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F.A.Gareev, G.S.Kazacha, Yu.L.Ratis,
E.A.Strokovsky, R.G.Airapetyan

PHENOMENOLOGICAL INVESTIGATION OF BARYONIC RESONANCES

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We develop [1-4] 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. Within the R-matrix approach we put at the boundary of this region the condition of radiation of physical particles which can be observed at large (asymptotic) distances and require 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 P of decay products of a resonance was obtained in the framework of this conception: $Pr_0 = n+\gamma$; $Pr_0 = n+1/2$ can be interpreted as a radial quantization and $Pr_0 = l$ can be considered to be the well-known Bohr-Sommerfeld orbital quantization. It results in the Balmer-like mass formula used in our study:

$$m_n(R) = \sqrt{m_1^2 + P^2} + \sqrt{m_2^2 + P^2} = \sqrt{m_1^2 + (\frac{n+\gamma}{r_0})^2} + \sqrt{m_2^2 + (\frac{n+\gamma}{r_0})^2} + \Delta m_n, \quad (1)$$

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 $R \rightarrow 1 + 2$, respectively.

Formula (1) 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 $R \rightarrow 1+2$. 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 which are not contained in the approach [1,2]. Therefore, the condition $\Delta m_n < \Gamma$ is to be considered as an empirical fact.

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 [1-4]. The accuracy of the mass formula (1) is surprisingly high and unusual for this branch of physics. The invariant masses of unknown hadronic resonances were also predicted.

1. Quantization of the asymptotic momenta of resonances

The asymptotic quantization condition (1) can be obtained by applying the R-matrix [5] formalism to particle reactions [6]. 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:

$$\left(\frac{r}{u_{in}}\frac{du_{in}}{dr}\right)\Big|_{r=r_0-0} = f \equiv \frac{1}{R}, \tag{2}$$

which should be calculated in the framework of some modern quark models.

For simplicity, let us consider only the systems with one dominating open channel. As has been argued in the papers [1-4] the decay of hadronic resonances can be considered in a full analogy with open classical electrodynamic resonators [7] 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*):

$$\left(\frac{r}{h_l^{(1)}(Pr)}\frac{dh_l^{(1)}(Pr)}{dr}\right)\Big|_{r=r_0+0} = f, \tag{3}$$

where $h_l^{(1)}(Pr) = \sqrt{\frac{\pi Pr}{2}}H^{(1)}_{l+\frac12}(Pr)$ are the spherical Riccati-Hankel functions which are equal to $exp[i(Pr - \frac{l\pi}{2} - \frac{\pi}{4})]$ for $|Pr| \gg 1$. Using the well-known asymptotic expansions for the Hankel function and its derivative [8] one can get formula uniform for $|\arg Pr| \leq \pi - \epsilon, \epsilon > 0$

$$H^{(1)}_{l+\frac12}(Pr) \approx 2e^{-\frac{\pi i}{3}}\left(\frac{4\zeta}{1-z^2}\right)^{\frac14}\frac{Ai(\xi)}{(l+\frac12)^{\frac13}}, \quad [H^{(1)}_{l+\frac12}(Pr)]' \approx -4\frac{e^{\frac{\pi i}{3}}}{z}\left(\frac{1-z^2}{4\zeta}\right)^{\frac14}\frac{Ai'(\xi)}{(l+\frac12)^{\frac23}}, \tag{4}$$

where $z = Pr/(l+\frac12)$, $\xi = e^{\frac{2\pi i}{3}}(l+\frac12)^{\frac23}\zeta$, $\frac23\zeta^{\frac32} = \log\frac{1\pm\sqrt{1-z^2}}{z} - \sqrt{1-z^2}$. From the well known asymptotics for the Airy functions

$$Ai(\xi) \approx \frac12\pi^{-\frac12}\xi^{-\frac14}e^{-\frac23\xi^{\frac32}}\left(1+O(\xi^{-1})\right), \quad Ai'(\xi) \approx -\frac12\pi^{-\frac12}\xi^{\frac14}e^{-\frac23\xi^{\frac32}}\left(1+O(\xi^{-1})\right), \tag{5}$$

we get $Ai'(\xi)/Ai(\xi) \approx -\xi^{1/2}$. Therefore, we can obtain the following logarithmic derivative:

$$[H^{(1)}_{l+\frac12}(Pr)]'/H^{(1)}_{l+\frac12}(Pr)\Big|_{r=r_0+0} \approx -\sqrt{1-z^2}/z. \tag{6}$$

