broken lines; they are similar to each other and may relate to the filling of the $g_{9/2}$ states (for $40<n\leqq 50$) and $h_{11/2}$ states (for $70<n\leqq 82$) in the scheme of Mayer, but more accurate data in these regions are required to establish their reality. The remaining minor fluctuations of the order of 0.2 magneton seem rather irregular.

Current theories suggest that our presentation should be plausibly interpreted as a variation of the "anomalous moment," due to modifications of the meson field by the binding of the odd nucleon.[6] Accordingly, the values $|\mu_P-1|$ and $|\mu_N|$ of $\Delta\mu$ in Fig. 1 represent the limits where the anomalous moment would be completely quenched; with very few exceptions, the points are seen to fall between zero and these limits, indicating partial quenching as the general case. We hope that further developments of the meson theory of nuclear forces will tend to corroborate this interpretation and to explain the characteristic features of our plot.[7]

[1] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949); E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949); L. W. Nordheim, Phys. Rev. **75**, 1894 (1949); M. G. Mayer, Phys. Rev. **75**, 1969 (1949), **78**, 16 (1950); E. Feenberg, Phys. Rev. **77**, 771 (1950).

[2] T. Schmidt, Z. Physik **106**, 358 (1937).

[3] L. W. Nordheim (reference 1), and A. L. Schawlow and C. H. Townes [Phys. Rev. **82**, 268 (1951)] have recently pointed out that approximately equal mixtures are found for nuclei with the same spin and the same number of odd protons or odd neutrons.

[4] L. L. Foldy and F. T. Milford, Phys. Rev. **80**, 751 (1950).

[5] In spite of its different interpretation, this agreement is closely related to that observed by Schawlow and Townes (reference 3) for nuclei of equal spin; it is noteworthy, however, that it holds also for O^{17} and F^{19} with spins 5/2 and 1/2, respectively.

[6] F. Villars [Phys. Rev. **72**, 256 (1947); Helv. Phys. Acta **20**, 476 (1947); **21**, 354 (1948)] has previously considered such variations, due to exchange currents of the meson field, and has applied them successfully to the nuclei H^1 and He^3.

[7] The mechanism introduced by F. Villars (reference 6), will certainly have to be considered in this connection. In another approach, which seems to us more promising, nonlinear terms are introduced in the meson field to explain the validity of the single-particle model and the saturation of nuclear forces; they appear at the same time to lead quite naturally to the quenching of the anomalous moments, postulated here. (Private communication by L. I. Schiff and S. D. Drell.)

Resonant Scattering of Slow Neutrons by Cadmium

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SCATTERING of slow neutrons by cadmium has been measured over a range of neutron energy (0.02 to 0.4 ev) which includes the resonance at 0.176 ev. The apparatus shown in Fig. 1 was mounted on the arm of the crystal spectrometer previously described,[1] replacing the usual counter and shielding. Two circular apertures in slabs of boron carbide limited the monoenergetic beam to ½-inch diameter. Scattered neutrons were detected in six boron trifluoride counters symmetrically arranged in an annular bank about the neutron beam. To reduce background, the scattering chamber was evacuated and the equipment was shielded with paraffin wax and boron carbide. A thin sample of vanadium was used as a standard scatterer because of the almost complete lack of coherent scattering in vanadium.[2]

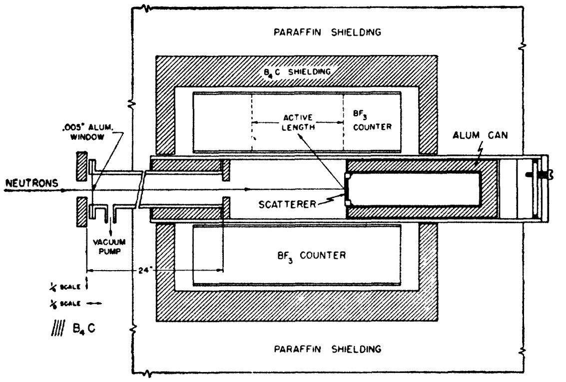

FIG. 1. Resonant scattering apparatus. The vertical and horizontal scales are such that the figure is compressed horizontally in a ratio 2:1,

