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FINE STRUCTURES IN NEUTRON RESONANCE POSITIONS

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1. Introduction

Parameters of fine (ε'=1.2 keV) and superfine (ε''=1.34 eV) structures were introduced empirically [1] as the manifestation of the nonstatistical effects in neutron resonances, noticed long ago [2,3]. It was shown [1] that discreteness in nuclear states is associated with general properties of the particle mass spectrum confirmed in recent [4] mass-difference distributions in which all known masses with uncertainties less than 10 MeV are analyzed simultaneously, see Tables 1, 2, and Fig. 1.

In Table 1 [4,5], the muon and pion masses are compared with integer numbers N of fermions in the central field in a representation $N \cdot \delta$ of masses m_μ, f_π, $m_{\pi^\pm}$, ΔM_Δ (half of the nucleon Δ-excitation of 294 MeV), m_τ and ratios m_e/M_q and m_μ/M_Z (the discreteness parameter $\delta = 16m_e$=8.176 MeV [1], the pion parameter f_π=130.7 MeV±0.4 MeV coincides with $m_e \times 16 \times 16$=130.81571 MeV, the constituent quark mass M_q=441 MeV).

Table 1: Comparison of the number of fermions in the central field. Boxed are hole configuration in $1p$ shell ($1s^4_{1/2}$, $1p^8_{3/2}$, $1p_{1/2}$) and valence configuration over the shells $1s^4_{1/2}$, $1p^8_{3/2}$, $1p^4_{1/2}$.

N^{ferm}	16	$\boxed{16\cdot13\text{-}1=\mathrm{L}}$	16·16	$\boxed{16\cdot17+1}$	16·18	2L+2·16 $\cdot\, m_e$
N(δ)	N = 1	13	16	17	18	$2\cdot13 + 2\cdot6\cdot16$
Part.	$\delta = 16m_e$	m_μ	f_π	$m_{\pi^\pm}$	ΔM_Δ	m_τ
MeV	8.176	106.0	130	140	147	1777
Ratio.	m_e/M_q	m_μ/M_Z				
Value	$\alpha/2\pi$	$115.87\cdot10^{-5}$				
Comm.		$\boxed{\text{hole in } 1p}$	filled shells	$\boxed{\text{valence}}$		

2. Fine Structure in nuclear excited states

In Table 3, top, positions E'_n (keV) of strong neutron resonances in light and magic nuclei and periodicity in the spacing distributions in resonances ^{61}Ni (right) are presented. At the center, values E_n (keV) in nuclei with N=83=82+1, maxima in spacing distributions ^{141}Ce are given. At the bottom (left) positions of strong neutron resonances in isotopes with Z=35-39 are compared with the integer of the period ε'=1.188 keV=9.505 keV/8, found in the positions of strong resonances in Z=57-59, N=83 nuclei (center). At the bottom (right) the excitation energies E^* (keV) of ^{143}Ce are given. The values ε', δ', $2\delta'$ and $(9/4)\delta'$, where δ'=9.5 keV, are boxed.

Nonstatistical effects were also found at higher excitation energies of the order of several MeV corresponding to a single-particle interactions. In Fig. 2, the grouping effect of stable excitations in different elements observed as maxima in E^* distributions with the averaging interval of 7 keV [6] is shown. Maximum in the range of 3000-3100 keV is equal to $3\varepsilon_o$=1022 keV=$6m_e$. Other grouping effects are considered elsewere.

