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Gerson Goldhaber

August 9, 1967

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It is suggested that the peculiar variation in structure observed in the $K\pi\pi$ mass enhancement in the region 1.1 to 1.4 BeV as a function of incident momentum could be due primarily to interference between two resonances with the same J^P values. On the basis of the quark model it is appealing to associate these with the 3P_1 and 1P_1 $q\bar{q}$ systems, in which $J^P = 1^+$ for each. It is also suggested that the $A_1(1080)$ may constitute a real resonance, which, however, is obscured at some momenta by interference effects in this case with coherent background.

A very large enhancement in the $K\pi\pi$ system has been observed in a series of experiments both in K^+p and K^-p reactions for incident momenta from 2.6 to 13 BeV/c.¹⁻¹² This enhancement lies roughly in the mass region 1.1 to 1.5 GeV. Most experiments agree that the enhancement consists of at least two phenomena:

(a) The $K^*(1420)$ in the $K\pi\pi$ decay mode. This has been clearly resolved from the main enhancement in a number of experiments.^{8,9} As noted by Morrison,¹³ the cross section for this resonance in the K^-p reaction, which can be most readily ascertained from its $K\pi$ decay mode, decreases with p_{lab} , the incident laboratory momentum as

$$\sigma \sim p_{\text{lab}}^{-n} \quad \text{with } n = 2.2 \pm 0.2.$$

(b) A large enhancement, roughly in the mass region 1.1 to 1.4 BeV, recently called the "Q enhancement." The cross section for the Q enhancement does not vary much with incident momentum.¹⁴ The structure of the Q enhancement, however, has shown distinct, statistically significant differences for various incident momenta. It is the latter feature we wish to discuss here.

Considerations in terms of the quark model

The quark model¹⁵ has been successful in providing a framework for the well-known boson octets and singlets (or nonets). We can associate the $J^{PC} = 0^{-+}$, 1^{--} and 2^{++} bosons (namely the π , ρ , and A_2 nonets) with the 1S_0 , 3S_1 , and 3P_2 states of the $q\bar{q}$ system. For a $q\bar{q}$ system--considered here as a fermion-antifermion pair--P and C are given by $P = (-1)^{L+1}$ and $C = (-1)^{L+S}$. Here L is the angular momentum in the $q\bar{q}$ system and S the total $q\bar{q}$ spin.

In view of this success it is tempting to take the next step and try to identify bosons belonging to the other $L = 1$ states; 3P_0 , 3P_1 , and 1P_1 , having $J^{PC} = 0^{++}$, 1^{++} , and 1^{+-} . If we consider the K^* 's belonging to the four $L = 1$ nonets we find the following simplest allowed decay modes:

$$\begin{aligned} K^*(^3P_0) &\rightarrow K\pi, \\ K^*(^3P_1) &\rightarrow K^*(890)\pi \text{ or } K\rho \rightarrow K\pi\pi, \\ K^*(^1P_1) &\rightarrow K^*(890)\pi \text{ or } K\rho \rightarrow K\pi\pi, \\ K^*(^3P_2) &\rightarrow K\pi \text{ and } K^*(890)\pi \text{ or } K\rho \rightarrow K\pi\pi, \end{aligned}$$

where the last one is already identified as $K^*(^3P_2) \equiv K^*(1420)$.

Aside from $K^*(1420)$ we thus expect two more distinct K^* 's in the $K\pi\pi$ mass spectrum, both with $J^P = 1^+$. In connection with these a new and so far unique situation can arise. The two isovector mesons corresponding to

the 3P_1 and 1P_1 states¹⁶--presumably the $A_1(1080)$ and $B(1220)$ --are eigenstates of G (and their neutral components are eigenstates of C), and thus form distinct entities with $J^{PC} = 1^{++}$ and 1^{+-} respectively. The same also holds for the four possible isoscalars belonging to these two nonets. On the other hand, the K^* 's are not eigenstates of C , in fact the values of C here can be considered to refer to the two different $q\bar{q}$ ¹⁷ structures 3P_1 and 1P_1 . Let us define for brevity the K^* 's in the two nonets as $K^*(^3P_1) \equiv K_{A_1}$ and $K^*(^1P_1) \equiv K_B$. The possibility thus exists that the two K^* 's will mix so that the two physical particles, say K_I and K_{II} , may each be a mixture of the 3P_1 and 1P_1 states.¹⁸ These are related by

$$\begin{aligned} K_I &= K_{A_1} \cos \beta + K_B \sin \beta, \\ K_{II} &= -K_{A_1} \sin \beta + K_B \cos \beta, \end{aligned}$$

where β is the mixing angle between the quark spin singlet and triplet states.^{19,20}

Interference in the mass distributions

In addition to, and aside from, the possibility of particle mixing, if we are dealing with two adjacent states with the same J^P values, we may expect interference effects in the $K\pi\pi$ mass distributions.²¹ In general a mass distribution corresponds to an average over all decay angular distributions. Thus K^* 's with different J^P values, such as a 1^+K^* and the $2^+K^*(1420)$, will not give any interference effect in the $K\pi\pi$ mass distributions and the amplitudes will add incoherently. However, two K^* 's each with $J^P = 1^+$ will add coherently.

