*Work supported in part by U. S. Atomic Energy Commission Contract No. AEC AT(11-1)34 P107A.

[1] S. W. MacDowell, Phys. Rev. 116, 774 (1959); also see W. R. Frazer and J. R. Fulco, ibid. 119, 1420 (1960).

[2] V. Singh, Phys. Rev. 129, 1889 (1963).

[3] It is possible that there are two trajectories, $\alpha_1(W)$ which dominates the positive-parity amplitude and $\alpha_2(W)$ which dominates the negative-parity amplitude. However, this picture would lead to crossing of the trajectories and will not be within the conventional Regge framework.

[4] J. D. Stack, Phys. Rev. Letters 16, 286 (1966); G. F. Chew and J. D. Stack, University of California Radiation Laboratory Report No. UCRL-16293 (unpublished).

[5] V. Barger and D. Cline, Phys. Rev. Letters 16, 913 (1966).

[6] C. Chiu (University of California Lawrence Radiation Laboratory, Berkeley, private communication).

[7] For instance, it has been suggested by Chiu (Ref. 6) that a $\frac{5}{2}^-$ πN resonance (for which there is some experimental evidence) may lie on the same trajectory on which the nucleon lies. As far as Δ_δ and N_γ trajectories are concerned, even though the analysis of Barger and Cline (Ref. 5) suggests that they are almost straight lines, there are as yet no opposite-parity partners observed experimentally.

[8] At this point it is interesting to compare our results with those of (spin-zero) meson-meson amplitudes where parity and signature signify the same thing. These amplitudes are functions of W^2. Therefore, the corresponding $\alpha(W)$ is a symmetric function of W and gives rise to the same particles on both sides of the W plane. This is in contrast to the meson-baryon case where the two sides correspond to states with opposite parities. The meson-baryon amplitudes have an additional factor $(E+m)^{-1}$ [see (1)] which is just the factor which insures proper threshold behavior in the negative-W plane. It is this factor which is responsible for the negative sign in (1), so that while the meson-meson residues do not change sign, the meson-baryon residues do.

[9] What constitutes a right-half J plane in the relativistic case is, of course, unclear, but one should certainly expect all the bound states and resonances to lie in it.

[10] The notations $g(W)$ and $A_1^u(W)$ given below are the same as in Ref. 6.

[11] The other possibility is that the function $\beta_R(W)$ or $g(W)$ develops an imaginary part, so that instead of going through zero, it goes along a contour around it. This would imply singularities in addition to the normal ones. Such possibilities have not been considered in the conventional Regge framework.

[12] See, for instance, B. R. Desai, Phys. Rev. 138, B1174 (1965).

[13] Also see comments in Ref. 3 and 11.

[14] In the (spin-zero) meson-meson case mentioned above (Ref. 8) both $d(W)$ and $\partial D/\partial W$ vanish at $W=W_{\min}$. It is conceivable that this particular property would be true also for the meson-baryon case. If this is so, then alternative (ii) would be preferred.

NEW DETERMINATION OF THE φ SPIN AND G PARITY

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The present knowledge of the φ quantum numbers ($J^{PG}=1^{--}, I=0$) has been obtained from an interpretation of its decay modes into $\bar{K}K$ and the search for charged φ's in the final states $\Sigma K\bar{K}$ produced in K^-p collisons.[1] The data overwhelmingly favor the 1^{--} assignment; however, the spin determination is based on the assumption that the φ meson has a "reasonable" structure to which neutral and charged kaons are equally coupled. In fact, the structure assumed is an approximation by a square potential well of "reasonable" radius. Although this assumption is very plausible it has not been tested yet, and doubts could be raised about its validity.

Due to the important role that the φ meson plays in SU(3) symmetry, an independent method yielding the φ spin has been desirable. In this Letter a new determination of the φ spin which is independent of any assumption on the structure of the φ is reported; at the same time we obtain confirmation that $G_\varphi=-1$.

