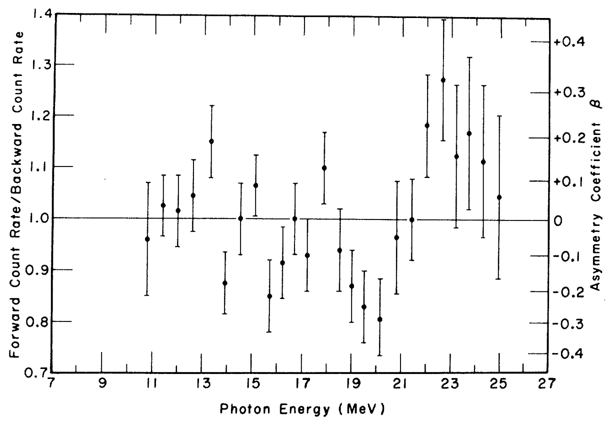

FIG. 2. Fore-aft asymmetry of the photoneutrons. The asymmetry coefficient β is computed on the assumption that the angular distribution is given by $\sin^2\theta(1+\beta\cos\theta)$.

related with observed peaks in the cross section at those energies. Thus, between these two energies, there is a sign reversal in the interference between the dominant $E1$ amplitude and an underlying positive-parity contribution.

The authors gratefully acknowledge the help of Dr. M. A. Kelly in designing the cryostat, J. Nutter and C. Flack for maintaining it, C. Orton for help in taking the data, E. Dante and staff for the accelerator operation, and Dr. B. F. Gibson and Dr. J. S. O'Connell for valuable discussions.

*Permanent address: Department of Physics and Astronomy, Rensselaer Polytechnic Institute, Troy, N. Y. 12181.

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

[1]B. L. Berman, L. J. Koester, Jr., and J. H. Smith, Phys. Rev. 133, B117 (1964).

[2]V. N. Fetisov, A. N. Gorbunov, and A. T. Varfolomeev, Nucl. Phys. 71, 305 (1965).

[3]H. M. Gerstenberg and J. S. O'Connell, Phys. Rev. 144, 834 (1966).

[4]B. L. Berman, J. T. Caldwell, R. R. Harvey, M. A. Kelly, R. L. Bramblett, and S. C. Fultz, Phys. Rev. 162, 1098 (1967).

[5]M. A. Kelly, B. L. Berman, R. L. Bramblett, and S. C. Fultz, Phys. Rev. 179, 1194 (1969).

[6]S. C. Fultz, J. T. Caldwell, B. L. Berman, R. L. Bramblett, and R. R. Harvey, Phys. Rev. 143, 790 (1966).

[7]R. L. Bramblett, J. T. Caldwell, B. L. Berman, R. R. Harvey, and S. C. Fultz, Phys. Rev. 148, 1198 (1966).

POLARIZATION IN COULOMB STRIPPING REACTIONS

J. A. R. Griffith and S. Roman
Department of Physics, University of Birmingham, Birmingham, England
(Received 11 May 1970)

Distorted-wave Born-approximation calculations of polarization effects in (d,p) stripping reactions near the Coulomb barrier have been carried out which predict large polarization values and strongly j-dependent patterns for the angular distributions of polarization. Coulomb-wave calculations showed that for reactions in the Coulomb field the coupling of the orbital angular momentum to the spin of the captured neutron is simply related to the predominant sign of the polarization.

Arguments have been put forward by Goldfarb[1] showing that the description of (d,p) stripping reactions below the Coulomb barrier will be free from the complications due to the distorting influence of the nuclear field. Experiments were suggested to help in resolving ambiguities associated with the bound-neutron form factors as used in direct-reaction theories. In practice, however, the differential cross-section measurements at energies below the Coulomb barrier are not likely to reveal much relevant detail; polarization values, which depend largely upon interference terms, ought to be more sensitive to the bound-state configuration. Recent measurements of the vector-analyzing power of (d,p) reactions above the Coulomb barrier[2] have shown a strong dependence of the observed angular distributions upon the total angular momentum j of the captured neutron. The results were generally reproduced by calculations in the distorted-wave Born approximation (DWBA). However, in such cases the derivation of reliable spectroscopic information from the DWBA is often obscured by the freedom of choice in the optical-model parameters normally used in describing the bound state and the nuclear distortions. For reactions below the Coulomb barrier only the bound-state problem should remain.

