NUCLEOSYNTHESIS

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10th semester, Lectures: 34 hours

The aim of the course "Nucleosynthesis" is the study by the students of the basic processes and possible scenarios of the creation of nuclei (i.e. chemical elements), which can be observed in the visual part of the Universe, models of stars and basic laboratory research trends in the synthesis of new elements and isotopes.

During the course a student should acquire a clear idea of modern models of the evolution of the Universe and stars, which are based on the description of the observed abundance of element in nature. All these models are based on the "big bang" hypothesis, data about the parameters of the Universe expansion and standard scenarios of the appearance and evolution of stars as the basic source of the heavy elements synthesis. During the course students study the results of the laboratory research on the basic nucleosynthesis processes, extracting of nuclear constants, which are necessary for the understanding of the scenarios of the evolution of the stars, and the possible use of nuclear reactions of thermonuclear fusion for the power generation. This course presupposes that students have already studied general courses "Nuclear physics" and "Quantum mechanics", as well as special courses on nuclear reactions with neutrons, gamma quanta and charged particles.

<u>The contents of the sections of the discipline</u>

1. Introduction

1.1 Nuclear chart, stability limits

1.2 Abundance of element in nature

1.3 "Big bang" model

1.4 Possible reactions of nuclear synthesis and their basic characteristics

2. Conceptual issues of nuclear astrophysics

2.1 The expansion of the Universe

2.2 Helium-hydrogen ratio and nucleosynthesis of the "big bang"

2.3 Star production and their systematics

2.4 Star evolution and supernova explosion

2.5 Heavy elements production

2.6 Critical density and dark matter

3. Nucleosynthesis in stars and solar model

3.1 Thermonuclear reactions, basic issues

3.2 Astrophysical S-factor

3.3 Gamow peak

3.4 Rate of thermonuclear reactions, resonance reactions

3.5 Standard solar model

3.6 Basic process of hydrogen combustion

3.7 CNO-cycle of hydrogen combustion

3.8 Solar neutrino, problems

3.9 Combustion of helium, carbon and other nuclei

4. Nucleosynthesis in supernovas

4.1 Completion of the star cycle, red giants and supernovas

4.2 Nucleosynthesis in supernovas

4.3 s-process

4.4 r-process and heavy elements production

4.5 rp-process

4.6 Gamma-process

5. Controlled thermonuclear reactions

5.1 Characteristics of basic thermonuclear reactions

5.2 Hot plasma and Lawson criterion

5.3 Gravity, inertial, magnetic, bubble and muonic synthesis

5.4 Principal tokamak scheme and basic results

6. Superheavy element synthesis

6.1 Main historical stages of laboratory heavy element synthesis

6.2 Stability island

6.3 Setting up of the experiments on superheavy elements synthesis

6.4 “Cold” and “hot” fusion reactions

6.5 Yield cross-section of evaporation remains

6.6 Competition of fusion and quasi-fission

6.7 Competition of light particles fission and evaporation

6.8 The latest experimental results of superheavy elements synthesis

6.9 Further prospects of superheavy elements synthesis

7. Exotic nuclei production and reactions with them

7.1 r-process and neutron-excess nuclei, their properties and production

7.2 rp-process and proton-excess nuclei, their properties and production

7.3 Extraction of nuclear astrophysical S-factors

7.4 Production of beams of radioactive nuclei, separation, experiments

Methodical recommendations for the tutor

This course is given to students after they have studied the basics of cosmology and special courses on nuclear reactions with neutrons, gamma-quanta and charged particles. Students are supposed to know regularities of these reactions at low energies and at subbarrier energies in particular. The focus is made on the discussion of modern models of the development of the Universe, which are worked out just on the basis of the properties of nuclear reactions of nucleosynthesis. As experimental data serve the abundance of elements in nature, which is studied quite thoroughly, and the observed regularities in the evolution of stars and the Sun. In the concluding parts of the course we study laboratory methods of the study of astrophysical reactions of nucleosynthesis, and focus on the experimental (not speculative) nature of nuclear astrophysics, which is in contrast to, for example, cosmology.

Methodical recommendations for the students

First of all, a student should get used to the idea that it’s necessary to learn nuclear physics terminology as soon as possible, because the basic literature on this course (as well as on other courses, by the way) and nuclear databases are written in English. During this course students are offered to apply the acquired knowledge about nuclear reactions to the explanation of fascinating cosmological phenomena, including the origin of the Universe and star combustion.