we see that to first order in $Z\alpha$:

$$\Phi(Z,E,k)=\frac{F(Z,E)}{F(Z,\,E+k)}\Phi(E,k). \tag{30}$$

The analogy with the Elwert correction in external bremsstrahlung is obvious. The theory of internal bremsstrahlung has been used primarily to predict photon intensity relative to the electron intensity.

We see from (30) that the ratio of photon intensity to electron intensity is less sensitive to the influence of the Coulomb field than either intensity by itself. There is a partial cancellation of the Coulomb effects on the two intensities in taking the ratio. Lewis and Ford[6] express the hope that a similar cancellation will take place in the higher order corrections. The second order terms which have been neglected, however, are not simply wave function normalization factors, and there is therefore no reason to anticipate further cancellations. The second order Coulomb terms are somewhat more difficult to calculate. A discussion of the $(Z\alpha)^2$ corrections will be given in a subsequent paper. It is our hope to investigate their bearing on the disagreement with the present theory, which has recently been reported by several experimenters.[7]

In closing we wish to express our gratitude to Professor R. J. Glauber, who suggested the problem, for many helpful discussions.

[7] K. Liden and N. Starfelt, Phys. Rev. **97**, 419 (1955); N. Starfelt and N. L. Svantesson, Phys. Rev. **97**, 708 (1955); H. Langevin-Joliot, thesis, Paris, 1956 (unpublished).

PHYSICAL REVIEW VOLUME 107, NUMBER 6 SEPTEMBER 15, 1957

Elastic Scattering of a Σ^+ Hyperon from a Free Proton*

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(Received June 3, 1957)

An event has been found in nuclear emulsion which is interpreted as an elastic scattering of a Σ^+ hyperon from a free proton. The center-of-mass scattering angle was 125 degrees and the energy of the hyperon at the point of scattering was 22.9 Mev.

DURING a systematic study of the interactions of K^- mesons in nuclear emulsion, an event was found which is interpreted as an elastic scattering of a Σ^+ hyperon from a free proton. A photomicrograph of this event is shown in Fig. 1. A K^- meson, which was identified by ionization *versus* range, came to rest and produced a star with only one prong, track A. After traversing 4.79 mm of emulsion, prong A interacted yielding prongs B and C. Prong B then decayed at rest into a lightly ionizing track D which interacted in flight after traversing 28.2 mm of emulsion. The decay was characteristic of a Σ^+ hyperon which decayed at rest into a π^+ meson. Prong C originated at the point of scattering and went 1.52 mm before stopping with a ρ-ending.

An important feature of the event is the coplanarity of the tracks A, B and C. Track A made an angle of only 0.2±1.5 deg with the plane of tracks B and C. The coplanarity suggests a two-body collision. From the measured angles and ranges that appear in Table I and energy and momentum conservation laws, the mass of the scattered particle can be calculated in a number of ways.[1] The results of seven of these calculations are shown in Table II. In the second column appear the measured quantities that were used in each method for calculating the mass, in the third column the conservation laws that were used, and in the fourth column the resulting mass values. In the third column E, LM, and TM stand for the conservation laws of energy, longitudinal momentum (the total momentum parallel to the direction of the incident particle A), and transverse momentum (the total momentum perpendicular to the direction of A in the plane of ABC), respectively. In method 5 the mass of the scattered particle, B, depends on the direction of the incident particle, A, but not on its mass. In method 7 the calculated mass is independent of the direction of the incident particle but not of its mass. In all calculations except for method 5 the mass of the incident particle was assumed to be the same as that of the scattered particle B, and particle C was assumed to be a proton.

* Work performed under auspices of U. S. Atomic Energy Commission.
[1] Gilbert, Violet, and White, Phys. Rev. **103**, 1825 (1956).

TABLE I. Range and angle measurements from event 659.

Prong	Range (mm)	θ^b (deg)
$A(\Sigma^+)$	4.79[a]	75.6±1.5
$B(\Sigma^+)$	0.161±0.003	152.4±1.5
$C(p)$	1.52 ±0.02	131.8±1.5

[a] This range was measured from the K^- capture point to the scattering point.
[b] Angle θ is the angle opposite the prong listed in the first column (i.e., the angle between the two other prongs).

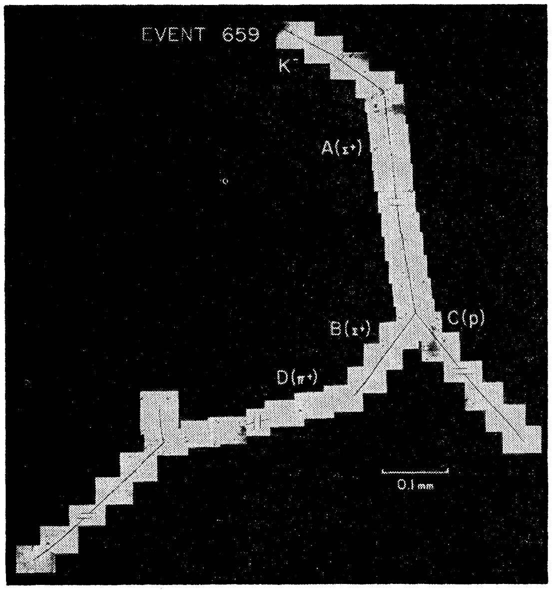

FIG. 1. Photomicrograph of the scattering of a Σ^+ hyperon from a free proton in nuclear emulsion. A K^- meson is captured at rest to produce one charged particle, $A(\Sigma^+)$. Particle A scatters from a proton, $C(p)$, and continues on as $B(\Sigma^+)$. Particle B comes to rest and decays into a π^+ meson, $D(\pi^+)$, which interacts in flight.