Note that $f = 0$ by the definition given in paper [5] for the well isolated resonances. So let us consider this case. For $|Pr_0| \gg 1$ we obtain

$$\frac{[H^{(1)}_{l+\frac12}(Pr)]'}{H^{(1)}_{l+\frac12}(Pr)}\Big|_{r=r_0+0} \approx \frac{1}{h_l^{(1)}(Pr)}\frac{dh_l^{(1)}(Pr)}{dr}\Big|_{r=r_0+0} = 0. \tag{7}$$

From (6)-(7) $Pr_0 \approx l+\frac12$ and we have to consider asymptotic expansions near the caustic surface. For $z = O(1)$ and $(l+\frac12) \gg 1$ we can use the following asymptotics

$$H^{(1)}_{l+\frac12}(Pr) \approx (Ai(-\tau) - iBi(-\tau))/\nu, \quad [H^{(1)}_{l+\frac12}(Pr)]' \approx -(Ai(-\tau) - iBi(-\tau))/\nu^2, \tag{8}$$

where $\tau = (Pr - l - 1/2)/\nu$, $\nu = ((l+1/2)/2)^{\frac13}$. Therefore

$$\frac{1}{h_l^{(1)}(Pr_0)}\frac{dh_l^{(1)}(Pr_0)}{dr} \approx \frac{1}{2r} - \frac{P}{\nu}\frac{Ai'(-\tau) - iBi'(-\tau)}{Ai(-\tau) - iBi(-\tau)}\Big|_{r=r_0+0}. \tag{9}$$

Besides $(l+\frac12) \gg 1$ and $z = O(1)$ we have

$$\frac{1}{h_l^{(1)}(Pr_0)}\frac{dh_l^{(1)}(Pr_0)}{dr} \approx -\frac{2\nu^2}{r}\frac{Ai'(-\tau) - iBi'(-\tau)}{Ai(-\tau) - iBi(-\tau)}\Big|_{r=r_0+0}. \tag{10}$$

Using the relations between the Airy functions we get

$$\frac{1}{h_l^{(1)}(Pr_0)}\frac{dh_l^{(1)}(Pr_0)}{dr} \approx -\frac{2\nu^2}{r}e^{\frac{2\pi i}{3}}\frac{Ai'(\tau e^{-\frac{\pi i}{3}})}{Ai(\tau e^{-\frac{\pi i}{3}})}\Big|_{r=r_0+0} \approx 0. \tag{11}$$

Therefore, we get an equation $Ai'(\tau e^{-\frac{\pi i}{3}}) = 0$. Thus we have

$$Pr_0 = l + \frac12 + e^{\frac{\pi i}{3}}\nu a'_s, \quad s = 1, 2, \ldots, \tag{12}$$

where a'_s are zeros of Ai', so a'_s are real negative numbers.

We assume for simplicity that $u_{in}(r) = j_l(P_0 r) = \sqrt{\frac{\pi P_0 r}{2}}J_{l+1/2}(P_0 r)$. Using the asymptotic expansion $J_{l+\frac12}(l+1/2+\tau\nu) \approx Ai(-\tau)/\nu$ and known estimate [9] for the Airy function $|Ai(x)| \leq (2\sqrt{\pi})^{-1}x^{-1/4}e^{-\frac23 x^{\frac32}}$, for $x > 0$ one can easy obtain that $j_l(P_0 r)$ exponentially decreases when $P_0 r$ decreases in $0 < P_0 r < l + 1/2$. So inside the ball $r \leq r_c$ ($r_c = (l+1/2)/P_0$ is the radius of the caustic surface) the wave function is concentrated inside the ring $l + 1/2 \leq P_0 r \leq P_0 r_0$, the width of which is approximately equal to $\nu|a'_s|$. It corresponds to the phenomenon of the "whispering gallery" waves (see also [7, 10]).

Finally, we can generalize the usual quantum-mechanical method [11] for calculations of the widths of hadronic resonances using the fact of the localization of the resonance wave functions near $r = r_0$

$$\Gamma = \frac{(Pr_0)^{2l+1}}{2Q} \mid V(r_0) \mid^2, \tag{13}$$

where Q is the relative kinetic energy for given pairs of the decay product and $V(r_0)$ is the interaction between the decay products at $r = r_0$.

