Pion-exchange tensor forces in nuclear excitations

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Tensor nuclear forces are result of the pion-exchange and we consider these forces in connection with the origin of the systematic character of excitations and spacing in many nuclei: the observed frequent appearance of stable energy intervals with values rationally connected with the nucleon and the lepton (m_e) mass differences. This tuning effect includes pion mass, its mass difference ($9m_e$), residual interaction of nucleon quarks and nucleon masses.

The pion plays an important role in nuclear physics. Nucleon interactions in nuclei are considered as a result of the meson exchange. The role of tensor forces connected with the pion exchange in descriptions of nuclear binding energies and excitations was discussed in [1-3]. A combinations of spin/orbit values (parallel spin, orbital motions in opposite directions) are conditions for a manifestation of the pion exchange. We performed an analysis of excitations (E^*) in nuclei at different nuclear shells where tensor forces are important.

In sum E^* distributions of all nuclei (A$\leqslant$70, A$\leqslant$150) maxima corresponding to frequently appeared excitations are found at E^*=1022 keV=$2m_e$ and E^*=646-1293-1942 keV connected as 1/2-1-3/2 with the nucleon mass differences δm$_{\rm N}$=1293.3 keV. This correlation was named "tuning effect" and some of coincidences observed in near-magic light nuclei are shown in Table 1 (top). The interval D=ε_o=1022.0 keV=$2m_e$ in ^{10}B (close to 2/9 of the pion mass difference [2,3]) corresponds to the spin-flip effect of nucleons in 1p shell.

The observed exact relation 3:1 in E^* of ^{41}Ca and ^{37}S (Table 1 right, valence neutron and pairs of protons in 1d$_{3/2}$ shell, number of pairs 3 and 1) and the exact 1:2 relation in E^* of ^{37}S and ^{38} (N=21-22, one-two valence neutrons and a pair of protons above the subshell Z=14) correspond to a stable character of the interaction between nucleons with opposite orbital motions (tensor forces due to pion exchange dynamics). Stable intervals D=1293 keV were noticed also in sum spacing distribution in levels of ^{32,33}S. The first excitation in ^{32}Si (E^*=1941.5 keV, two holes in 1d$_{3/2}$ subshell) coincides with (3/2)δm$_{\rm N}$. We use analyses of D-distributions to check the observed regularities in low-lying excitations. Stable intervals close or rational to parameters ε_o and δm$_{\rm N}$ were observed in spacing of near-magic ^{18}F (Fig.1, D=162 keV, other D=480-642-1288 keV, n=1,3,4,8), in ^{23}Na (D=337-428-514 keV), ^{57}Ni (D=341 keV), ^{55}Co (D=324-512-682 keV) and ^{89,90}Y (D=482, 511-1024 keV).

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Table 1: *Top:* Comparison of excitations (in keV) of near-magic nuclei with spin-flipp effect in ^{10}B (ε_o=1022 keV) and δm_N=1293.3 keV. *Bottom:* The same for ^{101,103}Sn, $^{123-133}$Sb.

^AZ	^{10}B	^{10}B	^{12}C	^{18}Ne		^{41}Ca	^{37}S	^{38}S
J^π	0^+-1^+	2^-	0^+ (T=2)	0^+	0_2^+	3/2-	3/2-	2+
E^*	$\boxed{1021.8(2)}$	5110.3	27595(2)	3576.2	4590(8)	1942.8	646.2	1292.0
n(ε_o)	1	5	27	7/2	9/2	$(3/2)\delta m_N$	$(1/2)\delta m_N$	δm_N
Diff.	0.2(2)	0.3	1(2)	1(2)	9(8)	2(1)		1
^AZ	^{101}Sn	^{103}Sn	^{123}Sb	^{125}Sb	^{127}Sb	^{129}Sb	^{131}Sb	^{133}Sb
J^π	$7/2^+$	$7/2^+$	$5/2^+$	$5/2^+$	$5/2^+$	$5/2^+$	$5/2^+$	$5/2^+$
E^*	$\boxed{171.7(6)}$	$\boxed{168.0(1)}$	$\boxed{160.3(1)}$	332.1	491.2	$\boxed{645.2(1)}$	798.5	$\boxed{962.3(1)}$
n(ε_o)	1/3	1/3	$(1/8)\delta m_N$	$\delta m_N/4$	$(3/8)\delta m_N$	$(4/8)\delta m_N$	$(5/8)\delta m_N$	$(6/8)\delta m_N$
n·ε_o	170	170	161	323	484	646	808	969

In ^{101,103}Sn with valence neutrons above Z=N=50 core a stable character of excitations 170 keV=(1/6)ε_o=m_e/3 is shown in Table 1. Intervals D=512-3×170 keV and D=648-1293 keV in ^{97,98}Pd, stable E^*=644 keV in nuclei around the tin, E_1^*=1293.6 keV in ^{116}Sn and the interval D=1292.0 keV from it to the 1^+ state (D=δm_N) correspond to the tuning effect.

