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On The History Of Nucleosynthesis And Creation Of Chemical Elements

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Annotation: This article focuses on the evolutionary astrophysical history of the formation of all substances, celestial and earth bodies, and the entire universe, cited and analyzed the scientific astrophysical processes associated with these issues, nuclear reactions.

Keywords: nucleosynthesis, nuclear reaction, s-process, r-process, star flash, explosion, synthesis, thermosynthesis, neutron compression, proton compression, red giant, beta-eating, black mass, black energy.

The question of where all the substances in the universe, heaven and earth, as well as the chemical elements and substances that make up all existence, came from is undoubtedly of interest to everyone. It is not difficult to understand how substances are formed from them, because they are the result of chemical reactions and gravitational forces. However, the study of the history and evolution of elements is a problematic issue, and the connection of this issue with nuclear reactions is becoming increasingly obvious. Nucleosynthesis solves the same problem. Nucleosynthesis is divided into three stages. These are: cosmological nucleosynthesis, nuclear fusion in stars and their explosions, third stage nucleosynthesis under the influence of cosmic rays. Among them, cosmological nucleosynthesis is associated with the appearance of the first elements in the Universe and with nuclear fusion at the stage preceding the appearance of stars in the Universe. For example, atomic nuclei heavier and more complex than protons began to appear approximately 100 s after the start of the expansion of the Universe [1]. At this time, protons and neutrons were formed in the Universe, and the temperature was T ~ 10^9 K. The synthesis of these lightest elements - deuterium, tritium and helium - can be represented as follows:

$$\begin{gathered} n+p \rightarrow D+\gamma, \quad D+D \rightarrow He^3+n, \quad D+D \rightarrow T+p \\ He^3+n \rightarrow T+p, \quad T+D \rightarrow He^4+n, \\ D+p \rightarrow He^3+\gamma, \quad T+p \rightarrow He^4+\gamma \end{gathered} \tag{1}$$

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Today's Standard Model also confirms that He4 in astrophysical objects constitutes a large percentage (22%) in the early stages of the creation of the Universe. However, it is somewhat problematic to explain that relatively heavier nuclei appeared after the expansion of the Universe. Because with the expansion of the Universe, the temperature should have decreased and the density should have decreased. It follows that the appearance of these nuclei may be associated with the next stages of the development of the Universe.

Most of the chemical elements we know can be linked to the formation of stars, galaxies and cosmic rays billions of years after the Universe began to expand. It is also more difficult to explain the appearance of elements such as deuterium, lithium, beryllium, and boron. It is also concluded that this could be the case. As a result of such processes, relatively large amounts of Li^6, Be^9, B^{10} can also be formed, but the appearance of Li and B isotopes is very difficult to explain. It is also surprising that there are more odd isotopes than even ones. In addition, it is said that supernova explosions can cause the appearance of such light elements [2].

The formation of heavy elements is said to be related to fusion processes and stellar explosions, from carbon to the long-lived actinium and even heavier elements. The elements most likely to form from high temperature fusion reactions are carbon and nickel. The formation of heavy elements is associated with the aging of massive stars and can be observed by neutron capture. The formation of carbon and oxygen is associated with the combustion of hydrogen and helium in old stars. At the observation temperature of this process ($T \sim 10^8$), the following nuclear fusion reactions are most effectively observed [3]:

$$3\alpha \to C^{12} + \gamma \quad \text{va} \quad C^{12} + \propto \to O^{16} + \gamma \qquad (2)$$

At high temperatures ($T \sim 10^9$ K), combustion reactions of carbon and oxygen occur and elements from neon to silicon are formed. At a slightly higher temperature ($T \sim 10^{10}$ K), explosive nucleosynthesis produces iron and similar elements. It is known that the specific binding energy of the iron nucleus is the highest, which means that the formation of elements heavier than iron is reduced due to fusion reactions involving neutron capture. There are two types of neutron capture reactions: the first is the slow s-process capture, in which the resulting unstable nucleus decays until the next neutron arrives and melts. The second is the rapid sequential capture of large numbers of neutrons as a result of the beta decay of the r-process. Slow neutron capture is observed at a neutron concentration of 10^7-10^8 cm^{-3} at an energy of ≈30 keV, and this process

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causes the formation of heavy elements up to Bi^{209}. In this type of neutron capture, neutron capture is accompanied by subsequent beta decay, and some parameters of the s-process can be determined through experimental modeling in laboratory conditions. In this sense, it is possible to determine the area of the neutron coating precisely at this neutron energy. To observe the S-process, the temperature of the astrophysical process (astrophysical objects where the process is observed and the regions within them) must first be greater than 10^8 K and the thermosynthesis reaction will be possible only with a sufficient concentration of neutrons. For neutron sources that maintain the neutron concentration at this level, the following reactions observed in old red giants are proposed [3]:

$$Ne^{22}+\propto\rightarrow Mg^{25}+n, \quad C^{13}+\propto\rightarrow O^{16}+n \qquad (3)$$

In the interior of stars, conditions are observed for the formation of heavy nuclei, which are covered by pulsed neutrons through the formation of a mixture of hydrogen and carbon due to flares in their helium shells, and sufficient temperature is provided. Such s-processes can be observed only in the class of stars of medium and high mass ($3M_S$-$10M_S$)[3].

