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2008 J. Phys.: Condens. Matter 20 104248

(http://iopscience.iop.org/0953-8984/20/10/104248)

J. Phys.: Condens. Matter **20** (2008) 104248 (3pp) doi:10.1088/0953-8984/20/10/104248

Neutron Compton scattering anomaly verified with Rh-resonance foil

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Received 16 July 2007, in final form 23 September 2007
Published 19 February 2008
Online at stacks.iop.org/JPhysCM/20/104248

Abstract
Compton scattering experiments with neutrons usually employ Au- or U-foils for energy selection of the scattered neutrons. A series of experiments on various H-containing materials have shown a large deficit in the scattering intensity of protons using Au-foils and it has been claimed that the anomalies arise from a faulty analysis of the data by neglecting effects of the tails of the Au-resonance lines. In the present experiments a Rh-103 resonance foil is used. It has considerably different resonance characteristics, but the H/metal ratio derived shows nearly the same anomalous value as with Au-foils. The present result therefore supports the existence of the mentioned anomalies.

Using neutron Compton scattering (NCS) a striking shortfall of proton scattering intensity was first found in mixtures of liquid H_2O/D_2O [1] and later in a great variety of materials [2]. Recently this effect was also observed in electron–proton Compton scattering from a solid polymer [3]. These observations have led to a flurry of theoretical activity, with several different proposed explanations [4].

However, serious criticisms were raised claiming that the considered effect could be due to instrumental artefacts and/or incorrect data analysis procedures. In particular, the convolution approximation (CA) of the standard reduction scheme routinely applied at ISIS (Rutherford-Appleton Laboratory) was discussed in a series of publications by Blostein *et al* [5]. These authors also proposed an alternative method, called 'exact', in which the resolution function $R(E)$ of the analyser foil was not approximated by a Lorentzian (or Voigt) function in the framework of CA; instead $R(E)$ was implemented in the data analysis by taking its measured shape over the whole range of energy transfer (say 1–100 eV), and without making use of convolution. As a result of various simulations it was claimed that the aforementioned effect is an artefact of CA and the associated 'incorrect' approximation of the $R(E)$-function. This, and other related reasons for criticism, was the focus of a detailed instrumental and data-reduction analysis by Mayers and Abdul-Redah [6], who provided evidence that a failure of CA could not be the reason for the low H cross-sections observed. Moreover the first application of the 'exact' method to real NSC data by Senesi *et al* [7] also led to low H intensities and the values were fully consistent with those obtained by the standard CA-based method, thus refuting the results from simulations [5c].

In these discussions the resonance foil used to select the scattered neutrons in the Compton scattering (see figure 1(a)) plays an important part. The data are collected as function of the time-of-flight of the neutrons from the source to detectors placed at a series of scattering angles in the range 35°–70°. A difference spectrum is obtained by subtracting the data for 'foil out' from those for 'foil in', by which the neutrons are absorbed in a small energy window. For each particular scattering angle the difference spectrum shows peaks corresponding to scattering on nuclei with different masses in the samples (see figure 1(b)). The areas of these peaks are, according to standard theory [8], expected to be proportional to the products $\sigma_M c_M$ of the tabulated cross-sections and the relative concentrations of nuclei of mass M. The resonance foil used in the majority of these investigations is made of the isotope Au-197, which has a resonance energy of 4.91 eV with a calibrated half-width of 0.28 eV.

