been demonstrated by means of a $\gamma-\alpha$ coincidence experiment that a $\gamma$-ray transition from the 17.63-Mev (1+) state of $Be^8$ occurs to the level concerned. In 1952 Trumpy, Grotdal, and Graue[7] repeated the $Li^7(d,n)Be^8$ experiment, confirmed the presence of a state at 4.1 Mev, and suggested a new state at 2.2 Mev. More recently, the Bristol group,[8] using the same reaction, have clearly resolved a group corresponding to a level at 4.05 Mev and at the same time confirm the presence of a group corresponding to a state at 2.2 Mev. Later, photodisintegration experiments[9,10] on the reactions $B^{11}(\gamma,t)Be^8$ and $B^{10}(\gamma,d)Be^8$ confirm the results mentioned in the foregoing.

(b) *Evidence against a 4.9-Mev $\gamma$-Emitting State*. In our photographic plate experiments on $B^{10}(\gamma,d)Be^8$ and $C^{12}(\gamma,\alpha)Be^8$ with $\gamma$ rays from the $Li^7(p,\gamma)$ 440-kev resonance, we have made a careful search for events which would correspond to formation of a $\gamma$-emitting state of $Be^8$ at 4.9 Mev. Such events would be characterized by an energy deficit of 4.9 Mev, the presence of two low-energy $\alpha$ particles from the ground state of $Be^8$ (provided the lifetime of the state is shorter than $10^{-12}$ sec) and, since the $\gamma$-ray momentum is negligible, the events should still satisfy momentum balance. Such events have not been observed in the boron experiments. However, "low-energy" events are observed in the $C^{12}(\gamma,\alpha)Be^8$ experiment but, in general, they are not characterized by the presence of the ground state of Be.[8] It has been shown[11,12,6] that they correspond to a weak $\gamma$-ray line in the $Li^7(p,\gamma)$ spectrum located at 12.3 Mev. These results, while not conclusive, indicate that, if a 4.9-Mev state of $Be^8$ exists at all, it is either long-lived or does not lead to $\gamma$-ray emission.

The original suggestion of the level came from the Rice group[13] who detected $\gamma$ rays of 4.9-Mev energy in the $Li^7(d,n)Be^8$ reaction. If their interpretation is correct, the $\gamma$ ray should be in coincidence with a neutron. Such coincidences have been searched for in an an experiment undertaken in the University of Melbourne,[14] the preliminary results of which are against the presence of coincidences.

The conclusions of these experiments are supported by recent work at the Rice Institute,[15] where it is now believed the original results can be explained as due to effects arising from the competing reaction $Li^7(d,p)Li^8(\beta^-)$.

(c) *The 5.3-Mev State of $Be^8$*. The first evidence for a state in this general vicinity came from the photodisintegration reactions,[4,5] $B^{10}(\gamma,d)Be^8$ and $B^{11}(\gamma,t)Be^8$. Apart from this, several observers noticed the "low-energy" $C^{12}(\gamma,3\alpha)$ events induced by the $Li^7(p,\gamma)$ radiation which were mentioned above. Nabholz, Stoll, and Wäffler[11] suggested that they were caused by a $\gamma$ ray of 12.7-Mev energy formed in a cascade transition via the reported 4.9-Mev state of $Be^8$. It was shown by Titterton[12] that this was unlikely and the alternative suggestion was made that the transition took place through the even state of $Be^8$ at 5.3 Mev observed in the photodisintegration experiments. To elucidate the point, a $(\gamma-\alpha)$ coincidence experiment was undertaken in this laboratory by Inall and Boyle,[6] the results of which confirm the presence of the 5.3-Mev state.

The new work at Bristol[8] on the neutron spectrum from $Li^7(d,n)Be^8$ gives further confirmation of these results—a clearly separated group is found corresponding to a state at 5.2 Mev.

(d) *The 7.5-Mev State of $Be^8$*. Evidence for this broad level was given by Richards[16] [$Li^7(d,n)Be^8$] and confirmed by Green and Gibson[3] in later experiments. The $(\gamma-\alpha)$ coincidence experiment[6] mentioned above gives direct confirmation of the assignment, and a recent $\alpha-\alpha$ scattering experiment by Steigert and Sampson[17] requires a state at 7.65 Mev, of spin zero, for its interpretation. This spin assignment is compatible with the $\gamma$-ray intensity observed in the $Li^7(p,\gamma)$ Canberra experiment[6] which implies a magnetic dipole or electric quadrupole transition.

The body of evidence outlined above strongly indicates the presence of even states of $Be^8$ at 4.05, 5.3, and 7.5 Mev, and a study of the $(\gamma-\alpha)$ angular correlations in the reaction $Li^7(p,\gamma)Be^8 \times(\alpha)He^4$ currently in progress in this laboratory should enable spin assignments to be made in due course.

