in Proceedings of the Conference on Lepton and Photon Interactions at High Energies, Stanford, California, 1975 (to be published)] show that if a new variable x_s is chosen, $x_s^{-1} \equiv x^{-1} + 1.5\ \mathrm{GeV}^2/Q^2$, then $W_1 \sim (1-x_s)^4$ for $0.2 \leq x_s \leq 0.85$. If experiment were to demonstrate conclusively that $\nu W_2 \not\sim (1-x)^3$, for x so near 1 and Q^2 so large that $\nu W_2 \sim W_1$, then this theory would be wrong. However, at present we are simply unable to test the theory with available data, since changing the scaling variable, and hence the treatment of nonscaling contributions, changes the apparent form of W_1, and even more νW_2, since x is not sufficiently close to 1 that $\nu W_2 \sim W_1$.

[9]Order κ corrections to σ_L/σ_T are expected to vanish near threshold as the first power of $1-x$; A. Zee, F. Wilczek, and S. B. Treiman, Phys. Rev. D 10, 2881 (1974).

[10]For a review of polarized e-p scattering see, e.g., F. J. Gilman, SLAC Report No. SLAC-167, 1973 (unpublished), p. 71.

[11]Our model certainly is not unique in giving $n/p \neq \frac{2}{3}$. For instance, see F. E. Close, Phys. Lett. 43B, 422 (1973), and R. Carlitz, University of Chicago Report No. EFI 75/6 (to be published). The interesting feature of the present work is that in a model with perfect SU(3) of flavor, which one would like to have if short distances are controlled by a color gauge interaction, we dynamically find $n/p \neq \frac{2}{3}$ in the $x \to 1$ limit.

[12]P. V. Landshoff points out that a consequence of $u/d = 5$ at $x \simeq 1$ would be that $\pi^+/\pi^- = 20$ for $z \simeq 1$ in the parton fragmentation region for $ep \to eX + \pi$.

[13]Drell and Yan, Ref. 1; West, Ref. 1; E. D. Bloom and F. J. Gilman, Phys. Rev. Lett. 25, 1140 (1970); R. P. Feynman has emphasized the need for care in distinguishing between transverse and longitudinal contributions in the pion case. See also D. Scott, Nucl. Phys. B74, 524 (1974).

[14]R. F. Schwitters *et al.*, Phys. Rev. Lett. 35, 1320 (1975).

[15]R. Hollebeek, Lawrence Berkeley Laboratory Report No. LBL-3874 (unpublished), analyzes the SPEAR data of the Stanford Linear Accelerator Laboratory–Lawrence Berkeley Laboratory collaboration at $\sqrt{Q^2} = 3.0$, 3.8, and 4.8 GeV. It is tantalizing, but statistically insignificant, that for each Q^2, α in the largest x bin drops off.

[16]Since $F_{\pi\rho}{}^L \equiv 0$ as a result of the vanishing of the Clebsch-Gordan coefficient of $|1,0\rangle$ in $|1,0\rangle \otimes |1,0\rangle$ and $F_{\pi\rho}{}^T \sim (Q^2)^{-2}$ we should expect very little $e^+e^- \to \rho\pi$ to be seen except near the ω resonance (similarly for $e^+e^- \to \omega\pi$). This may also account for the absence of an important meson current contribution to the deuteron form factor: R. G. Arnold *et al.*, Phys. Rev. Lett. 35, 776 (1975).

Small-Angle Scattering of 7–14-MeV Neutrons by Pb and U

W. P. Bucher and C. E. Hollandsworth
U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland 21005
(Received 3 March 1975)

Absolute cross sections for neutrons elastically scattered through small angles by Pb and U have been accurately measured at various energies in the range 7–14 MeV. The results disagree with many previously reported measurements and especially their interpretations regarding anomalous scattering. However, optical-model predictions based on the energy-independent, nonlocal potential of Perey and Buck are, apart from normalization, in agreement with the present measurements for Pb.

Previous experimental studies[1-7] of the forward elastic scattering of fast neutrons from heavy nuclei have resulted in many reports of anomalously strong scattering at small angles, and such effects have been variously attributed to the fission process, an unexpectedly high value for the induced electric dipole moment of the neutron, and the possible existence of long-range nuclear forces. On the other hand, other investigators have reported that little, if any, anomalous behavior was indicated from their measurements but in the process of interpreting their data have also relied on a variety of different nuclear models to represent the specifically nuclear component of the scattering. These differences still are not clearly resolved. It has been suggested[6] that the discrepancies in the above results are only apparent and are solely due to differences among the nuclear models employed. However, it can be shown that the application of a more uniform model to these data would not resolve the conflict but rather widen it. It will be demonstrated that the primary difficulty with many previous measurements on Pb and U in the 7–15 MeV energy range lies not only in the nuclear models employed but more so in the data.

