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PANJARADAGI UCH ZARRACHALI SISTEMA GAMILTONIANIGA MOS KANAL OPERATORLAR

Annotatsiya. *Mazkur maqolada* $d-$*o'lchamli panjaradagi uchta zarracha sistema Gamiltoniani chiziqli, chegaralangan va o'z-o'ziga qo'shma operator sifatida o'rganilgan. Bu Gamiltonianga mos ikkita kanal operatorlar qurilgan va ularning spektrlari tavsiflangan.*

Аннотация. *В данной статье Гамильтониан системы трех частиц на* $d-$*мерной решетке изучаются как линейный, ограниченный и самосопряженный оператор. Построены две канальные операторы, соответствующие этому Гамильтониану, и описаны их спектры.*

Annotation. *In the present paper, a Hamiltonian of a system of three particles on a* $d-$*dimensional lattice is considered as a linear, bounded and self-adjoint operator. Two channel operators corresponding to this Hamiltonian are constructed and their spectrum are described.*

Kalit so'zlar: *panjara, zarrachalar sistemasi, Gamiltonian, kanal operator, yoyiluvchi opertor, spektr.*

Ключевые слова: *решетка, система частиц, Гамильтониан, оператор канала, разложимый оператор, спектр.*

Key words: *lattice, system of particles, Hamiltonian, channel operator, decomposable operator, spectrum.*

Uch zarrachali diskret Shryodinger operatorlari [1,2,3] va uch zarrachali sistemaga mos model operatorlarining [4,5] muhim spektrlari ko'plab ishlarda o'rganilgan. Muhim spektrni o'rganishda odatda Veyl mezoni, Fredgolmning analitik teoremasi va Faddeyev tenglamasidan foydalaniladi. Ushbu maqolada $d-$o'lchamli panjaradagi uchta zarrachalar sistemasiga mos Gamiltonian qaralgan. Uning Hilbert fazosidagi chiziqli, chegaralangan va o'z-o'ziga qo'shma operator ekanligi ta'kidlab o'tilgan. Model operator muhim spektrini tadqiq qilishda foydalanish uchun qulay bo'lgan ikkita kanal operatorlar kiritilgan. Kanal operatorlar ta'sir qiluvchi fazolarning to'g'ri yig'indiga yoyilishidan foydalanib, kanal operatorlarning ham to'g'ri integral yig'indiga yoyilishi ko'rsatilgan. Bunda ikkita Fridrixs modellari oilasi hamda ularga mos Fredgolm determinantlari qurilgan. So'ngra kanal operatorlarning spektri Fridrixs modellari oilasining spektri orqali tavsiflangan.

$d\in N$ natural soni uchun $T^d :\equiv (-\pi;\pi]^d$ orqali d o'lchamli torni belgilaymiz. Faraz qilaylik, $T^1 :\equiv (-\pi;\pi]$ bo'lsin. T^1 to'plamda qo'shish va songa ko'paytirish amallarini haqiqiy sonlarni 2π modul bo'yicha qo'shish va songa ko'paytirish sifatida kiritamiz, masalan,

$$\frac{\pi}{2}+\pi=\frac{3\pi}{2}=-\frac{\pi}{2}(\mathrm{mod}\,2\pi),\ 6\cdot\frac{\pi}{5}=2\pi-\frac{4\pi}{5}=-\frac{4\pi}{5}(\mathrm{mod}\,2\pi).$$

