are once again underestimated.

Angular distributions for two additional states are included in Fig. 2, but little can be deduced about these states. The 325-keV state *might* be the 326.4-keV $\frac{5}{2}^-[523]$ proton state,[2] and the 1238-keV state (above the pairing gap) appears to have an $l=2$ shape; however, more work is needed to make any meaningful assignments for them.

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Emission of the ^{5}He in the Spontaneous Fission of ^{252}Cf

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The emission of ^{5}He ($T_{1/2}=8\times10^{-22}$ sec for decay into $\alpha+n$) in spontaneous fission of ^{252}Cf is established from a correlation measurement involving the direction and the kinetic energies of the neutrons and the long-range α particles. Approximately 11% of these α's are products of ^{5}He breakup. The initial energy of the fragments and of the ^{5}He at scission are calculated from the properties of the ^{5}He decay. They are 31 ± 11 and 3.2 ± 0.9 MeV, respectively.

The emission of a wide variety of light charged particles which accompany the process of fission has been studied extensively.[1] Among these particles ^{4}He is the most abundant with a rate of 3×10^{-3} per fission, while other particles are emitted at a lower rate, i.e., ^{1}H (1.8), ^{2}H (0.7), ^{3}H ($<5\times10^{-3}$), ^{6}He (2.6), ^{8}He (0.1), and $^{6-9}$Li (0.13). (The number in parentheses shows the yield of the particle relative to 100 α particles.) Although some of these light particles are unstable with respect to β decay, all of the particles which have been discovered so far were stable with respect to particle emission. The purpose of this Letter is to present evidence for emission of the particle-unstable ^{5}He. The ground state of ^{5}He is well known from the scattering of neutrons by ^{4}He to have a width $\Gamma=0.58$ MeV and consequently $T_{1/2}=8\times10^{-22}$ sec for the decay into a neutron and ^{4}He. The Q value of this decay is 0.957 MeV.[2] The positive identification of ^{5}He in fission is based upon the observation of a correlation between neutrons and α particles emitted in spontaneous fission of ^{252}Cf. Already in 1965 Nefedov *et al.*[3] found more neutrons [$(27\pm5)\%$] emitted in the direction of emission of the α particles than in the opposite direction; however, they did not interpret this fact as emission of ^{5}He. Halpern[1] noted that on the basis of the correlation between the "average energy costs" for production of various light particles in fission and their yields, ^{5}He should be emitted with about a 5% rate relative to ^{4}He and suggested that this emission can explain the results of Nefedov *et al.*

We have performed correlation measurements of neutrons and charged particles emitted from a thin 5×10^6-fissions/min ^{252}Cf source. Two surface barrier detectors with a 400-μm depletion layer were placed on both sides of the source to detect the long-range α particles. They were covered with an 18-mg/cm^2 gold foil, which stopped the fragments and the 6.1-MeV α's of ^{252}Cf. Behind the two α detectors, but outside the vacuum chamber and at a distance of 60 cm from the ^{252}Cf source, were placed two plastic scintillators of 12.5 cm diam and 5 cm thickness which served as the neutron detectors. The start signal for the neutron time-of-flight measurement was obtained from the α detectors, and the stop signal was given by one of two plastic scintillators. The charged-particle energy and the neutron time of flight were recorded simultaneously on magnetic tape by a multiparameter analyzer. The advantage of using two neutron detectors and two α detectors is in the inherent symmetry of the system in which the same neutron detectors detect the radiation both at 0° and 180°, with respect to the charged particle, at the same time.

