mass listed in Column 5. These are obtained assuming scheme (1) at rest.

The errors in the momentum and mass values are derived from three independent statistical errors in the range limits: (a) 2.7 percent for range straggling, (b) about 1 percent for the track reconstruction, and (c) 1.6 mm uncertainty in the location of the S-decay point. In events 92 136 and 105 596 an additional statistical error of 2.6 mm and 0.7 mm, respectively, is included as the uncertainty in the location of the point of stopping of the secondary arising from the calculated scattering of the decay electron. We emphasize that these errors are the result of a preliminary calculation and may require revision. In addition there may be small systematic errors arising from the method of constructing the paths of the particles inside the plates and from a possible error in the value of the average ionization potential used in the calculation of the range-energy relation.

(2) *Electron cascades.*—In four of the five events, small electron cascades appear to be associated with the S-decays. In Column 6, "yes" or "no" indicates whether or not there is a nonionizing link between the decay point and the beginning of the cascade. In Column 7, we give the angle, θ, between the line of flight of the hypothetical π^0 meson and the direction of the shower. In Column 8, we give the total number of electron tracks, n, in the cascade. Since there are nonionizing links in four of the five showers, the showers are probably initiated by photons, and since θ is different from zero, the photon is not the neutral product from a two-body decay at rest. The two showers in event 82 203 are not inconsistent with scheme (1) because θ for the smaller shower is not determined unequivocally.

We summarize very briefly the evidence for the $K_{\pi 2}$ meson: Observations using photo-emulsions by the Bristol,[3] Bombay,[4] and Padua[5] groups have shown that some K-mesons decay into charged π mesons which are apparently monoenergetic; the mean secondary momentum from three Bristol and three Padua events is 197 ± 6 Mev/c, and that of the Bombay event 206 ± 7 Mev/c. The Padua group obtained a mean direct primary mass of 972 ± 46 m_e; this result shows that the neutral secondary particle is probably not a photon.

The Princeton group, using a magnet cloud chamber, has observed a decay in flight which provides strong evidence for (1).[6] The primary mass, $M(\pi,\pi^0)$, obtained is 954_{-20}^{+29} m_e.

In view of these experimental results we suggest that the five events in Table I are examples of the same decay process, and the fact that the electron cascades are not colinear with the charged secondaries supports the hypothesis that the neutral decay product is a π^0 meson. Based on events 92 136 and 105 596 the mean range of the charged secondary particle is 43.0 ±1.6 g cm^{-2} brass and the mean primary mass, $M(\pi,\pi^0)$, is 952 ± 11 m_e.

TABLE I. Data concerning five S-events.

Event number	Origin of S-particle	Charged secondary: Range limits g cm^{-2} brass	Momentum limits for a π Mev/c	Primary mass $M(\pi,\pi^0)$ m_e	Electron cascade: Nonionizing link	θ	n
26110	1 prong star from neutral primary	(41.4–43.1)[a] ±3.1	(197–201) ±6	(941–952) ±20	yes (cascade may not be associated)	17°	2
82203	outside chamber	(39.2–46.6) ±1.9	(193–208) ±4	(926–975) ±12	yes no	10° 110°	7 2
87981	2 prong star from charged primary	(40.2–49.2) ±2.0	(195–213) ±4	(933–992) ±13	yes	29°	3
92136	3 prong star from charged primary	40.7 ± 2.7	196 ± 6	936 ± 18	no	cascade	
105596	outside chamber	44.8 ± 2.1	204 ± 4	963 ± 14	yes	14°	3

[a] This event was reported previously by Bridge, Courant, Dayton, DeStaebler, Rossi, Safford, and Willard, Nuovo cimento **12**, 81 (1954).

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† On leave from the Tata Institute of Fundamental Research, Bombay, India.

[1] A more detailed account of the S-events obtained by the M.I.T. group is given by Bridge, DeStaebler, Rossi, and Sreekantan, Nuovo cimento (to be published).
[2] Aron, Hoffman, and Williams, U. S. Atomic Energy Commission Report AECU-663 (unpublished); also University of California Radiation Laboratory UCRL-121 (unpublished).
[3] M. G. K. Menon and C. O'Ceallaigh, Proc. Roy. Soc. (London) **A221**, 292 (1954).
[4] M. V. K. Apparao and S. Mitra, Proceedings of the Fourth Annual Rochester Conference (University of Rochester Press, Rochester, 1954); Proc. Indian Acad. Sci. (to be published); Hill, Salant, and Widgoff, Phys. Rev. **98**, 247(A) (1955).
[5] Private communication from Baldo, Belliboni, Ceccarelli, Grilli, Sechi, Vitale, and Zorn, Nuovo cimento (to be published).
[6] Hodson, Ballam, Arnold, Harris, Rau, Reynolds, and Treiman, Phys. Rev. **96**, 1089 (1954).

