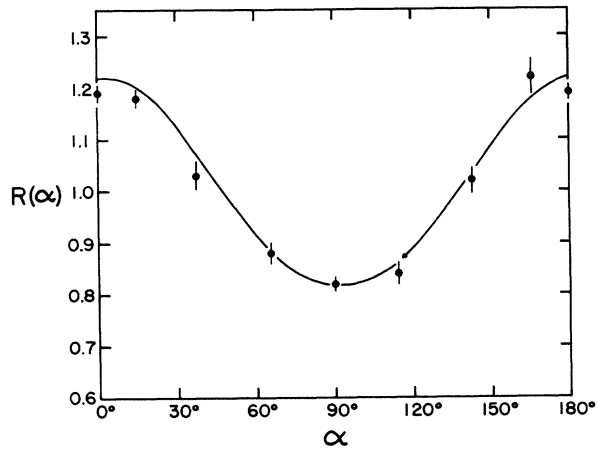

FIG. 2. The ratio R of counting rates in counter B and counter A, as a function of the angle α which the magnetic field in the ionization region makes with the x axis. The ratio R is normalized such that for an unpolarized beam $R=1$. The errors are statistical only and do not include the uncertainty in the normalization factor.

which is expected if $P_{33}=-0.28$, i.e., if there is no depolarization.

The reason for the small amount of depolarization in the charge-exchange process presumably lies in the fact that the transit time of the ions through the carbon foil is very short compared to the characteristic time of the characteristic time of the hyperfine interaction. In the negative ion we expect no depolarization if the electrons are in the $^1S_0$ state.

The beam intensity at the target, which has an area of 2 cm^2, is a few times 10^9 particles per second. In the present experiment the negative beam traveled over a distance of 3 m. Even if it should turn out that only a few percent of the beam can be accelerated and focused onto a target, a usable intensity would still remain.

We should like to thank Mr. C. A. Newton for his help in the construction of the apparatus and Mr. T. J. Yule for making the thin carbon foils.

*This work was supported in part by the U. S. Atomic Energy Commission.

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THE MASS EFFECT CORRESPONDING TO THE ONSET OF NUCLEAR DEFORMATION IN THE REGION $N\sim 90$†

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It is known that nuclei in the region $150<A<190$ are strongly deformed, as a result of collective motion of certain of the constituent nucleons.[1-3] Motion of this type implies the existence of a special bond between the nucleons that are acting in concert, in addition to the usual force with which they are bound to the nucleus as a whole. Hence, the onset of this mode of collective motion should manifest itself as a sudden increase in the nucleon binding energy. Such a mass effect was first observed in 1953 by Hogg and Duckworth (working with an accuracy of ~600 keV),[4] although its cause was imperfectly understood at the time. In 1957, the effect was shown by Johnson and Nier (working with an accuracy of ~100 keV)[5] to be especially pronounced at $N=90$, in agreement with other facts relating to nuclear deformation which nuclear spectroscopists had brought to light in the meantime.

We have recently used our high-resolution mass spectrometer[6,7] to determine double-neutron separation energies (S_{2n}) for many of the stable nuclides with $84\leq N\leq 98$. These values, which are accurate to a few keV, may be combined with existing data to provide the first accurate picture of the shape of the mass surface in this

Table I. New data and existing auxiliary data.

