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INTER the chemical interfaces reflectometer on target station 2 at ISIS

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Abstract

INTER is a high resolution, high-flux neutron reflectometer for the study of chemical interfaces with particular emphasis on adsorption at the air–water interface. One of the particular strengths of neutron reflection is that it can be applied to 'wet' interfaces to obtain information at better than molecular resolution. This, allied with H/D substitution, makes INTER especially suited to the study of chemical interfaces in soft condensed matter systems. INTER will improve upon the capabilities of the existing, world leading, reflectometers SURF and CRISP by make making use of an order of magnitude increase in neutron flux.

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Keywords: Neutron reflectometry; Instrumentation

1. Introduction

Neutron reflectivity is a technique that has seen significant growth in recent years. The traditional areas of interest such as thin polymer films, coatings, surfactants and Langmuir films [1,2] have been broadened to include a variety of chemical and biological interfaces.

It is becoming routine to study protein adsorption, drug transport, electrodeposition, self assembly and complex mixtures of surfactants and polymers. Whilst it is to be expected that structure resolution at the air–liquid, solid–liquid, solid–solid and liquid–liquid interfaces will be applied to ever more complex and diverse systems the technique remains flux limited. There is a significant trend towards the study of smaller 'device-like' samples and increasing interest in the application of NR to kinetic processes such as polymer diffusion, protein unfolding and non-equilibrium surfactant films in addition to temporal resolution of ion transfers, solvent transfers and polymer structure in electrochemical systems. These newer areas are limited by the flux and bandwidth currently available.

2. Mechanical design

INTER will be located on the grooved composite moderator of the second target station at ISIS (Fig. 1). This moderator is optimized for the production of long-wavelength neutrons and provides a significant flux gain over the hydrogen moderator on target station 1.

The guide entrance beyond the shutter is rectangular (30 mm vertical × 60 mm horizontal). This straight section of $m = 3$ guide at 2.3° to horizontal delivers the beam to a pair of beam choppers. The first chopper is a T0 or 'nimonic' operating at 20 Hz with a single 400 mm thick blade to attenuate the unmoderated spectrum of neutrons characteristic of a pulsed source. The second chopper is a counter-rotating disk which defines the instrument bandwidth. At 6.5 m from the moderator with a 100 ms time frame the maximum wavelength at 25 m will be 16 Å (Fig. 2.). Frame overlap neutrons will be of order λ_{min}~65 Å which will be removed from the beam by a set of frame-overlap mirrors. After 2 further sections of straight $m = 3$ guide the beam enters the fine collimation with slits 1.5 m apart. A supermirror facilitates angle adjustment onto a liquid surface. Low-efficiency glass scintillator monitors will be employed to record the incident wavelength distribution. At the sample position the scattering plane is vertical. The low-background ^{3}He gas detector is adjustable from 2 to

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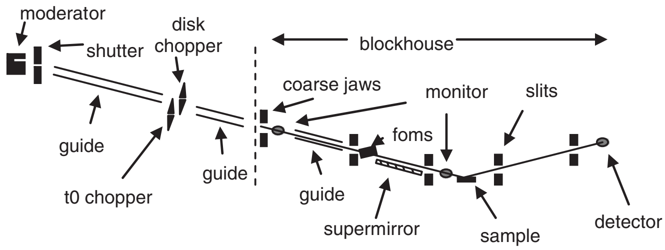

Fig. 1. INTER Schematic.

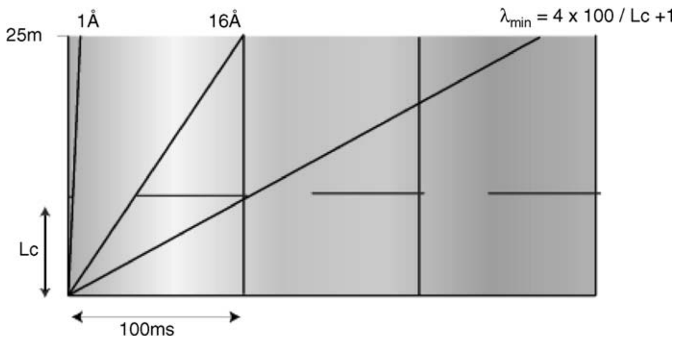

Fig. 2. Time distance nomogram.

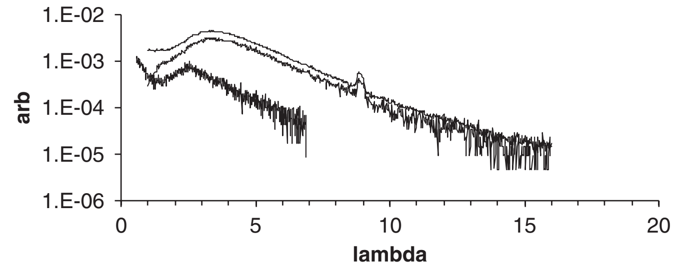

Fig. 3. Flux comparisons. From bottom to top: SURF, INTER with bender, INTER with straight guide (spike at ~9 Å is an artifact of the McStas moderator module).

