**O‘ZBEKISTON MILLIY UNIVERSITETI
HUZURIDAGI ILMIY DARAJALAR BERUVCHI
DSc.03/30.12.2019.FM.01.09 RAQAMLI ILMIY KENGASH**

O‘ZBEKISTON MILLIY UNIVERSITETI

YAXSHIYEV ULUG‘BEK TURDALIYEVICH

YADRO MUHITIDAGI ADRONLAR: KIRAL SOLITON ORQALI YAQINLASHISH

01.04.02 – Nazariy fizika

**Fizika-matematika fanlari doktori (DSc) dissertatsiyasi
AVTOREFERATI**

Toshkent – 2023

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Оглавление автореферата диссертации доктора наук (DSc)

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KIRISH (fan doktori (DSc) dissertatsiyasining annotatsiyasi)

Dissertatsiya mavzusining dolzarbligi va zarurati. Kuchli o‘zaro ta’sirlarning asosiy nazariyasi, Kvant Xromodinamikasi (KXD) materiyaning joriy fundamental bo‘lakchalari (kvarklar) va o‘zaro ta'sir tashuvchilari (glyuonlar) fizikasini nazariy tomondan tavsiflab beradi. Eksperimental tomondan ulkan tezlatgichlar va juda sezgir detektorlarga asoslangan zamonaviy ilmiy qurilmalar bizga fazoning $\sim 10^{-15}$ m gacha bo‘lgan kichik qismida, $\sim 10^{-23}$ s gacha bo‘lgan juda qisqa vaqt oralig‘ida sodir bo‘layotgan ajoyib hodisalarni o‘rganish imkonini beradi. Bular kuchli o‘zaro ta’sirlarning xarakterli makon va vaqt shkalalaridir. Fazo va vaqtning yana ham kichikroq bo‘lgan hududlarini tadqiq qilish uchun tezlatkichlardagi elementar zarrachalar juda katta $\sim 10^{12}$ eV energiyalarga qadar tezlashtiriladi. Shunday qilib, biz sehrli va ajoyib koinotning yaratilishi paytida sodir bo‘lgan hayratlanarli hodisalarni kuzatish yo‘nalishida tadqiqotlar olib boramiz.

KXD, universal o‘zaro ta’sir “doimiysi”, $\alpha \sim g^2$ (g – ta’sir konstantasi)ga asoslangan kuchli o‘zaro ta’sirlarning noabel kalibrlangan maydon nazariyasidir. Konstanta haqiqatan ham o‘zgarmas qiymatga ega emas va o‘zaro ta’sir energiyasiga qarab qiymati o‘zgaradi. Fazoning kichik hududlariga to‘g‘ri keladigan katta energiyalarda ta’sir doimiysining o‘lchovsiz qiymati impulsning sekin o‘zgaruvchan funksiyasiga aylanadi va qiymati birdan kichik bo‘ladi, $\alpha < 1$. Bu moddalarning asosini tashkil etuvchi kvarklarning xatti-harakatlaridagi asimptotik erkinlik deyiladi [1,2]. Shunday qilib, KXDning go‘zal matematik ifodasi g‘alayonlanishlar orqali yondashuvga asoslangan bo‘lib, kuchli o‘zaro ta’sirlashuvchi zarrachalar qatnashuvchi hodisalarni KXD doirasida o‘rganish imkonini beradi. G‘layonlanishlarga asoslangan KXD bilan bog‘liq ko‘plab texnik muammolar mavjud bo‘lsa-da, nazariy baholash va natijalarni zamonaviy tezlatgichlarda olingan eksperimental ma’lumotlar bilan taqqoslashni ozmi-ko‘p imkoniyati mavjuddir [3].

Aksincha, katta masofalarga to‘g‘ri keladigan kichik energiyalarda kuchli o‘zaro ta’sirlarning boshqa hodisalari mavjud. Bular kvark konfaynmenti [4] va kiral simmetriyaning spontan (o‘z-o‘zidan) buzilishidir [5]. Birinchisi, adronlar ichida kvarklarni doimiy saqlanib, ionlanishiga yo‘l qo‘ymaslik uchun javobgar bo‘lsa, ikkinchisi atrofdagi tabiat adronlari massalarining hosil bo‘lishi uchun javobgardir. Garchi konfaynment mexanizmi hali to‘liq tushunilmagan bo‘lsa-da, u kichik energiyalarda o‘zaro ta’sir konstantasining ortib borayotgan qiymati bilan ham o‘zaro bog‘liq bo‘lishi mumkin.

O‘zaro ta’sir konstantasining ortib borayotgan qiymati tufayli quyi energiyalrda KXDni to‘g‘ridan-to‘g‘ri qo‘llanilishida g‘alayonlanishlar yondashu-vini ishlatishning iloji yo‘q. Shuning uchun KXD o‘rniga, xususan, atom yadrolari fizikasini o‘rganish uchun qo‘llanilishi mumkin bo‘lgan effektiv maydon nazariyalari va fenomenologik modellar ishlab chiqilgan (masalan, [6]ga qarang). Ko‘plab yadro modellari butunlay fenomenologik asosda tuzilgan bo‘lsa-da, ba’zi adronik yondashuvlarda quyi energiyalardagi KXDning asosiy xususiyatlarini hisobga olishga harakat qilingan. Shu oʻrinda kiral simmetriya va uning spontan buzilishini esga olish mumkin. Bundan tashqari yana bir qiziq hodisa bor, bu yadro muhitidagi adron xossalari bilan bogʻliq kiral simmetriyaning qisman tiklanishidir (masalan, [7]ga qarang). Yadro muhitidagi adron xossalari adronlarning oʻzaro ta’sir dinamikasi orqali yadro materiyasining oʻziga xos xususiyatlari bilan ham bogʻliqdir.

Yadro muhitidagi adron xossalariga yoki umuman yadroviy materiya xususiyatlariga qaratilgan koʻplab yondashuvlarning zaif tomoni shundaki, bir vaqtning oʻzida ikkalasini (yadro moddasidagi adron xossalari va yadro materiyasining xossalari) bir xil nazariy asosda oʻrganishning iloji yoʻqligidir. Shu yerda bu muammoni hal qilishga qaratilgan yondashuvning ***zarurligi va ahamiyati*** aniq tushunarli boʻlgan boʻlsa kerak. Shuning uchun bunday yaqinlashuvlarni ishlab chiqish ushbu dissertatsiyada taqdim etilgan ilmiy tadqiqotlarimizning asosiy maqsadi boʻlib xizmat qiladi.

Tadqiqotni Respublika fan va texnologiyalari rivojlanishining ustuvor yo’nalishlariga mosligi. Dissertatsiya ishida olib borilgan tadqiqotlar Oʻzbekiston Respublikasi fan va texnikasi ustuvor yoʻnalishlariga mos keladi. Xususan, dissertatsiyada taqdim etilgan ilmiy tadqiqot natijalari energiya manbalari va energiya tejash muammolari, radiatsiya xavfsizligi muammolari va zamonaviy tibbiyot texnologiyalari bilan uzviy bogʻliq. Umuman olganda, dissertatsiya mavzusi dunyoning ilmiy muassasalarida olib borilayotgan fundamental fan tadqiqot dasturlari nuqtayi nazaridan ham e’tiborga molikdir. Shu nuqtayi nazardan qaraganda, dissertatsiyada keltirilgan tadqiqotlar Oʻzbekiston Respublikasida fundamental fanni rivojlantirish maqsadlariga ham mos keladi.

Dissertatsiya mavzusi boʻyicha xorijiy ilmiy tadqiqotlar sharhi. Dissertatsiya mavzusi yadro va adronlar fizikasining zamonaviy tadqiqot yoʻnalishlarining asosiy muammolari bilan bevosita bogʻliq. Su ma’noda, dunyoning bir qancha ilmiy tadqiqot muassasalarida va ilmiy laboratoriyalarda olib borilayotgan turli ilmiy loyihalarni eslatib oʻtish mumkin hamda quyida biz ulardan ba’zilarini qisqacha eslatib oʻtamiz.

1. Kiral simmetriya va uning spontan buzilishi quyi energiyalarda kuchli oʻzaro ta’sirlashuvchi sistemalarda yuz beradigan eng ajoyib hamda muhim hodisalardan biridir. Bu hodisa kiral kondensat $\langle q\bar{q}\rangle$ qiymatining kamayishi orqali yadro muhitidagi adron xossalari bilan oʻzaro bogʻliq. Kiral kondensatning kamayuvchi qiymati kiral simmetriyaning qisman tiklanishini ifodalaydi.

Xususan, adronlar massalari yadro muhitida qanday oʻzgarishini tushunish juda muhim, chunki bu kiral simmetriyaning tiklanishi bilan bogʻliq va hatto kvark konfaynmentiga aloqador boʻlishi ham mumkin [8-14]. Kiral kondensatning yadro muhitida oʻzgarishi ma’lum va bu yadro zichligi oshishi bilan spontan buzilgan kiral simmetriya qanday tiklanishi mexanizmini ochib beradi ([8]-ishdagi muhokamalarga qarang). Bu hodisa, shuningdek, yadro muhitida adron massalarining oʻzgarishini nazarda tutadi. Sababi, kvarkning dinamik massasi kiral simmetriyaning spontan buzilishi natijasida paydo boʻladi. Shunday qilib, adron massasining yadro muhitida modifikatsiyasini tushunish o'nlab yillar davomida eng muhim masalalardan biri bo‘lib kelgan [15-19]. Binobarin, so‘nggi yigirma yil davomida Jefferson Laboratoriyasida [1] o‘tkazilgan ko‘plab tajribalar yadro muhitida adron xossalarini o‘rganishga bag‘ishlanib kelmoqda. Xususan, eksperimentlar yadro muhitidagi nuklonlarning elektromagnit (EM) form factorlarnini o‘rganishga ham bag‘ishlandi. Masalan, geliy ^{4}He($\vec{e}$, e', $\vec{p}$)^{3}H [20-23] va kislorod ^{16}O($\vec{e}$, e',$\overrightarrow{p}$)^{15}N [24] dan protonni ionizatsiya qilish reaksiyalaridagi qutblanuvchi-almashish hodisasi so‘nggi o‘n yilliklarda uzluksiz ravishda tajribalardan kelib chiqadigan maqsadlardan birini tashkil qildi. Eksperiment qutblanish-almashish ikkilangan nisbati $\mathcal{R} = (P_x'/P_z')_{\,^4He}/(P_x'/P_z')_{\,^1H}$ kichrayishini ko‘rsatdi. Nazariya nuqtayi nazaridan kichrayish effekti yadro muhitida nuklonning EM form factorlarining o‘zgarishi sifatida [25-31] yoki yakuniy holatda zarralarning o‘zaro ta’siri va ikki jism toklarining hissasi sifatida talqin qilinishi ham mumkin [32]. Shuning uchun, energiya oblastiga qarab va [29,31] ishlarda ta’kidlanganidek, bog‘langan nuklonlarning EM form factorlaridagi o‘zgarishi qutblanish-almashish ikkilangan nisbatining eksperimental o‘lchovlari paytida kuzatilgan o‘zgarishining haqiqiy ifodasi bo‘lishi mumkin. Yadro muhitidagi EM form factorlar bo‘yicha o‘tkazilgan tadqiqotlar proton va neytronlarning xususiyatlari o‘rtasidagi farqni tahlil qilishga yordam beradi.

Turli xil boshqa laboratoriyalardan olingan eksperimental ma'lumotlar ham yadrolarda nuklon xossalarining modifikatsiyalanganligini ko'rsatadi [33-39]. Demak, boshqa barionlar xossalari ham yadro muhitida o'zgarishlarga duchor bo'lishi mumkin [40-44].

Yadrolardagi nuklonlar xossalarining o‘zgarishini ko‘rsatuvchi Yevropa Muon Hamkorligi [33] kuzatuvlari yadro muhitidagi adronlarning xossalariga katta qiziqish uyg‘otdi. Dastlab deyteriy va temir yadrolaridagi chuqur noelastik muyuon sochlishlarishining effektiv kesimlari bir-biridan masshtab omili bo‘lgan doimiy 28 soni bilan farq qilishi kutilgan edi. Tajriba esa boshqa natijani ko‘rsatdi va bu effekt EMC effekti deb nomlandi. Bu effektga qiziqish kuchsiz bog‘langan nuklonlardan (yadrolardagi nuklonlarning bog‘lanish energiyasi MeV tartibida) yuqori energiyali (GeV tartibida) elektronlarning sochilishiga qaramay, yadro ichidagi nuklonlarning strukturaviy o‘zgarishlarini ko‘rsatishi sababli paydo bo‘ldi. Ushbu mavzuga bag'ishlangan ko‘plab ishlarga qaramay, EMC effektining tabiati hali ham to‘liq tushunilmagan.

Shuning uchun yadro muhitidagi nuklonlarning xossalarini o‘rganish yadro fizikasining o‘ta muhim vazifasi bo‘lib, ushbu dissertatsiyaning ham asosiy maqsadlaridan biri bo‘lib hisoblanadi.

2. Boshqa tomondan ham assimetrik yadrolarning xossalarini o‘rganish zamonaviy yadro fizikasi va yadro astrofizikasida muhim hamda dolzarb masala hisoblanadi. Ko‘pgina eksperimental va nazariy yondashuvlar materiyaning assimmetrik xususiyatlariga bag‘ishlangan [45-47]. Ushbu tadqiqotlar va xususan, yadro materiyasining holat tenglamasini (EOS) o‘rganish noyob izotoplar fizikasini, og‘ir ion reaksiyalari va neytron yulduzlarining shakllanishi bilan

[1] Laboratoriyaning Yadro Fizikasi web-sahifasini ko‘ring: https://www.jlab.org/physics.

bog‘liq jarayonlarni tushunishda muhim rol o‘ynaydi. Ko‘p harakat qilingan bo‘lsa-da, yadro simmetriya energiyasining xususiyatlari haqida normal holatdagi yadro materiyasi zichligidan ancha kattaroq zichliklarda yetarlicha aniq ma’lumotlar hali ham yo‘q. Boshqa tomondan, normal yadro materiyasi zichligidan kichikroq zichliklarda yadrolarning simmetriya energiyasi haqidagi bilimlarimiz ozmi-ko‘p ma’lum hisoblanadi [45,48]. Misol uchun, kichik zichliklarda, EOSning simmetriya energiyasining xossalari mavjud yadrolarning neytron qobig‘i va stabillik liniyasi yaqinidagi yadrolarning barqarorligi bilan bog‘liqdir. Shuning uchun nisbatan kichikroq zichlikdagi mavjud eksperimental tadqiqotlardan foydali va batafsilroq ma’lumotlar olish mumkin. Nazariya tomonidan qaraganda, yadro simmetriya energiyasini o‘rganishga yo‘naltirilgan ko‘p zarrali modellar ma’lum bir cheklovlarni qondirishi kerak.

Yuqorida muhokama qilinganlar nuqtayi nazardan noyob izotoplar fizikasi hozirgi eksperiment markazlarining diqqat markazida bo‘lishda davom etmoqda, xususan, simmetriya energiyasi va assimetrik yadrolarning holat tenglamalarini o‘rganishni o‘z ichiga oladi. Masalan, Janubiy Koreyaning Daegeon shahridagi yangi tezlatkichdagi tajribalardan maqsad, ya’ni ON-line tajribalar uchun noyob izotop tezlatgich majmuasi (RAON) davriy sistemadagi elementlarning kelib chiqishi, koinotning tug‘ilishi va kengayishini o‘rganishni o‘z ichiga oladi. Tezlatkich, shuningdek, biotibbiyot, molekulyar, atom va yadro fizikasi kabi bir qancha sohalarda qo‘llanilishi ham kutilmoqda.[2]

Ushbu dissertatsiyada biz kichik zichlikli yadro muhitlaridagi eksperimental ma’lumotlarni tahlil qilishdan kelib chiqadigan cheklovlarni hisobga olgan holda yarim fenomenologik kiral soliton yondashuvi doirasida simmetrik va assimetrik moddalarning holat tenglamalari bo‘yicha tadqiqotlarimizni ham taqdim etamiz.