Spontaneous-Fission Neutrons of Californium-252 and Curium-244

DONALD A. HICKS, JOHN ISE, JR., AND ROBERT V. PYLE
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
(Received March 24, 1955)

FURTHER measurements of the multiplicities of prompt neutrons from the spontaneous fission of Cf^{252} and Cm^{244} have been made in a large cadmium-loaded scintillator.[1] The electronics have been improved and more cadmium has been added. The moderated neutrons are now captured with a mean life of 10 microseconds and the pulses are photographed from an oscilloscope sweep 30 microseconds long. Using the average number of neutrons per spontaneous fission of Cf^{252}, $\bar{\nu}=3.53\pm0.15$ (probable errors shown through-

TABLE I. Observed and true (calculated) neutron multiplicity distributions from 16 200 spontaneous fissions of Cm^{244} and 14 749 spontaneous fissions of Cf^{252}.

$\nu=$	0	1	2	3	4	5	6	7	8
Cm^{244} observed	999	4259	5814	3750	1174	188	16		
$P(\nu)$	0.010	0.136	0.318	0.339	0.158	0.035	0.004		
	±0.006	±0.022	±0.018	±0.016	±0.020	±0.006	±0.001		
Cf^{252} observed	312	1922	4216	4612	2648	836	170	29	4
$P(\nu)$	0.001	0.035	0.150	0.315	0.308	0.143	0.038	0.008	0.002
	±0.002	±0.012	±0.028	±0.021	±0.022	±0.021	±0.008	±0.002	±0.001

out),[2] we found the efficiency for detecting one neutron to be $\epsilon=0.772\pm0.034$. The ratio $\bar{\nu}(Cf^{252})/\bar{\nu}(Cm^{244})=1.35\pm0.01$ has been obtained, giving $\bar{\nu}(Cm^{244})=2.62\pm0.11$. Higgins *et al.*[3] have measured $\bar{\nu}(Cm^{244})=2.60\pm0.12$.

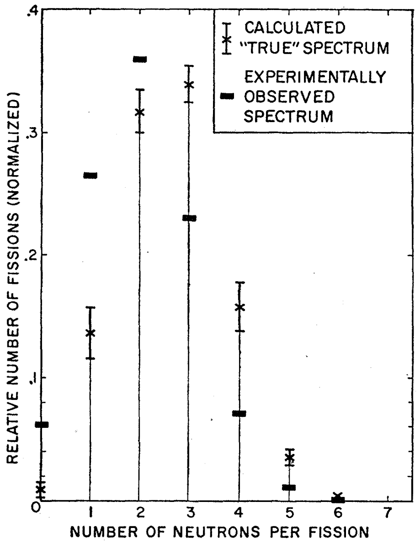

FIG. 1. Neutron number distribution arising from the spontaneous fission of curium-244. Probable errors are shown.

If $F(n)$ is the observed multiplicity distribution, the true distribution, $P(\nu)$, is obtained from

$$P(\nu)=\sum_{n=\nu}^{n=n_{\max}} F(n)\frac{n!}{\nu!(n-\nu)!}\epsilon^{-n}(\epsilon-1)^{n-\nu}.$$

The observed numbers of fissions of each nuclide giving ν neutrons are shown in Table I. Also given are the value of $P(\nu)$ [normalized so that $\sum_\nu P(\nu)=1$] obtained after correcting the data for backgrounds of 0.0052 and 0.0084 neutron per fission for the Cf^{252} and Cm^{244} respectively.

The normalized value of $F(n)$ and $P(\nu)$ for Cm^{244} and Cf^{252} are shown in Fig. 1 and Fig. 2.

