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ELECTRON MASS AS THE BASIC PARAMETER OF THE STANDARD MODEL

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1. Introduction

Nuclear physics and neutron resonance spectroscopy are based on the Standard Model (SM) as a theory of all interactions. The high accuracy in determining the neutron resonance energy (achieved by the time-of-flight method), as well as high accuracy in the mass measurements allowed us to consider together the empirical correlations in neutron resonances, nuclear data and particle masses.

Symmetry motivated and electron-based approach to development of the Standard Model [1] allowed us to determine three relations in SM parameters. All of them contain the electron mass m_e, and (1) and (2) - the parameter $\delta = 16m_e$=8.176 MeV=$m_\omega/96$=$m_\omega/6\cdot 16$ [1], introduced in [2] as close to 8.165 MeV, the doubled pion mass splitting value (4.5936(5) MeV [3]).

$$m_\tau = 2m_\mu + 2m_\omega \approx 2 \cdot 13 \cdot 16m_e - 2m_e + 2 \cdot 96 \cdot 16m_e = 2m_{K^*} \quad (1)$$

$$m_n = 115 \cdot 16m_e - m_e - \delta m_N/8 \qquad m_p = 115 \cdot 16m_e - m_e - 9(\delta m_N/8). \quad (2)$$

$$\alpha/2\pi = 115.9 \cdot 10^{-5} = \varepsilon'' : \varepsilon' = \varepsilon' : 2m_e = m_e : M_q = m_\mu : M_Z = M_q : 3M_{H^\circ}. \quad (3)$$

Here m_τ, m_μ and m_e are the lepton masses, m_ω and m_{K^*} are the meson masses, $\delta m_N = m_n - m_p$ – the nucleon mass splitting, $\alpha/2\pi$ – QED radiative correction to the magnetic moment of the electron [4], applied in [2] to the electron mass, ε''=1.34 eV and ε'=1.2 keV the parameters of superfine and fine structures in the positions of neutron resonances [2,5], M_q is the constituent quark mass [6,7], M_Z – Z boson mass, M_{H° is the scalar boson mass. In this work, we consider the lepton mass relations $m_\tau = 2m_\mu + 2m_\omega$ (1) and show the distinguishing character of each of its components [1].

2. Symmetry motivated empirical relations

The muon mass m_μ was discussed in literature [8-10] as a distinguishing parameter of the Standard Model.

In Table 1 numbers of fermions in the central field (top, N^{ferm}) are compared with numbers N in a representation $N \cdot \delta$ of the masses m_μ, f_π, $m_{\pi^\pm}$ and ΔM_Δ (the first line Table 1). Ratios m_e/M_q, m_μ/M_Z, $f_\pi/(2/3)m_t$, $\Delta M_\Delta/M_{H^0}$ are given in the third line of Table 2. Boxed are the 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=13 and 17 in the columns 3 and 5 in Table 1). Masses of leptons and $L = 207 = 9 \cdot 23 = 13 \cdot 16 - 1$ correspond to a hole configuration consisting of 13 mass/energy intervals (parameters δ).

It was mentioned in a number of works (see [5]) that the ratio 1:13 often appears when analysing neutron resonance spacings.

The exact coincidence of the mass of the third lepton m_τ with twice the sum of the mass of the second lepton m_μ and the vector omega meson mass m_ω (see (1) and

Table 1: Comparison of the number of fermions in the central field (top line, N^{ferm}) with numbers N in a representation $N \cdot \delta$ of masses m_μ, f_π, $m_{\pi^\pm}$, ΔM_Δ. Ratios m_e/M_q, m_μ/M_Z, $f_\pi/(2/3)m_t$, $\Delta M_\Delta/M_{H^0}$ are given in the third line.

