LARGE-ANGLE NEUTRON SCATTERING FROM LEAD AT 7 MeV*

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Data on elastic neutron scattering from nuclides in the lead region at 7 MeV contribute substantially to determination of the parameters of a nonlocal optical potential[1] which has proven to be successful in fitting a wide range of results on neutron scattering and reactions. The 7-MeV experimental data available,[2] however, have been insufficiently precise or extensive in angular coverage to distinguish between two potentials[1,3] which differ in their predictions at 180° by a factor of three. Hence methods of neutron spectroscopy[4,5] which increase substantially the range of angle and energy over which precise data may be obtained have been developed and applied to this problem.

New data were obtained from measurements of the spectra of scattered neutrons using the pulsed-beam time-of-flight spectrometer associated with the large Los Alamos electrostatic generator. The reaction $D(d,n)He^3$ furnished neutrons with energy spread of 150 keV. An over-all time resolution of 2.5 nsec full width at half-maximum and a flight path of 3 m made possible reliable separation of elastic from inelastic events while affording conditions favorable for accurate measurement. The maximum angle of observation of 165° was defined by mechanical considerations.

Preliminary runs with 50-g samples of Bi^{209} and of electromagnetically separated[6] Pb^{206}, Pb^{207}, and Pb^{208} gave results which were very similar for all four cases. The data presented here were taken with radiogenic lead (89% Pb^{206}) and bismuth. The samples were hollow cylinders dimensioned to minimize multiple scattering and angular resolution effects and weighed about 18 g each. Angular resolution was ±3.5°. Corrections were made for multiple scattering and angular resolution with the Aldermaston B-3 and B-4 codes modified to include the effects of a neutron source of finite size.[7] Corrections were less than 10%, except in the minima of the angular distributions where they ranged up to 35%. Corrected data for Bi^{209} are shown in Fig. 1, together with the earlier[2] data. The curve of Perey and Buck[1] generated by their fit to the earlier data is also shown.

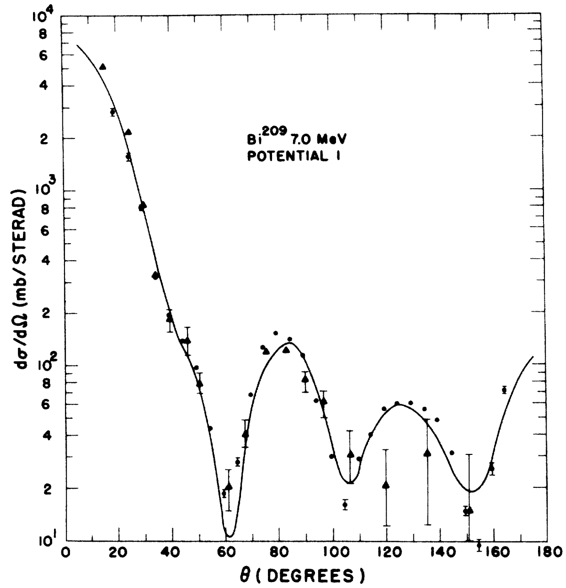

FIG. 1. The elastic scattering of 7-MeV neutrons compared with the prediction of the optical model in reference 1. Solid circles represent the present data; triangles represent the data of Beyster, Walt, and Salmi.[5] Errors are shown explicitly where larger than the plotting points.

The agreement between the Perey-Buck curve and the new data at large angles is clearly coincidental, considering the large errors associated with the data to which their curve was fitted. Indeed, their agreement is substantially better than that given by the earlier potential of Bjorklund and Fernbach,[3] who achieved a better fit to the older data by assuming an absorption about 30% greater than that of Perey and Buck.

In order to discern the effects on the optical analysis of more precise data at large angles, an analysis has been made of the new data based on a potential of the same form and with the same search code[8] as had been used previously[1] by Perey and Buck in fitting the older data. The potential is a Woods-Saxon real well with derivative absorption and spin-orbit terms. The values of the parameters reported by Perey and Buck which give the curve in Fig. 1 are given in Table I under the heading "Potential 1."

