Introduction

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Introduction

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X-rays, originally a tool for structural investigations and imaging purposes can nowadays be used for studies of the dynamics in materials. The first energy resolved observation of phonons with synchrotron radiation (Burkel *et al* 1987, Dorner *et al*, Burkel 1991) became feasible by using a three-axis spectrometer with crystal optics operating close to backscattering geometry. This technique was developed further with second generation instruments at the European Synchrotron Radiation Facility (ESRF, France) and at the Advanced Photon Source (APS, USA) allowing routinely an energy resolution of 1–2 meV (Burkel 2000).

With this technique one can determine the phonon dispersion curves in small and complex crystals as demonstrated with α-quartz (scattering volume 5×10^{-2} mm^3) by Burkel *et al* (1999) or with AlN single crystals $(0.5 \times 0.5 \times 0.5)$ mm^3 by Schwoerer–Böhning *et al* (1999).

A very important advantage of inelastic x-ray scattering lies in the fact that it has almost no restrictions in the accessible energy-momentum space, since the coupling of the energy to the momentum transfer is negligible.

Therefore, this method is extremely attractive for studying the coherent part of the dynamical structure factor of non-periodic structures like amorphous materials, glasses or liquids with high sound velocities. It opens up a new possibility to study in detail the dynamics of propagating and local modes in the whole range from the hydrodynamic limit to the many-particle behaviour.

The inelastic technique already contributed to a more detailed understanding of the dynamics in liquid metals like lithium (Burkel 1991, Sinn *et al* 1997) and sodium (Pilgrim *at al* 1999) and in liquid water (Sette *et al* 1996). In all these liquids there exist waves with mesoscopic wavelengths that propagate faster than ordinary sound. Also, new information on glasses and glass-forming liquids were achieved by Sette *et al* (1998) and others.

Another demonstration of the capabilites of the technique is the study of the dynamics in CdTe by Krisch *at al* (1997) at a pressure of 7.5 GPa using a diamond anvil cell with a photon beam size of only 100×100 μm^2.

Besides the backscattering technique, a different method was developed in recent years using nuclear resonant absorption (Seto *at al* 1995). In this technique, a synchrotron radiation pulse creates a collectively excited state of the nuclear system which decays either by radiative decay or by internal conversion and subsequent emission of x-ray fluorescence quanta (6.4 keV in the case of ^{57}Fe) and/or Auger electrons. If such a nucleus is excited by a synchrotron radiation pulse with its photon energy deviating from the resonance energy, the resonant excitation can nevertheless be achieved by energy exchange of the nuclei with excitations in the sample.

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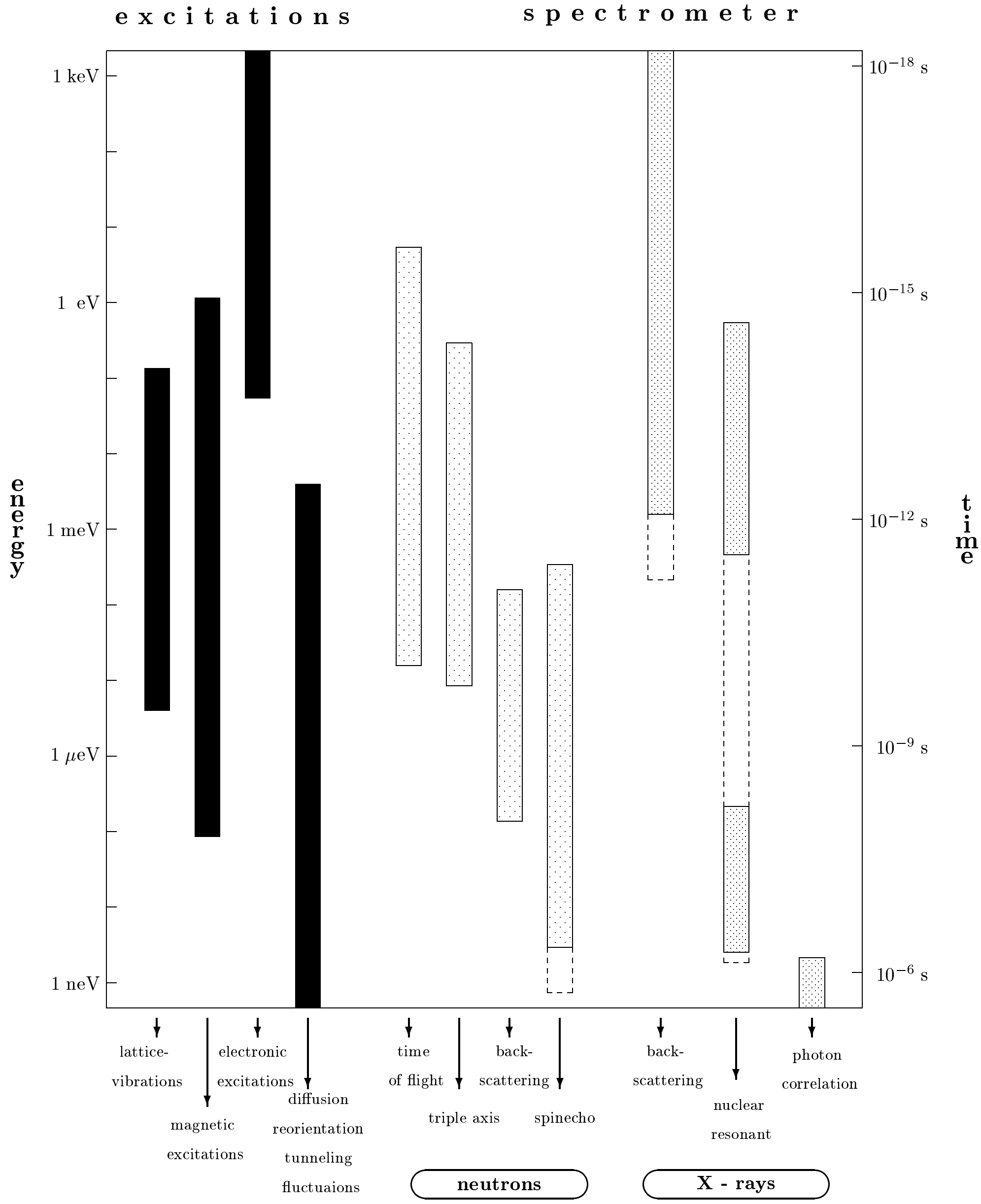