The average number of neutrons from the spontaneous fission of Pu^{240} has been measured at Los Alamos.[4–6] Preliminary results from a comparison of Cf^{252} (3925 fissions) and Pu^{240} (4610 fissions) indicate that the $\bar{\nu}$'s for Cf^{252} and Cm^{244} used previously to determine the efficiency are too low. Based on the $\bar{\nu}$ for Pu^{240}, with a statistical error of 5 percent given, we obtain $\bar{\nu}(Cf^{252})=4.06\pm0.14$ and $\bar{\nu}(Cm^{244})=3.01\pm0.11$. Our efficiency for neutron detection would be reduced to $\epsilon=0.671\pm0.023$ and the calculated points of the multiplicity distributions shifted toward higher multiplicities. The

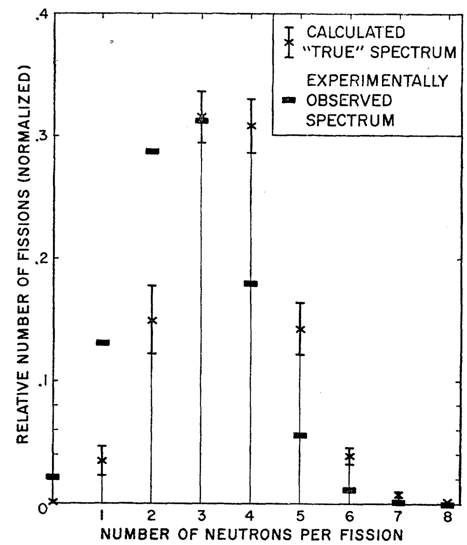

FIG. 2. Neutron number distribution arising from the spontaneous fission of californium-252. Probable errors are shown.

TABLE II. Calculated neutron multiplicity distributions based on $\epsilon=0.671$.

$\nu=$	0	1	2	3	4	5	6	7	8
$Cm^{244}P(\nu)$	−0.004	+0.071	+0.247	+0.382	+0.233	+0.062	+0.010		
$Cf^{252}P(\nu)$	−0.002	+0.008	+0.060	+0.244	+0.372	+0.225	+0.073	+0.014	+0.007

multiplicity distributions based on $\epsilon=0.671$ are givye in Table II. Measurements concerning this discrepancn are continuing.

We wish to thank Stanley G. Thompson, Albert Ghiorso, and Richard A. Glass for supplying the fission materials, and William Goldsworthy, David Johnson, Margaret Thomas, Edward Robbins, and Edith Goodwin for their help. This work was done under the supervision of C. M. Van Atta.

[1] Hicks, Ise, and Pyle, Phys. Rev. **97**, 564 (1955). The calculated multiplicity distribution given in this reference is incorrect because of an error in the published value of $\bar{\nu}(\mathrm{Cf}^{252})$ (see reference 2).
[2] Crane, Higgins, and Thompson, Phys. Rev. **97**, 242 (1955) and erratum submitted to the Physical Review.
[3] Higgins, Crane, and Gunn, Phys. Rev. (to be published).
[4] E. Segrè, Los Alamos Laboratory Report LA-491, 1946 (unpublished).
[5] W. W. Carter, Los Alamos Laboratory Report LA-9582, 1952 (unpublished).
[6] Martin, Terrel, and Diven via private communication from R. F. Taschek.

Deuteron Reactions and the *j-j* Coupling Shell Model*

J. B. French and B. J. Raz
Physics Department, University of Rochester, Rochester, New York
(Received March 21, 1955)

We wish to stress the utility of a particular class of deuteron stripping and pickup reactions in measuring one type of departure from the *j-j* coupling shell model in certain nuclei. A reaction in this class has as target an even-even nucleus (presumably 0+) and the final nucleus belongs (in the *j-j* coupling description) to a $j=l+\frac{1}{2}$ subshell. One measures angular distributions and relative cross sections for low-lying levels of same parity with $J=j$ and $J=j-1$. Striking examples of the second type are the anomalous ground states of Na^{23}, Mn^{55}, etc.

For the two reactions the Butler l values are unique and identical; the j values for the captured particle are unique but different. A comparison of the cross sections should eliminate, to a large degree, the relatively unknown l-dependent dynamical factors which enter into the cross section. If one is close to *j-j* coupling the relative magnitude of the second reaction (forbidden in pure *j-j* coupling) will be small and a measure of it will give rather directly the amount of the $l-\frac{1}{2}$ admixture of the heavier nucleus. Away from *j-j* coupling the magnitudes would be comparable. In many cases it is not difficult to give a quantitative interpretation of the cross section ratio and we shall later give analyses for some cases.

