their valuable aid in all phases of the experiment, and to the Bevatron staff and crew.

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

[1]Victor Perez-Mendez, Bull. Am. Phys. Soc. 8, 451 (1959).
[2]M. J. Longo, J. A. Helland, W. N. Hess, B. J. Moyer, and V. Perez-Mendez, Phys. Rev. Letters 3, 568 (1959).
[3]L. K. Goodwin, R. W. Kenney, and V. Perez-Mendez, Phys. Rev. Letters 3, 522 (1959).
[4]Duane B. Newhart, Victor Perez-Mendez, and William H. Pope, Lawrence Radiation Laboratory Report UCRL-8857, August, 1959 (unpublished).
[5]John H. Atkinson and Victor Perez-Mendez, Rev. Sci. Instr. 30, 865 (1959).
[6]R. M. Sternheimer, Rev. Sci. Instr. 25, 1070 (1954).
[7]H. C. Burrowes, D. O. Caldwell, D. H. Frisch, D. A. Hill, D. M. Ritson, R. A. Schluter, and M. A. Wahlig, Phys. Rev. Letters 2, 119 (1959).
[8]J. C. Brisson, J. Detoef, P. Falk-Vairant, L. van Rossum, G. Valladas, and L. C. L. Yuan, Phys. Rev. Letters 3, 561 (1959).
[9]R. Cool, O. Piccioni, and D. Clark, Phys. Rev. 103, 1082 (1956).

QUESTION OF THE EXISTENCE OF A STRANGENESS 2 MESON*

D. J. Prowse
Department of Physics, University of California, Los Angeles, California
(Received February 3, 1960)

Recently Yamanouchi[1] has suggested that there is strong evidence for the existence of a strangeness 2 meson with a mass of about 720 Mev. Among several events enumerated by Yamanouchi in support of this contention is the Bristol anomalous K^+-meson decay reported by Prowse and Evans.[2]

Yamanouchi points out that if the identity of the primary particle in this event is unknown one could set up a scheme, $D^+ \to \pi^+ + K^0$ rather than $K^+ \to \pi^+ + \pi^0 + \gamma$ or $K^+ \to \pi^+ + x^0$, because the identities of all the neutral particles involved are unknown. The argument on whether or not the decay involves two or three bodies is based upon the fact that in a similar event found by the Columbia group,[3] the π^+-meson energy was the same (approximately 60 Mev). If the existence of two decays giving the same π^+-meson energy can be considered as possible evidence of a unique π^+ energy, then one is justified in postulating the decay mode $K^+ \to \pi^+ + x^0$ or, if the nature of the primary particle is undetermined, $D^+ \to \pi^+ + K^0$ also. The purpose of this Letter is to point out that the mass of the primary particle is known in the Bristol event and it is not consistent with the mass value of 720 Mev.

The event in question was found during a systematic study of the interactions of K^+ mesons with nuclei.[4] In the course of this work it appeared of interest to determine the decay modes of those K^+ mesons which had interacted and to compare them with the decay modes of those K^+ mesons which had not interacted.[5] The decay particles of the K^+ mesons which had been followed to rest in the search for interactions were therefore examined. Details of the pickup criteria used for finding and following these tracks are given in reference 4; the details of the measurements on the secondary particles are given in reference 5. In the course of the grain density measurements on these secondaries it became important to normalize the values obtained very carefully in each pellicle utilized. The normalization used was the grain density of the beam π mesons ($1.01 \times$minimum); this value was carefully determined in each plate as outlined in reference 5 and shown in Fig. 2 of reference 2. A number of K^+-meson identities were established by g^* vs R measurements because not all secondaries were visible owing to the low minimum grain density in the stack. In particular the identity of the primary of the anomalous event was established in this way. Grain density measurements were made at three residual ranges and the values were normalized using the minimum-ionization results mentioned above. The K^+-meson track was quite flat (1.4 cm/pellicle) and so no difficulties were encountered because of steepness. The three values obtained are shown graphically in Fig. 1. The expected variations of g^* vs R are shown for π mesons, K mesons, D particles, and protons. The mass of the primary is thus determined to be 532 ± 24 Mev. The identity can be seen to be well established.

