where A and B are simple expressions involving exponential integrals. By comparison with R and R', the parameters are determined to be as follows: exchange of two zero-kinetic energy pions, $\mu^{-1} = 0.70$ F, $r_\infty = 0.30$ F, $V_0 = 4.5$ MeV; ρ-meson exchange, $\mu^{-1} = 0.38$ F, $r_\infty = 0.32$ F, $V_0 = 13$ MeV. The comparison of r_∞ and R illustrates the fact that because of the outside attraction, the wave function appears to come from inside the repulsive core, an effect which could be more pronounced if the attraction were stronger.

In summary, the phenomenology of a strong repulsion is somewhat different from that of a strong attraction, and the significance of the parameters is quite different. The sign of the cubic term in the expansion of δ gives information about the sign of the tail of the potential. The experimental s-wave phase shifts for $K^+ - p$ scattering may possibly indicate that although the center is strongly repulsive, the tail of the interaction is weakly attractive, if the nonrelativistic potential scattering derivation given here has any validity.

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[1] S. Goldhaber, W. Chinowsky, G. Goldhaber, W. Lee, T. O'Halloran, T. F. Stubbs, G. M. Pjerrou, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 9, 135 (1962); T. F. Stubbs, H. Bradner, W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Slater, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 7, 188 (1961).

[2] The fact that it is a, not r_0, that characterizes the range in the repulsive case may already have been observed by H. Feshbach *et al.*, Bull. Am. Phys. Soc. 7, 40 (1962), fourth sentence of Abstract L2.

[3] H. A. Bethe, Phys. Rev. 76, 38 (1949).

[4] Potential models of this kind have been used by H. P. Noyes, Phys. Rev. 99, 618(A) (1955), in a discussion of low-energy s-wave π-p phase shifts. Particular examples have been considered by Noyes and Woodruff, in that context (see the above abstract for references) following the original suggestion of R. Marshak, Phys. Rev. 88, 1208 (1952). The object was to describe a phase shift which appeared to be positive at very low energy, and then became negative. The situation would seem to be intermediate between the usual attraction, and our dominant repulsion. The particular results obtained agree qualitatively with our predictions. We thank Dr. Marshak for pointing out this work to us.

[5] A little care must be taken in applying the usual $k \cot\delta$ expression to such an attraction because as the scattering length a tends to zero, r_0 is proportional to a^{-1}.

NOTE ON THE POSSIBLE RESONANT STATE IN THE $K\bar{K}$ SYSTEM

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The recent experimental data[1] for $K^- - p$ collisions at 2.24 and 2.5 BeV/c have shown that (1) in the $K^- + p \to \Xi + \pi + K$ reaction there is evidence for the existence of a Ξ^* state in addition to the well-known K^* state; (2) the mass spectrum of the $K\bar{K}$ system in the final state of the reaction $K^- + p \to \Lambda + K + \bar{K}$ seems to have a peak.

Bertanza *et al.*[1] have pointed out on the basis of their results, mentioned above, that the $K\bar{K}$ peak may be due to a $K\bar{K}$ resonance or to an S-wave final-state interaction between the K and $\bar{K}$ mesons. They have said that if the peak is due to the decay of a resonant state (which we will call the Z particle), the mass of this state is equal to 1020 MeV. If this peak is not due to a statistical fluctuation, it would be very desirable to know which isotopic spin state is responsible for the peak, $I = 0$ or $I = 1$. In this note we shall focus our attention on this problem.

A recent experiment[2] on the $\pi^- + p \to \pi^+ + \pi^- + n$ reaction at 3.3 BeV/c has shown the existence of a resonant state in the 2π system whose mass is nearly equal to 1040 MeV. It is said that this resonant state probably corresponds to the Pomeranchuk particle (X particle) with spin $J = 2$ which has been predicted by Chew and Frautschi.[3] We assume that this interpretation is correct. Although the mass of the Z particle is nearly equal to that of the X particle, it is not very plausible that $Z \equiv X$, because one would not expect a strong d-wave $K\bar{K}$ interaction at an energy as low as 30 MeV ($= m_Z - 2m_K$). In order to give a semiquantitative justification for this statement, we shall make a crude estimate of the decay rates for $X \to 2\pi$ and $X \to K\bar{K}$:

$$\Gamma(X \to 2\pi) \propto \{p^2(pR)^2/[9+3(pR)^2+(pR)^4]\} \times (p/m_X)(2S_\pi+1)^2R^3, \tag{1}$$