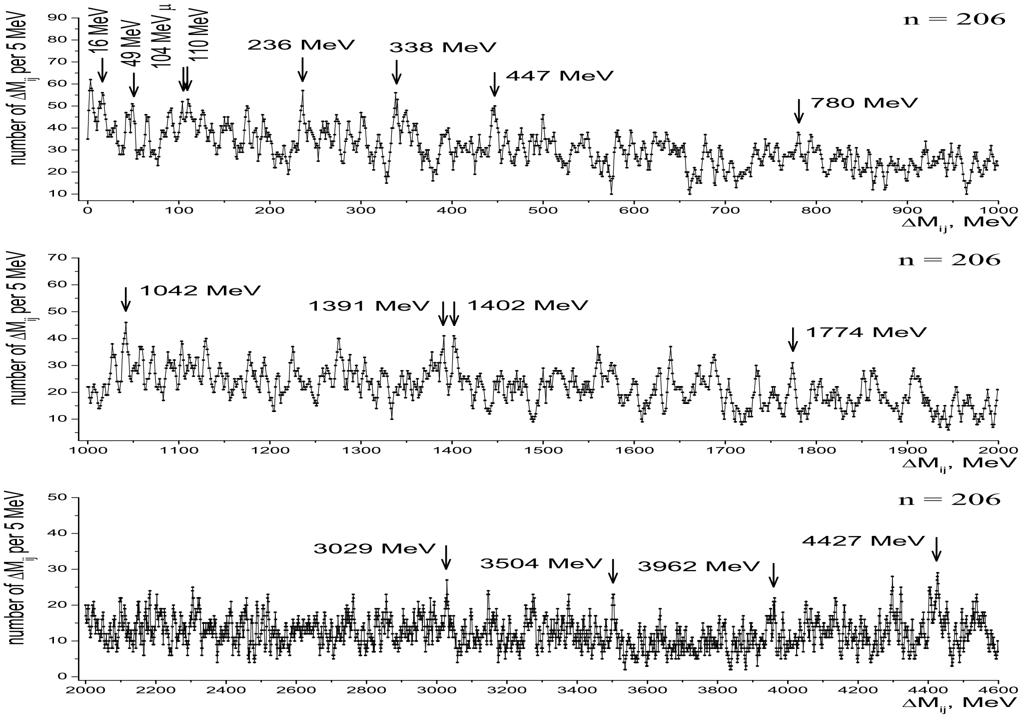

Figure 1: ΔM distribution of all differences between particle masses from PDG-2021 (averaging 5 MeV) the region 0–4600 MeV. Maxima at 16 MeV= 2δ, 49 MeV=6δ, 338 MeV≈ $m_\omega - M_q$, 447 MeV≈ M_q, 780 MeV=m_ω, 1042 MeV=$8f_\pi$, 1931-1402 MeV=$10m_\pi$ and 1774 MeV≈ m_τ. Intervals 3504 MeV≈ $8M_q$, 3962 MeV≈ $9M_q$ and 4427 MeV≈ $10M_q$ are considered in [4].

3. Superfine structure

In some papers [1] attention was drawn to the "structure" in the spacing between neutron levels D$_{ij}$ for some N-odd (compound) heavy nuclei. If single particle or to be more precise few-particle effects play any role in the complex spectra of levels in heavy nuclei they will first of all manifest itself in N-odd compound nuclei. These systems are thought as N-even excited core plus neutron. If the structure in D$_{ij}$ is due to anomalously strong statistical fluctuations then, these data taken together for the large number of nuclei, will give smooth distributions. But it doesn't happen, and distinguishing effect in D$_{ij}$ near 5.5 eV maintains even in cases in levels with relatively broad neutron widths which, as one would expect, correspond to larger contribution of single particle configurations. The distinguishing effect of the interval (5.5 eV) has also been confirmed by the analysis of the summary data on positions (E$_o$) of neutron resonances, e.g. distances from levels to the binding energies of neutron [3,5]. The interval 5.5 eV was also noticed by M. Ohkubo and K. Ideno in Sb and 11 eV×13=143 eV in As in 1971.

A large amount of information on neutron resonances of heavy nuclei with Z=90-96 allows us to perform the analysis of the levels positions and spacings to check the distinguishing character of the superfine structure parameter. There is a system of stable energy intervals that are multiples of each other [4]. The superfine structure parameter ε''=1.34 eV was found in spacing distribution of neutron resonances of compound nucleus

Table 2: Parameters of the particles from the PDG-2022 compilation.

