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F.A.Gareev, G.S.Kazacha, Yu.L.Ratis

RESONANCES
IN MICRO- AND MACRO-PHYSICS

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1 Introduction

A comparatively small number of examples of the so called "crude" systems is known in physics whose the "gross" or "global" properties can be described by the simplest approaches while the accuracy of description deteriorates in the case of detailed elaboration. For the first time, such a behaviour of systems in classical mechanics was established by Poincare. The reduction of accuracy with increasing number model parameters has in detail been studied in the mathematical theory of polynomial approximation of tabulated functions. It is well-known that the beating starts at the interjunction points with increasing of polynomial order and the problem of correct interpolation of experimental data becomes in general not feasible. A classical example of correct deal with crude systems in physics is the theory of diffraction. The aim of this paper is the application of diffraction theory methods (together with the dimension analysis, the principles of similitude and automodelity, the methods of analogy) to study the gross structure of resonances in micro- and macrophysics.

2 General Results

We have developed (see review papers and references therein [1, 2]) the following general physical conception of resonances: the periodic motion and refraction of waves in the restricted region of space are responsible for creation of resonances in any resonating system. This conception is considered here for quantum mechanical systems, whose wave nature plays a decisive role in our approach. Within the R-matrix formalism we put at the boundary of this region a condition of radiation of physical particles which can be observed at large (asymptotic) distances and requires proper matching of the corresponding "external" wave functions with the "inner" part of the wave function of the considered system. This "inner" part can be constructed by using any reasonable existing model and must be projected at the boundary into physically observed states for matching with the "external" part.

The new quantization condition for asymptotic momenta of decay products of a resonance has been obtained in the framework of this conception. It results in the Balmer-like mass formula used in our study; its accuracy is surprisingly high and unusual for this branch of physics. Following the outlined conception we carried out the systematical investigation of the gross structure of spectra and mass distributions of all known hadronic resonances starting from light mesons and ending with bottomonium resonances. We have used a simplified version of the strength function method in this study.

Regular periodic structures in distributions of invariant masses of resonances are established. They have the period $\Delta m \approx$200 MeV in regions of the light unflavored ψ and Υ mesons and $\Delta m \approx$100 MeV for baryon resonances. Such a regular behaviour of the invariant mass of resonances is due to emergence of many-dimensional closed orbits where some states have regions of high amplitude as in the standard nuclear physics.

We found also that the charmonium and bottomonium systems might have "molecular type" states in three-meson (1^{--}) decay channels. They should play an essential role in understanding mass distributions of the ψ and Υ mesons. The main characteristic feature of these states is that the relative momentum in any their binary subsystems is very low: ~ 100 MeV/c. Therefore, this is a typical low energy phenomenon.

The asymptotic quantization condition can be obtained by applying the R-matrix[3] formalism to particle reactions[4]. According to these papers, one can assume that the resonating system having several two-particle decay channels is free at relative separation $r \geq r_0$ in the center of mass; hence, the following logarithmic radial derivative of the internal wave functions can be introduced:

$$\left(\frac{r}{u_{in}}\frac{du_{in}}{dr}\right)\Bigg|_{r=r_0-0} = f \equiv \frac{1}{R} \tag{1}$$

which should be calculated in the framework of some microscopic models, for example, modern quark models.

For simplicity let us consider only systems with one dominating open channel. As has been argued in the papers[1, 2], the decay of hadronic resonances can be considered in full analogy with open classical electrodynamic resonators[6], and the mathematical formalism given in this excellent monograph can be used. Therefore the boundary conditions for the emitted waves must be written as follows (*the conditions of radiation*):

$$\left(\frac{r}{h_l^{(1)}(Pr)}\frac{dh_l^{(1)}(Pr)}{dr}\right)\Bigg|_{r=r_0+0} = f \tag{2}$$