3. Materiyaning hossalarini ekstremal (katta zichlik va temperaturalar) sharoitlarda tahlil qilish va neytron yulduzlar tuzilishini o‘rganish zamonaviy astrofizikaning qiziqarli mavzusidir. Xususan, yadro astrofizikasida neytron yulduzlarning tuzilishini o‘rganish yadro materiyasining holat tenglamalari bilan bog‘liq bo‘lib, u yadro zichligi qiymatlarining keng diapazoni uchun bosim va energiya zichliklarining o‘zaro bog‘liqligini ifodalaydi [46, 49, 50].

Yuqorida aytib o‘tganimizdek, holat tenglamarining o‘ziga xos xususiyatlari simmetrik yadro moddasining to‘yinganlik zichligidan past bo‘lgan zichliklarda yaxshi ma’lum, yuqori zichlikli hududlarda esa hali ham aniq emas. Laboratoriyalarda to‘g‘ridan-to‘g‘ri eksperimental sharoit yaratish qiyinligi va ab-initio (asosdan boshlab) nazariy hisob-kitoblarning yo‘qligi sababli holat tenglamalrining yuqori zichliklardagi xususiyatlari yaxshi o‘rganilmagan. Shuning uchun eksperiment nuqtayi nazaridan neytron yulduzlarini o‘rganish holat tenglamalarining yuqori zichliklardagi xususiyatlarini o‘rganish uchun laboratoriya bo‘lib xizmat qilishi mumkin. Nazariy nuqtayi nazardan boshlang‘ich asoslardan boshlab hisob-kitoblar o‘rniga, holat tenglamalrining kichik zichlikli muhitlardagi yaxshi ma’lum xossalarini hisobga olgan holda fenomenologik asosdan boshlash

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[2] Fundamental Tadqiqotlar Instituti (IBS) web-sahifasini ko‘ring: https://www.ibs.re.kr/eng/sub01–05.do.

va yuqori zichlikli oblastlarga ekstrapolyatsiya qilish hamda shu orqali yadro materiyasining xossalarini tavsiflashga harakat qilish mumkin.

Shu nuqtayi nazardan og‘ir ionlar to‘qnashuvlarida kvark-glyuon plazmasining hosil bo‘lishi materiyaning muvozanatlashuvga yuz tutishi jarayonida yadro zichligining turli bosqichlaridan (oddiy yadro materiyasi zichligi bilan solishtirilganda o‘nlab darajada yuqori zichliklardan boshlab) o‘tadi. Brukxaven Milliy Laboratoriyasida relativistik og‘ir ion to‘qnashuvlari bo‘yicha o‘tkazilgan tajribalar bizga yadro materiyasi va yadro materiyasidagi adron xossalari orasidagi bog‘liqlikni turli xil zichlik qiymatlarida aniqlash imkonini beradi[3].

Ushbu dissertatsiyada biz o‘ta yuqori zichliklarda materiya bilan bog‘liq bo‘lgan ishlanishlarimizni va neytron yulduzining xossalari haqidagi tadqiqotlarimizni muhokama qilamiz.

4. Yuqorida qayd etilgan barcha eksperimental tadqiqotlar Yevropa Yadroviy Tadqiqotlar Markazi (CERN)dagi Katta adron kollayderi (LHC)da o‘tkazilgan tajribalarning ham alohida maqsadlari hisoblanadi.[4] LHCda zarralar juda zich, oddiy yadroviy materiya zichligidan ($\rho_0 \approx 0{,}16 - 0{,}17 fm^{-3}$) 30-40 baravar zichroq va kuchli magnit maydoni ($\sim 10^{19} G$) muhitida hosil bo‘ladi. Bunday muhitda adron xususiyatlarini o‘rganish olimlarning hozirgi vaqtdagi maqsadlaridan biridir. Xususan, LHCb guruhining tajribalaridan maqsad bunday muhitda yaratilgan og‘ir zarralarni kuzatishdir va shuning uchun yadro muhitidagi og‘r zarralar ham adronlar fizikasida qiziqarli mavzudir.

Yadro muhitidagi og‘ir adronlar hossalarining modifikatsiyalari yengil adronlar hossalarining modifikatsiyalariga qaraganda ancha kam o‘rganilgan bo‘lsa-da maftunkor yadrolar bo‘yicha bir qancha ishlar [51-54] charmoniy J/ψ va Σ_c topilganidan [55-57] ko‘p o‘tmay chop etilgan. Keyinchalik yadro muhitidagi og‘ir barionlar o‘rganildi [58-61]. Yaqinda og‘ir adronlarga bo‘lgan qiziqish yana kuchaydi. Chunki ular ustida o‘tkazilgan tajribalar, jumladan, ekzotik og‘ir adronlar ham qiziqarli natijalarni berdi [62-66] (nostandart og‘ir hadronlar bo‘yicha tajribalar holatini yaqinda ko‘rib chiqishga atalgan [67]ni ham qarang). Bu, shuningdek, yadro muhitidagi og‘ir barion xossalari bilan bog‘liq tadqiqotlarni ham boshlab berdi [68-73] (shuningdek, [74] qarang). Og‘ir barionlarning yadro muhitida va yadrolarda qanday o‘zgarishlarga duchor bo‘lishi to‘g‘risida eksperimental ma’lumotlar mavjud emasligi sababli, kelajakdagi tajribalarni boshqarish uchun ularning muhitdagi modifikatsiyasini nazariy jihatdan o‘rganish katta ahamiyatga ega.

Ushbu dissertatsiyada biz yadro muhitidagi og‘ir barion xossalari bilan bog‘liq tadqiqotlarimizni ham taqdim etamiz.

Muammoning o‘rganilganlik darajasi. Hozirgi vaqtda eksperimental obyektlar va astrofizik kuzatishlarga, asosan, zich materiya hodisalari bilan bog‘liq ko‘plab eksperimental va fenomenologik ma’lumotlar kiradi. Shunga qaramay,

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[3] Yadro va Elementar Zarralar Fizikasi Bo‘limining web-sahifasini ko‘ring: https://www.bnl.gov/npp/.

[4] CERN web-sahifasini ko’ring: https://home.cern/science/physics.

zich materiya hodisalarini yagona shaklda tahlil qilish uchun umumiy qabul qilingan va mustahkam asosda (to‘g‘ridan-to‘g‘ri QCDdan) shakllantirilgan yondashuv mavjud emas. Aksincha, juda ko‘p uslubiy yo‘nalishlar va ko‘plab yondashuvlar, asosan, zich materiya hodisasining muayyan qismiga qaratilgan. Masalan, atom yadrolarining xossalarini tavsiflovchi yadro modellari, asosan, atom yadrolarining xossalariga e’tibor qaratadi, yadro muhitidagi nuklonlarning xossalari haqida hech qanday ma’lumot bermaydi. Bundan farqli o‘laroq, yadro materiyadagi adron xossalarini tavsiflovchi va bu xossalarni yadro materiyasi xossalariga bog‘laydigan adron modellarini yaratish oson ish emas.

Shuning uchun iloji boricha yadro materiyasi bilan bog‘liq hodisalarni bir xil asosda ko‘rib chiqishga harakat qilinadigan har qanday yondashuv, albatta, yadro va adron fizikasi hamjamiyatida qiziqish uyg‘otadi. Bunday yondashuvlar quyi energiyalarda va zich materiya bilan bog‘liq tadqiqotlarda kuchli o‘zaro ta’sir hodisalari haqidagi umumiy tushunchamizga oydinlik kiritishi mumkin.

Tadqiqot mavzusining dissertatsiya bajarilgan oliy ta’lim muassasasining ilmiy tadqiqot ishlari rejalari bilan bog‘liqligi. Dissertatsiyada taqdim etilgan tadqiqot qisman O‘zbekiston Milliy Universiteti (O‘zMU) nazariy fizika kafedrasida, kafedra a’zolari bilan yaqin hamkorlikda bajarilgan.[5]

Dissertatsiyadagi asosiy vazifalarining boshlang‘ich qismi nazariy fizika kafedrasida muallifning kandidatlik ishi dasturi doirasida bajarilgan (Qarang: [P1-P9][6]). Muallifning fan kandidati maqomini olishga doir ilmiy ishlari O‘zbekiston Respublikasi Fan va texnika davlat qo‘mitasi (Gr.N°11/97 va Gr.N°18/99), INTAS uyushmasi (Gr.N°93-0239ext va Gr.N°YSF00-51) hamda SCOPES dasturi (Gr.N°7UZPJ65677) tomonidan qisman qo‘llab-quvvatlanib kelingan.

Ushbu DSc dissertatsiya bilan bog‘liq tadqiqotlar, shuningdek, Pusan Milliy Universitetida (Pusan, Koreya) PostDoc dasturi bo‘yicha (Qarang: [D1,D2]), Yadro fizikasi tadqiqotlar markazida (Juelich, Germaniya) Aleksandr fon Gumboldt fondining Postdoc dasturi bo‘yicha (Qarang: [D3-D6]), Janubiy Koreya Milliy tadqiqotlar fondi, “Ta’lim, fan va texnologiyalar vazirligi” (NRF MEST) ilmiy dasturlari bo‘yicha [Bu yerda muallif bosh tadqiqotchi bo‘lgan: Gr.N°2011-0023478 & Gr.N°2012-0008469 “Yadro materiyasi va astrofizikada kiral dinamika” (Qarang:[D7-D22]), Gr.N°2016R1D1A1B0393505 “Og‘ir adronlarda noperturbativ ta’sirlar va adron strukturasining ekstremal sharoitlarda o‘zgarishlari” (Qarang:[D23-D27]) va Gr.N°2020R1F1A1067876 “Og‘ir adronlar va yadro materiyasi” (Qarang:[D28-D31])] moliyalashtirilgan. Shuningdek, tadqiqotlar qisman NRF MEST granti Gr. N°2009-0089525 (Qarang: [D32-D35]) va Inha Universitetining (Incheon, Koreya) xususiy tadqiqot grantlari (qarang: Ref. [D36-D39]) doirasida ham qo‘llab-quvvatlangan.

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[5] 2009-yilgacha TPD izlanuvchining asosiy ish joyi bo‘lib kelgan. Shundan so‘ng u TPDning jamoatchilik asnosidagi a’zosi bo‘lib, hozirgi kungacha O‘zMU ilmiy ishlariga faol hissa qo‘shib kelmoqda. Shuni ta’kidlash joizki, muallifning 64 ta Web of Science asosiy to‘plamida chop etilgan maqolalaridan 30 tasida O‘zMU muallifning ish joyi sifatida ko‘rsatilgan.

[6] Muallifning kandidatlik ishiga ham qarang [P10].

Shunday qilib, tadqiqotchining ilmiy izlanishlari doimo u ishlayotgan ilmiy muassasalar va universitetlardagi ilmiy loyihalarning bir qismi bo‘gan[7].

Tadqiqotning maqsadi zich yadro muhitida adronlarning, yadrolarning o‘zini va materiyaning katta zichliklardagi xossalarini bir xil Lagranjian asosida ko‘rib chiquvchi effektiv fenomenologik modelini ishlab chiqishdir.

Tadqiqotning vazifalari:

– mezon atomlari fenomenologiyasi asosida Lagranjianni ishlab chiqish va yadro materiyasidagi nuklon xossalarini hamda chekli yadro xossalarini o‘rganish uchun amaliy dasturlarni amalga oshirish[8];

– atom yadrolarining to‘yingan zichlikdagi fenomenologiyasi asosida keyingi yondashuvlar va natijalarni fenomenologik ma’lumotlar hamda boshqa yondashuvlar natijalari bilan taqqoslash[9];

– modelning zich muhitdagi adron xossalarini o‘ganishda, neytron yulduzlarning holat tenglamarini va xossalarining yadro materiyasi tenglamalarini o‘rganishda qo‘llanilishi[10];

– yadro materiyasidagi giperonlarni [11] va yadro materiyasidagi og‘ir adronlarni[12] hisobga olgan holda yaqinlashuvlarni SU(3) sektorga kengaytirish;

– g‘alati materiyaning holat tenglamalarini o‘rganish [13] va neytron yulduzlarning xossalarini o‘rganishda qo‘llash.

Tadqiqotning obyekti: oddiy, g‘alati va og‘ir adronlar, adron sistemalari, atom yadrolari va neytron yulduzlari.

Tadqiqotning predmeti yadro muhiti va umuman yadro muhitidagi adronlarning xossalari nuqtayi nazaridan kuchli o‘zaro ta’sir qiluvchi adron sistemalarining xossalarini o‘rganish uchun nazariy modellar hamda usullarni ishlab chiqishdan iborat.

Tadqiqotning usullari: Kiral Lagranjian yondashuvlari, chiziqli bo‘lmagan differensial tenglamalar va solitonik yechimlar, mezon nazariyalar va kiral soliton-nuklonlar, adron-yadro o‘zaro ta’siriga fenomenologik optik model yondashuvi, atom yadrolariga fenomenologik yondashuvlar, neytron yulduzlarini o‘rganishda umumiy nisbiylik nazariyasi tenglamalari.

Dissertatsiya maqsadlarini amalga oshirish uchun biz raqamli usullardan foydalandik: chiziqli bo‘lmagan differensial tenglamalar, integralar, funksional minimizatsiyalar, interpolyatsiyalar va ekstrapolyatsiyalar.

Tadqiqotning ilmiy yangiliklari:

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[7] Aytish joizki, muallifning 91 ta ilmiy ishlari chop etilgan bo‘lib 53 tasi dissertatsiya mavzusiga tegishli. Ulardan 39 tasi hozirgi dissertatsiya ishining bir qismi sifatida qayd etilgan. Muallifning dissertatsiya mavzusiga aloqador bo‘lmagan boshqa ishlari orasidan ko‘p qismini O‘zMU nazariy fizikasi kafedrasida bajarilgan va turli ilmiy jamg‘armalar, jumladan, O‘zbekistondagi jamg‘armalar tomonidan qo‘llab-quvvatlangan.

[8] Bu vazifa fan nomzodi ilmiy darajasini olishdan oldin qisman bajarilgan ([P1, P3]larga va muallifning nomzodlik dissertatsiyasi [P10]ga qarang) va fan nomzodi ilmiy darajasini olganidan keyin ham davom ettirilgan. Masalan, [D3-D5]larni va ushbu dissertatsiya ishining I hamda II boblarini qarang.

[9] [D15, D32]larni va dissertatsiyaning III bobini qarang.

[10] [D21]ni va dissertatsiyaning IV bobini qarang.

[11] [D23, D28]larni, dissertatsiyaning V va VI boblarini qarang.

[12] [D29, D31]larni va dissertatsiyaning VII bobini qarang.

[13] [D28]ni va dissertatsiyaning VI bobini qarang.

– yadro muhitidagi adron xossalarini va atom yadrolarining xossalarini o‘rganish uchun effektiv model yondashuvi ishlab chiqildi hamda bu yondashuv atom yadrolarining oddiy zichligidan tortib kompakt yulduzlarda mavjud bo‘lgan o‘ta yuqori zichlikli hududlarga tegishli bo‘lgan turli xil fenomenologik hodisalarni to‘g‘ri tavsiflaydi;

– simmetrik va assimmetrik yadro moddasining tenglamalari to‘g‘ri ishlab chiqildi va yadro zichligining keng diapazonida fenomenologik dalillar bilan moslik o‘rnatildi;

– xususan, model ikki quyosh massasiga teng massali neytron yulduzlarining xossalarini to‘g‘ri tasvirladi;

– dastlab SU(2) aromatlar sektorida ishlab chiqilgan usul SU(3) aromatlar sektoriga kengaytirilib, g‘alati kvark bilan bog‘liq hodisalar va og‘ir kvark bilan bog‘liq hodisalar qamrab olindi;

– yadro muhitidagi giperonlarni o‘rganishda kaon massa o‘zgarishlarining ahamiyati ko‘rsatildi;

– yadro muhitidagi og‘ir barionlar massalarining o‘zgarishi va ularning yadro muhitidagi og‘ir mezon massalari bilan aloqasi bo‘yicha bashoratlar ham soliton modellari doirasida birinchi marta amalga oshirildi;

– model yaqinlashuviga bog‘liq bo‘lmagan SU(3) kvantlash doirasida o‘rtacha maydon yondashuviga asoslangan qo‘llashlarni amalga oshirildi.