No	No	mass MeV	uncert. MeV	part.	prop.	No No	mass MeV	uncert. MeV	part.	prop.
1		leptons				204	5935.02	0.05	$\Xi_b'(5935)^-$	$1/2^+$
	1	0.51099895		e	1/2	205	5952.3	0.6	$\Xi_b(5945)^\circ$	$3/2^+$
	2	105.6583755		μ	1/2	206	5955.33	0.13	$\Xi_b(5955)^-$	$3/2^+$
	3	1776.86	0.12	τ	1/2	207	6100.3	0.6	$\Xi_b(6110)^-$	$3/2^+$
2		light	unflavored	mesons		208	6227.9	0.9	$\Xi_b(6227)^-$	$?^?$
	5	139.57039	0.00018	$\pi^\pm$	$1^-(0^-)$	209	6226.8	1.6	$\Xi_b(6227)^\circ$	
3		strange	mesons			210	6045.2	1.2	Ω_b^-	$0(1/2^+)$
	36	493.677	0.016	$K^\pm$	$1/2(0^-)$	211	4311.9	7.0	$P_c(4312)^+$	
	39	895.55	0.20	$K^*(892)^{*\circ}$	$1/2(1^-)$	212	4440	4	$P_c(4440)^+$	
	213	4457.3	4	$P_c(4457)^+$						

Table 3: Comparison of positions and spacings in light and near-magic nuclei with integer values of the fine structure parameter $\varepsilon' = \delta'/8 = 1.188\,\text{keV}$ [5].

Nucl.	Ca-Ni	^{61}Ni	^{61}Ni	^{61}Ni	^{61}Ni	^{61}Ni
l_n	l_n=0	D(keV)				
E_n	18.8	4.8	9.3	14.1	19.0	24.7
$k(\varepsilon')$	16	4	8	12	16	20
$k \times \varepsilon'$	19.0	4.8	9.6	14.4	19.0	24.7
Nucl.	^{141}Ce	^{141}Ce	^{142}Pr	^{141}Ce	^{141}Ce	^{141}Ce
J_i^π	$1/2^+$	$1/2^+$	$(5/2^-)$			
Γ_n^o,meV	660	3060	160	D	D	D
E_n	9.573	21.570	9.598	21.7	43.1	86.2
E^*,E_n'	$\boxed{9.505}$	$\boxed{21.418}$	$\boxed{9.530}$			
$k\times 8\varepsilon'$	$\boxed{9.504}$	21.384	$\boxed{9.504}$	21.4	42.5	85
Nucl.	^{140}La	^{80}Br	^{82}Br	^{86}Rb	^{143}Ce	J_o^π=$3/2^-$
J_i^π	3^+	l_n=0	l_n=0	l_n=0	$7/2^-$	$5/2^-$
Γ_n^o,meV	54	72.0	120	159	E^*	E^*
E_n	1.179	1.201	1.209	2.398		
E^*,E_n'	$\boxed{1.170}$	$\boxed{1.186}$	$\boxed{1.194}$	2.370	$\boxed{18.9}$	42.3
$k\times 8\varepsilon'$	1.188	1.188	1.188	2.376	19.0	42.77

^{238}Np: maximum at 1.1 eV [7]. This value is close to the position of the first strong resonance at E$_n$=1.321 eV in this nucleus. The next strong resonance at E$_n$=5.777 eV is four times larger than the position of the first strong resonance and is close to the parameter 5.5 eV observed in N-even target nuclei of U: 5.98 eV ^{232}U, 5.1570 eV ^{234}U, 5.45 eV ^{236}U. The same situation as in Np is noticed in Pa: 1.341 eV and 5.152 eV (see Table 4).

The intervals 5.5 eV=4ε'' and ε', as well as intervals that are multiples of them, were found in many heavy nuclei as maxima in positions and spacings distributions of neutron resonances.

