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Neutron Interferometric Measurement of the Coherent Scattering Length of Holmium

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Abstract

The coherent scattering amplitude of neutrons by holmium has been redetermined. The method used here is interferometric based on the neutron refraction index of a metallic holmium platelet. The value found by this method, $b_{Ho} = 8{\cdot}01\ (8)$ fm, agrees with that determined with polarized neutrons: $b_{Ho} = 8{\cdot}08\ (5)$ fm.

Introduction

The coherent scattering amplitude of neutrons by the single isotope element holmium is still somewhat uncertain for neutron users. It was first measured (Koehler, Wollan & Wilkinson, 1958) by Bragg diffraction on powders of the cubic sesquioxide Ho_2O_3, and found to be 8·5 (2) fm. In 1979, other authors (Boucherle, Quezel, Schweizer & Tcheou, 1979), also studying a powder of the same compound, showed that at room temperature as well as at low temperature there are strong correlations between the holmium scattering length and the thermal parameter of oxygen, and that b_{Ho} was in the range 8·0–8·4 fm. These authors then measured b_{Ho} by Bragg diffraction on a powder of the trigonal oxysulfide Ho_2O_2S and, using polarized neutrons, on a single crystal of the intermetallic compound $HoAl_2$. Their final value, 8·08 (5) fm, was rather far from the original determination. The following year, Schneider (1980)* reported another polarized neutron experiment in which he compared the transmission through metallic holmium for the two spin states of neutrons. He deduced a value of $b_{Ho} = 8{\cdot}37\ (50)$ fm.

* This result was reported with an error by Koester & Rauch (1981). The correct value is $b_{Ho} = 8{\cdot}37 \pm 0{\cdot}50$ not $8{\cdot}37 \pm 0{\cdot}05$ fm as reported.

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In order to bring this question to a conclusion, we measured the holmium amplitude using an interferometric method based on the neutron index of refraction. The real part of that index is directly related to the scattering amplitude b by

$$\mathrm{Re}\,(n) = 1 - (\lambda^2/2\pi)Nb$$

where λ is the neutron wavelength and N the specific number of nuclei.

Experiment

The measurements were done on the D18 neutron interferometer (Bauspiess, Bonse & Rauch, 1978; Bauspiess, 1979) of the ILL. For measuring refraction indices interferometrically, different arrangements are possible as described by Bonse & Graeff (1977), all based on differences in the optical path of the coherent beams I and II (Fig. 1) in the interferometer. The method used here (Cusatis & Hart, 1975; Bonse & Kischko, 1982) minimizes spurious phase shifts: a parallel-sided phase shifter (PS) of aluminium is rotated in steps around an axis normal to the plane of the rays to produce interferograms; at each step the sample SA, here the metallic holmium platelet, is introduced perpendicular to one beam and then removed, allowing two interferograms to be recorded simultaneously without the sample (Fig. 2*a*) and with the sample (Fig. 2*b*). These interferograms present a phase shift that can be measured within the limits of a multiple of 2π.

$$\Delta\Phi = \Delta\Phi_0 + m2\pi$$

with m an integer.

This phase shift is directly related to the real part of the index of refraction n of the specimen

$$\Delta\Phi = (2\pi/\lambda)[1 - \mathrm{Re}\,(n)]t,$$

where t is the thickness of the sample, here 1·1 mm.

The integer m has to be calculated with values for the scattering length already reported. It is unambiguously 8 with $b_{Ho} = 8{\cdot}0$ fm or $b_{Ho} = 8{\cdot}5$ fm. The phase shift was obtained by a least-squares fit of a cosine function and a final value $\Delta\Phi = 51{\cdot}702\,(28)$ rad was determined.

Data treatment and results

With the above formulae the scattering length b_{Ho} is deduced from the phase shift $\Delta\Phi$ and three other quantities: the sample thickness t, the neutron wavelength λ and the number of nuclei N. The sample thickness is measured directly with a micrometer screw. The neutron wavelength is known from two Bragg reflections (220, 331) of the interferometer crystal itself. The number of nuclei has been deduced from the mass of the sample, which has been measured with an Archimedes balance and found equal to $8{\cdot}802\,(6)$ g cm^{-3}, in agreement with the tabulated value (*Handbook of Chemistry and Physics*, 1982-1983) of $8{\cdot}7947$ g cm^{-3} for pure holmium. All these values, relevant in this experiment, are reported with their uncertainties in Table 1. They give $b_{Ho} = 8{\cdot}01\,(8)$ fm for the scattering length of holmium, after a small correction, for the refractive index of the air slab occupied by the sample, is made. The final accuracy is limited by the relative uncertainty in the sample thickness.

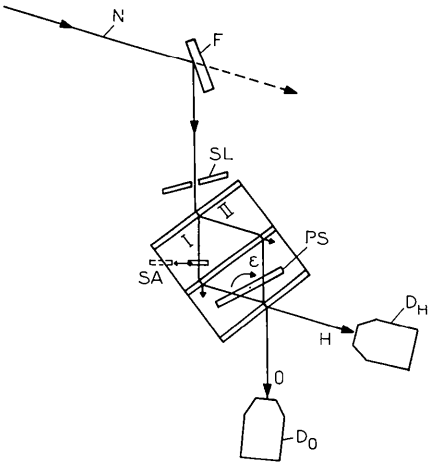

Fig. 1. D18 neutron interferometer: N neutron beam, F monochromating crystal, SL slit, SA sample, PS aluminium phase shifter, O, H outgoing beams behind the interferometer, D_O, D_H neutron detectors. The monochromating crystal and the interferometer are set to diffract the 220 reflection of silicon.

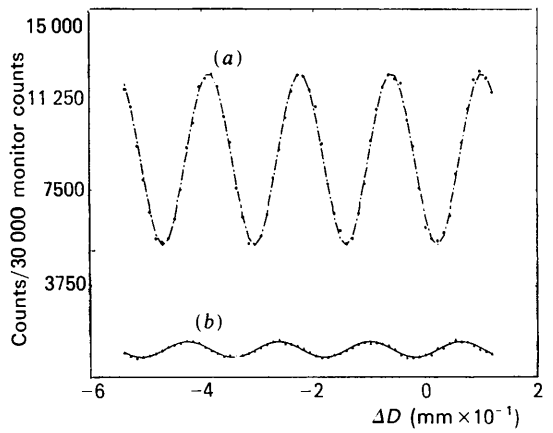

Fig. 2. Interferograms obtained by rotating the phase shifter (a) without the holmium sample in the beam, (b) with the holmium sample in the beam. ΔD is the optical path difference in the phase-shifter plate.

Table 1. *Quantities relevant to the b_{Ho} determination*

	Value	Uncertainty
Wavelength (Å)	1·8257	0·0006
Phase shift (rad)	51·702	0·028
Sample thickness (mm)	1·101	0·011
Sample mass (g cm^{-3})	8·802	0·006

The purity of the sample was checked by emission spectrography. The only impurities detected are 700 in 10^6 Fe and less than 200 in 10^6 Si, which imply negligible corrections.

Our final value, for the scattering length of holmium, $b_{Ho} = 8{\cdot}01\,(8)$ fm, agrees very well with that obtained by crystallography with polarized neutrons (Boucherle *et al.*, 1979): $b_{Ho} = 8{\cdot}08\,(5)$ fm. This should remove the ambiguity due to the spread of the previous experimental results.

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