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Recent developments of the e.VERDI project at ISIS

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Abstract

Epithermal neutrons are unique probes for deep inelastic neutron scattering (DINS) at high-energy and high-momentum transfer and inelastic neutron scattering (INS) at high-energy and low-wave vector transfers. In the latter case the kinematic range has recently been revisited given that the high values of initial and final wave vectors achievable in a scattering process coupled to small scattering angles allow to access a so far unexplored region in q,ω, i.e $\omega > 1$ eV and $q < 10$ Å^{-1}. In order to exploit DINS and INS in the high-energy and low-momentum range, a very low angle detector (VLAD) bank will be delivered within the e.VERDI Project together with a novel bank at intermediate scattering angles. The former will provide a new tool for investigating high-energy excitations in magnetic systems and semiconductors. The VLAD bank will be constructed following the concept of a resonance detector (RD) spectrometer, recently revised for DINS experiments in the range 1–100 eV.This is a more promising approach in terms of efficiency and signal-to-noise ratio compared to standard neutron counting techniques at eV energies. Results from two devices, cadmium zinc telluride (CZT) solid-state detectors and $YAlO_3$ perovskite (YAP) scintillators used in RD configurations, will be presented.

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Keywords: Neutron instrument; Detector; Deep inelastic neutron scattering

Deep inelastic neutron scattering (DINS) technique as applied on the VESUVIO instrument is a powerful tool for condensed matter investigations of dynamic properties (e.g. atomic momentum distributions) by taking full advantage of the high flux of high-energy neutrons available at ISIS (Rutherford Appleton Laboratory, UK). Inverse geometry neutron spectrometers, such as VESUVIO (described in detail in a separate paper in this proceeding), can also be used to study the q dependence of excitations in magnetic systems and semiconductors. To achieve this, one needs to position detectors at very low angles ($1^\circ < 2\theta < 5^\circ$) in order to access high-energy transfer ($\omega > 1$ eV), coupled to low wave vector transfer ($q < 10$ Å^{-1}) [1]. The e.VERDI spectrometer, the current

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EEC-funded VESUVIO upgrade project, is dedicated to this aim. It will enhance the present performance of VESUVIO by extending the accessible q,ω range (being presently $1\,\text{eV} > \omega > 30\,\text{eV}$ and $20\,\text{Å}^{-1} > q > 200\,\text{Å}^{-1}$). Furthermore, it will increase the sensitivity of VESUVIO for neutron Compton scattering measurements on proton-containing systems, such as molecular systems [2–4], hydrogen-bonded systems [5,6] and metal hydrides [7,8], by constructing a new intermediate angle (40–60°) detector bank which will provide higher resolution and count rates than currently available. As far as DINS measurements are concerned, recent developments in data analysis have allowed to directly derive the proton momentum distribution in KH_2PO_4 and KHC_2O_4 [9,10] and hence to calculate in a model independent way the proton wavefunction and the effective Born–Oppenheimer potential. A specific aim of e.VERDI is to deliver a forward scattering detector (FSD) bank with high count-rate capability and high angular resolution in order to allow users to routinely access these data analysis techniques for the study of hydrogen-containing systems. At present, VESUVIO is operating in the resonance filter (RF) configuration. The incident neutron beam is polychromatic and the final energy of the scattered neutron is determined by the resonance energy of a neutron absorbing foil cycled in and out of the flight path between sample and ^{6}Li neutron detector (see Fig. 1a). To obtain high-energy transfer at low q, the final neutron energy must be higher than presently used. The ^{6}Li neutron detectors used thus far are not suitable for neutrons of energy above 20 eV due to an intrinsic decrease of detection efficiency and high background [12]. Therefore, new concepts for detection systems are being investigated for inelastic measurements. A promising method for epithermal neutron spectroscopy is VESUVIO operating in the resonance detector (RD) configuration. In the latter, the final neutron energy is determined by the detection of the prompt γ-photon cascade, produced in a n,γ reaction after the neutron capture in a foil (e.g. ^{238}U) attached to the photon detector (see Fig. 1b). The RD configuration achieves a higher detection efficiency for neutron energies above 20 eV and the reconstruction of the DINS spectrum can be obtained by a single measurement, while two measurements are necessary in the RF configuration.

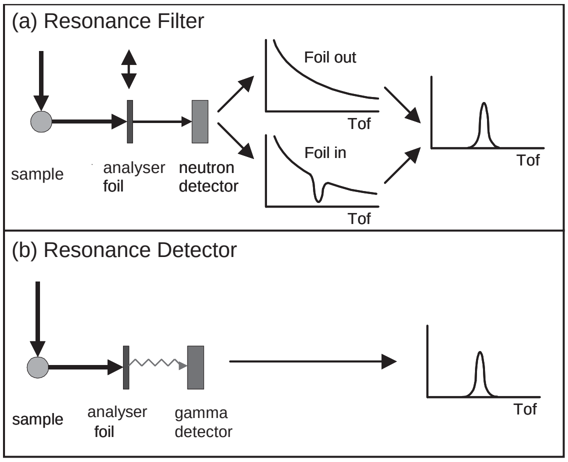

Fig. 1. Schematic principles of VESUVIO spectrometer in the RF and RD configurations. In the RF method (a), the scattered neutrons are recorded with a ^{6}Li neutron detector. In the RD method (b) the electromagnetic radiation emitted by the analyzer foil is recorded with a CZT or YAP γ-photon detector. In the RF configuration the difference of two measurements (foil in and foil out) is taken in order to obtain the recoil peak of the scattering nuclei, whereas only one measurement is needed in the RD configuration.

