Table I. Delayed coincidence events observed in 1942 h with a 200-liter liquid scintillation detector at a depth of 1440 hg/cm^2 standard rock.

Time delay interval (μsec)	Trigger pulse (MeV)	Delayed pulse (MeV)
1.5	10	25
1.5	25	~20
2	60	30
2	90	10
2	25	25
2	25	25
3	120	20
3.5	~250	25
3.5	90	~15
3.5	165	10
4	10	5
4	40	30
~5.5	>200	25

I are, considering the small number of events, consistent with that expected from muon decay.

The number of cosmic rays expected to stop in the detector during the experiment is calculable from the slope of the depth-intensity curve[5] [1.16×10^{-11} cm^{-2} sec^{-1} sr^{-1} (g/cm^2)$^{-1}$] and the angular distributions. Since we had a low-Z scintillator, a negligible fraction of stopping muons would be expected to be nuclearly absorbed before decay. Accordingly, if the particles are muons, the number of decays observed should equal this number modified by the efficiencies. The calculation requires the detector aperture and the average path length in the detector for a penetrating particle. The aperture is obtained from the ratio of the rate at which cosmic rays were measured to penetrate the detector (8.4 h^{-1}) to the vertical intensity (5.1×10^{-7} cm^{-2} sec^{-1} sr^{-1}). The result is 4.5×10^3 cm^2 sr. The average path length through the detector is 61 g/cm^2. The number expected to stop is thus found to be 22; taking into account the angular distribution increases this number by ~10%. Thus the number of decays we expect to observe is about 9.

These results support the usual conclusion that the penetrating component consists only of muons, and cast doubt on the recent speculation of a weakly interacting primary.[7]

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Λp INTERACTION NEAR ΣN THRESHOLD*

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The conversion process $\Sigma^+n\to\Lambda p$ has been observed using the sequence $K^-d\to\pi^-(\Sigma^+n)\to\pi^-(\Lambda p)$. The results of this study are that (1) the conversion process at very low energy is dominated by the (ΣN) triplet state; and (2) the reaction is strongly enhanced for Λp masses below Σ^+n threshold, suggesting the existence of a bound state in the Σ^+n system and, hence, an elastic resonance in the Λp system.

As is well known, hyperon-nucleon scattering represents a formidable area of study for particle physics due to the present unavailability of rich hyperon beams. In absence of direct information the study of Y-N final-state interactions takes on considerable interest. In this note we present the essential details of a study of Λn interaction through the study of the process

$$K^-d\to\Lambda p\pi^-, \tag{1}$$

where the proton was specifically required to have a momentum that was unlikely for processes satisfying the impulse approximation. For the reasons outlined below we believe that in Reaction (1), Λp final-state interactions play an important role and that, furthermore, the existence of a resonance in the Λp system at a mass very near Σn threshold is suggested by the data presented here.

The study of Reaction (1) was carried out using film from a 400-MeV/c K^- exposure of the Lawrence Radiation Laboratory 25-in. bubble chamber.[1] This momentum was chosen because of the nearby occurrence of the $\Lambda(1520)$ in the K^-p channel which results in highly polarized Σ^+'s and Σ^+'s in the reactions[2]

$$K^-p \to \Sigma^\pm \pi^\mp. \tag{2}$$

Events of Reaction (1) were searched for by scanning for two-prong plus V events with the proton being identified by ionization on the scanning table. Events were analyzed using the Wisconsin space reconstruction-kinematic fitting programs DIANA-HASH. In this note we report on 1365 events of Reaction (1).