In addition to these levels, others have been suggested in the energy region under consideration, namely: 2.2 Mev,[7,8,10] 3.4 Mev,[10] 4.62 Mev,[18] 4.9 Mev (even state; not $\gamma$ emitter),[10] and 6.8 Mev.[10] As pointed out by Malm and Inglis in their Letter, more experimental evidence is required before these can be regarded as established.


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## Kinematics of $\Lambda^0$ Production*


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CLOUD-CHAMBER observations by the Princeton Cosmic-Ray Group indicate that an appreciable fraction of $\Lambda^0$ particles produced in heavy elements (lead and copper) have low kinetic energies in the laboratory system.[1] At least 10 percent of the observed $\Lambda^0$ particles have energies below 70 Mev; whereas chamber bias against the observation of high-energy $\Lambda^0$ particles is not serious below a few Bev.

In order to investigate the implications of this result, we have considered the kinematics of several fundamental interactions which might lead to $\Lambda^0$ production, of the type

$$m_0+m_1 \rightarrow m+m_2+\cdots, \qquad (1)$$

where $m_0$ is the incident particle (pion or nucleon), $m_1$ the target nucleon, $m$ the $\Lambda^0$ particle, $m_2$ a secondary particle, and the possibility is allowed that additional particles may be produced in the interaction. The essential assumption is that the interaction occurs with a single nucleon in the nucleus. It is also assumed that the $\Lambda^0$ particle suffers no appreciable loss of energy in escaping from the nucleus.

We then find that it is difficult to explain the large fraction of low-energy $\Lambda^0$ particles if the production is isotropic in the center-of-mass system. There is of course no *a priori* reason why the production should be isotropic; but the departure from isotropy indicated by our results is so pronounced as to merit quantitative discussion.

Let $P(E_0,<E')$ be the probability that an incident particle of energy $E_0$ in the target-nucleon rest frame $\Sigma$ gives rise to a $\Lambda^0$ particle of energy $<E'$ in the laboratory frame $\Sigma'$, taking into account the internal motion of the nucleons in the nucleus. Let $P(E_0,E)dE$ be the probability that the incident particle produce a $\Lambda^0$ particle of energy between $E$ and $E+dE$ in the $\Sigma$ frame; and let $w(E,<E')$ be the probability that this $\Lambda^0$ particle have energy $<E'$ in the $\Sigma'$ frame. Then,

$$P(E_0,<E')=\int P(E_0,E)w(E,<E')dE. \qquad (2)$$

To obtain the function $w(E,<E')$—which expresses the effect of the internal motion of the target nucleons—a Fermi gas model of the nucleus was adopted, with maximum nucleon kinetic energy of 20 Mev (our final numerical results are insensitive to this choice

of upper limit). The expression for $w$ is lengthy and will not be written here.

To obtain the function $P(E_0,E)$, it is necessary to specify the details of reaction (1). It turns out that for the particular reactions and energies considered here, the probability of obtaining low-energy $\Lambda^0$ particles (<70 Mev) is greatest when no "additional" particles are produced in reaction (1). With the neglect, then, of "additional" particles, the $\Lambda^0$ energy $E$ in the $\Sigma$ frame can be expressed as a unique function of the incident particle energy $E_0$ and the angle $\theta^*$ of the $\Lambda^0$ particle in the center-of-mass frame,

$$E=A(E_0)+C(E_0)\cos\theta^*, \tag{3}$$

where the functions $A(E_0)$ and $C(E_0)$ are lengthy, but easily obtained by standard methods of collision kinematics. Then

$$P(E_0,E)=u(\cos\theta^*)/C(E_0), \tag{4}$$

where $u(\cos\theta^*)d(\cos\theta^*)$ gives the angular distribution of $\Lambda^0$ production in the center-of-mass system; $\cos\theta^*$ is to be expressed here as a function of $E$, by means of Eq. (3).

We consider in the first place the case of isotropic $\Lambda^0$ production $[u(\cos\theta^*)=\frac{1}{2}]$. The results for four possible reactions are shown in Fig. 1, where the probability for producing $\Lambda^0$ particles below 70