2. Dibaryon resonances

The history of narrow dibaryon resonances is dramatic and controversial. The present status of the diproton resonances has recently been discussed by Yu.Troyan [12], B.Tatischeff [13] and E.Komarov [14] in their review papers where they analyzed experimental evidence of narrow dibaryon states in the region of invariant masses up to 2300 MeV. Despite the fact that there is disagreement between the results of different experimental groups, we have decided to use the experimental data coming from the Dubna collaboration [12]. It is well-known that the dibaryon resonances have anomalously narrow decay widths. This is one of the reasons why the searches for dibaryon states have been rather complicated. The explanation of such properties (narrow widths) of dibaryon resonances is a serious test for any theoretical models. A review of theoretical searches for dibaryon resonances was given in ref. [15] (see also recent publications [16, 17]). The existing theoretical models for calculations of the narrow decay widths Γ have a qualitative character (see for references [15]). The last publication [18] available for us gives $\Gamma \leq 40$ MeV. The values for the dibaryon mass calculated in the modern theoretical models are systematically higher than the experimental values, at least by three hundred MeV.

Let us consider the dibaryon resonances decaying into two or three particles in the framework of our approach. The parameter $r_0 = 0.86$ fm is fixed in all calculations presented below and in refs. [1–4] as well.

Below we present (see Table 1) the results of our calculations of the invariant masses (using formula (1)) and the widths of narrow dibaryon resonances(using formula (13)), see also refs. [2, 3, 4]. The widths were calculated with the Hulthen potential

$$V(r) = V_0 \frac{exp(-\mu r)}{1 - exp(-\mu r)}, \qquad (14)$$

where $\mu = 1.1 fm^{-1}$ and V_0=-49 MeV for the diproton resonances. One can see very exciting correlations between the calculated results and experimental data. So we are able to describe narrow widths of the dibaryon resonances by the usual quantum - mechanical methods. We can conclude that the observed narrow dibaryon resonances display the rotational-like structure in the mass distribution as in the usual nuclear physics.

It is worthwhile to mention here that the results of rather a large number of experiments can be interpreted as indications of broad dibaryon resonances at masses $\sqrt{s} \approx 2.4$, 2.7 and 2.9 GeV (for details see review [19]).

Table 1. Spectrum of the invariant masses and widths for the diproton resonances

	$l+\gamma$	$\frac{1}{2}$	1	$1+\frac{1}{2}$	2	$2+\frac{1}{2}$	3	$3+\frac{1}{2}$	4	$4+\frac{1}{2}$	5
M	theory	1890	1932	1998	2088	2198	2326	2468	2623	2788	2961
	exp [12]	1886	1937	1999	2087	2172					
Γ	theory	4	9	12	17	22					
	exp [12]	4 ± 1	7 ± 2	9 ± 4	12 ± 7	7 ± 3					

The question is now what we can say about wide resonances ? Let us consider the P-wave pion-nucleon scattering to discuss the latter question. The leading long-range attractive interaction in the channel P_{33} for the $\pi^+ p$-scattering corresponds to the crossing Born diagram (see details in [20]) and the corresponding amplitude can be calculated in the first Born approximation. We can introduce an effective potential and easily determine the long-range part of the πN interaction using the correspondence principle [3]

$$V(r) = -f^2_{\pi NN} \frac{m + m_\pi}{m m_\pi} (\frac{m}{m_\pi})^2 \frac{P^2_\pi}{\sqrt{s}} \frac{e^{-\alpha r}}{r}, \qquad (15)$$

where $\alpha = \sqrt{2mE_\pi}; E_\pi = \sqrt{P^2_\pi + m^2_\pi}; P_\pi = \frac{\lambda^{1/2}(s, m^2, m^2_\pi)}{2\sqrt{s}}$; $\lambda(x,y,z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2zx$. Here $m(m_\pi)$ is the nucleon (pion) mass, $P_\pi(E_\pi)$ is the pion momentum (energy) in the center of mass system, s is the squared invariant mass of the resonance and $f_{\pi NN}$ is the coupling constant of the πNN interaction. The calculated widths for the Δ-isobar and $N*(1440)$ resonance are given in Table 2, and one can see again a good description of widths for the wide resonances.