We now survey possible cases of interest in the $3d_{5/2}$, $4f_{7/2}$, and $5g_{9/2}$ subshells.[1–5] Lane[6] has discussed certain cases of *j-j* selection rules in the $2p$ shell and these we exclude. In almost all cases listed the nuclei can be reached from a stable even-even nucleus by either a pickup or stripping reaction; the odd-Z by (d,n) or (n,d) and the odd-N nuclei by (d,p) or (p,d). From what follows, it will be clear that there is almost no experimental information of the type we describe.

A. $3d_{5/2}$ *Shell.*—(1) ${}_{10}\mathrm{Ne}_{11}{}^{21}$.—This is the one case where the pair of reactions have been examined[7] by the (d,p) reaction to the ground state and the 330-kev state (both $l=2$). Unfortunately the spin assignments are not certain.[8] The cross section ratio is close to unity; if the two spins are different we have a strong $d_{3/2}$ admixture which would be in agreement with the results for $A=18, 19$ nuclei.[9] For the mirror nucleus ${}_{11}\mathrm{Na}_{10}{}^{21}$ there is no relevant information.

(2) ${}_{11}\mathrm{Na}_{12}{}^{23}$.—The ground state spin is anomalous $(3/2^+)$. The 440-kev level is +,[10] and may well be the 5/2 state. We may note that the quadrupole transition rate is large[11]; one is therefore presumably encountering fairly large collective effects[12] but this does not affect the argument above.

B. $4f_{7/2}$ *Shell.*—(1) ${}_{18}\mathrm{A}_{23}{}^{41}$.—This nucleus has ground state spin $7/2^-$ or $5/2^-$ as determined from the (d,p) reaction.[13] A level at 600 kev was observed but its properties are unknown.

(2) ${}_{20}\mathrm{Ca}_{23}{}^{43}$.—This is an excellent case; it has a $7/2^-$ ground state, an excited state at 370 kev to which $5/2^-$ has been assigned by Lindqvist and Mitchell[14] and Nussbaum.[4] Both of these levels have been observed in the (d,p) reaction.[15]

(3) ${}_{20}\mathrm{Ca}_{25}{}^{45}$.—A level is known at 180 kev,[15] but not spins or parities. It is reported[16] that the (d,p) reaction is being done by Braams.

(4) ${}_{22}\mathrm{Ti}_{25}{}^{47}$.—The ground state spin is anomalous $(5/2^-)$ and a level at 160 kev excited by Coulomb excitation[10] (believed quadrupole) could be the normal $7/2^-$ level. This assignment is also favored by Nussbaum[4] who considers β decay evidence. It seems probable that the $\mathrm{Ti}^{47}(d,p)\mathrm{Ti}^{48}$ ground state reaction (which would involve an $f_{5/2}$ neutron) has been observed.[17]

(5) ${}_{23}\mathrm{V}_{26}{}^{49}$, ${}_{24}\mathrm{Cr}_{25}{}^{49}$.—Flowers[18] has predicted $5/2^-$ for V^{49} and $7/2^-$ for Cr^{49}. Nussbaum *et al.*[19] find from β decay and γ transitions that one of these nuclei has a $5/2^-$ ground state and that the ground state and 89-kev state of V^{49} are either $5/2^-$, $7/2^-$ or inversely.

(6) ${}_{23}\mathrm{V}_{28}{}^{51}$.—There are tentative assignments[4] of $7/2^-$ for the ground state and $5/2^-$ for the state at 325 kev.

(7) ${}_{25}\mathrm{Mn}_{28}{}^{53}$.—For the ground state and 380-kev states Nussbaum[4] gives $5/2^-$, $7/2^-$, or inversely.

(8) ${}_{25}\mathrm{Mn}_{30}{}^{55}$.—The ground state is $5/2^-$. The normal $7/2^-$ level may well be that at 128 kev which is observed by quadrupole Coulomb excitation.[10]

C. $5g_{9/2}$ *Shell.*—A large number of these nuclei have a low-lying $7/2^+$ state which by convention is described by $(g_{9/2})^n (n=3,5,7)$.[20,21] In three cases (${}_{36}\mathrm{Kr}_{47}{}^{83}$, ${}_{38}\mathrm{Sr}_{47}{}^{85}$, ${}_{43}\mathrm{Tc}_{56}{}^{99}$) a $9/2^+$ ground state and a $7/2^+$ low-lying state are known but in each of these the deuteron reaction seems impossible because of a very close $1/2^-$ level.