Datum No.	New data (mu)	Datum No.	Existing auxiliary data
(1)	$^{144}Nd^{35}Cl - {}^{142}Nd^{37}Cl = 5.329 \pm 3$	(16)	$n = 1.008\,665\,4 \pm 4$ u [a]
(2)	$^{146}Nd^{35}Cl - {}^{144}Nd^{37}Cl = 6.003 \pm 3$	(17)	$u = 931.478 \pm 15$ MeV [b]
(3)	$^{148}Nd^{35}Cl - {}^{146}Nd^{37}Cl = 6.740 \pm 5$	(18)	$^{37}Cl - {}^{35}Cl = 1.997\,041\,4 \pm 36$ u [a]
(4)	$^{150}Nd^{35}Cl - {}^{148}Nd^{37}Cl = 7.006 \pm 4$	(19)	$^{144}Nd - {}^{143}Nd = n - (7.814 \pm 8$ MeV) [c]
(5)	$^{148}Sm^{35}Cl_2 - {}^{144}Sm^{37}Cl_2 = 8.710 \pm 10$	(20)	$^{146}Sm - {}^{142}Nd = {}^4He + (2.53 \pm 2$ MeV) [d]
(6)	$^{149}Sm^{35}Cl - {}^{147}Sm^{37}Cl = 5.257 \pm 4$	(21)	$^{147}Sm - {}^{143}Nd = {}^4He + (2.29 \pm 2$ MeV) [e]
(7)	$^{150}Sm^{35}Cl - {}^{148}Sm^{37}Cl = 5.452 \pm 5$	(22)	$^{148}Gd - {}^{144}Sm = {}^4He + (3.27 \pm 1$ MeV) [f]
(8)	$^{152}Sm^{35}Cl - {}^{150}Sm^{37}Cl = 5.429 \pm 4$	(23)	$^{150}Gd - {}^{146}Sm = {}^4He + (2.80 \pm 1$ MeV) [f]
(9)	$^{154}Sm^{35}Cl - {}^{152}Sm^{37}Cl = 5.480 \pm 4$	(24)	$^{152}Gd - {}^{148}Sm = {}^4He + (2.20 \pm 2$ MeV) [e]
(10)	$^{154}Gd^{35}Cl - {}^{152}Gd^{37}Cl = 4.016 \pm 30$	(25)	$^{152}Dy - {}^{148}Gd = {}^4He + (3.74 \pm 2$ MeV) [d]
(11)	$^{156}Gd^{35}Cl - {}^{154}Gd^{37}Cl = 4.199 \pm 5$	(26)	$^{154}Dy - {}^{150}Gd = {}^4He + (2.93 \pm 5$ MeV) [g]
(12)	$^{158}Gd^{35}Cl - {}^{156}Gd^{37}Cl = 4.956 \pm 4$	(27)	$^{150}Sm - {}^{149}Sm = n - (7.989 \pm 4$ MeV) [h]
(13)	$^{160}Gd^{35}Cl - {}^{158}Gd^{37}Cl = 5.890 \pm 5$		
(14)	$^{162}Dy^{35}Cl - {}^{160}Dy^{37}Cl = 4.555 \pm 6$		
(15)	$^{164}Dy^{35}Cl - {}^{162}Dy^{37}Cl = 5.347 \pm 5$		

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Table II. Double neutron separation energies (in MeV).

Nuclide	N	Double neutron separation energy (S_{2n})	Previous values [a, b]	Data Nos. used in calculation (from Table I)
^{144}Nd	84	13.935 ± 5	13.967 ± 65	(1), (16), (17), (18)
^{146}Nd	86	13.307 ± 5	13.455 ± 85	(2), (16), (17), (18)
^{148}Nd	88	12.621 ± 6	12.626 ± 75	(3), (16), (17), (18)
^{150}Nd	90	12.373 ± 6	12.077 ± 85	(4), (16), (17), (18)
^{146}Sm	84	15.168 ± 32	14.982 ± 130	(5), (16), (17), (18) plus S_{2n} for ^{148}Sm
^{148}Sm	86	14.517 ± 30	14.721 ± 130	(1), (6), (7), (16), (17), (18), (19), (20), (21), (27)
^{150}Sm	88	13.818 ± 6	13.828 ± 110	(7), (16), (17), (18)
^{152}Sm	90	13.842 ± 5	13.846 ± 160	(8), (16), (17), (18)
^{154}Sm	92	13.794 ± 5	13.753 ± 200	(9), (16), (17), (18)
^{150}Gd	86	15.638 ± 35	15.494 ± 180	(22), (23) plus S_{2n} for ^{146}Sm
^{152}Gd	88	15.117 ± 38	15.261 ± 200	(23), (24) plus S_{2n} for ^{148}Sm
^{154}Gd	90	15.158 ± 28	15.112 ± 75	(10), (16), (17), (18)
^{156}Gd	92	14.987 ± 6	14.917 ± 75	(11), (16), (17), (18)
^{158}Gd	94	14.282 ± 5	14.284 ± 75	(12), (16), (17), (18)
^{160}Gd	96	13.412 ± 6	13.362 ± 75	(13), (16), (17), (18)
^{154}Dy	88	16.448 ± 64	15.792 ± 220	(25), (26) plus S_{2n} for ^{150}Gd
^{162}Dy	96	14.656 ± 7	14.675 ± 75	(14), (16), (17), (18)
^{164}Dy	98	13.918 ± 6	13.976 ± 75	(15), (16), (17), (18)