The present calculations suggest that for (d,p) reactions in the Coulomb field, the j dependence

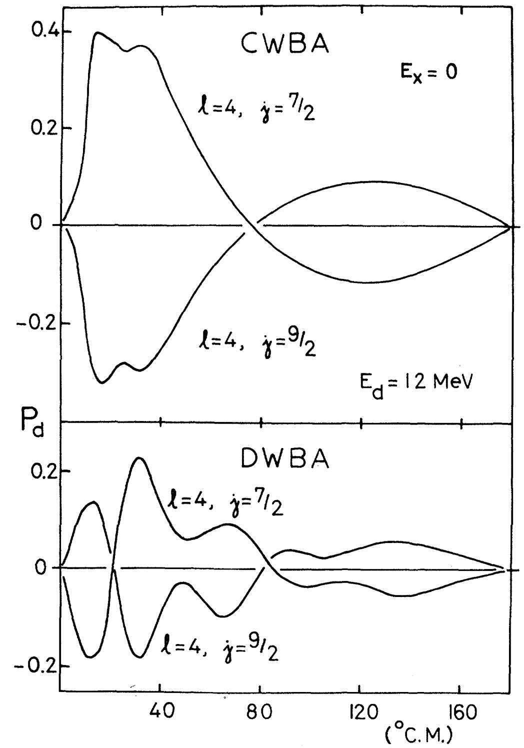

FIG. 1. Coulomb-wave Born-approximation (CWBA) and DWBA predictions for the polarization vector-analyzing power of the $^{209}Bi(\vec{d},p)^{210}Bi$, $l=4$ transition to the ground state of ^{210}Bi for 12-MeV deuteron energy. The cases for both $j=l+\frac{1}{2}$ and $j=l-\frac{1}{2}$ for the transferred neutron are shown.

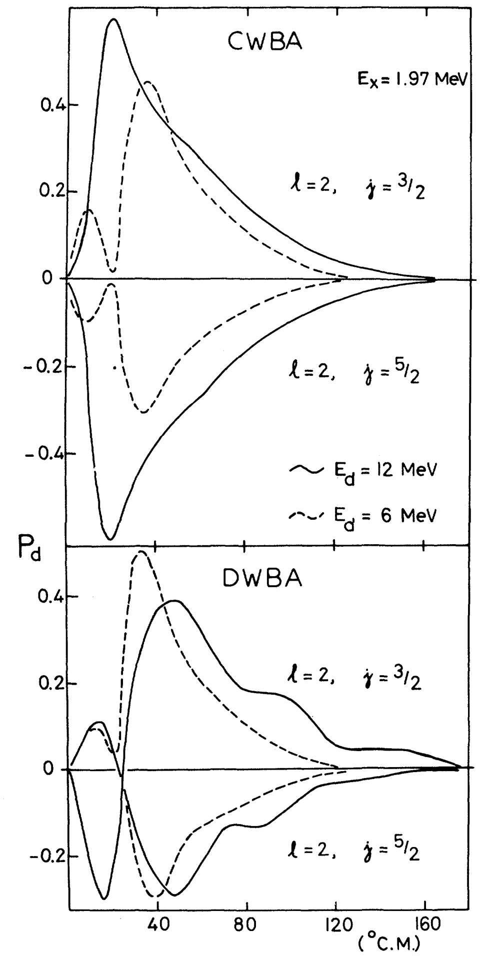

FIG. 2. CWBA and DWBA predictions for the polarization vector-analyzing power of $^{209}Bi(\vec{d},p)^{210}Bi$ for the $l=2$ transition to the 1.97-MeV excited state of ^{210}Bi for 12- and 6-MeV incident deuteron energy. The cases for both $j=l+\frac{1}{2}$ and $j=l-\frac{1}{2}$ for the transferred neutron are shown.

of the polarization is strong and the expected polarization values are large. There is a very simple rule connecting the sign of the polarization and the relative alignment of the orbital and spin angular momenta of the transferred neutron ($j=l\pm\frac{1}{2}$), similar to the approximate relations of the early stripping calculations.[3] The sign of the polarization or of the vector analyzing power, using the Basel convention, is predominantly negative (positive) over most of the angular range, if the orbital angular momentum and spin are parallel (antiparallel) for even l. For odd l values the situation is reversed, the sign being positive for parallel orbital angular momentum and spin. At energies well above the Coulomb barrier no such simple pattern of j dependence is found.

The reaction $^{209}Bi(\vec{d},p)^{210}Bi$ was chosen for the calculations; it offered a wide choice of energy levels with various j and l values, the assignments of many of which are known from the work of Erskine, Buechner, and Enge.[4] In terms of the shell model, ^{210}Bi has a straightforward structure consisting of an extra proton and neutron each added to the doubly magic ^{208}Pb core.