Yuqoridagi kabi aniqlangan T^1 to'plamga bir o'lchamli tor deyiladi. $d\in N$ natural soni uchun T^d orqali d o'lchamli torni, ya'ni $T^d=\underbrace{T^1\times T^1\times\ldots\times T^1}_{d\ \ marta}$ ni belgilaymiz. $\left(T^d\right)^2$ da aniqlangan kvadrati bilan integrallanuvchi (umuman olganda kompleks qiymatlarni qabul qiluvchi) simmetrik funksiyalarning Hilbert fazosi bo'lgan $L_2^S\left(\left(T^d\right)^2\right)$ fazoda

$$H_{\mu,\lambda}^{(\gamma)}:=H_0^{(\gamma)}-\mu(V_1+V_2)-\lambda V_3, \tag{1}$$

tenglik orqali aniqlanuvchi Gamiltonianni qaraymiz. Bunda $\mu,\lambda>0$ ta'sirlashish parametrlari, $H_0^{(\gamma)}$ qo'zg'almas operator $E_\gamma(\cdot,\cdot)$ funksiyaga ko'paytirish operatori kabi aniqlangan, ya'ni,

$$(H_0^{(\gamma)}f)(x,y)=E_\gamma(x,y)f(x,y),$$
$$E_\gamma(x,y):=\varepsilon(x)+\varepsilon(y)+\gamma\varepsilon(x+y),\ \varepsilon(x):=1-\cos(nx), n\in N.$$

V_α, $\alpha = 1,2,3 -$ operatorlar esa lokal bo'lmagan potensial operatorlari bo'lib, quyidagi ko'rinishdagi xususiy integralli operatorlardir:

$$(V_1 f)(x,y) = v(y)\int_{T^d} v(t) f(x,t)dt, \quad (V_2 f)(x,y) = v(x)\int_{T^d} v(t) f(t,y)dt,$$
$$(V_3 f)(x,y) = \int_{T^d} f(t, x+y-t)dt.$$

V_1 va V_2 operatorlar yadrosida ishtirok etuvchi $v(\cdot)$ funksiya T^d da aniqlangan haqiqiy qiymatli uzluksiz funksiya.

Funksionl analiz elementlaridan foydalanib, (1) tenglik yordamida ta'sir qiluvchi $H_{\mu,\lambda}^{(\gamma)}$ operator $L_2^s((T^d)^2)$ Hilbert fazosida chiziqli, chegaralangan va o'z-o'ziga qo'shma ekanligini ko'rsatish mumkin.

$H_{\mu,\lambda}^{(\gamma)}$ operatorning muhim spektrini tadqiq qilish maqsadida kanal operatorlar deb ataluvchi ikkita operatorni kiritamiz. Bunday operatorlar $L_2\left((T^d)^2\right)$ Hilbert fazosida

$$H_\mu^{(\gamma,1)} := H_0^{(\gamma)} - \mu V_1, \quad H_\lambda^{(\gamma,2)} := H_0^{(\gamma)} - \lambda V_3$$

tengliklar orqali aniqlanadi. Hosil bo'lgan $H_\mu^{(\gamma,1)}$ va $H_\lambda^{(\gamma,2)}$ operatorlar ham $H_{\mu,\lambda}^{(\gamma)}$ operator kabi $L_2\left((T^d)^2\right)$ Hilbert fazosida ta'sir qiluvchi chiziqli, chegaralangan va o'z-o'ziga qo'shma operatorlardir.

$L_2\left((T^d)^2\right)$ Hilbert fazoning

$$L_2\left((T^d)^2\right) = \int_{T^d} \oplus L_2\left(T^d\right)dk$$

to'g'ri integralga yoyilmasidan $H_\mu^{(\gamma,1)}$ va $H_\lambda^{(\gamma,2)}$ operatorlar uchun

$$H_\mu^{(\gamma,1)} == \int_{T^d} \oplus\left(h_\mu^{(\gamma,1)}(k) + \varepsilon(k)I\right)dk, \; H_\lambda^{(\gamma,2)} == \int_{T^d} \oplus\left(h_\lambda^{(2)}(k) + \gamma\varepsilon(k)I\right)dk$$

to'g'ri integralga yoyilmalar kelib chiqadi. Bunda I orqali $L_2(T^d)$ Hilbert fazosidagi birlik operator belgilangan, $h_\mu^{(\gamma,1)}(k)$ va $h_\lambda^{(2)}(k)$ operatorlar esa $L_2(T^d)$ Hilbert fazosida