The counting rates from the standard scatterer and from specimens of cadmium thick enough to absorb nearly all the incident neutrons were measured under the same conditions. The ratio of scattering to absorption cross sections for cadmium is then given by $\sigma_s/\sigma_a=Kn_v\sigma_{sv}N/N_v$, provided $\sigma_s\ll\sigma_a$, where K is an instrumental constant, n_v is the number of vanadium atoms per cm², σ_{sv} is the scattering cross section of vanadium, and N and N_v are the counting rates due to cadmium and vanadium, respectively.

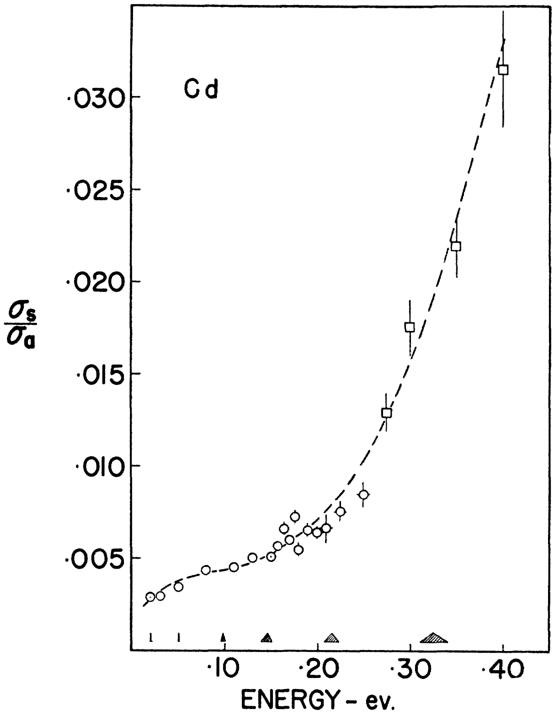

FIG. 2. Ratio of scattering to absorption cross sections in Cd. The circles and squares are experimental points with their standard deviations. The dashed curve is the Breit-Wigner curve calculated with $E_0=0.176$ ev, $\Gamma_a=0.115$ ev, $\sigma_{a0}=7200$ barns, $\sigma_P=5.3$ barns, $a=6.5\times10^{-13}$ cm, $f=0.1230$, $g=0.75$. The triangles indicate the resolution of the apparatus.

The essentially cylindrical symmetry of the apparatus permits the calculation of the angular distribution of the scattered neutrons for both specimen and standard. From these distributions and the measured counter sensitivity the constant K was computed. A small energy dependence of K, due to absorption in the vanadium, was taken into account.

The quantity $n_v\sigma_{sv}$ was determined by measuring the transmission of the standard vanadium sample as a function of energy. The total cross section of the sample was linear in $1/v$. The $1/v$ term was identified with absorption and the constant term with scattering. This constant term, which is considered accurate to ±3 percent, was used as $n_v\sigma_{sv}$.

The ratio σ_s/σ_a for cadmium is shown in Fig. 2 with standard deviations. A correction for contamination of the beam by higher diffraction orders has been applied.

In the same figure a curve is drawn showing the ratio predicted by the Breit-Wigner formula for a single level,[3] namely,

$$\frac{\sigma_s}{\sigma_a}=\left(\frac{E}{E_0}\right)^{\frac{1}{2}}\frac{\Gamma_{n0}}{\Gamma_a}+8.76\times 10^9\frac{(E-E_0)E^{\frac{1}{2}}}{\Gamma_a}a+\frac{\sigma_p}{\sigma_a},$$

where

$$\Gamma_{n0}/\Gamma_a=4.82\times 10^{18}E_0\sigma_{a0}/4\pi gf,\quad \Gamma_{n0}\ll\Gamma_a,$$