The empirical relation (1) was found between the scaling factor $\alpha/2\pi = 115.9 \cdot 10^{-5}$ (equal to the QED radiative correction to the magnetic moment of the electron) and the discussed above parameters of superfine and fine structures in the positions of neutron resonances ε'' =1.34 eV, ε'=1.2 keV, the parameter $\varepsilon_o = 2m_e$ (1022 keV), the electron

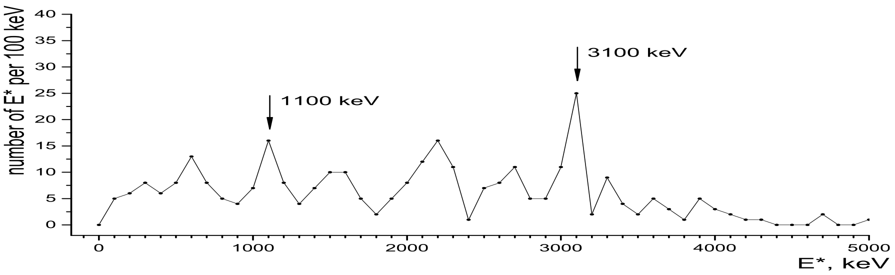

Figure 2: Distribution of stable excitations E^* in different elements.

Table 4: Neutron resonance energies (eV) of heavy compound nuclei. Parameter of superfine structure $\varepsilon'' = 1.34\,\mathrm{eV}$ and parameter $5.5\,\mathrm{eV} \approx 4 \times \varepsilon''$ are boxed. Data from [8].

Nucl.	Z	E_n	E_n	E_n	E_n	E_n	E_n	E_n	
^{233}Th	90				21.819	23.470			570.25
^{234}Pa	91	$\boxed{1.341}$	1.644	2.830	3.386	4.288	$\boxed{5.152}$		
^{233}U	92	$\boxed{5.980}$	12.7	20.80	23.75				
^{234}U	92	1.452	$\boxed{5.805}$			22.20	22.61	23.06	23.69
^{235}U	92	$\boxed{5.157}$						22.1	23.7
^{236}U	92	$\boxed{5.407}$	11.665	12.390	15.417	16.089	16.646	19.296	23.591
^{237}U	92	$\boxed{5.45}$							29.8
^{238}U	92							46.2	52.4
^{239}U	92	6.67	20.87						
^{238}Np	93	$\boxed{1.321}$	1.478	3.865	4.264	4.863	$\boxed{5.777}$		
^{240}Pu	94	0.296	7.826						
^{242}Pu	94	0.264	$\boxed{5.813}$	9.938	14.77	26.43	28.86		
^{242}Am	95	0.3051	$\boxed{5.415}$	14.682					

mass m_e (511 keV), the constituent quark mass M_q (441 MeV), the mass of Z boson M_Z (91 GeV) and the scalar boson mass M_{H°=125 GeV:

$$\alpha/2\pi = \varepsilon'' : \varepsilon' = \varepsilon' : 2m_e = m_e : M_q = m_\mu : M_Z = M_q : 3M_{H^\circ}. \qquad (1)$$

4. Historical background

The first indication of the so-called nonstatistical effects in neutron resonance positions was obtained during the heavy elements neutron cross-section measurements on the time-of-flight neutron spectrometer at the ITEP cyclotron. Then, when particle masses were precisely measured, the observation in the particle mass spectrum of the same stable nuclear intervals became the starting point for combined analysis of the particle masses and nuclear data.