Tadqiqotning amaliy natijalaridan eksperimental natijalar va fenomenologik kuzatishlar natijalarini tahlil qilishda foydalanish mumkin. Masalan, yadro muhitidagi nuklonlarning strukturaviy o‘zgarishlari bo‘yicha olib borilgan tadqiqotlarimiz Jefferson Laboratoriyasida bajarilgan ishlarni tushunishda va kelajakdagi eksperimentlarni rejalashtirishda o‘ziga yarasha qiziqish uyg‘otadi.

Ushbu dissertatsiyada amalga oshirilgan simmetriya energiyasini o‘rganish bo‘yicha natijalarimiz Janubiy Koreyaning Daegeon shahridagi ON-line eksperimentlari davomida, kamyob izotoplarni tezlatgich majmuasi (RAON)da kelajakda bajariladigan tajribalarni tahlil qilish uchun foydali bo‘ladi.

Yaqinlashuvimiz doirasida tadqiq qilingan yadro materiyasi tenglamalarining katta zichlikli hududlarga ekstrapolyatsiyasi neytron yulduzlarining tegishli xususiyatlarini ifodalashga imkon berdi. Masalan, muayyan holat tenglamalariga mos keladigan massasi ikkita quyosh massasiga teng neytron yulduzlarini tafsiflashga mufavvaq bo‘lindi. Ushbu natija yaqinda qayd qilingan astrofizik kuzatishlarni tahlil qilishda amaliy tomondan qiziqish uyg‘otadi.

Tadqiqot natijalarining ishonchliligi natijalarimizni kichik zichliklarga to‘g‘ri keluvchi pionik atom ma’lumotlari, to‘yingan zichlikdagi yadroviy modda xossalari va ko‘plab tajriba ko‘rsatkichlari bilan sifat hamda miqdor jihatidan mos kelishi bilan tasdiqlanadi. Xususan, nuklonning turlicha form factorlarining (energiya impulsi tenzori, zaryad va magnit form ractorlari) o‘zgarishlari Yevropa muyuon hamkorligi natijalaridan olingan eksperimental dalillar bilan, ya’ni EMC effekti bilan mos kelishi ko‘rsatildi. Tadqiqot natijalari xalqaro miqiyosda tan olingan jurnallarda nashr etilgan ilmiy maqolalarimiz, xalqaro konferensiyalar va seminarlarda qilgan taqdimotlarimiz hamda muhokamalarimiz, Koreya, Yaponiya va O‘zbekistonning turli ilmiy muassasalarida o‘tkazilgan seminarlarimiz bilan ham tasdiqlanadi.

Tadqiqot natijalarining ilmiy va amaliy ahamiyati adron hamda yadro fizikasi hamjamiyatining bizning nashr etilgan ishlarimizga qiziqishi bilan tasdiqlangan. Masalan, “Yadro muhitidagi nuklonning energiya-impuls tensor form factorlari”ga bo‘lgan qiziqishni eslatib o‘tish mumkin ([D7,D16,D20]larda bajarilgan ishlarimizga bo‘lgan tashqaridan e’tiborga qarang).

Ushbu dissertatsiyada muhokama qilingan asosiy yondashuv boshqa topologik va topologik bo‘lmagan soliton modellarida qo‘llanilishi mumkin. Bundan tashqari tadqiqotlarimiz adron va yadro fizikasi hamjamiyati Ichida pedagogik qiziqish ham uyg‘otadi.

Tadqiqot natijalarining joriy qilinishi. Tadqiqot natijalari qisman amalga oshirildi va kelajakda tezlatkichlarda rejalashtirilgan tajribalar asosida amalga oshirilishi kutilmoqda. Masalan, “Jefferson laboratoriyasida cheklangan yadrolardan nuklonlarni ionizatsiya qilish reaksiyalari” davomida kutilmoqda ([22, 23, 28, 29]larda bizning ishimiz [P9]ga tegishli bolgan muhokamalarga qarang).

Tadqiqot natijalarining aprobatsiyasi. Ushbu dissertatsiyada taqdim etilgan tadqiqotlar natijalari 40 dan ortiq xalqaro konferentsiyalar va seminarlarda, Koreya Fiziklar Jamiyatining ko‘plab yig‘ilishlarida taqdim etilgan va muhokama qilingan. Dissertatsiyada muhokama qilingan ishlar asosida O‘zbekiston, Koreya, Yaponiya va Germaniyaning turli ilmiy tadqiqot muassasalarida seminarlar o‘tkazilib, maxsus ma’ruzalar o‘qilgan.

Tadqiqot natijalarining e’lon qilinganligi. Mazkur dissertatsiyada ko‘rib chiqilgan tadqiqotlar asosida jami 39 ta ilmiy ish[14] (xususan, 9 ta yakka mualliflik asari[15]) nashr etilgan. Ulardan 23 ta ilmiy maqola (xususan, 6 ta yakka mualliflik maqolasi) Web of Science ma’lumotlar bazasining asosiy to‘plamiga kiritilgan va xalqaro miqyosda e’tirof etilgan retsenziyalanadigan jurnallarda chop etilgan. Qolgan 16 tasi ilmiy ishlar konferensiya materiallari sifatida nashr etilgan, shu jumladan, 6 tasi maqola xalqaro miqyosda tan olingan ilmiy jurnallarda chop etilgan.

Dissertatsiyaning tuzilishi va hajmi. Dissertatsiya kompyuterda tayyorlangan matndan iborat bo‘lib, shu yerda keltirilgan kirish qismi, 7 bobdan, asosiy qismining qisqacha mazmuni, bibliografiya va ilovalardan (qo‘shimcha qism) iborat. Asosiy qismga tegishli bo‘lgan va aniq vazifani tavsiflovchi har bir bob boshlanishida berilgan o‘ziga xos qisqacha kirish qismi hamda tegishli bo‘lgan nazariya, muhokama, xulosa qismlaridan iborat. Ilova va adabiyotlardan tashqari asosiy qismi 162 betdan iborat.

[14] Muallifning [D1-D39] maqolalarida keltirilgan asosiy g‘oyalar qisman ushbu dissertatsiyada batafsil muhokama qilingan (I-VII boblarga qarang). Maqolalarning aksariyati dissertatsiya ishi hajmining rasmiy chegaralanganligi sababli qisqacha eslatib o‘tilgan, xolos.

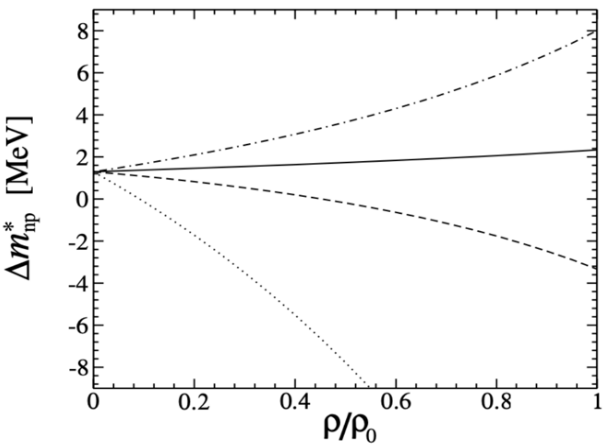
[15][D9,D15,D21,D24,D27,D36-D39]larni qarang.

DISSERTATSIYANING MAZMUNI

Kirish qismida tadqiqotlarning dolzarbligi va ahamiyati, ularning asoslari, maqsadi, vazifalari va mavzulari tavsiflangan. Tadqiqotning O‘zbekiston Respublikasi va jahon miqyosidagi fan hamda texnika taraqqiyotining ustuvor yo‘nalishlariga aloqadorligi tushuntirilgan. Tadqiqotning ilmiy yangiligi va amaliy natijalari bayon etilgan. Natijalarning ilmiy-amaliy ahamiyati ochib berilib, xulosalarning amaliyotga tatbiq etilishi muhokama qilingan. Ushbu munozaralarning barchasi dissertatsiya mazmuni tavsifidan yuqorida, shu yerda takrorlandi.

Nihoyat, asosiy qism oxirida dissertatsiyaning umumiy xulosasi keltirilgan. Bu yerda nashr etilgan ishlarni dissertatsiyada bajarilgan ishlarga nisbati ko‘rsatilib, qisqacha ko‘rinishda sarhisob qilingan. O‘quvchiga qulay bo‘lishi uchun dissertatsiyning oxirida va bibliografiyadan oldin bir nechta qo‘shincha ma’lumotlarni tashkil qiluvchi ilovalar ham keltirilgan.

Dissertatsiyaning I bobida yadro materiyasidagi nuklonlarning xossalari o‘ganilgan. Shu maqsadda Skirmi modeli asosida mezonik nazariyalardagi izospin symmetriyasining buzilish effektlari va ularning yadro materiya hodisalari bilan bog‘liqligi ko‘rib chiqilgan. Biz bu bobda yerda nuklonlarni kiral solitonlar sifatida tavsiflovchi mezon nazariyalarida izospin symmetriyasining buzilish effektlarini amalga oshirishni muhokama qildik va yadro muhitidagi nuklon xususiyatlarini tavsiflovchi modifikatsiyalarini ko‘rib chiqdik. Misol sifatida Skirmi modelini ko‘rib chiqdik. Kiral soliton modellari va xususan, Skirmi modeli boshqa adron modellariga solishtirganda o‘ziga xos afzalliklarga ega. Chunki ular kiral symmetriyaga asoslangan va nuklonlarning xususiyatlarini hamda o‘zaro ta’sirlashuvlarini bir asosda ko‘rib chiqadi [75-76].



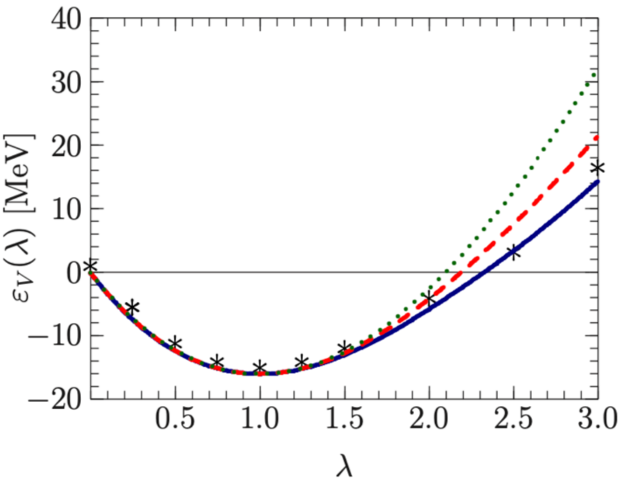
1-rasm. Neytron-proton massasi farqining yadro muhitida zichlikka bog’liq ravishda o’garishi. Zichlikning qiymatlari normal yadro zichligi $\rho_0 = 0.5m_\pi^3$ birligida berilgan. Uzluksiz chiziq isospin symmetrik yadro muhitiga $\rho_n = \rho_p$, chiziqchalardan iborat chiziq neytronlarga boy muhitga $(\rho_n - \rho_p)/\rho_0 = 0.2$, nuqta-chiziqli chiziq protonlarga boy muhitga $(\rho_n - \rho_p)/\rho_0 = -0.2$ va nuqtalardan iborat chiziq to’liq neytronlardan iborat muhitga $\rho_n = \rho$ to’g’ri keladi.

Masalan, 1-rasmda neutron-proton massalarining farqini yadro muhitida zichlikka bog‘liq ravishda o‘zgarishi ko‘rsatilgan.

II bobda haqiqiy yadrolardagi nuklonlarning xossalari ko‘rib chiqilgan va oyna yadrolarda kuzatilgan Nolen-Shiffer anomaliyasini o‘rganishga qo‘llanilgan. Shu maqsadda chekli yadrolardagi nuklon xossalarining modifikatsiyalarini va yadro fizikasida uchraydigan hodisalarni ko‘rib chiqish orqali tadqiqotlarimizni davom ettirdik. Yadro materiyasidagi neytron-proton massalarining farqi, $\Delta m_{\rm np}^*$, hali ham empirik jihatdan ma’lum emas [77]. Hozircha, izospin-assimetrik yadro materiyasidagi bu miqdor haqida turli xil nazariy bashoratlar bor xolos. Yadro muhitidagi effektiv neytron-proton massasi farqiga bag‘ishlangan tadqiqotlar Nolen-Shiffer anomaliyasini (NSA) hal qilish uchun muhim bo‘lishi mumkin [78]. NSAni tushuntirishga bag‘ishlangan ko‘plab nazariy yondashuvlar mavjud bo‘lsa-da, bu hodisa hali ham to‘liq tushunilmagan.

Bu bobda cheksiz, assimetrik yadrodagi nuklon xossalari va Δm_{np} o‘zgarmas zichlikli materiyadagi tadqiqotlarning haqiqiy yadrolardagi nuklon xususiyatlarini baholash uchun kengaytirildi. Bunday tadqiqotlar qisman izospin-buzilish effektini hisobga olgan holda kandidatlik ishida amalga oshirilgan edi. [16] Bu dissertatsiyamizda eslatilgan tadqiqotlarni chekli yadrolardagi kuchli va elektromagnit izospin-buzilush effektlarini hisobga olgan holda amalga oshirdik. Bu izlanishlarni chekli yadrolardagi neytron-proton massasi farqini yakka nuklonning effektiv xususiyatlari orqali o‘rganish va Skirmi modeli doirasida Nolen-Shiffer anomaliyasini tushuntirishga harakatlar orqali davom ettirdik. [17]

III bobda yadro materiyasining xossalarini modifikatsiyalash muhokama qilingan va yadro materiyasining holat tenglamalari olingan [18]. Bu yerda natijalarimizni mavjud bo‘lgan tajriba ma’lumotlari bilan solishtirdik. Ma’lum bir zichlik va haroratdagi nuklonlarning xossalarini o‘rganish yadro materiyasining xossayalarini tushunish uchun muhimdir. Buning sababi shundaki, yadroviy materiyasining xususiyatlarini ko‘rib chiqishda, barionlarning yadro muhitidagi mos ravishda modifikatsiyalashishini yodda tutish kerak. Biroq barionlarning yadro muhitidagi modifikatsiyasini yadro muhiti xossalariga mos ravishda bog‘lash qiyin muammo. Bu bobdagi tadqiqotlarimizning asosiy maqsadi cheksiz yadro materiyasi xossalarini yadro materiyasidagi nuklon xossalari bilan bog‘liq ravishda modifikatsiyalash edi.



2-rasm. Simmetrik yadro materiyasi energiyasini zichligiga bog’liqligi. Zichlikning qiymatlari normal yadro zichligi birligida $\lambda = \rho/\rho_0$ berilgan. Uzliksiz, uzlikli va nuqtali chiziqlar 3 ta model parameter toplamlariga mos keladi. (Parametrlarning qiymatlari dissertatsiyaning 3.1-jadvalida keltirilgan.) Solishtirish uchun Akmal-Pandharipande-Ravenhall natijalari [79] ham yulduzchalar orqali berilgan.

Biz qo‘llagan yondashuv yarim fenomenologik yondashuvdir. Bu yondashuvni asoslash uchun fenomenologik talablarni iloji boricha ko‘proq qondirish kerakligi ochiq-oydin tushunarli. Shuning uchun biz model eksperimental ma’lumotlarni takrorlay olishi va tegishli hodisalarni tushuntira olishi kerakligiga e’tiborimizni qaratdik. Xususan, model dissertatsiyaning oldingi boblarida olib borilgan tadqiqotlarga mos kelishini talab qildik. Izlanishlarni bosqichma-bosqich bajardik. Dastlabki bosqich sifatida, II bobda bo‘lgani kabi simmetrik va assimetrik yadro

[16] [P7,P9] larni qarang.
[17] [D7,D9] larni qarang.
[18] [D15] ni qarang.

muhitidagi nuklonlarning xossalarini tahlil qilishga e’tiborimizni qaratdik. Shu o‘rinda III bobda nuklonlarning yadro muhitidagi xossalarini cheksiz nuklon sistemalarining umumiy xossalari bilan bog‘lashga muvaffaq bo‘ldik.

