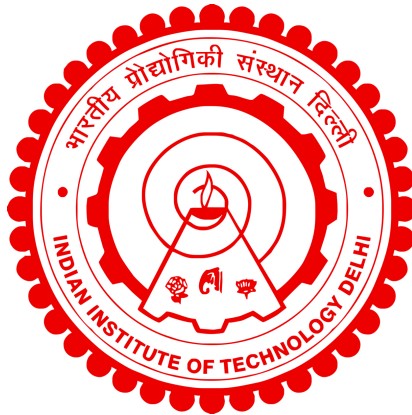


MASSES AND DECAY WIDTHS OF HEAVY FLAVOR MESONS

SOURODEEP DE



DEPARTMENT OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY DELHI

APRIL 2024

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by

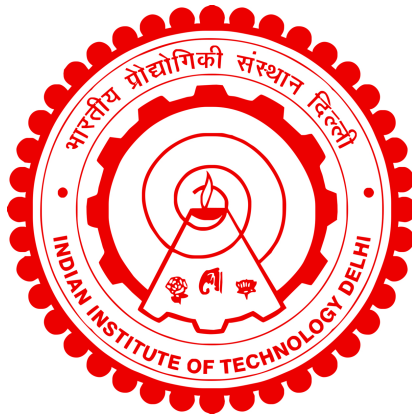
SOURODEEP DE

Department of PHYSICS

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



Indian Institute Of Technology Delhi

APRIL 2024

Dedicated to my parents

Shri Surajit De and Smt. Dipa De

Certificate

This is to certify that the thesis entitled “**Masses and Decay Widths of Heavy Flavor Mesons**”, submitted by **Sourodeep De** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in Physics, is a record of the original, bona fide research work carried out by him under my supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

Prof. Amruta Mishra

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Sourodeep De

Abstract

We investigate the masses of the pseudoscalar ($D, \bar{D}, D_s^\pm$), and vector ($D^*, \bar{D}^*, D_s^{*\pm}$) open charm mesons in isospin asymmetric magnetized nuclear matter, taking into account the effects of Dirac sea. The pseudoscalar mesons interact with the nucleons and the scalar mesons. The free energy of the magnetized vacuum and the Landau energy levels of protons along with the anomalous magnetic moments (AMM) of the nucleons are considered while calculating the Dirac sea contribution to the scalar densities of the nucleons in the magnetized nuclear matter. The (reduction) enhancement of the QCD light quark condensates with magnetic field indicates (inverse) magnetic catalysis. Magnetic field induced phenomena like Pseudoscalar-Vector (PV) mixing between ($D(\bar{D}) - D^{*\parallel}(\bar{D}^{*\parallel})$), and ($D_s - D_s^{*\parallel}$) cause further modification in the masses of the pseudoscalar and vector charm mesons. The lowest Landau Level contribution to the ground state energy of the charged mesons as point particle correction has been considered. For the charmonium state $\Psi(3770)$, the effects of the magnetized Dirac sea are incorporated to the mass modifications through the medium modified scalar dilaton field χ within the chiral model. The masses are used to study the in-medium partial decay widths of $D^* \rightarrow D\pi$ ($\bar{D}^* \rightarrow \bar{D}\pi$) and $\Psi(3770) \rightarrow D\bar{D}$, $\Psi(4040) \rightarrow D_s^+ D_s^-$, using the 3P_0 model. Next, we investigate the in-medium masses of the pseudoscalar and vector open bottom mesons ($B, \bar{B}, B_s$ and $B^*, \bar{B}^*, B_s^*$) in the magnetized nuclear matter by considering the effects of Dirac sea, within the chiral effective model. The effects of the magnetized Dirac sea lead to the considerable changes in the scalar fields with magnetic field, which are related to the condensates of light quark-antiquark pairs. The contribution of the magnetic field on the Fermi sea of nucleons are taken into account through the Landau energy levels of protons and anomalous magnetic moments of the nucleons. The additional contribution of the lowest Landau level for the charged open bottom mesons are considered. PV mixing between the states ($B(\bar{B}) - B^{*\parallel}(\bar{B}^{*\parallel})$), and ($B_s - B_s^{*\parallel}$) are studied, which lead to a level repulsion between their masses with magnetic field. The in-medium masses and decay widths of the open charm, charmonium and open bottom mesons thus obtained should have important observable consequences in the production of the open charm mesons and charmonia in peripheral ultra-relativistic heavy ion collision experiments.

