National Research Nuclear University “MEPhI”

Department 40 (Physics of Elementary Particles)

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**Anomalous Isotopes as a Probe for**

**New Stable Forms of Matter**

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9. **Introduction.**

It is known that Standard Big Bang Nucleosynthesis gives rise to formation of light elements only and its theory predicts negligible pre-galactic abundance of elements, heavier than lithium. This point can change drastically, if there exist stable charged leptons and/or quarks. Several elementary particle frames for heavy stable charged particles were considered:

1. A heavy quark and heavy neutral lepton (neutrino with mass above half the Z-Boson mass) of fourth generation, which can avoid experimental constraints and form composite dark matter species [1];
2. A Glashow’s “Sinister” heavy tera-quark U and tera-electron E, which can form a tower of tera-hadronic and tera-atomic bound states with “tera-helium atoms” (UUUEE) considered as dominant dark matter [2];
3. AC-leptons, predicted in the extension of standard model, based on the approach of almost-commutative geometry, can form evanescent AC-atoms, playing the role of dark matter [3];
4. Finally, it was shown in [4], that an elegant solution is possible in the framework of walking Technicolor models and can be realized without an *ad hoc* assumption on charged particle excess, made in the approaches (a)-(c) [5].

In all these models, predicting stable charged particles, the particles escape experimental discovery, because they are hidden in elusive atoms, maintaining dark matter of the modern Universe. It offers new solution for the physical nature of the cosmological dark matter. The main problem for these solutions is to suppress the abundance of positively charged species bound with ordinary electrons, which behave as anomalous isotopes of hydrogen or helium.

Indeed, it turned out that the necessary condition for the considered scenario, avoiding anomalous isotopes overproduction, is absence of stable particles with charge -1, so that stable negatively charged particles should only have charge -2.After it is formed in Big Bang Nucleosynthesis, $^{++}$ screens the $A^{--}$charged particles in composite ($^{++}A^{--}$) O-helium “atoms”. These neutral primordial nuclear interacting objects contribute the modern dark matter density and play the role of a nontrivial form of strongly interacting dark matter.

The active influence of this type of dark matter on nuclear transformations seems to be incompatible with the expected dark matter properties. However, it turns out that the considered scenario is not easily ruled out and challenges the experimental search for various forms of O-helium and its charged constituents.

Binding of various types of such particles with $$ results in different forms of O-helium atoms: O-helium, OLe-helium, ANO-helium or techni-O-helium. However, all these different forms of O-helium have the same size (see 3), the same cross section for interaction with baryonic matter and play the same role in nuclear transformations.

In all these forms of O-helium $X^{--}$ behave either as leptons or as specific ”hadrons” with strongly suppressed hadronic interaction. Therefore O-helium interaction with matter is determined by nuclear interaction of He. These neutral primordial nuclear interacting objects contribute the modern dark matter density and play the role of a nontrivial form of strongly interacting dark matter. I will not specify in this work the property of O-nuclei and will consider the general case of OHe.

1. **Formation of O-helium.**

In the Big Bang Nucleosynthesis, $$ is formed with an abundance $r\_{He}$ =0.1$r\_{B}$ = 8·$10^{-12}$and, being in excess, binds all the negatively charged species into atom-like systems.

At a temperature T <$I\_{0}$ = $Z\_{TC}^{2}Z\_{He}^{2}α^{2}m\_{He}$/2 ~1.6MeV, where α is the fine structure constant, and $Z\_{TC}^{}$ = −2 stands for the electric charge of $\overbar{UU}$and/or of ζ, the reaction



and/or



can take place. In these reactions neutral O-helium “atoms” (tOHe) are produced. The size of these “atoms” is



Virtually all the free ($\overbar{UU}$) and/or ζ (which will be further denoted by $A^{--}$)are trapped by helium and their remaining abundance becomes exponentially small.