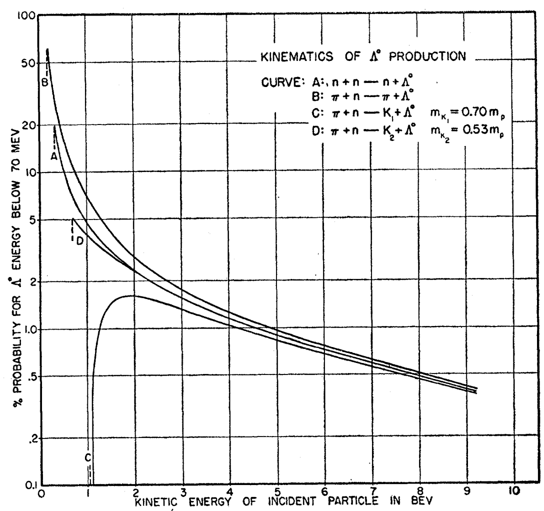


FIG. 1. Probability for $\Lambda^0$ energy less than 70 Mev in the laboratory frame, expressed as a function of the incident particle energy in the target-nucleon rest frame (for the large energies involved, this does not differ appreciably from the incident particle energy in the laboratory frame). These results are for the case of isotropic $\Lambda^0$ production. In curve C, the mass of the $K$ meson is taken to be 1300 $m_e$; in curve D, $970m_e$.

Mev in the laboratory frame is plotted against the energy of the incident particle in the target-nucleon rest frame. The curves begin at the respective threshold energies; at large energies they coincide and go as $E_0^{-1}$. Only for reactions $A$ and $B$ is it possible to obtain probabilities larger than 10 percent and then only very near threshold.

Several explanations may be suggested to account for the large fraction of low-energy $\Lambda^0$ particles. Consider an anisotropy of the form

$$u(\cos\theta^*)=\tfrac{1}{2}(n+1)\,|\cos^n\theta^*|.$$

It can then be shown from Eqs. (2) and (4) that

$$P_n(E_0,<E')<(n+1)P_0(E_0,<E').$$

Thus to explain our observed results, on the basis of anisotropy and assuming $\Lambda^0$'s to be produced well above threshold in the cosmic-ray beam, we require $n>6$.

Alternately, one might consider $\Lambda^0$ production to result from a multiple process, or cascade, in which $\pi$'s or nucleons produce $\pi$'s which in turn produce $\Lambda^0$'s at energies near threshold. However, the Brookhaven results[2] indicate that $\Lambda^0$'s produced by 1.5-Bev $\pi$'s (i.e., near threshold energy) also show a strong backward peaking in the center-of-mass system.

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## Small-Angle Neutron-Proton Scattering at 90 Mev*

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THE relative neutron-proton differential cross section has been measured for several angles near zero degrees. This range of angles has been difficult to investigate because of the very short range of the recoil protons. Previously published work,[1–5] done by measurement of proton recoils, has not covered these angles. However, some cloud-chamber experiments are currently in progress at this laboratory[6] in which recoil protons are employed in this range.

The neutron beam was obtained by stripping 190-Mev deuterons on a $\frac{1}{2}$-in. beryllium target in the 184-inch Berkeley cyclotron. A steel shielding block 6 ft long×6 in. high×3 in. thick was placed close to the beam on the same side as the counters to reduce background.

The target was of liquid hydrogen contained in a cylindrical vessel of 5.6-in. diameter with axis vertical. The beam dimensions at the target were 3 in. high×1 in. wide. A bismuth fission counter was employed as a beam monitor.

Scattered neutrons were counted at small angles to the neutron beam. Figure 1 shows the neutron counter, which consisted of the

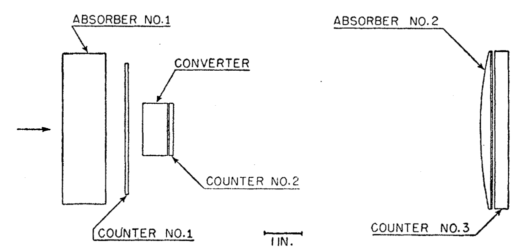


FIG. 1. Arrangement of components of neutron counter.

following components, listed in the order that they would be traversed by a scattered particle: (a) absorber number 1, 25 g cm$^{-2}$ of copper to prevent protons from reaching the scintillation counters directly; (b) scintillation counter number 1, made of plastic scintillant 4.0 in.×3.5 in.×0.080 in. thick; (c) the converter, 1.74 g cm$^{-2}$ of polyethylene; (d) scintillation counter number 2, a liquid counter with active volume 2.2 in.×1.4 in. ×0.118 in. thick; (e) absorber number 2, which was from 1.0 to 1.8 g cm$^{-2}$ of copper plus a shaped aluminum absorber of maximum thickness 1.8 g cm$^{-2}$; (f) scintillation counter number 3, made of plastic scintillant 6.6 in.×4.2 in.×0.4 in. thick. The distance from the center of the target to the center of the converter was 48 in. for the range of the laboratory scattering angle $\Theta$ from 18.5° to 5.0° and 70 in. for the range of 5.0° to 2.5°.

The neutrons actually counted were those that were "converted" in the polyethylene converter or in counter number 2. The term "converted neutron" refers to a neutron that yields a high-energy proton by $n$-$p$ scattering or nuclear interaction. These recoil protons were counted in coincidence in counters 2 and 3. In order to reject charged particles originating in other