सार

हम डिराक सागर के प्रभावों को ध्यान में रखते हुए, आइसोस्पिन असममित चुंबकीय परमाणु पदार्थ में स्फूडोस्केलर ($D, \bar{D}, D_s^\pm$), और वेक्टर ($D^*, \bar{D}^*, D_s^{*\pm}$) के खुले आकर्षण मेसॉन के द्रव्यमान की जांच करते हैं। स्फूडोस्केलर मेसॉन न्यूक्लियॉन और स्केलर मेसॉन के साथ परस्पर क्रिया करते हैं। गणना करते समय चुंबकीय निर्वात की मुक्त ऊर्जा और प्रोटॉन के लैंडौ ऊर्जा स्तर के साथ-साथ न्यूक्लियॉन के विषम चुंबकीय क्षणों (एएमएम) पर विचार किया जाता है। चुंबकीय परमाणु पदार्थ में न्यूक्लियॉन के अदिश घनत्व में डिराक सागर का योगदान। चुंबकीय क्षेत्र के साथ क्यूसीडी प्रकाश क्वार्क संघनन की (कमी) वृद्धि (उलटा) चुंबकीय उत्प्रेरण को इंगित करती है। $D(D^*) - D^{*||}(\bar{D}^{*||})$, और $(D_s - D_s^{*||})$ के बीच स्फूडोस्केलर-वेक्टर (PV) मिश्रण जैसी चुंबकीय क्षेत्र प्रेरित घटनाएँ स्फूडोस्केलर के द्रव्यमान में और संशोधन का कारण बनती हैं और वेक्टर आकर्षण मेसॉन। सबसे निचला लैंडौ लेवल कॉन्- बिंदु कण सुधार के रूप में आवेशित मेसॉन की जमीनी अवस्था ऊर्जा में योगदान पर विचार किया गया है। चारमोनियम अवस्था $\Psi(3770)$ के लिए, चुम्बकित डायराक सागर के प्रभावों को चिरल मॉडल के भीतर मध्यम संशोधित स्केलर डिलाटन क्षेत्र χ के माध्यम से बड़े पैमाने पर संशोधनों में शामिल किया गया है। द्रव्यमान का उपयोग $D^* \rightarrow D\pi (\bar{D}^* \rightarrow \bar{D}\pi)$ की मध्यम आंशिक क्षय चौड़ाई का अध्ययन करने के लिए किया जाता है। और $\Psi(3770) \rightarrow D\bar{D}$, $\Psi(4040) \rightarrow D_s^+ D_s^-$, 3P_0 मॉडल का उपयोग करते हुए। इस प्रकार प्राप्त खुले आकर्षण और चारमोनियम मेसॉन के मध्यम द्रव्यमान और क्षय चौड़ाई के परिधीय अल्ट्रा-सापेक्ष भारी आयन टकराव प्रयोगों में खुले आकर्षण मेसॉन और चारमोनियम के उत्पादन में महत्वपूर्ण अवलोकन योग्य परिणाम होने चाहिए। इसके बाद, हम छद्म के मध्यम द्रव्यमान की जांच करते हैं। डॉस्कलर और वेक्टर ओपन बॉटम मेसॉन ($B, \bar{B}, B_s$ और $B^*, \bar{B}^*, B_s^*$) चिरल प्रभावी मॉडल के भीतर, डिराक समुद्र के प्रभावों पर विचार करके चुंबकीय परमाणु पदार्थ में। बड़े पैमाने पर संशोधन न्यूक्लियॉन और स्केलर मेसॉन के साथ खुले तल वाले मेसॉन की परस्पर क्रिया के कारण उत्पन्न होते हैं, जिनकी गणना न्यूक्लियॉन के स्केलर और संख्या घनत्व और स्केलर फ़ील्ड के उतार-चढ़ाव के संदर्भ में की जाती है। चुंबकीय डिराक सागर के प्रभाव से चुंबकीय क्षेत्र वाले अदिश क्षेत्रों में महत्वपूर्ण परिवर्तन होते हैं, जो संबंधित हैं- प्रकाश क्वार्क-एंटीक्वार्क जोड़े का घनत्व। न्यूक्लियॉन के फर्मी समुद्र पर चुंबकीय क्षेत्र के योगदान को प्रोटॉन के लैंडौ ऊर्जा स्तर और न्यूक्लियॉन के असामान्य चुंबकीय क्षणों के माध्यम से ध्यान में रखा जाता है। चार्ज किए गए ओपन बॉटम1 मेसॉन के लिए निम्नतम लैंडौ स्तर के अतिरिक्त योगदान पर विचार किया जाता है। राज्यों $B(\bar{B}) - B^{*||}(\bar{B}^{*||})$, और $(B_s - B_s^{*||})$ के बीच पीवी मिश्रण का अध्ययन किया जाता है, जिससे उनके द्रव्यमानों के बीच एक स्तर का प्रतिकर्षण होता है चुंबकीय क्षेत्र के साथ। यह देखा गया है कि डायराक समुद्री प्रभाव के माध्यम से खुले तल वाले मेसॉन के मध्यम द्रव्यमान पर चुंबकीय क्षेत्रों का महत्वपूर्ण योगदान होता है, उस मामले की तुलना में जब इस प्रभाव पर विचार नहीं किया जाता है। निर्वात में, शून्य और परिमित न्यूक्लियोनिक एएमएम पर चुंबकीय डिराक सागर के कारण ही महत्वपूर्ण परिवर्तन प्राप्त होते हैं।

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Abbreviations

VEV	V acuum E xpectation V alue
SSB	S pontaneous S ymmetry B reaking
ESB	E xplicit S ymmetry B reaking
HIC	H heavy I on C ollision
GSI	G esellschaft für S chwerionenforschung
CBM	C ompressed B aryonic M atter
FAIR	F acility A ntiproton and I on R esearch in E urope
GFST	G luon F ield S trength T ensor
PCAC	P artially C onserved A xial C urrent
CEM	C hiral E ffective M odel
HFM	H heavy F lavor M esons
MFA	M ean F ield A pproximation
CEL	C hiral E ffective L agrangian
QCD	Q uantum C hromo D ynamics
BSI	B roken S cale I nvariance
COM	C entre O f M ass
RHIC	R elativistic H heavy I on C ollider
LHC	L arge H adron C ollider
MC	M agnetic C atalysis
IMC	I nverse M agnetic C atalysis
AMM	A nomalous M agnetic M oment
LLL	L owest L andau L evel
WT	W einberg T omozawa
SME	S calar M eson E xchange
EOM	E quation O f M otion
NJL	N ambu J ona L asinio

DS **Dirac Sea**