Figure 1(a) shows the Λp invariant-mass spectrum for all events of type (1). A strong enhancement near ΣN threshold is evident. Such an enhancement with smaller statistics has been previously observed for K^-d absorption at rest.[3] Figure 2(a) shows the Λp spectrum with a variety of cuts applied to the angle of the π^- with respect to the incident K^- direction in the K^-d center-of-mass system. The requirement of a forward-going π^- in the $\bar{K}d$ c.m. system considerably enhances the strong Λp peak near 2125 MeV. We interpret this angular dependence as evidence that the majority of events in the peak region are produced by the two-step process

$$\begin{array}{l} K^-d \to \pi^-(\Sigma^+ n) \\ \qquad\qquad \llcorner\!\!\to \Lambda p, \end{array} \tag{3}$$

$$\begin{array}{l} K^-d \to \pi^-(\Sigma^0 p) \\ \qquad\qquad \llcorner\!\!\to \Lambda p, \end{array} \tag{4}$$

with the forward-going π^- resulting in a predominantly low-momentum $\Sigma^{0,+}$.[4] Figure 1(b) shows a diagramatic representation (triangle diagram) of processes (3) and (4). The amplitude for diagram 1(b) can be written as[5]

$$M_{\text{triangle}} = M_A M_B M_C h,$$

where M_A, M_B, and M_C represent the amplitudes for the transitions A $(d \to np)$, B $(\bar{K}N \to \Sigma\pi)$, and C $(\Sigma N \to \Lambda N)$. The term h represents the effects of various kinematic factors. h is expected to have a variety of kinematic singularities. A basic assumption of our analysis is that the vertex-B process is identical to the scattering process of Reaction (2) and that the polarization and the spin-flip probability for the intermediate-state Σ is described by the known amplitudes for Reaction (2). The nature of the process at vertex A $(d \to pn)$ suggests that the neutron or proton will be predominantly at low momentum and also not far from the mass shell; this leads to the expectation that the reaction at vertex B will be dominantly at the same center-of-mass

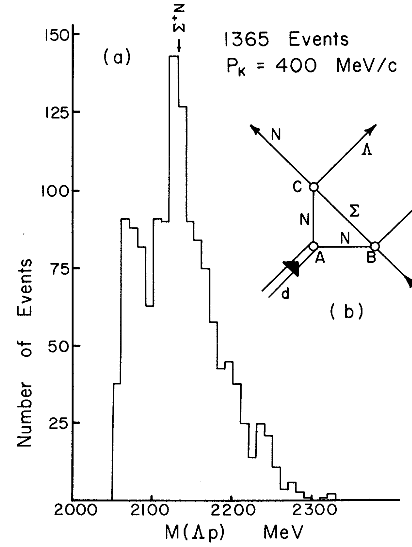

FIG. 1. (a) Λp invariant mass spectrum for Reaction (1). (b) The triangle diagram which is presumed to play an important role in Reaction (1) for Λp masses above 2100 MeV.

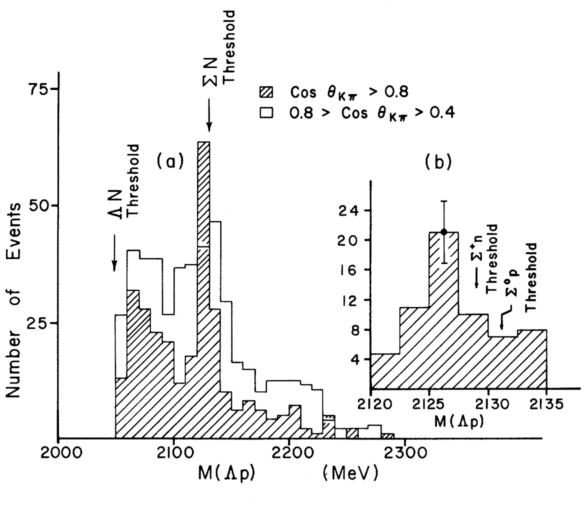

FIG. 2. (a) Λp invariant mass spectrum for two $\cos\theta_{K\pi}$ cuts, where $\theta_{K\pi}$ is the angle between the incident K and the outgoing π in the $\bar{K}d$ center of mass. (b) The mass region of 2120-2135 is shown with 2.5-MeV bins.