The results of the time-of-flight measurements corrected for the flight time of the charged particle (which we will consider to be an α particle) are shown in Fig. 1. They confirm the earlier results that more neutrons are emitted in the ^{4}He direction (0°) than in the opposite direction (180°). Also shown in Fig. 1 is the difference between the two spectra. It is evident that the difference has an energy dependence quite unlike either the 0° or the 180° spectra. After correction for the neutron detection efficiency, one finds that for neutrons above 1 MeV the average energy of the 0°-180° difference is 4.0 ± 0.3 MeV as compared

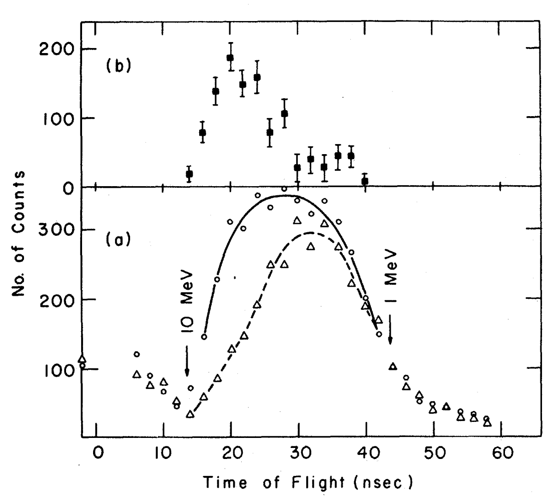

FIG. 1. Time-of-flight spectra of neutrons in coincidence with long-range α particles. (a) Circles, neutrons at 0° with respect to the α direction; triangles, neutrons at 180° to the α direction. Both spectra are normalized to the same number of detected α particles. (b) The difference between the 0° and 180° neutron spectra.

with the 1.9 ± 0.1 MeV of the 180° spectrum.

The excess of neutrons at 0° compared with 180° relative to the α-particle direction is attributed to the decay in motion of the ^{5}He. The alternative possibility, that this excess is due to some preferential emission of neutrons from the fragments, has been investigated experimentally. It could presumably arise from the fact that the α particles are emitted with a most probable angle of ~81° with respect to the light fragment and that in ^{252}Cf more neutrons are emitted from the light fragment than from the heavy one[4]; thus more neutrons from the fragments would appear as correlated with the direction of the α particle than with the opposite direction. For this purpose an additional experiment was carried out with the two α detectors placed at 162° to each other and with the neutron detectors placed behind each of the α detectors. A fission-fragment detector gating light fragments only was placed at 81° to each of the α detectors. The same asymmetry mentioned earlier in neutron emission was observed in this experiment. Had the excess neutrons come only from a correlation with the light-fragment direction, no excess neutrons at 0° to the α's relative to 162° should have been observed in this experiment. Consequently, the "difference spectrum" of Fig. 1 represents the spectrum of neutrons from the decay of ^{5}He.

The velocity of the neutron from the decay of ^{5}He is determined by the velocity of the ^{5}He at the moment of its decay. The neutrons detected in the direction of the α particles are predominantly emitted in the direction of motion of the ^{5}He. Based on the (4.0 ± 0.3)-MeV average kinetic energy of the neutron and the Q value of 0.957 MeV of the ^{5}He, the average energy of the ^{5}He at the time of breakup is 6.3 ± 0.8 MeV. Most of the neutrons which are emitted in the opposite (180°) direction in the c.m. system of the ^{5}He particle move also forward (0°) in the laboratory system but with an average energy of 60 keV, and are below the detection threshold in this experiment. When a neutron is emitted in the forward (0°) direction (in the c.m. system) from a moving ^{5}He, the α particle recoils back and loses some of its velocity. The effect upon the final energy of the α particle (which may still experience a strong Coulomb repulsion at that time) is seen in the spectrum of α particles originating from the ^{5}He, which is obtained from the difference between the ^{4}He spectra associated with 0° and 180° neutrons. In Fig. 2 we show the subtracted α spectrum, the spectrum in coincidence with