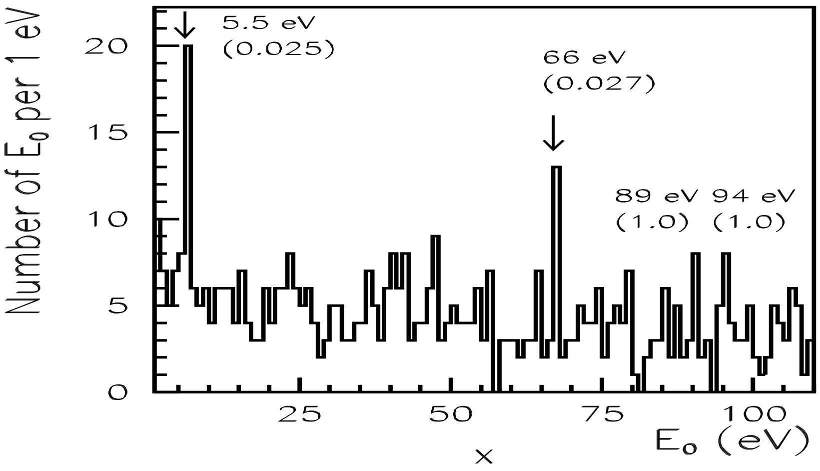

Figure 3: Distribution of neutron resonance positions known in 1966 year [3]. Selection of one strongest resonance (max Γ_n^o) in the interval 10 eV (random probability is given in parentheses).

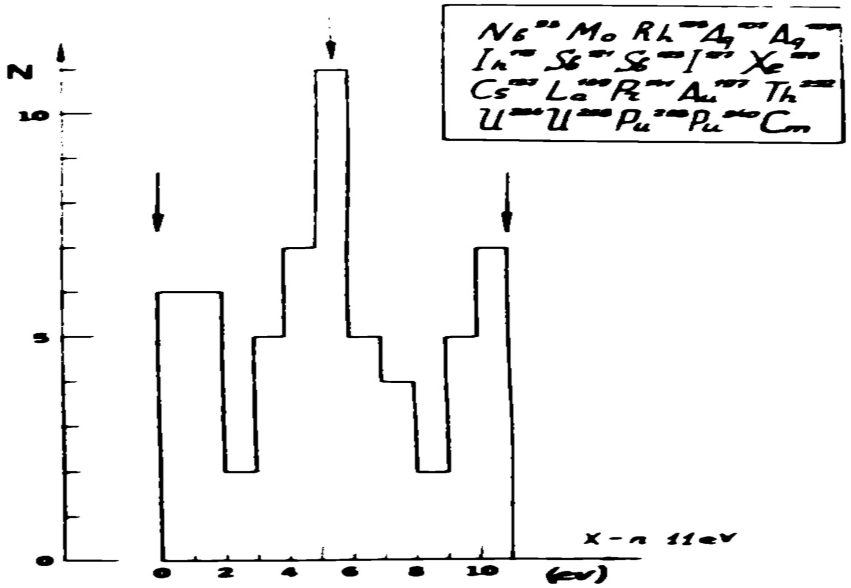

Fig. 4 [1]. Distribution of residual values after subtracting an even number of intervals 11 eV from the values of the spacings indicated between the neutron levels of many nondeformed and even-even target nuclei.

Discreteness in the positions and spacings of neutron resonances with a period of 5.5 eV, shown in Fig. 3 and Fig. 4 is considered as effects of the second and first order from the discreteness in single-particle excitations of light and near-magic nuclei with a period of 1.022 MeV=$\varepsilon_\circ$, found, for example, in levels ^{10}B, ^{12}C, ^{16}O and neon, as well as the discreteness in nuclear binding energies.

Dimensionless empirical relations (1) between the above mentioned parameters $\varepsilon_\circ = 2m_e$=1.022 MeV, ε' =1.2 keV (the fine structure) and ε'' =5.5 eV/4 (the superfine structure) were considered in [1] empirically as a sequence of a similar empirical relation between the electron mass m_e and the stable interval $M_q = M_{gammon} = m_\Xi/3$=441 MeV found by R. Sternheimer and P. Kropotkin. Now the value of M_q is known as the mass of the baryon constituent quark in NonRelativistic Constituent Quark Model (NRCQM), and the scaling factor $\alpha/2\pi$ has been considered as a possible manifestation of physical condensate. Moreover, the parameters NRCQM M_q and M_q^ω have a very general character manifestating themselves in the masses of leptons and heavy quarks and being responsible for grouping effects in the total spacing distribution (Fig. 1). In the top part of Table 5 [4], these parameters are presented as powers of the scaling factor $\alpha/2\pi$ (equal to QED radiative correction). In the bottom part, other examples of comparison of stable nuclear intervals are presented.

