



Experimental Tests for Exotics in the Baryon-
Antibaryon System*

HARRY J. LIPKIN[†]

Argonne National Laboratory
Argonne, Illinois 60439

and

National Accelerator Laboratory
P. O. Box 500, Batavia, Illinois 60510

*Work performed under the auspices of the U. S. Atomic Energy Commission

[†]On leave from Weizmann Institute of Science, Rehovoth, Israel.



Experimental Tests for Exotics in the Baryon-
Antibaryon System^{*}

Harry J. Lipkin[†]

Argonne National Laboratory, Argonne, Illinois 60439

and

National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510

A new FESR based on dominance of ρ and ω exchange for high-energy odd-signature amplitudes gives quantitative estimates for production of doubly-charged exotic meson resonances via Δ exchange in nucleon-antinucleon and pion-nucleon reactions. Absence of exotic resonances with predicted cross sections would indicate serious disagreement with two-component duality. Observation of non-resonant exotic states could test for a "third component."

The search for exotics has made little progress since the first suggestion that resonances with exotic quantum numbers need not be coupled to the common two-body meson-meson and meson-baryon systems.¹ Theoretical suggestions about where to look for such resonances¹⁻⁴ have led to searches, which so far have been inconclusive. The failure to find exotics is not proof for their absence.

Strong theoretical arguments for the existence of some kind of exotic contribution in baryon-antibaryon scattering have been given by finite-energy sum rules. These require an exotic s-channel contribution²⁻⁴ to amplitudes that have no diffractive component at high energy—e.g., charge-exchange amplitudes.⁵ Whether this exotic component is resonant or nonresonant is still unknown. Three possible answers to this "baryon-antibaryon catastrophe" have been suggested.

1. Exotic resonances.² These are required in the "two-component-duality description,"⁶ which has nonresonant background appearing in the imaginary parts of only those amplitudes that have a diffractive component at high energies. This description is supported by experimental data in nonexotic cases, in which it has been shown that the imaginary part of a nondiffractive amplitude can be approximated very well with resonances alone.⁷

2. A nonresonant "third component." This might be associated with annihilation in baryon-antibaryon scattering.³ The success of the ω -universality relation,⁸ which links nucleon-antinucleon and kaon-nucleon scattering in the Regge region, implies that such a third component cannot exhibit anomalous behavior at high energies, but must combine with the resonances at low energies to satisfy a FESR together with the conventional Regge component at high energies.

3. The null solution.⁹ The finite-energy sum rule is trivially satisfied if all nondiffractive baryon-antibaryon amplitudes involving decuplet baryons vanish.

So far there has been no experimental test of these alternatives. Experimental investigation of baryon-antibaryon exotics has been difficult. The accessible \overline{NN} system has no exotic channels; and while exotics have been proved to exist⁵ in the $\Delta\overline{\Delta}$ system, it is not directly accessible to experiment. Between these two extremes is the $\overline{N\Delta}$ system which has an exotic $I = 2$ channel accessible to experimental study in reactions involving Δ exchange on nucleon targets. However, one consistent solution of the finite-energy sum rules for this system has a vanishing exotic amplitude, and this possibility has thus far prevented any conclusive quantitative investigation of exotics in this system.¹⁰

The purpose of this letter is to show how a new type of superconvergence sum rule¹¹ enables one to test the above three alternatives by means of a quantitative experimental search for exotics. This sum rule is very nearly model-independent and does not assume SU(3); and by use of it in the discussion below, the cross sections for the production of exotic states by Δ exchange are shown to be comparable to cross sections for the production of nonexotic resonances by Δ exchange in related reactions accessible to experiment. The sum rule is based on the experimental observation that odd-signature-exchange amplitudes are dominated at high energies by exchange of the ρ and ω trajectories. A finite-energy sum rule can therefore be written for a linear combination of amplitudes with contributions from both

ρ and ω exchange, with coefficients adjusted to make the ρ and ω contributions cancel on the right-hand side. Thus for the $N\Delta$ system, the amplitudes $A(N\Delta)$ and $A(\overline{N}\Delta)$ in different charge states are related by the sum rule

$$\int_0^N \nu^n \{ [A(\overline{p}\Delta^{++}) - A(p\Delta^{++})](1 - \tau) - [A(\overline{p}\Delta^-) - A(p\Delta^-)](1 + \tau) \} d\nu = 0, \quad (1)$$

where the parameter τ is chosen to make the right-hand side vanish as a result of the cancellation of the ρ and ω exchange contributions.

