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Research Article

LENR Solution of the Cosmological Lithium Problem

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Abstract

This paper considers a mechanism for solving the "lithium problem" in cosmology: a very significant difference in the observed (measured) concentration of lithium isotopes in the Universe in comparison with the results of a detailed analysis of the process of primary nucleosynthesis in the Big Bang model. It is shown that such isotope anomalies (a great decrease of the Li^7 concentration and a 500-fold increase of the Li^6 concentration) can be associated with a very significant increase of the probability of $Li^6(d, He^4)He^4$ and $Li^7(p, He^4)He^4$ reactions involving protons and deuterium in the near-surface region of stars with temperature $T \leq 100\, eV$. The process of optimization of nuclear fusion reactions is associated with the formation of coherent correlated states of protons and deuterons, which leads to a short-term generation of very large fluctuations in the momentum and energy of these particles, and occurs under the action of shock waves and impulse changes of the magnetic field of the star. These effects are identical to the processes that correspond to the standard LENR concepts and proceed at even lower energy.

Keywords: Big Bang nucleosynthesis, LENR in cosmology, Coherent correlated states, Lithium problem

1. INTRODUCTION

The basis of modern cosmology is the Big Bang theory. Its reliability is based on three fundamental results: a) redshift of radiation from distant stars due to the expansion of the Universe; b) the presence of microwave background radiation, the spatial structure of which is associated with the dynamics of the expansion of the Universe; c) the theory of primary nucleosynthesis (Big Bang nucleosynthesis, BBN), which lasted in the range from 13.8 sec to 38 minutes after the Big Bang and led to the formation of light nuclei H^2, He^3, He^4, Li^6 and Li^7 in the volume of an expanding plasma with a temperature that has changed during this time from $4.5 \cdot 10^9 K$ (390 keV) to $3.5 \cdot 10^9 K$ (30 keV).

The quantitative characteristics of the BBN theory were obtained from a very detailed analysis of the evolutionary processes of different isotopes, taking into account their mutual transformations during the time after the Big Bang (e.g. [1]). From this analysis, reasonable estimates were obtained for the ratio of the concentrations of the main light

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isotopes (n_X) and hydrogen (n_p), calculated both on the basis of the model of primary nucleosynthesis (BBN) at $t = t_0$, and obtained during the process of making astronomical measurements (short designation - am) at the present time $t = t_{am}$

$$(\tilde{n}_d)_{am} \equiv \tilde{n}_d(t_{am}) = n_d(t_{am})/n_p \approx 1.4 \cdot 10^{-5},\ (\tilde{n}_{He^3})_{am} \equiv \tilde{n}_{He^3}(t_{am}) \approx 3.5 \cdot 10^{-6},$$
$$(\tilde{n}_{He^4})_{am} \equiv \tilde{n}_{He^4}(t_{am}) \approx 0.06;$$
$$(\tilde{n}_d)_{BBN} \equiv \tilde{n}_d(t_0) \approx 1.3 \cdot 10^{-5},\ (\tilde{n}_{He^3})_{BBN} \equiv \tilde{n}_{He^3}(t_0) \approx 3.1 \cdot 10^{-6},$$
$$(\tilde{n}_{He^4})_{BBN} \equiv \tilde{n}_{He^4}(t_0) \approx 0.06. \quad (1)$$

These data demonstrate very good agreement between the calculation results and the experimental data.