Unlike the s-process, the r-process is a process of rapid neutron capture in an environment with a high neutron concentration (more than 10^{18}), and this process depends on the beta decay rate, neutron energy and neutron concentration. Although laboratory models of this process exist, the process itself is not fully understood. According to the classical explanation of the r-process, the replenishment of neutrons continues until a balance of these forward and reverse $(n,\gamma)\leftrightarrow(\gamma,n)$ reactions is reached. At this moment, beta decay is observed, the more the nuclear charge increases, the more the number of neutrons decreases (Z+1, N-1). The passage of the r-process leads to the appearance of heavier nuclides (Th^{232}, U^{238}) than actinium [5]. So, the origin of neutron-rich nuclides is associated with this r-process.

In fact, there seems to be no need to divide neutron capture reactions in astrophysical objects into s- and r-processes. Because neutron capture in astrophysical objects is a complex mixture of these processes. However, special attention must be paid to the appearance of nuclides after iron. For these nuclides, the importance of magic numbers is noticeable in both processes in the formation of stable nuclei, especially for doubly magic nuclei.

However, these processes are not associated with the formation of stable isotopes of most heavy elements, starting with selenium (Se^{74}, Kr^{78}, Sr^{84} and

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others). The formation of nuclei with a relatively small number of such neutrons is associated with the coverage of protons (p, γ), (p, n). This is called a p-process. In addition, this is also due to the knocking out of neutrons from nuclei under the influence of light, and such reactions are explained by weak influence [4]:

$$e^{+} + (A, Z) \rightarrow (A, Z+1) + \tilde{\nu},$$
$$\gamma + (A, Z) \rightarrow (A, Z+1) + e^{-} + \tilde{\nu} \qquad (4)$$

However, the process of formation of isotopes with a relatively small number of neutrons has not yet been fully proven. It should also be emphasized that the above-mentioned processes of element formation are more true for elements common in the Solar System. There are plenty of problems with the history of the appearance of common elements distributed throughout the Universe. It should also be emphasized that the mass of substances visible to our eyes and affecting our senses, the history of which is discussed in this article, is only 5% of the mass of the Universe. The physical nature of the remaining dark matter and dark energy is unknown (Picture 1). The problems associated with such issues are endless and limitless.

As can be seen from the figure, according to the structure of the Universe, based on the latest scientific ideas, the ordinary elements we are talking about, during the history of their formation, make up only 5% of the mass of the Universe (only hydrogen and helium make up 4% of the mass), dark matter - 25% and dark energy - 70%. Although we have a better understanding of light radiation than of neutrinos, light radiation makes up 0.005% of the mass of the Universe, and neutrinos make up 0.17% (Picture 1).

However, ideas about the structure of the Universe are extremely broad and colorful. There are quite a lot of problems with this issue.

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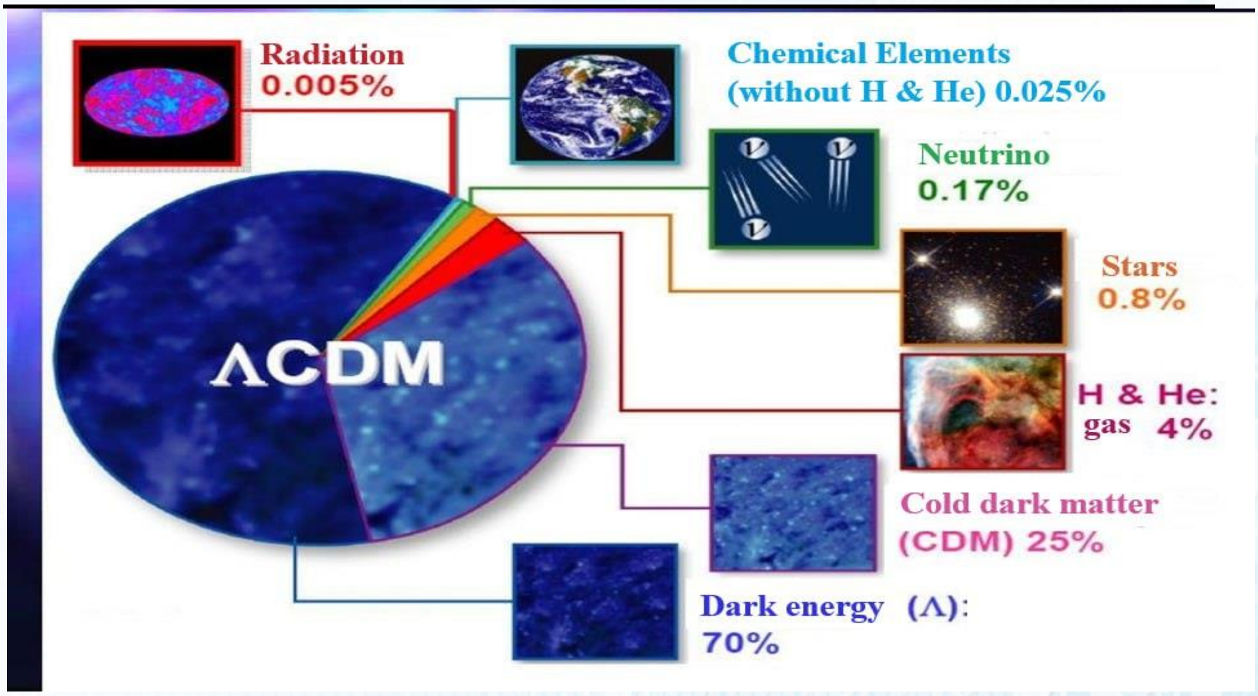

Picture 1. Modern presentation of the structure of the Universe in percentages.

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