If the ρ and ω trajectories are degenerate, as they seem to be to a good approximation, then τ is given by the ratio of the products of Regge residues. That is,

$$\tau = \beta_{\rho NN} \overline{\beta}_{\rho \Delta \overline{\Delta}} / \beta_{\omega NN} \overline{\beta}_{\omega \Delta \overline{\Delta}}. \quad (2)$$

In this case τ is independent of N , and N can be taken to be infinite to give a superconvergence sum rule. However, the treatment below does not require exact degeneracy of the ρ and ω trajectories. In the absence of degeneracy τ depends upon N and is not given by Eq. (2). However, for a given fixed value of N , the value of τ is well defined by N and the Regge parameters of the ρ and ω trajectories.

It is conventional to assume that the nondiffractive component of the imaginary part of an amplitude can be approximated by resonances⁶ in such sum rules. Since the diffractive contribution cancels in the difference between the $\overline{N}\Delta$ and $N\Delta$ amplitudes, we obtain

$$\int_0^N A^R (\bar{p} \Delta^-)_{\nu}{}^n d\nu = \frac{1-\tau}{1+\tau} \int_0^N A^R (\bar{p} \Delta^{++})_{\nu}{}^n d\nu, \quad (3)$$

where A^R denotes the contribution of resonances to the amplitude and we make the conventional assumption that there are no dibaryon resonances.

Equation (3) relates an exotic contribution on the left-hand side to a nonexotic contribution on the right-hand side with a coefficient of order unity. The amplitudes on the two sides of the relation (3) can be measured experimentally in the pairs of reactions

$$\bar{p} + p \rightarrow \pi^+ + M^-, \quad (4a)$$

$$p + n \rightarrow \pi^+ + X^{--}, \quad (4b)$$

where M denotes a negatively charged meson resonance, X^{--} denotes a doubly-charged exotic state. Both reactions are assumed to go via Δ exchange when the outgoing pion is in the direction of the incident antiproton with small momentum transfer. In this kinematic region, the cross sections for these two reactions should satisfy the relation (3). The Δ exchange contributions shown in Fig. 1 differ only in the lower vertex which is described by the relation (3), since the $(\Delta \bar{p} \pi)$ vertex is the same for the two reactions. Present experimental data on reaction (4a) show it to have a non-negligible cross section. Reaction (4b) should therefore be examined to determine the nature of X^{--} . If exotic resonances provide the answer to the baryon-antibaryon

catastrophe² they should appear in this reaction. They are not expected to be coupled to two pions^{1, 2} and should be observed as 3π or 4π states, depending on G parity.¹³ The most plausible decay modes are

$$X^{--} \rightarrow \pi^{-} + \pi^{-} + \pi^{0}, \quad (5a)$$

$$X^{--} \rightarrow \pi^{-} + \pi^{-} + \pi^{+} + \pi^{-}, \quad (5b)$$

$$X^{--} \rightarrow K^{-} + K^{0} + \pi^{-}. \quad (5c)$$

If no exotic resonances are found, the nature of the exotic contribution that satisfies the sum rule (3) can be investigated by examining the forward inclusive π^{+} production in the reactions (4). The inclusive cross sections as a function of the missing mass should show peaks associated with quasi-two-body final states on a background due to multiparticle final states. The sum rule (3) for the reactions (4a) and (4b) requires that the cross sections integrated over missing mass should be of the same order of magnitude. Two-component duality together with the sum rule (3) require the quasi-two-body portion of the cross sections integrated over missing mass also to be of the same order of magnitude. Thus if appreciable production of resonances in quasi-two-body reactions is found for the case (4a), while no exotic resonances are found in the exotic case (4b), there is a clear experimental proof of the violation of two-component duality. If the nonresonant cross section for the reaction (4b) is comparable to the cross section for (4a), this might be evidence for a third component

to satisfy the sum rule. However, if the nonresonant background (final states that are not quasi-two-body) is large for the reaction (4a), the third component in the reaction (4b) would be masked by this nonresonant component that is associated with diffraction at high energy. This component corresponds to the Pomeron-exchange contribution in the diagrams of Fig. 2, which shows the reactions (4) in the triple-Regge region.