In what follows we consider a very simple model corresponding to the coherent addition of two resonances together with a third added incoherently.

Here we express each resonance by a Breit-Wigner amplitude and allow an arbitrary phase between two of them.

Let $B_k = \frac{1}{2} \Gamma_k / (E_k - E - i \frac{1}{2} \Gamma_k)$, with $k = 1, 2$, and 3 , correspond to the Breit-Wigner amplitude for each of these resonances; then the resulting mass distribution can be expressed as

$$\frac{d\sigma}{dM} \propto (|a_1 B_1 + B_2 e^{i\phi}|^2 + |a_3 B_3|^2) P$$

where E_k and Γ_k are the resonant masses and widths respectively, ϕ is a relative phase angle, and a_1 and a_3 relative amplitudes, all of which must be determined from experiment, and P is a phase-space factor. As an illustration, this expression was evaluated for $E_1 = 1250$ MeV, $\Gamma_1 = 50$ MeV, $E_2 = 1320$ MeV, $\Gamma_2 = 80$ MeV, $E_3 = 1420$ MeV, $\Gamma_3 = 90$ MeV, $a_1 = 1$, $a_3 = 1/\sqrt{2}$, and values of ϕ from 0 to $9\pi/5$ in ten equal steps. Figure 1 shows the resulting mass distributions. As may be noted, aside from the $K^*(1420)$ peak, the shape of the mass distribution in the Q enhancement can appear as a single peak at E_2 for $\phi \approx 6\pi/5$, a broad flat-topped peak centered at $\approx (E_1 + E_2)/2$ for $\phi \approx \pi$, indications of a single peak at E_1 for $\phi \approx 3\pi/5$, and two separate peaks at $\approx E_1$ and $\approx E_2$ for $\phi \approx \pi/5$ or lower. Thus in a variation of ϕ by about π radians the mass distribution can go through an entire gamut of shapes, some of which are very similar to the experimental $K^+ p$ data in the 4.6- to 9-BeV/c region.

In addition to the resonances discussed above there is little doubt that a considerable amount of background amplitude must be present as well. To the extent that this may be due to pomeron exchange it will also lead primarily to $J^P = 1^+$ amplitudes. A more realistic model must therefore include both a coherent and an incoherent background term, where the phase of the former can also vary relative to the two Breit-Wigner amplitudes.

We have not yet attempted to actually "fit" the available experimental data with this model, primarily because observation of the splitting between the "1250-MeV" and "1360-MeV" peaks discussed in the preceding letter for the 9-BeV/c data is strongly dependent on the experimental resolution, a quantity which is not known to us for much of the data in the literature. Furthermore, for a significant fit, considerably higher statistical accuracy will be required at many of the momenta studied.

It is clear, however, that a fit to the experimental data can be obtained, although if we include a coherent and an incoherent background term such a fit will not be unique without more detailed information than given by the mass distributions alone. A possible approximate solution for the K^+p interaction which ignores background interference effects would be $\phi \approx 6\pi/5$ radians at 4.6 BeV and either $\phi \approx 2\pi/5$ to $\pi/5$ radians or $\phi \approx 8\pi/5$ radians at 9 BeV/c. Thus $\Delta\phi = \phi(4.6) - \phi(9.0) \approx \pi$ radians or $\approx -2\pi/5$ radians. These assignments would then imply that in the first case at some intervening momenta the Q enhancement should appear as a single wide peak centered at ≈ 1285 MeV, while not so in the second case.

The above cases should be considered as examples only and do not represent an exhaustive search for solutions.

