

VESUVIO—the double difference inverse geometry spectrometer at ISIS

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Abstract

The VESUVIO spectrometer at the ISIS pulsed neutron source performs inelastic neutron scattering at high-energy and wave vector transfers, employing gold and uranium resonant foils. A factor of two improvement in the instrumental resolution has been achieved by making use of the double filter difference method. Experimental results are presented for measurements on polycrystalline Pb, which indicate that accurate measurements of single-particle momentum distribution $n(p)$ in quantum fluids are now possible at eV energy transfers.

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1. Introduction

The purpose of the EEC funded VESUVIO project was to develop new experimental techniques and data analysis procedures, for exploiting neutrons with energies in excess of 1 eV, specifically for inelastic neutron scattering studies at high momentum, ($20 \text{ \AA}^{-1} < q < 150 \text{ \AA}^{-1}$), and energy transfer ($0.5 \text{ eV} < \hbar\omega < 50 \text{ eV}$). A new sample tank and cryogenic foil-changer, and a new back-scattering detector were constructed. Results

obtained on VESUVIO as part of the project included a determination of the single-particle kinetic energy in solid and liquid ^3He [1], a measurement of single-particle dynamics in fluid and solid hydrogen sulphide [2], a full account of the calibration procedure for the instrument [3] and the implementation of a Monte Carlo instrument simulation program [4].

2. The double-difference technique

In measurements preceding the VESUVIO innovations a single nuclear resonance absorption

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foil was used to select the final energy of the scattered neutrons. Two measurements were taken, one with the foil between sample and detectors and one with the foil removed. The difference between these two data sets (i.e. the number of neutrons absorbed by the foil) is the experimental signal, which provides a measurement of the intensity of neutrons scattered from the sample with final energy E_1 . The energy resolution of the spectrometer in single difference is defined by

$$R_1(E) = 1 - T(E) = 1 - \exp[-Nt\sigma(E)], \quad (1)$$

where $T(E)$ is the foil transmission at energy E , N is the number of atoms/unit volume and t is the foil thickness. The nuclear resonance cross-sections $\sigma(E)$ have a Breit–Wigner form for their intrinsic line shape. This has Lorentzian wings which are difficult to deal with in the analysis of data. The double-difference (DD) technique [5] consists of taking three measurements, with no foil, a foil of thickness t_1 and transmission T_1 and

a foil of thickness t_2 and transmission T_2 . The “double difference” of the three measurements is

$$R_2(E) = [1 - T_1(E)] + \frac{t_1}{t_2}[1 - T_2(E)]. \quad (2)$$

The double-difference technique relies upon the fact that when $\sigma(E)$ is small,

$$1 - T_1(E) = 1 - \exp[-Nt_1\sigma(E)] \sim Nt_1\sigma(E) \quad (3)$$

with a similar expression for $1 - T_2(E)$. Thus when $\sigma(E)$ is small $R_2(E) = 0$ and the Lorentzian wings of the resolution function in single difference are removed.

3. New instrument components

In order to incorporate the DD technique, it was necessary to construct a new sample tank and set of beam tubes. These were constructed by RMP—Costruzioni Meccaniche [Acilia (RM), Italy]. The sample compartment-filter exchanger unit (see Fig. 1) is a single vacuum vessel made up of