In order to shed more light on this important issue, we therefore carried out a different type of experiment with the objective of testing possible effects of a failure of the standard method of data analysis applied at ISIS (i.e. CA and the approximated $R(E)$, see [6]). Another resonance foil, made of Rh-103, with characteristics different from the Au-197 foil, was introduced and the results were compared with those using the Au-foil under the same conditions. Considering that the resolution functions $R(E)$ for these two resonances are significantly different [9], both with respect to resonance

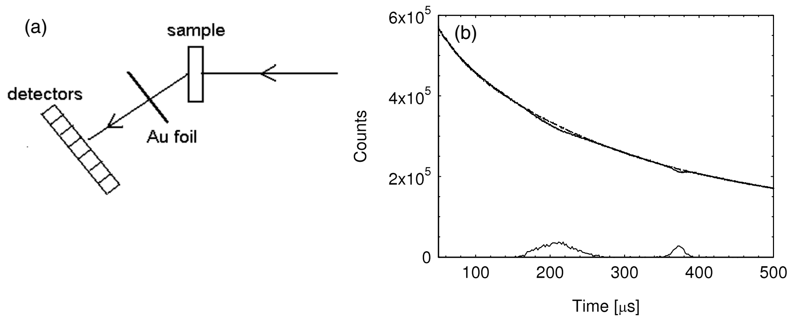

Figure 1. (a) Experimental arrangement for observation of neutron Compton scattering, using the 'foil out/foil in' technique. (b) Typical time-of-flight spectra showing foil out and foil in data. (The difference spectrum in the figure is enlarged four times.)

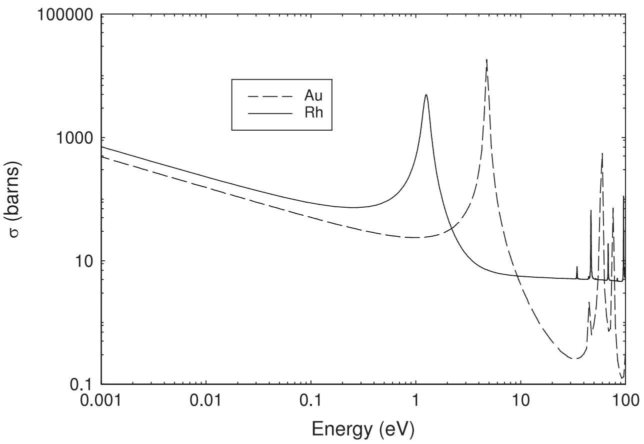

Figure 2. The neutron resonances in Rh (full line) and Au (dashed) as taken from [9].

energies (4.91 eV for Au; 1.23 eV for Rh), calibrated half-widths (0.28 eV, resp. 0.22 eV) and long-range tails between the two resonance maxima and 100 eV (figure 2), the claimed failure [5] of the standard method is expected to cause large variations in the peak areas derived from these two sets of data.

The Rh-foil had the dimensions 50 mm × 50 mm × 0.025 mm. Time-of-flight spectra from the metallic hydride YH_2 were recorded from Au- and Rh-foils in the same experiment with detectors placed on both sides of the beam. Figure 3 shows spectra using Au- and Rh-foils at about the same scattering angle. The recoil peaks appear at widely different positions on the time scale and the peaks obtained with Rh-foil are considerably wider than those using the Au-foils. However, both H-peaks can be well resolved from the metal peak (arising from Y + Al-container). Since data for the two foils correspond to different ranges of transferred momenta, we have chosen to display (in figure 4) the comparison of the results after transformation to the scattering-time representation, as first done in [10], with the help of the relation $\tau_{sc} = M\hbar/(q(\theta)\sqrt{\langle p^2\rangle})$ where $\sqrt{\langle p^2\rangle}$ is the width of the H-momentum distribution in the ground state.

The H/Y ratios obtained with Rh- and Au-foils are both strongly anomalous over the common τ_{sc}-range. To obtain background-corrected H/Y-ratios the Y/Al-ratio must be known. This was carried out in an earlier experiment [11] using the same sample/container package (and Au-foil), the result of which is reproduced in the inset of figure 4 and shows an average shortfall of 20% over the range 0.7–1.2 fs for the