Here we show experimental results from two resonance detectors, namely CZT (cadmium zinc telluride) solid-state detectors and YAP ($YAlO_3$ perovskite) scintillators, and compare these results with data obtained by the standard RF configuration presently used on VESUVIO.

In the first experiment, the DINS of a polycrystalline Pb sample has been measured using a CZT detector positioned at 90° scattering angle, 30 cm from the sample. The CZT crystal ($A = 25\,\text{mm}^2$; $d = 2\,\text{mm}$) was placed after a ^{238}U foil and was protected by an aluminum housing. The electronics was set up so that the CZT measured γ-photons with an energy above 40 keV. Measurements were also made using the standard 2000 mm^2 ^{6}Li neutron detector (distance from sample = 50 cm). In both cases, the ^{238}U foil had a thickness of 50 μm providing a good compromise between signal intensity and energy resolution [11]. Example spectra recorded with the CZT and the ^{6}Li detector (foil-in) are shown in

Fig. 2a and b. Whereas, four Pb recoil peaks (due to the four strongest resonances of ^{238}U) are clearly visible with CZT, only three of them are visible with the ^{6}Li detector. This example reveals very clearly that the CZT detector exhibits a higher sensitivity to high-energy neutrons than the ^{6}Li detector. In the second experiment, a YAP detector ($A = 875\,\text{mm}^2$; $d = 6\,\text{mm}$) was positioned at 30° scattering angle and at a distance of 100 cm from the sample. The YAP detector was also covered by a 50 μm thick ^{238}U foil. An example spectrum of Pb is shown in Fig. 2c. Again, four Pb recoil peaks are clearly visible. Biparametric (time and pulse-height) data were recorded to optimize the signal/background ratio. A relatively high discriminator threshold (about 600 keV equivalent γ-energy) effectively suppresses the background to a level where YAP-based RD measurements outperform ^{6}Li glass measurements using the RF approach. As can be seen in Fig. 2 the CZT and YAP detectors exhibit a large γ-background superimposed on the recoil peaks. This background is very much less than that associated with the ^{6}Li detectors operating in RF mode. Part of the background is due to the natural radioactivity of the foils, which is constant in time of flight and easily subtracted. Once this is done the peak to background ratios of the CZT and YAP detectors are comparable. The remaining background is not falling off with the sample to detector distance at the same rate as the signal. The YAP detector is 3 times further from the sample than the CZT detector; the performance of the YAP detector is therefore superior. Neither the CZT nor the YAP detectors suffered from radiation damage and both could be used without any shielding. The results show that the resonance detector (RD) technique is suitable for epithermal neutron scattering and that both the CZT and the YAP detectors are promising candidates to exploit the dynamic range where high-energy transfers are coupled to low-wave vector transfers. As a result of its lower cost and more reliable operation, the YAP detector will be used for the VLAD bank in the near future.

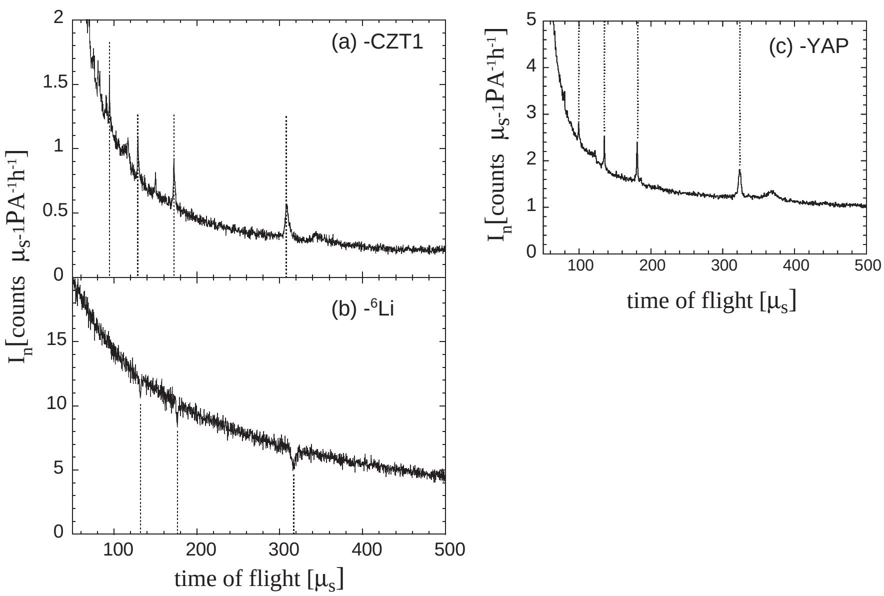

Fig. 2. (a) Normalized time of flight DINS spectrum from Pb measured with a CZT detector. (b) Normalized time of flight foil-in DINS spectrum from Pb measured with a standard ^{6}Li neutron detector. (c) Normalized time of flight spectrum from Pb measured with a YAP detector. In all figures the recoil peak positions are indicated by vertical dashed lines. As can be seen, the peak/background ratios of the CZT and YAP measurements are much better than those for the ^{6}Li neutron detector. See text for comparison between CZT and YAP detectors.

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