have been calculated using harmonic oscillator radial wave functions. Results for diagonal and nondiagonal elements in states of lowest total angular momentum J, using a charge symmetric operator, $T_{12}=(\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2)$, are expressed in Table I in terms of radial integrals defined later.

TABLE I. Noncentral force matrix elements for $(3d)^2$ configuration with harmonic oscillator wave functions and symmetric charge operator.

	Tensor force				Spin-orbit force			
$\langle {}^{2T+1,2S+1}L_J \mid {}^{2T+1,2S+1}L_{J'} \rangle$	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
$\langle {}^{33}P_0 \mid {}^{33}P_0 \rangle$	$\frac{7}{6}$	$-\frac{5}{3}$	$+\frac{7}{6}$		-7	$+10$	-7	
$7^{-\frac{1}{2}}\langle {}^{13}S_1 \mid {}^{13}D_1 \rangle$	$-\frac{31}{60}$	$+\frac{19}{12}$	$-\frac{17}{12}$	$+\frac{3}{4}$				
$\langle {}^{13}D_1 \mid {}^{13}D_1 \rangle$	$\frac{14}{15}$	$-\frac{65}{84}$	$-\frac{7}{6}$	$+\frac{3}{4}$		$\frac{51}{2}$	-21	$\frac{27}{2}$
$7^{\frac{1}{2}}2^{-\frac{1}{2}}\langle {}^{33}P_2 \mid {}^{33}F_2 \rangle$		1	$-\frac{7}{5}$					
$\langle {}^{33}F_2 \mid {}^{33}F_2 \rangle$	$\frac{1}{5}$		$-\frac{1}{5}$		$-\frac{2}{3}$		$-\frac{22}{3}$	
$3^{-\frac{1}{2}}\langle {}^{13}D_3 \mid {}^{13}G_3 \rangle$	$-\frac{3}{10}$	$+\frac{33}{98}$	$-\frac{1}{2}$	$+\frac{9}{14}$				
$(28)^{-1}\langle {}^{13}G_3 \mid {}^{13}G_3 \rangle$		$+\frac{55}{7}$		$+15$		210		630

1. The corresponding matrix elements for the remaining allowed values of J are given by the relations:

Tensor force	Spin orbit force
$\langle {}^{33}P_0\rangle=-2\langle {}^{33}P_1\rangle=10\langle {}^{33}P_2\rangle$	$\langle {}^{33}P_0\rangle=2\langle {}^{33}P_1\rangle=-2\langle {}^{33}P_2\rangle$
$2\langle {}^{13}D_1\rangle=-2\langle {}^{13}D_2\rangle=7\langle {}^{13}D_3\rangle$	$2\langle {}^{13}D_1\rangle=6\langle {}^{13}D_2\rangle=-3\langle {}^{13}D_3\rangle$
$5\langle {}^{33}F_2\rangle=-4\langle {}^{33}F_3\rangle=12\langle {}^{33}F_4\rangle$	$3\langle {}^{33}F_2\rangle=12\langle {}^{33}F_3\rangle=-4\langle {}^{33}F_4\rangle$
$28\langle {}^{13}G_3\rangle=-20\langle {}^{13}G_4\rangle=55\langle {}^{13}G_5\rangle$	$4\langle {}^{13}G_3\rangle=20\langle {}^{13}G_4\rangle=-5\langle {}^{13}G_5\rangle.$

2. Results for a neutral charge operator $T_{12}=1$ may be derived from the above by multiplying matrix elements involving singlet charge states by -3^{-1}, and leaving triplet charge state elements unaltered.

3. The radial integrals $I_l(a, b)$ are functions of the force range a and wave function parameter b, and are defined as follows:

$$I_l(a, b)=\int_0^\infty R_l^2(r, b)V(r, a)dr.$$

The single particle wave functions,

$$R_l(r, b)=N_l \exp[-(r/2b)^2]r^{l+1},$$

are subject to the normalizing condition

$$\int_0^\infty R_l^2(r, b)dr=1,$$

which yields

$$N_l^2=2[(2l+1)!!b^{2l+3}(2\pi)^{\frac{1}{2}}]^{-1}.$$

4. For a Yukawa type distance dependence, i.e., $V(r, a) =Be^{-r/a}(r/a)^{-1}$, the integrals $I_l(ab)$ may be calculated either by the method of Talmi[3] or from the Hh functions tabulated in the British Association Mathematical Tables, Vol. I (1931), by using the relation