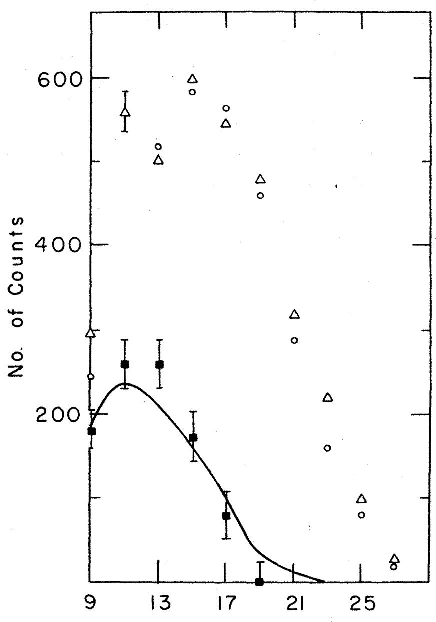

FIG. 2. Particle spectra: triangles, α particles detected in coincidence with neutrons at 180° to the α direction; circles, α particles with no coincidence requirements; squares, difference between the α spectrum at 0° and at 180° to the neutron direction, both taken in coincidence with neutrons between 1.0 and 10.0 MeV; solid line, calculated curve for α particles emitted in the decay of ^{5}He.

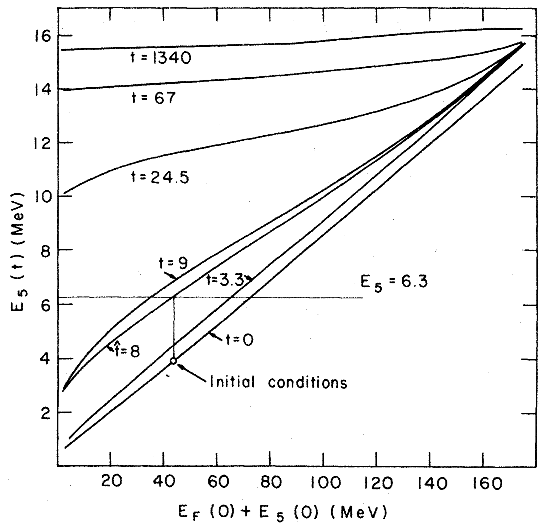

FIG. 3. Graphical solution for the initial conditions at the scission point. $E_5(t)$ is the ^{5}He energy at time t; $E_5(0)$, the initial energy of the ^{5}He emitted at 90° to the fragments; $E_F(0)$, the energy of the two fragments at the moment of scission. The curve denoted by $t=0$ is the locus of initial conditions at scission which reproduce the observed average kinetic energies in long-range α fission of ^{252}Cf. The curves denoted by various values of t describe the energies of the ^{5}He at time t (in units of 10^{-22} sec). The curve denoted by $\hat{t}=8$ represents the average energy of the ^{5}He at the moment of its decay. The solution for the initial condition is obtained from the projection of the intersection of the experimentally determined average ^{5}He energy at the time of its decay (6.3 MeV) with the $E_5(\hat{t}=8)$ curve on the $E_5(t=0)$ curve. This yields a unique solution for $E_F(0)+E_5(0)$ and $E_5(0)$.

180° neutrons, and the ^{4}He spectrum measured without neutron correlations. It is seen that the spectrum in coincidence with 180° neutrons has the same shape as that of uncorrelated α particles, whereas the difference spectrum has a lower most probable energy. The average energy of the correlated α's above the detection threshold of 9 MeV is 12.4 ± 0.9 MeV; therefore the average total energy of the ^{5}He, had they not decayed, would have been $\overline{E}_\alpha+\overline{E}_n-Q=15.4$ MeV. Assuming isotropy of the ^{5}He decay, we obtain by transformation to the center of mass of the ^{5}He that $(11\pm2)\%$ of all the observed long-range particles above 9 MeV accompanying the spontaneous fission of ^{252}Cf are actually products of ^{5}He breakup. In the past they were identified as α particles.