Note that the presented approach is able to describe without free parameters both narrow dibaryon resonances and wide resonances (Δ-isobar and $N^*(1440)$ resonance). The explanation of this phenomenon is very simple. The NN interaction responsible for the formation of low lying dibaryon resonances is determined by the exchange of pion or pions far from the mass surface. The weakness of interaction causes the narrowness of the corresponding resonances according to (13). The virtual pion is on the mass-shell in the case of the Δ or $N^*(1440)$ resonance and the corresponding potential has the largest magnitude. As a result these resonances have large widths $\approx$ 100 MeV.

Table 2. Masses and widths of πN-resonances (MeV)

resonance	$\Delta(1232)$		$N^*(1440)$	
$n+\gamma$	1		1+1/2	
	M	Γ	M	Γ
theory	1234	100	1370	260
exp [21]	1230-1234	115-125	1430-1470	250-450

The existence of the new resonance S_{11} with the mass $m_{N^*(1115)} \approx 1105 - 1125$ MeV, width $\Gamma < 100$ MeV and the quantum numbers $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ was predicted in [2].

It allows us to understand in a rather natural way the well-known fact that the transition with $\Delta T = 3/2$ in the decay of the $\Lambda(1115)$-hyperon is hindered in comparison with the transition $\Delta(T = 1/2)$. Indeed, the branching ratio for $\Lambda \to \pi^- + p$ and $\Lambda \to \pi^0 + n$ is equal to 2, which is typical of the decay of particles having $T = 1/2$. Therefore, it is natural to consider the decay of the Λ-hyperon in analogy with the hindered α-decay and vector meson dominance phenomena. The Λ-hyperon remains to be a strange particle until the constituent s-quark does not decay into the d- or u-quark due to the weak interaction. As a result of the weak interaction, the enhancement of the state with $T = 1/2$ can be interpreted as a display of the $N^*(1115)$-resonance created as a product of the decay of the Λ-hyperon. Further this N^*-resonance decays into channels $\pi^- p$ and $\pi^0 n$. So the dynamical origin of the famous ΔI=1/2 rule can be related with the strong final state interaction between decayed particles resulting in the $N^*(1115)$ resonance (authors of ref. [22] claimed that the observed resonances in the subsystems $p\pi^-$ and $\bar{p}\pi^+$ at 1115 "were not the result of the weak decay")

The invariant mass spectrum for the proton+$N^*(1115)$ resonances is given in Table 3. Note that the cross section of the pionic double charge exchange on ^{54}Fe exhibits a pronounced resonance behaviour at low energies [23] that was interpreted as an indication of a resonance in the πNN subsystem with $J^P = 0^-$, I=0 and the invariant mass 2065 MeV. An indication of a narrow structure at a mass close to 2055 MeV has been observed in the $pp\pi^-$-system [24]. The predicted low energy $p+N^*(1115)$ resonance has the same quantum numbers and can be considered as a candidate for the one observed in [23]. Therefore, the resonance $pp\pi^-$ with the mass 2065 and the quantum numbers $J^P = 0^-, I = 0$ can decay in the this case via the channels $pp\pi^- \to p + N^*(1115) \to p + p + \pi^-$. Another possible interpretation of this resonance is given in ref. [23]: two nucleons in the (πNN) subsystem have to be in a relative s-state with spin S=0. It was argued that this resonance (peak) was probably a manifestation of a dibaryon resonance d' with quantum numbers $J^P = 0^-, I = 0$ and mass 2065 MeV. This dibaryon resonance cannot decay into the NN channel due to the Pauli principle. The authors of ref. [23] claimed that these pecularities could explain the very small width of the considered dibaryon.

The invariant mass spectrum of the resonances decaying via the mode $p(p\pi)_S(1115)$ and Δp is given in Table 3.

The relative contributions [27] of various decay channels of the resonance in $pp\pi^+$ at 2607 MeV were measured: $pp\pi^+ \to \Delta p$ 14±7% and $pp\pi^+ \to (pp)_{2090}\pi^+$ 38±9%. The calculated masses for these decay channels are equal to 2575 and 2618 MeV, respectively. They are close to the experimental values.