$$h_\mu^{(\gamma,1)}(k) := h_0^{(\gamma,1)}(k) - \mu v_1, \; k \in T^d, \; h_\lambda^{(2)}(k) = h_0^{(2)}(k) - \lambda v_2, \;\; k \in T^d$$

kabi ta'sir qiluvchi va Fridrixs modellari oilasi deb ataluvchi operatorlar bo'lib,

$$(h_0^{(\gamma,1)}(k)f)(x) = \left(\varepsilon(x) + \gamma\varepsilon(k+x)\right)f(x), \;\; (v_1 f)(x) = v(x)\int_{T^d} v(t) f(t)dt,$$
$$(h_0^{(2)}(k)f)(x) = \left(\varepsilon(x) + \varepsilon(k-x)\right)f(x), \;\; (v_2 f)(x) = \int_{T^d} f(t)dt.$$

Kiritilgan $h_\mu^{(\gamma,1)}(k)$ va $h_\lambda^{(2)}(k)$ operatorlar $L_2(T^d)$ Hilbert fazosida chiziqli, chegaralangan va o'z-o'ziga qo'shma ekanligini oson ko'rsatish mumkin.

Chekli o'lchamli qo'zg'alishlarda muhim spektrning o'zgarmasligi haqidagi Veyl teoremasiga ko'ra, $h_\mu^{(\gamma,1)}(k)$ operatorning muhim spektri $h_0^{(\gamma,1)}(k)$ operatorning muhim spektri bilan, xuddi shuningdek, $h_\lambda^{(2)}(k)$ operatorning muhim spektri $h_0^{(2)}(k)$ operatorning muhim spektri bilan ustma-ust tushadi va quyidagi

$$\sigma_{ess}\left(h_\mu^{(\gamma,1)}(k)\right) = \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right], \quad \sigma_{ess}\left(h_\lambda^{(2)}(k)\right) = \left[m_2(k); M_2(k)\right]$$

tengliklar o'rinlidir, bu yerda

$$m_1^{(\gamma)}(k) := \min_{k \in T^d}\left(\varepsilon(x) + \gamma\varepsilon(k+x)\right), \quad M_1^{(\gamma)}(k) := \max_{k \in T^d}\left(\varepsilon(x) + \gamma\varepsilon(k+x)\right),,$$
$$m_2(k) := \min_{k \in T^d}\left(\varepsilon(x) + \varepsilon(k-x)\right), \quad M_2(k) := \max_{k \in T^d}\left(\varepsilon(x) + \varepsilon(k-x)\right)$$

formulalar orqali aniqlanadi.

Har bir fiksirlangan $\mu, \lambda, \gamma > 0$ sonlari va $k \in T$ element uchun mos ravishda $C \setminus \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right]$ va $C \setminus \left[m_2(k); M_2(k)\right]$ sohada analitik bo‘lgan

$$\Delta_\mu^{(\gamma,1)}(k,z) := 1 - \mu \int_{T^d} \frac{v^2(t)dt}{\varepsilon(t) + \gamma\varepsilon(k+t) - z}, \ \Delta_\lambda^{(2)}(k,z) := 1 - \lambda \int_{T^d} \frac{dt}{\varepsilon(t) + \varepsilon(k-t) - z}$$

yordamchi funksiyalarni kiritamiz.

Xususiyatiga ko‘ra, $\Delta_\mu^{(\gamma,1)}(k,\cdot)$ va $\Delta_\lambda^{(2)}(k,\cdot)$ funksiyalarga mos ravishda $h_\mu^{(\gamma,1)}(k)$ va $h_\lambda^{(2)}(k)$ operatorlarga mos Fredgolm determinantlari deyiladi.

