IN-MEDIUM PROPERTIES OF STRANGE AND HEAVY FLAVOR MESONS

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by

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Department of Physics

submitted

in fulfillment of the requirements of the degree of

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To my younger self,
who dared to dream inspite of all imperfections..

CERTIFICATE

This is to certify that the thesis entitled **In-medium properties of strange and heavy flavor mesons** being submitted by **Arpita Mondal** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** in Physics, is a record of bonafide research work carried out by her under my supervision and guidance. She has fulfilled the requirements for the submission of the thesis, which, to the best of my knowledge, has reached the required standard. The material contained in the thesis has not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

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Arpita Mondal
Date: ....
Place: New Delhi

ABSTRACT

In this thesis, we explore the influence of the nuclear environment on the properties of strange and heavy-flavor (charm and bottom) mesons. These studies are directly relevant to experimental investigations of the strong interaction in the non-perturbative, low-energy regime in understanding the low-energy meson-nucleon interaction. The implications of this work extend across diverse areas, from the search for exotic meson–nucleus bound states (mesic nuclei) to insights into the structure of compact astrophysical objects such as neutron stars. The study encompasses a comprehensive analysis of meson properties in both nuclear matter and finite nuclei. A significant focus of the thesis is dedicated to explore the possibility of formation of meson (K, D, B as well as ϕ, charmonia, and bottomonia) bound in atomic nuclei, mesic-nuclei bound states, arising due to the potentials experienced by the mesons while inside the nuclei.

The thesis starts with the investigations of in-medium masses of open strange and open heavy flavor mesons in symmetric and asymmetric nuclear matter, using quark–meson coupling (QMC) model, which are then extended to study formation of their bound states in atomic nuclei. The hidden-flavor (ϕ) meson-nucleus bound states are explored with the medium modification of ϕ meson properties, such as masses and decay widths, using the tree level $\phi K \bar{K}$ lagrangian, employing the in-medium masses of K and $\bar{K}$ mesons as calculated within the QMC model. On the other hand, masses of the hidden heavy flavor mesons are evaluated using a generalized linear sigma model, where the medium modifications are driven by a scalar dilaton field, which simulates the gluon condensates of QCD. This work also attempts to understand the effects of density, isospin asymmetry, and temperature of the nuclear medium on the quarkonia masses and using the effective quarkonia-nuclei potentials, estimates the binding energies of the heavy Quarkonium-nuclear bound states. In addition, we discuss the feasibility of observing such states and examine the influence of the nuclear environment by tracing their possible signatures.

सार

यह शोध प्रबंध (थीसिस) परमाणु वातावरण का स्ट्रेंज और हेवी-फ्लेवर (चार्म और बॉटम) मेसॉन के गुणों पर प्रभाव का अध्ययन करता है। ये अध्ययन स्ट्रॉन्ग इंटरैक्शन के नॉन-पर्टर्बेटिव, लो-एनर्जी क्षेत्र में, लो-एनर्जी मेसॉन-न्यूक्लिऑन इंटरैक्शन को समझने के लिए किए जा रहे प्रायोगिक अनुसंधानों से प्रत्यक्ष रूप से जुड़े हुए हैं। इस कार्य के परिणाम विविध क्षेत्रों में महत्वपूर्ण हैं, जैसे एक्सोटिक मेसॉन-न्यूक्लियस बाउंड स्टेट्स (मेसिक न्यूक्लि) की खोज से लेकर न्यूट्रॉन स्टार्स जैसे कॉम्पैक्ट एस्ट्रोफिजिकल ऑब्जेक्ट्स की संरचना को समझने तक। यह अध्ययन न्यूक्लियर मैटर और फाइनाइट न्यूक्लि, दोनों में मेसॉन गुणों के व्यापक विश्लेषण को सम्मिलित करता है। इस शोध का एक महत्वपूर्ण फोकस, परमाणु न्यूक्लि में बंधे हुए मेसॉन ($K,\ D,\ B$ तथा ϕ , charmonia, और bottomonia) बाउंड स्टेट्स के निर्माण की संभावना का अन्वेषण है, जो न्यूक्लि के भीतर मेसॉन द्वारा अनुभव किए गए पोटेंशियल्स के कारण उत्पन्न होते हैं।

शोध की शुरुआत, क्वार्क–मेसॉन कपलिंग (QMC) मॉडल का उपयोग करते हुए, सिमेट्रिक और एसिमेट्रिक न्यूक्लियर मैटर में ओपन स्ट्रेंज और ओपन हेवी फ्लेवर मेसॉन के इन-मीडियम मासेस की जांच से होती है, जिसे आगे परमाणु न्यूक्लि में इनके बाउंड स्टेट्स के निर्माण के अध्ययन तक विस्तारित किया गया है। हिडन-फ्लेवर (ϕ) मेसॉन-न्यूक्लियस बाउंड स्टेट्स का अध्ययन, ϕ मेसॉन के मास और डिके विड्थ्स जैसे मीडियम मॉडिफिकेशन के साथ, ट्री लेवल $\phi K\overline{K}$ लैग्रेंजियन का उपयोग करते हुए किया गया है, जिसमें K और $\overline{K}$ मेसॉन के इन-मीडियम मासेस QMC मॉडल के अंतर्गत निकाले गए हैं। दूसरी ओर, हिडन हेवी फ्लेवर मेसॉन के मासेस का मूल्यांकन जनरलाइज्ड लिनियर सिग्मा मॉडल का उपयोग करके किया गया है, जिसमें मीडियम मॉडिफिकेशन एक स्केलर डाइलेटॉन फील्ड द्वारा संचालित होते हैं, जो QCD के ग्लूऑन कंडेन्सेट्स का अनुकरण करता है। यह कार्य न्यूक्लियर मीडियम के डेंसिटी, आइसोस्पिन एसिमेट्री और टेम्परेचर के प्रभावों को भी क्वार्कोनिया मासेस पर समझने का प्रयास करता है, और इफेक्टिव क्वार्कोनिया-न्यूक्लि पोटेंशियल्स का उपयोग करके हेवी क्वार्कोनियम-न्यूक्लियर बाउंड स्टेट्स की बाइंडिंग एनर्जी का अनुमान लगाता है। इसके अलावा, हम ऐसे स्टेट्स के प्रेक्षण की संभाव्यता पर चर्चा करते हैं और उनके संभावित संकेतों को ट्रेस करके न्यूक्लियर वातावरण के प्रभाव की जांच करते हैं।

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