Table 3. Spectrum of the invariant mass for the $pp\pi$ resonances decaying into the channels $p(p\pi)_S(1115)$

	$n+\gamma$	$\frac{1}{2}$	1	$1+\frac{1}{2}$	2	$2+\frac{1}{2}$	3	$3+\frac{1}{2}$	4
theory	2067	2106	2167	2251	2354	2474	2609	2756	2913
exp	2065 [23]		2160 [25]		2390 [26]	2511 [27]	2607 [27]	2716 [27]	
	2055 [24]		2140 [28]						

Spectrum of the invariant mass for the $pp\pi$ resonances decaying into the $p\Delta$ channels.

	$n+\gamma$	$\frac{1}{2}$	1	$1+\frac{1}{2}$	2	$2+\frac{1}{2}$	3	$3+\frac{1}{2}$	4	$4+\frac{1}{2}$
theory	2184	2221	2280	2360	2459	2575	2705	2848	3001	3164
exp	2164 [29]				2511 [27]	2607 [27]	2716 [27]			

3. Exotic baryonic resonances

In the naive quark model mesons are bound states of valence quark-antiquark pairs (M=$q\bar{q}$) and baryons are bound states of three valence quarks (B=qqq). These states are grouped into SU(3) supermultiplets (see details in [30]). A fast progress of the hadronic spectroscopy gives some indications of the existence of states with a more complicated structure, multiquark states (M=$qq\bar{q}\bar{q}$, B=$qqqq\bar{q}$), glueballs (M=gg, ggg) and hybrids (M=$q\bar{q}g$, B=qqqg). These new hadrons are now called exotic hadrons. These new states do not fit the SU(3) systematics of $q\bar{q}$ mesons and qqq baryons.

The simplest possible multiquarks are the **diquonia** $q^2\bar{q}^2$ introduced by Jaffe [31]. Even for such simple systems, the lattice and "QCD inspired model" (for references see ref. [32]) calculations are not accurate enough to give convincing results. Even recent calculations [32] are restricted only by l=0 $q^2\bar{q}^2$. Since the systematic research is performed, we want to present some results of our calculations and to make some predictions for new candidates and also to compare them with the existing experimental data that are available for us. It is worthwhile to note that multiparticle decays can be considered as a chain of binary decays: the 2-particle decay of a "primary" resonance into two clusters, further these clusters again decay into 2-particles and so on. This is consistent with the observation that multiparticle production processes proceed mainly through the intermediate resonances production. Therefore, the multiparticle decay can be treated as a tree-like phenomenon where the intermediate resonances play an essential role. It indicates a way how to use the suggested mass formula (1) in studies of multiparticle decays of resonances. **Our approach gives a simplest way to estimate the invariant masses of resonances decaying into multiparticles.**

It is well known that the baryon resonances do not decay into the channel $N\omega^0$ (see [33]) but a resonance structure has been observed in the $p\pi^+\pi^-\pi^0$ system with the mass 1780±40 MeV and the width 250±80 MeV in the ω^0 mass region of the $\pi^+\pi^-\pi^0$

system. This resonance was explained as a manifestation of the cryptoexotic structure $uuds\bar{s}$. We suggest treating the structure of the $N^*(1780)$ resonance as a molecular state of the system $p\omega^0$ (see Table 4). The N^* resonance with the mass 1700 MeV and width 150 MeV was published in ref. [34]. It decays into the channels $p\eta$, $\Delta 2\pi$ and $p3\pi$.

Table 4. Spectrum of the invariant mass for the $p\pi^+\pi^-\pi^0 \equiv p\omega^0$ resonances

	$n+\gamma$	1/2	1	1+1/2	2	2+1/2	3	3+1/2	4
M	Theory	1736	1781	1854	1951	2069	2205	2355	2517
	Exp	1700 [34]	1780 [33]						

The present status of the narrow exotic baryonic resonances is presented by L.G. Landsberg in the review paper [30]. Therefore, we would like to give the results of our calculations with brief comments only.

Table 5. Spectrum of the invariant mass for the $\Sigma(1385)K$ resonances

	$n+\gamma$	1/2	1	1+1/2	2	2+1/2	3	3+1/2	4
M	Theory	1897	1948	2029	2133	2255	2392	2542	2702
	Exp		1956 [35]	2050 [36]					

The resonance in the system $\Sigma(1385)K$ with the invariant mass 1956^{+8}_{-6} MeV and width 27±15 MeV was the first observed in [35] and was interpreted as an $N_\phi(1960)$ baryon. The structure of this resonance was interpreted in ref. [35] as a candidate for the exotic baryon resonance with hidden strangeness ($udds\bar{s}$). The resonance with mass 2050±6 MeV and width ≈120 MeV in ref. [36] was considered as a new baryon with hidden strangeness. These conclusions must be considered as preliminary and need to be confirmed with further measurements with increased statistics.

