Unveiling the Cosmos: Exploring the Matter-Antimatter Asymmetry

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June 2024

Picture the early universe, beginning with the Big Bang. According to our current understandings, the Big Bang should have produced equal amounts of matter and antimatter. However, we find ourselves in a universe dominated by matter, with antimatter relatively scarce. This asymmetry presents one of the most captivating mysteries in physics:
Why is there more matter than antimatter in our universe today?

The key to unravel this mystery may lie in a phenomenon known as $\mathcal{CP}$-violation. To grasp this concept, we first need to understand the role of symmetry in physics. Symmetries represent the fundamental building blocks of physics, describing how certain properties of a system remain unchanged under specific transformations. $\mathcal{CP}$-violation occurs when the laws of physics do not apply equally to matter and antimatter— in simpler terms, it is the breakdown of this symmetry under certain conditions. This phenomenon may hence hint at an explanation as to why matter dominates our current universe.

Since the effects of $\mathcal{CP}$-violation tend to be almost negligible, scientists have sought for conditions where these effects are highly amplified. One prominent indicator to $\mathcal{CP}$-violation is the existence of a permanent electric dipole moment, EDM of atoms. This results from an imbalance of charges within an atom, deviating from a perfectly spherical distribution. The permanent EDM arises from the nuclear Schiff moment, a property emerging from $\mathcal{CP}$-violating forces. This Schiff moment is of much interest as it is particularly enhanced in specific deformed nuclei, notably in octupole-deformed nuclei, which resembles a pear shape.

These pear-shaped nuclei serve as notable candidates to study these phenomena because they break spatial symmetries, significantly enhancing $\mathcal{CP}$-violating effects i.e. the nuclear Schiff moment. Some isotopes, particularly certain radium isotopes which exhibit pear-shaped nuclei, have been found to exhibit these enhanced Schiff moments. This project focuses on the properties of these nuclei, mainly by predicting and comparing their shapes and ground states using computational programs.

The forces between nucleons in the nucleus are taken into account by Skyrme forces in this study. These are effective forces obtained by fitting experimental data of nuclear properties such as mass and binding energies to theoretical models. Skyrme parameterizations refer to different sets of parameters within the Skyrme force model, each fitted to specific experimental data sets. By comparing predictions for these different Skyrme parameterizations, e.g. SLY4 and UNEDF1, we evaluate how different models affect the predictions of nuclear properties of pear-shaped nuclei.

The main objective of our research is the analysis of nuclear properties for well-known Radium isotopes, namely $^{220-228}$Ra, suggested in previous studies to exhibit highly amplified octupole deformation. The goal? To identify potential candidates for experimental validation by ongoing research groups in this field. This area of research aims to deepen our understanding of nuclear properties and potentially lead to groundbreaking discoveries in fundamental physics, ultimately explaining the matter-antimatter asymmetry of the universe.