1-lemma. Har bir fiksirlangan $k \in T$ element va $\mu, \gamma > 0$ sonlari uchun $z \in C \setminus \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right]$ soni $h_\mu^{(\gamma,1)}(k)$ operatorning xos qiymati bo‘lishi uchun $\Delta_\mu^{(\gamma,1)}(k,z) = 0$ bo‘lishi zarur va yetarlidir.

Isbot. Zaruriyligi. Faraz qilaylik, $z \in C \setminus \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right]$ soni $h_\mu^{(\gamma,1)}(k)$ operatorning xos qiymati, $f \in L_2(T^d)$ esa unga mos xos funksiya bo‘lsin. U holda f funksiya $h_\mu^{(\gamma,1)}(k) f = zf$ xos qiymatga nisbatan tenglamani, ya’ni,

$$\left(\varepsilon(x) + \gamma\varepsilon(k+x)\right) f(x) - \mu v(x) \int_{T^d} v(t) f(t)dt = zf(x)$$

tenglikni qanoatlantiradi.

$z \notin \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right]$ bo‘lganligi bois barcha $x \in T^d$ lar uchun

$$\varepsilon(x) + \gamma\varepsilon(k+x) - z \neq 0$$

munosabat bajariladi. Endi

$$\left(\varepsilon(x) + \gamma\varepsilon(k+x) - z\right) f(x) = \mu v(x) \int_{T^d} v(t) f(t)dt. \tag{2}$$

(2) tenglamaga quyidagicha belgilash kiritamiz:

$$a = \int_{T^d} v(t) f(t)dt. \tag{3}$$

U holda (2) tenglikdan $f(x)$ uchun quyidagi ifodani topib olamiz:

$$f(x) = \frac{\mu v(x) a}{\varepsilon(x) + \gamma\varepsilon(k+x) - z}. \tag{4}$$

$f(x)$ uchun topilgan (4) ifodani (3) tenglikga qo‘yamiz va

$$a = \int_{T^d} v(t) \frac{\mu v(t) a}{\varepsilon(t) + \gamma\varepsilon(k+t) - z} dt$$

tenglikni, ya’ni,

$$a\left(1 - \mu \int_{T^d} \frac{v^2(t)}{\varepsilon(t) + \gamma\varepsilon(k+t) - z} dt\right) = 0. \tag{5}$$

tenglikni hosil qilamiz. Agar (5) tenglikda $a = 0$ bo‘lsa, u holda (4) tenglikga ko‘ra, $f(x) = 0$ hosil bo‘ladi. Bu esa $f(x)$ ning xos funksiya ekanligiga zid.

Demak, $a \neq 0$. Shu sababli (5) tenglikdan

$$1 - \mu \int_{T^d} \frac{v^2(t)}{\varepsilon(t) + \gamma\varepsilon(k+t) - z} dt = 0,$$

ya’ni $\Delta_\mu^{(\gamma,1)}(k,z) = 0$ ekanligi kelib chiqadi.

Yetarliligi. Faraz qilaylik, biror $z_0 \in C \setminus \left[m_1^{(\gamma)}(k); M_1^{(\gamma)}(k)\right]$ soni uchun $\Delta_\mu^{(\gamma,1)}(k,z_0) = 0$ bo‘lsin. U holda

$$f(x)=\frac{\mu v(x)a}{\varepsilon(x)+\gamma\varepsilon(k+x)-z_0}$$

funksiya $h_\mu^{(\gamma,1)}(k)f=z_0 f$ tenglikni qanoatlantirishi va $f\in L_2(T^d)$ ekanligini ko‘rsatamiz. Haqiqatan ham,

$$\left(h_\mu^{(\gamma,1)}(k)f\right)(x)=\left(\varepsilon(x)+\gamma\varepsilon(k+x)\right)f(x)-\mu v(x)\int_{T^d} v(t)f(t)dt=$$

