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Nuclear Instruments and Methods in Physics Research A 552 (2005) 463–476
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Resolution of the VESUVIO spectrometer for High-energy Inelastic Neutron Scattering experiments

S. Imberti[a,b,*], C. Andreani[c,b], V. Garbuio[c,b], G. Gorini[d,e], A. Pietropaolo[c,b], R. Senesi[c,b], M. Tardocchi[d,e]

[a]*Università degli Studi di Roma Tre, Dipartimento di Fisica "E.Amaldi", Roma, Italy*
[b]*CNR-INFM, Roma, Italy*
[c]*Università degli Studi di Roma Tor Vergata, Dipartimento di Fisica, Roma 60133, Italy*
[d]*Università degli Studi di Milano-Bicocca, Dipartimento di Fisica "G.Occhialini", Milano, Italy*
[e]*CNR-INFM, Milano, Italy*

Received 1 June 2005; accepted 30 June 2005
Available online 21 July 2005

Abstract

New perspectives for epithermal neutron spectroscopy have been opened up as a result of the development of the Resonance Detector and its use on inverse geometry time-of-flight spectrometers at spallation sources. A special application of the Resonance Detector is the Very Low Angle Detector Bank (VLAD) for the VESUVIO spectrometer at ISIS, operating in the angular range $1^\circ < 2\theta < 5^\circ$. This equipment allows High-energy Inelastic Neutron Scattering (HINS) measurements to be performed in the (q, ω) kinematical region at low wavevector ($q < 10\,\text{Å}^{-1}$) and high energy (unlimited) transfer $\hbar\omega > 500\,\text{meV}$, a regime so far inaccessible to experimental studies on condensed matter systems. The HINS measurements complement the Deep Inelastic Neutron Scattering (DINS) measurements performed on VESUVIO in the high wavevector q ($20\,\text{Å}^{-1} < q < 250\,\text{Å}^{-1}$) and high energy transfer ($\hbar\omega > 1\,\text{eV}$), where the short-time single-particle dynamics can be sampled. This paper will revise the main components of the resolution for HINS measurements of VESUVIO. Instrument performances and examples of applications for neutron scattering processes at high energy and at low wavevector transfer are discussed.

PACS: 28.20.Cz; 29.30.Hs; 78.70.Nx

Keywords: Neutron; Scattering; Resolution; Epithermal

*Corresponding author. Current address: Università degli Studi di Roma Tor Vergata, Dipartimento di Fisica, Roma, Italy. Tel.: +39 06 7259 4429; fax: +39 06 2023507.
E-mail address: silvia.imberti@roma2.infn.it (S. Imberti).

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doi:10.1016/j.nima.2005.06.067

1. Introduction

The advent of accelerator-based neutron sources has opened up new opportunities for epithermal (eV) neutron spectroscopy and favored the development of novel instrumentation concepts in this area. In recent years experimental efforts have been devoted toward extending the dynamical range of neutron spectroscopy aiming to study: (a) the short-time single-particle (atoms or molecules) dynamics in quantum and molecular systems [1] and (b) the high-energy excitations in materials [2], i.e. electronic transitions in rare-earth metals and compounds [3], vibrational levels in insulators, semiconductors and magnetic materials [4].

In case (a) neutron spectroscopy at the eV energy is the unique experimental tool available to derive the single-particle momentum distribution, $n(p)$, and its second moment, the mean kinetic energy $\langle E_k \rangle$ [5]. These physical quantities are of great interest in those systems where the short-time dynamics departs from the classical behavior. The experimental technique is well established and known as Deep Inelastic Neutron Scattering (DINS), or Neutron Compton Scattering, and it is the analog of the Compton scattering of photons off electrons. DINS assumes that, at sufficiently high energy and wavevector transfers (typically $\hbar\omega > 1\,\text{eV}$, $q > 20\,\text{Å}^{-1}$), the scattering process is incoherent and occurs from free recoiling particles, both atoms and single molecules (this assumption is known as Impulse Approximation [6]). The study of the second class of phenomena requires neutron scattering processes with energy transfer in excess of about 500 meV coupled to low wavevector transfer, typically $q < 10\,\text{Å}^{-1}$. In this case both nuclear interactions and electromagnetic coupling of the neutron magnetic moment with the electron spin are relevant scattering processes. Low wavevector transfers are required due to the inherent decrease of the magnetic scattering intensity for increasing q as the square of the magnetic form factor [29]. Nuclear and magnetic interactions provide access to forefront dynamical studies on high-lying vibrational states in molecular systems and high-energy excitations in magnetic systems and semiconductors, respectively. In recent years these studies have become possible thanks to the development of a novel technique, i.e. the High-energy Inelastic Neutron Scattering (HINS) [7], which has extended the dynamical range for eV neutron spectroscopy on VESUVIO.

Pioneering instrument developments in this dynamical range date back to the late 1970s, when Sinclair et al. [8] reported the general characteristics of an inverse geometry eV instrument exploiting the epithermal neutron flux on a pulsed neutron source. The adopted configuration was the Resonance Detector (RD), employing a metallic foil on the secondary flight path to define the energy of the scattered neutrons, via resonant neutron absorption, and a γ detector to reveal the prompt cascade following the (n,γ) reaction. After this original work, a few other instrument developments followed (see for example [9]); prototype instruments were constructed at the Harwell Linear Accelerator (UK) [10], at the Argonne National Laboratories (USA) [11] and at the ISIS pulsed neutron source of the Rutherford Appleton Laboratory (UK) [12].

At the time, large γ detectors were employed and thus the signal-to-background ratio was severely limited by the heavy γ and neutron background contamination typical of spallation sources, also demanding heavy shielding around the detectors. The RD concept was therefore soon abandoned in favor of the Resonance Filter (RF) configuration [13], which developed since the mid 1980s. The RF technique still employs an analyzer foil on the secondary flight path but in this case it is coupled with a neutron detector, e.g. ^{3}He or ^{6}Li-based neutron counters, to reveal the neutrons non-absorbed by the foil. The eVS spectrometer, installed at the ISIS facility [14], has been the first inverse geometry instrument routinely operating in the RF configuration for DINS measurements, in the range $1\,\text{eV} < \hbar\omega < 20\,\text{eV}$ and $20\,\text{Å}^{-1} < q < 250\,\text{Å}^{-1}$. Many DINS studies have been performed on a variety of systems. These include the single-particle dynamics of solid and fluid helium (^{3}He and ^{4}He) [15], noble gases in both solid and fluid phases [16], molecular systems [17], metals [18], fluid and solid hydrogen [19], glasses [20], graphite [21] and various metal hydrides [22].