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Analysis of the particle mass spectrum PDG-2016

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The discreteness in particle masses and parameters of the Standard Model with the period δ=16m_e was derived earlier from masses of the muon, the pion and nucleons. Corresponding integer values of this parameter (n=13,17 and 115) were redetermined from the exactly known relation between the nucleon masses and the electron mass in CODATA evaluation. For an independent check of these empirical relations the analysis of nuclear data and particle masses from the recent Particle Data Group Compilation PDG-2016 was performed.
On the distribution of differences ΔM between 137 mass values known with an accuracy better than 8 MeV the grouping effect in masses was found at ΔM=2δ, 6δ, 17δ=142 MeV=m_π, 12m_π, 24m_π, the constituent quark masses 445-460 MeV and at the b-quark mass (about 4 GeV).
Stability of the common CODATA mass–intervals observed in different mass regions and exactly expressed as 16 electron rest mass (the tuning effect) is a unique property of particle mass spectrum. This is in accordance with the suggestion by Y. Nambu that empirical relations in particle masses are important for the development of the Standard Model.

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The real hadrons are consisted of constituent quarks with values estimated with the QCD-based Dyson-Schwinger equations [1] dealing with the gluon quark-dressing effect. Evolution of these values is considered in the Nonrelativistic Constituent Quark Model (NRCQM) where the initial quark masses in baryons M_q are close to 1/3 of the mass of Ξ-octet hyperon 1324 MeV/3=441 MeV and three times the parameter of nucleon Δ-excitation in the same model 147 MeV=(m_Δ-m_N)/2, see Fig. 1 in [2]. Values M_q, ΔM_Δ, pion's mass $m_{\pi^\pm}$, the parameter of pion's β-decay f_π=130.4(7) MeV, the muon mass and nucleon masses are in integer relations (n=3×18, 18, 17, 16, 13, 115) with the common period $\delta = 16m_e$=8.176 MeV close to the doubled value of pion's β-decay energy [2,3]. This parameter δ was confirmed with results of CODATA evaluation [4] of relations between the shift of neutron mass δm_n=161.65(6) keV (from integer numbers of m_e) and nucleon mass splitting δm_N. The ratio $\delta m_N : \delta m_n$ =8.00086(3)≈8×1.0001(1) corresponds to the representation:

$$m_n = 115 \cdot 16m_e - m_e - \delta m_N/8 \qquad m_p = 115 \cdot 16m_e - m_e - 9\delta m_N/8 \tag{1}$$

which was checked with analyses of nuclear data [3] and particle masses from the PDG-2016 Review [2,5]. Discreteness (tuning effect) in the distribution of mass difference ΔM is shown in Fig. 1. Maxima in this distribution are located at 17 MeV=2δ, 48 MeV=6δ, 104 MeV≈ $m_\mu = 13\delta$, 142 MeV=$m_\pi = 17\delta$, 445–462 MeV (a doublet close to 441 MeV=M_q=54δ). Three other similar doublets (splitting 2δ) are located at 1871 MeV-1887 MeV, close to 12m_π, at 3940-3959 MeV, close to 9M$_q$; at 4406–4425 MeV, close to 10M_q; the maximum at 3370 MeV corresponds to 24m$_\pi$.