2-rasmda simmetrik yadro energiyasining zichligiga bog‘liqligi keltirilgan. Natijalarimiz Akmal-Pandharipande-Ravenhall natijalari [79] bilan mos kelgan.

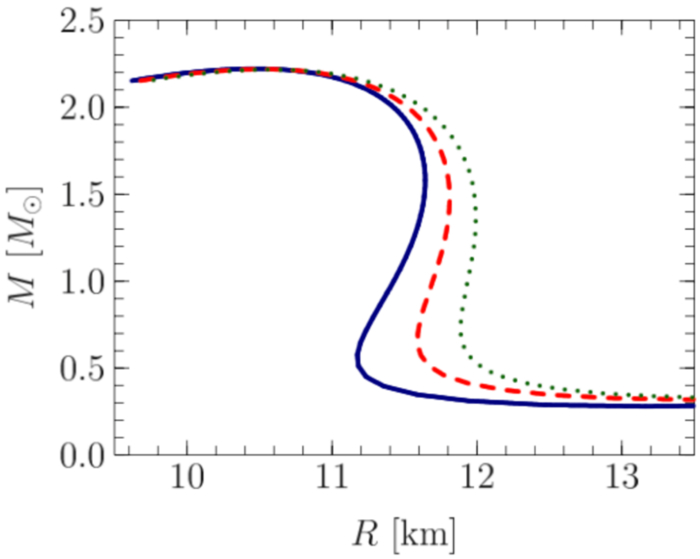
IV bobda yadro materiyasining holat tenglamari juda katta zichlikli hududlarga ekstrapolyatsiya qilingan va neytron yulduzlari xossalarining muhokamalari olib borilgan. Xususan, tadqiqotimizning asosini tashkil qiluvchi yaqinlashishlarimiz asosida massasi ikki quyosh massasiga $\sim 2M_{\odot}$ teng neytron yulduzlarini olish imkoni borligini ham ko‘rsatib bera oldik.

Neytron yulduzi tuzilishini tahlil qilish zamonaviy astrofizikaning qiziqarli mavzusidir. Xususan, yadro astrofizikasida neytron yulduzlarning tuzilishini o‘rganish yadro materiyasining holat tenglamalari (EOS) bilan bog‘liq bo‘lib, u zichlik qiymatlarining keng diapazoni uchun bosim zichligi va energiya zichligi orasidagi bog‘liklikni tavsiflaydi (masalan, [46]ga va undagi havolalarga qarang). EOSning o‘ziga xos xususiyatlari simmetrik yadro moddasining to‘yinganlik zichligidan kichik bo‘lgan zichliklarda yaxshi ma’lum, katta zichliklarda esa hali ham yaxshi ma’lum emas. EOSning katta zichlikdagi xossalari laboratoriyalarda to‘g‘ridan-to‘g‘ri eksperiment orqali aniqlashning qiyinligi va “ab initio” (asosdan kelib chiqib) nazariy hisob-kitoblarning yo‘qligi sababli yaxshi o‘rganilmagan. Shuning uchun eksperiment nuqtayi nazaridan neytron yulduzi tadqiqotlari katta zichliklarda EOS xusussiyatlarini tushunish uchun laboratoriya bo‘lib xizmat qilishi mumkin. Nazariy tomondan, ab initio hisob-kitoblar o‘rniga EOSning kichik zichliklardagi yaxshi ma’lum bo‘lgan xossalarini hisobga olgan holda fenomenologik asosdan boshlash va ekstremal sharoitlarda materiyaning xususiyatlarini tavsiflashga harakat qilib, yuqori zichlikli hududlarga ekstrapolyatsiya qilish mumkin.

Shu nuqtayi nazardan va erkin fazodagi nuklon xususiyatlarining yadro muhitida o‘zgarishini tadqiq qilish imkonini bersa, yaqqol vektor mezonlarni tavsiflovchi Skirmining kiral soliton modeli nazariy asos uchun boshlang‘ich nuqta bo‘lib xizmat qilishi mumkin. Yadro muhititdagi modifikatsiyalarni boshlang‘ich Lagrangianning erkin fazodagi konstantalarining zichlikka bog‘liqligini ta’minlagan holda ifodalash mumkin. Shuni ta’kidlash kerakki, umuman olganda, Lagrangianning yadro muhitidagi modifikatsiyasini fundamental tamoyillardan boshlab takrorlash mumkin. Ammo umumiy Lagrangianning shakli va uning tarkibiy qismlarining o‘ziga xos xususiyatlari hali ham yaxshi ma’lum emas. Shu sababli biz quyi energiyalardagi umumiy Lagrangianning qisqartirilgan variantini ifodalovchi kiral soliton modelidan foydalandik [D15, D39].

[D15, D39]larda keltirilgan tadqiqotlarda boshlang‘ich modelga bir oz ko‘proq fenomenologik ma’lumotlarni yuklash orqali modifikatsiyalashga erishildi, ya’ni zichlikka bog‘liq funksiyalarni erkin fazodagi Skirmi Lagrangianiga pionik-atom ma’lumotlariga ko‘ra va quyi energiyalarda assimmetrik yadro materiyasining to‘yinish zichligi ρ_0 atrofidagi xossalariga ko‘ra kiritildi. Garchi yadro muhitidagi modifikatsiyalangan Skirmi Lagrangiani umumiy Lagrangianning juda qisqartirilgan varianti bo‘lsa-da, u effektiv kiral Lagrangianlar ruhiga tayangan holda yadroviy ko‘p jism muammolarini o‘rganish uchun qo‘llanilishi mumkin. Bu yaqinlasish uchun to‘lov tavsiflash jarayonida eksperimental kuzatuvlardan ozroq farq qilishi mumkin bo‘lgan miqdoriy og‘ishlar bo‘lishi mumkin. Shunga qaramay, model aniq fazilatlarga ega: 1) u bir xil toifadagi Lagranjianlar orasida eng oddiy Lagranjianga ega va 2) kuchli o‘zaro ta’sir fizikasini sifatli tavsiflash uchun barcha kerakli jihatlarga ega. Bu g‘oyalar [D15, D39]larda ishlab chiqilgan yondashuvimizning asosini tashkil qildi va biz IV bobda shu asnodagi tegishli tadqiqotlarimizni taqdim etdik.

Model fenomenologik bo‘lsa-da, biz boshqa yondashuvlar va eksperimental ko‘rsatkichlar bilan solishtirdik, kuchli o‘zaro ta’sirlashuvchi sistemalarda qo‘llanilishi bo‘yicha testlarni o‘tkazdik. Yadro materiyasi bo‘yicha birlamchi tadqiqotlarimiz [D15] shuni ko‘rsatdiki, Lagrangiandagi modifikatsiya qilingan Skirmi qismi erkin fazodagiga o‘xshab, yadroviy materiyaning yuqori zichliklardagi singulyarlikka qulashini oldini olish uchun javobgardir. Bu xuddi erkin fazodagi Lagrangianning Skirmi qismi chekli razmerdagi solitonlarni barqarorlashtirish uchun javobgarligiga o‘xshashdir. Modifikatsiyalarimiz shuni ko‘rsatdiki, modelimiz parametrlarining ba’zi qiymatlarida cheksiz va isospin-assimetrik yadro materiyasining xossalari simmetrik yadro materiyasining to‘yingan nuqtasi ρ_0 atrofida yaxshigina tavsiflanishi mumkin.



3-rasm. Neytron yulduzi massasining radiusiga bog’liqligi. Yadro materiyasi siqiluvchanligining qiymati $K_0 = 270$ MeV va simmetriya energiyasising qiymati $\varepsilon_S(\rho_0) = 32$MeV qilib tanlab olingan. Uzluksiz, uzlukli va nuqtali chiziqlar simmetriya energiyasi parametri L ning 30, 40, va 50 MeV qiymatlariga mos keladi. Boshqa parametrlarning qiymatlari dissertatsiyaning 4.2-jadvalida (Set III) keltirilgan.

Bundan tashaqari yadro materiyasi holat tenglamalarini yuqori zichlikli hududlarga ekstrapolyatsiya qilib, ekstremal sharoitlarda kuchli o‘zaro ta’sir qiluvchi sistemalarga modelimizning qo‘llanilishi borasida testlar o‘tkazdik. Biz neytron yulduzlar tuzilishini o‘rganib, asosiy g‘oyalarimizning to‘g‘rili-gini qo‘shimcha ravishda tekshirdik.

3-rasmda neytron yulduzi massasining radiusiga bogliqligi keltirilgan. Hisoblashlarimiz massasi ikki quyosh massasiga $\sim 2M_\odot$ teng neytron yulduzlarining xossalarini fenomenologik kuzatuvlarga bilan solishtirganda juda qoniqarli ifodalab berdi.

V bobda tadqiqotlarimiz kengaytirilib, yondashuvimiz SU(3) sektorga umumlashtirilgan va yadro materiyasidagi giperonlarning xossalari muhokama qilingan. Xususan, yadro mihitidagi g‘alati barionlarning xossalari kaonning yadro muhitidagi xossalariga sezgirligini ko‘rsatdik. Ushbu yondashuvimizda ham adron xususiyatlarining yadro muhitidagi modifikatsiyalarining to‘g‘riligini natijalarimizni boshqa modellardagi natijalar bilan taqqoslash orqali muhokama qildik. Dissertatsiyaning oldingi boblarida aytib o‘tganimizdek, nuklonlarning xususiyatlari yadro muhitida o‘zgarishlarga uchraydi va nuklonlarning o‘zi yadro materiyasini tashkil etganligi sababli, yadro materiyasining xossalarining mos ravishda o‘zgarishiga olib keladi. Xuddi shu asnoda, yadro muhitidagi giperon ham xossalarini o‘zgartiradi. Neytron yulduzlari va giperyadrolarni yanada realroq tavsishlash uchun giperonlarning xossalarini ham yadro muhitida qanday o‘zgarishini tushunib yetishimiz kerak.

An’anaviy, g‘alati bo‘lmagan yadro materiyasi va uning tarkibiy qismlari bo‘yicha ko‘plab eksperimental hamda nazariy ishlar o‘nlab yillar davomida yadro materiyasi zichligining keng diapazonida o‘rganilgan bo‘lsa-da, yadro materiyasidagi giperonlar nisbatan kamroq o‘rganilgan (masalan, [41]ga qarang). Tadqiqotlarning aksariyati giperon-nuklon (YN) o‘zaro ta’siriga asoslangan. Misol uchun, Beane va boshqalar [80] yadroviy moddadagi Σ^--ning energiya siljishlarini aniqlash uchun panjaralar-KXDsidan foydalangan holda $n\Sigma^-$-sochilish fazalaridagi siljishlarni hisoblab chiqdi. Boshqa tadqiqotlarda [81, 82] esa YN potensiali effektiv maydon nazariyasi asosida qurilgan va yadro materiyasidagi giperonlarning xossalarini tekshirish uchun Brukner-Xartri-Fok (BHF) yaqinlashuvidan foydalanilgan. Yadro materiyasidagi giperonlarning xossalarini o‘rganish uchun zichlikning funksional nazariyalari ham ishlatilgan (sharhlovchi maqolaga [41] qarang).

Dissertatsiyaning V bobida biz nuklon va Δ izobara bilan birgalikda giperonlarning massa o‘zgarishlarini tekshirishning yana bir oddiy tizimini taklif qildik. Biz yadro materiyasida nuklon xossalari qanday o‘zgarishini kiral topologik soliton modellari [D7, D8, D14, D15] asosidagi bilimlarimiz doirasida qarab chiqdik, ya’ni yadro muhitidagi g‘alati bo‘lmagan barionlarning xossalaridaga o‘zgarishlarni sinchkovlik bilan tekshirishlar va turli xil form faktorlarini hisoblashlar asosida bajargan bilimlarimizdan foydalandik.

Bizning maqsadimiz yadro muhitida modifikatsiya qilingan modelning SU(2) versiyasini SU(3) versiyasiga sodda tarzda kengaytirish edi. Shunday qilib, biz yadro moddasidagi giperonlarni o‘rganish uchun oldingi tahlillarni umumlashtirdik. Maqsadga [83]da keltirilgan SU(3) Skirmi modelidan foydalanib, yadro materiyasida modelning tegishli parametrlarini zichlikka bog‘liq ravishda o‘zgartirish orqali erishdik. Hisoblashlarni va umumlishtirishlarni sodda tarzda olib borish uchun, birinchi navbatda, faqat SU(2) sektordagi mezon dinamikasining modifikatsiyalarini ko‘rib chiqdik. Biroq kaon xossalarining yadro muhitida o‘zgarishlarga duchor bo‘lishi ham ma’lum [84, 85]. Shulardan kelib chiqib, yadro muhitidagi kaon xossalarini zichlikka oddiy chiziqli bog‘lanishda o‘zgartirdik. SU(2) sektordagi umumiy dinamika SU(3) sektoriga umumlashtirish jarayonida saqlanib qoldi va model [D15, D21]larda muhoikama qilingan g‘alati bo‘lmagan sektordagi fenomenologiyani to‘g‘ri tushuntirib berishlari o‘zgarishsiz qoldi. Natijada, umumiylik saqlanib qoldi va yondashuvimiz kaonning yadro muhitidagi modifikatsiyasi SU(3) barionlarning xossalarini o‘zgarishiga qanday ta’sir qilishi haqida oddiy xulosalar chiqarish imkonini berdi.

1-jadavalda oktet barionlari massalarining yadro materiyasidagi o‘zgarishi kelritilgan. Jadavaldan yadro muhitidagi barionlar massalairining o‘zgarishlari kaon xossalarining yadro muhitidagi o‘zgarishlariga ta’sirchanligini kuzatish mumkin.

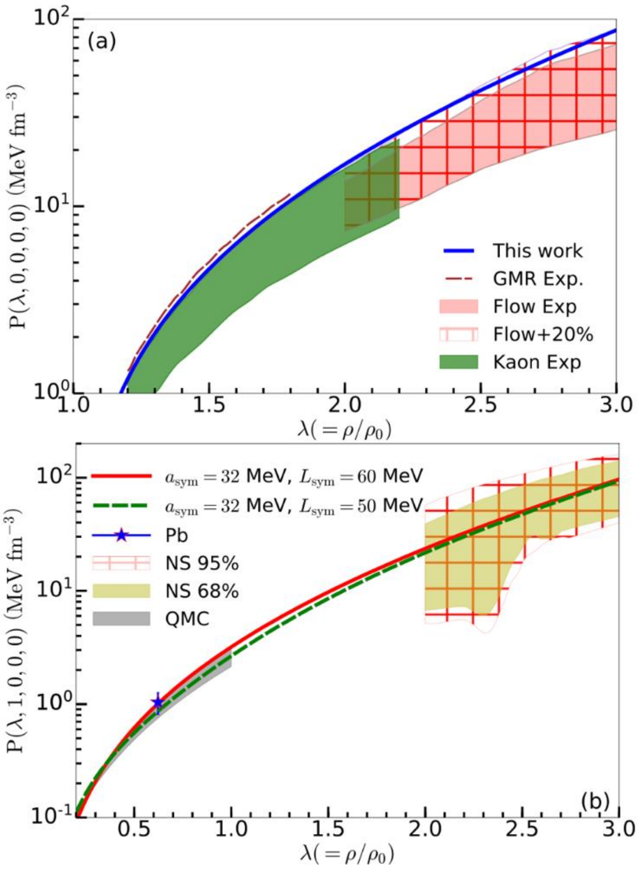
1-jadval. Oktet baryonlari massalarining yadro materiyasida o’zgarishi. Bu yerda C kaon massasining yadro muhitida o’zgarishini ifodalovchi parameter (detallari uchun disseratsiyaning V bobiga qarang). Hamma massalar MeV birligida berilgan.