In a systematic analysis, undertaken by our groups, of annihilations of antiprotons brought to rest in the BNL - Columbia 30-inch deuterium bubble chamber, exposed at the alternating-gradient synchrotron, we have identified 46 events of the type

$$\bar{p}+d\rightarrow p_{sp}+\pi^-+\varphi \qquad (1a)$$

$$\llcorner\!\!\rightarrow \bar{K}+K \qquad (1b)$$

among ~300 000 antiproton annihilations in deuterium. The events were identified, by examining appropriate topological configurations, through the usual kinematic fitting programs and ionization estimate. In Fig. 1 the squared $\bar{K}K$ effective-mass distribution below 1.38 BeV^2 is shown for the final states $pK^+K^-\pi^-$ and $pK_1K_2\pi^-$. The presence of the φ is strong and the background negligible. These events have proton momenta of <250 MeV/c and they may be considered, therefore, as annihilations of antiprotons with free neutrons at rest into $\pi^-\varphi$. In our analysis, dynamical effects due to the "spectator" proton will not be considered; we shall, however, consider the kinematical effect due to the internal motion of the deuteron.

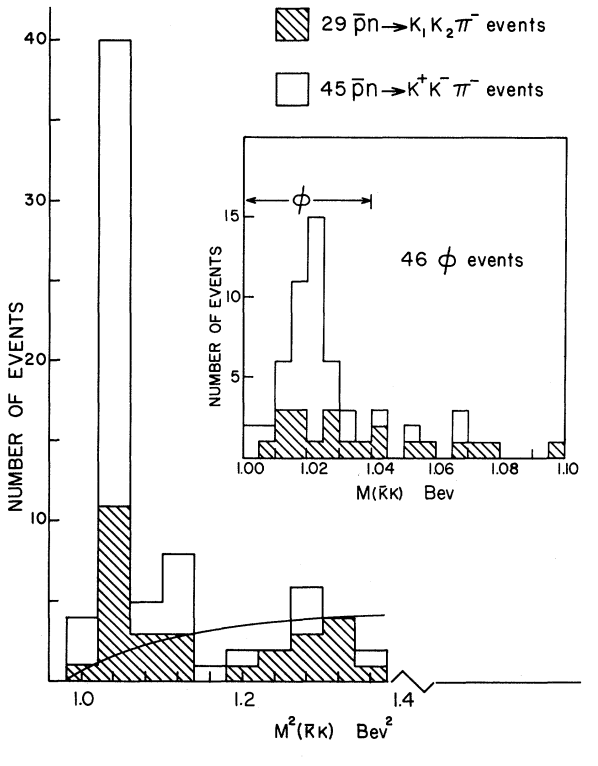

FIG. 1. The $\bar{K}K$ effective-mass-squared distribution below 1.38 BeV^2 for the final states $\bar{p}+n\rightarrow K^++K^-+\pi^-$, $K_1+K_2+\pi^-$. Insert shows details of this distribution around the φ mass and our criterion for the selection of the φ events.

Our belief in the "spectator" behavior of the proton is supported by the study of other channels[2] where we have obtained evidence that, with such a cut on the proton momentum, this approximation is valid. Furthermore, we assume that the $\bar{p}n$ annihilations predominantly proceed through s states.

The effectiveness of the Stark mixing mechanism, first proposed by Day, Snow, and Sucher,[3] which leads to dominance of absorption from an atomic s state in liquid hydrogen, has been tested by direct measurements of moderation times of π^-,[4] K^-,[5] and Σ^-,[6] and by the study of the reaction $\bar{p}+p\rightarrow K^0+\bar{K}^0$.[7] Since the atomic structure of deuterium is essentially the same as that of hydrogen and the $\bar{p}$ mass is intermediate between K^- and Σ^- masses, we are strongly led to the conclusion that $\bar{p}d$ absorption also takes place from an atomic s state. It should be noticed, however, that even in this case, because of the structure of the deuteron, the $\bar{p}n$ system will have some contamination of higher waves. The contribution to higher $\bar{p}n$ waves from the deuterium S state is negligible because of the large ratio of atomic to deuteron radius, and the contribution from the deuteron D wave is at most 7%. However, in our particular reaction we have experimental proof (ratio of seen to unseen protons) that at the time of annihilation the ($\bar{p}n$) wave is S and not D. We conclude that the contamination of higher $\bar{p}n$ waves is negligible.