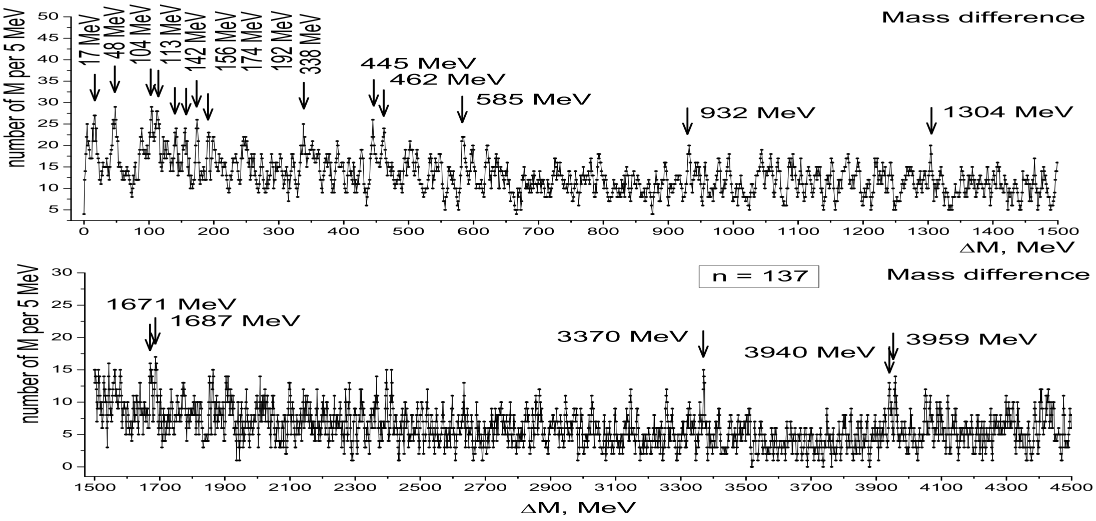

Fig. 1. Distribution of differences between particle masses ΔM in regions 0-1500 MeV, 1500-4600 MeV.

For obtaining this result from the total list in PDG-2016 (n=170 given in Table 1) 33 mass values of particles forming small splitting within multiplets (n-p mass nucleons δm_N=1.29 MeV etc.) were withdrawn [2]. Results were obtained with remaining n=137 values (from meson multiplet only a charged member was taken, from baryon multiplet - only neutral member). In Table 1, intervals ΔM forming observed maxima are given together with the corresponding numbers (in parentheses) in the list of pairs of intervals. Grouping effects at ΔM=142 MeV in unflavored and charmed mesons, at 48 MeV in bottom-strange and $c\bar{c}$ mesons and six intervals ΔM=3960 MeV in Tables 1 and 2 are boxed. Manifestation of doublets with splitting 2δ and stable intervals 17δ' is a confirmation of the dynamic connected with CODATA relation

Table 1. Particle masses (MeV) known with an uncertainty <8 MeV and intervals between masses forming maxima at 17, 48, 142 MeV (for averaging interval Δ=5 MeV), 1673, 1688, 3371, 3960 MeV. Values with uncertainties <0.6 MeV are marked (*), values without rounding up and with uncertainties less than 8 MeV are marked (**). Excluded from the analysis members of multiplets are marked with (***).