where $h_l^{(1)}(Pr) = \sqrt{\frac{\pi Pr}{2}}H^{(1)}_{l+\frac{1}{2}}(Pr)$ are the spherical Riccati-Hankel functions. We assumed that $f = 0$ for the well isolated resonances. Such surface waves localized at $r = r_0$ have exponentially small absorption (for $r < r_0$) in full analogy with the waves in the "whispering gallery". This phenomenon is very close to the phenomenon of the full refraction of the waves on the boundary separating two media with different refraction properties. Rainbow effects[5] and open resonators [6] can be considered as other examples of that kind. It means that nuclear and hadronic resonances have the same physical origin: emergence of well-localized surface waves with wavelengths of an order of r_0. Standing wave resonances provide a generally striking example, and it has long been recognized that the potential barrier resonances of scattering theory in all branches of physics, the transmission maxima of a Fabry-Perot interferometer, and the appearance of standing waves in waveguides, transmission lines, "whispering gallery", and musical instruments, open resonators in classical electrodynamics are all **manifestations of the same cavity-resonator principle.**

The new quantization condition for asymptotic momenta P of decay products of a resonance was obtained in the framework of this conception (see, for details ref.[7]):

$$Pr_0 = n + \gamma \tag{3}$$

here $Pr_0 = n + 1/2$ may be interpreted as a radial quantization and $Pr_0 = l$ may be considered as the well-known Bohr-Sommerfeld orbital quantization. It results in the Balmer-like mass formula used in our study

$$m_n(R) = \sqrt{m_1^2 + P^2} + \sqrt{m_2^2 + P^2} = \sqrt{m_1^2 + (\frac{n+\gamma}{r_0})^2} + \sqrt{m_2^2 + (\frac{n+\gamma}{r_0})^2} + \Delta m_n \tag{4}$$

where γ=0 or 1/2, R labels the resonance, while the indices 1 and 2 refer to the constituents 1 and 2 observed in the 2-particle decay of the resonance $R \to 1 + 2$, respectively.

Formula (4) describes the gross structure of the resonance spectrum with reasonable accuracy because of the relation $\Delta m_n < \Gamma$ that is valid in all investigated cases of strong decays $R \to 1 + 2$. The leading term of the mass formula describes only the "center of gravity" position of the corresponding multiplets, and thus the gross structure of the hadron and dibaryon resonances. The fine structure in each multiplet is determined by residual interactions and corresponding quantum numbers that are not contained in the approach[1, 2]. Therefore, the condition $\Delta m_n < \Gamma$ is to be considered as an empirical fact. Further, we neglected the contribution of Δm_n to the mass of resonances.

It is interesting to note that the eigenfrequences of the cavity-resonators having a cylindrical form with the radius R and with the length d have the same analytical form as a mass formula (4) for hadron resonances

$$\omega_n = \frac{\pi}{\sqrt{\mu\epsilon}}\sqrt{(\frac{x_{\nu j}}{\pi R})^2 + (\frac{n}{d})^2} \tag{4a}$$

where $x_{\nu j}$ are solutions of the equations

$$J_\nu(x_{\nu j}) = 0 \;\; or \;\; J'_\nu(x_{\nu j}) = 0 \tag{4b}$$

while $\nu \geq 0$ and j=1,2,3,.... The similitude of analytical forms for eigenfrequences of the cavity-resonators, invariant masses of hadron resonances and eigenvalue for hydrogen atoms is not accidental but represents the general law of the resonator principle. Note that in obtaining the mass formula (4) for hadron resonances we have used the same boundary conditions (2) as for the cavity-resonances (4b). It means that identity of the equation of motion and the boundary conditions in dimensionless representation leads to the identity of the eigenvalues and eigenfunctions in both the cases.

Let us consider the quantization of the hydrogen - like system. The kinetic energy of the system in the nonrelativistic limit can be obtained from (4):

$$T = m_n(R) - m_1 - m_2 = \sqrt{m_1^2 + P^2} + \sqrt{m_2^2 + P^2} - m_1 - m_2 = \frac{P^2}{2m_{12}} = \frac{l^2}{2m_{12}r^2} \tag{5}$$

where m_{12} is the reduced mass of the system and $l = Pr = m_{12}vr = n\hbar$ is the adiabatic invariant. The electrostatic force between the nucleus and the electron binds the hydrogen - like system. Equating the magnitude of the Coulomb force to the centrifugal acceleration (the classical equation of motion) we obtain

$$F = \frac{e^2}{r^2} = m_{12}a = \frac{m_{12}v^2}{r} = \frac{l^2}{m_{12}r^3} = \frac{n^2\hbar^2}{m_{12}r^3}. \tag{6}$$

