Discreteness in particle masses and parameters of the Standard Model

Sergey Sukhoruchkin
B.P. Konstantinov Petersburg Nuclear Physics Institute, 188300 Gatchina, Russia
E-mail: sergeis@pnpi.spb.ru

We performed simultaneous analysis of the discreteness in particle mass spectrum and relations in nuclear parameters connected with nuclear tensor force (one-meson exchange dynamics). Analysis of particle masses is in line with the suggestion that empirical relations in masses could be used for the development of the Standard Model. Due to a closeness of the pion mass splitting $\delta m_{\pi}=4594$ keV to the $9m_e=4599$ keV ($m_e$ is the electron mass) the parameter of the discreteness in particle mass spectrum is close to the doubled value of the pion $\beta$-decay energy $16m_e=\delta \approx 2\delta m_{\pi} - 2m_e$ (tuning effect in particle masses). This discreteness was found also in parameters of correlations in nuclear excitations and binding energies. Common tuning effect includes also the nucleon mass splitting $\delta m_N=1293.3$ keV which belongs to the fundamental manifestation of the nucleon structure. The value $\delta m_N$ and its $1/8$ part $\delta m_N/8=161$ keV were found also in the grouping effect in nuclear excitations and spacing. In the tuning effect in particle masses the value $(1/8)\delta m_N=161$ keV accounts the shift of the exactly known neutron mass $m_n$ relative to integer number of the electron rest mass (so-called CODATA relation). We consider these correlations, the possible role of the lepton ratio and the possible hints on the symmetry in the fermion spectra as the new approach to the SM-development.

The European Physical Society Conference on High Energy Physics
22-29 July 2015
Vienna, Austria

*Speaker.
1. Introduction

Nucleon interactions within nuclei are commonly considered as a result of one- and many-pion exchange. The role of tensor forces (one-pion exchange) was recently considered by J.Schiffer [1], T.Otsuka [2] and I.Tanihata [3]. They found the regions of nuclear chart where tensor-force effects are important. For example, in heavy antimony isotopes (N=72-82) the valence proton in Jπ=7/2+ state (π,1g7/2) strongly interacts with neutrons in the large v,1h11/2 subshell. Such deuteron-like situation (spin 1, orbital motion in different directions) with the dominant role of one-pion exchange dynamics in nucleon interaction exists also in light and heavy nuclei. Stable intervals in first excitations of the near-magic 116Sn (E*+1293.6 keV, E2-E1=1292.0 keV) correspond to n=8 in this systematics. They are close to the nucleon mass splitting δmN=1293.3 keV. The system E*, D =nΔFF was confirmed with stable excitations and spacing in many nearby nuclei [4-8].

The linear trend in excitations E* of odd Sn isotopes with a slope 161 keV, E*+n(ΔE=161 keV) is similar to that found in the first excitations of N=21,22 isotopes 41Ca and 38,37S. Here E*+1942.8–1292.0–646.2 keV coincide within 2-3 keV with n=12,8,4 in the system nΔFF. In Z=72,74 isotopes E*+1293–1293–1293–1295 keV (0+, 2+ in 160Yb,172,176Hf,178W) correspond to n=8. These E*, D and small intervals at high excitation with D close to E*(α/2π) are presented in Table 1 (bottom).

The stable character of excitation about 170 keV in the near-magic 101,103Sn (N=51,53) was confirmed with stable spacing of 97.98Pd (N=51,52). Here stable intervals D=512 keV (close to 3×170 keV, that’s n=3) and D=648 keV and 1293 keV (N=4,8 in the system with ΔM) was found. The latter interval corresponds to the excitations with ΔJ=2, 1295 keV and 2588 keV). In 10B the interval 1021.72(3) keV (n’=6) is a result of spin-flip effect (0+-1+). Its value is close to 2mπ=1022.0 keV=επ. Excitations k·επ were noticed in many light nuclei including the magic 55Co. Similar effects with n’=161 keV=(1/8)δmN and n’·170 keV=(1/6)επ are considered in [4-9].

Table 1. Presentation of particle masses and parameters from analysis of nuclear data (in lines marked X=-1, 0, 1, 2 at left) by the common expression n·mπ(α/2π)X M with the QED radiative correction α/2π (α=137−1) [9,10]. Boxed are values MZ, scalar boson mass Mπ, Mµ, mπ, mπ, Mπ, the neutron mass shift Nδ − mπ − mπ ≈ ΔFF and ΔMπ≈ mπ. Stable E*, Dij (at X=1,2) indirectly confirm values at X=1 (center).