Figure 1. Excitations with their typical energy and time scales and the appropriate spectrometer for the detection with x-rays and neutrons.

Therefore, the yield of nuclear decay products is a measure of the density of excitations in the sample in an incoherent and momentum-integrated way. In the presence of vibrational excitations with the creation and annihilation of phonons, the partial phonon density of states is obtained. Applications of this method are the investigations of partial phonon density of states of ^{57}Fe in Fe_3Al by Fultz *et al* (1998), in icosahedral quasicrystals $Al_{62}Cu_{25.5}Fe_{12.5}$ by Brand *et al* (1999), in myoglobin (Parak and Achterhold 1999) and in the anhydrous complex salt $[Fe(bpp)_2][BF_4]_2$ (Chumakov *et al* 1997).

The nuclear resonant absorption technique is an ideal tool to study the influence of reduced dimensionality or of confined geometry on the vibrational spectrum to get more insight into the unusual mechanical properties of such systems. Phonons are influenced in their propagation in nano-sized structures. Topological disorder caused by impurities or rough boundaries will lead to a reduced lifetime compared to perfect crystals. An example is the investigation in nanocrystalline iron by Fultz *et al* (1998).

For the studies of thin films, it is possible to optimize the method even further. Interference effects in grazing incidence geometry can be used to enhance the intensity of inelastic nuclear absorption significantly. Successful applications have been the studies of localized vibrational states in amorphous $Tb_{1-x}Fe_x$-alloy films by Keune and Sturhahn (1999). In investigations of the dynamics of ^{57}Fe in a 13 nm thick layer of vitreous $FeBO_3$ between a top and bottom Pd layer (Röhlsberger *et al* 1999a) a sensitivity of about one monolayer of the resonant nuclei was reached. Studies of the dynamics in two-dimensional islands (400 μm $\times$100 μm) ^{57}Fe islands on a W(110) surface were performed successfully by Röhlsberger *et al* (1999b).

Within little more than a decade, the technique of using photon beams with meV energy bandwidths for the study of vibrational excitations already achieved impressive results and allowed new insights into several scientific questions. Figure 1 shows a variety of excitations in materials like crystalline or non-crystalline solids or liquids and their typical energy and time scales together with the instruments for x-ray and neutron spectroscopy. In addition to the methods described, time correlation spectroscopy was developed in the last few years.

Nowadays, synchrotron radiation is a powerful tool for the study of the dynamics in materials. However, the present problem is that these capabilities are not yet common knowledge. An intensive course such as the Euro Summer School allows us to bring specialists into contact with researchers that have detailed knowledge on modern materials of technical interest and can rise the scientific questions to be worked on. Only such intensive discussion will really use the potential of these techniques. It is an interdisciplinary task to get material scientists, solid state physicists, chemists and biologists together for such an event to give an important impulse. Especially, young researchers of the different disciplines should become interested in using these new techniques intensively in the future.

There are unique experimental possibilities worldwide, with four dedicated beamlines for such investigations at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, one at the Advanced Photon Source (APS) at Argonne, USA and one at the Super Photon Ring (SPring 8) in Kansai, Japan. These research capabilities are an excellent base for successful aplications of these new methods.

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