which distorts the pattern in such a way as to render the spacing nearly uniform. In the latter, the intensities and separations are approximately those expected for $I=9/2$, but because of disturbing lines and the intermediate coupling they could not be relied upon for a quantitative result. Instead, we have used a method of finding which value of I gives the best fit to the second-degree hfs equation[6] for the resolved components in each of two lines of high J value (4621 and 5453 A). The result is unambiguous, and is confirmed by the fact that only for $I=9/2$ does the ratio of the quadratic coefficients for the two isotopes have the same value for the two lines. This ratio is equal to the ratio of the quadrupole moments of the two isotopes. Its mean value was found to be $Q(177)/Q(179)=0.99 \pm 0.02$.

From the coefficients of the linear term in the above solutions, the ratio of the magnetic moments is found to be $\mu(177)/\mu(179)=-1.276\pm 0.008$. The difference in sign is not surprising in view of the different spins. Calculations of the magnitudes of the magnetic and quadrupole moments are under way, and the results will be reported in the complete description of this work to be published elsewhere.

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[1] E. Rasmussen, Naturwiss. **23**, 69 (1935).
[2] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).
[3] B. Hartman and T. Wiedling, Phil. Mag. **46**, 1139 (1955).
[4] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).
[5] W. F. Meggers (private communication).
[6] H. Kopfermann, *Kernmomente* (Akademische Verlagsgesellschaft M. B. H., Leipzig, 1940), p. 64, Eq. (12.4).

Optical Model of Nucleus with Absorbing Surface*

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PREVIOUS optical-model calculations using square wells or almost square wells[1] have reproduced qualitatively the angular distribution of elastically scattered 14-Mev neutrons. Attempts to fit the 14-Mev data with tailed wells which fit the 17-Mev proton data so well[2] failed except for the very light elements.[3] For the heavy elements the cross sections in the region ~90° (lab angle) dropped off considerably. Other potential wells were then tried in order to bring the cross sections into better agreement with the experimental data.

Taking the Pauli principle into account, one is inclined to think of nonelastic events as taking place at the surface of the nucleus, at least for low-energy nuclear events. For this reason a Gaussian-type well was used for the imaginary part of the potential and the usual tailed well for the real part. These wells are indicated in Fig. 1. The real part is given approximately by

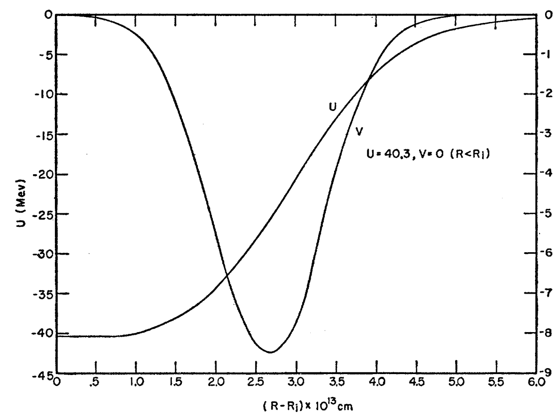

FIG. 1. Potential wells for the theoretical calculations.

$$U=U_0/[1+\exp(R-R_0)/a],$$

where $U_0=40.3$ Mev, $R_0=(1.2A^{\frac{1}{3}}+0.64)\times 10^{-13}$ cm, and $a=0.6\times 10^{-13}$ cm, and the imaginary part by

$$V=V_0\exp[-(R-R_0)^2/b^2],$$

where $V_0=8$ Mev, $b=0.978$, and R_0 is as defined above.

An exact phase-shift analysis using these wells was carried out for 14.6-Mev neutrons incident on Mg, Ca, Cd, and Bi, these being the only elements for which experimental data[4] were available over a range of 140°. The results obtained are extremely sensitive to the changes in U_0, R_0, b, and the position of the center of the Gaussian. The results of these calculations appear in Fig. 2. The total cross sections for elastic and nonelastic scattering appear in Table I.

TABLE I. Theoretical cross sections for elastic and nonelastic scattering of 14.6-Mev neutrons (in barns).

	Mg	Ca	Cd	Bi
σ_{el}	0.81	0.88	3.1	3.4
σ_{nonel}	0.99	1.23	1.9	2.3

It is possible to improve this fit somewhat by making the Gaussian wider as one goes to lighter elements. In the case of magnesium, a better fit is actually obtained by using the same shape for the imaginary part of the potential as for the real part. The width of the Gaussian