For particles $Q^{-}$with charge −1, as for tera-electrons in the sinister model**[Ref]**,$$ trapping results in the formation of a positively charged ion $(^{++}Q^{-})^{+}$,result in dramatic over-production of anomalous hydrogen. Therefore, only the choice of −2 electric charge for stable particles makes it possible to avoid this problem. In this case, 4He trapping leads to the formation of neutral techni-O-helium *techni-O-helium “atoms”* ($^{++}A^{--}$).

1. **Primordial heavy elements from O-helium catalysis.**

O-helium looks like an α particle with a shielded electric charge. It can closely approach nuclei due to the absence of a Coulomb barrier. Because of this in the presence of O-helium the character of Standard Big Bang Nucleosynthesis (SBBN) processes should change drastically. However, it might not lead to immediate contradictions with the observational data.

The interaction of the $$ component of ($^{++}A^{--}$) with a $$ nucleus can lead to a nuclear transformation due to the reaction



provided that the masses of the initial and final nuclei satisfy the energy condition



where $I\_{0}$ = 1.6MeV is the binding energy of O-helium and M(4, 2) is the mass of the $$ nucleus.

This condition is not valid for stable nuclei participating in reactions of the SBBN. However, tritium $$, which is also formed in SBBN with abundance$$/H ~$10^{-7}$ satisfies this condition and can react with O-helium, forming $$ and opening the path of successive O-helium catalyzed transformations to heavy nuclei. This effect might strongly influence the chemical evolution of matter on the pre-galactic stage and needs a self-consistent consideration within the Big Bang Nucleosynthesis network.

• On the path of reactions (4), the final nucleus can be formed in the excited(α,M(A,Z)) state, which can rapidly experience an α- decay, giving rise to O-helium regeneration and to an effective quasi-elastic process of($^{++}A^{--}$)-nucleus scattering. It leads to a possible suppression of the O-helium catalysis of nuclear transformations .

• The path of reactions (4) does not stop on $$ but goes further through$$, $$, $$, ... along the table of the chemical elements.

• The cross section of reactions (4) grows with the mass of the nucleus, making the formation of the heavier elements more probable and moving the main output away from a potentially dangerous Li and B overproduction.

 Charged massive particles Big Bang Nucleosynthesis (BBN), studying the influence of unstable negatively charged massive particles on BBN. Bound states of metastable singly charged particle $X^{-}$ with nuclei can catalyze formation of lithium and even elements with A> 8. The important difference of SBBN considered in these papers, from our approach, is that singly charged particles $X^{-}$ with charge −1 do not screen the +2 charge of He in a$(HeX)^{+}$ion-like bound system, and the Coulomb barrier of the $(HeX)^{+}$ion can strongly hamper the path for the creation of heavy isotopes.

1. **O-helium catalyzed processes in the Earth.**

The first evident consequence of the proposed model is an inevitable presence of OHe in terrestrial matter. This is because terrestrial matter appears opaque to O-helium and stores all its in-falling flux.

If the tOHe capture by nuclei is not effective, its diffusion in matter is determined by elastic collisions, which have a transport cross section per nucleon

 **** (6)

In atmosphere, with effective height $L\_{atm}$ = 106 cm and baryon number density $n\_{B}$ = 6 ·$10^{20}cm^{-3}$, the opacity condition is not strong enough. Therefore, the in-falling tOHe particles are effectively slowed down only after they fall down terrestrial surface in 16$S\_{2}$ meters of water (or 4$S\_{2}$ meters of rock). Then they drift with velocity cm/ s (where A ~ 30 is the average atomic weight in terrestrial surface matter, and g = 980 cm/$S\_{2}$), sinking down the center of the Earth on a timescale  s, where $R\_{E}$ is the radius of the Earth.

The in-falling techni-O-helium flux from dark matter halo is , where the number density of tOHe in the vicinity of the Solar System is $n\_{0}$ = and the averaged velocity cm/ s. During the lifetime of the Earth, about  O-helium atoms were captured. If tOHe dominantly sinks down the Earth, it should be concentrated near the Earth’s center within a radius , which is ≤ cm, for the Earth’s central temperature and density  .