N^{ferm}	16	16·13-1=L	16·16	16·17+1	16·18
N(δ)	N = 1	13	16	17	18
Part.	δ	m$_\mu$	f_π	$m_{\pi^\pm}$	ΔM_Δ
Value	in MeV	106.0	130.7(1)	139.57039(18)	147
Ratio.	m_e/M_q	m$_\mu/M_Z$	$f_\pi/M_{H'}$		$\Delta M_\Delta/M_{H^0}$
Value	$\alpha/2\pi$	$115.87 \cdot 10^{-5}$	$114 \cdot 10^{-5}$		$117 \cdot 10^{-5}$
Comm.		hole in 1p	filled shells	valence	
ECQM			$M^\omega{}_q=3f_\pi$		$M_q=3\Delta M_\Delta$

Table 2, 3rd column, 1776.86(12) MeV and 1776.62(24) MeV) was found in [11]. This is a manifestation of discreteness with the parameter $\delta = 16m_e$ in particle masses and nuclear excitations.

The equation (1) is a new [1,11] exact relation between three well-known parameters: masses of two leptons and the mass of the ω meson, which acts as two constituent quarks. Both lepton masses have been measured accurately, but their values have not been determined theoretically, not predicted: the origin of mass is still unresolved problem. Nevertheless, such an exact integer relation 1:2 should be taken into account in the future theoretical models.

It was noticed that the sum of the muon mass and the mass of omega meson is close to $m_{K^*}(892)^\pm$=891.66 MeV: 106 MeV+782 MeV=888 MeV, and $2 \cdot 96 \cdot 16m_e$ is close to $2m_{K^*}$=2×891.66 MeV [1]. In Fig. 1, where the particle masses are compared with the pion parameters, the proximity of the ratio m_τ/m_{K^*}=1776.9 MeV/891.7 MeV=1.99 to 2 is seen.

Table 2: Particle masses (in MeV) of different generations (families) [1,11].

Particle	Lepton	Mass	Quark Q=2/3	Mass	Quark Q=-1/3	Mass
1 fam.	e	0.511	u-quark	2.16(49)	d	4.67(48)
		m_e	($3m_e$)	(1.53) [6]	$9m_e$	4.60
2 fam.	μ	105.658	c	1270(20)	s	93(11)
			$9m_\pi$	1256		
3 fam.	τ	1776.86(12)	t	172900	b	4180(30)
$2m_\mu+4M_q^\omega=2m_\mu+2m_\omega$		1776.62(24)			$9M_q =$	3959
$2m_\mu+192\delta$		1781.108				
$2m_{K^*}$		1783.52(150)				

Correlations have been observed between the integer numbers of the pion masses (k=8, 10 and 12) and the masses of the constituent quarks M_q and M_q^ω [1]. The relations within the ECQM should be considered from the symmetry motivated point of view, including the 3:1 ratio between m_e and the value of $M_{H^\circ}(\alpha/2\pi)^2$ in addition to $M_q = m_e(\alpha/2\pi)^{-1}$.

The formation of constituent quarks masses described by symmetry motivated relations within ECQM can be continued on the basis of new results on the properties of particles containing heavy quarks.

This unexpected coincidence of the mass of the third lepton m_τ with twice the sum of the mass of the second lepton m_μ and the vector omega meson mass m_ω (see (1), 1776.86(12) MeV and 1776.62(24) MeV), and appearence of the masses of precisely these particles may be also connected with the closeness of the strange quark mass m_s to the muon mass: 93±10 MeV and 106 MeV, see Table 2. This means that the constituent strange quark mass K^* is close to the sum of masses of omega meson and strange quark. Taking into account that the mass of omega meson is exactly $96{\cdot}16m_e$ (from the exact equality of two parts equation (1)), it follows that the mass of τ lepton differs very little from the integer number of the electron mass.

The masses of fundamental fields $M_Z = m_\mu(\alpha/2\pi)^{-1}$ and $M_{H^0}=m_e/3(\alpha/2\pi)^{-2}$, and the main parameter of the NRCQM [6,7] $M_q = m_e(\alpha/2\pi)^{-1}$ are interconnected with symmetry motivated relations and QED correction to the electron mass (Table 1), which can be investigated by neutron resonance spectroscopy [1].