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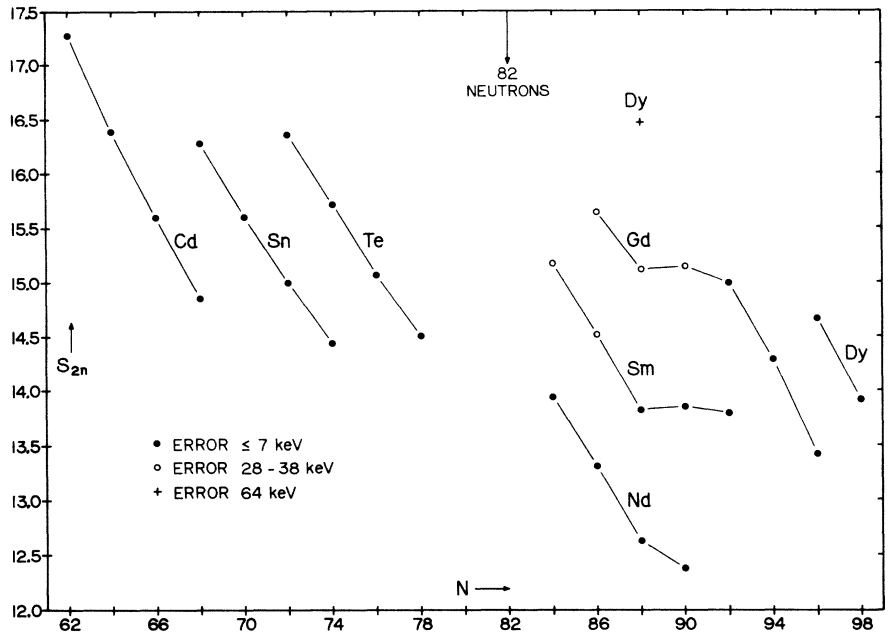

FIG. 1. Double-neutron separation energies for even-A nuclides plotted as a function of neutron number. Points belonging to the same element are joined.

region.

Our new primary data are given in Table I, together with useful auxiliary data and their provenance. These data may be combined to calculate the double-neutron separation energies shown in Table II and presented graphically in Fig. 1. Following each entry in Table II are listed the data used in the calculation of it.

Also shown in Fig. 1 are previously published S_{2n}-versus-N plots for a number of the even-A isotopes of cadmium, tin, and tellurium. These plots are strikingly regular, and the corresponding neodymium and samarium plots for $84 \leq N \leq 88$ are similar in this respect. In addition, their slopes are not unlike those for cadmium, tin, and tellurium, especially if one makes allowance for the fact that the curves immediately following a closed shell (here 82 neutrons) are steeper than those immediately preceding it. Also, the two points for gadolinium suggests that its S_{2n}- versus-N plot is also more or less "normal" for this same range of neutrons.

But at $N = 88$ the samarium and gadolinium curves undergo a striking change, corresponding to the onset of nuclear deformation. The effect is also present in neodymium, although it is much smaller.

We also see from the gadolinium S_{2n} curve in Fig. 1 that the dislocation corresponding to the onset of collective motion extends for a range of four neutrons (88-92), after which essentially "normal" behavior resumes. An extrapolation of the dysprosium curve to lower neutron numbers is consistent with the hypothesis that any dislocation in the dysprosium curve also terminates at $N = 92$. We are not able to determine the extent of the dislocation for samarium because no stable isotopes exist for $N > 92$, but it may also be limited to the range $88 < N \leq 92$.

One may reasonably generalize as follows:

(1) The mass effect associated with this nuclear deformation of neutrons begins suddenly for neodymium, samarium, and gadolinium as N exceeds 88 neutrons.

(2) The magnitude of the mass effect is dependent upon the atomic number of the nucleus, being large for samarium ($Z = 62$) and gadolinium ($Z = 64$), but much smaller for neodymium ($Z = 60$).