Sec.	No	Particle		m_i	17	48	142	1673	1688	3371	3960
1	1	leptons	electron, ν	0.5			140 (1)	1673 (1,2)	1688 (1)		
	2	μ		105.658				1673 (3,4)			
	3	τ		1776.82		46 (15)		1673 (4)			3960 (11)
2		Unflav.	mesons								
	5	π°	$1^-(0^-)$	134.977	***						
	6	$\pi^\pm$	$1^-(0^-)$	139.570			140 (1)			3371 (1)	
	7	η	$0^+(0^{-+})$	547.86							
	8	$\rho(770)$	$1^+(1^{--})$	775.26					1688 (2,3)	3371 (3)	
	9	$\omega(782)$	$0^-(1^{--})$	782.65				1673 (5,6)	1688 (4)		
	10	$\eta'(958)$	$0^+(0^{-+})$	957.78	$\boxed{18\ (1)}$			1673 (8)	1688 (7)	3371 (2)	
	11	$\phi(1020)$	$0^-(1^{--})$	1019.46				1673 (9)	1688 (8)		
	12	$b_1(1235)$*	$1^+(1^{+-})$	1229.5		46 (2)		1673 (11)			
	13	$f_2(1270)$*	$0^+(2^{++})$	1275.5	19 (2)	46 (2,5)			1688 (10)	3371 (5)	
	14	$f_1(1285)$	$0^+(1^{++})$	1282.0			$\boxed{142\ (2,3)}$		1688 (11)		
	15	$\eta(1295)$**	$0^+(0^{-+})$	1294	19 (2)			1673 (12)	1688 (1)		
	16	$a_2(1320)$	$1^-(2^{++})$	1318.3		46 (3)					3961 (3)
	17	$\eta(1405)$*	$0^+(0^{--})$	1408.8	18 (4,5)			1673 (17)	1688 (14)		3958 (7)
	18	$f_1(1420)$*	$0^+(1^{++})$	1426.4	18 (5)	47 (8,9)	$\boxed{142\ (3)}$	1673 (19)			
	19	$\eta(1475)$**	$0^+(0^{-+})$	1476		50 (7,9)	$\boxed{141\ (5)}$				
	20	$f_0(1500)$**	$0^+(0^{++})$	1504	16 (6)						
	21	$f_2'(1525)$**	$0^+(2^{++})$	1525		49 (11)	$\boxed{142\ (4,7)}$				
	22	$\pi_1(1600)$**	$1^-(1^{-+})$	1662			$\boxed{142\ (6)}$				$\boxed{3956\ (8)}$
	23	$\eta_2(1645)$**	$0^+(0^{-+})$	1617		50 (12)	$\boxed{141\ (5)}$				
	24	$\omega_3(1670)$**	$0^-(3^{--})$	1667		45 (12)	$\boxed{142\ (7)}$				
	25	$\pi_2(1670)$*	$1^-(2^{-+})$	1672.2	17 (7)		$\boxed{140\ (8)}$	1673 (1)			
	26	$\rho_3(1690)$*	$1^+(3^{--})$	1688.8	17 (7,8)				1688 (1)		
	27	$f_0(1710)$**	$0^+(0^{++})$	1723		50 (13)	$\boxed{142\ (10)}$		1688 (15)		
	28	$\phi_3(1850)$**	$0^-(3^{--})$	1854	16 (9)		$\boxed{142\ (11)}$	1673 (20)			$\boxed{3957\ (12)}$
	29	$a_4(2040)$**	$1^-(4^{++}$	1995	15 (10)	50 (17)	$\boxed{142\ (11)}$		1688 (19)	3371 (6)	3960 (16)
3		strange	mesons								
	30	$\boxed{K^\pm}$	$1/2(0^-)$	493.68							3956 (1)
	31	$K^*(892)^{*\pm}$	$1/2(1^-)$	891.66		48 (1)		1673 (7)	1688 (5)		
	33	$K_1(1270)$**	$1/2(1^+)$	1272		46 (3,4)					
	34	$K_1(1400)$**	$1/2(1^+)$	1403	19 (3)			1673 (15)			3964 (5) 7)
	35	$K_2^*(1430)^{\pm *}$	$1/2(2^+)$	1425.6	17 (4)	47 (6,7)	142 (2)	1673 (12)			
	37	$K_2(1770$**	$1/2(2^-)$	1773							3961 (9)
	38	$K_3^*(1780)$**	$1/2(3^-)$	1776		47 (14)		1673 (3)			3964 (10)
	39	$K_4^*(2045)$**	$1/2(4^+)$	2045		50 (17)				3371 (7)	
4		charmed	mesons								
	40	D°	$1/2(0^-)$	1864.83			$\boxed{142\ (10)}$		1688 (17)		3964 (13)
	41	$D^\pm$	$1/2(0^-)$	1869.58	16 (9)	47 (16)	$\boxed{141\ (12)}$		1688 (18)		3959 (14,15)
	43	$D^*(2010)^\pm$	$1/2(1^-)$	2010.28	15 (10,11)		$\boxed{141\ (12)}$	1673 (22)			
	44	$D_1(2420)^\circ$	$1/2(1^+)$	2420.8		50 (18,19)					
	46	$D_2^*(2460)^{\pm *}$	$1/2(2^+)$	2465.4					1688 (3)	3371 (11,14)	
5		charmed	strange	mesons							
	47	$D_s^\pm$	$0^+(0^-)$	1968.27			$\boxed{144\ (13)}$	1673 (12)			

Table 1. Continued (members of multiplets *** are withdrawn).