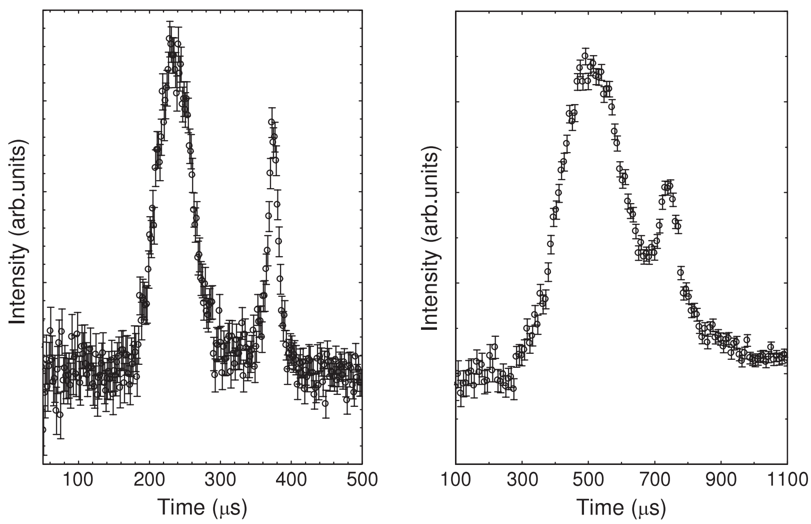

Figure 3. Time-of-flight spectra for neutrons scattered from the metal hydride YH_2 as observed with Au-foil at an angle of 53° (left) and Rh-foil at an angle of 51° (right).

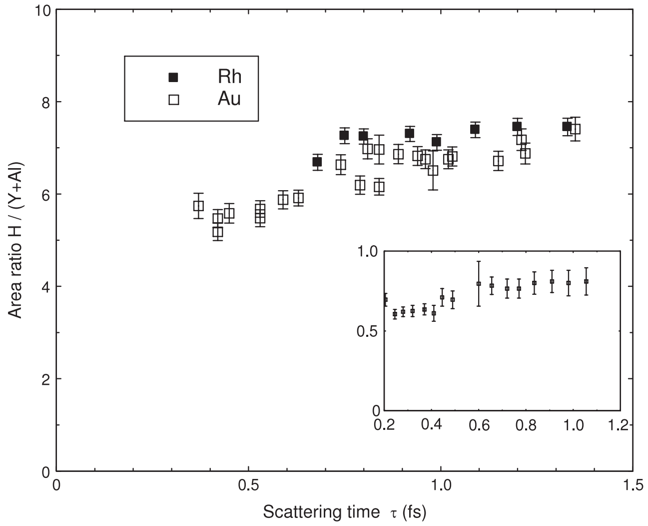

Figure 4. Comparison of area ratios H/Y, obtained in the same setup with Rh-foil (filled squares) and Au-foil (open squares), using the scattering-time representation. Error bars are due to counting statistics only. The inset shows H/Y area ratios (corrected for the Al background), divided by the tabulated value $\sigma_H/\sigma_Y = 10.6$. From [11].

YH_2 sample. A comparison of the data shows that the average anomaly obtained with the Rh-foil is smaller, but still as large as 15% over the same range.

Experiments with Rh- as well as with Au-foils therefore show anomalous H/Y ratios. The strongly different characteristics of the Rh- and Au-resonances do not cause any appreciable change in peak area ratios obtained with the standard data-reduction procedure employed at ISIS, which would be expected if the claims of Blostein *et al* were valid. The present result therefore confirms the conclusions of Mayers and Abdul-Redah [6] and Senesi *et al* [7].

The somewhat smaller anomaly obtained with the Rh-foil is explainable within the Karlsson–Lovesey model [4b] as a result of smaller neutron coherence length $l_{coh} \approx 1.8$ Å calculated for the Rh-foil as compared to $l_{coh} \approx 2.5$ Å for the Au-foil. In this model the destructive interferences for scattering on two protons within the coherence volume would lead to an anomaly which is 2.5/1.8 times larger for the Au-foil, as approximately found here.

Acknowledgments

The authors would like to thank Dr Jerry Mayers, ISIS, for help in providing the Rh-foil. This experiment was carried out under the auspices of the European network 'Quantum Complex Systems' (QUACS).

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