A fundamentally different situation occurs in the analysis of lithium isotopes [1], [2], [4]. These isotopes were formed in the reactions of the initial nucleosynthesis [1], [5]–[8]

$$He^4 + H^3 \to Li^7 + \gamma,$$
$$He^4 + He^3 \to Be^7 + \gamma + 1.59MeV \to Be^7 + \beta^- \to Li^7 + \gamma,$$
$$He^4 + d \to Li^6 + \gamma. \quad (2)$$

The currently recorded relative concentration of the nuclei of the Li^7 isotope turns out to be 3 times less of the calculated initial value:

$$(\tilde{n}_{Li^7})_{BBN} \equiv \tilde{n}_{Li^7}(t_0) = n_{Li^7}(t_0)/n_p \approx 6.68 \cdot 10^{-11}$$
$$(\tilde{n}_{Li^7})_{am} \equiv \tilde{n}_{Li^7}(t_{am}) = n_{Li^7}(t_{am})/n_p = K_{Li^7}\tilde{n}_{Li^7}(t_0) \approx 2.2 \cdot 10^{-11}, K_{Li^7} \approx 1/3, \quad (3)$$

which, according to theoretical estimations, should remain approximately the same at the present time t_{am}. This decrease of the Li^7 isotope, which currently corresponds to 92.41% of all lithium, leads to a decrease of the total amount of lithium in the Universe.

In contrast, the recorded relative concentration of the nuclei of the Li^6 isotope (which now corresponds to 7.59% of the total lithium) turns out to be $K_{Li^6} \approx 500$ times greater than the calculated by BBN theory initial value:

$$(\tilde{n}_{Li^6})_{BBN} \equiv \tilde{n}_{Li^6}(t_0) = n_{Li^6}(t_0)/n_p \approx 1.8 \cdot 10^{-15},$$
$$(\tilde{n}_{Li^6})_{am} \equiv \tilde{n}_{Li^6}(t_{am}) = n_{Li^6}(t_{am})/n_p = K_{Li^6}\tilde{n}_{Li^6}(t_0) \approx 0.9 \cdot 10^{-12}. \quad (4)$$

These fundamental inconsistencies are called the "lithium paradox" in astrophysics, and their presence requires either an explanation or a revision of the entire BBN theory.

2. ANALYSIS OF THE POSSIBLE EVOLUTION OF LITHIUM ISOTOPES BASED ON THE THEORY OF "STANDARD" NUCLEAR PROCESSES

2.1. Abnormal Features of the Evolution of Li^6 Isotope in the Universe

Let us first consider the dynamics of changes of the concentration of lithium isotopes after the initial nucleosynthesis based on standard thermonuclear fusion.

The process of changing the concentration of the Li^6 isotope nuclei at a constant concentration of hydrogen, deuterium, and helium is described by the balance equation

$$\frac{dn_{Li^6}}{dt} = n_{He^4}n_d{<}\sigma_{He^4+d=Li^6}v{>} - n_{Li^6}\{n_p[{<}\sigma_{Li^6+p=He^3+He^4}v{>} + {<}\sigma_{Li^6+p=Be^7}v{>}] + n_d{<}\sigma_{Li^6+d=2He^4}v{>}\}, \quad (5)$$

Table 1. Parameters of the rates of thermonuclear reactions.

Reaction	Li^6(p,He^3)α	Li^6(p,γ)Be^7	Li^6(d,α)α	α(d,γ)Li^6	Li^7(p,α)α	H^3(α,γ)Li^7
A	$5.8\cdot10^{-14}$	$2\cdot10^{-18}$	$1.3\cdot10^{-13}$	$9\cdot10^{-23}$	$1.2\cdot10^{-15}$	$1.4\cdot10^{-18}$
B	8.415	8.415	10.14	6.993	8.473	8.08
C	3.659	3.659	4.409	3.04	3.684	3.513

which is determined by a combination of two opposite processes: an increase of this concentration due to the basic reaction of Li^6 isotope synthesis

$$He^4 + d = Li^6 + \gamma + Q(1.474\,MeV) \tag{6}$$

and its decrease in three similar reactions

$$\begin{aligned} &Li^6 + d = 2He^4 + Q(22.373\,MeV),\\ &Li^6 + p = He^4 + He^3 + Q(4.019\,MeV),\\ &Li^6 + p = Be^7 + \gamma + Q(5.606\,MeV). \end{aligned} \tag{7}$$