No	Particle		m_i	17	48	142	1673	1688	3371	3960
48	$D_s^{*\pm}$	$0(?^?)$	2112.1			$\boxed{\text{144 (13,14)}}$				
49	$D_{s\circ}^*(2317)^\pm$	$0(0^+)$	2317.7			$\boxed{\text{142 (15)}}$				$\boxed{\text{3957 (17)}}$
50	$D_{s1}(2460)^\pm$	$0(1^+)$	2459.5			$\boxed{\text{142 (15)}}$	1673 (6)	1688 (2,20)	3371 (11,12)	
51	$D_{s1}(2536)^\pm$	$0(1^+)$	2535.10	17 (14)						
52	$D_{s2}^*(2573)*$	$0(2^+)$	2569.1				1673 (7)			
53	$D_{s1}^*(2700)^{\pm}*$	$0(1^-)$	2708.3					1688 (8)		
6	bottom	mesons								
54	$B^\pm$	$1/2(0^-)$	5279.31					1688 (22)		$\boxed{\text{3968 (2,3,4)}}$
56	B^*	$1/2(1^-)$	5324.65					1688 (24)		
59	$B_2^*(5747)^{+}*$	$1/2(2^+)$	5737.2						3371 (17)	3961 (9,10,11)
61	$B_J(5970)^+$	$1/1(?^?)**$	5964	15 (24)						
7	bottom	strange	mesons							
63	B_s°	$0(0^-)$	5366.82		$\boxed{\text{49 (27)}}$				3371 (6)	3962 (5,6,7)
64	$B_s^{*}*$	$0(1^-)$	5415.4		$\boxed{\text{49 (27)}}$				3371 (7)	
65	$B_{s1}(5830)^\circ$	$0(1^+)$	5828.63	17 (22)					3371 (10,11)	3959 (13,14)
66	$B_{s2}^*(5640)^\circ$	$0(2^+)$	5839.84		$\boxed{\text{48 (28)}}$		1673 (13)	1688 (12)	3371 (14,15)	
8	bottom	charmed	mesons							
67	$B_c^{*}*$	$0(0^-)$	6275.1						3371 (18)	$\boxed{\text{3957 (17,22)}}$
9	$c\bar{c}$	mesons								
68	$\eta_c(1S)$	$0^+(0^{-+})$	2983.4	15 (16)			1673 (13)	1688 (12)		
69	$J/\psi(1S)$	$0^-(1^{--})$	3096.90	17 (17)			1673 (18,19)	1688 (13.14)		
70	$\chi_{c0}(1P)$	$0^+(0^{++})$	3414.75			141 (18)		1688 (15)		
71	$\chi_{c1}(1P)$	$0^+(1^{++})$	3510.66	14 (18)	$\boxed{\text{46 (22)}}$			1688 (16)	3371 (1)	
72	$h_c(1P)$	$?^?(0^{+-})$	3525.38	14 (18)			1673 (20)			
73	$\chi_{c2}(1P)$	$0^+(2^{++})$	3556.20		$\boxed{\text{46 (22)}}$	141 (18)		1688 (17,18)		