$$=\left(\varepsilon(x)+\gamma\varepsilon(k+x)-z_0\right)\frac{\mu v(x)a}{\varepsilon(x)+\gamma\varepsilon(k+x)-z_0}-\mu v(x)\int_{T^d}\frac{v(t)\mu v(t)a}{\varepsilon(t)+\gamma\varepsilon(k+t)-z_0}dt+$$

$$+z_0 f(x)=\mu v(x)a-\mu^2 v(x)a\int_{T^d}\frac{v^2(t)}{\varepsilon(t)+\gamma\varepsilon(k+t)-z_0}dt+z_0 f(x)=$$

$$=\mu v(x)a\left(1-\mu\int_{T^d}\frac{v^2(t)}{\varepsilon(t)+\gamma\varepsilon(k+t)-z_0}dt\right)+z_0 f(x)=$$

$$=\mu v(x)a\Delta_\mu^{(\gamma,1)}(k,z_0)+z_0 f(x)=z_0 f(x).$$

Oxirgi tenglikda biz $\Delta_\mu^{(\gamma,1)}(k,z_0)=0$ ekanligidan foydalandik.

Endi $f\in L_2(T^d)$ ekanligini ko‘rsatamiz. Haqiqatan ham,

$$\int_{T^d}\left|f(t)\right|^2 dt=\int_{T^d}\left|\frac{\mu v(t)a}{\varepsilon(t)+\gamma\varepsilon(k+t)-z_0}\right|^2 dt\le\mu^2 a^2\max_{x\in T^d}\left|\frac{v(x)}{\varepsilon(x)+\gamma\varepsilon(k+x)-z_0}\right|^2\int_{T^d}dt=$$

$$=\mu^2 a^2(2\pi)^d\max_{x\in T^d}\left|\frac{v(x)}{\varepsilon(x)+\gamma\varepsilon(k+x)-z_0}\right|^2<\infty.$$

Shunday qilib, $f\in L_2(T^d)$ ekan. Lemma to‘liq isbotlandi.

1-lemmadan quyidagi natija kelib chiqadi.

1-natija. $h_\mu^{(\gamma,1)}(k)$ operatorning diskret spektri uchun

$$\sigma_{disc}\left(h_\mu^{(\gamma,1)}(k)\right)=\left\{z\in C\setminus\left[m_1^{(\gamma)}(k);M_1^{(\gamma)}(k)\right]:\Delta_\mu^{(\gamma,1)}(k,z)=0\right\}$$

tenglik o‘rinlidir.

Quyidagi lemma $h_\lambda^{(2)}(k)$ operator xos qiymatlari va $\Delta_\lambda^{(2)}(k,\cdot)$ funksiya nollari orasidagi bog‘lanishni ifodalaydi va 1-lemma kabi isbotlanadi.

2-lemma. Har bir fiksirlangan $k\in T$ element va $\lambda,\gamma>0$ sonlari uchun $z\in C\setminus\left[m_2(k);M_2(k)\right]$ soni $h_\lambda^{(2)}(k)$ operatorning xos qiymati bo‘lishi uchun $\Delta_\lambda^{(2)}(k,z)=0$ bo‘lishi zarur va yetarlidir.

2-lemmadan $h_\lambda^{(2)}(k)$ operatorning diskret spektri haqidagi quyidagi 2-natija kelib chiqadi.

2-natija. $h_\lambda^{(2)}(k)$ operatorning diskret spektri uchun

$$\sigma_{disc}\left(h_\lambda^{(2)}(k)\right)=\left\{z\in C\setminus\left[m_2(k);M_2(k)\right]:\Delta_\lambda^{(2)}(k,z)=0\right\}$$

tenglik o‘rinli bo‘ladi.

$H_\mu^{(\gamma,1)}$ va $H_\lambda^{(\gamma,2)}$ kanal operatorlarning spektri $h_\mu^{(\gamma,1)}(k)$ va $h_\lambda^{(2)}(k)$ operatorlarning spektri orqali quyidagicha tavsiflanadi.