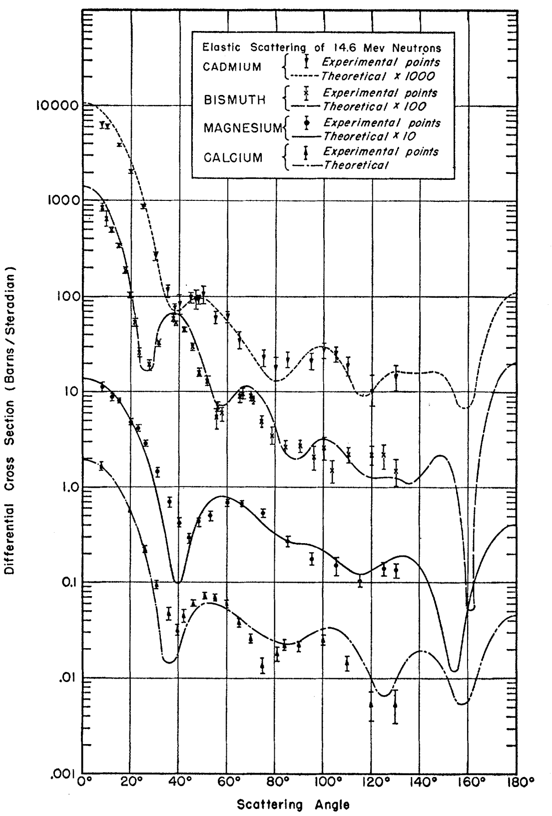

FIG. 2. The angular distributions for magnesium, calcium, cadmium, and bismuth—experimental and computed.

should also narrow as one decreases in incident neutron energy. Preliminary results obtained for 4.1-Mev neutrons show this to be the case.

Further calculations are in progress in the low-energy region. The same wells will be used in an attempt to fit the proton data presently available.

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

[1] Culler, Fernbach, and Sherman, Phys. Rev. **101**, 1047 (1956).

[2] Melkanoff, Nodvik, Saxon, and Woods, University of California at Los Angeles, Department of Physics, Technical Report No. 7-12-55, 1955 (unpublished).

[3] D. Saxon, private communication, as well as independent calculations performed at University of California Radiation Laboratory.

[4] W. Cross, Chalk River, Canada (private communication). These data were not corrected for multiple scattering and angular resolution.

Possible Origin of $\mathbf{l}\cdot\mathbf{s}$ Forces in Nuclei*

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IN a quantitative meson theory of nuclear forces, the $\mathbf{l}\cdot\mathbf{s}$ interaction between a nucleon's spin and orbital motion in a nucleus would be calculated in terms of all the interactions of both the core and meson cloud of this nucleon with all other nucleon cores and mesons in the nucleus. The following is a poor substitute, in which the $\mathbf{l}\cdot\mathbf{s}$ interaction is estimated from the average interaction of this whole nucleon with all the other mesons only.

A proton (or neutron) moving in a nucleus feels a meson wind in passing by the mesons from the other nucleons. If the proton has orbital angular momentum, from its standpoint the mesons appear to circulate around it, and if $\mathbf{l}$ and $\mathbf{s}$ are parallel the circulation is in a sense such as to form the $J=3/2$ state of the pion-proton system. If, on the other hand, $\mathbf{l}$ and $\mathbf{s}$ are antiparallel, the sense of rotation corresponds to the $J=1/2$ excited state of the pion-proton system. Now the $T=3/2$ part of the $J=3/2$ state appears from meson-nucleon experiments to have an exceptionally attractive force field compared with the $T=1/2$, $J=3/2$ state or with the $J=1/2$ states, i.e.,

$T=3/2$, $J=3/2$ attractive,
$T=1/2$, $J=3/2$ not so attractive,
$T=3/2$, $J=1/2$ not so attractive,
$T=1/2$, $J=1/2$ not so attractive.

Thus the coefficient c of the interaction energy $c\mathbf{l}\cdot\mathbf{s}$ should be negative, as observed.

An estimate of the magnitude of c is based on the following: (1) The density of mesons from other nucleons (added incoherently), relative to its own, is $(r_i/r_0)^3$, where $r_i\approx0.8\times10^{-13}$ cm is a guess at the average effective interaction distance from the center of the proton, and $r_0=1.2\times10^{-13}$ cm is defined as usual by $R=r_0A^{\frac{1}{3}}$. (2) The interaction energy is taken proportional to the velocity of meson circulation at r_i, so that the ratio of the interaction energy of the mesons from other nucleons to that from one of its own mesons at r_i is $(r_i/r_0A^{\frac{1}{3}})$. (3) The interaction energy for one meson in the $T=3/2$, $J=3/2$ state must be at least of the order of the energy of the resonance in pion-proton scattering, ≈200 Mev. We will take the interaction energy as ≈400 Mev, per meson with $\mathbf{l}=1$ at r_i. We must also multiply by the difference between the probabilities of being in the $T=3/2$, $S=3/2$ state when $\mathbf{l}\cdot\mathbf{s}$ is positive and when it is negative. (The other states are disregarded.) In the classical limit where the Clebsch-Gordan coefficients are either 1 or 0, the statistical factor is roughly 1/2, because the $T=3/2$ state for a proton can be formed only with the π^+ mesons from other protons rather than from all the other nucleons. Likewise neutrons interact only with the π^- mesons from neutrons and, assuming charge symmetry, one might thus expect the $\mathbf{l}\cdot\mathbf{s}$ interaction to be slightly larger for neutrons than for protons in heavy nuclei.

The result is $c\approx-(0.8/1.2)^3(0.8/1.2A^{\frac{1}{3}})(400\times\frac{1}{2})$, which for example for $A\approx100$ is ≈8 Mev instead of the "observed" 1 Mev.[1] But this crude estimate may be useful in indicating that the volume dilution of mesons and their low angular velocity around the