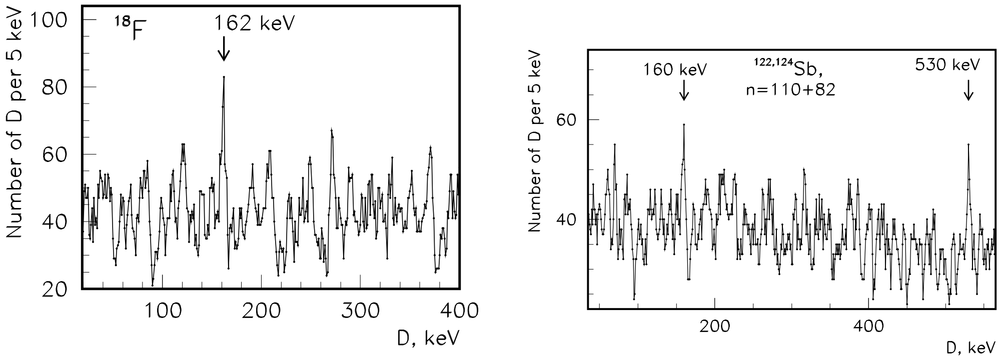

Figure 1: Maxima in spacing distributions in levels of ^{18}F and ^{122,124}Sb (right).

T.Otsuka [1] explained a linear trend of E^* in $^{123-133}$Sb (found by J.Schiffer et al.) as an action of tensor forces. The case in Sb isotopes ($\pi\ 2g_{7/2}$, $\nu\ 1h_{11/2}$) is similar to the discussed case of Ca-S-Si isotopes ($1d_{3/2}$, $1f_{7/2}$). The effect in Sb (constant slope 160 keV) is supported by the stable D=160 keV in neighbour ^{122,124}Sb (maximum in D-distribution, Fig.1 right).

The interval 3×161 keV=483 keV appears frequently together with D=492 keV and is substituted with it in ^{127}Sb. Stable D=492-984-3936 keV (n=1-2-4 of 492 keV=2×161 keV+170 keV) were found in many nuclei. In ^{38}Ar two stable intervals are D=1021 keV=2×511keV and

D=1476 keV=3×492 keV. Stable nucleon interaction was checked with data for all nuclei. Intervals (or periods) D=161 keV, 170 keV and 492 keV were found in many nuclei. Z-distribution of nuclei with such effects is shown in Fig.2. Maxima in regions Z=50-51 (ν $1h_{11/2}$) and Z=72-78 (π $1h_{11/2}$) are clearly seen. Stable interaction between nucleons was observed also as a linear dependence of proton separation energies (upon N, parameters ε_{p2n}=$S_p(N)$-$S_p(N-2)$=(2/3)ε_o and ε_{2n2p}=(4/3)ε_o for Z=51, 78 and 84).

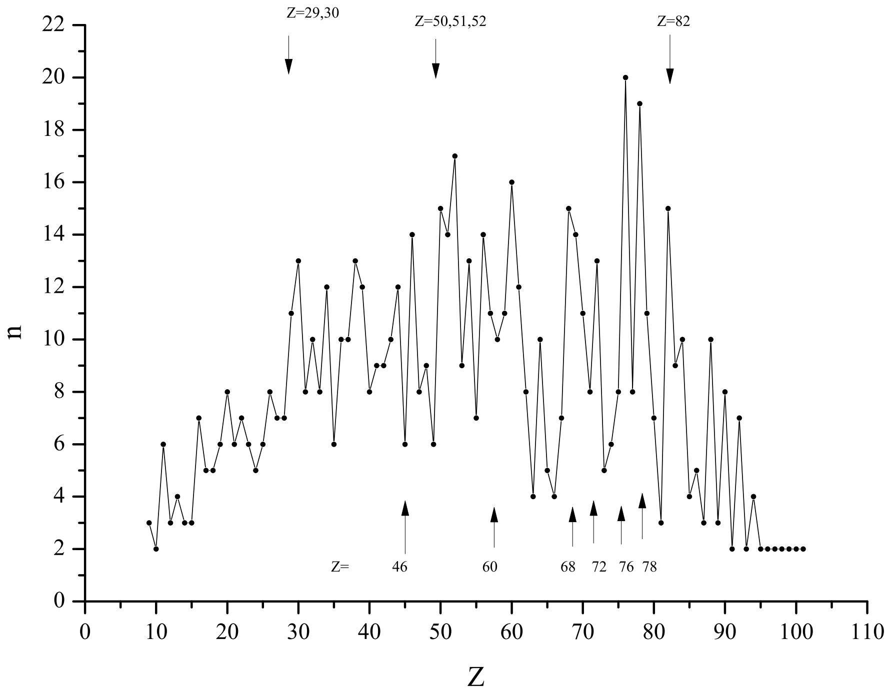

Figure 2: Distribution of Z-numbers of nuclei with stable intervals (arrows mark shells).