Baryon	Experimental mass	Free space mass	Mass at $\rho = \rho_0$ $C = 0$	Mass at $\rho = \rho_0$ $C = 0.2$
N	939	939*	923*	923*
Λ	1115	1075	1004	960
Σ	1189	1210	1236	1122
Ξ	1315	1302	1221	1088

VI bobda simmetrik yadro materiyasi, neytron materiyasi va g‘alati materiya kabi turli yadro muhitlaridagi holat tenglamalarini ko‘rib chiqilgan. Bu bobda biz holat tenglamalaridan kelib chiqadigan natijalar yadro materiyasining fenomenologiyasi bilan yaxshi mos kelishini ko‘rsatdik. Shuningdek, SU(3) barionlari massalari har xil turdagi yadro muhitlarida qanday o'‘zgarishlarga duchor bo‘lishini muhokama qildik. Xususan, biz nosimmetrik materiya, assimetrik materiya, neytron materiya va g‘alati barion materiyadagi energiya jihatidan past qatlamlardagi SU(3) barionlarining muhitdagi massalari modifikatsiyasini o‘rtacha pion maydoni yondashuviga asoslangan holda izchil ravishda o‘rganib chiqdik [86]. Bu yo‘nalishdagi umumiy g‘oyaga Edvard Vittenning mashhur ilmiy maqolasida [87] asos solingan. Katta N_c (ranglar soni) limitida nuklonni N_c valent kvarklarining o‘rtacha mezon maydonida bog‘langan holat sifatida tavsiflash mumkin. Bu o‘rtacha meson maydoni esa, o‘z navbatida, N_c valent kvarklarni mavjudligi tufayli paydo bo‘lishi bilan birga mezonik kvant holatlarining paydo bo‘lishi $1/N_c$ omil darajasida qiyinligidadir. Bu yondashuv yengil va bitta o‘gir kvarkli barionlarning turli xususiyatlarini birlashgan tarzda tavsiflash uchun muvaffaqiyatli qo‘llanilgan. Pion o‘rtacha maydon yondashuvining asosiy g‘oyasi pion o‘rtacha maydon yondashuvini aniq amalga oshiradigan kiral kvark-soliton modeli [86] doirasida dinamik parametrlarni hisoblashda emas, balki barcha dinamik parametrlarni tajribaga asosan aniqlashdadir. Masalan, barion dekupletining massalarini barion okteti va Ω barion massasi haqidagi tajriba ma’lumotlaridan foydalanib aniqlashtirish mumkin [88].

Pion o‘rtacha maydon yondashuvini yadro muhitidagi yengil va bir og‘ir kvarkli barionlarni tavsiflash uchun ham kengaytirilishi mumkin. Biroq model erkinlik darajalari sifatida kvarklarga asoslanganligi sababli kvark kimyoviy potensialini hisobga olish kerak. Ammo bu yondashuv natijalarini yadro materiyasidagi barionlarning xossalariga bevosita bog‘lash ancha qiyin muammo. Shuning uchun biz yadro muhitini hisobga olib modifikatsiya qilingan Skirmi modellarida ishlatiladigan variatsion yondashuvga amal qildik.

Shunday qilib, bu bobda biz yadroviy va g‘alati barion muhitida SU(3) barion xossalarini o‘rganish uchun pion o‘rtacha maydon yondashuvini qanday kengaytirish mumkinligini ko‘rsatdik. Bu maqsadga esa zichlikka bog‘liq funksiyalarni variatsion parametrlar sifatida kiritish orqali erishildi. Zichlik funksiyalari parametrlashtirildi va mavjud eksperimental hamda empirik ma’lumotlarni hisobga olgan holda SU(2) sektorida to‘liq o‘rnatildi va shu o‘rinda yadro funksiyalarida chiziqli yaqinlashuvi tanlandi. Bu bizga g‘alati barion aralashgan materiyaning va barionlarning turli xil muhitlarda (izospin simmetrik, assimetrik va g‘alati barion) xususiyatlarini tavsiflash imkonini berdi.



4-rasm. Yadro materiyasi bosimining zichligiga bog’liqligi. Natijalarimiz yuqoridagi chizmada (uzluksiz chiziq) symmetrik yadro materiyasi va qiyi chizmada (uzluksiz va uzlukli chiziqlar) neytron materiyasi uchun keltirilgan. Solishtirish uchun turli xil eksperiment natijalari ham keltirilgan. Qo’shimcha ma’lumotlar uchun dissertatsiyaning VI bobiga qarang.

4-rasmda yadro materiyasi bosimining zichlgiga bog‘liqligini symmetrik yadro materiayasi va neytron materiyasi uchun keltirilgan. Ko‘rinib turibdiki, natijalarimiz turli xil eksperimental natijalar bilan mos keladi.

VII bobda yadroviy moddadagi og‘ir-barion xossalari VI bobdagi tadqiqotlarni umumlashtirish asosida muhokama qilingan.

Bu bobda bitta og‘ir kvarkli barionlar massalarining yadro materiyasi zichligiga bog‘liqligini bashorat qilib, shunga xos tegishli muhokamalarni keltirdik. Dissertatsiyaning VI bobini muhokama qilishda aytib o‘tganimizdek, yadro muhitida modifikatsiyalangan pion o‘rtacha maydon yondashuviga asoslanib, SU(3) barionlari massalari yadro muhitida qanday o‘zgarishlarga duchor bo‘lishini o‘rganib chiqdik [D28]. Biz yadro muhitidagi bitta og‘ir kvarkli barionlarning massalarini avvaldan belgilangan parametrlar bilan o'rganishni davom ettirdik. Yuqorida aytib o‘tganimizdek, kiral kvark-soliton modeli sifatida ham tanilgan pion o‘rtacha maydon yondashuvi Vittenning asosiy g‘oyasiga asoslangan: N_c (ranglar soni)ning katta qiymatlarida nuklon N_c valent kvarklar tufayli paydo bo‘lgan o‘rtacha pion maydonida N_c valent kvarklarining bog‘langan holatidir. Xuddi shu fikrni bitta og‘ir kvarkli barionlarga nisbatan qo‘llash ham mumkin. Agar og‘ir-kvark massasining cheksiz deb oladigan bo‘lsak ($m_Q \rightarrow \infty$), og‘ir kvarkni barionni ichidagi $N_c - 1$ valent kvarklardan ajratib olish mumkin. Shunday qilib, bitta og‘ir kvarkli barion ichidagi og‘ir kvark shunchaki statik rang manbai sifatida qaraladi va barionning ichidagi kvark dinamikasi yengil kvarklar tomonidan amalga oshiriladi. Og‘ir kvark cheksiz og‘ir bo‘lganligi sababli, og‘ir-kvark spini saqlanib qoladi, bu esa yengil kvark spinining saqlanishiga olib keladi. Bu holat og‘ir kvark spin simmetriyasi sifatida tanilgan. Ushbu og‘ir kvark massasi cheksizligi yaqinlashuvida birgina og‘ir kvarkdan tashkil topgan barion og‘ir aromatdan mustaqil bo‘lib, bu og'ir kvark aromat simmetriyasi deb ataladi. Bu yaqinlashishda yakka og‘ir kvarkli barionlardan tashkil topgan 1/2 va 3/2 spinli barion antitripleti (**3**) hamda ikkita barion seksetlari (**6**) bilan ifodalangan. Shunday qilib, bitta og‘ir kavrkli barionlarni bitta og‘ir kvarkdan ajratilgan holda $N_c - 1$ valent kvarklarning bog‘langan holati deb hisoblash mumkin. Og‘ir kvark esa bitta og‘ir kvarkli barionni rangsiz qilish uchun (kvark konfainmenti uchun) talab qilinadi.

Ushbu g‘oyaga asoslanib, pion o‘rtacha maydon yondashuvi to‘g‘ridan-to‘g‘ri bitta og‘ir kvarkli barionlarga kengaytirilgan [89] va bu yaqinlashuv erkin fazodagi yakka og’ir kavarkli barionlarning turli xususiyatlarini muvaffaqiyatli tasvirlab bergan edi. VII bobda biz bu g‘oyalar asosida 1/2 va 3/2 spinli bitta og‘ir kvarkli barionlarning massalarini yadro muhitida tavsiflash ishlarini bajardik [D28]. Qo‘shimcha ma’lumotlar uchun dissertatsiyaning VII bobiga qarang.

XULOSALAR

Xulosa qilib aytganda, biz adron xossalarining yadro muhitidagi modifikatsiyalarini va shu asosda tegishli yadro materiyasi holat tenglamalarini o‘rganish uchun ishlatilishi mumkin bo‘lgan yondashuvni ishlab chiqdik. Masalan, bu yaqinlashuvni bitta Lagrangiandan boshlab bajarish mumkin bo‘ldi. Xulosa qismida tadqiqot ishimizning muhim natijalarining nashr qilingan ilmiy ishlarimizga nisbatini ham qisqacha qilib ko‘rsatib berilgan.

1. Amaliy maqsadlarda ikkita muhim faktorlarni (atrofdagi yadro muhitining yakka nuklon xossalariga ta’sirini va mezonik sektorda aniq izospin-buzilishi effektini) o‘z ichiga olgan effektiv Lagranjianni yaratdik.

2. Yaratilgan Lagrangianning xususiy ko‘rinishlaridan foydalanib, cheksiz yadro materiyasidagi izospin simmetriyasi buzilish effektlarining o‘zgarishini o‘rgandik [D1, D2].

3. Shuningdek, chekli yadrolardagi izospin simmetriyasi buzilish effektlarini ham baholadik [D3, D4, D36]. Xususan, Nolen-Schiffer anomaliyasini [D5, D6] o‘rganib chiqdik. Bu tadqiqotlar nuklonning yadro muhitidagi massasini modifikatsiyalash uchun qat’iy shartlar zarurligni ko‘rsatdi.

4. Simmetrik va assimetrik materiyaning xususiyatlarini yuqorida belgilangan yondashuv asosida ko‘rib chiqdik [D11, D15, D24, D27, D32, D34, D35, D38]. Xususan, simmetrik va assimetrik yadro materiyalarining holat tenglamalari muvaffaqiyatli ravishda ishlab chiqildi.

5. Yadro materiyasi holat tenglamalarini yuqori zichlikli hududlarga ekstrapolyatsiya qilib, neytron yulduzi xossalarini ham o‘rgandik [D21]. Hisob-kitoblarimiz shuni ko‘rsatdiki, $\sim 1.4M_{\odot}$ and $\sim 2M_{\odot}$ massali neytron yulduzlarining xossalari yondashuvimiz doirasida juda yaxshi ifodalab berildi.

6. Yaqqol mezon erkinlik darajalariga ega bo‘lgan kiral-soliton modellariga yondashuvimizning kengaytirilishi ham ishlab chiqildi [D8, D10, D12]. Bu yerda biz yadro materiyasi xossalariga nisbatan vektor mezon xususiyatlarining yadro muhitida bo‘lishi mumkin bo‘lgan modifikatsiyalarini ham muhokama qildik. Biz vektor mezon xususiyatlarining yadro muhitidagi modifikatsiyalari yadro muhitidagi skirmion-nuklonlarning asosiy xossalarining modifikatsiyalariga bog‘liq bo‘lishi mumkinligini ko‘rsatib berdik.

7. Shuningdek, nuklonlarning elekromagnetik struktura o‘zgarishlari [D9, D18, D39], ko‘ndalang zaryad zichligi [D14, D22] va energiya-momenti tensor form faktorlarining [D7, D13, D16, D17, D19,D 20, D30] ham yadro muhitida o‘zgarishi o‘rganildi. Ushbu tadqiqotlar yadro muhitidagi nuklonlarning struktura o‘zgarishlari haqida qiziqarli ma’lumotlar berdi. Tadqiqotlar natijalari boshqa yondashuvlar natijalariga mos keldi.

8. Shuningdek, biz g‘alatilik sektoriga umumlashtirilgan yondashuvni Skirmi modeli [D23, D25] va modelga bog‘liq bo‘lmagan yondashuv [D28] asosida o‘rganib chiqdik. Nihoyat, yadro muhitidagi bitta og‘ir kvarkli barionlar xossalarining o‘rganishga bag‘ishlangan va umulashtirilgan yondashuvni ham amalga oshirishga muvaffaq bo‘ldik [D29, D31].

Xulosa sifatida shuni ta’kidlashni istardikki, ushbu dissertatsiyada muhokama qilingan yondashuv universal bo‘lib, yadro zichligining keng diapazonidagi turli yadro hodisalarini o‘rganishda qo‘llanilishi mumkin.

**НАУЧНЫЙ СОВЕТ DSc.03/30.12.2019. FM.01.09
ПО ПРИСУЖДЕНИЮ УЧЕНОЙ СТЕПЕНИ
ПРИ НАЦИОНАЛЬНОМ УНИВЕРСИТЕТЕ УЗБЕКИСТАНА**

НАЦИОНАЛЬНЫЙ УНИВЕРСИТЕТ УЗБЕКИСТАНА

ЯХШИЕВ УЛУГБЕК ТУРДАЛИЕВИЧ

АДРОНЫ В ЯДЕРНОЙ СРЕДЕ: ПРИБЛИЖЕНИЕ КИРАЛЬНОГО СОЛИТОНА

01.04.02 – Теоретическая физика

АВТОРЕФЕРАТ
диссертации доктора наук (DSc) по физико-математическим наукам

Ташкент – 2023

Тема диссертации доктора наук (DSc) по физико-математическим наукам зарегистрирована в Высшей аттестационной комиссии при Министерстве высшего образрвания, науки и инноваций Республики Узбекистан за номером B2023.2.DSc/FM214.

Диссертация выполнена в Национальном университете Узбекистана имени Мирзо Улугбека.

Автореферат диссертации на трех языках (узбекский, русский (короткая аннотация), английский) размещен на веб-странице Научного совета (www.nuu.uz) и на Информационно-образовательном портале «ZiyoNet» (www.ziyonet.uz).

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Защита диссертации состоится «___» _______2023 года в ___часов на заседании Научного совета DSc.03/30.12.2019.FM.01.09 при Национальном университете Узбекистана. (Адрес: 100174, г. Ташкент, Алмазарский район, ул. Университетская, дом 4. Тел.:(+99871)227-12-24, факс:(+99871)246-53-21,e-mail:nauka@nuu.uz).

С диссертацией можно ознакомиться в Информационно-ресурсном центре Национального университета Узбекистана. (зарегистрирована за №____) (Адрес: 100174, г. Ташкент, Алмазарский район, ул. Университетская, дом 4. Тел.:(+99871)227-02-24).

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Автореферат диссертации доктора наук (DSc)

(Короткая аннотация)

В данной диссертации мы разработали подход, который может быть использован для изучения модификаций свойств адронов в ядерной материи и соответствующих уравнений состояния ядерной материи, начиная с одного и того же базиса, например, с одного и того же лагранжиана. Некоторые основные моменты диссертационной работы в связке с нашими опубликованными работами можно коротко сформулировать нижеследующим образом.

1. Для прикладных целей мы предложили эффективный лагранжиан, который включает в себя как среднее влияние окружающей ядерной среды на свойства отделно взятого нуклона, так и явный эффект расщепления изоспина в мезонном секторе.

2. Используя конкретные версии этого лагранжиана, мы изучили изменение эффектов расщепления изоспина в бесконечной ядерной материи [D1,D2].

3. Мы также оценили эффекты расщепления изоспина в конечных ядрах [D3,D4,D36]. В частности, мы изучили аномалию Нолена-Шиффера [D5,D6], которая указывает на жесткие условия для модификации массы нуклонов в среде.

4. На основе сформулированного подхода [D11,D15,D24,D27,D32,D34, D35,D38] мы рассмотрели свойства симметричной и асимметричной материи. В частности, успешно воспроизведена уравнения состояния симметричной и асимметричной ядерной материи.

5. Экстраполируя наши уравнения состояния ядерной материи на области высокой плотности, мы также изучили свойства нейтронных звезд [D21]. Расчеты показали, что свойства нейтронных звезд с массами $\sim 1.4 M_{\odot}$ и $\sim 2 M_{\odot}$ могут быть хорошо воспроизведены в рамках настоящего подхода.