The Pomeron-exchange contribution can be eliminated by considering also the reactions

$$p + p \rightarrow \pi^- + (BB)^{+++} \quad (4c)$$

$$p + n \rightarrow \pi^- + (BB)^{++}, \quad (4d)$$

where (BB) denotes a dibaryon ($B = 2$) state. In the triple Regge region, the reactions (4c) and (4d) have the same $N\pi\Delta$ vertex as the reactions (4a) and (4b), while the remaining portion of the diagram describes ΔN scattering, rather than $\bar{\Delta}N$. These reactions thus all have the same Pomeron contribution. The usual exchange-degeneracy arguments require the nondiffractive component to vanish in baryon-baryon amplitudes.⁶ Thus the reaction (4d) should be purely diffractive and should give a direct measure of the Pomeron component in the reaction (4b). The difference between the two cross sections then gives a measure of the nondiffractive part of the reaction (4b), and this part should satisfy the sum rule (3).

If exchange-degeneracy arguments break down for the exotic baryon-baryon case, there could be a non-Pomeron contribution to the reaction (4d). In this case the four reactions (4a), (4b), (4c), and (4d) can be used in the original sum rule (1) rather than in the simplified sum rule (3). These reactions provide all the four amplitudes appearing in the sum rule, and their investigation can determine which of the exotic reactions (6b), (6d), and (6e) give contributions to the FESR to balance the production of nonexotic meson resonances M^- in the reaction (4a).

Another set of reactions with similar Δ exchanges are obtainable by line reversal from the reactions (4).

$$\pi^- + p \rightarrow p + M^-, \quad (6a)$$

$$\pi^- + n \rightarrow p + X^{--}, \quad (6b)$$

$$\pi^+ + p \rightarrow \bar{p} + (BB)^{+++}, \quad (6c)$$

$$\pi^+ + n \rightarrow \bar{p} + (BB)^{++}, \quad (6d)$$

$$\pi^+ + n \rightarrow n + M^+, \quad (6e)$$

$$\pi^+ + p \rightarrow n + X^{++}, \quad (6f)$$

where the outgoing baryon is in the direction of the incident pion with a small momentum transfer. Reactions (6e) and (6f) are charge-symmetry mirrors of (6a) and (6b) and may be more convenient for experimental comparisons. Reactions (6a), (6f), and (6c) all have proton targets and can be used to test the sum rule (3) under the

assumption that the baryon-baryon amplitude is purely diffractive. The reactions (6c), (6d), (6e), and (6f) are in principle all measurable in the same π^+d experiment, and can be used in the sum rule (1).

The above argument breaks down if $\tau = 1$ and the sum rule (1) is trivially satisfied with no exotic contributions. However, it seems reasonable to overlook this pathological value. By symmetry arguments, the ratio of the nucleon residues appearing in Eq. (2) has been predicted to be considerably smaller than unity, and this is checked by experimental observation. Thus $\tau = 1$ implies both that $g_{\rho\Delta\bar{\Delta}}/g_{\omega\Delta\bar{\Delta}} \gg 1$ and that this ratio has a peculiar accidental value. Although there are no experimental measurements of these couplings, this accident appears highly unlikely. Furthermore, symmetry schemes and quark models predict^{14, 15} that $g_{\rho\Delta\bar{\Delta}} = g_{\omega\Delta\bar{\Delta}}$, and this value is also required to avoid exotics in the $K\Delta$ system¹⁵ for which a sum rule analogous to (1) can be written with the ratio $g_{\rho\Delta\bar{\Delta}}/g_{\omega\Delta\bar{\Delta}}$ replacing the parameter τ . The pathological value $\tau = 1$ eliminates the difficulty with exotics in the $\bar{N}\Delta$ sum rule (1), but the analogous $K\Delta$ sum rule then requires the existence of doubly charged Y^* resonances coupled to the $K\Delta$ system, while still keeping the baryon-antibaryon exotics in the $\Delta\bar{\Delta}$ system. Although there is no conclusive proof against this possibility, it does seem rather far fetched.