We have made an analysis of the $\pi^-K\bar{K}$ final state as a function of the φ quantum numbers. It is based only on the assumption of predominance of the $\bar{p}n$ S wave and on the following well established facts: (i) Total angular momentum is conserved in both production and decay; (ii) $\bar{p}, n$ have opposite intrinsic parities, and $I=1$ for the $\bar{p}n$ system; (iii) P and G are conserved in the production process; and (iv) kaons have spin zero.

The above conditions applied to Reactions (1a) and (1b) result in the following relations:

$$G_\varphi=(-1)^S, \qquad (2)$$

$$P_\varphi=(-1)^L, \qquad (3)$$

$$\vec{S}=\vec{J}_\varphi+\vec{L}, \qquad (4)$$

where $\vec{S}$ is the $\bar{p}n$ total spin which, in this case, is the total angular momentum of the system, and L the $\pi\varphi$ relative angular momentum.

In Table I all final states subject to relations (2), (3), and (4) for the ${}^1S_0$ and ${}^3S_1$ $\bar{p}n$ states and various J^{PG} φ assignments are presented. If we define $x=\cos\theta$, where θ is the angle between the $\bar{K}$ and π^- momenta in the φ rest frame, then the angular distributions for the φ decay from Reactions (1a) and (1b) are

$$|\mathfrak{M}|^2 \propto \sum_{M=-S}^{M=S} |C_{J_\varphi L}(S,M|0,M)Y_L^M(x)|^2, \qquad (5)$$

considering that the $\bar{p}n$ system is unpolarized. The $C_{J_\varphi L}$ are Clebsch-Gordan coefficients. These angular distributions are shown in Table I as well as their χ^2 probability for fitting our data, which are presented in Fig. 2.

We conclude that the only possible φ spin-parity assignment is $J^P=1^-$. Moreover, this assignment gives a good fit only if Reaction (1a) proceeds from the ${}^3S_1$ $\bar{p}n$ state; it follows that $G=-1$ independently of the determination of its isospin and decay modes.

Recently, there have been speculations that kaons may not obey Bose-Einstein statistics.[8] The most recent theoretical analysis[9] shows that kaons, like all the other known particles, should follow ordinary statistics. It may be interesting, in this regard, to note that our data, independently of any assumption on kaon statistics, yield an odd value for J_φ. If kaons are bosons, the decay $\varphi \rightarrow K_1+K_2$ implies odd spin for the φ; hence we have a confirmation of the fact already established,[8] that kaons cannot obey Fermi statistics. The case of mixed statistics cannot be tested.

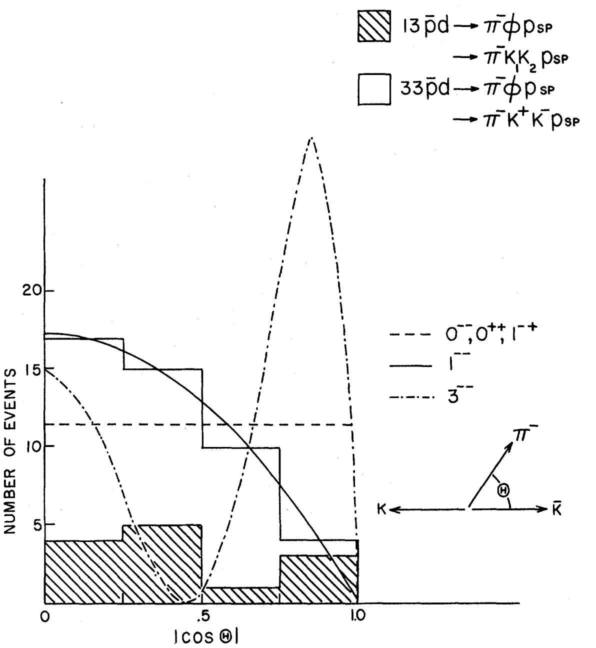

FIG. 2. The angular distribution of the π^- with respect to the $\bar{K}$ in the φ c.m. system. The theoretical curves are for various J^{PG} φ assignments and S-state $\bar{p}n$ absorption.