6. Расширение подхода на кирально-солитонные модели с явными мезонными степенями свободы было также развито [D8,D10,D12], где мы обсудили возможные модификации свойств векторных мезонов в связи со свойствами ядерной материи. Мы показали, что модификации свойств векторных мезонов в ядерной среде могут иметь отношение к модификациям остова нуклон-скирмионов в ядерной среде.

7. Мы также изучали изменения электромагнитной структуры нуклонов [D9,D18,D39], плотности поперечных зарядов [D14,D22] и форм-факторов тензора энергии-импульса нуклонов в ядерной материи [D7,D13,D16,D17,D19,D20,D30]. Эти исследования дали интересные

результаты об изменении структуры нуклонов в ядерной среде. Результаты исследований находились в согласии с результатами других подходов.

8. Мы также изучили обобщения подхода к учетом странности в модели Скирма [D23,D25] и в независимом от моделей подходе [D28]. Наконец, было сделано обобзщение подхода на изучение тяжелого бариона с одним тяжелым кварком в ядерной материи [D29,D31].

В конце хотим подчеркнуть, что подход, обсуждаемый в настоящей диссертации, является более универсальным и может быть применен для изучения различных ядерных явлений в широком диапазоне ядерных плотностей.

SCIENTIFIC COUNCIL DSc.03/30.12.2019.FM.01.09
ON AWARD OF THE SCIENTIFIC DEGREES
AT NATIONAL UNIVERSITY OF UZBEKISTAN

NATIONAL UNIVERSITY OF UZBEKISTAN

YAKHSHIEV ULUGBEK TURDALIEVICH

HADRONS IN NUCLEAR MATTER: THE CHIRAL SOLITON APPROACH

01.04.02 - Theoretical physics

DISSERTATION ABSTRACT
Doctor of Science (DSc) on Physical and Mathematical sciences

Tashkent – 2023

The theme of dissertation of doctor science (DSc) on physical and mathematical sciences was registered at the Supreme Attestation Commission at the Ministry of Higher Education, Science and Innovations of the Republic of Uzbekistan under number B2023.2.DSc/FM214.

Dissertation has been prepared at the National University of Uzbekistan.

The abstract of the dissertation is posted in three languages (Uzbek, Russian (short annotation), English) on the website of Scientific council (www.nuu.uz) and on Information and educational portal "ZiyoNet" (www.ziyonet.uz).

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Dissertation defense will take place "___" _______ 2023 at _____ at the meeting of the Scientific Council DSc.03/30.12.2019.FM.01.09 at National University of Uzbekistan. (Address: University str. 4, Tashkent, 100174, Uzbekistan.Tel.:(+99871)227-12-24, fax:(+99871)246-53-21, e-mail: nauka@nuu.uz).

The dissertation is possible to review in Information Resource Center at National University of Uzbekistan (registered under No. ____) (Address: University str. 4, Tashkent, 100174, Uzbekistan. Tel.:(+99871)227-02-24).

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INTRODUCTION (annotation of DSc dissertation)

Necessity and importance of the research topic. The fundamental theory of strong interactions, Quantum Chromodynamics (QCD) describes the physics of the current constituents of matter (quarks) and the interaction carriers (gluons) in a consistent manner from the theoretical side. From the experimental side, the modern scientific technologies based on huge accelerators and very sensitive detectors allow us to study the spectacular phenomena taking place in tiny regions of space $\sim 10^{-15}$ m during an extremely short time intervals $\sim 10^{-23}$ s. These are characteristic space and time scales of strong interactions. In order to approach even smaller regions of space and time, the elementary particles in accelerators are accelerated up to the very high energies of the order of $\sim 10^{12}$ eV. In such a way, we are moving in the direction of observing the astonishing phenomena that took place during the creation of the magic and wonderful Universe.

QCD is a nonabelian gauge field theory of strong interactions based on the universal interaction «constant», $\alpha \sim g^2$ (g is gauge coupling). The constant is not a real constant and changes its value depending on an interaction scale. At large energies, corresponding to small regions of space, the value of dimensionless constant becomes a slowly varying function of the momentum and smaller than one, $\alpha < 1$. That is called an asymptotic freedom in behavior of the current constituents of matter [1, 2]. Consequently, the beautiful mathematical advantage of QCD is based on the systematic perturbative approach, which allows us to study the strongly interacting particle phenomena directly in the framework of QCD itself. Although there are many technical problems with perturbative QCD, it is more or less straightforward to perform the theoretical evaluations and to compare of the results with the experimental data obtained in modern accelerators [3].

In contrast, in the low energy region corresponding to large distances, there are other strong interaction phenomena – the confinement of quarks [4] and the spontaneous breaking of the chiral symmetry [5]. The former is responsible for confining the quarks inside the hadrons and preventing them from ionization, while the latter is responsible for generating the mass of hadrons in the surrounding nature. Although the mechanism of confinement is not fully understood, it could also be interrelated to the increasing value of interaction constant α at small energies.

The increasing value of the interaction constant is problematic in direct applications of QCD because of the lack of a perturbative approach. Therefore, instead of QCD, effective field theories and phenomenological models have been developed, which can be applied to study in particular the physics of atomic nuclei (e.g. see Ref. [6]). While many nuclear models are formulated completely on a phenomenological basis, some hadronic approaches try to keep the trace of the basic features of QCD at low energies, e.g. the chiral symmetry and its spontaneous breaking. There is yet another interesting phenomenon, a partial restoration of the chiral symmetry in a dense environment, which is related to the hadron properties in nuclear matter (e.g. see Ref. [7]). The hadron properties in nuclear matter are related to the properties of nuclear matter itself by the in-medium dynamics of hadrons.

The weak point in many approaches focused on the properties of hadrons in nuclear matter or on properties of nuclear matter as a whole is the impossibility of performing the simultaneously studying both (the properties of hadron in nuclear matter and the properties of nuclear matter) on the basis of the same theoretical framework. Now, the ***necessity and importance*** of the model approach focused on solving such a problem should be clear and, therefore the formulation of such a model was our goal within the framework of the scientific studies presented in the current dissertation.

Relevance of the research work to the priority directions in science and technology of the Republic of Uzbekistan. The research carried out in the dissertation is in accordance with the priority directions in science and technology of the Republic of Uzbekistan. In particular, the results of the research work presented in the dissertation are closely related to the problems of energy sources and energy saving, problems of radiation safety and technologies of modern medicine. In general, the subject of the dissertation is of great interest from the point of view of basic scientific research programs carried out in scientific institutions all over the world. From this point of view, it is also in accordance with the goals for the development of basic science of the Republic of Uzbekistan.

A brief review of the research going on worldwide in relation to the topic of the dissertation. The dissertation topic is directly related to the main problems of contemporary research direction in nuclear and hadron physics. One can quickly mention the various scientific projects going on in research institutions and in scientific laboratories worldwide and below we will review some of them briefly.

1. The chiral symmetry and its spontaneous breaking is one of the most spectacular and important phenomena of strongly interacting systems at low energies. This phenomenon is closely related to the hadron properties in a dense medium via the decreasing value of the chiral condensate $\langle q\bar{q}\rangle$. The decreasing value of chiral condensate manifests the partial restoration of chiral symmetry.

In particular, it is very important to understand how the masses of hadrons undergo changes in the nuclear medium, since they are deeply rooted in the restoration of chiral symmetry and even the quark confinement in QCD [8–14]. As discussed in Ref. [8], the chiral condensate is known to be modified in nuclear matter, which reveals the mechanism as to how the spontaneous broken chiral symmetry is restored as the nuclear density increases. This also implies the changes of hadron masses in it, since the dynamical quark mass arises as a consequence of the spontaneous breakdown of chiral symmetry. Thus, understanding the medium modification of the hadron mass has been one of the most significant issues well over decades [15–19]. Consequently, the numerous experiments at Jefferson Laboratory[1] during the last two decades were devoted to

[1]See Nuclear Physics homepage of the laboratory: https://www.jlab.org/physics.

the studies of hadron properties in a dense nuclear environment. The measurements, particularly, have been devoted to the studies of electromagnetic (EM) form factors of bound nucleons. For example, the polarization-transfer phenomenon in proton knock-out reaction from the Helium ^{4}He($\vec{e}$, e', $\vec{p}$)^{3}H [20–23] and ^{16}O($\vec{e}$, e',$\vec{p}$)^{15}N [24] had the continuous experimental interest during the last decades. Those experimental measurements showed the quenching effect in the polarization-transfer double ratio $\mathcal{R} = (P'_x/P'_z)_{^4He}/(P'_x/P'_z)_{^1H}$. From the theoretical point of view, the quenching effect can be interpreted as an indication of the changes of the nucleon's EM form factors in the nuclear medium [25–31] or as an effect of final state interactions and two-body current contributions [32]. Therefore, depending on the energy scale and as is asserted in Refs. [29, 31], the changes in EM structures of the bound nucleons may be the actual case observed during the experimental measurements of the polarization-transfer double ratio $\mathcal{R}$. Those studies of in-medium EM form factors will help to analyze the difference in behaviors of in-medium protons and neutrons.

Experimental data from different laboratories also indicate that the nucleon is modified in the nuclei [33–39]. This means that other barions may also undergo changes in the nuclear medium [40–44].

The observations of the European Muon Collaboration [33], which indicate changes in the properties of nucleons in nuclei, have led to a great interest in the properties of hadrons in the nuclear medium. It was originally expected that the deep inelastic muon scattering cross sections on deuterium and iron nuclei should differ from each other by a constant number 28, which is purely a scale factor. The experiment showed something else, and this effect was called the EMC effect. The interest in this effect arose from the fact that the experiment, carried out at high energies of electrons (of the order of GeV) scattering on weakly bound nucleons (binding energy of nucleons in nuclei of the order of MeV), nevertheless indicated structural changes of the nucleons inside the nuclei. Despite of a large number of works devoted to this topic, the nature of the EMC effect has not yet been explained.

Therefore, the study of the properties of nucleons in nuclear matter is a very important task of nuclear physics and one of the main goals in the dissertation.

2. On the other hand, studies of the properties of asymmetric nuclei are important and a hot issue in contemporary nuclear physics and nuclear astrophysics. Many experimental and theoretical approaches are devoted to the asymmetric matter properties [45–47]. These studies and, in particular, studies of the equation of state (EOS) will play an essential role in understanding the physics of rare isotopes, heavy-ion reactions and the processes related to the formation of neutron stars. Although much effort has been made, the behavior of nuclear symmetry energy remains not well established at densities much bigger than the normal nuclear matter density. On the other hand, at sub-saturation densities, our knowledge of nuclear symmetry energy is more or less established [45, 48]. For example, at low densities, the symmetry energy term of the EOS has a close relation to the neutron skins of existing nuclei and the stability of nuclei near the dripline. Therefore, one can get some useful and detailed information from available experimental studies at relatively low densities. From the theoretical point of view, nuclear many-body models oriented to the studies of nuclear symmetry energy must satisfy certain constraints.

In this context, rare isotope physics has continued to be under the focus of current experimental facilities and includes, in particular, the studies of symmetry energy and relevant EOS of asymmetric nuclear matter. For example, the goals of the new accelerator facility in Daegeon in South Korea, Rare isotope Accelerator complex for ON-line experiments (RAON), include studies of the origin of elements in the periodic table, the beginning and expansion of the universe (origin of elements and evolution of stars). The accelerator will also be used in multiple fields, including material and biomedical science, atomic and molecular science, and nuclear science.[2]

In the present dissertation, we will present our studies of EOS of symmetric and asymmetric matter within the semi-phenomenological chiral solitonic approach guided by the constraints coming from the analysis of experimental data in the low-density region.

3. Analysis of the matter under extreme conditions and the corresponding studies of neutron star structure is an interesting topic of modern astrophysics. In particular, in nuclear astrophysics, the structure studies of neutron stars are related to the EOS of nuclear matter, which describes the pressure density versus energy density relation for a broad range of density values [46, 49, 50].

As we mentioned above, the features of EOS are well known at the densities below the saturation density of symmetric nuclear matter ρ_0, while in the high density regions they still remain not clear. The high density behavior of EOS is poorly understood because of the difficulty of direct experimental accessibility in laboratories and because of the absence of *ab initio* theoretical calculations. Therefore, from the experimental point of view, the neutron star studies may serve as a laboratory for understanding the behavior of EOS at high densities. From the theoretical point of view, instead of *ab initio* calculations, one can start from the phenomenological framework, taking into account the well known properties of EOS in the low density region and extrapolate to the high density regions, trying to describe the properties of matter under the extreme (high density and high temperature) conditions.

In this context, the creation of the quark-gluon plasma in Heavy Ion Collisions passes through different stages of nuclear densities (starting from the tens of orders of magnitude in comparison with ordinary nuclear matter densities) during the equilibration process of matter to its ground state. Relativistic Heavy Ion Collider experiments at the Brookhaven National Laboratory allow us to gain on the different density regions in relation to the hadron properties in nuclear matter and nuclear matter itself.[3]

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[2] See homepage of the Institute for Basic Science (IBS): https://www.ibs.re.kr/eng/sub01–05.do.

[3] See Nuclear & Particle Physics Departments homepage: https://www.bnl.gov/npp/.

In the present dissertation we discuss our research work related to the matter under extreme high density conditions and the corresponding studies of neutron star's properties.

4. All the mentioned experimental studies are also particular goals of the experiments at the Large Hadron Collider (LHC) at the European Center for Nuclear Research (CERN).[4] At LHC, a multiplicity of particles are created under the extremely dense ($\sim$ 30 to 40 times the amount of ordinary nuclear matter density $\rho_0 \simeq 0.16 - 0.17\ \mathrm{fm}^{-3}$) and strong magnetic field ($\sim 10^{19}$ G) environments. The studies of hadron properties in such environments are the current goal of scientists. In particular, LHCb experiments observe the heavy particles created in such environments. Consequently, the heavy particles in nuclear matter are also an interesting topic in hadron physics.

While medium modifications of heavy hadrons in nuclear matter have been much less studied than those of light ones, there have been several s [51–54] on charmed nuclei soon after the charmonium J/ψ and Σ_c were found [55–57]. Then the heavy barions in nuclear matter have been studied [58–61]. Recently, interest in heavy hadrons was renewed as the experiments on them including exotic heavy hadrons have yielded interesting findings [62–66] (see a recent review for the status of experiments on nonstandard heavy hadrons [67]). This has also triggered the investigation in relation to the heavy barion properties in nuclear matter [68–73] (see also a review [74]). Since there is no experimental data on how the heavy barions undergo changes in the nuclear medium and in nuclei, it is of great importance to study the medium modification of them theoretically to guide future experiments.

In the present dissertation we also present our studies related to the heavy baryon properties in nuclear matter.

Current status of the problem. At present there is a lot of experimental data and phenomenological information related to the dense matter phenomena from experimental facilities and astrophysical observations. Nevertheless, there is no generally accepted and formulated on a solid basis (directly from QCD) approach for the analysis of dense matter phenomena in unified form. In contrast, there are plenty of methodological directions and many approaches mainly focused on some specific part of the dense matter phenomenon. For example, nuclear models describing the properties of atomic nuclei mainly concentrate on the properties of atomic nuclei, giving no information on the properties of nucleons in the nuclear environment. In contrast, hadron models describing the hadron properties in nuclear matter and relating these properties to nuclear matter properties is not an easy and clear task.

Any approach which tries to consider as much as possible nuclear matter phenomena on the same footing will definitely have interest among the nuclear and hadron physics community. Such approaches may shed light on our common

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[4] See homepage of the CERN: https://home.cern/science/physics.

understanding of the strong interacting phenomena at low energies and dense matter related studies.