The above discussed symmetry motivated relations in particle mass spectrum are shown in Fig. 1.

The relations between the masses of nucleons and the electron (CODATA relations (2)) are now very accurately determined. The ratio of the neutron and electron masses m_n/m_e=1838.6836605(11) means that the shift $\delta m_n = 161.6491(6)$ keV from integer number of electron masses $115{\times}16m_e$ - m_e is exactly 1/8 of the nucleon mass splitting $\delta m_N = m_n - m_p$=1293.3322 keV, or $\delta m_N : \delta m_n = 8.00086(3) = 8{\times}1.000(1)$.

The relation (3) is considered in [5].

A number of authors [12-19] drew attention to the distinguishing character of nuclear excitations close to δm_N, m_e and $2m_e$.

The parameter $\delta = 16m_e$ can be considered as a general discreteness parameter [1], which allows us to represent particle masses and NRCQM parameters in integers: $m_\mu = 13\delta - m_e$, $m_\pi = 17\delta + m_e$, $f_\pi = 16\delta$ [20], $\Delta M_\Delta = 18\delta$, $m_\tau = 2m_\mu + 2m_\omega \approx 2\cdot 13\delta + 2\cdot 2\cdot 48\delta$ and $M_q = 3\Delta M_\Delta = 3 \times 18\delta$, $M_q^\omega = 3f_\pi = 3{\times}16\delta$ (integers n=13, 16, 17, 18, 54=3×18, 3×16=48 and the corresponding parameters are given in the Table 1). Integers n=13, 16, 17 and 18 are of great importance in the symmetry motivated approach to the Standard Model development. The distinguishing character of the n=13 and n=17 is shown in the Table 2 where the hole and valence configurations the most close to the filled shell are boxed.

There are two exact empirical relations with the parameter f_π=130.7±0.1 ± 0.36 MeV [20]. The first, between the vector omega meson mass m_ω=782.66 MeV and f_π=130.7 MeV, equal to 5.988 (the value $m_\omega/2$=391.33 MeV, is an estimate of the mass of constituent quark M_q^ω). The second, $M_q^\omega/16 \cdot 3$=8.153 MeV, is close to 8.176 MeV=$16m_e = \delta$.

The shift δm_n = 161.6491(6) keV = 17×1.2 keV = $17\varepsilon'$ coincides with the parameter of the tensor forces Δ^{TF} = 161 keV found in nuclei where one-pion excange dynamics dominates (^{18}F, ^{55}Co, ^{124}Sb...), and with the radiative correction $\alpha/2\pi$ to the pion mass: 139.57 MeV$\times 115.9 \cdot 10^{-5}$ ≈161 keV. Similar fine structure interval [2] in CODATA relations, namely, 170 keV = 511 keV/3 = $m_e/3$ connected with a shift in the mass of each of constituent quarks that form nucleons, is observed in many near-magic nuclei.

