sigma) = E_b$ = Binding energy of the Four-Body system, where $W(\sigma) < 0$ guarantees that the system is bound and can be formed in nature,

E = is the total energy of the Four-Body system,

$\varepsilon(\sigma) = E(\sigma)/E_{thr}$ is the energy ratio between the total energy of the considered Four-Body system and the sum of the total energies of the two exotic atoms of the lowest possible dissociation channel, and

$\omega(\sigma) = \varepsilon(\sigma) - 1$, where. $\varepsilon(\sigma) > 1$ and $\omega(\sigma) > 0$ indicate that the system is bound.

3. Binding Energies of Four-Body Systems

The calculation of the variational binding energies has been started by determining the optimum values of the nonlinear parameters appearing in $|\chi_i\rangle$. The convergence of the resulting binding energies with increasing number of superpositions was tested. It was found that the first 50 superpositions of $|\chi_i\rangle$ are enough to provide quite stable converging results.

The final calculations of the parameters mentioned above are displayed in Table 1.

The results presented in the fourth and sixth column of the table supports the conclusion that all Four-Body systems given in the first column are bound and could form exotic molecular structures in nature stable against dissociation to their lowest possible channels. Thus, apart from direct annihilation channels, particle-antiparticle interactions at low energies are also accompanied with the formation of exotic atomic structures and exotic molecular compounds.

4. Consequences of the Matter-Antimatter Coexistence

In the following subsections we discuss three possible consequences of the possible coexistence of matter-antimatter at low energies.

Table 1. Total, threshold and binding energies of various four-body systems.

System	Lowest Channel	E_{thr} (eV)	$W(\sigma) = E_b$ (eV)	$\omega(\sigma)$	E (eV)	$\sigma = m^-/m^+$	γ	β	α
$e^-e^+e^+e^-$	2Ps	−13.6	−0.4352	0.0320	−14.0352	1.0	1.53	0.87	1.95
$e^-e^+\mu^-\mu^+$	Ps - Mu	−1412.8243	−2.8451	0.00197	−1415.6694	0.005	1.08	0.03	3.02
$e^-e^+\pi^-\pi^+$	Ps - $A_{2\pi}$	−1905.36	−1.8659	0.000979	−1907.225	0.004	2.03	0.03	3.18
$e^-e^+p^-p^+$	Ps - Pn	−12,492.28	−0.9369	0.000075	−12,493.217	0.000545	1.53	0.87	1.95
$e^-e^+p^-d$	Ps - P^-d^+	−16,654.59	−0.94099	0.0000563	−16,655.531	0.000408	1.53	0.87	1.95
$e^-e^+p^-t$	Ps - P^-t+	−18,735.567	−0.93780	0.0000501	−18,736.505	0.000363	1.53	0.87	1.95
$\mu^-\mu^+\pi^-\pi^+$	Mu - $A_{2\pi}$	−3304.584	−102.419	0.0310	−3407.003	0.757	1.82	0.05	1.40

4.1. Matter-Antimatter Chemistry

Compounds composed of atoms and antiatoms could lead to the discovery of a new field to be referred to as matter-antimatter Chemistry (Abdel-Raouf [10]) and better understanding of chemical bonds. In this work we studied possible formation of exotic molecules based on the interaction of antihydrogen with hydrogen, deuterium and tritium atoms. Theoretical investigations of positronic compounds are given by different authors, (see e.g., Yukiumi [11] and Masanori and Kita *et al.* [12]). Much earlier calculations on Ps_2O, (the so called positronium water), were performed by Jiang and Schrader [13]. Antimatter chemical compounds are subjected to various chemical operations and could be implemented in laboratory.

4.2. Cold Fusion and Production of Fuel for Space Shuttles

The idea of nuclear cold fusion was theoretically and experimentally studied by Fleischman and Pons [14] and Fleischman [15]. It demands the injection and fusion of hydrogen, deuterium, tritium and muonium in palladium molecular crystal.

The creation of large number of antihydrogens at laboratory, (see e.g. ATRAP Experiment at CERN) suggests a new scenario of cold fusion (see Abdel-Raouf [16]) in which Hydrogen followed by Antihydrogen is injected in a sheet of Palladium Crystals. The advantage of the realization of fusion energy based on matter-antimatter annihilation is threefold:

1) It is considerably larger than fusion energy obtained from nuclear reactions,

2) It is cold, and

3) Controllable.

