Here S is the total spin, $\boldsymbol{\sigma}_1$ and $\boldsymbol{\sigma}_2$ are the Pauli spin matrices for particles 1 and 2, θ and ϕ are the c.m. scattering angles, k is the c.m. momentum/$\hbar$ of each proton, ϵ is the c.m. total energy of each particle/mc^2, $\eta=e^2/\hbar v$, with v the incident velocity in the laboratory system and $\mathbf{n}$ is the unit normal to the scattering plane $(\mathbf{n}=(\mathbf{k}_i\times\mathbf{k}_f)/|\mathbf{k}_i\times\mathbf{k}_f|)$.[2] In order to make M_c reduce to the exact nonrelativistic formula, M_{c+} as given by Eq. (1) was multiplied by the Coulomb phase factor $\exp[-2i\eta\times\ln\sin(\theta/2)]$ for the numerical computations.

The total scattering matrix is $M=M_c+M_N$, where M_N is the nuclear scattering matrix which can be expressed in terms of phase shifts in the manner of Ashkin and Wu,[3] except that each factor $[\exp(2i\delta_L{}^J)-1]$ has been multiplied by $\exp 2i(\eta_L-\eta_0)$, where $\eta_L=\arg\Gamma(1+L+i\eta)$. The scattering matrix M so expressed may be substituted into the formulas of Wolfenstein and Ashkin[4] for the unpolarized cross section $\sigma(\theta)$ and the polarization $P(\theta)$:

$$\sigma(\theta)=\tfrac{1}{4}\,\mathrm{Tr}MM^+,\quad \sigma(\theta)P(\theta)\mathbf{n}=\tfrac{1}{4}\,\mathrm{Tr}MM^+\boldsymbol{\sigma}_1,\qquad(3)$$

giving expressions for σ and P in terms of the phase shifts.

This has been done for the case where only s and p phase shifts are supposed to exist, yielding expressions for σ and P in terms of the following $\delta_L{}^J$; $\delta_0{}^0$, $\delta_1{}^0$, $\delta_1{}^1$, and $\delta_1{}^2$. Calculations reported previously[5] enable one to select, subject to the restriction to $L<2$, all phase shifts consistent with isotropy of the unpolarized cross section and any given values of σ and P in the angular region where Coulomb effects are negligible. For such angles experimental data gives $\sigma(\theta)=3.56$ mb/sterad, $P(45)^\circ=0.22$, at 213 Mev.[6–7] By the use of these values the possible $\delta_L{}^J$ are limited to values lying on a one-parameter curve with four branches, in the space of the four $\delta_L{}^J$. These branches differ from each other in the sign of $\delta_0{}^0$ and of the $\delta_1{}^J$. Thus, if a certain point on one branch is $\delta_0{}^0$, $\delta_1{}^J$ the corresponding points on the other branches are $\pm\delta_0{}^0$, $\pm\delta_1{}^J$ (all of the $\delta_1{}^J$ preserve the same sign relative to each other). For the present calculation the values of the phase shifts given in Table I of the previously published letter[5] (which are representative points on one of these branches corresponding to 200 Mev) have been revised to fit the lower value of $\sigma(\theta)$ quoted above.

Of all possible phase shifts so determined, seven sets were found which also give $\sigma(\theta)$ in accord with the small-angle measurements,[8–9] where Coulomb effects are important. These are given in Table I, along with values of the corresponding polarization at 15°, where the Coulomb interference effect is strongest.[10]

TABLE I. Phase shifts $\delta_L{}^J$ for 213 Mev chosen to fit the following data: $\sigma(\theta)=3.56$ mb/sterad independent of θ with no Coulomb interference, $\sigma(15°)=1.02\sigma(90°)$, $|P(45°)|=0.22$. The last column gives the polarization at 15°.

Set	$\delta_0{}^0$	$\delta_1{}^0$	$\delta_1{}^1$	$\delta_1{}^2$	$P(15°)$
a	29	48	−7	−7	−0.133
b	20	−13	25	−12	−0.106
c	0	−69	5	4	0.065
d	37	−37	6	10	0.103
e	−36	41	−6	−8	−0.120
f	−38	−31	4	12	0.112
g	−30	10	−16	17	0.132

It turns out that the spin-dependent term in the Coulomb scattering matrix, Eq. (1), plays a negligible role in the unpolarized cross section, while for the polarization it is of about the same importance as the spin-independent term.

Recent experiments at Harwell[11] at 133 Mev indicate that $P(\theta)$ does not vary as $\sin(2\theta)$ between 30° and 45° c.m. The Coulomb effects are not large enough at these angles to explain the divergence, so that there appears to be some contribution from other than s and p waves at this energy.

Further details about these and related calculations will be published later. The author wishes to thank Professor Lincoln Wolfenstein, who suggested looking into Coulomb interference effects, for his interest and valuable advice. He is also grateful for helpful discussions with Professors Gian-Carlo Wick and Julius Ashkin.