The second and last forms may be solved to determine the allowed values for r, yielding

$$r = \frac{l^2}{m_{12}e^2} = \frac{n^2\hbar^2}{m_{12}e^2} = n^2 a_0 \tag{7}$$

where a_0 is the Bohr radius by the definition and is given by $a_0 = \hbar^2/m_{12}e^2$.

The total energy of the system is the sum of the kinetic and potential energy

$$E = T + V = \frac{m_{12}v^2}{2} - \frac{e^2}{r} = -\frac{e^2}{2r} = -\frac{e^2}{2n^2 a_0}. \quad (8)$$

Thus, one concludes that the mass formula (4) for resonances in the nonrelativistic limit is reduced to the Bohr result or to the Balmer formula.

It is easy to obtain useful relations by using (3) and (6) for $\gamma = 0$

$$\alpha = n\frac{\lambda_C}{\lambda_D} = n\frac{v}{c}, \quad \frac{r}{\lambda_D} = n \quad (9)$$

where λ_C and λ_D are the lengths of Compton and de Broglie waves, respectively. It means that the Compton and de Broglie waves play a fundamental role in the quantization of an electronic orbit in a hydrogen - like atom. Such a quantization is possible only if the ratio of the Compton wave length to the de Broglie wave length (v/c) is commensurable with the fine structure constant α. The ratio (9) can be interpreted as a definition of a similitude parameter for a hydrogen - like atom where r is the Bohr radius while $\lambda_D = \hbar/P = \hbar/mv$ is the de Broglie wave length.

The hypothesis of automodelity introduced in elementary particle physics in ref.[8] means that some physical observables are invariant in respect of the transformation of the momentum space $P_i \to \xi P_i$. Further development of the principles of similitude and automodelity was achieved in ref.[9] devoted to the relativistic theory of a dynamical system. Let us rewrite (4)

$$m_n(R) = \sqrt{m_1^2 + P^2} + \sqrt{m_2^2 + P^2} = \sqrt{\lambda(1)_C^{-2} + \lambda_D^{-2}} + \sqrt{\lambda(2)_C^{-2} + \lambda_D^{-2}}. \quad (10)$$

Here λ_D/λ_C and r_0/λ_C are the similitude parameters. The magnitudes of invariant masses of resonances at the given value of the similitude parameters remain fixed for different values of other parameters (at $r_0/\lambda_D \gg 1$). This is the automodelity of the second type. The invariant masses of resonances are changing as a homogencous function

$$m_n(R) \to \xi m_n(R) \quad (11)$$

under scale transformation $P \to \xi P, m_i \to \xi m_i$. This is the formulation of the principle of automodelity for hadronic resonances decaying into two particles with equal masses.

Subtracting $m_1 + m_2$ in (10), we obtain, under the conditions $m_1 > P$ and $m_2 > P$ (in the nonrelativistic limit), that the "excitation energy" E_n is

$$E_n(R) = \sqrt{m_1^2 + P^2} + \sqrt{m_2^2 + P^2} - m_1 - m_2 \approx \frac{P^2}{2m_{12}} = \frac{\lambda_C(m_{12})}{2\lambda_D^2} = \frac{1}{2m_{12}}\left(\frac{n+\gamma}{r_0}\right)^2 \quad (12)$$

where $m_{12} = m_1 m_2/(m_1 + m_2)$ is a reduced mass. This expression is completely the same as the well known formula for the rotational energy of a diatomic molecule [10] in the quasiclassical approach. Indeed, the quantity $m_{12}r_0$ plays the role of a moment of inertia of a molecule while $n + \gamma$ (if $\gamma = 1/2$) is a quasiclassical analog of the total angular momentum of the molecule.