$$I_l(a, b)=2^{l+1}l!\exp(b^2/2a^2)(a^2/2\pi b^2)^{\frac{1}{2}}Hh_{2l+1}(b/a).$$

Values of the $I_l(a, b)$ for the distance dependence suggested by Case and Pais,

$$V(r, a)=\frac{-Ba^2}{r}\frac{d}{dr}(e^{-r/a}(r/a)^{-1}),$$

may be obtained from those evaluated for Yukawa by using a relation established by Elliott:[4] Replace each function $Hh_{2l+1}(b/a)$ by $(a^2/b^2)\{(2l)^{-1}Hh_{2l-1}(b/a)-Hh_{2l+1}(b/a)\}$.

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[1] G. Racah, Phys. Rev. **62**, 438 (1942).
[2] An account of an application of these results to early d shell nuclei is given in a thesis for the degree of PhD (London) which the author proposes to submit shortly.
[3] I. Talmi, Helv. Phys. Acta **25**, 185 (1952).
[4] J. P. Elliott, Ph.D. thesis, London, 1952 (unpublished).

Observation of V^0 Particles Produced at the Cosmotron*

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TWO definite examples of V^0 particles similar to those found in cosmic rays by many workers[1] have been observed in a cloud chamber exposed to a neutron beam from the Cosmotron. These two cases, in addition to several other less definite ones, were found in a total of about 4000 photographs scanned up to date. Further work is in progress.

The events were observed when the machine was operating with a circulating beam of 10^8 to 10^9 protons per pulse, reaching an energy of about 2.2 Bev. The protons were allowed to strike carbon targets 1.25 in. and 2.5 in. thick. Neutrons emerged through a 1-in.×2-in. hole in the shielding wall, located at 0° to the proton beam direction. The number of the neutrons can only be estimated very roughly, and their energy distribution is not known at the present time except that the maximum energy is 2.2 Bev. The neutron beam passed through a permanent magnet which deflected charged particles away from the cloud chamber, and then through 1.5 in. or 3 in. of lead into the cloud chamber. A diffusion cloud chamber was used, filled with hydrogen at 18 atmospheres and methyl alcohol vapor. A pulsed magnetic field of 11 000 gauss was applied.

The V^0 particles show the characteristic inverted V-shaped track originating in the cloud-chamber gas. Their identification follows from the usual arguments.[1] In this case the identification is especially certain because neutron-proton collision processes in hydrogen can only result in events with an odd number of prongs rather than 2-prong events such as V particles. The amount of alcohol present is less than that used in expansion cloud chambers, very few stars produced in the alcohol were seen, and it is very unlikely that "alcohol stars" could have the appearance of V particles.

The photographs are shown in Figs. 1 (event A) and 2 (event B).

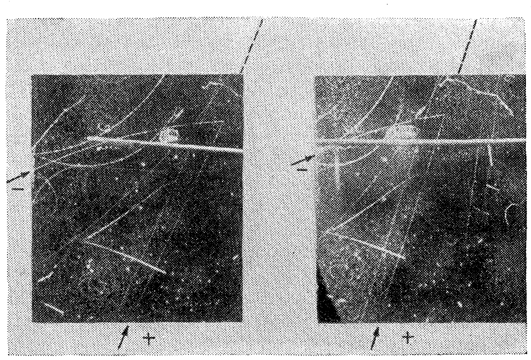

FIG. 1. Stereoscopic photograph of V^0 decay "A." Its apex is just above the horizontal bar across the picture, which is a sweeping field electrode suspended above the sensitive layer of the cloud chamber. The tracks pass underneath this electrode, not through it. The dashed line at the top of the picture points toward the part of the lead shield struck by the neutron beam. Information concerning the V^0 is given in Table I.

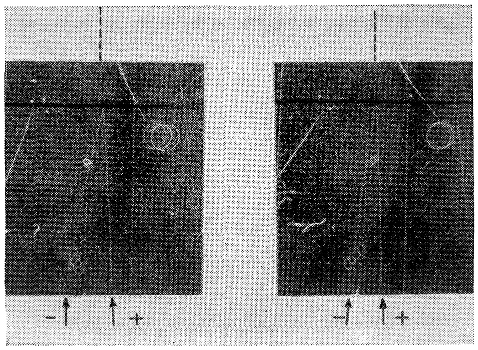

FIG. 2. Stereoscopic photograph of V^0 decay "B." Its apex is just below the horizontal bar across the picture, which is a sweeping field electrode suspended above the sensitive layer of the cloud chamber. The apex of the V^0 particle is vertically separated from the sweeping field electrode by about 5 cm in depth. The dashed line at the top of the picture points toward the part of the shield struck by the neutron beam. Information concerning the V^0 is given in Table I.