In any case, experimental investigation of the reactions (4) and (6) should give new insight into the question of what exotic

contributions to these reactions enable the baryon-antibaryon system to satisfy the finite-energy sum rules.

It is a pleasure to thank G. F. Chew for stimulating discussions and for calling Ref. 12 to my attention. Discussions with M. Jacob, S. Meshkov, and J. L. Rosner are also gratefully acknowledged.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

†On leave from Weizmann Institute of Science, Rehovoth, Israel.

¹D. Horn, H. J. Lipkin, and S. Meshkov, Phys. Rev. Lett. 17, 1200 (1966).

²J. L. Rosner, Phys. Rev. Lett. 21, 68 (1968); P. G. O. Freund, R. Waltz, and J. L. Rosner, Nucl. Phys. B13, 237 (1969).

³H. J. Lipkin, Nucl. Phys. B9, 349 (1969).

⁴M. Jacob and J. Weyers, Nuovo Cimento 69A, 521 (1970); 70A, 285 (E) (1970).

⁵H. J. Lipkin, Phys. Lett. 32B, 301 (1970).

⁶M. Jacob, in Proceedings of the Lund International Conference on Elementary Particles, edited by G. Van Dardel (Lund 1969), p. 125; M. Kugler, Acta Phys. Austriaca, Supplementum VII, p. 443, (1970).

⁷H. Harari and Y. Zarmi, Phys. Rev. 187, 2230 (1969).

⁸H. J. Lipkin, Phys. Rev. D5, 776 (1972), V. Barger, to be published.

⁹M. Kugler, Phys. Lett. 32B, 107 (1970).

¹⁰T. Buhl, D. Cline, and R. Terrell, Nucl. Phys. B37, 421 (1972), have looked for exotics in this system. M. Jacob and J. Weyers (Ref. 4) have attempted to give a quantitative estimate of exotic production but have used additional assumptions of SU(3) symmetry, factorization of Regge trajectories, and the absence of exotics in meson-meson and meson-baryon scattering.

¹¹H. J. Lipkin, Phys. Lett. 35B, 450 (1971) and to be published.

¹²J. Finkelstein, Stanford University Preprint ITP-407. The finite-energy sum rule he used for ρN scattering was obtained by neglecting the isovector exchange amplitude. This corresponds to the case $\tau = 0$ in the sum rule (1).

¹³Equal contributions from even-G and odd-G exotics are required by the FESR for the reaction $\bar{N}\Delta \rightarrow N\bar{\Delta}$ in the $I = 2$ state. The vanishing of the sum rule, required by the exotic dibaryon exchange, is achieved by having equal and opposite contributions from even- and odd-G resonances.

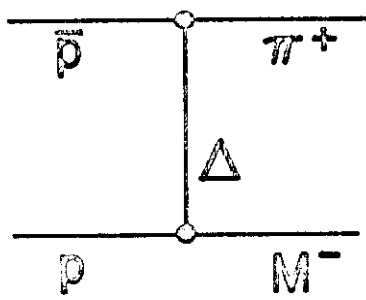
¹⁴H. J. Lipkin and V. Rabl, Nucl. Phys. B27, 464 (1971).

¹⁵C. Rebbi, R. Slansky, and J. L. Rosner, Phys. Rev. 188, 2367
(1969).

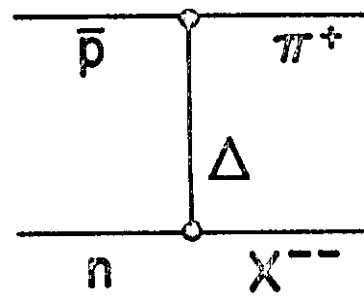
FIGURE CAPTIONS

Fig. 1. Contribution of Δ exchange to reactions (4a) and (4b).