If $m_1 < P$ and $m_2 < P$, then

$$E_n(R) \approx 2P = \frac{2}{\lambda_D} = 2\frac{n+\gamma}{r_0}. \quad (13)$$

This is in full analogy with the formula of vibrational energy of nuclei within the molecule.

Thus, the Lorenz-invariant mass formula (10) obtained from the resonance condition by using the Heisenberg uncertainty relation contains two limiting cases: 1) the rotational spectra and 2) the vibrational spectra. It is well-known in nuclear physics that pure elementary states (say, rotational, vibrational etc.) are model concepts in nuclei and are only approximately realized for the ground and low-lying parts of spectra in nuclei having large spectroscopic factors (branching ratios, see for details, ref. [11]). Such states played a decisive role in the development of modern nuclear physics. A similar situation could take place in the particle physics.

We assumed that resonances are the result of interplay between the "effective size" (r_0) and wavelength of the system (the automodelity of the second type by the definition). We have demonstrated[1, 2] that this hypothesis does not contradict the existing experimental data; it is useful for systematic analysis of hadronic resonances and for predictions of new resonances. We have established the similarity of spectra between different systems (see for details [1, 2, 12]) in nuclear, atomic, elementary particle physics and metallic clusters.

Let us return to the 2-particle decay of the hadron resonances $R \Rightarrow 1 + 2$ and introduce the evident notation $\lambda_C(m_i)$, $i = 1, 2$ where m_1 and m_2 are the masses of decay product particles of hadron resonances. We should like to generalize quantization conditions (3) as a working hypothesis to test from existing experimental data that the resonances are the result of the commensurability between the Compton and de Broglie wavelengths:

$$\lambda_C(m_i) = \frac{n}{j}\lambda_D \;\; or \;\; P = \frac{n}{j}m_i \quad (14)$$

where $n = 1, 2, 3, ...$ and $j = 2, 4$. Indeed the quantization conditions can be more rich or quite different from the assumed ones but they are very attractive due to the fact that they do not contain any free parameters. We will analyze here only strange particles for which experimental data are given with high accuracy.

We will use the same notations as Particle Data Group [13] and will analyze first $K_S^0(m = 497.672 \pm 0.031 \;\; MeV)$. This meson has two dominating decay channels

$$\pi^+\pi^-(68.61 \pm 0.28)\%, \;\; P_1 = 206 \;\; MeV/c, \quad (15a)$$

$$\pi^0\pi^0(31.39 \pm 0.28)\%, \;\; P_2 = 209 \;\; MeV/c. \quad (15b)$$

One can see that $P_1/m_{\pi^0} \approx P_2/m_{\pi^\pm} \approx 3/2$. So the quantum numbers n and j are equal to 3 and 2, respectively. It means that there are interesting commensurabilities between two subsystems: the ratio of the Compton wavelength from the first channel to the de Broglie one from the second channel is equal to the ratio of the Compton wavelength from the second channel to the de Broglie one from the first channel. The common system is created in a such way that the Compton and the de Broglie waves of subsystems or masses and relative motions of subsystems should be selfconsistent by the quantization conditions (14). This leads to the definite commensurable ratios of the eigenfrequencies from different channels and, as the result, to the quantum beat of the common amplitude of motion or in another words to the constructive interference between different partial amplitudes. This phenomenon is observed in all cases considered below.

The following is $\Lambda(m = 1115.684 \pm 0.006 \ \ MeV)$ decaying via two dominating channels:

$$\Lambda \Rightarrow p\pi^-(63.9 \pm 0.5)\%, \ \ P_1 = 100.58 \ \ MeV/c, \qquad (16a)$$

$$\Lambda \Rightarrow n\pi^0(35.89 \pm 0.5)\%, \ \ P_2 = 103.98 \ \ MeV/c. \qquad (16b)$$

In this case we have $P_1/m_{\pi^0} \approx P_2/m_{\pi^-} \approx 3/4$ and $P_2/m_p \approx P_1/m_n \approx 0.11$. The resonance conditions are fulfilled in a such way that the self-consistency of relative motion of pions in different channels occurs with the simultaneous self-consistency conditions of relative motion of neutrons and protons.