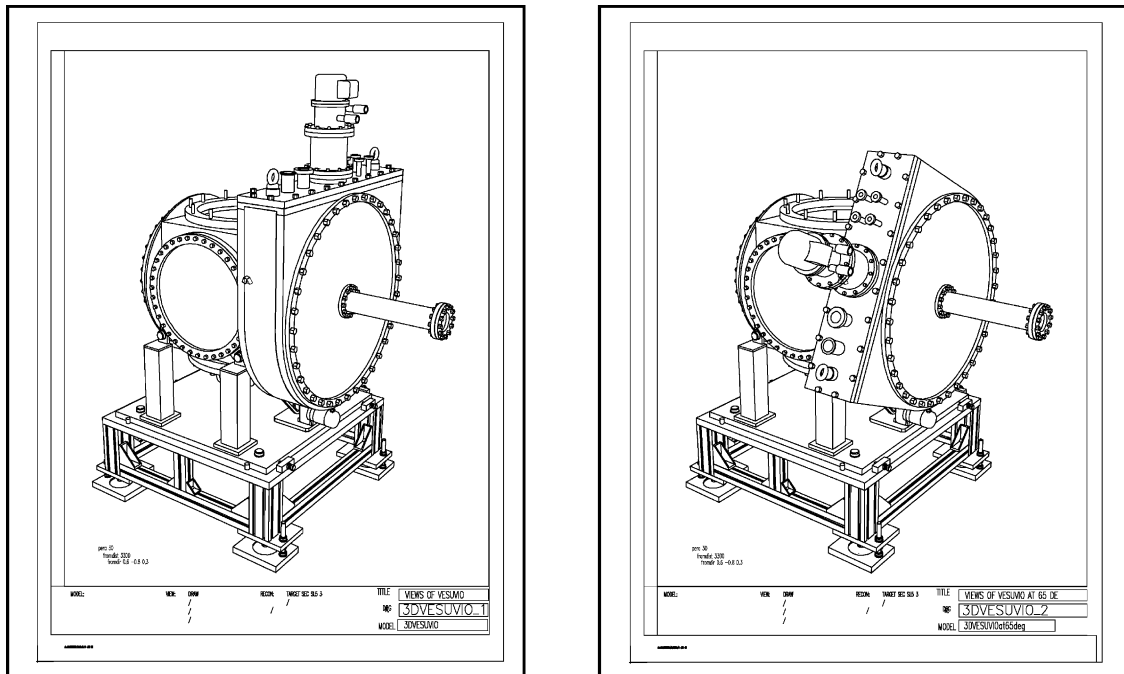


Fig. 1. The operation of the new foil cooler and filter changer. By rotating the assembly by $\pm 60^\circ$ from the vertical position the thin filter, thick filter or no filter can be positioned between the sample and detector.

two mechanically independent parts. A special kinematic vacuum seal allows the rotation of the entire filter chamber under vacuum. The filter chamber contains a removable aluminium filter holding wheel, which can be cooled using a closed-cycle refrigerator and is divided into six equal sectors, two of which hold a thin-analyser foil, two thick-analyser foil and two no foil. Both single- and double-difference measurements can be performed by rotating the wheel by $\pm 60^\circ$ about the beam axis. The rotation is performed by a motor controlled by the instrument computer.

A new back scattering detector for use with the double-difference technique was also constructed. Conventional ^3He gas counters are not suitable for use at eV energies, where their detection efficiency is low at attainable pressures. Furthermore, the dead times in He detectors are long and faster detectors are required to cope with the large instantaneous count rates. We built a high-efficiency detector based on the prototype eVS detectors already in operation. The new detector consist of ^6Li -doped glass scintillator elements geometrically arranged to match the 60° segments of the energy analysis filter.

4. Measurements using the double-difference method

The performance of the new cryogenic foil-changer and detector has been tested for both gold and uranium foils, using a lead calibration sample which has a very narrow intrinsic width. Fig. 2a shows the broad neutron Compton profile measured using a gold foil analyser in single-difference and the narrower double-difference result. Fig. 2b shows the corresponding results measured with a cooled uranium foil analyser. The resolution of the instrument was determined by fitting a convolution of a Lorentzian and a Gaussian to the data and subtracting the Gaussian component due to the intrinsic width of the Pb sample. The results of the analysis are given in Table 1. It can be seen that the resolution width is reduced by a factor ~ 2 for both uranium and gold foils.

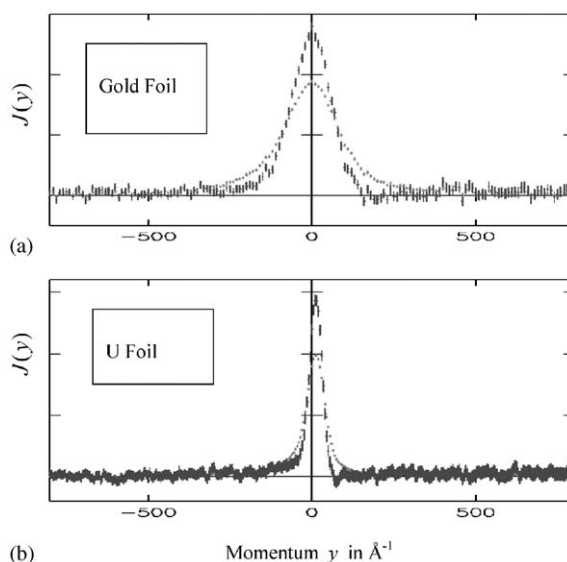


Fig. 2. The improvement in resolution obtained by utilisation of the double-difference technique (a) with a gold analyser foil (b) with a uranium analyser foil.

Table 1

Gives the analyser foil resolution in for different energy analysers

Foil type	ΔE_L (eV)	ΔE_G (eV)
Single difference Au foil	0.129	0.043
Double difference Au foil	0.072	0.050
Single difference U foil	0.00	0.040
Double difference U foil	0.00	0.026

ΔE_L is the HWHM of the Lorentzian component of the resolution function and ΔE_G the standard deviation of the Gaussian component.

5. Conclusions

The double-difference technique, incorporated under the VESUVIO project has provided around a factor two improvement in the energy resolution available for measurements at high angles. This will be utilised in future studies, particularly for the measurement of momentum distributions in quantum fluids such as ^4He [6–10], He3–He4 mixtures [11] and Neon [12].

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