The relevance of the research work presented in the dissertation to done and going on research works at the scientific research institutions of the dissertant. The research presented in the dissertation was partially curried out at the Theoretical Physics Department (TPD) of the National University of Uzbekistan (NUU) in close collaboration with the members of TPD.[5]

The origin of the main tasks of the dissertation was formulated at TPD NUU. The initial tasks performed under the PhD program of the author (see Refs. [P1–P9][6]). The corresponding PhD works were partially supported by the State Committee for Science and Technology of the Republic of Uzbekistan (Gr.N° 11/97 and Gr.N° 18/99), INTAS association (Gr.N° 93-0239ext and Gr.N° YSF 00-51) and SCOPES program (Gr.N° 7UZPJ65677).

The present dissertation related research was also carried out at the Pusan National University (Busan, Korea) under the PostDoc program (see Refs. [D1, D2]), at the Research center for Nuclear Physics (Juelich, Germany) under the PostDoc program of the Alexander von Humboldt Foundation (see Refs.[D3–D6]), at Inha University (Incheon, Korea) under the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (NRF MEST) where author was the principal investigator: Gr.N° 2011-0023478 & Gr.N° 2012-0008469 "Chiral dynamics in nuclear matter and astronuclear physics" (see Refs. [D7–D22]), Gr.N° 2016R1D1A1B0393505 "Nonperturbative effects on heavy hadrons and changes of hadron structure under extreme conditions" (see Refs. [D23–D27]) and Gr.N° 2020R1F1A1067876 "Heavy hadrons and Nuclear Matter" (see Refs. [D28–D31]). It was also partially supported by NRF MEST grant Gr.N° 2009-0089525 (see Refs.[D32–D35]) and Inha University personal research grants (see Refs. [D36–D39]).

In such a way, the research work of the dissertant was always a part of research projects at research institutions and Universities where he was working.[7]

The aim of the research work is to develop a more consistent phenomenological model of nuclear systems which considers the hadron properties in dense environments, nuclear systems, and matter under extreme conditions on the same basis by starting from the same Lagrangian.

The tasks of the research work:

- developing the Lagrangian on the basis of mesonic atoms' phenomenology, and performing applications to study the nucleon properties in nuclear

[5] TPD was the main working place of the dissertant until 2009. After that, he became a voluntary member of TPD and actively contributed to the research of NUU up to the present time. It is necessary to note, that among 64 Web of Science core-collection papers of the author, 30 of them show NUU as an affiliation of the author.

[6] See also PhD thesis of the author [P10].

[7] It is necessary to note that the author has 91 publications. 53 of them are related to the topic of the dissertation. Among them, 39 are mentioned as a part of the present dissertation work. Among the other publications by the author which are not related to the topic of the dissertation, the majority are done at TPD NUU and supported by different scientific foundations, including those in Uzbekistan.

matter and finite nuclei properties[8];

- further developments on the basis of atomic nuclei phenomenology at saturation density, and comparisons of results with phenomenological indications and the results from other approaches[9];
- applications of the model in studying the hadron properties in a dense environment, nuclear matter equations of state and properties of neutron stars[10];
- extensions to SU(3) sector by considering the hyperons in nuclear matter[11] and heavy hadrons in nuclear matter[12];
- studies of strange matter equations of state[13] and possible applications in the studies of neutron stars' properties.

The objects of the research work are ordinary, strange and heavy hadrons, hadronic systems, atomic nuclei and neutron stars.

The subject of the research work was to develop theoretical models and methods for studying strongly interacting hadron systems from the perspective of the properties of individual hadrons in the nuclear environment and the nu- clear environment as a whole.

The methods of the research work are Chiral Lagrangian approaches, nonlinear differential equations and solitonic solutions, mesonic theories and nucleons from the chiral solitons, phenomenological optical model approach to the hadron-nucleus interactions, phenomenological approaches to the atomic nuclei, general relativistic equations in studies of neutron stars.

For the realization of the dissertation goals, we have used numerical methods from the theories: nonlinear differential equations, integrations, functional minimizations, interpolations and extrapolations.

Scientific novelties of the research work:

- it developed a more consistent model approach to the physics of atomic nuclei and hadron properties in the nuclear environment which properly describes the phenomenology at different regimes of nuclear densities starting from the ordinary densities of atomic nuclei ending with the extreme high densities existing in compact stellar objects;
- the equations of symmetric and asymmetric nuclear matter were correctly described and agreed with the phenomenological evidence over a wide range of nuclear densities;
- in particular, it was shown that the model correctly describes the properties of the two solar-mass neutron stars;

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[8] This task was partially done before obtaining PhD degree (see Refs.[P1, P3] and PhD thesis of the author [P10]) and continued after obtaining PhD degree, e.g. see Refs. [D3–D5] and Chapters I & II of the dissertation work.
[9] See Refs. [D15, D32] and Chapter III of the dissertations work.
[10] See Ref. [D21] and Chapter IV of the dissertations work.
[11] See Refs. [D23, D28] and Chapters V & VI of the dissertations work.
[12] See Refs. [D29, D31] and Chapter VII of the dissertations work.
[13] See Refs. [D28] and Chapter VI of the dissertations work.

– the method originally developed in the ordinary SU(2) light-flavor sector is extended to the SU(3) flavor sector, including the strange quark related phenomena and also heavy quark related phenomena;
– importance of kaon mass modifications in the study of hiperons in nuclear matter has been demonstrated;
– predictions on the behavior of the heavy baryon masses in nuclear matter and their relation to the heavy meson masses in nuclear matter are also made for the first time in the framework of soliton models;
– further application of the approach to the model-independent mean-field theories based on SU(3) quantization is formulated.

The practical results of the research work can be used during the analysis of experimental results and phenomenological observations. For example, our studies on structure changes of the nucleons in nuclear matter have the corresponding interest in understanding the work done and in planning future experiments at Jefferson Laboratory.

The symmetry energy studies performed in this dissertation will be useful for the analysis of future experiments at the Rare Isotope Accelerator Complex for ON-line Experiments (RAON) in Daegeon City, South Korea.

The extrapolations of our EOS to the extreme density regions allowed us to get the proper neutron star properties, e.g. two solar mass neutron stars corresponding to the specific equations of state. This result has practical interest in the content of analysis of the recent astrophysical observations.

Authenticity of the research results is supported by comparisons of our results with the pionic atom data at low densities, with nuclear matter properties at saturation density and with the multiple predictions which are in qualitative agreement with experimental indications. In particular, it was shown that the changes in the various form factors of the nucleon (energy momentum tensor, charge and magnetic form factors) are in agreement with the experimental evidence from the results of the European Muon Collaboration, i.e. with EMC effect. The research results are also supported by peer-reviewed scientific publications in internationally recognized journals, presentations and discussions at interna- tional conferences and workshops, and seminars at various scientific institutions in Korea, Japan and Uzbekistan.

The scientific and practical values of the research results are shown by the interest of the hadron and nuclear physics community in our published works, e.g."Energy-momentum tensor form factors of nucleon in nuclear matter" (see citations to our works in Refs. [D7, D16, D20]).

The main approach discussed in the present dissertation can be used in other topological and non-topological soliton models. It also has a pedagogical interest among the hadron and nuclear physics community.

Implementation of the research results was partially done and is expected in future on the basis of planned experiments in accelerator facilities, e.g. "Nucleon knock-out reactions from the finite nuclei at Jefferson Lab" (see discussion in Refs. [22, 23, 28, 29] which refer to our work [P9].).

Approbation of the research results. The results of studies presented in this dissertation have been presented and discussed at more than 40 international conferences and workshops, in the numerous meetings of the Korean Physical Society. On the basis of works discussed in the dissertation, they have been given seminars and delivered special lectures in the various research institutions of Uzbekistan, Korea, Japan and Germany.

Publications of the research results. In total, 39 scientific works[14] (in particular, 9 single authored works[15]) have been published on the basis of studies reviewed in the present dissertation. Among them, 23 scientific articles (in particular, 6 single-authored articles) have been published in internationally recognized peer-reviewed journals which are entered into the core-collection papers of the Web of Science database. The remaining 16 scientific works have been published as conference proceedings, including 6 papers in internationally recognized peer-reviewed journals.

The outline of the dissertation. The dissertation comprises a typewritten text and consists of an introduction given here, 7 chapters, summary of the main part, bibliography and appendices (supplementary part). Each chapter belonging to the main part and describing the specific task has its own introduction part given at the beginning of the chapter and theory, discussion, conclusion parts in the form of corresponding sections and subsections. Excluding the appendices and the bibliography the main part of the dissertation has 162 pages.

CONTENT OF THE DISSERTATION

The introduction describes the relevance and importance of the studies, their justification, the purpose, objectives and subjects. The relevance of the studies to the priority areas of the development of science and technology of the Republic of Uzbekistan and worldwide is explained. The scientific novelty and practical results of the research are outlined. The scientific and practical significance of the results are revealed and the implementation of the findings into practice discussed. All those discussions are re-presented above the description of the content of dissertation.

Finally, at the end of the main part, the general summary of the dissertation is presented. We very briefly summarize the work that has been done in the dissertation in relation with our published works. For the convenience of the reader, at the end of dissertations and before the bibliography, several appendixes are also presented.

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[14] The main ideas from the publications of the author listed as Refs. [D1–D39] are represented in this dis- sertation by detailed discussions of some of the publications (see Chapters I-VII). The majority of those publications are briefly mentioned because of the formal limit to the volume of the dissertation work.

[15] See Refs. [D9, D15, D21, D24, D27, D36–D39].

In chapter I of the thesis its discussed the nucleons in nuclear matter. For that purpose, it has been considered the isospin breaking effects in mesonic theories and their relation to the nuclear matter phenomena on the basis of the Skyrme model. We discussed there the implementation of isospin breaking effects in the mesonic theories describing the nucleons as chiral solitons and considered further medium modifications in order to describe the nucleon properties in the nuclear environment. As a simple example, we considered the Skyrme model. The chiral soliton models and, in particular, the Skyrme model have the inherent advantage compared with other hadronic models that they are based on chiral input and that they treat the properties and interactions of the nucleons on an equal footing [75–76].

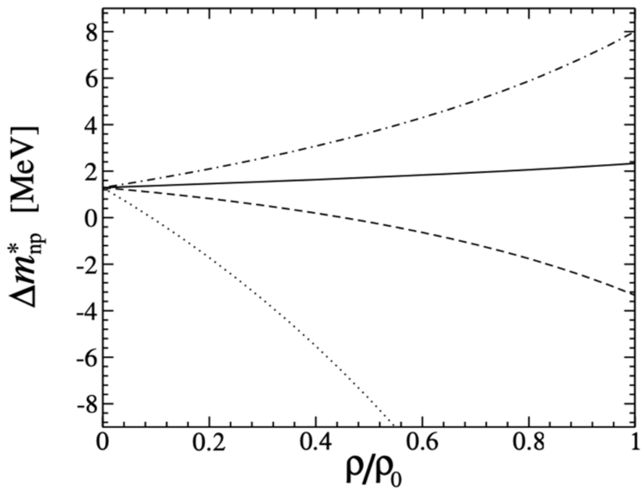

Fig. 1. The neutron-proton mass difference in nuclear matter. Density is given in units of normal nuclear matter density $\rho_0 = 0.5m_\pi^3$. The solid curve corresponds to the isospin symmetric matter $\rho_n = \rho_p$, the dashed curve corresponds to the neutron reach matter $(\rho_n - \rho_p)/\rho_0 = 0.2$, the dot-dashed curve corresponds to the proton reach matter $(\rho_n - \rho_p)/\rho_0 = -0.2$ and the dotted curve corresponds to the pure neutron matter $\rho = \rho_n$.

As an example, in Fig.1. it is presented the neutron-proton mass difference in nuclear matter.

In chapter II we considered the properties of nucleons in finite nuclei and studied the possible applications by considering the Nolen-Schiffer anomaly observed in mirror nuclei. We continued our studies by considering the modifications of nucleon properties in finite nuclei and the corresponding phenomenon in nuclear physics. The effective neutron-proton mass difference in nuclear matter, Δm_{np}^*, is still not known empirically [77]. There exist very different theoretical predictions of this quantity for isospin-asymmetric nuclear matter. Such studies of the effective neutron-proton mass difference inside nuclei may be relevant to resolve the Nolen-Schiffer anomaly (NSA) in nuclear physics [78]. Although there are many theoretical approaches devoted to the explanation of the NSA this phenomenon is still not fully understood.

Here the single nucleon properties and Δm_{np}^* in infinite, asymmetric nuclear matter with a constant density was extended to evaluate the nucleon properties in *finite* nuclei. Such kind of studies, however with only partial isospin-splitting effects, were been performed during the PhD work.[16] We performed further developments to extend these studies to the strong and electro-magnetic isospin-breaking effects in finite nuclei. We considered the neutron-proton mass difference

[16] See our works [P7, P9].

in finite nuclei by studying the single-nucleon effective properties and by trying to explain the Nolen-Schiffer anomaly within a medium-modified Skyrme model.[17]

In chapter III we discussed the modifications of nuclear matter properties and reproduced the corresponding equations of state of nuclear matter.[18] We compared our results with the possible experimental data. The studies of nucleon properties at finite density and temperature are important for understanding the properties of nuclear matter. This is due to the reason that when one considers nuclear matter properties one should keep in mind that the medium modification of baryons will take place self-consistently. However, it is very difficult to relate the medium modification of baryons to the nuclear medium in a consistent way. The main purpose of the chapter was the modifications of infinite nuclear matter properties relating them to the nucleon properties in nuclear matter.

The approach, which we used is semi-phenomenological. To justify it was necessary to satisfy as much as possible phenomenological requirements. Therefore, we concentrated on that the model must be able to reproduce the experimental data and explain the related phenomena, e.g. we reqired that the model must be in accordance with the studies performed in the previous chapters of dissertation. We performed our studies step by step. As an initial step, we concentrated on the analysis of nucleon properties in symmetric and asymmetric nuclear matter as it was done in chapter II. However, in the chapter III we related those nucleon properties to the bulk properties of infinite nucleonic systems.

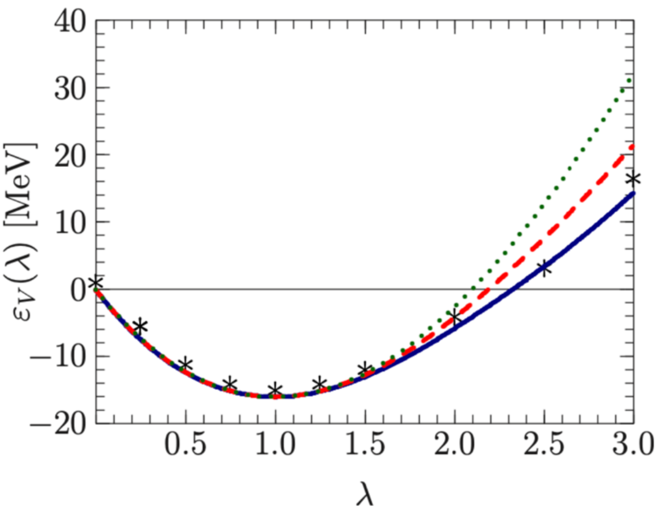

Fig.2. Symmetric nuclear matter energy dependence on its density. Density is given in units of normal nuclear matter density $\lambda = \rho/\rho_0$. Solid, dashed and dotted curves correspond to 3 model-parameter sets. (The values of parameters are given in Table 3-1 of the dissertation.) For comparison, Akmal-Pandharipande-Ravenhall predictions [79] are also given.

In Fig.2, it is presented the energy symmetric nuclear matter depending on its density. Our results agree with the Akmal-Pandharipande-Ravenhall predictions [79].

In chapter IV, we extrapolated our EOS to the extreme density regions and discussed the properties of neutron stars. We showed that our EOS will allow us to obtain $\sim 2M_{\odot}$ neutron stars.

Analysis of the neutron star structure is an interesting topic of the modern astrophysics. In particular, in the nuclear astrophysics the structure studies of neutron stars are related to the Equations of State (EOS) of nuclear matter which

[17] See our works [D5, D6].