As alternative to the preceding scenario, we consider the possible production of huge amount of Energy through the formation of highly populated medium (Plasma), composed of electrons and positrons, injected via electron and positron guns into palladium sheets. In this case we argue that if a thermalized beam of positrons passes through a palladium sheet in which a large number of free (or localized) electrons are populated, different positronium entities could be formed as well as positron-electron plasma. The resulting annihilation processes could provide us with a source of considerable amount of energy (In **Table 2** are presented the orders of magnitudes of energies gained by different sources).

Table 2. Comparison between the orders of energies produced by different processes.

Chemical Reaction	1×10^7 Joule/Kilogram
Nuclear Fission	8×10^{13} Joule/Kilogram
Nuclear Fusion	3×10^{14} Joule/Kilogram
Fusion based on Annihilation	9×10^{16} Joule/Kilogram

One of the most interesting consequences of low energetic matter-antimatter interaction is the development of a novel source of energy which could be employed as fuel for engines for space Labs, (see Abdel-Raouf [17]). The idea is to store a tiny amount (few micrograms) of antimatter (say antihydrogen) in electromagnetic controlled cavity and allows part of it to mix with a huge amount of stored matter (say hydrogen, deuterium, tritium or helium gas). The resulting annihilation energy could be stored and used as a fuel for space shuttle engines, (see Deutsch [18] and Abdel-Raouf [19]).

The vigorous interest of space scientists and engineers working at NASA in building up such engines for space shuttles is twofold:

1) The engine would be extremely light, i.e. the mass of the whole Space Shuttle would be considerably small,

2) The energy gained from the fuel of this engine is much larger than the energy produced by any other fuel, which means that it would be extremely useful for carrying out long distance space trips in short times.

On the other hand, the annihilation of thermalized antiparticles may find wide medical applications, e.g. Diagnosing and Therapy of Cancer. For example, positron emission tomography (PET) is considered now as one of the most effective treatments of cancer see e.g. Chen and Chen [20]).

4.3. Fate of Antiparticles Produced by the Big Bang

One of the most difficult dilemmas facing our understanding of the structure of our Universe as a result of the big bang is the fact that the number of antiparticles occurring is minimal in comparison with the number of particles. Modern particle physics was established on the following well known fundamental concepts:

1) Einstein's mass-energy equivalence principle is true. Which means that mass can be fully converted into energy and energy can be fully converted into mass. This fact has found over the years wide experimental proofs.

2) The Big Bang Theory is the ultimate explanation of the creation of our Universe. The theory is supported by the standard model which is supported by all recent fundamental discoveries in Particle Physics.

3) The numbers of particles and antiparticles produced by the Big Bang must be identical, which is the basis of the baryon conservation law. The fact that there are rare traces of antiparticles in our Universe violates this law and suggests the occurrence of symmetry breaking accompanied with the Big Bang.

Apart from the rareness dilemma of antiparticles, two other dilemmas were

exposed by astrophysics, namely dark matter (Trimble [21]) and dark energy (Peebles [22]). On the other hand, the coexistence of matter and antimatter discussed in the preceding sections suggests a different hypothetical explanation for the fate of antiparticles immediately after the Big Bang (Abdel-Raouf [19] [23] and [24]). According to this proposed explanation, particles and antiparticle were subjected to two different forms of gravity immediately after their production, which led to the creation of our Universe and an Antiuniverse. This argument contradicts with Einstein picture of gravity; it encourages searching the existence of an opposite form of gravity referred to as antigravity, (ALPHA Collaboration [25] and perhaps the discovery particles with negative masses. It was also argued that there is an overlapping area between the two universes in which continues creation and annihilation processes take place. The antiparticles appearing in our Universe are the ones escaping from this area: The hypotheses of overlapping Universe and Antiuniverse could provide us with plausible explanation for the sources of dark matter and dark energy in our Universe as well as an alternative explanation the source of high energetic Gamma Rays detected at the edge of our Universe (Starr [26]). (For very recent support for the possible existence of antiuniverse, see Turok [27], Johnson and Lehners [28], Czech [29] and Carr [30]).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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