SPONTANEOUS EMISSION OF ENERGETIC He^6 PARTICLES FROM Cf^{252}†

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(Received 12 July 1965)

We have observed what appear to be He^6 particles spontaneously emitted from a Cf^{252} source. This is the first observation, to our knowledge, of the spontaneous emission of particles (other than fission fragments) heavier than He^4 from nuclei.[1-2] Long-range alpha-particle emission from Cf^{252} is well known. Energetic He^4 particles are observed in coincidence with fission, and are believed to be emitted at the time of scission.[3] The emission of[4-7] H^3 and[5] H^5 from Cf^{252} has also been reported. Although it has not yet been shown experimentally that the emission of charged particles other than He^4 is associated with fission, such a conclusion, from energy considerations, seems inescapable.

It appears probable that particles even heavier and of higher charge number than He^6 are emitted, although more rarely; in particular, we have found evidence for He^8, lithium, and beryllium. The identification of these products is much less certain than that of He^6, because of their relative rarity and the result of a control experiment with the Cf^{252} source removed.

In our experiments we also clearly observe the emission of energetic H^1 and H^3 particles. The yield of H^2 is apparently much lower than those of its isotopic neighbors, in agreement with Wegner's observation.[5] In our studies He^3 is masked to a large extent by dispersion from the relatively much more abundant He^4.

The charged particles were detected in a ΔE-E counter telescope consisting of two silicon semiconductor detectors: a totally depleted "ΔE" detector, 47 μ thick, followed by an "E" detector, depleted to a depth of 400 μ. Aluminum foils, totaling 7.6 mg/cm^2 in surface density, prevented fission fragments and natural-decay alpha particles from reaching the detectors. Amplified pulses from the detectors were analyzed by a two-parameter pulse-height analyzer. A typical display is shown in Fig. 1, where the ΔE pulse height is proportional to the ordinate, and the summed pulse height $E+\Delta E$, to the abscissa of the two-dimensional plot. Particles that stop in the ΔE detector produce points that lie along the diagonal line corresponding to ΔE equal to $E+\Delta E$. Particles that penetrate into the E detector must deposit less than their full energy in the ΔE detector and therefore produce points that lie below the diagonal line. The point of departure from the line and the locus of points for higher particle energy is dependent on the charge and mass of the particle and on the thickness of the ΔE detector. The loci for the various particles were calculated from the range-energy relations of Williamson and Boujot.[8] Their results for He^4 were extended to He^6 and He^8 by the customary assumption that the ratio of the range to mass is represented by the same function of the velocity for all masses of particles with the same charge. Our energy calibrations are based upon the response of the detectors individually to the 6.11-MeV natural-decay alpha particles from Cf^{252} and the response of the amplifiers to a pulser.

The particles detected in greatest abundance are the long-range alphas. We have therefore used the points due to these particles to determine the actual thickness of the ΔE detector. The calculated loci for H^1, H^3, He^6, and He^8 are shown on Fig. 1. For the 60-h run shown in Fig. 1 a fairly large number of events are observed along the locus for He^6. A few events corresponding to particles of higher mass and/or charge number than He^6 are also seen in Fig. 1. The experiment was repeated with different ΔE and E detectors (including one 100μ ΔE detector) with essentially the same results. A series of runs made with reduced gain to search for more highly ionizing particles than He^6 resulted in the detection of five events with the E versus $E+\Delta E$ characteristics of lithium (with masses between six and eight) and three events attributable to beryllium. These eight, especially energetic, events were accompained by approximately 10 000 long-range alpha particles. A background run of comparable duration, with the Cf^{252} source removed, yielded one event (berylliumlike) in the region beyond helium, however. Therefore our evidence for the spontaneous emission of particles heavier or of higher charge than He^6 is not conclusive.