Table I. Matrix elements for $\bar{p}n \rightarrow \pi^- + \varphi$ from the ${}^3S_1$ and ${}^1S_0$ $\bar{p}n$ states with various J^{PG} φ assignments. $P(\chi^2)$ is the χ^2 probability obtained by comparing these angular distributions with our experimental data. Symbols are explained in the text.

$\bar{p}n$ state	J_φ	P_φ	L	Angular distribution	$P(\chi^2)$
${}^1S_0$, $G_\varphi=1$	0	+	0	1	10^{-2}
	1	−	1	x^2	$<10^{-6}$
	2	+	2	$(3x^2-1)^2$	6×10^{-6}
	3	−	3	$(5x^3-3x)^2$	$<10^{-6}$
${}^3S_1$, $G_\varphi=-1$	0	−	1	1	10^{-2}
	1	−	1	$1-x^2$	0.92
	1	+	0	1	10^{-2}
			2	$1+3x^2$	$<10^{-6}$
	2	−	1	$1+3x^2$	$<10^{-6}$
			3	$4x^2(1-x^2)+(3x^2-1)^2$	6×10^{-6}
	2	+	2	$x^2(1-x^2)$	$<10^{-6}$
	3	−	3	$(5x^2-1)^2(1-x^2)$	$<10^{-6}$
	3	+	2	$4x^2(1-x^2)+(3x^2-1)^2$	6×10^{-6}
			4	$175x^6-165x^4+45x^2+9$	4×10^{-6}

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Computing Center.

†On leave from Wihuri Physical Laboratory, University of Turku, Turku, Finland.

[1] P. L. Connolly, E. L. Hart, K. W. Lai, G. London, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, M. Gundzik, J. Leitner, and S. Lichtman, Phys. Rev. Letters 10, 371 (1963); P. Schlein, W. E. Slater, L. T. Smith, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 10, 368 (1963). For recent data and discussions see G. W. London, R. R. Rau, N. P. Samios, S. S. Yamamoto, M. Goldberg, S. Lichtman, M. Primer, and J. Leitner, Phys. Rev. 143, 1034 (1966); James S. Lindsey and Gerald A. Smith, University of California Radiation Laboratory Report No. UCRL-16526 (to be published).

[2] A detailed study of the reaction $p+d \rightarrow p+2\pi^- +\pi^+ +\pi^0$ has shown that the proton spectrum can be interpreted in terms of the complete deuteron wave function with an additional contribution of about 16% of protons distributed according to "phase space" of the $p+4\pi$ system. However, this last contribution accounts for only 1.2% of the protons with $P_{sp} \leq 250$ Mev/c. A search for $N_{33}^*(1238)$ in this final state has shown that it is slightly produced only when $P_{sp} > 250$ Mev/c.

[3] T. B. Day, G. A. Snow, and J. Sucher, Phys. Rev. Letters 3, 61 (1959); B. Desai, Phys. Rev. 119, 1385 (1960) has applied the same arguments to $\bar{p}p$ at rest, and concludes that $\bar{p}$ will be captured predominantly from s states.

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[5] R. Knop, R. A. Burnstein, and G. A. Snow, Phys. Rev. Letters 14, 767 (1965); M. Cresti, S. Limentani, A. Loria, L. Peruzzo, and R. Santangelo, Phys. Rev. Letters 14, 847 (1965).

[6] R. A. Burnstein, G. A. Snow, and H. Whiteside, Phys. Rev. Letters 15, 639 (1965).

[7] R. Armenteros et al., Phys. Letters 17, 344 (1965); C. Baltay et. al., Phys. Rev. Letters 15, 532 (1965).

[8] See Ref. 9 for a full list of references of previous work on this subject. R. Gatto, Phys. Letters 5, 56 (1963) has shown, on the basis of the observation of the reaction $\bar{p}+p \rightarrow K+\bar{K}$, that kaons cannot obey pure Fermi statics.

[9] O. W. Greenberg and A. M. L. Messiah, Phys. Rev. 138, B1155 (1965).