The distorted-wave calculations were carried out using the University of Colorado code due to Kunz,[5] including spin-orbit coupling in the distorting potentials. As examples, results of the calculations for the transitions leading to the ground state ($l=4$) and the 1.97-MeV excited state ($l=2$) of ^{210}Bi are shown in Figs. 1 and 2. For both transitions predictions are shown for both possible relative orientations of the orbital and spin angular momenta of the captured neutron. Results of the Coulomb-wave calculation with no nuclear distortions are shown, as well as predictions of full DWBA calculations using optical-model potentials in the distorting chan-

Table I. Optical-model potential parameters.

	Real central			Surface imaginary			Spin orbit		
Particle	V (MeV)	r_0 (fm)	a_0 (fm)	W_d (MeV)	r_d (fm)	a_d (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
d	137.1	1.25	0.76	14.3	1.42	0.72	6.0	1.1	0.91
p	60.03	1.17	0.75	11.3	1.32	0.657	6.2	1.01	0.75

nels as shown in Table I. A Saxon-Woods potential well was used for the bound-state calculations with $R_n = 1.25A^{1/3}$ fm and $a_n = 0.65$ fm, the depth of the well being automatically adjusted to match the asymptotic neutron wave function to the specified neutron separation energy. A Thomas-type spin-orbit term was included and the calculations were performed in the zero-range local approximation. The incident energies chosen were 6.0 and 12.0 MeV. The classical Coulomb barrier for Bi would be about 14 MeV, but more realistic figures based on the parameters of Table I would be 9.8 MeV for deuterons and 11.0 MeV for protons. The ground-state-reaction Q value is 2.37 MeV for the reaction considered; therefore the two energies chosen for the calculations lie, respectively, just below and above the Coulomb barrier.

The validity of the distorted-wave approximation in this region has been experimentally confirmed for the Pb (d,p) transitions.[6] The large polarizations predicted by the present calculations and the simple features of the polarization angular distributions suggest that experimental measurements of this parameter in the Coulomb-stripping region could be particularly useful in providing spectroscopic information free from the usual ambiguities associated with the distorting potentials.

It should be noted that while the differential cross section for stripping under these conditions is very small in the angular region forward of 60°, it then rises rapidly to values which for some states studied by Erskine, Buechner, and Enge[4] at $E_d = 8$ MeV exceed 1 mb/sr at 100°. The proposition thus represents a viable experiment.

[1]L. J. B. Goldfarb, Nucl. Phys. 72, 537 (1965); L. J. B. Goldfarb and K. K. Wong, Nucl. Phys. A90, 361 (1967).

[2]T. J. Yule and W. Haeberli, Phys. Rev. Letters 19, 756 (1967); A. M. Baxter, J. A. R. Griffith, and S. Roman, Phys. Rev. Letters 20, 1114 (1968).

[3]H. C. Newns, Proc. Phys. Soc. (London) A66, 477 (1953); H. Ruby, M. Y. Refai, and G. R. Satchler, Nucl. Phys. 9, 94 (1958).

[4]J. R. Erskine, W. W. Buechner, and H. A. Enge, Phys. Rev. 128, 720 (1962).

[5]P. D. Kunz, University of Colorado computer program DWUCK, 1969 (unpublished).

[6]A. A. Debenham, J. A. R. Griffith, M. Irshad, and S. Roman, to be published.

NEW ELEMENT HAHNIUM, ATOMIC NUMBER 105 *

Albert Ghiorso, Matti Nurmia, Kari Eskola,† James Harris, and Pirkko Eskola
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720
(Received 17 April 1970)

An isotope of element 105 with mass number 260 has been formed by bombarding ^{249}Cf with ^{15}N ions. The Z and A of the nuclide have been unambiguously identified by recoil-milking the 30-second ^{256}Lr daughter. ^{260}105 has a (1.6 ± 0.3)-sec half-life and decays by alpha-particle emission with groups at 9.06 (55%), 9.10 (25%), and 9.14 MeV (20%). Branching decay by spontaneous fission is less than 20%. Some comments are made on the earlier results of the Dubna group concerning a few alpha-particle events at 9.4 and 9.7 MeV which they claim to be due to element 105.

Using the same target of ^{249}Cf that was instrumental in the discovery of the alpha-emitting isotopes of element 104,[1] rutherfordium,[2] we have produced with moderate yield a 1.6-sec, 9.1-MeV alpha-particle activity by bombardment with ^{15}N ions at the heavy-ion linear accelerator (HILAC). By the alpha-recoil milking of a known isotope of element 103 we have obtained evidence that assigns this new radioactivity unambiguously to an isotope of element 105.