$$\Gamma(X \to K\bar{K}) \propto \{q^2(qR)^2/[9+3(qR)^2+(qR)^4]\} \times (q/m_X)(2S_K+1)^2R^3, \tag{1'}$$

where $p \cong 500$ MeV/c and $q \cong 160$ MeV/c. The first factors in (1) and (1′) account for the d-wave barrier penetration, p/m_X and q/m_X are the respective Lorentz-invariant phase-space factors, $(2S_\pi+1)=1$ and $(2S_K+1)=1$ are the multiplicities of the π and K spins, respectively, and R is some radius of interaction. If we tentatively assume equal radii with $R = \frac{1}{2}m_\pi$ for both processes, we obtain $\Gamma(X \to 2\pi)/\Gamma(X \to K\bar{K}) \cong 10^2$.

We shall now examine the following four cases, remembering that the G-parity of the $K\bar{K}$ system is given by $(-1)^{I+J}$: (i) $I=1$ and $J=1$, (ii) $I=0$ and $J=1$, (iii) $I=1$ and $J=0$, and (iv) $I=0$ and $J=0$. In case (i) [or case (iii)], the Z particle has the same quantum numbers (spin, isotopic spin, parity, and G-parity) as the ρ (or ω) meson.[4] However, these cases may be unlikely because there seems to be no evidence for the peak due to a strong interaction of $J=1$ states in 2π or 3π systems in the neighborhood of 1020 MeV. The only peak observed in this energy region is that from the resonance corresponding to the X particle. It should be pointed out that in order to exclude these two cases with confidence, it will be necessary to obtain detailed experimental data for 2π and 3π interactions in the neighborhood of 1020 MeV.

Also for case (iv), the decay $Z \to 2\pi$ becomes the dominant process. If we make a crude estimate similar to the calculation made above [Eqs. (1) and (1′)], the result is $\Gamma(Z \to 2\pi)/\Gamma(Z \to K\bar{K}) \cong 4$. In this case, of course, there is no barrier penetration because the Z particle is in an S state of $K\bar{K}$ or $\pi\pi$ systems. We may exclude the possibility of case (iv) for the same reason as we excluded cases (i) and (ii).

Now let us examine case (iii). Because the G-parity of the Z particle is odd in this case, the Z particle must decay into an odd number of pions through a strong interaction. However, the $Z \to 3\pi$ decay mode which one might consider to be the most likely process turns out to be forbidden owing to the need to conserve parity and total angular momentum. Thus the decay $Z \to K+\bar{K}$ should be one of the most important decay processes. We conclude that case (iii) would be the most consistent with the present experiments; that is, the observed $K\bar{K}$ peak in the neighborhood of 1020 MeV is due to a strong interaction in the $J=0$ and $I=1$ state.[5] It should be pointed out that if the Z particle has $J=0$ and $I=1$, it may decay into 5π and (if the η is a 0^{-+} meson) into $\eta+\pi$.

Finally we suggest the following possible model for the reaction $K^-+p \to \Xi+\pi+K$ in which the strong K-$\bar{K}$ interaction is taken into account.[6] There is a rather large probability for the physical nucleon to be dissociated into a virtual pion and a nucleon core. If the interaction between the incident K^- and the nucleon core takes place in a very short time interval, the pion may play the role of a spectator during the collision in the inner region. The reaction in the inner region may then take place with the incident K^- meson interacting with a virtual K^+ meson around a Λ (or Σ) particle producing a Z particle which then decays into a K-$\bar{K}$ pair. The decay product $\bar{K}$ is absorbed by the Λ (or Σ) particle and the Ξ particle is produced, that is,

$$[K^-+N]+\pi \to [\Lambda \text{ (or } \Sigma)+Z]+\pi \to [\Xi+K^+]+\pi.$$

The final step in the reaction would involve the pion interacting with either the Ξ particle or the K meson in the outer region leading, respectively, to the final states Ξ^*+K or $\Xi+K^*$.

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[1] L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, L. Gray, L. Leitner, S. Lichtman, and J. Westgard, Phys. Rev. Letters 9, 180 (1962).

[2] Z. G. T. Guiragossian (to be published).

[3] G. F. Chew and S. C. Frautschi, Phys. Rev. Letters 8, 41 (1962).