Table 5. Presentation of the tuning effect parameters in particle masses (3 top sections) and nuclear data (bottom) by expression n·16m$_e(\alpha/2\pi)^X$M with QED correction $\alpha/2\pi$ [1]. Values m_μ, M_Z, m_π, M_{H°, $\Delta M_\Delta = m_s$, m$_e$/3, δm_n and parameters $\delta^\circ, \delta, \delta', \delta''$ are boxed. Mass groupings M^{L3}=58 GeV and M'_H=115 GeV at X=-1, M=1, 1/2 are unconfirmed.

X	M	n = 1	n = 13	n = 16	n = 17	n = 18
-1	3/2			$\mathrm{m_t}=173.2$		
GeV	1	$\boxed{16\mathrm{M}_q=\delta^\circ}$	$\boxed{\mathrm{M_Z}=91.2}$	$M'_{\mathrm{H}}=115$		$\boxed{M_{\mathrm{H}^\circ}=125}$
	1/2	$(m_b\text{-}M_q)$		$\mathrm{M^{L3}}=58$		
0	1	$16m_e=2m_d\text{-}2m_e$	$\boxed{\mathrm{m}_\mu=106}$	$\mathrm{f}_\pi=130.7$	$\boxed{\mathrm{m}_\pi\text{-}\mathrm{m_e},\ \Lambda_{QCD}}$	$\boxed{\Delta M_\Delta=147}$
MeV	1		$106=\Delta\mathrm{E_B}$		$140=\Delta\mathrm{E_B}$	$147.2=\Delta\mathrm{E_B}$
	3	NRCQM		$\mathrm{M''_q}=\mathrm{m}_\rho/2$		$\mathrm{M_q}=441=\Delta\mathrm{E_B}$
1	1	$\boxed{16m_e=\delta=8\varepsilon_\circ}$			$\boxed{k\delta\text{-}\mathrm{m_n}\text{-}\mathrm{m_e}=}$	$\boxed{170 = \mathrm{m_e}/3}$
					$\boxed{=161.651(6)}$	
keV	8				$\delta m_N=1293.3$	
1	1	$\boxed{9.5=\delta'=8\varepsilon'}$	123	152	$\Delta^{TF}=161$	170 (Sn)
keV	2		247 (^{91}Zr)		322 (^{33}S)	340 (^{100}Mo)
	3				484 (E^*)	512 (Pd, ^{42}Ca, Co, ^{89}Y)
	4		492	606 (Te)	648 (Pd)	682 (Co)
	6		736 (^{42}Ca)			1022 (E^*, ^{38}Ar, ^{89}Y)
	8		984	1212 (Sn)	1293 (E^*, Pd)	1360 (Te)
	12		1475 (^{38}Ar)			
2	1	$\boxed{11=\delta''=8\varepsilon''}$	143 (As)	176 [11]	749 (Br, Sb)	Neutron
eV	4		570 (Sb)		1500 (Sb, Pd)	resonances

The pion mass, the fine structure interval 161 keV (interconnected with $\alpha/2\pi$, Table 5, n=17, boxed) and other pairs of intervals discussed here are located one under another due to the proximity $\alpha/2\pi = 115.9 \cdot 10^{-5}$ to $1/(27\times32)$=$115.7\cdot10^{-5}$ (X=0 and 1).

The proximity of $\alpha/2\pi$ to the ratio of the electron mass to the parameter NRCQM $3\Delta M_\Delta$=M_q=$\mathrm{m}_\Xi/3$ was connected [1] with the possibility of representing parameters of fine and superfine structures ε'=1.2 keV and ε''=1.35 eV observed in the analysis of spacing distributions as the results of the first and second order effects from discreteness in single-particle energies with a period of ε_o=$2M_q(\alpha/2\pi)$.