Table I. Optical-model potential parameters.[a]

	Potential 1	Potential 2	Potential 2a	Potential 3
V (MeV)	45.31	45.10	45.16	45.93
R_0 (F)	1.25	1.25	1.25	1.23
a (F)	0.65	0.65	0.65	0.69
W (MeV)	6.57	6.09	6.19	5.16
R_i (F)	1.25	1.25	1.25	1.34
a_i (F)	0.47	0.47	0.47	0.48
U (MeV)	1202	950	958	995.1
R_S (F)	1.25	1.25	1.25	1.23
a_S (F)	0.65	0.65	0.65	0.69

[a]The parameters given in the above table refer to an optical-model potential of the form

$$V\frac{1}{1+\exp(r-R_0A^{1/3})/a_0}+iW\frac{4\exp(r-R_iA^{1/3})/a_i}{[1+\exp(r-R_iA^{1/3})/a_i]^2}+U\frac{\vec{1}\cdot\vec{\sigma}}{r_s}\left(\frac{\hbar}{2M_pc}\right)^{1/2}\frac{d}{dr}\frac{1}{1+\exp(r-R_sA^{1/3})/a_s}.$$

The geometrical parameters of the potential were set equal to those of Perey and Buck, and a search was made for three potential strengths: the real depth, V; the surface imaginary term, W; and the spin-orbit potential, U. The curves obtained are shown in Fig. 2. The potentials 2 and 2a, which gave a minimum value of chi-squared, are given in Table I. Potential 2 gave the best fit to the Bi^{209} data; potential 2a gave the best fit to the Pb^{206} data. The data for Pb^{206} differ only slightly from those for Bi^{209}. In both cases significant discrepancies remain between the values calculated and observed at the minima and at the maximum at about 130°, as seen in Fig. 2. Further investigations were carried out with the bismuth data only.

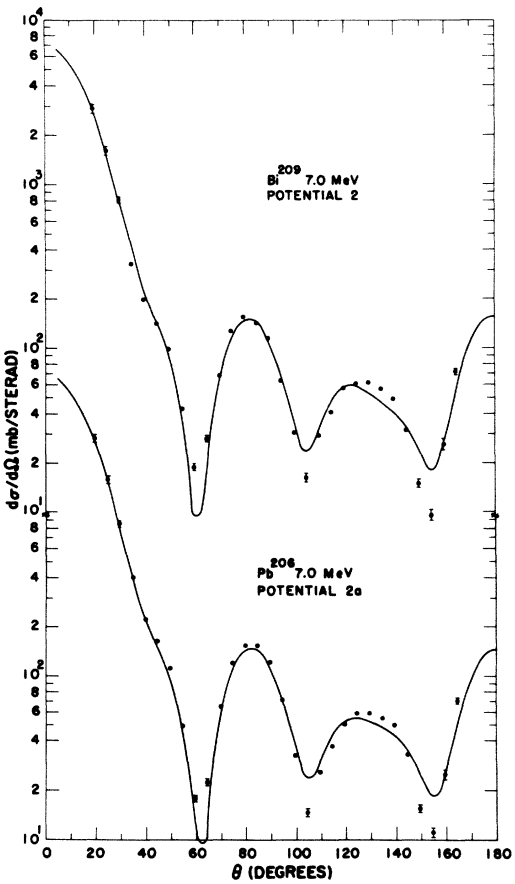

FIG. 2. The best fits to the data obtained by searching on V, W, and U.

First, all parameters were allowed to vary and the starting values of the parameters were changed in several different searches to test whether the search was terminating only in a local minimum of chi-squared. Essentially the same final potential was reached each time. Second, since zero degrees was known only to $\pm\frac{1}{2}°$, a search was made with the data shifted by $\frac{1}{2}°$. The potential strengths changed by less than 2%. Third, to enhance the influence of back-angle data, a search was made introducing only the data beyond 50°. The effect on the potential strengths was small. Finally, a search was made in which all parameters were allowed to vary, using the data at all angles. Figure 3 shows the improved fit that was obtained. This potential is labeled "potential 3" in Table I.

A special series of searches was made in which a volume absorption term was included in the potential. No improvement was obtained over the results shown for potential 2 of Table I.

All the potentials given in Table I predict absorption cross sections which agree with the 2.5-b value reported[2] for bismuth within 0.15 b.