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High-Energy Electron Pair Produced by 113-Mev Positive Pion*

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A HIGH energy pair of electrons has been found in a nuclear emulsion exposed to the 122-Mev positive pion beam of the University of Chicago synchrocyclotron.

During measurements on positive pion-proton scattering,[1] 600-micron Ilford G-5 plates were scanned for "possible hydrogen events," that is, all stars which in addition to the incident pion had a single black prong in the forward hemisphere. The average energy of the pions in the plate is 113±2 Mev. These "possible

hydrogen events" were examined under high magnification to determine whether one or more light tracks were also associated. One example of a pair of light tracks, assumed to be electrons, was found (Fig. 1).

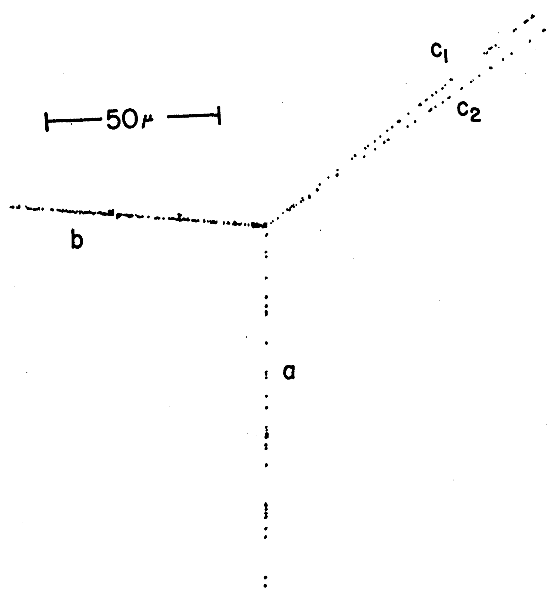

FIG. 1. Electron pair produced by 113-Mev positive pion: a, incident pion; b, proton of 75±10 Mev or other fragment of same ionization; c_1, c_2 electrons of 27±9 and 56±14 Mev, respectively.

The angle between the two electron tracks θ is 5.2 ±1.0° and the angle between the direction of the incident pion and the direction of the center of mass of the pair ϕ is 62±2°. The energies of the two electrons are 27±9 Mev and 56±14 Mev. These data are consistent with the earlier results obtained on the negative-pion-produced pairs[2] except for the angle ϕ, which is smaller than any of the angles reported earlier and which seemed in the earlier work to have an improbably sharp distribution centered around 115° in the laboratory system. Since this is the only case in the positive beam, the significance of the occurrence of such an angle is not clear.

In the area scanned for this experiment, there were $(1.56\pm0.05)\times10^5$ cm of pion track.[2] Since the mean free path for pions at very nearly the same energy[3] is 33.6±17 cm, approximately 4600 interactions must have occurred. Approximately one-eighth of these would be "possible hydrogen events" as described earlier. Thus one pair was found in about 600 stars examined.

There is no visible gap on this pair, and a gap would have been seen if it were as large as one micron.

It is suggested that this pair can be interpreted as the result of the charge-exchange scattering of a pion on a neutron in a nucleus of the emulsion:

$$\pi^+ + n \rightarrow \pi^0 + p, \qquad (1)$$

followed by the direct decay of the neutral pion, as predicted by Dalitz[4] and as observed by various authors:[5]

$$\pi^0 \rightarrow e^+ + e^- + \gamma. \qquad (2)$$

Process (1) is the charge-symmetric analog of the process which was used to explain the pairs in the negative pion beam:

$$\pi^- + p \rightarrow \pi^0 + n. \qquad (3)$$

Since there are approximately as many neutrons as protons in the emulsion the cross sections for (1) and (3) should be nearly the same, which is not inconsistent with the results reported here. The lack of a visible gap between the pair and the star is in agreement with the short lifetime reported earlier.

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Long-Lived Radioactive Aluminum 26*

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THERE are experimental[1–5] and theoretical[6–9] indications of a state in Al^{26} lying below the 6-second positron-emitting 0^+ state. The ground state apparently[4,5] lies 4.0 Mev above that of Mg^{26} and is expected[6–9] to have a 5^+ configuration. If the Mg^{26} states at 1.83 and 2.97 Mev[10] both have 2+ configurations, Al^{26g} should decay predominantly by positron emission to the 1.83-Mev state with a half-life estimated[4,9] at 10^4–10^6 years, with smaller amounts of electron capture to both states.

We have sought radioactivity in aluminum carrier isolated from a target of commercial magnesium bombarded with 400 μa-hr of 15-Mev deuterons in the University of Pittsburgh cyclotron. After numerous NH_4OH precipitations at pH∼6, numerous NaOH precipitations of $Fe(OH)_3$, and two 8-hydroxyquinoline precipitations, the aluminum was weighed and counted as Al_2O_3 ("Alx"). It was then dissolved by a $Na_2B_4O_7$ fusion and put through a cycle consisting of: NH_4OH precipitation at pH∼6 with Zn hold-back carrier; CuS precipitation in dilute HCl; $BaSO_4$ precipitation