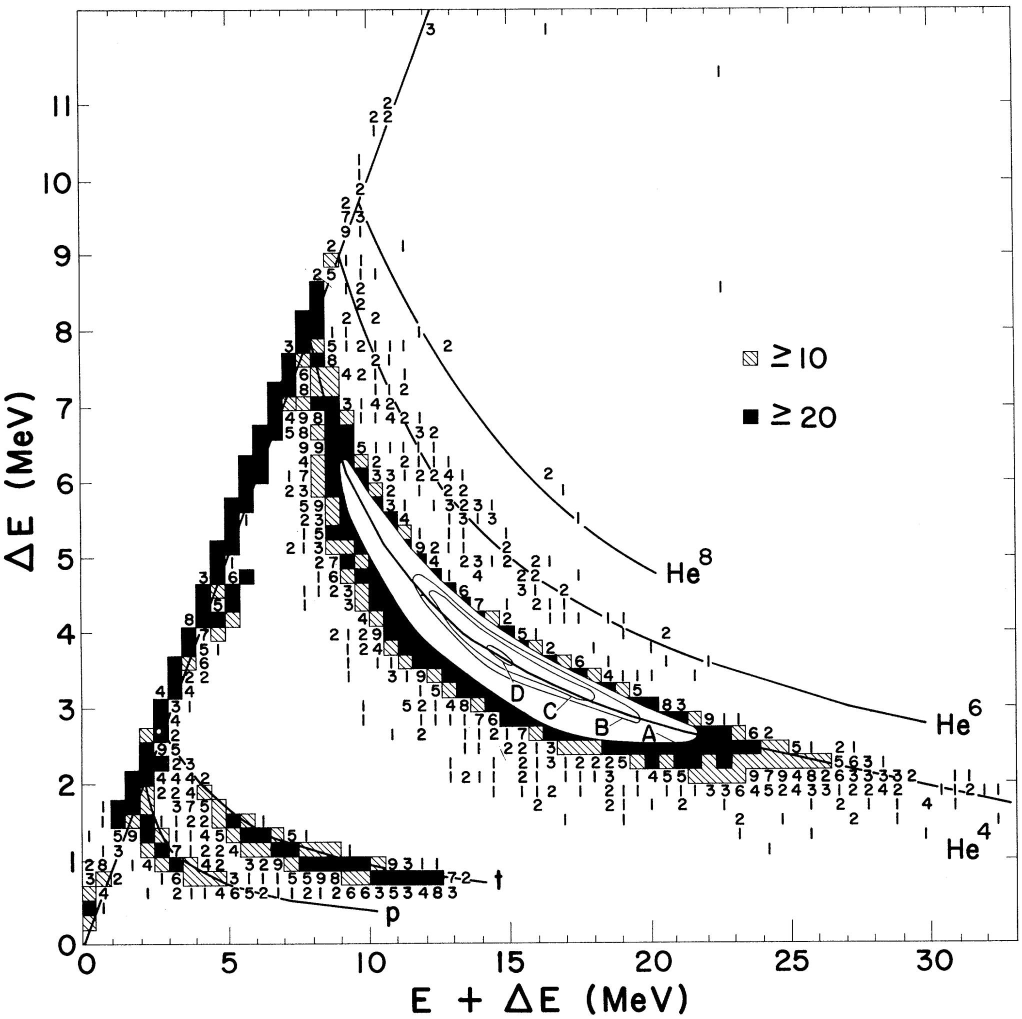

FIG. 1. ΔE versus $E+\Delta E$ characteristics of particles emitted from Cf^{252}. The contour lines are drawn at 40 events (A), 80 events (B), 100 events (C), and 140 events (D). Dark shading indicates 20 or more events, light shading 10 or more.

The energy spectrum of He^6 particles detected is shown and compared with that of He^4 in Fig. 2. These data have been corrected for energy loss in the aluminum cover foil. Although the statistical uncertainties are large, it appears that the peak of the He^6 spectrum is at a lower energy than that of He^4.

In this run 119 He^6 events were detected, with energies above 13.5 MeV. Above this energy there were 8190 long-range alpha particles, giving 1.45 ± 0.13 He^6 particles per hundred He^4. Extrapolating our measured spectrum for He^4 from 11.4 down to 1.5 MeV using the results of Nobles's measurement,[6] we find the number of He^6 (with energy greater than 13.5 MeV) per long-range alpha particle to be $119/11\,700 = (1.02 \pm 0.10) \times 10^{-2}$. This is a lower limit for the He^6 yield. If the He^6 spectrum is approximately symmetric about 13.5 MeV, the total yield of He^6 relative to the long-range alpha particles is about 2×10^{-2}, or about 6 $\times 10^{-5}$ per fission.

