Nuclide 99^{254}†

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The nuclide 99^{254} has previously been reported[1,2] and found to decay[2,3] with a half-life of 36 hours by emission of β^- particles. Further investigation has revealed the existence of another isomer of 99^{254} which decays almost entirely by emission of alpha particles. The 36-hour isomer has been found to exhibit electron-capture branching to produce Cf^{254}.

1. *The long-lived isomer.*—Samples of the 20-day 6.6-Mev alpha-emitting 99^{253} subjected to neutron bombardment were shown by alpha pulse analysis to contain a nuclide emitting 6.44 ± 0.01 Mev alpha particles. This new alpha radioactivity showed no decrease in intensity during 3 months, so that the nuclide responsible for it must have a half-life longer than about 2 years.

Chemical purification of the 99^{253} by the method of ion-exchange elution, using Dowex-50 cation resin and ammonium α-hydroxy-isobutyrate as eluant,[4] showed that the 6.44-Mev alpha emitter could not be separated from element 99.

Its assignment, based on the systematics of alpha radioactivity,[5,6] was most logically to mass 254. This assignment was confirmed by collecting recoil nuclei from a very thin sample of the new alpha emitter. These daughter nuclei were shown to decay, by emission of β^- particles, with a half-life of approximately 3 hours. This radiation is characteristic of Bk^{250}.[7]

The absence of any 7.2-Mev alpha particles of 100^{254} [1,2,3,8] in equilibrium with this long-lived isomer of 99^{254} shows that the partial half-lives of the latter species for both β^- decay and isomeric transition to the 36-hour isomer are more than 100 times longer than the alpha half-life. It is perhaps more likely that the 36-hour isomer is the metastable state, and it will be convenient provisionally to refer to it as 99^{254m}.

2. *Electron capture in* 99^{254m}.—Preliminary experiments[9] showed that a californium isotope decaying by spontaneous fission, with no detectable emission of alpha particles, grew into very carefully purified samples containing 99^{253}, 99^{254}, 99^{254m}, and 99^{255}. The californium exhibited a half-life of 85 ± 15 days. This observation has since been repeated and confirmed with much larger amounts of activity.

The californium isotope responsible for such a short-lived spontaneous fission decay is most likely of even mass, and is therefore probably Cf^{254}, since Cf^{250} and Cf^{252} are already known. [7,10,11] Some Cf^{256} might have been formed by electron capture decay of the (unknown) nuclide 99^{256}, which might have been present in the sample. However, 99^{256} is expected to be short-lived,[12] and any Cf^{246} produced by its electron-capture decay would have been removed in the initial purification of the 99 sample. Samples containing only 99^{253} and 99^{254} exhibit only a very small spontaneous fission activity. The Cf^{254} must therefore grow from the 36-hour 99^{254m}, by the electron-capture process, and not from the 99^{254}. The amount of Cf^{254} produced by a known amount of 99^{254m} gave a value of 1000 for the ratio of β^- decay to electron capture.

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[1] Harvey, Thompson, Ghiorso, and Choppin, Phys. Rev. **93**, 1129 (1954).
[2] Fields, Studier, Mech, Diamond, Friedman, Magnusson, and Huizenga, Phys. Rev. **94**, 209 (1954).
[3] Choppin, Thompson, Ghiorso, and Harvey, Phys. Rev. **94**, 1080 (1954).
[4] Choppin, Harvey, and Thompson (unpublished work).
[5] Perlman, Ghiorso, and Seaborg, Phys. Rev. **77**, 26 (1950).
[6] Ghiorso, Thompson, Higgins, and Harvey, Phys. Rev. **95**, 293 (1954).
[7] Ghiorso, Thompson, Choppin, and Harvey, Phys. Rev. **94**, 1081 (1954).
[8] Studier, Fields, Diamond, Mech, Friedman, Sellers, Pyle, Stevens, Magnusson, and Huizenga, Phys. Rev. **93**, 1428 (1954).
[9] Ghiorso, Harvey, Choppin, and Thompson (unpublished work).
[10] Diamond, Magnusson, Mech, Stevens, Friedman, Studier, Fields, and Huizenga, Phys. Rev. **94**, 1083 (1954).
[11] Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. **93**, 908 (1954).
[12] Glass, Thompson, and Seaborg, J. Inorg. and Nuclear Chem. **1**, 3 (1955).

Absorption Experiments Involving Heavy Mesons

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The purpose of this note is to point out that several interesting properties of some of these new elementary particles may be obtained by performing certain absorption experiments.