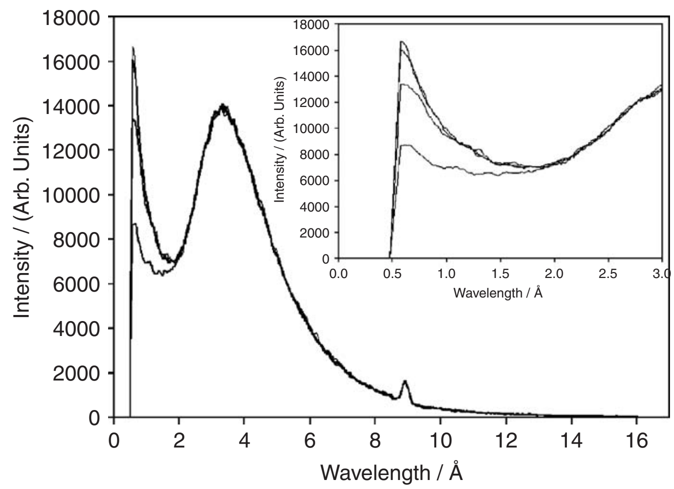

Fig. 4. Simulation of INTER guide with (from bottom to top) $m = 1$, 2, 3 and 4 coatings (arbitrary cut off at short wavelength).

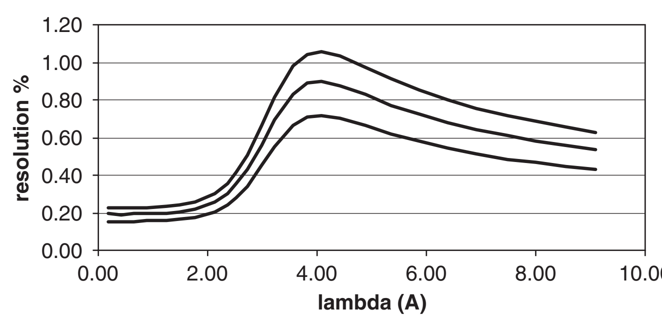

Fig. 5. Δt_{pulse}/tof contribution to instrument resolution at 17, 20 and 25 m (top to bottom).

8 m sample–detector distance. A second, identical detector will measure the incoherent background. For off-specular measurements a 1-dimensional scintillator detector will be provided. Upstream of the sample position both guides and fine collimation will be under vacuum. Downstream of the sample position a He-filled beam tube will be employed to reduce background scatter associated with N_2.

3. Design considerations

In choosing a straight guide configuration over a bender or curved guide several factors were considered. Firstly it is desirable to avoid transporting the 'fast' neutrons and gammas associated with the spallation event. Although a T0 chopper can be employed it is not 100% effective. Secondly we wish to ensure maximal flux and bandwidth. Fig. 3 shows a comparison of the relative flux available on the SURF reflectometer and that predicted for INTER with a straight guide and with a bender. It is clear that INTER enjoys an order of magnitude gain in flux across a wider bandwidth. The bender suffers a loss of flux at short wavelengths. Whilst this loss is over a comparatively short wavelength range it does, however, impact strongly on the available q range for a given incident angle. For a liquid surface at 2.3° and a band width of $0.5\,\text{Å} \leqslant \lambda \leqslant 16\,\text{Å}$ then $0.03\,\text{Å}^{-1} \leqslant q \leqslant 1.0\,\text{Å}^{-1}$ whereas q_{max} is halved if λ_{min} is doubled to 1 Å. To maximize the potential for kinetic studies instrumental bandwidth is the paramount concern and thus a straight guide will be employed. Fig. 4 shows the flux gain from using $m = 3$ guides at short wavelengths. In practice the cutoff will be determined by the chopper characteristics and will be ~0.5 Å. This combination of acceptance angle and mirror coating results in a doubling of flux at the shortest wavelengths. The inclination of the beam to the horizontal (2.3°) was chosen to maximize the integrated flux onto a liquid surface for a given beam footprint whilst maintaining peak flux at a q value consistent with the thickness of an adsorbed monolayer. The instrumental resolution has contributions from the spreads in both incident angle and wavelength, i.e., $(\Delta q/q)^2 = (\Delta\theta/\theta)^2 + (\Delta\lambda/\lambda)^2$ The first term is determined by the fine collimation and the second is characteristic of the source being equivalent to $(\Delta t_{pulse}/\text{tof})^2$ where t_{pulse} is the width of the neutron pulse and tof is the time of flight

(Fig. 5). It can be seen that the instrumental resolution is dominated by the collimation term.

All slits, mirror, detector and sample position movements will be motorised (~50 axes) to appropriate precision. The sample to detector position will be variable from 2 to 8 m. At the shortest distances the full benefit of an order of magnitude increase in flux will be realized whereas at longer sample–detector distances the discrimination against incoherent background arising from the sample will be maximized, resulting in a potential 10 × reduction in background levels.

4. Conclusions

INTER will be a high-flux vertical scattering geometry reflectometer ideal for the study of chemical and biological interfaces with a particular emphasis on liquid interfaces. The increased simultaneous bandwidth together with flux gains from the target, moderator and instrumental geometry will facilitate not only parametric studies but will open up a range of kinetic studies on timescales of the order of seconds. INTER will provide sample environment equipment for a full range of air–liquid, solid–liquid, solid–solid and liquid–liquid experiments and will be supported by a dedicated sample environment laboratory in addition to chemistry and biology laboratories. INTER is scheduled to begin commissioning towards the end of 2007.

References

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