1-teorema. Quyidagi tengliklar o'rinlidir:

$$\sigma\left(H_{\mu}^{(\gamma,1)}\right)=\sigma_{two}\left(H_{\mu}^{(\gamma,1)}\right)\cup[0;3+3\lambda/2],\ \sigma\left(H_{\lambda}^{(\gamma,2)}\right)=\sigma_{two}\left(H_{\lambda}^{(\gamma,2)}\right)\cup[0;3+3\lambda/2]$$

bunda,

$$\sigma_{two}\left(H_{\mu}^{(\gamma,1)}\right):=\bigcup_{k\in T}\left\{\sigma_{disc}\left(h_{\mu}^{(\gamma,1)}(k)\right)+\varepsilon(k)\right\},\ \sigma_{two}\left(H_{\lambda}^{(\gamma,2)}\right):=\bigcup_{k\in T}\left\{\sigma_{disc}\left(h_{\lambda}^{(2)}(k)\right)+\gamma\varepsilon(k)\right\}.$$

2-teorema. $H_{\mu,\lambda}^{(\gamma)}$ opertorning muhim spektri quyidagicha

$$\sigma_{ess}\left(H_{\mu,\lambda}^{(\gamma)}\right)=\sigma\left(H_{\mu}^{(\gamma,1)}\right)\cup\sigma\left(H_{\lambda}^{(\gamma,2)}\right)$$

aniqlanadi.

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IKKI ZARRACHALI SHRYODINGER OPERATORI XOS SONLARI UCHUN YUQORI BAHOLAR

Annotatsiya. *Ushbu maqolada uch o'lchamli panjarada, ikki zarrachali sistemaga mos energiya operatori H qaralgan. Bu sistemaga mos Shryodinger operatorining muhim spektridan tashqari yotuvchi xos qiymatlar soni uchun yuqori baholar olingan.*

Аннотация. *В данной статье рассматривается оператор энергии H, соответствующий системе двух частиц на трехмерной решетке. Получены верхние оценки числа собственных значений, лежащие вне существенного спектра оператора Шредингер, соответствущего этой системе.*

Annotation. *In this paper it is considered the energi operator H corresponding to a system of two particles on a three-dimensionalgrid. High estimates are obtained for the number of the eigenvalues lying outside the critical spectrum of the Shrödinger operator corresponding to this system.*

Kalit so'zlar: *panjara, zarracha, energiya operatori, Shryodinger operatori, to'la kvaziimpuls, muhim spektr, xos qiymat.*

Ключевые слова: *рещетка, чатица, оператор энергии, оператор Шредингера, полный квазиимпульс, существенный спектр, собственное значение.*

Key words: *grating, particle, energy operaror, Shrödinger operator, field quasimomentum, essential spectrum, eigenvalue.*

Kvant mexanikasining bir qator masalalari (qarang: [1-11]) quyidagi

$$(Hf)(q)=u(q)f(q)+\lambda\int_{\mathbb{T}^d}K(q,s)f(s)ds\in L_2(\mathbb{T}^d),\qquad (1)$$

operatorning spektral xossalarini o'rganishga keltiriladi. Bu yerda u uzluksiz funksiya, K yadro $L_2((\mathbb{T}^d)^2)$ fazoning elementi. Jumladan, ikki zarrachali sistema Hamiltonianlarining xossalarini o'rganish (1) ko'rinishdagi H operatorning spektral xossalari bilan uzviy bog'liq (12-18). (1) ko'rinishdagi operator, aniqrog'i,

$$(H_\lambda f)(q)=qf(q)+\lambda\int_{-1}^{1}K(q,s)f(s)ds,\ f\in L_2[-1,1],\qquad (2)$$

MUNDARIJA

FIZIKA-MATEMATIKA

FALSAFA

TILSHUNOSLIK

ADABIYOTSHUNOSLIK

PEDAGOGIKA