energy as that for collisions with free protons. In addition, the π^- angle in the overall K^-d system is expected to follow closely the π^- angle in the $\Sigma\pi$ rest system for $\bar{K}N \to \Sigma\pi$ in the intermediate state. The Σ^+ spin-flip amplitude at vertex B is expected to have a $\sin^2\theta \cos\theta$ dependence in the intermediate-state $\Sigma^+\pi^-$ rest system because of the interference of S and D waves for Reaction (2).[2] Therefore, for near-forward π^- the Σ spin-flip probability should be small, whereas for $\cos\theta_{K\pi} = 0.4\text{-}0.7$ the spin-flip probability should be large. If the spin-flip probability is small, the intermediate Σ^+n state will be in a ${}^3S_1$ state (the same as the deuteron state) whereas for large Σ spin-flip amplitudes the Σ^+n system will be prepared in a mixed ${}^3S_1$ and ${}^1S_0$ state (for the Σ^+n system with an invariant mass very near threshold). Figure 2(a) shows the Λp mass spectrum with $\cos\theta_{K\pi}$ cuts for which the Σ^+n system is expected to be predominantly in the triplet state ($\cos\theta > 0.8$) and for the cut which prepares a mixed triplet and singlet state ($0.8 > \cos\theta_{K\pi} > 0.4$). The sharp spike near ΣN threshold is strongly enhanced for the ΣN system prepared in the ${}^3S_1$ state while the peak is shifted up in mass and is not so pronounced in the mixed ${}^3S_1\text{-}{}^1S_0$ initial state. It should be especially noted that the overall shape of the Λp mass spectrum appears to change as a result of these cuts suggesting that the triplet $\Sigma^+n \to \Lambda p$ amplitude dies off much more rapidly below ΣN threshold than the ${}^1S_0 + {}^3S_1$ mixed state. Below the Λp mass of 2100 the internal conversion process probably does not play an important role. The extent to which this mass region is affected by Λp final-state interactions is presently being studied and will not be reported here. A study of the $\Sigma^0 p\pi^-$ final state in the present experiment indicates that the inverse process $\Lambda p \to \Sigma^0 p$ is not important. Figure 2(b) shows the Λp mass region from 2120 to 2135 MeV in 2.5-MeV bins. It is evident that the peak of the Λp spectrum is shifted below Σ^+n or $\Sigma^0 p$ threshold. We believe that resolution in this experiment is adequate to reliably observe such a shift as has been demonstrated by studying the unfitted Λ mass spectrum. Figure 3 shows the ratios $(F-B)/(F+B)$ and $(P-E)/(P+E)$ for the Λ angular distribution in the Λp center-of-mass system. The angular distribution becomes strikingly isotropic near 2130 MeV. This provides strong support that the process $\Sigma N \to \Lambda p$ is being observed in this experiment and that near ΣN threshold the orbital angular momentum state is primarily $l = 0$. In addition, the Λ polarization with respect to the normal to the $\bar{K}\pi$ plane appears large and is consistent with small depolarization as expected if the transition is dominated by the triplet state.[6]

The above considerations provide strong evidence that the ΣN conversion process is dominated by the triplet state for energies near threshold. The fact that the Λp mass spectrum is peaked <u>below</u> threshold suggests that there is a pole in the conversion process below ΣN threshold. The triangle-singularity mechanism would give a cusp <u>at</u> threshold. In reactions with all particles on the mass shell in the initial and final state it would only be possible to observe such a pole directly in the elastic Λp amplitude. However, if the Σ and N particles are allowed to go off the mass shell, as is possible in the present experiment, then the transition amplitude would be expected to display the effects of such a pole.