[4] Then the Z particle corresponds to the particle belonging to the secondary ρ (or ω) Regge trajectory. Previously we have pointed out that the ρ and ω mesons can be regarded as the bound states in the N-$\bar{N}$ system [S. Minami, Progr. Theoret. Phys. (Kyoto) 27, 217

(1962)] or in the K-$\bar{K}$ system [S. Minami, Progr. Theoret. Phys. (Kyoto) 27, 215 (1962)].

[5] If the Z particle is regarded as a bound state in the N-$\bar{N}$ system, it would then correspond to the $_3{}^3P_0$ state. For an explanation of the notation, see the first paper cited in reference 4.

[6] Another possible reaction mechanism is one in which the incident K^- meson interacts directly with the nucleon and a K meson is produced through a Yukawa-type interaction without any $K\bar{K}$ interaction.

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n-*p* ELASTIC CHARGE EXCHANGE IN THE BeV ENERGY REGION*

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The n-p elastic charge-exchange cross section is expected, on the basis of isotopic-spin considerations, to decrease with increasing nucleon energy because the total cross sections for n-p and p-p approach equality with increasing energy. The highest energy charge-exchange measurements were reported by Larsen[1] at 710 MeV. He found the differential center-of-mass cross section at zero degrees to equal 6.3 mb/sr. In the BeV energy region the search for nucleon charge-exchange events has usually been ancillary to some other measurement.[2] This has resulted in little positive information, except for the conclusion that the charge-exchange cross section is small. We have measured this process at 2.04 and 2.85 BeV using the Cosmotron at Brookhaven.

The experimental arrangement of the apparatus is shown in Fig. 1. The internal proton beam is incident on a 2-in. × 2-in. × 2-in. Be target, and the target is viewed by means of a 2-in. diameter collimator extending through the shielding at an angle of 0° with respect to the incident protons. The beam consists of neutral particles, mostly neutrons and γ rays from π^0 decay. To remove the γ rays a 4-cm lead filter is placed at the exit of the collimator. A 12-in. × 24-in. sweep magnet removes charged particles produced in the Pb and the collimator. The beam of neutrons falls on a liquid hydrogen target and produces protons which are velocity analyzed by means of a threshold Cherenkov counter. Mesons produced in the hydrogen having velocities of the same magnitude as the exchange protons are swept by a second 12-in. × 24-in. sweep magnet, operating at a field of ~15 000 Oe. A recorded event requires a null signal from an anticoincidence scintillation counter placed before the hydrogen target plus signals in scintillation counters: $S1$, placed after the hydrogen target; $S2$, placed after the meson sweeping magnet; $S3$, placed before the Cherenkov counter, and the Cherenkov counter itself. The time resolution of the coincidence chain is approximately 7 nsec. The Cherenkov counter is a CO_2 threshold counter one meter long with an entrance aperture of 4-in. diameter. It normally operates at 40°C. The pressure is varied between 1200 and 600 lb/sq-in., thereby varying the β threshold between 0.930 to 0.980. The intensity of the incident neutron beam is

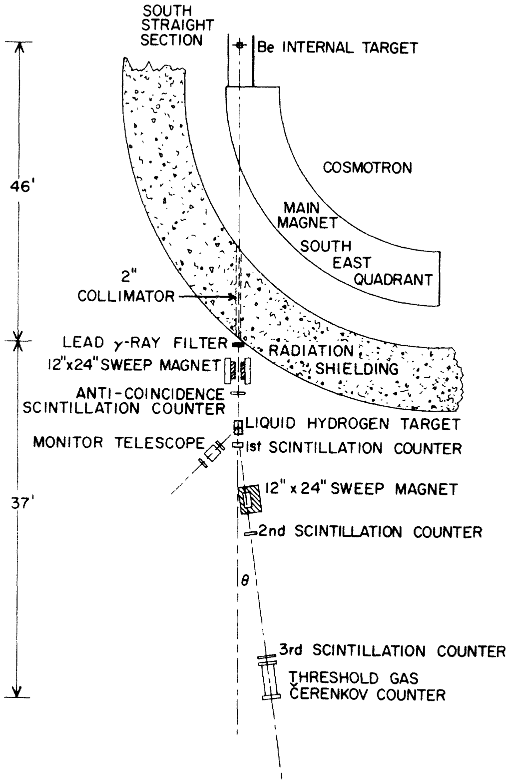

FIG. 1. Experimental arrangement of apparatus at the Brookhaven cosmotron.