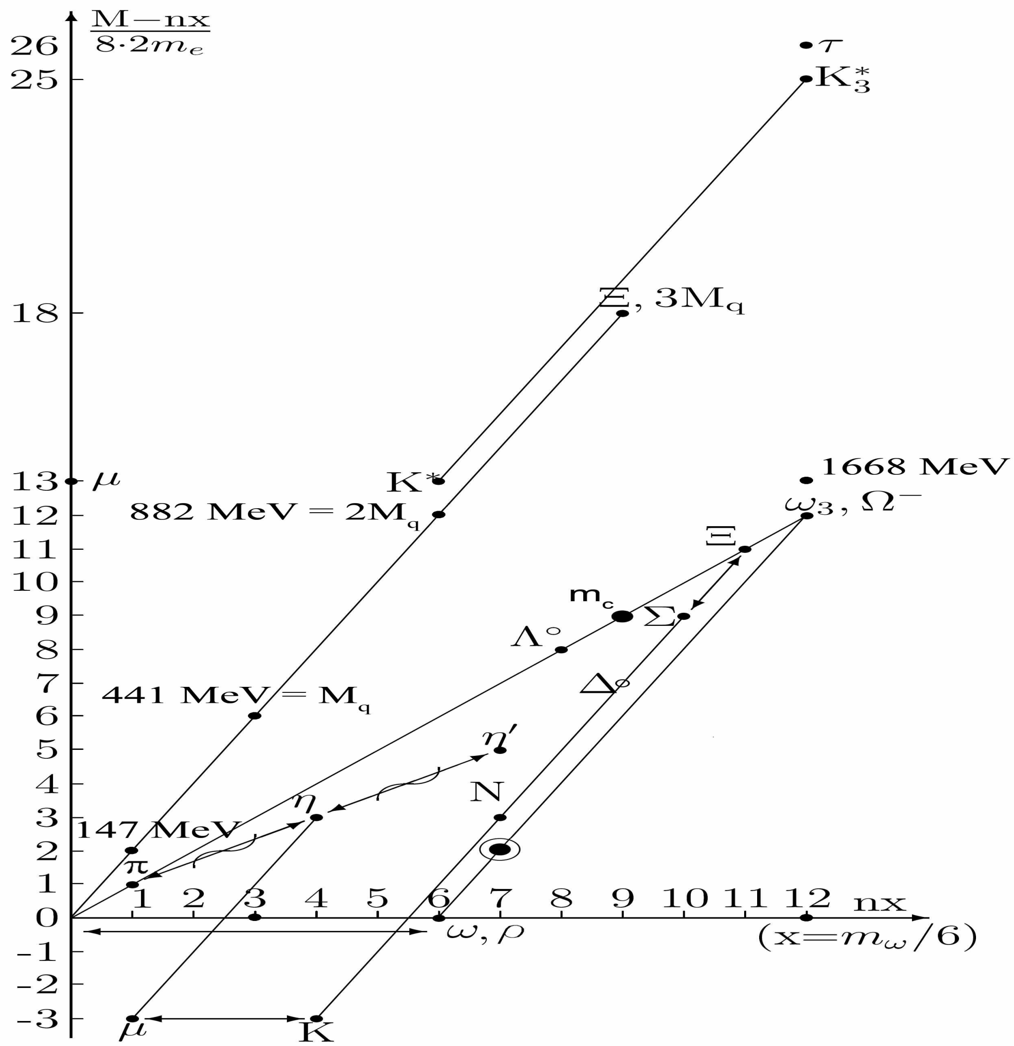

Figure 1: Evolution of baryon mass from $3M_q$ to M_N in a two-dimensional presentation: the values in the horizontal direction are given in units of $16 \cdot 16m_e = f_\pi$=130.7 MeV, the remainders M_i-n$(16 \cdot 16m_e)$ are plotted along vertical axis in $16m_e$. Nucleon mass in a nuclear medium (circled point) is close to $\Delta M_\Delta + 6f_\pi$. Different slopes correspond to 3 pion parameters: $f_\pi = 16\delta$, $m_{\pi^\pm} = 17\delta$ and $\Delta M_\Delta = 18\delta$. The mass of τ lepton (marked as τ) is $2m_\mu + 2m_\omega$=1776.86(12) MeV (n=26 at the left axis).

Table 3: Representation [1,12] of particle masses (3 top sections) and nuclear data (bottom) by the expression n·16m$_e$$(\alpha/2\pi)^X$M with QED correction to the mass $\alpha/2\pi$, where X is the degree and M is the factor. Boxed values m_μ, M_Z, M_{H°, $\delta^\circ, \delta, \delta', \delta''$ and $\Delta M_\Delta = m_s$, $m_e/3$ are considered in [1,12]. Double boxed are the constituent quark masses. Intervals in nuclear binding energies (X=0) and fine structure in nuclear states are considered elsewhere.