It is the purpose of this paper to present results which contribute to the resolution of the above problem. Absolute measurements of the elastic scattering of neutrons by Pb and U were carried out to high accuracy for angles in the interval 3 to 15 deg and over the range of energies from 7 to 14 MeV. This energy range spans a large body of existing data and, in addition, is sufficiently wide to provide a good test for optical-model predictions of differential scattering cross sections at small angles.

A detailed description of the experimental technique developed for measurements at small angles has been reported elsewhere.[8] The experimental results, from which Schwinger scattering has been subtracted, are shown in Fig. 1. The error bars indicate the total uncertainty in the *absolute* values of the cross sections and include, besides counting statistics (0.5 to 2.5%), uncertainties in the corrections to the data (multiple scattering, finite geometry, and air scattering) and experimental uncertainties. The data for either element are well represented by a functional relationship of the form

$$\ln\sigma(\theta, E) = A(E) + B(E)\chi + C(E)\chi^2, \qquad (1)$$

where $\chi = 1 - \cos\theta$, $A(E)$ is a polynomial of fourth order in E, and $B(E)$ and $C(E)$ are quadratic in E. It was first verified that the form of the angular dependence of Eq. (1) is sufficiently general so

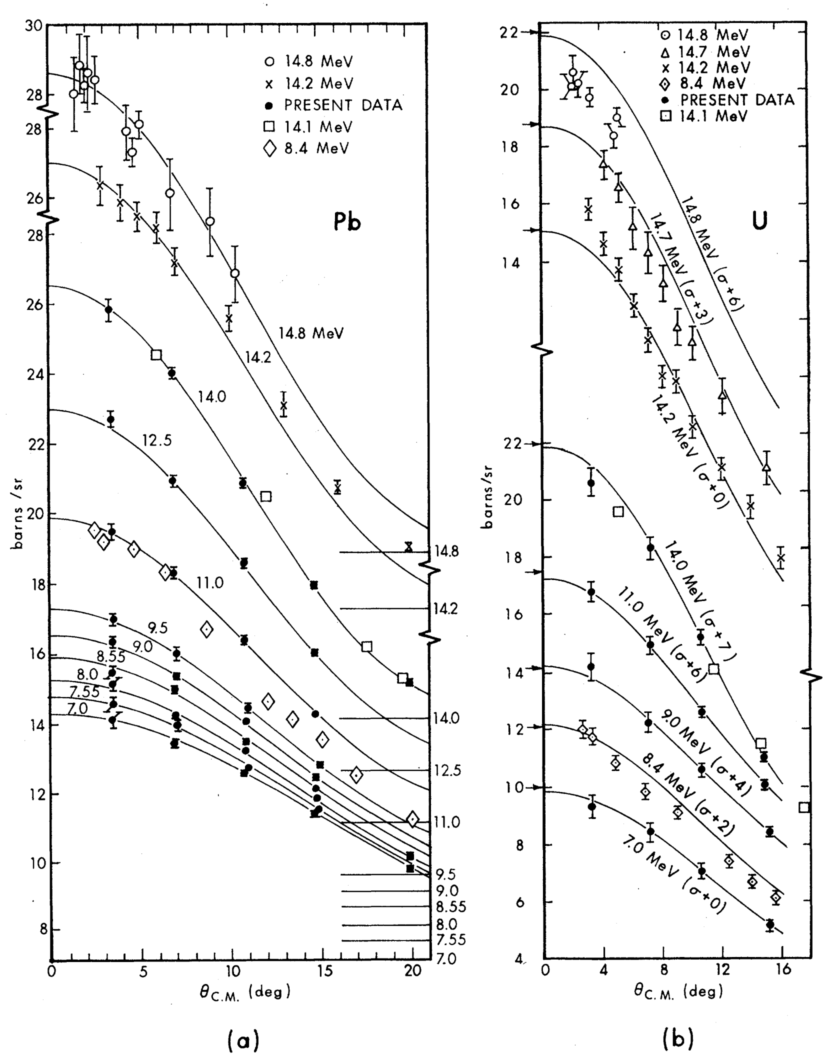

FIG. 1. Neutron scattering from Pb and U. The curves represent the best fit of Eq. (1) to the present data for Pb at 7.0, 7.55, 8.0, 8.55, 9.0, 9.5, 11.0, 12.5, and 14.0 MeV and for U at 7.0, 9.0, 11.0, and 14.0 MeV. For comparison with the data of Refs. 1, 2, 4, 5, and 9, curves obtained from Eq. (1) are also plotted at several other energies. In (a) cross sections are displaced vertically by an amount in b/sr equal to E in MeV; zero baselines are indicated at the right-hand margin for each energy. In (b) the displacements are as indicated on each curve.