The decay of the ^{5}He particle occurs mostly at a time at which the fragments and the ^{5}He are still strongly accelerated; thus the emitted neutron is a probe of the conditions at the average time of 8×10^{-22} sec after scission. From the average conditions at this time we shall attempt to calculate the initial conditions at scission. We make the customary assumptions that the fragments at scission are represented by two point charges with the ^{5}He being emitted from the point of minimum potential energy between the fragments. The final energies of the fragments, $E_F(\infty)$, and the final energy of the ^{5}He, $E_5(\infty)$, are each a function of the initial conditions at the scission point, which are (1) the distance between the two fragments, (2) the initial energy of the ^{5}He $[E_5(0)]$, and (3) the initial energy of the fragments $[E_F(0)]$. The initial direction of the ^{5}He is assumed to be 90° with respect to the light fragment. The solution of the equations of motion using the method of Boneh, Fraenkel, and Nebenzahl[5] leads to a definite relationship between the values of the initial energies $E_F(0)$ and $E_5(0)$ for any given final-energy values $E_F(\infty)$ and $E_5(\infty)$. This is shown in Fig. 3 for $E_5(\infty)=15.4$ MeV (the average ^{5}He final energy) and $E_F(\infty)+E_5(\infty)=184$ MeV (the average of the total energy in ternary fission). The lower curve represents the loci of initial conditions of ternary fission which produce the observed average final energies. On the basis of these initial conditions we further calculated by the method of Boneh, Fraenkel, and Nebenzahl[5] the average energy of the ^{5}He at the time of its decay taking into consideration its exponential decay with a half-life of 8×10^{-22} sec. This curve is also shown in Fig. 3. The measured average energy of the ^{5}He at the time of breakup (6.3 ± 0.8 MeV) yields a unique graphical solution to the initial conditions, i.e., $E_F(0) = 40\pm11$ MeV and $E_5(0)=3.9\pm0.9$ MeV. This solution applies only to neutrons which are coincident with α particles above 9 MeV. An approximate correction for the missing events gives $E_F(0) = 31\pm11$ MeV and $E_5(0)=3.2\pm0.9$ MeV.

The average initial conditions obtained here for the emission of ^{5}He are similar to those obtained in Ref. 5 from trajectory calculations which were used to reproduce the properties of the long-range α particles in spontaneous fission of ^{252}Cf and in particular their angular distribution relative to the fragments. Our results are also in good agreement with a similar trajectory calculation performed by Musgrove[6] who fitted his calculation to the experimental angular distribution of Raisbeck and Thomas[7] which is narrower than the experimental angular distribution[8] used by Boneh, Fraenkel, and Nabenzahl. Rajagopalan and Thomas[9] recently remeasured this angular distribution and found it to be in substantial agreement with the results of Raisbeck and Thomas.[10] We have also performed trajectory calculations in which $E_F(0)$ is a Gaussian distribution with $\sigma=12$ MeV and a mean $\bar{E}_F(0)=28$ MeV, $E_5(0)$ has a Maxwellian distribution with $\bar{E}_5(0) = 3.0$ MeV, and the initial emission of the ^{5}He is isotropic between 30° and 150° with respect to the fragment direction. The calculated α spectrum (which takes into account the lifetime of ^{5}He and the backward recoil of the α in the ^{5}He decay) is shown in Fig. 2 to be in good agreement with the experimental results.

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(^{6}Li, d) on ^{58}Ni and ^{64}Ni

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The (^{6}Li,d) reaction has been performed on ^{58}Ni and ^{64}Ni at 38 MeV. For ^{58}Ni angular distributions were obtained and compared to distorted-wave Born-approximation calculations. One spectrum was taken for ^{64}Ni. A reduction in cross section is observed and is compared with the results of (^{16}O, ^{12}C), (p,t), and (^{3}He,n) experiments.

The investigation of four-particle configurations in nuclei has recently been extended from nuclei of the sd shell into the Ni region[1-3] via the (^{16}O,^{12}C) reaction. However, extraction of reliable spectroscopic information is difficult because of the strong Q-value dependence of the cross section[4] and the uncertainties in knowing the various configurations of the transferred four-nucleon cluster.[5] A more attractive approach is the (^{6}Li,d) reaction which extensive studies[6-7] on light nuclei have shown to be a good α-transfer reaction. Furthermore, distorted-wave Born-approximation (DWBA) calculations[7] indicate that the Q-value dependence of the cross section is