X	M	n = 1	n = 13	n = 16	n = 17	n = 18
-1	3/2			m_t=173.2		
GeV	1	$16M_q=\delta^\circ$	M_Z=91.2	M'_H=115		M_{H°=125
0	1	$16m_e$=$2m_d$-$2m_e$	m_μ=106	f_π=130.7	m_π, Λ_{QCD}	ΔM_Δ=147
MeV	1	ΔE_B	106	130	140	147
	2	Fig. 3	212	262		296
	3	NRCQM		M_q^ω=391		M_q=441
	4	Radial excit.			$(b\tilde{b})$=563.0	$(c\tilde{c})$=589.1
	6			m_ω=782		$2M_q$=882
	9				m_c=1270(20)	
	10	$m_\Lambda = 19m_\pi$			1390-1407	
	12	$m_\Omega = 12m_\pi$			1671-1688	
	60	Fig.7 [11]				8848
	64	$\eta_b(1S), \Upsilon(1S)$				9399-9460
1	1	$16m_e=\delta=8\varepsilon_\circ$			$k\delta$-m_n-m_e=161.651	170 = $m_e/3$
keV	$8{,}8 \cdot 4$	CODATA, Fig.1[12]	3936	δm_N=1293.3		
1	1	$9.5=\delta'=8\varepsilon'$	123	152	Δ^{TF}=161	170 (Sn)
keV	2		247 (^{91}Zr)		322 (^{33}S)	340 (^{100}Mo)
2	1, 4	$11=\delta''=8\varepsilon''$	143 (As)		749 (Br, Sb)	Neutron
eV	4, 8		570 (Sb)		1500 (Sb, Pd)	reson.

3. Global analysis of particle masses

To check independently relations (1) and (2), we used a global analysis of the particle mass spectrum, similar to the analysis of the positions of neutron resonances [5,21]. In Fig. 2, ΔM distribution of all differences between particle masses, leptons and hadrons contains maxima in the region of 0-1000 MeV (top): at 3 MeV (not shown, corresponding to zero, since the averaging interval ΔM_{ij} is 5 MeV), 16 MeV (corresponding to stable intervals with the double value of the common period 8.176 MeV=δ=16m$_e$, introduced in [2] and observed in the CODATA relations), and 49 MeV≈ 6δ. An unexpectedly large number of maxima in the distributions in Fig. 2 coincide with constituent quark masses and the τ-lepton mass: M_q^ω=391 MeV, M_q=445 MeV, $2M_q^\omega$=781 MeV, $4M_q^\omega$=1563 MeV, m$_\tau$ ≈ 1774 MeV.

The sequence of maxima at 3504 MeV, 3962 MeV, 4427 MeV (Fig. 2, bottom) corresponds to integer number of k = 8, 9, 10 of the constituent quark mass M_q.