The nearness of the pole to Σ^+n threshold suggests that the state is probably a bound state of the Σ^+n system. The magnitude of the "binding energy" is ~3 MeV which is surprisingly similar to the binding energy of the deuteron. The fact that both systems are in ${}^3S_1$ states makes the analogy even stronger. This result provides per-

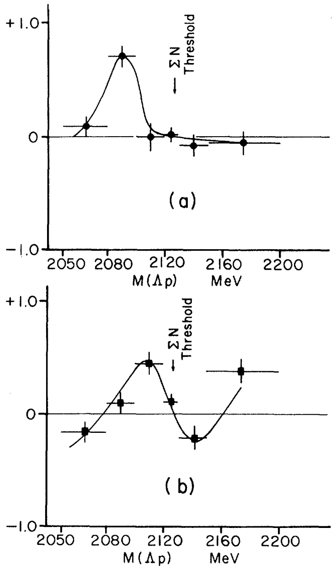

FIG. 3. (a) Forward-backward ratios in the Λp center of mass for the cut $\cos\theta_{K\pi} \geq 0.8$ and plotted as a function of Λp mass. Forward is defined for the Λ being in forward hemisphere with respect to the direction of the Λp center-of-mass system. (b) Polar-equatorial ratios in the Λp rest system for the cut $\cos\theta_{K\pi} > 0.8$ and as a function of Λp mass.

haps some evidence for SU(3) symmetry of the baryon-baryon amplitudes.[7] The conclusion that the $I=\frac{1}{2}$ triplet ΣN system may have a bound state is consistent with observations of low-energy Σ^-p scattering and absorption.[8] The low-energy Σ^-p cross sections are above the unitarity limit for pure triplet scattering, suggesting that at least the triplet channel is very important.[8]

In summary, the results presented here suggest that the ΣN conversion process is dominated by the triplet channel near threshold and that a bound state of the ΣN system exists with a binding energy of ~3 MeV and coupled to the open Λp channel. Since the Λp channel is the only open channel, an elastic resonance in the Λp system is implied with a mass of 2126 MeV and a width of less than 10 MeV.

We wish to thank Professor C. Goebel for a discussion on threshold anomalies. In addition, thanks are due to Mr. E. Shettle for help with data analysis and to members of the Bevatron operations staff and the 25-in. bubble chamber staff for a pleasant exposure.

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SOME RADIATIVE MESON DECAY PROCESSES IN CURRENT ALGEBRA

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The two-body radiative decays of nonstrange vector and pseudoscalar mesons are calculated by using the technique of current algebra, partial conservation of axial-vector current, and hard pion and eta. The predictions agree quite well with the available experimental results.

As far as it is known to us, the problem of calculating the two-body radiative decay of vector and pseudoscalar mesons in current algebra remains unsolved. In fact, it was shown by Sutherland[1] that because of the conditions of gauge invariance alone, the decays $\pi^0\to 2\gamma$, $\eta^0\to 2\gamma$, $\omega^0\to\pi^0\gamma$, etc., are inhibited in the conventional current algebra with partially conserved axial-vector current (PCAC) and the soft-pion (eta) limits. The technique of hard pion in the context of current algebra, recently introduced by Schnitzer and Weinberg,[2] has now enabled us to calculate the two-body radiative decays of vector and pseudoscalar mesons. The predictions agree quite well with the presently available experimental results. In deriving the results we have made use of the Gell-Mann–Okubo type of first-order symmetry-breaking relation between the pion, kaon, and eta decay constants as well as some results from the Weinberg sum rules.[3,4] We have also assumed the vector dominance model of Gell-Mann, Sharp, and Wagner[5] in relating the process which involves a single photon to that consisting of two photons. It may be mentioned that the present work indicates yet another success of the technique of current algebra with PCAC, hard pion, and the vector dominance, which has already been used with success to correlate the processes[2,6] $\rho\to\pi\pi$, $A_1\to\rho\pi$; $K^*\to K\pi$, $K_A\to K^*\pi$; to predict the π-π and π-N scattering lengths[7,8]; and also to calculate the K_{l3} form factors in weak decays.[9]

Let us first consider the two-photon processes $\pi^0\to 2\gamma$, $\eta_8\to 2\gamma$, and $X_1\to 2\gamma$, where η_8 and X_1 are the