74	$\eta_c(2S)*$	$0^+(0^{-+})$	3639.2		$\boxed{\text{47 (23)}}$		1673 (21)	1688 (22)		
75	$\psi(2S)$	$0^-(1^{--})$	3686.10		$\boxed{\text{47 (23)}}$		1673 (26)	1688 (19)		
76	$\psi(3770)$	$0^-(1^{--})$	3773.13		$\boxed{\text{49 (24)}}$					
77	$\psi(3823)*$	$?^?(2^{--})$	3822.2		$\boxed{\text{49 (24)}}$					
78	$X(3872)$	$0^+(1^{++})$	3871.69	15 (19)	$\boxed{\text{49 (25)}}$					
79	$X(3900)*$	$1^+(1^{+-})$	3886.6	15 (29)						
80	$X(3915)*$	$0^+(?^{++})$	3918.4		$\boxed{\text{47 (26)}}$				3371 (2)	
81	$\chi_{c2}(1P)*$	$0^+(2^{++})$	3927.2				1673 (23)	1688 (23)		
82	$X(4020)*$	$1(?^?)$	4024.1	15 (20)						
83	$\psi(4040)**$	$0^-(1^{--})$	4039	15 (20)				1688 (24)		
84	$X(4140)*$	$0^+(?^{?+})$	4146.9				1673 (24)	1688 (20,	3371 (3)	
85	$\psi(4160)**$	$0^-(1^{--})$	4191				1673 (25)			
86	$X(4260)**$	$?^?(1^{--})$	4251				1673 (28,26)	1688 (26)		
89	$X(4660)**$	$?^?(1^{--})$	4643				1673 (27)		3371 (4,5)	
10	$b\bar{b}$	mesons								
93	$\chi_{b1}(1P)$	$0^+(0^{++})$	9892.78	19 (25)						$\boxed{\text{3958 (18)}}$
95	$\chi_{b2}(1P)$	$0^+(2^{++})$	9912.21	19 (25)						3963 (20,21)
96	$\Upsilon(2S)$	$0^-(1^{--})$	10023.26			140 (21)				
97	$\Upsilon(1D)*$	$0^-(2^{--})$	10163.7			140 (21)				
98	$\chi_{b0}(2P)$	$0^+(0^{++})$	10232.5							$\boxed{\text{3957 (22)}}$
102	$\chi_{b1}(3P)*$	$0^+(1^{++})$	10512.1	17 (26)						
103	$\Upsilon(4S)*$	$0^-(1^{--})$	10529.4	17 (26)						
11		baryons								
108	n	$1/2(1/2^+)$	939.565	$\boxed{\text{18 (1)}}$	48 (1)			1688 (6)		
109	Λ	$0(1/2^+)$	1115.68				1673 (10)			
110	$\Lambda(1405)1/2^{-}*$	$0(1/2^-)$	1405.1				1673 (16)	1688 (13)		3962 (6))