(3) The mass effect is mainly confined to the region $88 < N \leq 92$. This suggests that the nuclear distortion exhibited by nuclei in this region of the mass table is established during the addition of the 89th, 90th, 91st, and 92nd neutrons.

The new data reported herein are part of a larger body of data relating to mass differences in this region which we shall be publishing in the near future. We are presenting this portion in advance, however, in the hope that the information which it provides concerning the extent and magnitude of the mass effect will be of some im-

mediate use.

We have greatly benefited from conversations and/or correspondence with R. A. Kenefick, R. D. Macfarlane, B. R. Mottelson, M. A. Preston, D. W. L. Sprung, L. E. H. Trainor, and, especially, with R. K. Sheline whose research group has obtained accurate values for many of the single neutron binding energies in this region. We also appreciate the permission of A. Siivola to quote the unpublished value [datum No. (20)] for the Q of the alpha decay of ^{146}Sm.

†This work was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command, and by the National Research Council of Canada.

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EVIDENCE THAT THE f^0 HAS ISOTOPIC SPIN ZERO*

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We have analyzed 50 000 pictures of 3.65-BeV/c π^+ in deuterium from the BNL 20-inch chamber. The results of this analysis, along with results of a similar π^--p exposure, show that the f^0 is $(J = \text{even})^{++}(T=0)$ and cannot, therefore, be identified with the ω-π resonance (B meson), as suggested by Frazer, Patil, and Xuong.[1]

The arguments presented here are based on observation of the following reactions.

$$\pi^+ + n + (p) \rightarrow (p) + p + \text{neutrals}, \quad (1)$$

$$\rightarrow (p) + p + \pi^+ + \pi^-, \quad (2)$$

$$\rightarrow (p) + p + \pi^+ + \pi^- + \text{neutrals}, \quad (3)$$

where (p) stands for the spectator proton and "neutrals" in Reaction (3) stands for something besides a single π^0. We have selected events in which the spectator proton is measurable (range between 1 mm and 8 cm and stops in the chamber), and the other proton has a momentum less than 1.7 BeV/c. This allows us to positively identify both protons by ionization. We chose to have a low track density (~10 tracks/picture) in an effort to obtain bias-free samples of (1), (2), (3) and also to facilitate the differentiation of π, K, p by bubble counting.

The invariant-mass distribution of the "neutrals" from Reaction (1) is shown in Fig. 1(a). There is a definite peak in the region of the f^0 (1250 ± 80 MeV) mass. We note first that this cannot be due to the neutral decay of the B^0, since the $B^+ \rightarrow \omega^0\pi^+$ decay, if it proceeds via a strong interaction, requires that the B have $T=1$, $G=+1$, and $C=-1$. This means that $B^0 \rightarrow n\pi^0$ ($n = 2, 3, 4, \cdots$) is forbidden by C and hence $B^0 \rightarrow$ neutrals must contain an odd number of γ's and proceed via the electromagnetic interaction. The most likely process of this kind would be $B^0 \rightarrow \omega^0 + \pi^0 \rightarrow \pi^0 + \gamma + \pi^0$, which would have a branching ratio of 10%[2] relative to $B^0 \rightarrow \omega^0 + \pi^0 \rightarrow \pi^+ + \pi^- + \pi^0 + \pi^0$. By looking at the mass of the $(\pi^+ + \pi^- + \text{neutrals})$ from Reaction (3), we see [Fig. 1(b)] that there is no evidence for a strong $B^0 \rightarrow \pi^+ + \pi^- + \pi^0 + \pi^0$ peak, so that $B^0 \rightarrow \omega^0 + \pi^0 \rightarrow \pi^0 + \gamma + \pi^0$ in Reaction (1) must be completely negligible.[3]

We now look at the $\pi^+\pi^-$ mass distribution from Reaction (2), shown in Fig. 2(a). The ρ^0 and f^0 peaks stand out clearly. The mass spectrum of Reaction (2) is actually well known from the charge-symmetric process $\pi^- + p \rightarrow n + \pi^+ + \pi^-$, which we have investigated at the same energy.[4] We show these data in Fig. 2(b) for comparison. Since the peak in Fig. 1(a) cannot be due to the B^0, we interpret it as $f^0 \rightarrow$ neutrals and obtain a branching ratio [we include a correction based on the fact that the events in Reaction (2) are