The solution of this equation has the form

$$\begin{aligned} \tilde{n}_{Li^6}(t) &= \tilde{n}_{He^4}\tilde{n}_d < \sigma_{He^4+d}v > \tau_{Li^6} n_p \left(1 - e^{-t/\tau_{Li^6}}\right) + \tilde{n}_{Li^6}(t_0)e^{-t/\tau_{Li^6}}\\ &\equiv \tilde{n}_{Li^6}(\infty)\left(1 - e^{-t/\tau_{Li^6}}\right) + \tilde{n}_{Li^6}(t_0)e^{-t/\tau_{Li^6}}\\ &= \tilde{n}_{Li^6}(\infty) + \left[\tilde{n}_{Li^6}(t_0) - \tilde{n}_{Li^6}(\infty)\right]e^{-t/\tau_{Li^6}},\\ \tau_{Li^6} &= 1/n_p\left\{\left(<\sigma_{Li^6+p=He^3+He^4}v> + <\sigma_{Li^6+p=Be^7}v>\right) + \tilde{n}_d<\sigma_{Li^6+d=2He^4}v>\right\}. \end{aligned} \tag{8}$$

In this solution, the first term characterizes the synthesis process, which determines the increase of the concentration of the nuclei of the Li^6 isotope, and the second determines its decrease due to the participation of these nuclei in the synthesis of other elements. These oppositely directed processes proceed with the same characteristic relaxation time τ_{Li^6}.

From the general solution (8) follows the expression for the limiting (at $t \gg \tau_{Li^6}$, i.e., formally at $t \to \infty$) relative concentration of Li^6

$$\tilde{n}_{Li^6}(\infty) = \frac{\tilde{n}_{He^4}\tilde{n}_d < \sigma_{He^4+d}v >}{\{< \sigma_{Li^6+p=He^3+He^4}v > + < \sigma_{Li^6+p=Be^7}v >\} + \tilde{n}_d < \sigma_{Li^6+d=2He^4}v >}, \tag{9}$$

which is the amplitude of the first term.

From the same general solution (8), one can determine the time

$$t_{K,Li^6} = \frac{\ln\left\{\left[\tilde{n}_{Li^6}(\infty) - \tilde{n}_{Li^6}(t_0)\right]/\left[\tilde{n}_{Li^6}(\infty) - \tilde{n}_{Li^6}(t_{am})\right]\right\}}{n_p\left(< \sigma_{Li^6+p=He^3+He^4}v > + < \sigma_{Li^6+p=Be^7}v >\right) + n_d < \sigma_{Li^6+d=2He^4}v >} \tag{10}$$

during which the relative concentration of the Li^6 isotope increases in $K_{Li^6} \approx 500$ times with respect to the initial calculated value $\tilde{n}_{Li^6}(t_0)$ to the current experimentally measured value $\tilde{n}_{Li^6}(t_{am}) = K_{Li^6}\tilde{n}_{Li^6}(t_0)$.

The parameters of the rates of the corresponding thermonuclear reactions [10]

$$< \sigma v >= (A/T_9^{2/3})e^{-B/\sqrt[3]{T_9}} \equiv (A/T_9^{2/3})10^{-C/\sqrt[3]{T_9}} \tag{11}$$

are presented in the Table (here T_9 is the temperature in units of 10^9 K).

In these and subsequent formulas the reaction rate is measured in [cm^3/sec].