The high strangeness number of 2 suggested by Yamanouchi for the new particle is sufficient to

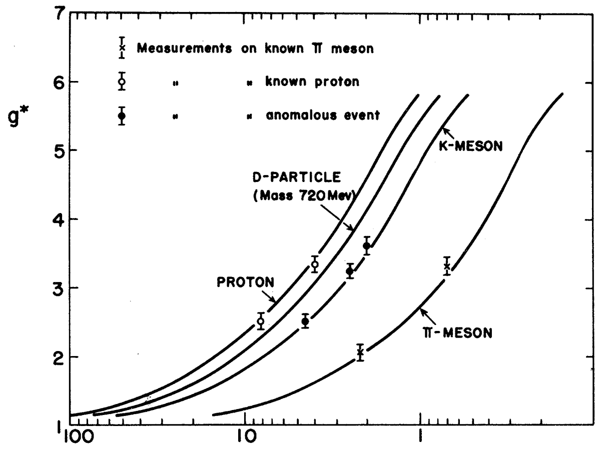

FIG. 1. Grain density measurements plotted against residual range (R). The expected variations of g^* (normalized to minimum) with R for the various particles are computed from the curves of G. Alexander and R. H. W. Johnston [Nuovo cimento 5, 363 (1957)] for g^* values below 2.9. Above this value the curves are computed from the values of $(g^*)_{\text{F.P.}}$ given by P. H. Fowler and D. H. Perkins [Phil. Mag. 46, 587 (1955)].

explain the apparent absence of conclusive proof of its existence. It is likely to be removed from any mass-separated beam which has been used heretofore and the energies of the separated strange-particle beams have not been high enough to produce it. The only experiments which might have detected the particle are those involving momentum-separated beams only. The emulsion stack in which the Bristol anomalous K^+ meson was found was exposed to such a beam (of positive sign) of 375 Mev/c momentum. During the systematic scan for K^+ particles, a search was also made in this stack for stopping particles of mass $500m_e$ and mass $1480m_e$; this search was inspired by previous reports of particles of this mass. No particles were found stopping and decaying in the regions of the emulsion stack corresponding to these mass values. If the particles have the same lifetime as the K^+ meson, the ratio of $(D^+ \text{ or } X^+)/K^+$ at production is less than 0.5%.

The evidence for the existence of the particle, $D^\pm$, is partially listed by Yamanouchi. The results given in this paper show, however, that the 2 anomalous events[6] have to be deleted from this list. This is unfortunate for two reasons: (a) The exact mass value is not now known, and (b) it materially decreases the probable lifetime of the particle. Both of these factors will make it harder to detect.

The interpretation of the Wisconsin events[7] which are also listed as supporting evidence for the particle is not convincing. In each of these events a K^- meson of 40 Mev is produced alone by a singly charged particle which may be at rest. The K mesons are arrested in the stack and they give rise to ρ endings. Yamanouchi proposes that they are due to an interaction of D^- mesons according to the scheme,

$$D^- + n_{\text{bound}} \rightarrow \Lambda^0 + K^-.$$

Such an interpretation does not explain the equality of the K-meson energy in each event because the momentum of the bound neutron would considerably broaden the spectrum; evaporation prongs would also be expected. A better interpretation is that they are due to the decay of a heavy particle as originally suggested by the authors.[7]

There have been reports of other mass 1450 particles; in 1955 Menon reported the result of Fowler and Perkins at the Rochester Conference.[8] Mass determinations by grain density and scattering measurements on flat particles from cosmic-ray stars gave some indication of a peak at $1480m_e$. When these measurements became more accurate, however, in larger stacks where the particle ranges could be determined, these mass values were not confirmed.

An event which can be interpreted as a $D^\pm$-meson decay according to the scheme suggested by Yamanouchi has been observed by Sen Gupta and Sinha[9] in a cloud chamber.

In conclusion we may say that although a number of hitherto unexplained events can be interpreted if such a particle is postulated, concrete evidence for its existence is lacking and is certainly not provided by the anomalous K^+ decays.

We are grateful to Professor H. K. Ticho, Dr. J. H. Mulvey, Professor J. Orear, and Professor E. C. G. Sudarshan for many discussions. We also wish to thank Professor J. Orear for prepublication information on the mass value of the Columbia anomalous K^+ decay.

*Partially supported by the U. S. Atomic Energy Commission.

[1]T. Yamanouchi, Phys. Rev. Letters 3, 480 (1959).
[2]D. J. Prowse and D. Evans, Nuovo cimento 8, 856

(1958).

[3]G. Harris, J. Lee, J. Orear, and S. Taylor, Phys. Rev. 108, 1561 (1957).

[4]B. Bhowmik, D. Evans, S. Nilsson, D. J. Prowse, F. Anderson, D. Keefe, A. Kernan, and J. Losty, Nuovo cimento 6, 440 (1957).

[5]B. Bhowmik, D. Evans, D. J. Prowse, F. Anderson, D. Keefe, and A. Kernan, Nuovo cimento 8, 147 (1958).

[6]J. Orear has informed us that the mass value of the primary particle in the Columbia event is also consistent with the K^+-meson mass [private communication, and Bull. Am. Phys. Soc. 5, 12 (1960)].