The details of the events are given in Table I. For both cases the given momenta and ionization densities show that the negative particles are light particles, most probably π-mesons.[1] The identification of the positive particles is not definite, although in both cases their ionization densities appear to be somewhat larger than minimum. If this were certain, these particles could be identified as protons, and V_1^0 particles ($V_1^0 \rightarrow p+\pi^- + Q_1$) would be involved. The Q values calculated for this assumption are given in Table I. They agree with the generally accepted $Q_1 = 35$ to 40 Mev. Assuming that these particles were produced in the lead or possibly in the steel wall of the chamber, lower and upper limits for their lifetimes are also given. These lifetimes are high compared to the lifetime of the V_1^0 of 3×10^{-10} sec given in the literature.[1] The parameter $\alpha=(P_+^2-P_-^2)/P_0^2$ may have any value between the limits given with equal probability. Both computed values for α fall within these ranges.

TABLE I. Data on V^0 particles.

		Event A	Event B
Positive particle	Momentum, P_+	910 ± 230 Mev/c	1200 ± 180 Mev/c
	Estimated density of ionization	>1 (?), $<2\times$minimum	>1 (?), $<2\times$minimum
Negative particle	Momentum, P_-	72 ± 3 Mev/c	270 ± 30 Mev/c
	Estimated density of ionization	$3\times$minimum	$1\times$minimum
Angle between tracks		$61.5\pm1°$	$26\pm1°$
V^0 momentum, P_0		940 ± 240 Mev/c	1450 ± 210 Mev/c
Manchester parameter, $\alpha=(P_+^2-P_-^2)/P_0^2$		0.92	0.65
If V_1^0	Q value	39 ± 16 Mev	37 ± 8 Mev
	Lifetime (10^{-10} sec)	>8, <12	>5, <8
	Range for possible values of α	0.40 to 0.98	0.45 to 0.93
If V_2^0	Q value	236 ± 55 Mev	157 ± 30 Mev
	Lifetime (10^{-10} sec)	>3, <5	>2, <3
	Range for possible values of α	-0.90 to $+0.90$	-0.85 to $+0.85$

If one assumes that V_2^0 particles ($V_2^0 \rightarrow \pi^+ + \pi^- + Q_2$) are involved, the calculated Q values are also consistent with the value of $Q_2 = 190$ Mev given in the literature.[1] The lifetimes are again higher than the mean lifetime of 10^{-10} sec for V_2^0. Here both of the computed values for α lie at the upper end of the possible ranges for α. This fact, the particularly good agreement of the calculated Q values with Q_1, and the apparently somewhat higher-than-minimum ionization density of the positive decay products, make it more probable that the observed particles are V_1^0 rather than V_2^0.

Assuming that the V^0 is produced in a collision of an incident neutron of maximum energy of 2.2 Bev with a nucleon in a nucleus, which may have itself an energy of 20 Mev, the maximum energy available in the center-of-mass system of the two nucleons is 1.11 Bev, which would be just sufficient to produce the total mass of a V_1^0. But then the kinetic energy of the V_1^0 in the laboratory system could be at most 400 Mev. The actual kinetic energies observed (assuming V_1^0) are 349 ± 140 and 714 ± 150 Mev for events A and B, respectively. The high kinetic energy observed for B, if not in error, rules out this possibility experimentally. Production of V_1^0 from pre-existing nucleons, singly or in pairs,[2] or of (V_1^0, V_2^0) pairs, would still be consistent with the present observations. The possibility of single V_1^0 production by 230-Mev π^- mesons has already been indicated by Schein.[3]

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

[1] *Progress in Cosmic Ray Physics*, edited by J. G. Wilson (Interscience Publishers, Inc., New York, 1952), Chapter II by C. C. Butler, pp. 65–123; Leighton, Wanlass, and Anderson, Phys. Rev. **89**, 148 (1953); Fretter, May, and Nakada, Phys. Rev. **89**, 168 (1953); Bridge, Peyrou, Rossi, and Safford (to be published); Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953). All references to previous work are cited in these articles.
[2] A. Pais, Phys. Rev. **86**, 663 (1952). References to previous work are cited in this article.
[3] M. Schein, *Proceedings of the Third Annual Rochester Conference on High Energy Physics* (Interscience Publishing Company, New York, 1953).