The significance of ϕ

Finally, if we accept this model, one must ask about the physical significance of ϕ . In this connection it is appropriate to remember one further experimental fact. The K^-p data at various momenta¹⁰⁻¹² have shown very clearly that the production of the Q peak disappears completely when charge exchange occurs at the nucleon vertex, such as in the reaction $K^-p \rightarrow K^{*-}\pi^+n$. This feature suggests that Q production does not occur for isovector exchange, leaving the possibility of pomeron and isoscalar exchange. If the two 1^+K^* 's are indeed mixed, we may then have amplitudes for the two physical K^* 's which consist, for example, of the sum and difference of A_P and A_M with appropriate coefficients. Here A_P is the amplitude for pomeron exchange and A_M is the

amplitude for exchange of one or more isoscalar mesons: ω , f_0 , or P' . If this is the case one amplitude, A_P , remains essentially constant while the other, A_M , may decrease rapidly with increasing incident momentum. The phase angle ϕ would then reflect this relative change in the two amplitudes.

One other feature which follows is that the alignment of the two K^* 's may also change with incident momentum as the relative strength of A_P and A_M change. Thus at low momentum we would expect an alignment characteristic of a considerable component due to meson exchange which, as the momentum increases, should go over to an alignment characteristic of pomeron exchange.

There is experimental evidence for a change in the alignment of the structure in the Q enhancement. Thus in the K^+p experiment⁸ at 4.6 BeV/c it was observed that the $K^*(1320)$ peak corresponds primarily to a $K_{in} K_{out}$ scattering angle α in the $K^*(890)$ c.m. system in the equatorial region, i.e., $|\cos \alpha| < 0.8$. The same result can be noted for the peak at 1270 MeV observed in a K^-p experiment at 3.8 BeV/c by Field et al.²² These results are thus indicative of an isotropic or $\sin^2 \alpha$ distribution for the respective peaks observed in the Q enhancement at these momenta. On the other hand, in the K^+p experiment⁵ at 9 BeV/c, both peaks observed in the Q enhancement occur both in the equatorial and the polar regions in $\cos \alpha$. This corresponds to a $\cos^2 \alpha$ distribution, which, as pointed out in the preceding letter, is indicative of 1^+ resonance formation by pomeron exchange.

Consideration on the A_1 resonance

We have also briefly considered the possibility that similar arguments could be responsible for the variation observed in the intensity of the A_1 peak with incident momentum.²³ In this case we have to assume the presence of a coherent background interfering with a 1^+ resonance, viz.,

$$\frac{d\sigma}{dM} \propto (|G + B_1 e^{i\phi}|^2 + |B_2|^2)P$$

where G represents a uniform background term. We have performed the numerical evaluation of this expression with $E_1 = 1080$ MeV, $\Gamma_1 = 130$ MeV, and $G = 1$, as well as $E_2 = 1300$ MeV and $\Gamma_2 = 80$ MeV, to represent the incoherent effects due to the A_2 . On this model for $\phi = 0$ there is an " A_1 peak" at 1080 MeV. The peak wanders down to 960 MeV for $\phi \approx 3\pi/5$, and disappears completely for $\phi \approx 4\pi/5$. It then reappears at 1140 MeV for $\phi \approx \pi$, and moves back to 1080 MeV as $\phi \rightarrow 2\pi$. If this is indeed the correct interpretation of the A_1 behavior with suitable variation of ϕ as a function of incident momentum, we must still ask about the origin of G . The background $\pi\rho$ production is presumably due to pomeron exchange (or Deck effect), which should lead to a predominantly $J^P = 1^+$ state, just as in the $K^*\pi$ enhancement above.²⁴ The reason for the variation of ϕ with incident momentum is however not clear in this case.

I would like to thank G. F. Chew and H. Harari for helpful discussions on this subject.

FOOTNOTES AND REFERENCES

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

1. For earlier references on this subject see Gerson Goldhaber, Rapporteur Talk, Boson Resonances in Proceedings of the XIIIth International Conference on High Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, 1967), p. 103.
2. Jerome H. Friedman and Ronald R. Ross, Bull. Am. Phys. Soc. 12, 539 (1967).
3. C.-Y. Chien, P. M. Dauber, D. J. Mellema, P. Schreiner, W. E. Slater, D. H. Stork, and H. K. Ticho, Bull. Am. Phys. Soc. 12, 506 (1967).
4. R. Zdanis, Bull. Am. Phys. Soc. 12, 567 (1967).
5. G. Goldhaber, A. Firestone, and B. C. Shen, Phys. Rev. Letters (preceding letter).
6. J. Berlinghieri, M. S. Farber, T. Ferbel, B. Forman, A. C. Melissinos, T. Yamanonchi, and H. Yuta, Phys. Rev. Letters 18, 1087 (1967).
7. T. Ludlam, J. Kim, J. Lach, J. Sandweiss, and H. Taft, Bull. Am. Phys. Soc. 12, 540 (1967).
8. B. C. Shen, I. Butterworth, C. Fu, G. Goldhaber, S. Goldhaber, and G. H. Trilling, Phys. Rev. Letters 17, 726 (1966).
9. Y. Goldschmidt-Clermont, R. Jongejans, and V. Henri (CERN), personal communication on the data from the Bruxelles-CERN collaboration.
10. J. Bartsch et al. [Aachen-Berlin-CERN-Imperial College (London)-Vienna Collaboration], Phys. Letters 22, 357 (1966).
11. T.P. Wangler, M. Derrick, L. G. Hyman, J. G. Loken, F. Schweingruber, R. G. Ammar, R. E. P. Davis, W. Kropac, J. Mott, and J. Park, Bull. Am. Phys. Soc. 12, 540 (1967).