<table>
<thead>
<tr>
<th>X</th>
<th>M</th>
<th>n</th>
<th>Particle masses</th>
<th>M with QED correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/2</td>
<td>16 mπ=8επ</td>
<td>mπ =171.2</td>
<td>(Mπ=115)</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>16mπ=8επ</td>
<td>mπ =105.7</td>
<td>fπ=130.7</td>
</tr>
<tr>
<td>3</td>
<td>Particle masses</td>
<td>M∗π = mπ/2</td>
<td>Wick – Sternheimer</td>
<td>Mπ=441</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>9.5=8επ</td>
<td>Nuclear data</td>
<td>132</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>649 (M.Ohkubo)</td>
<td>533</td>
<td>606</td>
</tr>
<tr>
<td>3-6</td>
<td>28-56</td>
<td>749,150 (Sb,Pd,Rh)</td>
<td>570 (Sb)</td>
<td>44</td>
</tr>
</tbody>
</table>
Discreteness in particle masses and parameters of the Standard Model

Sergey Sukhoruchkin

Figure 1: Position of the nucleon mass N among different mass intervals and particle masses in two-dimensional presentation. Values on the horizontal axis are in units $16 \cdot 16m_e$ coinciding with the pion parameter $f_\pi=130.7(4)$ MeV close to $m_\rho/6 \approx m_\rho/6$. The remainder – values $M_i-k\delta=M_i-k16 \cdot 16m_e$ – are displayed along the vertical axis in units $16 \cdot 16m_e$. Three lines with different slopes correspond to:

1) the main parameter $\Delta M_\Delta=147$ MeV of baryon constituent quark masses from the nucleon $\Delta$-excitation $(m_\Delta-m_n)/2=18\delta$ and initial constituent quark mass $M_q=3 \times 147$ MeV; initial baryon mass $3M_q=m_\Xi$ (top);
2) the pion mass $140$ MeV=$f_\pi+\delta$ (n=16+1), masses of $\Lambda$, $\Xi$ and $\Omega$ hyperons are close to $8m_\pi$, $11m_\pi$, $12m_\pi$;
3) stable interval in pseudoscalar meson $m_{\eta'}-m_\eta=m_\eta-m_\pi$ (crossed arrows, n=50 in units $\delta=16m_e$.

Nucleon $\Delta$-excitation and two s-quark masses $m_s$ result in a long line from the kaon (K, n=4-16-3=61) and the neutron mass (N, n=7-16+3=115) to the $\Xi^-$ hyperon mass ($\Xi$).

Nucleon mass in nuclear medium ($m_{N_{\text{nuc}}}^{\text{nuc}}$, circled large point) is close to the sum of $\Delta M_\Delta=147$ MeV and $6f_\pi=6 \cdot 16 \cdot 16m_e \approx m_\rho \approx m_\rho$. It is the last member of the sequence of the baryon mass transformation from the initial mass $3M_q=9\Delta M_\Lambda$ (at top, n=9-18) to $m_{N_{\text{nuc}}}^{\text{nuc}}$ at the bottom.

The mass of $\tau$ lepton and $2^+$ excitation of vector mesons (shown at top) are considered elsewhere. They are close to integer numbers of the $M_q \approx 3\Delta M_\Lambda=(\alpha/2\pi)M_H$. 

3
2. CODATA relation in the tuning effect

Nucleon mass is a result of constituent quark-mass evolution: First, a reduction of each quark mass from $M_q^0$ ($n=3$-18) to $\Delta M + 2f_\pi$ ($n=18$-2+16 about 50-51). In Fig.1 it corresponds to the shift downwards from $3M_q^0$ to $\Delta$. At the second step, due to spin-dependent interaction between quarks, nucleon mass looses $2\Delta M$ ($n=151-36=115$). Nucleon mass in the nuclear medium $m_N^{nucl}$ (circled dot in Fig.1, about 8 MeV $\approx \delta$ below $m_N^0$) is shifted due to residual quark interaction. The generation of the initial mass and its reduction is explained in QCD and NRCQM [15-17]. The value $m_N^{nucl}$ is the last in a sequence from the initial mass $3M_q^0=9\Delta M$ – to the $\Delta$-baryon mass $1320$ MeV $= 3(2f_\pi + \Delta M)$ – to $m_N$ – and finally to $6f_\pi + \Delta M$. So, number $n=115$ corresponds to the neutron mass.