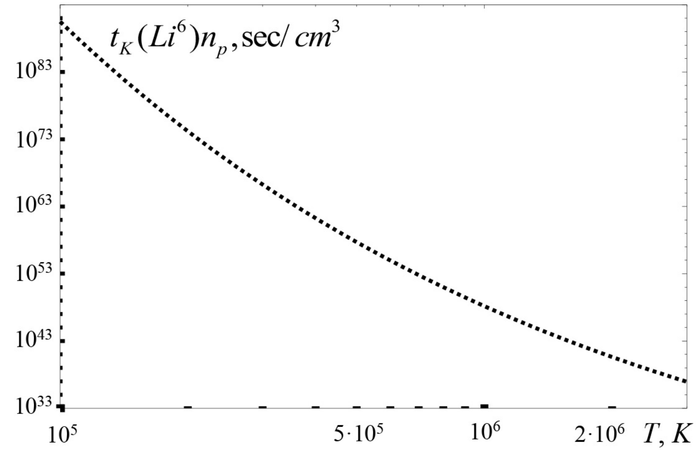

Figure 1. Dependence of the duration t_{K,Li^6} of the process of increasing the concentration of the Li^6 isotope by K = 500 times on temperature in "standard" nuclear reactions (6) and (7).

Using these parameters, it is easy to verify that the maximum possible (at $t \to \infty$) relative concentration of Li^6 isotope (9) exceeds both the initial (calculated) relative concentration $\tilde{n}_{Li^6}(t_0) \approx 3.5 \cdot 10^{-16+0.426/\sqrt[3]{T_9}}$ of this isotope and the observed (registered) value $\tilde{n}_{Li^6}(t_{am}) = K_{Li^6}\tilde{n}_{Li^6}(t_0) \approx 0.9 \cdot 10^{-12}$ only if the temperature does not exceed $T_9 \leq 0.0012$ $(T \leq 1.2 \cdot 10^6 K,\ kT \leq 100\,eV)$.

From this condition it is obvious that such processes can occur only in the near-surface and relatively cool layers of stars, where the probability of thermonuclear reactions is very small.

Figure 1 shows the dependence (10) of the time t_{K,Li^6} of Li^6 isotope formation on temperature and proton concentration.

From these data, it follows that even at a very high (for the surface layers of a star) proton concentration n$_p$ = 10^{23} cm^{-3}, the duration of the increase Li^6 isotope concentration at a temperature $T \leq 1.2 \cdot 10^6 K$ is many orders of magnitude longer than the duration of the existence of the Universe, which proves the impossibility of such a process if we consider it based on the standard approach! This is one side of the cosmological lithium paradox.

2.2. Paradoxes of Li^7 Isotope Evolution in the Universe

The basic relations characterizing the change of the concentration of the nuclei of the Li^7 isotope can be found in a similar way.

After the completion of the stage of the primary nucleosynthesis of the Li^7 isotope (including $He^4 + H^3 = Li^7$ reaction with the participation of unstable tritium), the peculiarities of the change of its concentration are determined by two oppositely directed processes: an increase due to the reactions of Be^7 isotope synthesis and subsequent electron capture

$$He^4 + He^3 \to Be^7 + 1.59MeV \to Be^{\,7} + \beta^-(100\%) \underset{53.2day}{\longrightarrow} Li^7 + \gamma$$

and a decrease due to the $Li^7 + p = 2He^4$ reaction, which is described by the balance equation

$$\frac{dn_{Li^7}}{dt} = n_{He^4} n_{He^3} \langle\sigma_{He^4+He^3=Be^7+\beta^-=Li^7} v\rangle - n_{Li^7} n_p \langle\sigma_{Li^7+p=2He^4} v\rangle \tag{12}$$

with the corresponding solution

$$\tilde{n}_{Li^7}(t \geq t_0) = \frac{\tilde{n}_{He^4}\tilde{n}_{He^3} < \sigma_{He^4+He^3=Be^7+\beta^-=Li^7}v >}{< \sigma_{Li^7+p=2He^4}v >}\left\{1 - \exp[-n_p < \sigma_{Li^7+p=2He^4}v > t]\right\}$$
$$+ \tilde{n}_{Li^7}(t_0)\exp\left[-n_p < \sigma_{Li^7+p=2He^4}v > t\right]$$
$$\equiv \tilde{n}_{He^4}\tilde{n}_{He^3} < \sigma_{He^4+He^3=Be^7+\beta^-=Li^7}v > \tau_{Li^7}n_p(1 - e^{-t/\tau_{Li^7}}) + \tilde{n}_{Li^7}(t_0)e^{-t/\tau_{Li^7}} \quad (13)$$