$$g_{i\pm\frac{1}{2}}=\tfrac{1}{2}[1\pm 1/(2i+1)],$$

E is the neutron energy in ev, Γ_n and Γ_a are, respectively, the neutron and absorption widths in ev, σ_p is the potential scattering cross section of the mixture of isotopes, a is the potential scattering length of the resonant isotope, i is its spin, and f is its abundance. The subscript 0 refers to the energy of the resonance. Values of Γ_a, σ_{a0}, E_0, σ_p were obtained from transmission measurements of Rainwater *et al.*[4] g was taken to be 0.75 in agreement with Beeman,[5] corresponding to spin 1 for the compound nucleus Cd^{114}. The scattering length a was assumed to be $(\sigma_p/4\pi)^{\frac{1}{2}}$; i.e., the potential scattering of the resonant state was assumed to be the same as that of the average for the element.

The general agreement is excellent, except that in the region 0.180 to 0.250 ev the measured values are low in comparison with those at lower energies. A possible cause is discussed in the following letter in connection with scattering by Sm_2O_3. This agreement is further support for the Breit-Wigner formulation, in particular for the proportionality of neutron width to wave number.

[1] Hurst, Pressesky, and Tunnicliffe, Rev. Sci. Instr. **21**, 705 (1950).
[2] C. G. Shull and E. O. Wollan, Phys. Rev. **81**, 527 (1951). Use of vanadium as a standard was suggested by Dr. G. H. Goldschmidt.
[3] See, for example, Feshbach, Peaslee, and Weisskopf, Phys. Rev. **71**, 145 (1947).
[4] Rainwater, Havens, Wu, and Dunning, Phys. Rev. **71**, 65 (1947).
[5] W. W. Beeman, Phys. Rev. **72**, 986 (1947).

Resonant Scattering in Samarium and Gadolinium

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SAMARIUM.—Scattering of low energy neutrons by samarium has been investigated by the method outlined in the preceding letter.[1] The ratio σ_s/σ_a for neutrons of energy 0.02 ev to 0.150 ev is shown in Fig. 1 for two samples of Sm_2O_3. The dotted curves are Breit-Wigner curves which involve only parameters from the literature. The resonance at 0.096 ev has been assigned[2] to Sm^{149}. Since the spin of this isotope is not known, curves for several values of spin have been plotted. In the formula (see preceding letter) σ_{a0}, Γ_a, E_0 were taken from the transmission data of Sturm,[3] and a was calculated from the Amaldi[4] $A^{\frac{1}{3}}$ relation for nuclear radii. The potential cross section for this value of a is 9 barns, and if 4 barns is taken as the scattering cross section of oxygen, the potential cross section of $\frac{1}{2}(Sm_2O_3)$ is $\sigma_p=9+6=15$ barns. The two most recent determinations[5, 6] of isotope abundance give $f=0.1368$ for Sm^{149} when weighted according to their stated accuracies.

The shapes of the experimental and theoretical curves are closely alike. Comparison of the curves suggests that the spin of Sm^{149} is high $(i>\frac{5}{2})$, in agreement with Brix and Kopfermann,[7] who found $i>\frac{1}{2}$, and that the spin of the compound nucleus Sm^{150} is $i+\frac{1}{2}$. On the Mayer shell model[8] the spin of Sm^{149} is expected to be 9/2. Larger ground-state spins are not observed. The agreement between theory and experiment for spin 9/2 is within the combined experimental errors of the transmission measurements and these results.

In this discussion three related effects have been neglected. These are Bragg scattering, the Debye correction to the scattering cross sections, and the change of neutron energy due to recoil of the nucleus. The first and third do not occur together. Insufficient data exist for accurate calculation of these effects but qualitative examination suggests that they are small. The general result is to raise the measured value of the ratio σ_s/σ_a at low energies compared with its value at high energies. It may be significant that the deviations between theory and experiment shown in Fig. 1, and also in Fig. 2 of the preceding letter, are in this direction.