Table 1. Continued (members of multiplets *** are withdrawn).

No	Particle		m_i	17	48	142	1673	1688	3371	3960
113	Σ°	$1(1/2^+)$	1192.64					1688 (9)		
116	$\Sigma(1385)^\circ*$	$1(3/2^+)$	1383.7	19 (3)		144 (3)	1673 (14)			
118	Ξ°	$1/2(1/2^+)$	1314.86				1673 (13)			3964 (2)
119	Ξ^-	$1/2(1/2^+)$	1321.71		50 (4,5)					$\boxed{3958\ (4)}$
120	$\Xi(1530)3/2^{+\circ}$	$1/2(3/2^+)$	1531.80			$\boxed{140\ (8,9)}$				
122	$\Xi(1820)3/2^-$	$1/2(3/2^-)$**	1823		47 (14)			1688 (16)		
123	$\Xi(2030)$**	$1/2(\geq 3/2^?)$	2025	18 (11)						
124	Ω^-	$0(3/2^+)$	1673.45	15 (8)	50 (13)	$\boxed{141\ (9)}$	$\boxed{1673\ (2)}$			
125	$\Omega(2250)^-$**	$0(?^?)$	2252			140 (14)	1673 (23)		3371 (8)	
12	charmed	baryons								
126	Λ_c^+	$0(1/2^+$	2286.46							
127	$\Lambda_c(2595)^+$	$0(1/2^-)$	2592.25						3371 (17)	
128	$\Lambda_c(2625)^+$	$0(3/2^-)$	2628.11	18 (15)	50 (20)		1673 (8)	1688 (6)		
129	$\Lambda_c(2880^+)$	$0(5/2^+)$	2881.53					1688 (9)		
130	$\Lambda_c(2940^+)*$	$0(5/2^+)$	2939.3			141 (17)				
133	$\Sigma_c(2455)^\circ$	$1(1/2^+)$	2453.75	17 (12)			1673 (5)		3371 (10)	
136	$\Sigma_c(2520)^\circ$	$1(3/2^+)$	2518.48	17 (14)	48 (19)		1673 (12)			
138	$\Sigma_c(2800)^\circ$**	$1(3/2^+)$	2906			140 (16)	1673 (11)		3371 (18)	
140	Ξ_c°	$1/2(1/2^+)$	2470.85	17 (12)	50 (18)		1673 (24)	1688 (4)	3371 (15)	
142	$\Xi_c^{\prime\circ}*$	$1/2(1/2^+)$	2577.9		50 (20)		1673 (26)	1688 (5)	3371 (16)	
144	$\Xi_c(2645)^\circ$	$1/2(3/2^+)$	2645.9	18 (15)	49 (21)			1688 (7)		
146	$\Xi_c(2790)^\circ*$	$1/2(1/2^-)$	2791.9				1673 (10)			
148	$\Xi_c(2815)^\circ*$	$1/2(3/2^-)$	2819.6							
150	$\Xi_c(2970)^\circ*$	$1/2(?^?)$	2968.0	15 (16)			1673 (12,27)	1688 (10,11)		
151	$\Xi_c(3055)*$	$1/2(?^?)$	3055.1				1673 (14)			
153	$\Xi_c(3080)^\circ*$	$1/2(?^?)$	3079.9	17 (17)		141 (17)	1673 (15-17)			
154	$\Omega_c^\circ*$	$0(1/2^+)$	2695.2		49 (21)		1673 (9)			
155	$\Omega_c(2770)^\circ*$	$0(3/2^+)$	2765.9			140 (16)		1688 (21)		
13	bottom	baryons								
156	Λ_b°	$0(1/2^+)$	5619.51					1688 (23)	3371 (8)	$\boxed{3957\ (8)}$
157	$\Lambda_b(5912)^\circ$	$0(1/2^-)$	5912.11							
158	$\Lambda_b(5920)^\circ$	$0(3/2^-)$	5919.81	15 (23)						
159	Σ_b^+*	$1(1/2^+)$	5811.3	17 (21,22)		144 (20)				$\boxed{3957\ (12)}$
161	$\Sigma_b^{*+}*$	$1(3/2^+)$	5832.1					1688 (25)	3371 (12,3)	3962 (15)
164	Ξ_b°	$1/2(1/2^+)$	5791.9	19 (21)	48 (28)	143 (19)			3371 (9)	
165	$\Xi_b'(5935)^-$	$1/2(1/2^+)$	5935.02	15 (23)		143 (19)		1688 (26)		$\boxed{3958\ (18,19)}$
166	$\Xi_b(5945)^\circ*$	$1/2(3/2^+)$	5948.9	15 (24)					3371 (16)	3963 (20)
167	$\Xi_b^*(5955)^-$	$1/2(1/2^+)$	5955.33			144 (20)				3960 (16,21)
169	$P_c(4450)^+*$		4449.8					1688 (21)		3960 (1)

Table 2. Proximity of values ΔM=M_i-M_j in particles containing b-quarks is shown in Table 2 top. Boxed are four accurately known values, double boxed are two of them which are in the sequence.