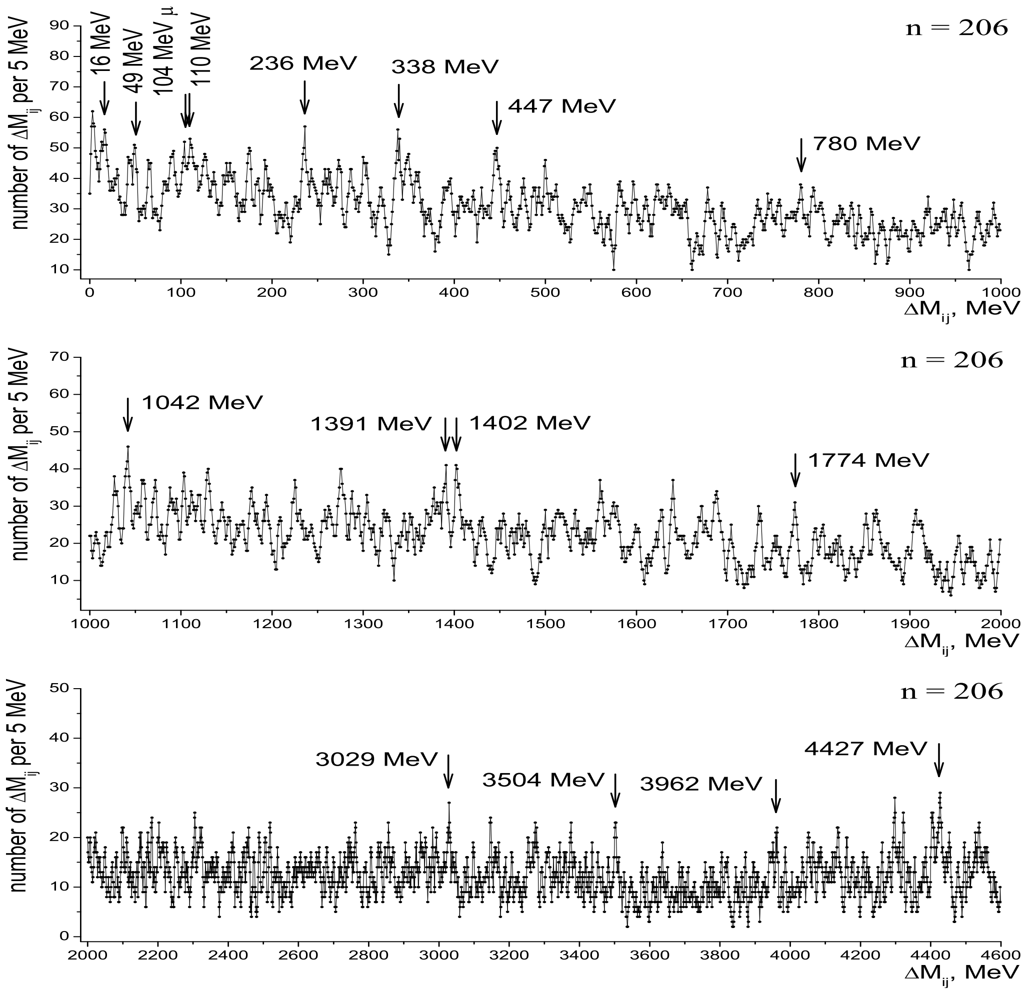

Figure 2: ΔM distribution of all differences between particle masses from PDG-2021 (averaging 5 MeV) the region 0–4600 MeV. Maxima at 16 MeV= 2δ, 49 MeV=6δ, 338 MeV≈ $m_\omega - M_q$, 447 MeV≈ M_q, 780 MeV=m_ω, 1042 MeV=$8f_\pi$, 1931-1402 MeV=$10m_\pi$ and 1774 MeV≈ m_τ. Intervals 3504 MeV≈ $8M_q =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