We considered nonstatistical effects in neutron resonances of the same nuclei. Maxima at D=373-745-1501 eV and 570 eV in D-distribution of resonances in ^{124}Sb are close to D=572 and 749-1496 eV in ^{105}Pd, ^{104}Rh, Th, ^{80}Br, Hf. One of exactly measured small splitting in low-lying levels of near-magic nuclei is D=1.078 keV between E^*=1022.394 and E^*=1021.326 in ^{82}Br corresponding to the grouping effect at E^*=ε_o. The relative values of this splitting 1.08/1022=1.06·10^{-3} and ratios between Sb intervals 373 eV/323 keV=1.15·10^{-3}, 570 eV/490 keV=1.16·10^{-3} are close to the QED radiative correction $\alpha/2\pi$=1.16·10^{-3}.

Long-range correlations in differences of nuclear binding energies ΔE_B connected with nucleon cluster effects were considered in [3] where the similar tuning effect was discussed.

Nucleons have a complex structure consisting (in the first approximation) of three con-

Table 2: Presentation of parameters of tuning effects in particle masses and nuclear binding energies ΔE_B (upper parts marked X = -1, 0, 1 at left) and in nuclear data (X = 1, 2 bottom) by expression $n{\cdot}16m_e(\alpha/2\pi)^X M$ with QED radiative correction $\alpha/2\pi$ (α=137^{-1}). Boxed values m_π-m_e, $m_e/3$ and neutron mass shift $N\delta - m_n - m_e$ relate to $(2/3)m_t = M_H$ with parameters α_Z=129^{-1} and α=137^{-1}. Stable intervals in E*, D_{ij} (X=1) and in neutron resonances (X=2) are considered as confirmation of intervals in particle masses (X=-1), namely, the mass grouping in TEVATRON experiment Δ°=4 GeV, 3:2:1 ratio between masses of top quark, Higgs boson and mass grouping effect in LEP experiment (M^{L3}) [3].

X	M	n = 1	n = 13	n = 14	n = 16	n = 17	n = 18
-1	$\frac{3}{2},\frac{1}{2}$				m_t=171, M^{L3}=58		
GeV	1	$2\Delta^\circ$ - $2M_q$	M_Z=91.2		$\boxed{M_H=115}$		
0	1	$16m_e$=δ	m_μ = 105.7		(f_π=131)	$\boxed{m_\pi\text{-}m_e}$	m_Δ-$m_n/2$=147
MeV	1	2Δ-ε_0	106 = ΔE_B		130 = ΔE_B	140 = ΔE_B	147.2 = ΔE_B
	3				M''_q = $m_\rho/2$	M'_q = 420	M_q = 441 = ΔE_B
1	1					$\boxed{N\delta - m_n\text{-}m_e = 161.6}$	$\boxed{170 = m_e/3}$
keV	1,3	9.5 = δ'	123	134	152, 455	162 (^{18}F), 160 (Sb)	172, 512 (Co)
	4,6		492	530		648 (^{97,98}Pd)	682(Co), ε_0
	8		984	1060	1212	1293 (Pd), ΣE^*	1360 (Te)
2	1,2,4	δ'',22,44	143		176	187, 373 (Sb), 749 (Br)	D in neutron
eV	8	88	570 (Sb)			1500 (Sb,Pd,Rh,Hf)	resonances

stituent quarks with the initial mass M_q ≈440 MeV originated from gluon quark-dressing effect. The residual quark interaction (nucleon Δ-excitation) and the effect of nearly constant binding energy of nucleons in nuclei correspond to strong interaction. Relations between particle masses, nuclear excitations and ΔE_B are given in Table 2 [3].

It was suggested by Y.Nambu that empirical relations in particle masses should be used for the development of the Standard Model. The appearance of the SM-parameter m_e and nucleon mass difference δm_N in nuclear data confirms this suggestion. For construction of Table 2 a proximity of QED factor $\alpha/2\pi$ to ratios between lepton masses (m_e, m_μ) and well-known parameters (Δ-excitation, Z-boson mass) were used. We use also exactly known experimental ratio between proton and electron masses to obtain relation between them (boxed in the central part of the Table). Both discussed intervals in nuclear excitations are related to the pion mass with QED factors $\alpha/2\pi$ and $\alpha_Z/2\pi$ (α_Z=1/129).

References

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