errors in all cases except Hf and Ir. The rotational character of these levels seems difficult to refute.

(3) If the rotational interpretation is accepted, we of course automatically obtain spin and parity assignments for all levels. The second rotational states will probably never be observed except in Coulomb excitation because of their high spins.

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Mean Lives of Positive and Negative Mu Mesons*

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It is now well established that the apparent mean life of negative mu mesons decreases very rapidly as the atomic number of the absorbing medium increases and that this is entirely due to the rapid increase in the capture probability of the mu mesons by the gradually increasing positive charge of the nucleus.[1-5] The mean life for free decay of negative mu mesons is the same as that of the positives, and the apparent mean life of negative mesons is given by $1/\tau_- = 1/\tau_+ + \Lambda$, where Λ is the capture probability of the negatives by the nucleus. Under these circumstances the number of mesons remaining undecayed at any time t is given by

$$N_t = N_0^+ \exp(-t/\tau_+) + N_0^- \exp(-t/\tau_-), \quad (1)$$

where N_0^+ and N_0^- are the number of positive and negative mu mesons available for decay at $t=0$. The number of negatives remaining undecayed after a time t equal to three times its apparent mean life is less than five percent. Hence if an integral decay curve is plotted with points close together, starting from a time as small as possible avoiding counter lags, we expect that the line joining the first few points would show a slope much sharper than that joining the points where the number of negative decays has falled to a very low value. The slope of the latter part of the curve, in fact, would give the mean life of positives as has been shown by Morewitz and Shamos[6] in the case of sulfur.

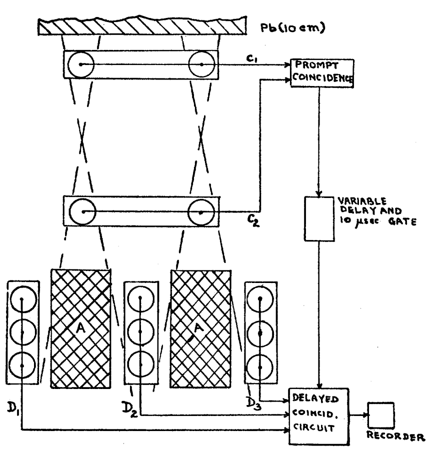

FIG. 1. Experimental arrangement.

The integral decay curves for a composite beam of mesons in Al, S, C, and Pb have been obtained in this laboratory by the delayed-coincidence technique. In the experimental arrangement as shown in Fig. 1, the twofold counter telescopes select an almost vertical beam of mesons and the trays D_1, D_2, D_3 detect the decay electrons. The meson-absorbing medium has been split up into two (A,A) in order to reduce the path length that a decay electron has to traverse to enter any of the D trays. The arrangement as a whole favors to increase the counting rates of the decay events.

Of the decay curves shown in Fig. 2, those for Al and S show

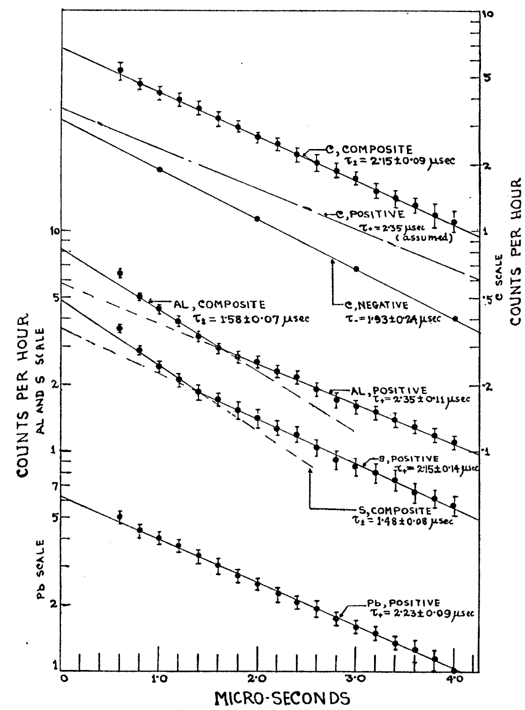

FIG. 2. Decay curves for μ mesons in C, Al, S, and Pb.

distinctly two separate slopes while those for C and Pb with the same experimental setup show only one. This is expected since the apparent mean life of negatives in C is not much less than that of the positives, which implies that the negatives were still available for decay at 4.0 microseconds. In the case of Pb the decay curve yields a mean life of 2.23±0.09 microseconds, which can be attributed to the decay of positives alone, because the number of negatives recorded in this case is negligible on account of their high capture probability by the lead nucleus. The point corresponding to 0.6 μsec was not given much importance because it is suspected to include some spurious events due to the distribution of random lags in the discharge of the G.M. counters.[7] This has also been the case with curves obtained by Rossi and Nereson[8] and Sigurgeirsson and Yamakawa.[9]

For elements of $Z \leq 16$, the composite decay mean lives show a gradual increase with decrease of Z, thereby indicating that τ_- increases as Z decreases and reaches the limit of τ_+ for $Z<6$. In Al and S, the determination of the mean lives of negatives alone could be done by subtracting the extrapolated dashed line (positive decays) from the composite curve, but this was not attempted since the statistical errors were too large to estimate the values of

τ_- with reasonable accuracy. Further experiments are in progress to evaluate τ_- by this method.

The value of τ_- in C has been determined in the following way. We chose the thickness of the carbon absorber such that it stopped the same number of mesons as in the case of Al. Hence the same number of positives must have decayed in C as in Al in the same time although the number of decay electrons recorded due to positives alone were smaller in C than in Al, because the solid angle subtended by the D trays with respect to the total thickness of the absorber was smaller in case of C due to its larger thickness. The positive decay curve in Al has been reduced by a factor equal to the ratio of the solid angles and this reduced curve represents the positive decay curve in C as shown in Fig. 2. The mean life of negatives evaluated by subtraction, gives the value 1.93 ± 0.24 μsec.