Two strange ($S = -2$) baryons Ξ^0 and Ξ^- have practically one decay channel:

$$\Xi^0(m = 1314.9 \pm 0.6 \ \ MeV) \Rightarrow \Lambda\pi^0(\approx 100)\%, \ \ P_1 = 135.2 \ \ MeV/c, \qquad (17a)$$

$$\Xi^-(m = 1321.32 \pm 0.13 \ \ MeV) \Rightarrow \Lambda\pi^-(\approx 100)\%, \ \ P_2 = 139 \ \ MeV/c. \qquad (17b)$$

The quantization conditions are $P_1/m_{\pi^0} \approx P_2/m_{\pi^-} \approx 1$. It seems that the beat phenomena are not observed in these two cases because these baryons have only one dominating decay channel. The decay channel contains the baryon Λ decaying as we have discussed above via two channels. It is easy to see that the commensurabilities are established between different subsystems again.

The strange baryon $\Omega^-(1672.45 \pm 0.29 \ \ MeV)$ has three remarkable decay channels:

$$\Omega^- \Rightarrow \Lambda K^-(67.8 \pm 0.7)\%, \ \ P_1 = 211.2 \ \ MeV/c, \qquad (18a)$$

$$\Omega^- \Rightarrow \Xi^0\pi^-(23.6 \pm 0.7)\%, \ \ P_2 = 293.7 \ \ MeV/c, \qquad (18b)$$

$$\Omega^- \Rightarrow \Xi^-\pi^0(8.6 \pm 0.4)\%, \ \ P_3 = 289.8 \ \ MeV/c. \qquad (18c)$$

The quantization conditions are in the case considered: $P_1/m_{\pi^-} \approx 3/2$ and $P_2/m_{\pi^0} \approx P_3/m_{\pi^-} \approx 2$. Further one can established very simple commensurable ratios between the Compton and the de Broglie wavelengths in different subsystems considered above.

The unique example is the decay of Σ^0 to $\Lambda\gamma(\approx 100\%)$ by electromagnetic interaction. The electromagnetic waves of γ-quantum come into the resonance beat with the de Broglie waves of relative motion in the $(p\pi^-)$ and $(n\pi^0)$ subsystems. While this example is extremely interesting and important for us, let us write the constituent subsystem of Σ in detail:

$$\Sigma^0 \Rightarrow \Lambda\gamma(\approx 100)\%, \ \ P_\gamma = 74.39 \ \ MeV/c, \qquad (19a)$$

$$\Lambda \Rightarrow p\pi^-(63.9 \pm 0.5)\%, \ \ P_1 = 100.58 \ \ MeV/c, \qquad (19b)$$

$$\Lambda \Rightarrow n\pi^0(35.89 \pm 0.5)\%, \ \ P_2 = 103.98 \ \ MeV/c. \qquad (19c)$$

We have

$$\frac{P_1}{m_{\pi^0}} \approx \frac{P_2}{m_{\pi^-}} \approx \frac{P_\gamma}{P_1} \approx \frac{3}{4}. \qquad (20)$$

Therefore we can imagine Σ^0 as a general composite system containing three subsystems $\Lambda\gamma$, $p\pi^-$ and $n\pi^0$ in self-consistent way that all wave ratios or quantization conditions are equal to the same number 3/4 **independent of the form of interaction in subsistems.** We can bring many examples, all of them supporting without exceptions this observation.

As a final result we have shown below (Tables 1 and 2) the invariant masses for the $(\pi^-\pi^+)$ and $(N\overline{K})$ resonances calculated using the formulae (10) and (14). Note, we have no free parameters. One can see a good description of existing experimental data. We hope that this is not accidental.