K Mesons

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SIX K mesons[1] coming to rest in the emulsion have been observed in a series of 600 μ Ilford G5 plates exposed to the cosmic radiation at balloon altitude (140 cm³ of emulsion×hours of flight above 70 000 feet). Most of the plates were exposed under a copper absorber 3 cm thick. Among these K mesons, three are ejected from stars (see Fig. 1);[2] their ranges are sufficiently long (5000μ, 6000μ, and 9000μ) to allow accurate measurements of their masses. Two of the three remaining mesons are observed in favorable conditions to give some indication of the nature of the secondary particles.

(1) *Mass measurements of the K mesons emitted from stars.*—Scattering-range measurements have been carried out by several observers using different methods. One observer derives the scattering angle from measurements made with continously variable cell-lengths, as suggested by the Brussel group; while others employ the method indicated by the Bristol group.[3] All the measurements yield results in good agreement.

Ionization measurements have been made with a specially designed set-up to determine the opacity of the track by means of a photomultiplier associated to a microscope.[4,5] Appropriate corrections have been made to take into account the depth as well as the dip of the track. The results thus obtained are perfectly consistent, allowing good precision. This precision has been controlled by means of particles of known mass.

The measurements are listed in Table I. If we put together

TABLE I. Mass measurements for the three events.

	Star[a]	K meson[b] Length μ	Mass from scatt. range	Mass from ioniza. range	Secondary Length μ	Ionization[c]
K_{P_2}	$13+18p$	4950	850 ± 150	902 ± 80	155	0.85 ± 0.2
K_{P_3}	$9+2p$	6040	1065 ± 160	1015 ± 85	a few grains	
K_{P_4}	$6+1p$	9000	920 ± 130	910 ± 75	850	1.0 ± 0.1

[a] The notation $m+np$ is used to describe a star initiated by a singly charged primary: m indicates the number of heavy tracks (black and gray) and n that of minimum ionization.
[b] The masses are expressed in terms of electron rest-mass.
[c] The ionizations are relative to the plateau.

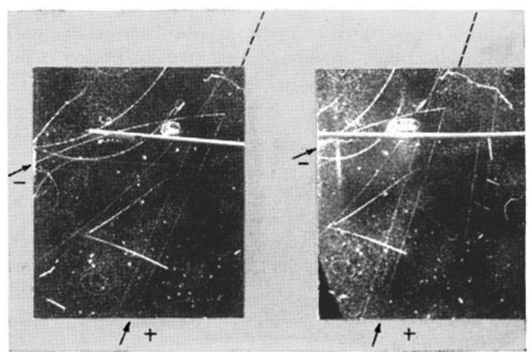

FIG. 1. Stereoscopic photograph of V^0 decay "A." Its apex is just above the horizontal bar across the picture, which is a sweeping field electrode suspended above the sensitive layer of the cloud chamber. The tracks pass underneath this electrode, not through it. The dashed line at the top of the picture points toward the part of the lead shield struck by the neutron beam. Information concerning the V^0 is given in Table I.

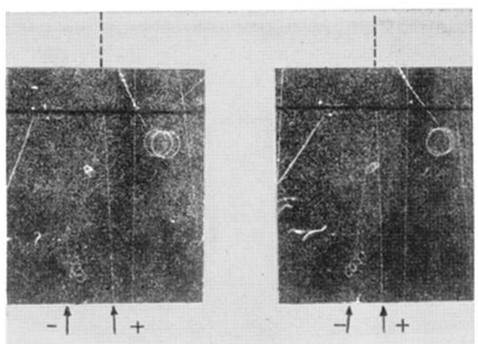

FIG. 2. Stereoscopic photograph of V^0 decay "*B*." Its apex is just below the horizontal bar across the picture, which is a sweeping field electrode suspended above the sensitive layer of the cloud chamber. The apex of the V^0 particle is vertically separated from the sweeping field electrode by about 5 cm in depth. The dashed line at the top of the picture points toward the part of the shield struck by the neutron beam. Information concerning the V^0 is given in Table I.