Some resonance-like structure with the mass 2170 MeV and $\Gamma \approx 110$ MeV was observed in experiment [36] for the $p\phi$ and $\Lambda(1520)K^+$ systems. Both these experimental spectra have a similar character and our model describes this fact extremely well. The $p\phi$ and $\Lambda(1520)K^+$ systems have resonances at the mass 2160 and 2162 MeV, respectively (see Table 6), and as the result the sum of two resonances displays a sharp peak in the experimental spectra. The interpretation of these resonances is quite unclear from the existing models.

Table 6. Spectrum of the invariant mass for the $\Lambda(1520)K$ resonances

	$n+\gamma$	1/2	1	1+1/2	2	2+1/2	3	3+1/2	4
M	Theory	2031	2081	2160	2261	2380	2514	2660	2816
	Exp			2170 [36]					

Spectrum of the invariant mass for the ϕp resonances

	$n+\gamma$	1/2	1	1+1/2	2	2+1/2	3	3+1/2	4
M	Theory	1972	2011	2075	2162	2269	2393	2532	2683
	Exp				2170 [36]				

V.M. Karnaukhov et al. [37] observed the resonance-like structure in the $K^0_sK^+p\pi^-\pi^-$ system with the mass 3521±3 MeV and width 6^{+21}_{-6} MeV. The statistical significance of the observed structure is 10 s.d. This structure has zero strangeness and was designated as R(3520). The R(3520) baryon has a considerably higher mass than the threshold for the system $K^0_sK^+p\pi^-\pi^-$ and was interpreted in ref. [37] as a candidate for a pentaquark state. We can interpret it as a manifestation of a quasimolecular resonance for a many particle system $K^0_sK^+p\pi^-\pi^-$. There are many combinations that can be tested in the experiment in principle. For example combinations $(((\overline{K}^0p)_{1520}K^+)_{2031}(\pi^-\pi^-)_{361})$ with the estimated mass 3532 MeV or $(((\overline{K}^0\pi^-)_{892}K^+)_{1406}p)_{2446}\pi^-$ with the estimated mass 3539 MeV can be considered as candidates for this structure. Therefore, some of the quasimolecular states can overlap at the mass 3520 MeV and display a sharp peak as a result of the coherent enhancement amplitudes for such states.

Most of the experimental data on the strange baryonic sector were obtained by using the propane bubble chamber technique (Dubna Collaboration, see ref. [38] and references therein). Calculations in the framework of our model describe these data surprisingly well.

It was reported (for references see paper [22]) on the possible existence of a narrow baryonium (denoted by M_S for the systems $\Lambda\bar{p}\pi$, $\Lambda\bar{p}\pi\pi$ with S=-1 and by $\overline{M}_S$ for the systems $\overline{\Lambda}p\pi$, $\overline{\Lambda}p\pi\pi$ with S=+1) with the mass $3060 \pm 5(st.) \pm 20(syst.)$ MeV and width not greater than 35 ± 5 MeV. This result confirms the WA-62 data [39]. The invariant masses of resonances in our model are independent of strangeness. Therefore, for example, the systems $\Lambda\bar{p}\pi$, $\overline{\Lambda}p\pi$ and $\Lambda p\pi$ must have almost the same invariant masses. The predicted mass for these systems in our model is equal to 3030 MeV (see Table 7). It is close to the value reported in ref. [22]: $3060 \pm 5(st.) \pm 20(syst.)$ MeV.

The narrow baryonium M_Φ [22] was observed in the mass spectra $\Lambda\bar{p}K\pi$, $\overline{\Lambda}pK\pi$, $\Lambda\bar{p}\overline{K}$, $\overline{\Lambda}pK$, $p\bar{p}K\overline{K}$ with the mass $3260 \pm 5(st.) \pm 20(syst.)$ MeV and width $\Gamma \leq 35 \pm 5$ MeV. There are many possible quasimolecular resonances with the closest masses. For example: the $(\Lambda\bar{p})_{2166}\overline{K}$ state with the mass 3251 MeV, the $((p\bar{p})_{1890}K)_{2448}\overline{K}$ state with the mass 3270 MeV and the $((\overline{\Lambda}p)_{2067}K)_{2624}\pi$ state with the mass 3275 MeV. All such quasimolecular states in subsystems can have resonances with almost the same mass and this fact is responsible for the pronounced peak of the considered resonance. It is of great interest to study multibaryonic resonances. We gave some examples in this direction. Finally, we would like to mention the observation [41] of a resonance in a three proton system with the mass 3.27±0.02 GeV and width 0.07±0.04 GeV. The estimated mass in our model is equal to 3288 MeV for the $((pp)_{1890}p)$ quasimolecuar state.