ΔM	$\boxed{3957.6}$	3957.5	3957.8	$\boxed{\boxed{3957.4}}$	$\boxed{3957.8}$	$\boxed{\boxed{3957.4}}$
M_i	5279.3	5619.5	5811.3	$\boxed{6275.1}$	9892.8	$\boxed{10232.5}$
Name	$B^\pm$	Λ_b°	$\Lambda_b(5920)^\circ$	B_c^**	$\chi_{b1}(1P)$	$\chi_{b0}(2P)$
parameters	$1/2(0^-)$	$0(1/2^+)$	$0(3/2^-)$	$0(0^-)$	$0^+(0^{++})$	$0^+(0^{++})$
M_j	1321.7	1662(8)	1854(7)	$\boxed{2317.7}$	5855.0	$\boxed{6275.1}$
Name	Ξ^-	$\pi_1(1600)$**	$\phi_3(1850)$*	$D_{s\circ}^*(2317)^\pm$	Σ_b^{*-}*	B_c^**
Parameters	$1/2(1/2^+)$	$1^-(1^{-+})$	$0^-(3^{--})$	$0(0^+)$	$0^+(0^{++})$	$0(0^-)$

Table 3. Comparison of ratios between masses m_μ/M_Z, $f_\pi/(2/3)m_t$, $\Delta M_\Delta/M_H$, with the QED parameter $\alpha/2\pi$=115.95 $\cdot$ 10^{-5} (close to 1/32×27=115.74 $\cdot$ 10^{-5}) and numbers of fermions in the central field (boxed in the bottom line is the hole configuration in $1p$ shell). One asterisk: configuration $1s^4_{1/2}$, $1p^8_{3/2}$, $1p_{1/2}$; two asterisks – configuration: new principal quantum number; three asterisks – configuration: $1s^4_{1/2}$, $1p^8_{3/2,1/2}$.

N ferm.	N = 1	N = 16	16·13-1	16·16	16·17+1	16·18
Part./param.	m_e/M_q	δ	m_μ/M_Z	f_π/M'_H	$m_{\pi^\pm}$	$\Delta M_\Delta/M_H$
Ratio	115.9·10^{-5}		115.87 $\cdot$ 10^{-5}	114·10^{-5}		117.8 $\cdot$ 10^{-5}
Config.			(*)	(***)	(**)	
Comm.			$\boxed{\text{hole in } 1p}$	filled shells		

An analogy between the lepton ratio $L = 207 \approx (m_\mu/m_e)$ and the number of fermions in the central field N,ferm. (1-st line of Table 3) was used in [2,3] for presentation of the muon/pion masses as integers of $\delta = 16m_e$. Muon mass m_μ and pion's parameters f_π, m_π, ΔM_Δ (n=13,16-18), CODATA period 16m_e and relations 1:2:17, 1:3 and 1:12:24 between positions of maxima in Fig. 1, namely, m_π (n=17), maxima at ΔM=1687 MeV and 3370 MeV (n=12×17 and 24×17) have a symmetry–motivated representation. It is based on CODATA values $\delta = 16m_e$, $m_e/3$=$(\alpha/2\pi)^2M_H$ and $\delta m_n = (\alpha/2\pi)m_{\pi^\pm}$ which are main elements of a new approach to deal with SM mass problem. Many years of the collection and analysis of nuclear data (in ITEP and PNPI [7,8]) resulted in the establishment of the fine structure system of stable nuclear intervals rationally related with the charge mass splitting of the nucleon and the electron. New nuclear data were considered in [6-8]. Appearance of such system in CODATA relation is the reflection of their common QCD–based origin. Introduced earlier empirically (from periods of superfine– and fine structures in nuclear spectroscopic data) the QED parameter of the radiative correction $\alpha/2\pi = 115.95 \cdot 10^{-5}$ was later confirmed with the same ratio between two principal SM–parameters $m_\mu/M_Z = 115.87 \cdot 10^{-5}$. R. Feynman, V. Belokurov and D. Shirkov noticed that such a factor presents in the electron mass.

We conclude that performed analysis confirms the unique properties of CODATA relation. An analysis of symmetry motivated integer relations and combinations of the main CODATA parameters δ and $m_e/3$ are discussed in [6]. Presence of extremely accurate CODATA relation 1/(3×16) for m_e/3 and 1/8 for the second fine structure parameter δm_n=161 keV means that these observed parameters are unique values, and their interconnection with the real mass splitting should be a base for a further development of the Standard Model.

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