Table 1
The invariant masses (MeV) of $\pi^-\pi^+$ or $\pi^-\pi^-$ systems. Experimental data are taken from [13, 14]

n/j	$m(\pi^-\pi^+)_{theor}$	$m(\pi^-\pi^+)_{exp}$	$m(\pi^-\pi^-)_{exp}$
1/4	287		
1/2	310		313 ± 3
3/4	345	332 ± 3	340
1	388	388 ± 2	388 ± 5
5/4	438	435	441
3/2	492	$K_S^0(497.672 \pm 0.031)$	
7/4	549	$\eta(547.45 \pm 0.19)$	
2	608		
9/4	668	652 ± 2	640 ± 5
5/2	730	$\rho(769.9 \pm 0.8)$	
11/4	793	$\omega(781.9 \pm 0.12)$	
3	856		
13/4	921		
7/2	985	$f_0(980 \pm 10)$	
15/4	1050		
4	1115		
17/4	1181		
9/2	1246	$f_2(1275 \pm 5)$	
19/4	1312	$f_0(1000 - 1500)$	
5	1378		
21/4	1444	$\rho(1465 \pm 25)$	
11/2	1511		
23/4	1577		
6	1644		
25/4	1710	$f_J(1710)$	
13/2	1777		
27/4	1843	$f_2(1810)$	
7	1910	$X(1910)$	
29/4	1977	$X(1952 \pm 14)$	
15/2	2044	$f_4(2044 \pm 11)$	
31/4	2111		
8	2178	$\rho(2150)$	
33/4	2245	$\rho(2250)$	
17/2	2312	$f_4(2300)$	
35/4	2379	$\rho_5(2350)$	
9	2446		
37/4	2513	$f_6(2510 \pm 30)$	

Table 2
The invariant masses (MeV) of $N\overline{K}$ systems. Experimental data are taken from [13]

n/j	$m(N\overline{K})_{theor}$	$m(N\overline{K})_{exp}$	$m(N\overline{K})_{exp}$
1/4	1434		
1/2	1439		
3/4	1448		
1	1460		
5/4	1475		$\Sigma(1480)$
3/2	1493		
7/4	1515	$\Lambda(1519.5 \pm 1.0)D_{03}$	
2	1539		
9/4	1566		
5/2	1595	$\Lambda(1560-1700)P_{01}$	$\Sigma(1580)D_{13}$
11/4	1627		$\Sigma(1620)S_{11}$
3	1660	$\Lambda(1660-1680)S_{01}$	$\Sigma(1630-1690)P_{11}$
13/4	1696	$\Lambda(1685-1695)D_{03}$	$\Sigma(1665-1685)D_{13}$
			$\Sigma(1670)$
			$\Sigma(1690)$
7/2	1734	$\Lambda(1720-1850)S_{01}$	$\Sigma(1730-1800)S_{11}$
15/4	1773	$\Lambda(1750-1850)P_{01}$	$\Sigma(1770-1780)D_{15}$
			$\Sigma(1770)P_{11}$
4	1814	$\Lambda(1815-1825)F_{05}$	
		$\Lambda(1810-1830)D_{05}$	
17/4	1857	$\Lambda(1850-1910)P_{03}$	
			$\Sigma(1880)P_{11}$
9/2	1900		$\Sigma(1900-1935)F_{15}$
19/4	1946		$\Sigma(1900-1950)D_{13}$
5	1992	$\Lambda(2000)$	$\Sigma(2000)S_{11}$
21/4	2039	$\Lambda(2020)F_{07}$	$\Sigma(2025-2040)F_{17}$
11/2	2088	$\Lambda(2090-2110)G_{07}$	$\Sigma(2070)F_{15}$
			$\Sigma(2080)P_{13}$
23/4	2137	$\Lambda(2110-2140)F_{05}$	$\Sigma(2100)G_{17}$
6	2188		
25/4	2239		$\Sigma(2210-2280)$
13/2	2291	$\Lambda_c^+(2285.1 \pm 0.6)$	
27/4	2344	$\Lambda(2325)D_{03}$	
		$\Lambda(2340-2370)H_{09}$	
7	2398		
29/4	2452		$\Sigma(2455)$
15/2	2507		

Table 2 (continuation)

n/j	$m(N\overline{K})_{theor}$	$m(N\overline{K})_{exp}$	$m(N\overline{K})_{exp}$
31/4	2562	$\Lambda(2585)$	
8	2618		$\Sigma(2620)$
33/4	2674		
17/2	2731		
35/4	2788		
9	2846		
37/4	2904		
19/2	2963		
39/4	3022		$\Sigma(3000)$

We come to the fundamental approach to the elementary particle physics problem that has been suggested by Chew and Frautschi [15]: They assume that **all hadrons are equally fundamental. Each hadron is assumed to "be made up" of all others so that it is impossible to say which are elementary and which are composite.** Gell-Mann called this picture nuclear democracy. It is assumed that such model leads to self-consistency conditions and that they are such that the masses of all hadrons and their coupling constants are the unique result of the self-consistency requirement, or bootstrapping.