The shift of the neutron mass relative to the value $115\delta$ equal to $\delta m_n = 161.65(6)$ keV was derived from the recent precise ratio between neutron and electron masses evaluated by CODATA [18] $m_n/m_e = 1838.6836605(1)$. The shift accounts an integer ratio with nucleon mass splitting $\delta m_N = 1293.3$ keV $\delta m_N/\delta m_n = 8(1.0001(1))$. Such unexpected relation in CODATA results

$$m_n = 115 \cdot 16m_e - m_c - \delta m_N/8$$

$$m_p = 115 \cdot 16m_e - m_c - 9 \delta m_N/8$$

allows conclusions concerning the general properties of the tuning effect in particle masses.

First of all, there are other mass parameters with integer representation of values with the period $\delta$ (three top lines in Table 2 [9]). Muon mass with the lepton ratio $L = m_\mu/m_e = 13.16-1=207$ has the same combination of $n\delta - m_e$ as the neutron mass. Other examples - values $f_\pi$ and $\Delta M$.

Secondly, constituent quark masses ($M_q$ and $M_q''$, Table 2) which are produced with the gluon-quark-dressing effect [15,19] are in the lepton ratios $L=207$ with the vector boson masses, namely, $L^Z=M_Z/M_q=207.4$ and $L^W=M_W/M_q''=207.5$.

Table 2. Comparison of particle masses with the period $16m_e=\delta=8176$ keV (comments – in MeV, constant shift $\Delta=9m_e$ is boxed).

<table>
<thead>
<tr>
<th>Particle</th>
<th>$m_e$, MeV</th>
<th>$k$</th>
<th>$m_e-k\cdot16m_e$</th>
<th>Diff.</th>
<th>Comments (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>105.658367(4)</td>
<td>13</td>
<td>-0.6294</td>
<td>-m_e-0.118</td>
<td></td>
</tr>
<tr>
<td>$f_\pi$</td>
<td>130.7(4) [20]</td>
<td>16</td>
<td>$\approx 0$</td>
<td>$\Delta M$=147.1, $\Delta E_B=147.2$ [4]</td>
<td></td>
</tr>
<tr>
<td>$\Delta^2$-$n$</td>
<td>294.2(2)</td>
<td>36</td>
<td>$\approx 0$</td>
<td>$2(\Delta M=147.1)$, $\Delta E_B=441$ [4]</td>
<td></td>
</tr>
<tr>
<td>$M_q$ NRCQM, $m_{X_{1-3}}/3$</td>
<td>441</td>
<td>3-18</td>
<td>$5=\Delta$</td>
<td>$m_d=\Delta$</td>
<td></td>
</tr>
<tr>
<td>$M_q/18-16$</td>
<td>436</td>
<td>3-18-$\Delta$</td>
<td>$\approx -2m_e$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_q/L$</td>
<td>440.5</td>
<td>3-18</td>
<td>$\approx -2m_e$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta', \eta, \pi^\pm$</td>
<td>409</td>
<td>50</td>
<td>$\approx 0$</td>
<td>$\Delta E_B=409$ [4]</td>
<td></td>
</tr>
</tbody>
</table>

| $M_q''$ NRCQM, $m_{p/2}$ | 387.7 | 48 | $4.60=2-\Delta$ | $m_d=\Delta$, $m_p=775.49(34)$ [14] |
| $M_q/L$              | 388.4 | 3-16 | $\approx 2m_e$ |

| $n$                 | 939.5654(1) | 115 | -0.6726(1)     | -m_e-(1/8) $\delta m_N$ |
| $p$                 | 938.2720(1) | 115 | -1.9666(1)     | -m_e-(9/8) $\delta m_N$ |
| $\Sigma^0$          | 1192.64(2)  | 146 | -1.05(2)       | -2m_e=-1.022             |
| $\Xi^0$             | 1314.86(20) | 161 | -1.47(20)      | -3m_e=-1.533             |
3. Empirical relations in SM-parameters