Table 7. The resonances decaying into the channels $p\Lambda$, $(p\Lambda)_{2067}\pi$, $((p\Lambda)_{2067}\pi)_{2250}\pi$, $(((p\Lambda)_{2067}\pi)_{2250}\pi)_{2434}\pi$

	decay $p\Lambda$		decay $p\Lambda\pi$		decay $p\Lambda\pi\pi$		decay $p\Lambda\pi\pi\pi$	
$n+\gamma$	exp	theor	exp	theor	exp	theor	exp	theor
1/2	2095 [38]	2067		2250		2434		2617
1	2129 [38]	2105		2348		2530		2713
1+1/2	2181 [38]	2166	2495 [38]	2466		2647		2829
2	2224 [38]	2250		2595		2775		2956
	2263 [38]							
2+1/2	2357 [38]	2353		2734		2912	3100 [39]	3090
3	2500 [21]*	2473		2879	3060 [22]	3054		3230
3+1/2		2608	3060 [22]	3031		3203		3376
4		2755		3188		3357		3528

*Note that the mass 2500 MeV was taken from [21] for the $p\bar{\Lambda}$ system but our approach does not distinguish between particles and anti-particles.

Table 8. The resonances decaying into the channels $\Lambda\Lambda$, $(p\Lambda)_{2067}\Lambda$, $\Lambda(\pi\pi)_{361}$, Σp

	decay $\Lambda\Lambda$		decay $p\Lambda\Lambda$		decay $\Lambda\pi\pi$		decay Σp	
$n+\gamma$	exp	theor	exp	theor	exp	theor	exp	theor
1/2		2243		3192		1500		2148
1	2290 [40]	2278		3219		1566	2173 [38]	2185
1+1/2	2365 [38]	2335		3263	1704 [38]	1666	2218 [38]	2245
2		2412		3323		1789		2326
2+1/2		2508		3393		1931	2408 [38]	2426
							2384 [38]	
3		2621		3489	2071 [38]	2087		2544
3+1/2		2748	3568 [38]	3591		2253		2675
4		2887		3705		2428		2819
4+1/2		3038		3829	2604 [38]	2611		2974
5		3198		3962		2800		3138

Now there are experimental data [42] on the production of quasi-stationary states for a many nucleon (clusters of nucleons containing up to 6 nucleons) systems. Therefore, the study of the properties of clusters as multiparticle resonances is a wide and interesting domain of physics.

Finally, we can say that mass distributions of resonances and their widths can be understood in full analogy with the modern nuclear structure concepts especially with the theory of α-decay.

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Гареев Ф.А. и др. E2-95-9

Феноменологическое исследование барионных резонансов

В рамках R-матричного формализма предложен новый подход к описанию резонансных явлений в ядерной физике и физике элементарных частиц. Получены условия квантования асимптотического импульса P продуктов двухчастичного распада резонанса. Предложена приближенная формула для оценки парциальных ширин. Сделан вывод о том, что для объяснения малости ширин так называемых узких дибарионных резонансов не требуется введения дополнительных гипотез. Ширина резонанса определяется глубиной потенциала взаимодействия продуктов распада на некотором характерном относительном расстоянии (примерно 0,9 фм).

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Phenomenological Investigation of Baryonic Resonances

The approach to resonance phenomena in nuclear and particle physics is formulated within the R-matrix formalism. The new quantization condition for asymptotic momenta P of decay products of a resonance was obtained as well as approximate formulae for estimation of partial widths. We concluded that in order to explain small widths of the so-called narrow dibaryon resonances one has no need to introduce new hypothesis. The strength of the interaction potential between the decay products at some characteristic distance (about of 0.9 fm) is one of the main component responsible for the width of the resonance.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

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