These assumptions were roughly checked from measurements on the tracks themselves. From ionization *versus* multiple scattering the mass of prong A was found to be $(1.3\pm0.2)m_p$. Measurement of the scattering by the constant sagitta method on prong C gave a mass of $(1.4\pm0.6)m_p$. Prong B was too short for a reliable mass estimate.

It is stressed that the mass calculations are not independent and the best measure of the mass of the scattered particle may be obtained almost equally well from methods 2, 3, or 4. The values for the mass of the scattered particle that were obtained from the collision calculations are in good agreement with the known mass[2] of the Σ^+ hyperon of 1189 Mev. Because of the coplanarity of the three tracks, the agreement of the measured Σ^+ hyperon mass with the accepted value, the agreement among the values obtained by the different methods of calculation, and because of the lack of a blob, electron, or recoil track at the point of scattering which would indicate a scattering event from a bound proton, the event is interpreted as an elastic scattering of a Σ^+ hyperon from a free proton in the emulsion. The kinetic energy of the Σ^+ hyperon at the point of scattering is 22.9 Mev and the angle of scattering in the center-of-mass system of the Σ^+ hyperon and proton is 125 deg.

To the best of our knowledge no other example of the elastic scattering of a Σ^+ hyperon from a free proton has been observed.[3] As this type of event would not easily escape observation by other experimenters, it is of some interest to estimate the total path length of the Σ^+ hyperons that have been observed to date. The authors have followed only 6 cm of Σ^+ hyperon track. It is estimated that as of April, 1957 a total of about 100 cm of hyperon track[4] has been followed by all emulsion groups. As 500 cm of track corresponds to a 60-millibarn cross section (approximately geometric) for interactions with free protons in emulsion, it is not surprising that only one event has been seen to date.

TABLE. II. Mass of prong B (or A) as calculated from measurements of Table I.

Method	Measurements used[a]	Conservation laws used[b]	Mass (Mev)
1	R_B, R_C, θ_{AC}	E, LM, TM	1360±340
2	R_B, R_C, θ_{AB}	E, LM, TM	1218±35
3	R_B, θ_{AB}, θ_{AC}	E, LM, TM	1221±38
4	R_C, θ_{AB}, θ_{AC}	E, LM, TM	1222±38
5	R_B, R_C, θ_{AB}, θ_{AC}	TM	1203±103
6	R_B, R_C, θ_{AB}, θ_{AC}	E, LM	1225±51
7	R_B, R_C, θ_{BC}	E, LM, TM	1230±220

[a] R_B and R_C here stand for ranges of particles B and C, respectively. Angles θ_{AC}, θ_{AB}, and θ_{BC} are the angles between particles A and C, A and B, and B and C, respectively.
[b] E indicates conservation of energy; LM indicates conservation of longitudinal momentum; and TM indicates conservation of transverse momentum.

ACKNOWLEDGMENTS

The authors wish to acknowledge the excellent support given by Dr. E. Lofgren and his associates during exposures at the Berkeley Bevatron. The event was found by Mrs. Henrietta Fankhauser.

[2] See for example, Gilbert, Violet, and White, Phys. Rev. **107**, 228 (1957).

[3] Interactions of Σ^+ hyperons in flight with nuclei in emulsion have been observed by Fry, Schneps, Snow, and Swami, Phys. Rev. **100**, 939 (1955); and by R. G. Glasser and N. Seeman, Phys. Rev. **107**, 277 (1957).

[4] From data presented at the 1957 Rochester Conference on High-Energy Physics it is estimated that about 10 000 K^- captures have been observed in nuclear emulsion. In about 5% of the captures an identified Σ^+ hyperon is emitted. As the mean range of the Σ^+ hyperon is about 2 mm of emulsion, the resulting total path in emulsion is about 100 cm. An additional 20 cm of path length in liquid hydrogen, whose density was near that of the hydrogen density in emulsion, has been followed with no Σ^+ hyperon-proton scattering events (private communication from R. D. Tripp of the Berkeley hydrogen bubble chamber group).

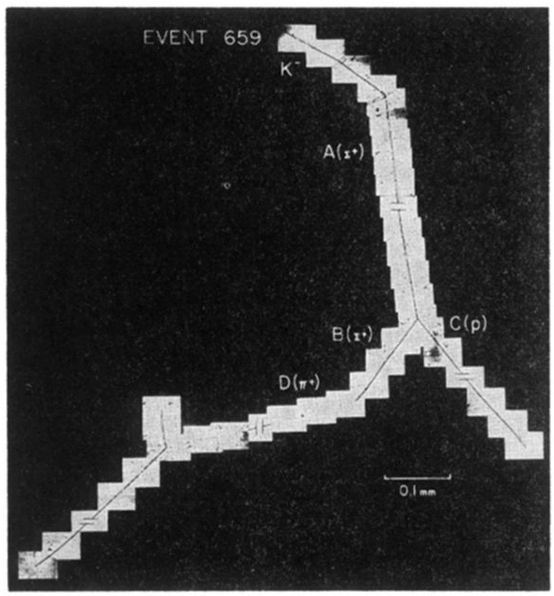

FIG. 1. Photomicrograph of the scattering of a Σ^+ hyperon from a free proton in nuclear emulsion. A K^- meson is captured at rest to produce one charged particle, $A(\Sigma^+)$. Particle A scatters from a proton, $C(p)$, and continues on as $B(\Sigma^+)$. Particle B comes to rest and decays into a π^+ meson, $D(\pi^+)$, which interacts in flight.