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Baryon Resonances in a Quark Model

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An interestiong classification of meson resonances has recently been given by Iizuka[1)] and Sinanoğlu[2)] on the basis of a quark-antiquark system. Mesons are placed on Regge trajectories of this system.[2)] A straightforward extension of their idea to baryon resonances would lead to too many levels, however. In this Letter we consider a specific three-quark model of low-lying baryon resonances, which necessitates a few unobserved ones. Quarks are assumed to obey para-Fermi statistics.

We suppose that baryons consist of a qq pair (or a diquark) and another quark moving around it with orbital angular momentum L. In order that for $L=0$ our model can produce the $1/2^+$ octet and the $3/2^+$ decuplet, which belong to the "56" of $SU(6)$, the qq pair must be in a ${}^3S_1$ state and form an $SU(3)$ sextet. Unwanted levels of a $1/2^+$ decuplet and a $3/2^+$ octet can be excluded if the three quarks are required to be totally symmetric in accordance with $SU(6)$. We regard $SU(6)$ as an approximate dynamical symmetry respected by states with $L=0$.

In the hypothetical limit of no exchange potentials between a quark and a diquark, we would obtain an octet Regge trajectory with the $1/2^+$ octet as its starting resonance (see Table I). We find $J=L+1/2$ and $P=(-1)^L=(-1)^{J-1/2}$ for resonances lying on it. In reality exchange potentials cause signature splitting, which explains the existence of the two octet trajectories, $\alpha(1/2^+, 5/2^+, \cdots)$ and $\gamma(3/2^-, 7/2^- \cdots)$. Experimentally the splitting does not appear to be so large as to invalidate the concept of exchange degeneracy, which was originally introduced by Arnold[3)] for meson resonances. There can be another octet trajectory with $J=L-1/2$. We have no firm experimental evidence in favor of its existence, however.

Table I. Possible Regge trajectories in the limit of exchange degeneracy. The asterisk indicates trajectories with maximum J.

$SU(3)$ \ L	0	1	2	3	…	J
8	$1/2^+$	$3/2^-$	$5/2^+$	$7/2^-$	…	$*L+1/2$
		$1/2^-$	$3/2^+$	$5/2^-$	…	$L-1/2$
10	$3/2^+$	$5/2^-$	$7/2^+$	$9/2^-$	…	$*L+3/2$
		$3/2^-$	$5/2^+$	$7/2^-$	…	$L+1/2$
		$1/2^-$	$3/2^+$	$5/2^-$	…	$L-1/2$
			$1/2^+$	$3/2^-$	…	$L-3/2$

In a similar way we get a decuplet Regge trajectory with the $3/2^+$ decuplet as its starting member (see Table I). Resonances lying on it have $J=L+3/2$ and $P=(-1)^L=(-1)^{J+1/2}$. Signature splitting gives rise to the well-known $\delta(3/2^+, 7/2^+, \cdots)$ decuplet and a $\beta(5/2^-, 9/2^-, \cdots)$ decuplet. There can be three more decuplet trajectories with $J=L+1/2$, $L-1/2$ and $L-3/2$. Again we have no experimental evidence suggesting their existence. There seems to exist a rather strong spin-orbit coupling which makes states with maximum J the lightest. We summarize our classification of the baryon resonances in Table II, in which we list only the states with maximum J.

Table II. Classification of baryon resonances.

$SU(3)$ \ L	0	1	2	3	$\cdots$	trajectory name
8	$1/2^+$		$5/2^+$		$\cdots$	α
		$3/2^-$		$7/2^-$	$\cdots$	γ
10	$3/2^+$		$7/2^+$		$\cdots$	δ
		$(5/2^-)$		$(9/2^-)$	$\cdots$	β

The existence of a β decuplet, which is essentially based on the assumption of exchange degeneracy, seems desirable from the standpoint of this Letter. In particular, we expect a $5/2^-$ decuplet lying between the $3/2^+$ and $7/2^+$ decuplets. At present we know only one resonance with $J^P=5/2^-$; that is $Y^*(1765)$,[4] which we denote by Σ_β. It is encouraging for the decuplet assignment of Σ_β that Λ_β has not been observed in this energy region. We cannot get good agreement with experiment on the decay branching ratios of Σ_β if it belongs to a decuplet. It is not clear whether this is a serious obstacle or not, because the disagreement cannot be removed even if Σ_β is assigned to an octet.

The assignment of Σ_β to a decuplet requires the existence of a Δ_β. Its mass may be estimated to be around 1616 MeV in terms of the relation,

$$\Sigma_\beta(1765)-\Delta_\beta\approx\Sigma_\delta(1385)-\Delta_\delta(1236).$$

This value corresponds to the energy region in which the so-called shoulder effect has been observed in the π^+-p total cross section. Some experiments[5] in this energy region suggest the importance of $D_{5/2}$, with which we are now concerned, although there appears to be no single state which is very prominent. It will be noted that the decay modes of Δ_β should be mainly inelastic.

As for Ξ_β, the only known candidate is $\Xi^*(1933)$, which is usually assigned as a member of the $5/2^+$ octet. So far as the mass relation is concerned, the $5/2^-$ assignment seems to be preferable. Anyhow, we require another $\Xi^*(J=5/2)$ in the neighborhood of $\Xi^*(1933)$ as well as Ω_β with a mass around 2050 MeV.

If $\Sigma_\beta(1765)$ with $J^P=5/2^-$ lies on a Regge trajectory, why can we not find a Σ_β with $J^P=1/2^-$? It seems difficult to answer this question from a purely S-matrix theoretical point of view. In our model, however, J^P cannot take the value $1/2^-$ for states with maximum J, and hence $\Sigma_\beta(1765)$ with $J^P=5/2^-$ should be the starting resonance of the β trajectory on which it lies. In this connection we note that $Y_0^*(1405)$, which belongs to unitary singlet and is likely to have $J^P=1/2^-$, cannot be included in the present scheme. We take the viewpoint that it is an S-wave bound state of $\bar{K}$ and N just as the deuteron is one of p and n.

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2) O. Sinanoğlu, Phys. Rev. Letters **16** (1966), 207; Phys. Rev. **145** (1966), 1205.
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4) R. Armenteros et al., Phys. Letters **19** (1965), 338.
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5) J. A. Helland et al., Phys. Rev. **134** (1964), B1062.
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