Only a fraction τ_-/τ_+ of the negative mesons present in the cosmic-ray beam can decay in an absorber. Since the number of negative and positive mesons decaying in the interval $t=0$ to $t=\infty$ are separately known in the case of C, the ratio of positive to negative mu mesons can be determined from the equation

$$\mu^+/\mu^- = (n_0^+\tau_-)/(n_0^-\tau_+), \qquad (2)$$

where n_0^+, n_0^- are the number of decay electrons recorded from $t=0$ to $t=\infty$. Substituting the relevant values from the decay curves of C, the value of this ratio is found to be 0.95 ± 0.16, agreeing well with the value 1.06 ± 0.03 obtained recently by Morewitz and Shamos.[6]

A detailed report of the experiment will be published in the Transactions of the Bose Research Institute. The authors acknowledge with thanks the advice and encouragement from Professor D. M. Bose, Director, Bose Institute during the course of the experiment.

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Phenomenology of the Pion-Nucleon *S* Waves*

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As was pointed out by Anderson and Fermi,[1] knowledge of the cross section for photoproduction of π^+ mesons from hydrogen at threshold combined with the π^-/π^+ ratio for photoproduction from deuterium and the ratio of radiative capture to charge exchange capture of π^- mesons in hydrogen as measured by Panofsky[2] allows one to calculate the difference in slope between the pion-nucleon S phase shifts at zero energy. Calling these phase shifts α_1 and α_3 for the states of $I=1/2$ and $I=3/2$, respectively, Bernardini[3] reported at the Fourth Rochester Conference that recent photoproduction results give $\alpha_1-\alpha_3=(0.16\pm0.04)p/\mu c$, where p is the center-of-mass momentum of the pion and μ its mass. However, pion-nucleon scattering experiments at 33,[4] 40,[5,6] 46,[7] and 58[8] Mev all indicate that near 40 Mev α_1 is about 10° while α_3 lies between $-1°$ and $-4°$. The assumption that 40 Mev is a low enough energy for the pion-nucleon system to insure that the phase shifts below 40 Mev are simply proportional to momentum would therefore predict that $\alpha_1-\alpha_3=(0.3-0.35)p/\mu c$, and hence a zero energy cross section differing by a factor of four from the observed result. Further confirmation of the peculiar behavior of these phase shifts at low energy is given by Lederman's observation[3] of five scatterings of 5-Mev π^- mesons in hydrogen, corresponding to a cross section of 20 to 25 mb. In spite of poor statistics, this positive result is by no means trivial, since linear extrapolation from 100 Mev would predict 0.1 mb, and from 40 Mev, 5 mb. The combination of these two results, namely that $\alpha_1-\alpha_3$ is small and $\alpha_3+2\alpha_1$ is large near threshold clearly shows that *α_3 and α_1 must have the same sign near threshold* and not opposite signs as observed at higher energies.

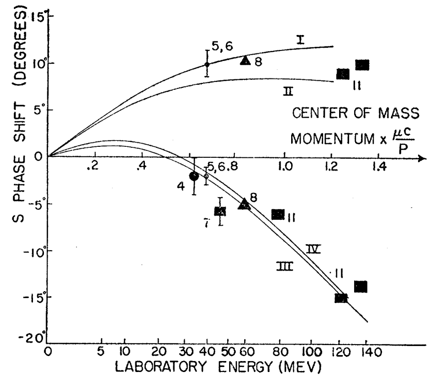

FIG. 1. S phase shifts *vs* center-of-mass momentum for models given in Table I. Numbers indicate references for data.

The purpose of this note is to point out that this is precisely the behavior predicted by the S-wave potential model proposed by Marshak[9] as extended by Woodruff.[10] The predictions of this model, which uses an attractive exponential for α_1 and a hard-core attractive exponential tail potential for α_3 (see Table I), are compared with experiment[4-8,11] in Fig. 1. Comparison with the threshold data is given in Table II. Since 20 mb is reached near 5.5 Mev, and the energy in Lederman's experiment is probably not as closely defined as this, the agreement with experiment is clearly very good.

It must be emphasized that the present success of this model does not justify taking it seriously in a quantitative sense. There is no good theoretical reason to expect a static potential model to hold up to energies equal to the rest mass of the pion, and as has already been pointed out in the nucleon-nucleon case,[12] a hard core, attractive tail potential is peculiarly sensitive to kinematic relativistic corrections. Further, until it is shown experimentally that the S phases are positive around 5 Mev, the possibility exists that both are negative, which would imply an energy dependence that could not be readily duplicated by any simple potential model. If this possibility is ignored, the results presented here are rather to be taken to indicate the qualitative features that a successful theory of the meson-nucleon force should exhibit, namely

TABLE I. Parameters for the potentials α_1: $V=-V_0\exp(-r/r_0)$; α_3: $V=\infty$, $r\le r_c$; $V=-V_0\exp[-(r-r_c)/r_0]$, $r>r_c$.

Phase shift	Model No.	V_0 (Mev)	r_0 $(\mu c)/\hbar$	r_c $(\mu c)/\hbar$
α_1	I	277	0.336	...
	II	105	0.465	...
α_3	III	187	0.428	0.386
	IV	163	0.460	0.375

TABLE II. Predictions at low energy.

Model α_1	α_3	$\lim_{E\to0} (\alpha_1-\alpha_3)\mu c/p$	σ_{tot}^- (5 Mev), mb
I	III	0.241	15
II	III	0.211	12
I	IV	0.185	17
II	IV	0.154	14
Experiment		0.16 ± 0.04	20–25