Fig. 2. Reactions (4) in the triple-Regge region.



(a)



(b)

Figure 1

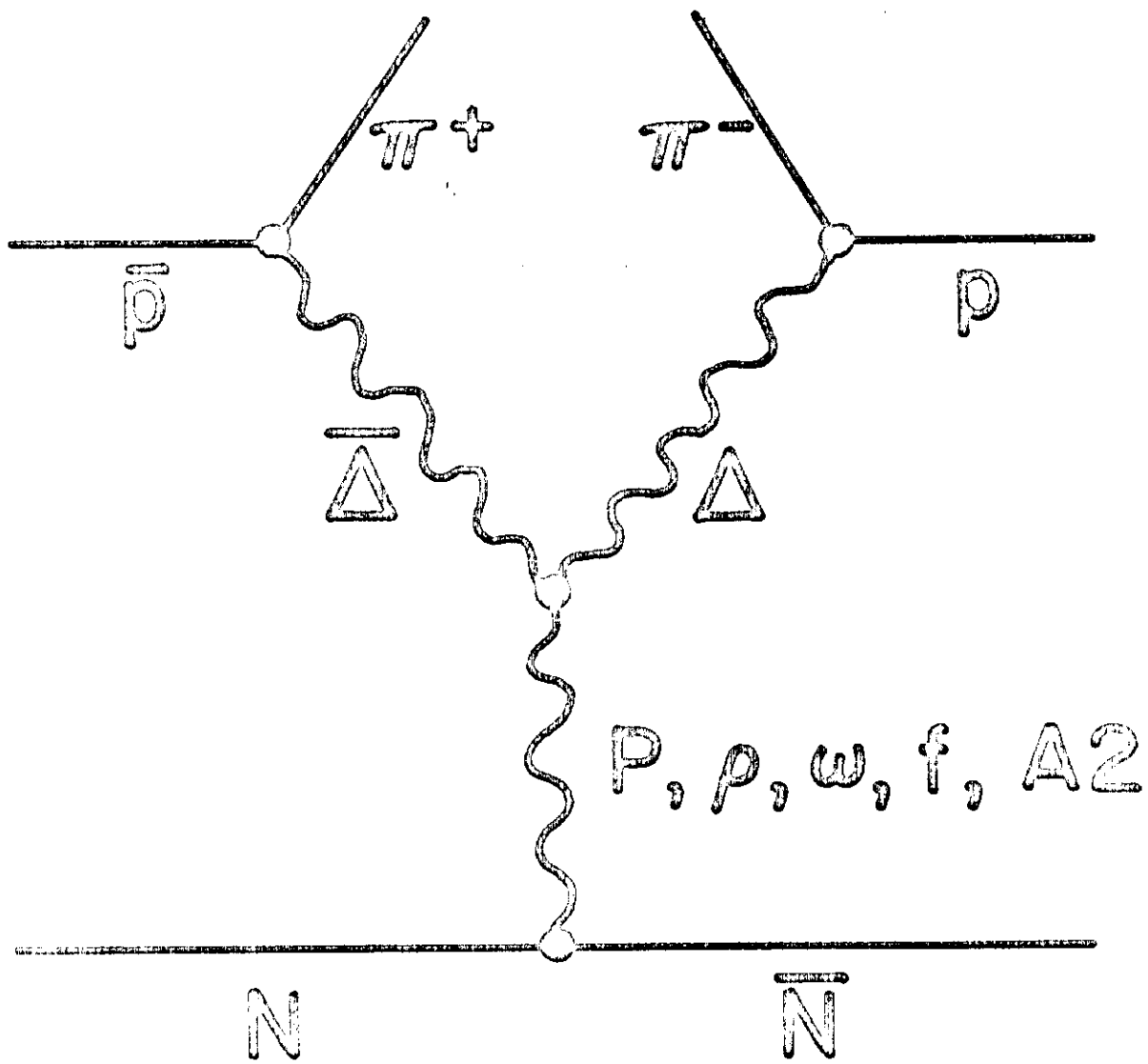


Figure 2