We can conclude that the decay of a resonance into two particles obeys the similitude principle according to which the Compton and de Broglie wavelengths have to be commensurable independently of a particular form of the interaction.

In conclusion, we would like to say that the Balmer-like mass formula (10) and quantization conditions (14) have been applied to systematic analysis of the gross structure of all known hadronic resonances. It means that these equations could be useful at least for prediction and estimation of the invariant masses of unknown resonances. We can say that the correspondence principle between old classical and new quantum theories plays an outstanding role in the interpretation of the results and this "correspondence" allows us to go even into fine details. We have demonstrated that the dimensional analysis, the principles of similitude and automodelity and the methods of analogy can put some bridge between the various branches of physics.

Therefore, we can conclude that the classical and quantum mechanical principles **are sufficient** for explanation of the gross properties of hadron resonances. That means that new quantum numbers, new particles or other exotics **are not necessary**.

3 Paradigms of Similarity and Conclusion

Shell structure, as we know from the periodic system of elements and from magic numbers in nuclei, has been extended [16, 17] to much larger systems (metal clusters, fullerenes, ^4He and ^3He clusters and quantum dots, or clusters as they are called). All these clusters have a common property: the mean path of their constituent particles is of the same order as the size of the system that creates conditions for quantization of the system and forming **the mean field** like in nuclei and atoms. The dimensions and energy scale in metal drops are quite different and the corresponding forces have a completely different origin. It seems very important that there are **many interesting analogies between atoms, nuclei and small drops of metal.** Thereby, the correspondence between closed orbits (standing waves) in a classical system with sufficient symmetry to allow ordered motion and quantum shell structure has become strikingly visible. The quantum beat in the form of supershells is a new and particularly interesting manifestation of this correspondence. Standing wave resonances provide a particularly surprising example, and it is well-known that the potential barrier resonances of the scattering theory in all branches of physics, the transmission maxima of Fabry - Perot - type interferometers and the appearance of standing waves in waveguides, transmission lines, and musical instruments, and open resonators in classical electrodynamics, acoustics, optics... are all manifestation of the same resonator principle. This type of resonances can be in any wave system if the corresponding wave lengths (de Broqlie wave lengths in quantum mechanics) are commensurable with geometrical (effective) size of the considering system. Therefore, such a standing wave resonance theory became a useful interdisciplinary science of general laws of resonances in micro- and macrophysics.

Recent developments in high energy physics clearly indicate that there is a deep connection (Regge trajectory) between spins (angular momentum) and masses of strongly interacting elementary particles, hadrons. Further, this connection has been extended by R.M.Muradian[18] for planets, stars, galaxies and their clusters. Muradian demonstrated that angular momenta of galaxies and other celestial objects could be predicted from Regge-like spin/mass relations containing only fundamental constants $\hbar$, c, G and m_p-the proton mass. He concluded that **the success of the application of the concepts of Regge trajectories in astrophysics witnessed unity and simplicity of nature in the range from particles up to clusters of galaxies.... On the other hand, these relations show that there is a deep interconnection between quantum mechanical and macroscopic gravitational phenomena.** We can here add that the observation of similarity of some gross properties of different micro- and macrosystems can be considered as the verification of the above-mentioned conclusion about **unity and simplicity of nature in the range from particles up to clusters of galaxies.**

This is a good example of developing sufficiently universal and unified methods of investigation of the phenomena from different domains of physics. So, theories of resonances and rotations became a fruitful interdisciplinary science of general laws of rotational processes in various branches of physics; particles, nuclei, atoms,... clusters of galaxies.

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