Exactness of CODATA integer relation could mean the presence of the common general origin of all SM-interactions. It was R.Feynman who draw attention to the common vector character of all interactions [21]. He suggested that in the future "super-duper model" an understanding of the main parameters like \( \alpha \) could be achieved. Relations with factor \( \alpha=1/137 \) are shown in Table 1 (boxed values related as \( \alpha/2\pi \)). The proximity of \( \alpha/2\pi = 115.9 \cdot 10^{-5} \) to the ratio between the well-know main SM-parameters – masses of the \( \mu \)-lepton and Z-boson \( m_\mu/M_Z=115.9 \cdot 10^{-5} \) was noticed long ago. Similar relations with QED parameter for a short \((1/M_2)\) distance \( \alpha_2=1/129 \) can be added: the ratio between \( m_e \) and the pion mass \( 170 \text{ keV}/140 \text{ MeV}=121 \cdot 10^{-5} \) and between the pion mass and unconfirmed mass \( M'_\mu=116 \text{ GeV} \) of the possible scalar boson (twice the mass of the groping effect at 58 GeV discussed by S.Ting [22]), namely, \( 140 \text{ MeV}/116 \text{ GeV}=121 \cdot 10^{-5} \). It was suggested by V.Belokurov and D.Shirkov [23] that the small QED factor \( \alpha/2\pi \) could be found in the electron rest mass itself. We briefly consider here four possible connection of the obtained unexpected CODATA relations with other empirical observations.

1) Integer ratios \( 1:16 \) and \( 1:9 \) in CODATA relations \( (m_e: \delta \text{ and } 161 \text{ keV}: \delta m_N) \) as well as the ratio \( 1:9 \) in charge splitting \( (m_e: \delta m_{\pi}) \) could be considered together with the recent quark masses estimations \( m_q=4.78(9) \text{ MeV close to } \Delta=9m_e=4.60 \text{ MeV and } m_q=4.18(1) \text{ GeV close to } 9M_q=4.0 \text{ GeV} \) [9,14] (if values would be confirmed). Observed integer relations in lepton masses \( m_\mu/m_e=L=13 \cdot 1.61 \) coinciding with the similar ratio between masses of Z-boson and the constituent quark \( M_q \) were considered [9] in connection with the parity nonconservation as the result of a possible symmetry motivated properties of fermions (currents) composed the mass. It could mean that masses \( m_e \) and \( M_q=m_e(\alpha/2\pi)^{-1} \) might be considered together with the rational relation \( 3\cdot18\cdot16m_e \) for the large mass. Difference between these two large values accounts about \( m_e \). We need theoretical understanding of the observed tuning effect supplemented with CODATA relation. The general trend in QCD-development based on lattice-calculations should be combined with symmetry properties of common components.

2) Indirect confirmation of the tuning effect in particle masses was obtained from analysis of excitations of nuclei where tensor phrases connected with one-meson exchange play the dominant role. Development of nuclear model where nucleon structure would be directly included should take into account existing results from analysis of nuclear binding energies. Here in cluster effects with systems like \( ^4 \text{He} \) and \( ^6 \text{He} \) parameters of the grouping of difference of binding energies \( \Delta E_B \) clearly demonstrate the distinguished role of intervals connected with integer values of the electron mass \( m_e \) (for example, \( \Delta=9m_e \) etc.). In Table 2 values \( \Delta E_B=147.2 \text{ MeV}=32\Delta \) coinciding with \( \Delta M_\Delta, \Delta E_B=441 \text{ MeV close to } 3\Delta M_\Delta, \Delta E_B=409 \text{ MeV close to } M''_q \) are given in comments.

3) Observed additional shift in masses of strange hyperons \( \Sigma^0 \) and \( \Xi^- \) (possibly correlated with the strangeness, boxed in two bottom lines of Table 2) could be connected with transformations into the mass of the constituent quark. This effect could be important for understanding of the origin of the dark matter and possible estimation of the gravitation intercity considered in [24]).

4) Rational relations with the masses of heavy fermions \( (M_q, M''_q) \) were extended to the scalar boon masses [9,11] (see the fifth line in Table 2). We expect theoretical interpretation of observed empirical effects. Some relations in masses of heavy bosons and quarks were discussed in [9,11].
4. Conclusions

Combined analysis of particle mass spectrum and nuclear data, considered both as results of quark-structure hadronization process, shows a distinguished role of values of charge mass splitting of the nucleon, the pion and leptons. Rational relations in particle masses including the lepton ratio could be considered as the manifestation of symmetry properties of the common fundamental components directly connected with the electron rest mass and properties of the physical condensate. Presence of CODATA relation, if confirmed, demands drastic modification of property of SM-condensate. Frank Wilczek named the electron rest mass "theoretical puzzle". If the empirical CODATA relation will be confirmed and commonly accepted, it will demonstrate an important role of the electron mass and the QED in the SM-development.

References