Absorption of K^- by deuteron.—We consider the following reactions:

$$K^- + d \rightarrow \Sigma^0 + \pi^- + p, \qquad (A_1)$$

$$K^- + d \rightarrow \Sigma^- + \pi^0 + p, \qquad (A_2)$$

$$K^- + d \rightarrow \Sigma^- + p. \qquad (B_1)$$

The reactions (A_1) and (A_2) are of interest because they may give a direct verification as to whether in the strong interactions of these new particles the total isotopic spin is a good quantum number or not. It may be emphasized that while *charge independence* has become a fundamental principle used in almost all recent theoretical analyses of these particles,[1] no evidence as to its validity concerning these particles has yet been established. We note that if the total isotopic spin is conserved and if we assume that (a) there exists no charged particle of about the same mass as Λ^0 and (b) there exists no doubly charged particle of about the same mass as either Σ^- or K^-, then from the known reactions,[2]

$$\pi^- + p \rightarrow \Lambda^0 + K^0,$$
$$\pi^- + p \rightarrow \Sigma^- + K^+,$$

it is necessary to assume that the isotopic spin values for these particles are

$$I_\Lambda = 0, \quad I_K = \tfrac{1}{2}, \quad \text{and} \quad I_\Sigma = 1,$$

which is precisely the Gell-Mann scheme.[3] Thus, charge independence would imply that the differential cross sections for the above reactions (A_1) and (A_2) are the same.

$$\sigma(A_1) = \sigma(A_2).$$

On the other hand, information concerning the spins of K^- and Σ^- can be obtained by performing the reaction (B_1) together with its inverse reaction:

$$\Sigma^- + p \rightarrow K^- + d. \qquad (B_2)$$

From the principle of detailed balance the ratio of cross sections for these two reactions gives immediately the ratio $(2J_K+1)/(2J_\Sigma+1)$ with J_K and J_Σ as the spins of K^- and Σ^-, respectively.

Charge independence may also be verified by other reactions from K^- and d. However, they all involve some reactions with too many neutral particles as resultants, which make these reactions much harder to detect.

Absorption of K^- *by* He^4 *or* C^{12}.—It is also possible to verify the validity of charge independence by examining the absorption of K^- by He^4. We consider the following reactions:

$$K^- + He^4 \rightarrow \Sigma^0 + H^3, \qquad (C_1)$$

$$K^- + He^4 \rightarrow \Sigma^- + He^3, \qquad (C_2)$$

$$K^- + He^4 \rightarrow \Lambda^0 + H^3 + \pi^0, \qquad (D_1)$$

$$K^- + He^4 \rightarrow \Lambda^0 + He^3 + \pi^-, \qquad (D_2)$$

$$K^- + He^4 \rightarrow \Sigma^0 + He^3 + \pi^-, \qquad (E_1)$$

$$K^- + He^4 \rightarrow \Sigma^- + He^3 + \pi^0. \qquad (E_2)$$

If charge independence were true, the differential cross sections of the above reactions are related by

$$\sigma(C_2) = 2\sigma(C_1),$$
$$\sigma(D_2) = 2\sigma(D_1),$$
$$\sigma(E_1) = \sigma(E_2).$$

The same relations between these reactions still hold if one uses C^{12} instead of He^4 and adds two α particles to the right-hand sides of the above reactions.

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[1] See A. Pais, Proceeding of the Fifth Annual Rochester Conference on High-Energy Physics (to be published) for a review of these analyses.
[2] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **93**, 861 (1954).
[3] M. Gell-Mann, Phys. Rev. **93**, 933 (1953).

Further Observations of Negative *K* Mesons*

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CONTINUED examination of the emulsions for which observations of negative K mesons have been reported[1] has revealed 22 such particles producing stars at the end of their range. Measurements of the masses of those particles are presented below.

The experimental arrangement was like that sketched earlier,[2] but with the following differences: the proton energy was 2.8 Bev, the collimator aperture was narrowed to 1 inch, the mesons incident on the emulsions were emitted at $(4\pm1)^\circ$ to the proton beam, and a magnet M (10 000 gauss) was interposed between the collimator and the stack of emulsions. The masses of the K^- mesons have been determined from their initial momenta and their ranges in the emulsions.

The mean momentum p of the meson beam was established in two ways. One way depended on measurements of the Cosmotron's magnetic field and the locations and orientations of target and collimator. This gave (310 ± 4) Mev/c for p; the error is due mainly to uncertainty in the value of the Cosmotron's field strength. The other way depended on the deflection of the negative pion beam by the magnet M; for this the collimator was narrowed to $\frac{1}{4}$ inch and the deflection was measured by locating the displaced pion beam in the emulsions. The correlation between p and deflection was established by the wire method to an accuracy of 0.5 percent. This procedure gave (316 ± 4) Mev/c for p; the error is due mainly to the statistical uncertainty in locating the beam's center in the emulsions.

An average of the two methods is taken, namely $p = (313\pm3)$ Mev/c. The average spread in momentum is ±8 Mev/c.

The emulsions were conditioned before packing in an atmosphere of 60 percent relative humidity. The spread in K^- ranges is entirely consistent with a unique mass value and the average spread in momentum. The average range of the K^- mesons is (45.8 ± 0.8) mm, a figure that includes a small allowance for packing material and a correction for distortion. Masses were computed with the range-energy relationship of