JANUARY 1, 1937 PHYSICAL REVIEW VOLUME 51

The Magnetic Scattering of Slow Neutrons

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(Received October 15, 1936)

To determine whether the large cross sections for the scattering of slow neutrons by iron and nickel arise in part from the ferromagnetic nature of these materials, a comparison of the scattering at room temperature and above the Curie point was made. As no significant change in scattering was found, the conclusion is drawn that the largeness of these cross sections is not of magnetic origin. It is pointed out, however, that this result does not preclude the neutron possessing a magnetic moment of the order of magnitude of a nuclear magneton.

1. INTRODUCTION

THE scattering of slow neutrons by nonhydrogenous substances has been investigated by several authors.[1–7] The last results of Mitchell,[4] as well as those of Pontecorvo and Wick,[6] show greater scattering (measured in the backward direction) for iron and nickel than for neighboring elements in the periodic table. As iron and nickel are ferromagnetic substances and as the neutron is believed to possess a magnetic moment, it might be thought that this increase in scattering is chiefly of magnetic origin and would disappear, at least in part, if these scatterers should be raised above their Curie temperatures.

That the scattering cross sections apparently do not differ markedly[4, 6] for the various slow neutron groups is evidence against this explanation. Bloch[8] has published a formula for the magnetic scattering to be expected in a ferromagnetic substance; the substitution of reasonable values in this formula indicates the change in scattering as the material is raised from room temperature to above the Curie point would be small (very likely less than ten percent and probably less than one percent), even for thermal neutrons. The experiment reported here was undertaken at the suggestion of Professor Bloch, however, in the hope of finding some effect, which could, then, be regarded as due to the neutron possessing a magnetic moment. A negative result, within ordinary limits of error, would not, of course, constitute evidence against a magnetic moment for the neutron equal in order of magnitude to a nuclear magneton, but would show without reference to any theory that the high values for the scattering by iron and nickel are primarily due to other causes.

2. EXPERIMENTAL ARRANGEMENT

The primary source of neutrons was a beryllium target in the Berkeley cyclotron.[9] This target was bombarded with some ten microamperes of $5\frac{1}{2}$ Mev deuterons and produced fast neutrons, with a large spread in energy, according to the reaction[10, 11]

$$_4\mathrm{Be}^9+{}_1\mathrm{H}^2={}_5\mathrm{B}^{10}+{}_0n^1.$$

The scattering material and detector were located about one meter from this target at the end of a tunnel in a large water-box (see Fig. 1). Within the tunnel was placed either a block of paraffin ten centimeters thick (at *A*) or a container for water twelve centimeters thick (at *A or B*). The location of this hydrogenous material, which had the purpose of producing slow neutrons from the primary fast ones, did not seem to make any important change in the scattering measurements.

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A thin silver piece (0.15 mm thick, 3.2 cm diameter) was used as a detector of the incident and reflected neutrons, for much of the previous work[4, 6] was carried out with a similar detector. Because it was found that two-thirds of the activity produced in this silver arose from neutrons readily absorbed in cadmium, it was not thought desirable to introduce the complication of calculating C group intensities from runs made with and without cadmium filtering. A second silver sample, similar to the first, was in every run placed in a definite position beside the water-box and used as a control to integrate the effective neutron intensity; if the anisotropy of the neutron distribution about the cyclotron changed markedly during a series of runs, it thus introduced some error in the measurements, but this error was not a systematic one, for the temperature of the scatterer was alternated from cold to hot every few runs. The samples, after activation for a definite time (usually six minutes), were rushed to a Lauritsen electroscope and the activities read alternately for some ten minutes. The decay curves plotted logarithmically from these activities (consisting of two periods) were drawn with the same template and the intensity ratio of detector to control then obtained from them.

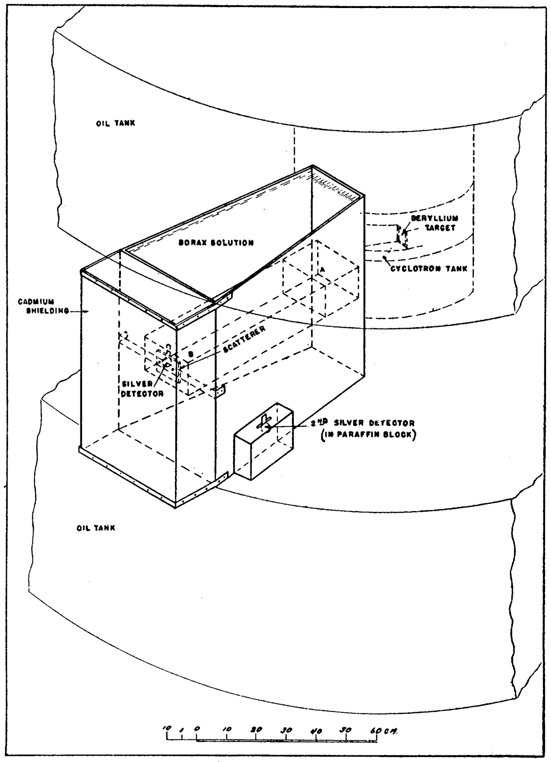

FIG. 1. Sketch showing arrangement of detector, scatterer and water-box between the oil tanks of the cyclotron.