The samarium oxide, as received, contained an amount of volatile material, presumably water and CO_2, sufficient to affect the measurements seriously. This was removed by heating one sample for 24 hours in a vacuum at 500°C, and the other in air at 700°C. The fact that the two samples of different origin and heat treatment gave essentially the same result indicates that there was no serious contamination.

Gadolinium.—Measurements of σ_s/σ_a were made on a sample of Gd_2O_3 in the condition received. The experience with Sm_2O_3 suggests that the measured values are about 20 percent too high, because of contamination. Nevertheless, the results are of some interest.

Sturm[3] and Brill and Lichtenberger[9] fitted their transmission measurements in the region 0.01 to 0.20 ev by a one-level Breit-Wigner formula for absorption. Our measurements of σ_s/σ_a lie significantly below all the Breit-Wigner curves calculated from their data, being about 15 percent below the lowest curve, that with $g=0.75$. Any correction for contamination increases the discrepancy.

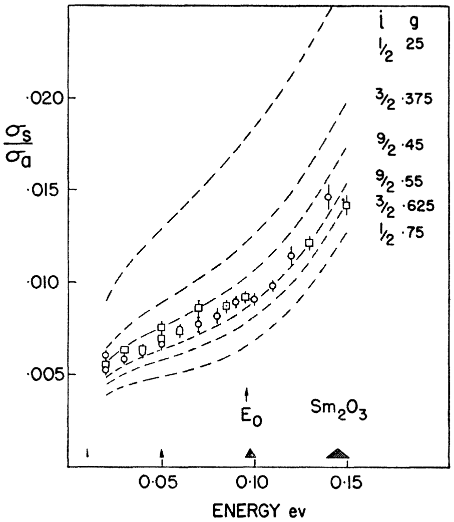

FIG. 1. Ratio of scattering to absorption cross sections in Sm_2O_3. The circles and squares are experimental values, with their standard deviations, for two samples of different origin. The dashed curves are the Breit-Wigner curves calculated with $E_0=0.096$ ev, $\sigma_0=15{,}500$ barns, $\Gamma_a=0.074$ ev, $\sigma_p=15$ barns, $a=8\times 10^{-13}$ cm, and $f=0.1368$, for different values of i and g.

We believe this disagreement shows that the low energy absorption in gadolinium cannot be described by a one-level formula. This is supported by measurements of Lapp *et al.*,[2] which show cross sections for pile neutrons of 2.5×10^5 barns for Gd^{157} and 0.7×10^5 barns for Gd^{155}. The cross section for Gd^{157} is the larger by a factor of 3.5; hence, description in terms of one level of Gd^{158} may have a limited meaning. If so, the conclusion may be drawn that the g-value for Gd^{157} is high and hence that its spin is low, and that the compound nucleus Gd^{158} has spin $i+\frac{1}{2}$.

[1] Brockhouse, Hurst, and Bloom, Phys. Rev. **83**, 839 (1951), (preceding letter).
[2] Lapp, Van Horn, and Dempster, Phys. Rev. **71**, 745 (1947).
[3] W. J. Sturm, Phys. Rev. **71**, 757 (1947).
[4] Amaldi, Bocciarelli, Cacceapuoti, and Trabacchi, Nuovo cimento **3**, 203 (1946).
[5] J. Mattauch and H. Scheld, Z. Naturforsch. **3a**, 105 (1948).
[6] Inghram, Hayden, and Hess, Phys. Rev. **73**, 180 (1948).
[7] P. Brix and H. Kopfermann, Z. Physik **126**, 344 (1949). K. Murakawa and J. S. Ross have reported the spin of Sm^{149} to be 5/2 [Phys. Rev. **82**, 967 (1951)].
[8] M. G. Mayer, Phys. Rev. **75**, 1969 (1949); **78**, 16 (1950).
[9] T. Brill and H. V. Lichtenberger, Phys. Rev. **72**, 585 (1947).