as not to preclude good fits (i.e., <0.5%) to a variety of optical-model calculations over the range 0–15°. The curves shown in Fig. 1 are the result of a least-squares fit of Eq. (1) to the present data for either element; the percent deviations of the Pb data points from the fit are shown in Fig. 2(a). All zero-degree cross sections are in close agreement with the energy-averaged Wick-limit values, which for U are indicated by arrows in Fig. 1(b). For Pb, the percent deviations of $\sigma(0)$

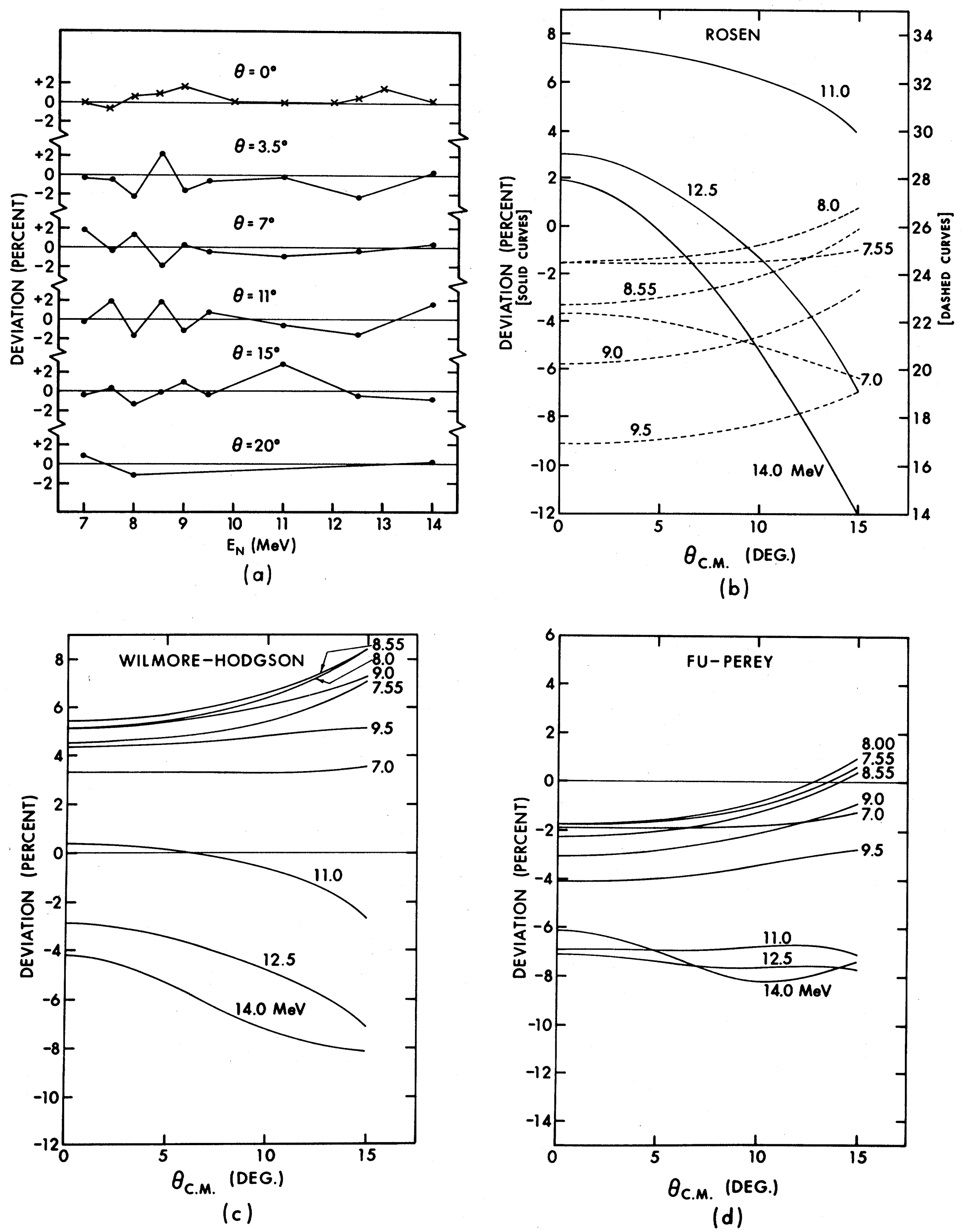

FIG. 2. Comparison of Pb data. (a) Percent deviation of Eq. (1) from present data and, at 0°, from the Wick limit. (b)–(d) Percent deviations of several optical-model predictions (Refs. 10–12) from Eq. (1) (see text).

from the Wick limits are shown in Fig. 2(a) by the zero-degree plot.