[18] See our work [D15,].

describes the pressure density versus energy density relation for a broad range of density values (e.g. see review [46] and references therein). The peculiarities of EOS are well know at the densities below the saturation density of symmetric nuclear matter ρ_0 while at the high density regions they are still remaining not clear. The high density behavior of EOS are poorly understood because of the difficulty of direct experimental accessibility in laboratories and because of the absence of *ab initio* theoretical calculations. Therefore, from the experimental point of view, the neutron star studies may serve as a laboratory for understanding the behavior of EOS at high densities. From the theoretical point of view, instead of *ab initio* calculations one can start from the phenomenological framework taking into account the well known properties of EOS at the low density region and extrapolate to the high density regions trying to describe the properties of matter under the extreme (high density and high temperature) conditions.

In this context and if one able to formulate further in-medium modifications, a chiral soliton model of Skyrme, describing the single nucleon properties in free space, or its variations including the explicit vector mesonic degrees of freedom may serve as a starting point for the theoretical framework. The in-medium modifications may be expressed allowing the density dependencies of the constants entering into the initial free space Lagrangian. It is necessary to note, that in principle one should be able also to reproduce the medium dependencies in the effective Lagrangian starting from the first principles but it is not known yet the form of general low energy Lagrangian and the peculiarities of its ingredients. For this reason, we used an in-medium modified chiral soliton model [D15, D39] which may be considered as a truncated version of the general low energy Lagrangian.

In Refs. [D15, D39] the medium modifications were achieved putting a bit more phenomenology into the initial model, i.e. putting the density dependent functions into the free space Skyrme Lagrangian according to the pionic-atoms data at low energies and properties of asymmetric nuclear matter at saturation density ρ_0. Although the in-medium modified Skyrme Lagrangians is assumed to be very truncated version of the possible general Lagrangian, it must be applicable to the studies of nuclear many-body problems in the spirit of chiral effective Lagrangians. The pay for the truncation may be the possible deviations from the experimental observables in the sense of quantitative description. Nevertheless, the model has obvious virtues: i) it has the simplest Lagrangian among the same class Lagrangians, and ii) has all necessary ingredients for the qualitative description of the strong interaction physics. These ideas were the basic ruling philosophy behind of the approach developed in Refs. [D15, D39] and we represented the corresponding studies in the chapter IV.

While the model was a phenomenological, we performed tests on its applicability to strong interacting systems comparing with other approaches and the experimental indications. The previous nuclear matter studies [D15] showed that the in-medium modified Skyrme term is responsible for preventing the collapse of nuclear matter to the singularity at high densities in analogy to the free space case where the Skyrme term is responsibly for the stabilization of finite size solitons. The modifications showed that at some values of model parameters the properties of infinite and isospin asymmetric nuclear matter can be reproduced well near the saturation point of symmetric nuclear matter ρ_0.

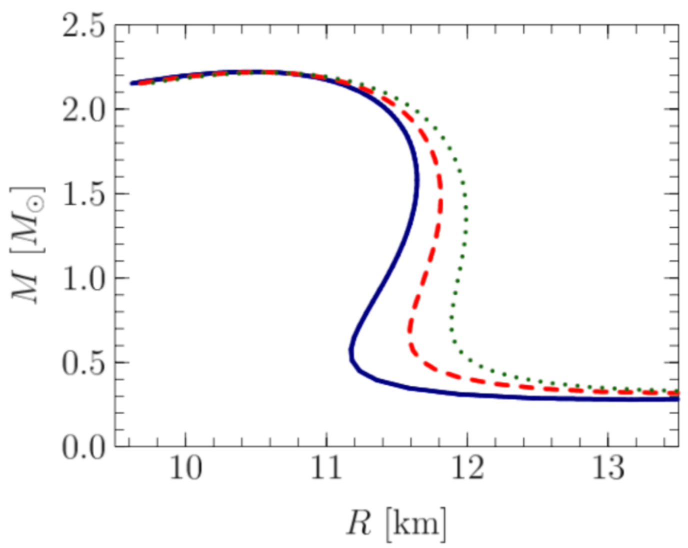

Fig.3. The mass-radius relation of a neutron star. The compressibility and symmetry energy values are fixed at $K_0 = 270$ MeV and $\varepsilon_S(\rho_0) =$ 32MeV. Solid, dashed and dotted curves correspond to the values of slop parameter L = 30, 40 and 50 MeV. The values of other parameters are given in Table 4.2 (Set III) of dissertation.

We performed test for the applicability of model to the strong interacting systems under the extreme conditions extrapolating the modified Equations of State to the high-density regions. We made further check of the basic philosophy considering an application of the model for the studies of neutron stars structure.

In Fig.3. the mass-radius relation of a neutron star is represented. Our calculations gave very satisfactory results for two solar-mass $\sim 2M_\odot$ neutron starts in comparison with the pehenomenological indications.

In chapter V we generalized our approach to the SU(3) sector and discussed the properties of hyperons in nuclear matter. We showed that the properties of baryons in the strange sector are sensitive to the in-medium modifications of the kaon properties. We discussed the consistency of the in-medium modifications of hadron properties in this approach, comparing our results with those from other models. As we already discussed in previous chapters of dissertation, the nucleons undergo the changes in nuclear matter and since they themselves constitute nuclear matter, the medium modifications of nucleon properties bring about the changes of nuclear matter in a self-consistent manner. Similarly, a hyperon lying in nuclear matter is also altered. It is essential to understand how its attributes become different in nuclear medium so that neutron stars and hypernuclei can be described in a more realistic way.

While a plethora of experimental and theoretical works on conventional nonstrange nuclear matter and its constituents in a wide range of nuclear matter densities has been compiled well over decades, hyperons in nuclear matter have been relatively less studied (e.g. see Ref. [41]). Most of the works are based on the hyperon-nucleon (*YN*) interactions. For example, Beane et al. [80] computed the $n\Sigma^-$ scattering phase shifts using lattice QCD to quantify the energy shift of the Σ^- in nuclear matter. In Refs. [81,82] the *YN* potential was constructed from effective field theory and the Bruecker-Hartree-Fock (BHF) approximation was employed to investigate hyperons in nuclear matter. Density functional theories were also used to study the hyperons in nuclear matter (see a recent review [41]).

In the chapter IV of dissertation, we proposed yet another simple framework of investigating the mass shifts of the hyperons together with the nucleon and the Δ isobar. We performed our studies according to our knowledge how the nucleon properties change in nuclear matter within the framework of the chiral topological soliton models [D7, D8, D14, D15], where the mass shifts of the nonstrange baryons were scrutinized and various in-medium modified form factors were computed.

Our aim was to extend the SU(2) version of the in-medium modified model to the SU(3) one in a straightforward and simple manner. So, we generalized the previous analyses to investigate the hyperons in nuclear matter. We employed an SU(3) Skyrme model developed in Ref. [83] and modify the relevant parameters of the model in nuclear matter. For simplicity, we first considered only the in-medium modification of meson dynamics in the SU(2) sector. However, the kaon is also known to undergo the changes in nuclear matter [84, 85]. Thus, we altered the kaon properties in nuclear medium, assuming a simple linear-density approximation. While the dynamics in the SU(2) sector remained intact in the course of generalization to the SU(3) sector, the model still properly explains the phenomenology in the nonstrange sector as discussed in Refs. [D15, D21]. The approach allowed one to draw a simple conclusion as to how the in-medium modified kaon can influence the changes of the SU(3) baryons in nuclear matter.

In Table 1, it is represented changes in the masses of octet baryons in nuclear matter. Ona can see that the changes in the masses of octet baryons are sensitive to the changes in the kaon properties in nuclear matter.

Table 1. The masses of octet baryons in nuclear matter. Here parameter C is related to the kaon properties in nuclear matter (for more details, see chapter V in the dissertation). All baryon masses are given in MeV.

Baryon	Experimental mass	Free space mass	Mass at $\rho = \rho_0$	
			$C = 0$	$C = 0.2$
N	939	939*	923*	923*
Λ	1115	1075	1004	960
Σ	1189	1210	1236	1122
Ξ	1315	1302	1221	1088

In chapter VI we discussed the equations of state in different nuclear environments, such as symmetric nuclear matter, neutron matter and strange matter. We showed that the results for the equations of state are in good agreement with the phenomenology of nuclear matter. We also discussed how the SU(3) baryons masses undergo changes in these various types of nuclear matter. In particular, we investigated the medium modification of the low-lying SU(3) baryons in symmetric matter, asymmetric matter, neutron matter, and strange baryonic matter consistently, based on a pion mean-field approach [86]. The general idea is based on the seminal paper by E. Witten [87]. In the large N_c (the number of colors) limit, the nucleon can be viewed as a state of N_c valence quarks bound by the meson mean fields that is produced self-consistently by the presence of the N_c valence quarks, since the mesonic quantum fluctuations are suppressed by the $1/N_c$ factor. Before, this approach has been successfully applied for describing the various properties of both light and singly heavy baryons in a unifying manner. The main idea of the pion mean-field approach is not to compute dynamical parameters within the chiral quark-soliton model [86], which realizes the pion mean-field approach explicitly, but to fix all relevant dynamical parameters by using the experimental data. For example, the masses of the baryon decuplet can be predicted by using the experimental data on those of the baryon octet and the mass of the Ω baryon [88].

The pion mean-field approach can be also extended to the description of light and singly heavy baryons in nuclear medium. However, since the model is based on the quark degrees of freedom, one should consider the quark chemical potential, which means that it is rather difficult to connect the results from this approach directly to the properties of the baryons in nuclear matter. Thus, we will followed a variational approach that was adopted in the medium modified Skyrme models.

Thus, we showed how the pion mean-field approach can be extended to the investigation of the SU(3) baryon properties in both nuclear and strange baryonic environments. That was achieved by introducing the density-dependent functionals as variational parameters. The density functionals parametrized and fitted completely in the SU(2) sector by taking into account available experimental and empirical data, the linear-response approximation being emphasized. That enabled us to describe the strange baryonic matter and properties of baryons in different media (isospin symmetric, asymmetric and strange baryonic matter).

In Fig.4 it is given the pressure-density dependence of the symmetric matter (upper plane) and the neutron matter (lower plane). One can see that our results in a good agrrement with the different experimental results.

In chapter VII we discussed the heavy-baryon properties in nuclear matter on a basis and generalizations of studies in chapter **VI**. We predicted and discussed the density dependence of the masses of the singly heavy baryons.

As we mentiones in discussion of the chapter VI of dissertation, we have investigated how the masses of the SU(3) baryons undergo changes in nuclear medium, based on the medium-modified pion mean-field approach [D28]. We proceeded further to study the masses of the singly heavy baryons in nuclear medium with parameters already fixed. As we mentioned before the pion mean-field approach, also known as the chiral quark-soliton model (χQSM), was constructed by Witten's seminal idea: in the large N_c (the number of colors) limit, the nucleon can be regarded as a state of N_c valence quarks bound by the pion mean field generated self-consistently by the presence of the N_c valence quarks. The same idea can be applied to the singly heavy baryons. If we take the limit of the infinitely heavy-quark mass ($m_Q \to \infty$), a heavy quark resided in a singly heavy baryon can be decoupled from the $N_c - 1$ valence quarks inside it. Thus, the heavy quark inside a singly heavy baryon is considered as a mere static color source and the quark dynamics inside it is governed by the light quarks. Since the heavy quark is infinitely heavy, the heavy-quark spin is conserved, which leads to the conservation of the light-quark spin. It is known as the heavy-quark spin symmetry. In this heavy-quark mass limit, the singly heavy baryon is independent of the heavy flavor, which is called the heavy-quark flavor symmetry. In this picture, the singly heavy baryons are represented by a baryon antitriplet (**3**) and two baryon sextets (**6**) with spin 1/2 and 3/2. Thus, the singly heavy baryons can be considered as a bound state of the $N_c - 1$ valence quarks with the single heavy quark detached. The heavy quark is required only for making the singly heavy baryon a color singlet.

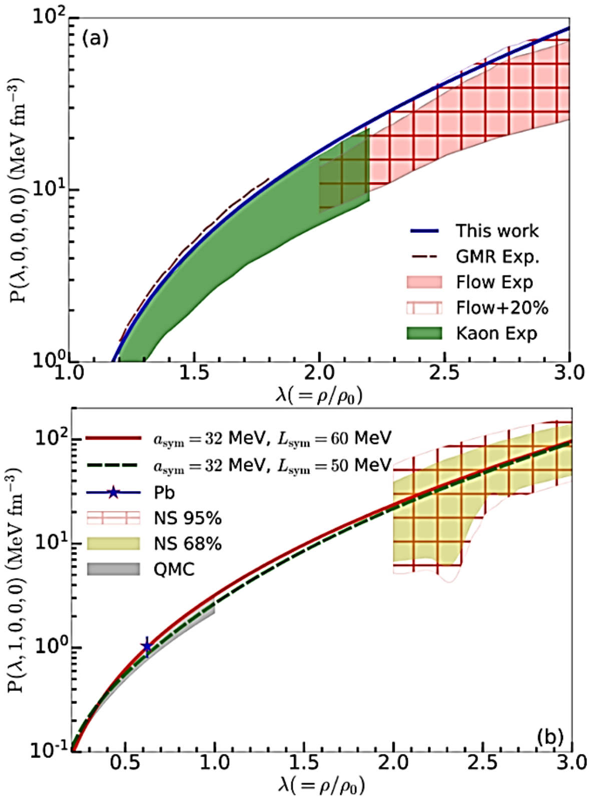

Fig.4. Our results for the pressure-density dependence for the symmetric matter (upper plane, solid curve) and the neutron matter (lower plane, solid and dashed curves). For comparison the results from the different experiments are also presented. For more details, see chapter VI of the dissertation.

Based on this idea, the pion mean-field approach was directly extended to the singly heavy baryons [89]. It has successfully described various properties of the singly heavy baryons in free space. In chapter VII we proceeded to describing the masses of both, spin 1/2 and 3/2 the singly heavy baryons, in nuclear matter.

CONCLUSIONS

In summary, we have developed an approach which can be used to study the medium-modifications of hadron properties and the corresponding nuclear matter equations of state starting from the same basis, e.g. from the same Lagrangian.

Here we also briefly summarize some main points in relation to our published works.

1. For application purposes, we proposed an effective Lagrangian which incorporate both: the medium influence of the surrounding nuclear environment on the single nucleon properties and an explicit isospin-breaking effect in the mesonic sector.
2. Using the particular versions of that Lagrangian, we have studied the change in isospin breaking effects in infinite nuclear matter [D1,D2].
3. We also estimated the isospin breaking effects in finite nuclei [D3,D4,D36]. In particular, we have studied the Nolen-Schiffer anomaly [D5,D6] which indicated stringent conditions for the in-medium mass modifications of nucleons.
4. We have considered the symmetric and asymmetric matter properties on the basis of a formulated approach [D11,D15,D24,D27,D32,D34,D35,D38]. In particular, the EoS of symmetric and asymmetric nuclear matter was successfully reproduced.
5. Extrapolating our EoS to high density regions, we also studied the neutron star properties [D21]. The calculations showed that the properties of $\sim 1.4M_{\odot}$ and $\sim 2M_{\odot}$ neutron stars can be well reproduced in the framework of the present approach.
6. The extensions of the approach to chiral-solitonic models with explicit mesonic degrees of freedom were also developed [D8,D10,D12] where we have discussed the possible modifications of vector meson properties in relation to nuclear matter properties. We have shown that the in-medium modifications of vector meson properties may be relevant to the core modifications of in-medium nucleon-skyrmions.
7. We have also studied EM structure changes of nucleons [D9,D18,D39], transverse charge densities [D14,D22] and Energy-momentum tensor form factors in nuclear matter [D7,D13,D16,D17,D19,D20,D30]. These studies gave interesting results about the structure changes of nucleons in a nuclear medium. The results of the studies were in agreement with the results of other approaches.
8. We also have studied the generalizations of the approach to the strangeness sector in the Skyrme model [D23,D25] and in a model independent approach [D28]. Finally, the extension of the approach to studying a single heavy baryon in nuclear matter was also done [D29,D31].

Finally, we want to emphasize that the approach discussed in the present dissertations is more universal and can be applied to studies of the different nuclear phenomena at a broad range of nuclear densities.

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E’LON QILINGAN ISHLAR RO‘YXATI
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