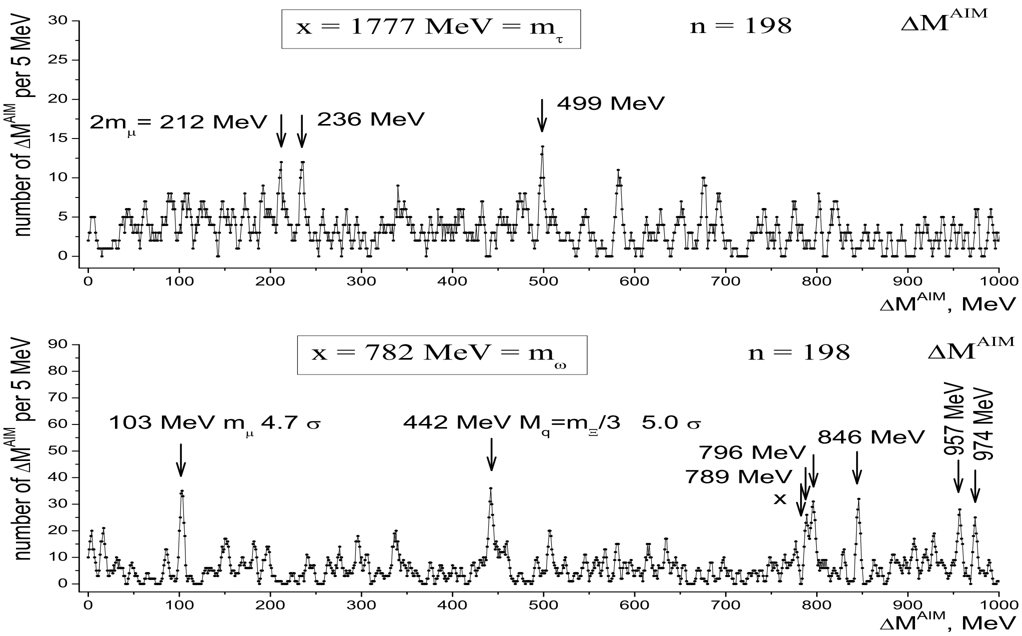

Figure 3: ΔM^{AIM} distribution of particle masses from PDG–2020 for the energy region 0–1000 MeV adjacent to fixed intervals x [1]. *Top:* $x = m_\tau$=1777 MeV, maximum at 212 MeV=$2m_\mu$. *Bottom:* $x = m_\omega$=782 MeV with the maximum at 103 MeV=m_μ and 442 MeV=M_q.

To check the systematic character of the observed grouping of the energy intervals the correlation Adjacent Interval Method (AIM) program was used [22-24]. In this method, not all intervals were analyzed, but only those adjacent to previously selected states. The selection of states (to analyze the intervals between them or between them and other states of the spectrum) was made taking into account their participation in the formation of maxima in the total distribution of intervals (which corresponded to their distinguishing character). Fixing the intervals x in the full spectrum of states (which formed a maximum at this value x), the distribution of intervals from the ends of x intervals to all other states of the spectrum was analyzed. Such accompanying intervals were denoted as ΔM^{AIM}.

In Fig. 3, top, the distribution of intervals adjacent to 1777 MeV=m_τ=x is shown, and the maximum at 212 MeV=$2m_\mu$=m_τ-$2m_\omega$ in the response function of the AIM program is seen. This means that the value 1777 MeV is the sum of $2m_\mu$=212 MeV and $2m_\omega$=1564 MeV=2·782 MeV (see also Fig. 1). The distinguishing character of intervals 103 MeV and 442 MeV can be seen in Fig. 3, bottom.

From the integer ralations between the positions of maxima at 16 MeV and 49 MeV (Fig. 2, top, ratio 3.06), at 780 MeV and 49 MeV (Fig. 2, top, ratio 15.92), 442 MeV and 49 MeV (Fig. 3, bottom, ratio 9.02) we see that there is a common period of about 16 MeV$\approx 2\delta$ in the energies forming these maxima.

The parameter δ being determined from the positions of two first maxima in Fig. 2, top, and their ratio 1:3, is (16 MeV+49 MeV=65 MeV)/2(1+3=4)=8.125 MeV. From positions of maxima at 780 MeV and 442 MeV ($\approx$441 MeV, the mass of the constituent quark) and ratios 16 and 9 (780 MeV+442 MeV=1222 MeV)/(9+16=25)=48.88 MeV=6δ, it is 8.147 MeV. These obtained values practically coincide with δ=8.176 MeV=$16m_e$ [2].

5. Conclusions

Considering the particle masses of three generations (families), new important accurate relation was found between the masses of leptons and hadrons: $m_\tau = 2m_\mu + 2m_\omega$ (1). The muon mass m_μ contained in this expession manifests the distinguishing character of the symmetry motivated dynamics of the lepton ratio L=m_μ/m_e=13×16-1. The lepton mass relation is indirectly confirmed in neutron resonance spasing distributions by appearing the ratio 1:13 (see [5]). From the integer ralations between the positions of maxima in distribution of all differences between particle masses, discreteness with the parameter $\delta = 16m_e$ was confirmed. A possible extension of the Standard Model was considered in [25-27]. All this confirms the role of the electron mass as the main parameter of the Standard Model.

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