and the time of relaxation

$$\tau_{Li^7} = 1/n_p < \sigma_{Li^7+p=2He^4}v >. \quad (14)$$

From formula (14) it follows that the limiting (at $t \gg \tau_{Li^7}$) relative concentration of the Li^7 isotope should be equal to

$$\tilde{n}_{Li^7}(\infty) = \frac{\tilde{n}_{He^4}\tilde{n}_{He^3}<\sigma_{He^4+He^3=Be^7+\beta^-=Li^7}v>}{<\sigma_{Li^7+p=2He^4}v>} \quad (15)$$

The final expression for the current relative concentration of this isotope takes the form

$$\tilde{n}_{Li^7}(t \geq t_0) = \tilde{n}_{Li^7}(\infty)(1 - e^{-t/\tau_{Li^7}}) + \tilde{n}_{Li^7}(t_0)e^{-t/\tau_{Li^7}}$$
$$= 2.3 \cdot 10^{-10+0.172/\sqrt[3]{T_9}}(1 - e^{-t/\tau_{Li^7}}) + 6.3 \cdot 10^{-11}e^{-t/\tau_{Li^7}} \quad (16)$$

From solution (17), one can determine the time

$$t_{K,Li^7} = \frac{1}{n_p < \sigma_{Li^7+p=2He^4}v >}\ln\left\{\frac{\tilde{n}_{Li^7}(t_0) - \tilde{n}_{Li^7}(\infty)}{\tilde{n}_{Li^7}(t_{am}) - \tilde{n}_{Li^7}(\infty)}\right\} \quad (17)$$

during which the relative concentration of the Li^7 isotope changes (decreases in 3 times, $K_{Li^7} \approx 1/3$) to the current measured value $\tilde{n}_{Li^7}(t_{am}) \equiv \tilde{n}_{Li^7}(t_{K\approx 1/3,Li^7}) = K_{Li^7}\tilde{n}_{Li^7}(t_0)$.

From (16) it follows that the calculated limiting concentration of the Li^7 isotope $\tilde{n}_{Li^7}(\infty) \approx 2.3 \cdot 10^{-10+0.171/\sqrt[3]{T_9}}$ is much higher than both the initial $\tilde{n}_{Li^7}(t_0) \approx 6.68 \cdot 10^{-11}$ and current measured $\tilde{n}_{Li^7}(t_{am}) \approx 2.2 \cdot 10^{-11}$ concentrations of this isotope.

This directly contradicts the experimental data, which indicate a decrease in this concentration. This is another side of the cosmological paradox of lithium.

Based on these results, it is obvious that it is impossible to solve the "lithium paradox" on the basis of standard thermonuclear fusion models, and explain the very large difference between the BBN theory and the results of experimental measurements of the concentrations of Li^6 and Li^7 isotopes.

3. FORMATION OF COHERENT CORRELATED STATES AND OPTIMIZATION OF REACTIONS INVOLVING LITHIUM ISOTOPES TAKING INTO ACCOUNT DYNAMIC PROCESSES IN STAR VOLUME

3.1. Features of Dynamic Processes in the Near-Surface Layers of Stars

All traditional methods for analyzing nuclear transformations in stars (including the analysis of the evolution of lithium) are based on the standard concept of an active medium as an isolated plasma, and do not take into account other significant factors that strongly influence nuclear reactions, such as:

a) the action of shock waves generated in the volume, on the surface and in the atmosphere of stars;

b) the action of a nonstationary magnetic field, which is formed in a moving inhomogeneous plasma.