The chief difference between potential 3 and the others given in Table I, to which the im-

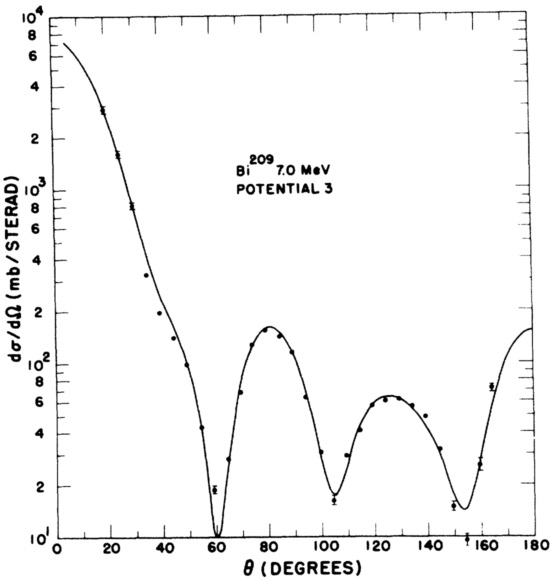

FIG. 3. The best fit to the data obtained with all parameters free to vary.

proved fit at back angles must be attributed, lies in the fact that the maximum of the imaginary part is located 0.4 F beyond the half-maximum of the real potential rather than at the half-maximum point. Such a relationship has been predicted on the basis of nuclear-matter calculations,[9] and has been postulated[10] to account for inadequacies in calculations of s-wave strength functions. Evidence for an absorptive "fringe" effect of 0.5 to 1 F has been reported by Moldauer[11,13] from analysis of lower energy neutron scattering data, and of reduced widths from stripping.

The analysis and data reported here may be interpreted as consistent with an absorptive fringe effect at 7-MeV neutron energy. More convincing statements on this point must await analysis which is based on further accurate measurements at large angles.

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[1]F. Perey and B. Buck, Nucl. Phys. 32, 353 (1962).

[2]J. R. Beyster, M. Walt, and W. E. Salmi, Phys. Rev. 104, 1319 (1956).

[3]F. Bjorklund and S. Fernbach, Phys. Rev. 109, 1295 (1958).

[4]L. Cranberg, R. A. Fernald, E. S. Hahn, and E. F. Shrader, Nucl. Instr. Methods 12, 335 (1961).

[5]L. Cranberg, C. D. Zafiratos, J. S. Levin, and T. A. Oliphant, Phys. Rev. Letters 11, 341 (1963).

[6]Furnished by Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

[7]J. B. Parker, J. H. Towle, D. Sams, and P. G. Jones, Nucl. Instr. Methods 14, 1 (1961); and private communications.

[8]F. Perey, private communication.

[9]L. Verlet and J. Gavoret, Nuovo Cimento 10, 505 (1958). See also references 56-62 in P. A. Moldauer, Nucl. Phys. 47, 65 (1963).

[10]A. M. Lane, J. E. Lynn, E. Melkonian, and E. R. Rae, Phys. Rev. Letters 2, 424 (1959).

[11]P. A. Moldauer, Phys. Rev. Letters 9, 17 (1962).

[12]P. A. Moldauer, Phys. Rev. Letters 10, 525 (1963).

[13]Moldauer, reference 9.

PROTON-CORE EXCITATION IN THE GROUND STATE OF O^{18}

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With the exception of the α particle, the doubly magic nucleus O^{16} has the highest first excited state. Consequently, it should be one of the most stable nuclear cores, and a measurement of the degree to which it is excited in the low-lying states of the neighboring oxygen isotopes should give a limit on the purity of any closed shell. It is, of course, clear that any given measurement will yield information only on a specific type of excitation and will tell nothing about the over-all purity of a state. Brown[1] and Engeland[2] have suggested that the most important core excitations involve highly deformed states whose intrinsic configuration arises from that of the Ne^{20} ground state by removal of two $1p$ protons. A detailed study along these lines by Federman and Talmi[3] yields an intensity of about 15% for the core-excited component in the O^{18} ground-state function. The influence which admixtures of this size