It was S. Devons, one of pupils of E. Rutherford, who suggested that high-quality nuclear data [8] allow us to find out fine effects associated with the nucleon structure. All results presented here demonstrate that the recent high accuracy data on particle masses and nuclear data allow us to find out the new physics based on the unique role of the electron and its symmetry, in conjunction with the scaling factor $\alpha/2\pi$. Number 16 in the presentation of the general discreteness parameter of all particle masses $\delta = 16m_e$ was assigned to particle-hole configuration, schematically, 16=16-1+1.

For a long period of time, the small value of the electron mass was considered as the theoretical puzzle, which became an important element of the system of empirical relations connected with the fermion symmetry of the electron, and was called the tuning effect in particle masses and nuclear data. The properties of physical condensate containing heavy fundamental bosons, the top and bottom quarks, as well as discreteness of their masses in units of the constituent quark mass $M_q = (\alpha/2\pi)^{-1}m_e = 3\Delta M_\Delta = 3(\alpha/2\pi)M_{H^0}$ are reflected in the accurate relations between the masses of leptons and pion parameters.

The unique property of the electron mass, observed as long-range correlations in particle masses and nuclear data, opens the way for the further development of the Standard Model and the transformation of nuclear physics into a very powerful scientific branch of modern science with many important applications. According to F. Wilczek a new aspect of nuclear spectroscopy ("nuclear chemistry" with very accurate results for energies of nuclear states) can be used, for example, in laser technologies.

4. Conclusions

1) The empirical relations discussed here reflect the stability of the intervals connected with the pion: m_π, the pion parameter f_π and ΔM_Δ (N=16, 17 and 18). For example, it was noted that the neutron mass shift $\delta m_n = 161.6491(6)$ keV and the pion mass 140 MeV are interconnected by the scaling factor $\alpha/2\pi$ (described in (1)).

The pion parametr f_π=130.7(4) MeV is equal to the value $16\delta = 16\times16m_e$=130.8 MeV. We see that the pion parameter corresponding to strong interactions coincides with integer the electron rest mass, the lepton parameter, associated with electromagnetic interactions.

The pion and muon masses are related as 17:13:1 to the doubled pion β-decay energy, which is very close to $16m_e = f_\pi/16$ and is named here as the general discreteness parameter $\delta = 16m_e$=8.176 MeV:

$$\delta = 16m_e = f_\pi/16. \tag{2}$$

2) Nucleons and the electron are stable particles that determine the visible mass of the universe. They are in a ratio that is very accurately estimated in the CODATA (Committee on Data for Science and Technology) Reconmmended Values as m_n/m_e=1838.6836605(11). Then the exactly known shift of the neutron mass from $115\cdot16m_e$ - m_e is $\delta m_n = 161.6491(6)$ keV, which is equal to 1/8 of the nucleon mass splitting δm_N=1293.3322(4) keV (see also (1)).

The unexpectedly exact ratio $\delta m_N : \delta m_n = 8.00086(3) {\approx} 8{\times}1.0001(1)$ allows the representation (named here the CODATA relations):

$$m_n = 115 \cdot 16 m_e - m_e - \delta m_N/8; \quad m_p = 115 \cdot 16 m_e - m_e - 9\delta m_N/8. \tag{3}$$

3) The recently determined mass of the third lepton m_τ=1776.86(12) MeV coincides with the doubled sum of masses of the muon and ω-meson ($m_\omega = 6 f_\pi$) 1776.62(24) MeV:

$$m_\tau = 2m_\mu + 2 \cdot 6 \cdot 16 \cdot 16 m_e = 2m_\mu + 2m_\omega = 2m_\mu + 2 \cdot 6 f_\pi. \tag{4}$$

In equation (4) the distinguishing role of lepton masses is manifestated [9]. These are the main results of this study, which began with the empirical observation the distinguishing character of the superfine (ε''=1.34 eV) and fine (ε'=1.2 keV) structure parameters in the positions of neutron resonances [1,3].

4. Acknowledgments

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