[7]W. F. Fry, J. Schneps, and M. Swami, Phys. Rev. 97, 1189 (1955) and Nuovo cimento 2, 346 (1955).

[8]M. G. K. Menon, Proceedings of the Fifth Annual Rochester Conference on High-Energy Nuclear Physics (Interscience Publishers, New York, 1955), p. 77; work of P. H. Fowler and D. H. Perkins. Preliminary results were also reported by P. H. Fowler, Proceedings of the Fourth Annual Rochester Conference on High-Energy Nuclear Physics (University of Rochester Press, Rochester, 1954), p. 80; and by D. H. Perkins, Proceedings of the Third Annual Rochester Conference on High-Energy Nuclear Physics (University of Rochester Press, Rochester, 1952), p. 42.

[9]S. N. Sen Gupta and M. S. Sinha, Phil. Mag. 2, 936 (1957).

PARTIAL-WAVE DISPERSION RELATIONS FOR MESON-NUCLEON SCATTERING*

Reinhard Oehme
Enrico Fermi Institute for Nuclear Studies and Department of Physics, University of Chicago, Chicago, Illinois
(Received February 3, 1960)

It is of interest to compute the implications for the pion-nucleon scattering amplitude of possible resonance effects in the two-pion system.[1] In this note we propose a form of the π-N partial-wave dispersion relations[2] which is suitable for this purpose. Our formulas can be easily generalized for amplitudes involving other particles with unequal mass.

We write the covariant π-N amplitude in the form[3] $F=A-i\gamma\cdot\frac{1}{2}(k+k')B$, where $A_{\alpha\beta}=A^+\delta_{\alpha\beta}+A^-\frac{1}{2}[\tau_\alpha,\tau_\beta]$, etc. and $k+p=k'+p'$, $k^2=k'^2=-\mu^2$, $p^2=p'^2=-m^2$. In the following we discuss explicitly only the invariant amplitudes $A^\pm$; the extension to $B^\pm$ and to center-of-mass quantities is straightforward. Let us first consider the $A^\pm$ as functions of the invariant variables $z=-(k+p)^2$, $\zeta=-(k-k')^2$. We assume that they are analytic in both variables except for the absorptive singularities[4] due to the possible intermediate states of the three physical reactions associated with the π-N Green's function. Then we have the branch lines[3]

$$z=s\geq(m+\mu)^2,\ \ \bar{z}=\bar{s}\geq(m+\mu)^2,\ \ \text{and}\ \zeta=t\geq(2\mu)^2, \tag{1}$$

where $\bar{z}=2m^2+2\mu^2-z-\zeta$. The single nucleon poles $z=m^2$, $\bar{z}=m^2$ appear only in the amplitudes $B^\pm$. The variables z and ζ may be expressed in terms of q^2 (q = c.m. momentum) and θ (c.m. angle) by

$$z=m^2+\mu^2+2q^2+2[(q^2+m^2)(q^2+\mu^2)]^{1/2}, \tag{2a}$$

$$\zeta=-2q^2(1-\cos\theta). \tag{2b}$$

Note that the complex z plane is mapped into a Riemann surface with two leaves which are connected through the cut $-m^2\leq q^2\leq-\mu^2$. We define sheet I (II) by the requirement that the root in Eq. (2a) is positive (negative) for real $q^2>-\mu^2$. In the z plane, the exterior of the circle $|z|=m^2-\mu^2$ corresponds to sheet I and the interior to sheet II.

Let us now consider the amplitude A as an analytic function of q^2 for $-1\leq\cos\theta\leq+1$. It is regular on the Riemann surface mentioned above except for cuts along the real axes in both sheets. In particular, the partial-wave amplitudes,

$$A_J(q^2)=\frac{1}{2}\int_{-1}^{+1}d\cos\theta\, P_J(\cos\theta)A(q^2,\cos\theta), \tag{3}$$

have the following cuts: (πN) from 0 to $+\infty$ in I, due to $s\geq(m+\mu)^2$; ($\bar{\pi}N$) from 0 to $+\infty$ in I and from $-\infty$ in II up to $-m^2$ and then down to $-\infty$ in I, both due to $\bar{s}\geq(m+\mu)^2$; ($\pi\bar{\pi}$) from $-\mu^2$ to $-\infty$ in I and II, due to $t\geq(2\mu)^2$. The weight functions associated with the unphysical branch lines ($\bar{\pi}N$) and ($\pi\bar{\pi}$) can be expressed in terms of the absorptive parts $N(\alpha,\beta)$ and $M(\alpha,\beta)$ (α,β being the squares of energy momentum transfer), cor-