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Plasma-Induced Modification of Nuclear β-Decays and Application to Nucleosynthesis

The abundance of elements in the cosmos is a topic of active investigation. Since the dawn of nuclear astrophysics, various processes have been identified to explain the synthesis of elements, both qualitatively and quantitatively. Among these, the slow (s-) and rapid (r-) neutron capture processes are responsible for the synthesis of roughly 99% of all elements beyond the iron peak.

Nucleosynthesis models are sensitive to a variety of inputs, such as neutron capture cross sections and β-decay rates. Among these, the latter is known to be strongly modified in the presence of hot and dense plasmas, such as those found in s- and r-process nucleosynthesis sites [1]. As such, there is a need to study the variation of nuclear decay rates as a function of plasma properties, to improve the accuracy in calculated elemental abundances.

In this talk, we will present the concept of plasma-induced modification of β-decay rates through the examples of electron capture in ^{7}Be and ^{140}Pr and bound-state β-decay in ^{163}Dy. We will begin from the model of Takahashi and Yokoi [1] to calculate the lepton phase volume of the radionuclides as a function of their ionisation state and excitation level, and consequently, the configuration-dependent decay rate. By combining this with the ion charge state distribution (CSD), the decay half-life can be mapped to the plasma density and temperature. Additionally, we will also discuss the enhancement of decay rates through excitation of isomeric levels in certain nuclei such as ^{176}Lu. The talk will include a short description of the upcoming PANDORA (Plasmas for Astrophysics, Nuclear Decay Observations and Radiation for Archaeometry) facility at INFN-LNS, Catania, which aims to measure decay rates and light element opacity in stable plasmas produced in an electron cyclotron resonance ion trap (ECRIT) [2]. The talk will conclude with perspectives on similar studies that may be performed in short-lived laser-generated plasmas, discussing the pros and cons compared to ECRITs.

[1] Takahashi K. and Yokoi K., Nuclear β-Decays of Highly Ionised Heavy Atoms in Stellar Interiors. Nucl. Phys. A 404, 578 (1983)

[2] Mascali D., Santonocito D. et al, A Novel Approach to β-Decay: PANDORA, a New Experimental Setup for Future In-Plasma Measurements. Univese 8, 80 (2022)

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