Near the Earth’s surface, the O-helium abundance is determined by the equilibrium between the in-falling and down-drifting fluxes. It gives

 **** (7)

This number density corresponds to the fraction

  (8)

relative to the number density of the terrestrial atoms 

 These neutral ($^{++}A^{--}$) “atoms” may provide a catalysis of cold nuclear reactions in ordinary matter (much more effectively than muon catalysis). This effect needs a special and thorough investigation. On the other hand, if $A^{--}$ capture by nuclei, heavier than helium, is not effective and does not lead to a copious production of anomalous isotopes , the ($^{++}A^{--}$) diffusion in matter is determined by the elastic collision cross section (6) and may effectively hide O-helium from observations.

1. **Direct search for O-helium.**

In underground detectors, tOHe “atoms” are slowed down to thermal energies and give rise to energy transfer ~2.5·$10^{-3}$eVA/S2, far below the threshold for direct dark matter detection. It makes this form of dark matter insensitive to the CDMS constraints. However, tOHe induced nuclear transformation can result in observable effects.

Therefore, a special strategy of such a search is needed, that can exploit sensitive dark matter detectors on the ground or in space. In particular, a few g of superfluid $$ detector, situated in ground based laboratory can be used to put constraints on the in-falling O-helium flux from the galactic halo.

1. **Detection of O-helium**

The nuclear interaction of O-helium with cosmic rays gives rise to ionization of this bound state in the interstellar gas and to acceleration of free $X^{--}$ in the Galaxy. Assuming a universal mechanism of cosmic ray acceleration the anomalous low Z/A component of −2 charged $X^{--}$ can be present in cosmic rays and be within the reach for PAMELA and AMS02 cosmic ray experiments.

Inelastic interaction of O-helium with the matter in the interstellar space and its de-excitation can give rise to radiation in the range from few keV to few MeV. One can expect two kinds of inelastic processes in the matter with nuclei (A,Z), having atomic number A and charge Z: first one was described in (4) and (5) and the second one is

()

In the both types of processes energy release is of the order of MeV, which seems to have nothing to do with the signals in the DAMA experiment. However, in the reaction (6) such energy is rapidly carried away by He nucleus, while in the remaining compound state of [(A, Z)$ X^{--}$] the charge of the initial (A,Z) nucleus is reduced by 2 units and the corresponding transformation of electronic orbits with possible emission of two excessive electrons should take place. The energy difference between the K orbits of the lowest lying electronic 1s level of the initial nucleus with the charge Z and the respective levels of its compound system with $X^{--}$is given by

 (7)

 Here we took into account that the energy difference comes from the change in the nuclear charge with the initially unchanged structure of electronic shells. It is interesting that the energy release in such transition for two 1s electrons in $$ is about 2 keV, while for $$ it is about 4 keV. Taking into account that the signal in the DAMA experiment was detected with similar energy of ionization, this idea deserves more detailed analysis, which might be useful for interpretation of this experiment. Since the experimental cuts in the CDMS experiment 27, exclude events of pure ionization, which are not accompanied by phonon signal, if valid, the proposed mechanism could explain the difference in the results of DAMA and CDMS and other direct dark matter searches that imply nuclear recoil measurement, which should accompany ionization.

 An inevitable consequence of the proposed explanation is appearance in the matter of DAMA/NaI or DAMA/Libra detector anomalous superheavy isotopes of antinomy (Sb with nuclear charge Z = 53 − 2 = 51) and gold (Au with nuclear charge Z = 81 − 2 = 79), created in the inelastic process (6) and having the mass roughly by mo larger, than ordinary isotopes of these elements. If the atoms of these anomalous isotopes are not completely ionized, their mobility is determined by atomic cross sections and becomes about 9 orders of magnitude smaller, than for O-helium. It provides conservation in the matter of detector of at least 200 anomalous atoms per 1g, corresponding to the number of events, observed in DAMA experiment. Therefore mass-spectroscopic analysis of this matter can provide additional test for the O-helium nature of DAMA signal.

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