With the scatterer located at the end of the water-box, a larger percentage of the slow neutrons reaching it came directly from the hydrogenous material in the tunnel than if the experiment had been performed closer to the beryllium target, for, with the latter arrangement, a large fraction of the neutrons striking the scatterer and detector would arise from the large oil tanks of the magnet. However, even at the end of the water-box, a considerable percentage of the neutrons arriving at the scatterer would have come from the back and sides (probably after being scattered by the walls of the room) had not fairly complete shielding been accomplished for the C group neutrons by surrounding the scatterer on all sides but the front with sheet cadmium metal (approximately 1 mm thick). This shielding was in place in every series of runs except the first series made with nickel; as will be seen it had the effect of raising the scattering observed from approximately twelve percent to forty percent—a value still not to be regarded as an accurate estimate of the scattering percentage.

The scatterers were mounted on an iron support left in place even when no scatterer was present. This support did not scatter much itself (perhaps three percent), but was fairly rigid in order to resist the pull of the magnetic field from the cyclotron on the nickel and iron samples when they were below their Curie temperatures. The heating was accomplished by use of one to three oxygen torches always left in place and lit when needed; due to the presence of the magnetic field (approximately 170 gauss at this point), the attainment of the Curie temperature was directly manifested by the scatterer ceasing to attract a small test piece of iron or steel.

3. RESULTS

Because the present experiment was concerned chiefly with *changes* in scattering, the neutron intensity without scatterer present was not investigated as carefully as when the scatterers were in place. For this reason the scattering percentages found for a given element varied somewhat from one series of runs to another. The values may differ considerably from those of other workers for the additional reasons that the shielding with sheet cadmium could be expected to be complete only for *C* group neutrons and that scattering is known to depend markedly upon geometrical conditions, e.g., decreasing with increased parallelism of the incident neutrons.[1] In every series of runs, however, at least one or two runs without scatterer would be introduced in the series to verify that scattering was actually taking place; in the second series made with nickel, a pair of runs was inserted in which a copper scatterer was used in order to verify that the difference in scattering by these two materials was easily detectable with the arrangement described above.

The results of four series of runs are tabulated in Table I. The errors attached are probable errors, calculated in all cases of two or more runs by the usual formula involving the deviations from the mean. No attempt was made to discard runs deviating from the mean by several times the probable error, for it was felt that, as the intensity for each run was calculated from decay curves each determined by several points, the possibility of huge, accidental errors could not be admitted. The order in which the runs of a series were made is indicated in the table, using the following abbreviations: n, cold nickel; N, hot nickel; f, cold iron; F, hot iron; c, cold copper; and o, no scatterer.

TABLE I. *Scattering of slow neutrons by various elements below and above their Curie temperatures* (*Ag detector*).

SERIES	I	II	III	IV
NO SCATTERER	100±2	100±2	100±2	100±14
COLD NICKEL	112±2	139±1	136±4	
HOT NICKEL	112±2	141±2		
COLD IRON			139±2	153±1
HOT IRON			134±2	152±1
COLD COPPER		128±2		
ORDER OF RUNS	oonnNNn	oonnNNncco	offFFFffon	fffFFFfffFFffo
DIMENSIONS (cm)				
Nickel	10.2×7.7×1.3	10.2×7.7×1.3	10.2×7.7×1.3	
Iron			10.2×7.7×1.6	8.4×8.1×1.6
Copper		10.2×7.7×1.3		

4. CONCLUSIONS

From Table I one may conclude that, with a probable error of 5½ percent for nickel and 2½ percent for iron, there is no change in the scattering of slow neutrons by these elements as they are raised above their Curie temperatures. Recalling that two-thirds the activity of the silver detector was found to arise from *C* group neutrons, one may draw a similar conclusion for thermal neutrons, but with a somewhat higher probable error—8 percent and 4 percent for nickel and iron, respectively. As was pointed out in the introduction, this shows the large slow neutron scattering cross sections found by Mitchell and co-workers[2, 4] for nickel and iron are not of magnetic origin; in view of the calculations of Bloch,[8] it does not, however, constitute evidence against a magnetic moment for the neutron equal, in order of magnitude, to a nuclear magneton.

An experiment similar to the one here reported but which eliminates the annoyance of heating the samples would be to compare the scattering of a Heusler alloy with that of its nonalloyed constituents.

5. ACKNOWLEDGMENTS

The author is deeply indebted to Professor Bloch for suggesting this experiment and for many helpful discussions, as well as to Professors J. R. Oppenheimer, E. O. Lawrence, and members of the laboratory staff for their active interest in the problem. This investigation was aided by grants from the Research Corporation, the Chemical Foundation, and the Josiah Macy, Jr. Foundation.