12. P. J. Dornan, V. E. Barnes, B. B. Culwick, P. Guidoni, G. R. Kalbfleisch, R. B. Palmer, D. Radojicic, D. C. Rahm, R. R. Rau, C. R. Richardson, N. P. Samios, I. O. Skillicorn, B. Goz, M. Goldberg, T. Kikuchi, and J. Leitner, Bull. Am. Phys. Soc. 11, 342 (1966).
13. D. R. O. Morrison, CERN Preprint, D. Ph. II/Physics 67-15, submitted to Phys. Letters.
14. C.-Y. Chien, UCLA High Energy Physics Note 41, 1967, unpublished.
15. See, for example, R. H. Dalitz, Rapporteur Talk, Symmetries and the Strong Interactions, in Proceedings of the XIIIth International Conference on High Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, 1967), p. 215.
16. In this assignment we are following the common usage. It must be remembered, however, that the existence of the A_1 as a distinct resonance is not yet fully established (although arguments in favor of a resonance are given in this paper), and that the spin of the B is not clearly established.
17. A wider generalization of C referred to as "unitary-parity" has been introduced by Dothan and is called $\mathcal{C}$ in the literature. The precise definition and references are given by B. W. Lee in High Energy Physics and Elementary Particles, 1965 Trieste Seminars (International Atomic Energy Agency, Vienna, 1965). See also G. L. Kane, Phys. Rev. 156, 1739 (1967).
18. This was pointed out by H. Lipkin at the XIIIth International Conference on High Energy Physics, Berkeley, September 1966.
19. Until the $K\pi\pi$ mass spectrum for a series of incident momenta is fitted with unique values of E_1 and E_2 we will not be able to evaluate β reliably. Present indications are that β is small.

20. Here it must be stressed that in view of the new experimental evidence (Ref. 5) and the present arguments, the earlier assignment (Ref. 1) of A_1 and $K^*(1320)$ to a single nonet is no longer valid.
21. Interference phenomena in mass distribution have been invoked previously in the ρ - ω mixing for the 2π decay of the ω , for example, by Bernstein and G. Feinberg, Nuovo Cimento 25, 1343 (1962), and more recently in connection with the splitting of the A_2 by G. Chikovani, M. N. Focacci, W. Kienzle, G. Lechanoine, B. Levrat, B. Maglic, M. Martin, P. Schubelin, L. Dubal, M. Fischer, P. Grieder, H. A. Neal, and C. Nef, Phys. Letters 25B, 44 (1967).
22. J. Field, T. Hendricks, O. Piccioni, and P. Yager, Phys. Letters 24B, 639 (1967).
23. The A_1 "peak" appears as a reasonably clear signal in the 2.75 to 5 BeV/c incident momentum region, but not so in the 6- to 7-BeV/c region; it then reappears from 11 BeV/c on up as far as measurements have been carried out. (See Ref. 1, Figs. 7-35 to 7-40.) A more recent complication is the appearance of the $A_{1.5}$ effect at ~ 1180 MeV. The behavior in the 8-9 BeV/c region for π^+p experiments is somewhat confused at present in that the ABC collaboration at 8 BeV/c observed evidence for an A_1 peak while the Columbia-Rutgers collaboration do not observe a clear peak at 8.4 BeV/c; they do however observe a possible enhancement in the $A_{1.5}$ region.
24. M. Ross and Y. Y. Yam, Phys. Rev. Letters 19, 546 (1967).

FIGURE CAPTION

Fig. 1. Computation of the interference patterns in the $K\pi\pi$ mass distribution for two K^* resonances at 1250 and 1320 MeV added coherently and a third at 1420 MeV added incoherently. The computation was done for a series of values of the phase angle ϕ between the two coherent amplitudes as described in the text, and is shown in parts a to j. In Part k is shown the incoherent sum of the three resonances.

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Fig. 1

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