The phenomenon of "channeling" in the passage of particles through crystalline materials can cause a small fraction of the particles to lose considerably less energy than expected in traversing the ΔE detector.[9] This loss of pulse height from the ΔE detector is regained in the $\Delta E + E$ summed pulse height. As a result, for example, some of the relatively abundant long-range alpha particles are dispersed into the vicinity of the He^3 locus, effectively

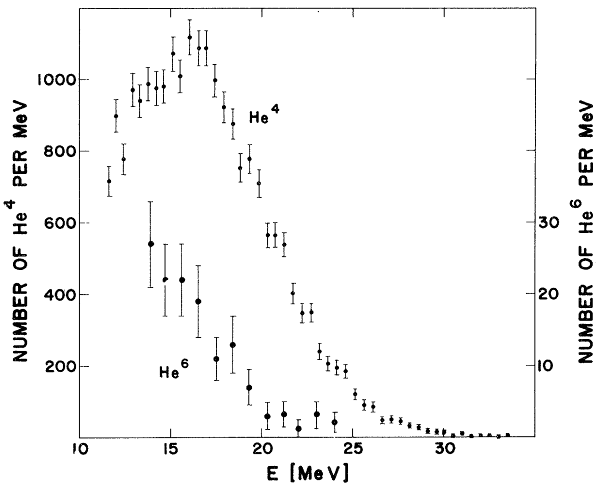

FIG. 2. Energy spectra of long-range He^4 and He^6 particles spontaneously emitted from Cf^{252}. Energies have been corrected for energy loss in the absorber foil. The spectra are shown only for energies high enough for the particles to penetrate to the E detector, so that the identification of the particle species is unambiguous.

masking these apparently rather rare particles. Evidence has also been reported in channeling studies for the occasional loss of somewhat more than the expected energy in a transmission detector.[9] This effect or the Landau effect could conceivably disperse He^4 particles into the vicinity of the He^6 locus. Neither of these effects, however, to our knowledge, could produce the relatively clean separation between the He^4 and He^6 events that is obtained. The absence of any events immediately above the H^3 locus toward the He^4 locus is further evidence that the He^6 events we observe are real.

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

[1]The detection of particles more ionizing than alpha particles in coincidence with induced fission has been reported. It is not clear that these particles are emitted from nuclei. See H. de Laboulaye, C. Tzara, and J. Olkowsky, J. Phys. Radium 15, 470 (1954) for a review of this subject.

[2]The emission of Li^9 from induced fission has been hypothesized, but the evidence is not conclusive. P. J. Bendt and F. R. Scott, Phys. Rev. 97, 744 (1954).

[3]See, for example, E. K. Hyde, The Nuclear Properties of the Heavy Elements (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964), Vol. III, pp. 131-140.

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[9]C. Erginsoy, H. E. Wegner, and W. M. Gibson, Phys. Rev. Letters 13, 530 (1964).

Li^4 AND THE EXCITED LEVELS OF He^4†

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(Received 16 July 1965)

There is a continuing interest in a characterization of such nuclei as H^4 and Li^4; in addition, a determination of the mass of either should aid in locating the lowest $T=1$ state of He^4, which is the subject of considerable current speculation. To accomplish this we have again[1] utilized the technique of simultaneous observation of (p,t) and (p, He^3) transitions to analog final states—here applied to the $(T=1)$ reactions $Li^6(p,t)Li^4$ and $Li^6(p, He^3)He^{4*}$. The latter reaction and the reaction $Li^7(p,\alpha)He^4$ also allow the investigation of the $T=0$ states of He^4.

Some of the recent data concerning the two lowest excited states of He^4 are summarized in Table I.[2-8] Since state I (≈20 MeV, probably $0^+, T=0$) lies just above the p-t threshold at 19.81-MeV excitation and state II (≈22 MeV, probably 1^- or $2^-, T=0$), above the n-He^3 threshold at 20.58 MeV, their exact nature is uncertain. Besides these two states, Vlasov and Samoilov suggest[9] the possibility that the lowest $T=1$ state lies at 24 or 25 MeV. This would require Li^4 to be unbound by 4.5 to 5.5 MeV.

We have used 43.7-MeV protons from the Berkeley 88-in. cyclotron to induce (p,t) and (p, He^3) reactions on Li^6 and (p,α) reactions on Li^7. Targets of separated isotopes were used; the general experimental setup was reported previously.[1]

Figure 1 presents a $Li^6(p,t)Li^4$ spectrum