The present results can be clearly compared with those of others at differing energies by means of Eq. (1); Fig. 1 includes curves of cross sections inferred from the present data for these other energies. It should be noted that in general the errors reported by previous workers represent statistical counting errors only and that the normalizations are in some cases uncertain to 10% or more. Dukarevich and Dyumin[2] measured the small-angle scattering from U and Pb at 14.2 MeV and report unexpectedly strong scattering from U at the small angles but no such anomalous effect for Pb. At 8.4 MeV however, Anikin and Kotukhov[1] find an anomaly in the scattering from Pb but none from U. The curves in Fig. 1 for U indicate that the 14.2-MeV scattering reported in Ref. 2 is excessive not only at 3° but also around 15° and that, apart from normalization, the 8.4-MeV data of Ref. 1 is deviant at small angles. For Pb, Fig. 1 indicates that the 14.2-MeV data are much too high for angles of 10° and greater, the 20° point being 70% higher than the curve; the 8.4-MeV data are approximately 40% too high, but when renormalized to the curve an excess of about 7% is indicated for $\theta < 7°$. The U data of Adam *et al.*,[4] at 14.7 MeV, while somewhat similar in shape to the 14.2-MeV data of Ref. 2, are in fair agreement with the corresponding curve of Fig. 1. Good agreement is obtained with the Pb data of Benenson *et al.*,[5] at 14.8 MeV; however, we do not support their claim that these data are best described by the optical-model parameters of Rosen *et al.*[10] It is especially noteworthy that the 14.1-MeV scattering cross sections for Pb and U measured over the angular range 5–150° by Coon *et al.*[9] in 1958 are in excellent agreement with our measurements.

In Fig. 2 the Pb data are compared to several optical-model predictions by means of Eq. (1). The optical-model parameters of Rosen *et al.*, which are derived from a study of the scattering of polarized protons, yield the poorest fit. The parameters of Wilmore and Hodgson[11] and of Fu and Perey[12] are basically local equivalents to the energy-independent, nonlocal potential of Perey and Buck.[13] Though the normalizations of the scattering cross sections calculated from these potentials show deviations outside the limits of experimental error, the shapes are in agreement with the measurements to within ± 2%. For U, predictions of the Wilmore-Hodgson spherical potential do not approximate the data satisfactorily; however, agreement is obtained between the present results of U and the theoretical curve of Palla[14] which takes into account the effects of nuclear deformation.

It is concluded that, while the optical-model potentials of Refs. 11 and 12 require some adjustments to describe properly the strength of the main diffraction peak of Pb, there are no anomalies in the shape of the angular distributions at small angles from Pb or U. Apparently, previous reports of anomalous scattering were primarily due to insufficient accuracy in the measurements.

[1]G. V. Anikin and I. I. Kotukhov, Yad. Fiz. 12, 1121 (1970) [Sov. J. Nucl. Phys. 12, 614 (1971)].

[2]Yu. V. Dukarevich and A. N. Dyumin, Zh. Eksp. Teor. Fiz. 44, 130 (1963) [Sov. Phys. JETP 17, 89 (1963)].

[3]A. J. Elwyn *et al.*, Phys. Rev. 142, 758 (1966); F. T. Kuchnir *et al.*, Phys. Rev. 176, 1405 (1968).

[4]A. Adam *et al.*, Acta. Phys. Acad. Sci. Hung. 25, 261 (1968).

[5]R. E. Benenson *et al.*, Nucl. Phys. A212, 147 (1973).

[6]G. V. Gorlov *et al.*, Yad. Fiz. 8, 1086 (1968) [Sov. J. Nucl. Phys. 8, 630 (1969)].

[7]For other references to small-angle scattering work see N. S. Lebedeva and V. M. Morozov, At. Energ. 28, 310 (1970) [Sov. At. Energy 28, 398 (1970)].

[8]W. Bucher *et al.*, Nucl. Instrum. Methods 111, 237 (1973).

[9]J. H. Coon *et al.*, Phys. Rev. 111, 250 (1958).

[10]L. Rosen *et al.*, Ann. Phys. (N.Y.) 34, 96 (1965).

[11]D. Wilmore and P. E. Hodgson, Nucl. Phys. 55, 673 (1964).

[12]C. Y. Fu and F. G. Perey, ORNL Report No. ORNL-4765, 1972 (unpublished).

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

[14]G. Palla, Phys. Lett. 35B, 477 (1971).