Resonance Scattering of Neutrons by Cobalt*

S. P. HARRIS, A. S. LANGSDORF, JR., AND F. G. P. SEIDL
Argonne National Laboratory, Chicago, Illinois

(Received September 17, 1947)

THE discovery that the Mn^{55} neutron resonance[1] about 300 ev is predominantly scattering[2–4] has induced us to search for other similar resonances. We have studied Co^{59} and conclude that the Co neutron resonance[5] near 115 ev is also mainly scattering.

If the neutron width is much greater than the absorption width, then according to the Breit-Wigner equation the peak scattering cross section for Co^{59} (spin 7/2, resonance 115 ev) should be 10,000 or 13,000 b ("b" is equivalent to 10^{-24} cm^2), depending upon the spin of the compound nucleus. Experimentally, we find a total peak cross section of at least 6000 b.

The transmission of a layer of $CoSO_4$ solution in D_2O (0.0233 g/cm^2 Co) was measured for neutrons detected by the 10.7-min. activity which they produced in a thin electrolytic Co foil (0.01 g/cm^2). The detector foil was located 200 cm behind the $CoSO_4$ solution and aligned in a collimated neutron beam from the heavy-water pile. The beam was passed through B^{10} and thin Cd to remove slow neutrons. Accordingly, the average total cross section was found to be 3100±500 b for neutrons filtered through 0.15 g/cm^2 B^{10} and 2700±500 b for the case of 0.31 g/cm^2 B^{10}. A large counting error resulted here because of the low counting rate caused by the softness of the 10.7-min. Co^{60} radiations.

In a second experiment, neutrons scattered by a Co foil were detected by an annular BF_3 counter surrounding the foil. The counting region lay between an outer Al tube 4 in. O.D. and a concentric inner Al tube $1\frac{7}{8}$ in. I.D. These were welded to suitable end rings so that the smaller tube formed an open path through the counter. The collecting electrode consisted of a cylindrical grid of 2-mil wires mounted coaxially within the annulus. The assembly was filled with pure BF_3 to 15-cm Hg and operated at about 1900 v as a proportional counter. When in use, a collimated pencil of neutrons was directed down the $1\frac{7}{8}$-in. tube through the system, and the scattering sample was placed in the beam near the center of this tube. The efficiency for detecting scattered neutrons was increased by surrounding the counter with a paraffin reflector, except in the path of the beam. To reduce background, the reflector was covered by Cd and by a shield of B_2O_3 and paraffin. Elimination of air scattering, by closing off the ends of the $1\frac{7}{8}$-in. tube with Al foils and evacuating, further decreased the background by a factor of ten.

In the second experiment an electrolytic Co foil was used as a scatterer. Near the Co resonance the efficiency of counter and reflector change relatively slowly with neutron energy; therefore, in this region the over-all sensitivity of Co scatterer, reflector, and counter should vary as the scattering cross section of Co. By means of this detector system the transmission of another Co foil (0.00677 g/cm^2) was measured. The thinner foil was inserted in the beam 15 in. in front of the counter, and an auxiliary collimator was placed between, so that practically

TABLE I. Summary of measurements.

Filters in neutron beam				Transmission T	
Cd g/cm^2	B^{10} g/cm^2	E_e* ev	E_m** ev	of 0.0067 g/cm^2 of Co	σ_{eff}*** b
0.00	0.000	—	—	0.919±0.003	1220± 40
0.34	0.000	—	—	0.850±0.006	2360± 90
0.34	0.157	37	8.4	0.852±0.005	2320± 85
0.34	0.313	163	33.6	0.869±0.009	2030±150
0.34	1.267	5600	550	0.976±0.026	360±360

* A neutron of energy E_e has the probability $1/e$ of penetrating the corresponding B^{10} thickness.
** Assuming a $1/E$ epi-Cd incident neutron spectrum, E_m is the most probable energy of a neutron traversing the corresponding B^{10} thickness.
*** $\sigma_{eff}=\ln(1/T)/\tau$, T being the transmission of a layer of thickness τ atoms/cm^2.

* This research has been carried out under contract No. W-31-109-eng-38 for the Atomic Energy Commission.

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none of the neutrons scattered by the first foil would be detected. The results appear in Table I, where the peak cross section should be at least twice σ_{eff}, which is an average over the resonance.

By the use of these data, the effect in the neighborhood of the Co resonance may be accentuated by computing the transmission for neutrons passed by 0.157 g/cm^2 B^{10}, but not by 0.313 g/cm^2 B^{10}; most such neutrons have energies between 2 and 200 ev. In this way $\sigma_{\text{eff}}=2920 \pm 150$ b, and an approximate integration shows that this value is consistent with a total *peak* Co cross section of 8000 to 9000 b.

Also, when the neutron transmission of thin Mn was investigated by means of scattering by a Co foil, the σ_{eff} for Mn was found to be ~ 10 b, and similarly for the transmission of Co as measured by Mn scattering. Thus resonance characteristics were exhibited by Mn and Co.

The annular counter was used in a third experiment to compare the scattering by Co, Mn, and graphite (1) for the total pile flux, including thermal neutrons, and (2) for neutrons filtered by Cd. If we assume the graphite-scattering cross section remains constant at 4.8 b, a large excess of epi-Cd scattering is apparent for both Co and Mn. Associating the excess scattering with a single level, we have roughly estimated a lower limit for $\sigma_0\Gamma$, where σ_0 denotes the peak *scattering* cross section and Γ the total width. In this calculation the sensitivity of counter plus paraffin reflector was assumed to vary with neutron energy E in either of two ways: (a) constant from $E=0$ to 10^4 or 10^6 ev, and thereabove zero; (b) $1/\sqrt{E}$. For Co $\sigma_0\Gamma \cong 20{,}000$ b-ev or 58,000 b-ev, respectively, for case (a) or (b); while for Mn $\sigma_0\Gamma \cong 30{,}000$ b-ev or 140,000 b-ev. These values are evidence of a very large resonance scattering.