application of inelastic x-ray scattering to the measurements of acoustic wave velocities in geophysical materials at very high pressure

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Abstract

Reference Earth global models used by geophysicists are mostly constrained by analysing seismic waves that travel in the Earth. The interpretation of these seismological models in terms of chemical composition and temperature thus relies on the knowledge of the chemical composition, structure and elastic properties of some candidate materials relevant to geophysics. We will describe some recent advances in experimental mineral physics which yield essential information on the elastic properties of pertinent materials of Earth’s mantle and core. In particular, we show that inelastic X-ray scattering (IXS) proves to be a well suited spectroscopic technique for the study of phonon dispersion in materials under high pressure. Inelastic scattering experiments carried out on polycrystalline samples provide measurements of orientationally averaged longitudinal acoustic velocities whereas investigations on single crystals yield elastic moduli. Such a technique is thus highly interesting for mineral physicists and offers a great potential in providing essential elastic data and their pressure and/or temperature dependence on most compounds of geophysical interest.

Keywords: Earth’s interior; Mineral physics; High pressure; Physical properties; Elasticity; Techniques

1. Introduction

Knowledge of the elasticity of minerals is essential to the understanding and interpretation of seismic data, in particular radial average sound velocity profiles or three dimensional images from tomographic studies. Successful interpretation of these seismic models in terms of chemical composition, mineralogy, and temperature indeed requires information on the elasticity of deep Earth materials under high pressure and temperature conditions. The experimental determination of elastic properties at extreme conditions is, however, not an easy task. Still, numerous experimental procedures have been developed during these last
The implementation of ultrasonic interferometric measurements along the Hugoniot in iron (Brown and McQueen, 1986), forsterite to 150 GPa (Duffy and Ahrens, 1992), periclase to 27 GPa (Duffy and Ahrens, 1995) or molybdenite to 81 GPa (Duffy and Ahrens, 1994).

Resonant ultrasound spectroscopy to study the behaviour of minerals at extreme temperature and room pressure, e.g. single crystal periclase or forsterite to 1800 K (Isaak et al., 1989a,b).

The implementation of ultrasonic interferometric measurements using a 1000 tonnes uniaxial split-cylinder apparatus (see Liebermann and Li, 1998) with applications to polycrystalline olivine to 10 GPa and 1300 K (Li et al., 1998), wadsleyite to 7 GPa and 873 K (Li et al., 2001) or MgSiO_3 perovskite to 8 GPa and 80 K (Sinelnikov et al., 1998).

Optical probes using phonon–photon scattering processes with stimulated Brillouin scattering in a diamond–anvil cell with measurements of single crystal elastic moduli of natural samples of olivine, orthopyroxene and garnet to 20 GPa (Brown et al., 1989; Yang et al., 1993; Chai et al., 1997a,b; Abramson et al., 1999).

The extension of pressure range using conventional Brillouin spectroscopy with measurements on periclase to 55 GPa (Zha et al., 2000) or silica glass to 58 GPa (Zha et al., 1994). Data on periclase and synthetic pyrope to 20 GPa (Sinogeikin and Bass, 2000) as well as polycrystalline materials such as natural majorite-pyrope solid solution under pressure (Sinogeikin and Bass, 2002).

Furthermore, first-principles methods have been applied to the study of the high-pressure phases relevant to the Earth’s deep interior such as MgSiO_3 perovskite (Karki et al., 2000; Oganov et al., 2001), hcp iron (Alfe et al., 2001; Steinele-Neumann et al., 2001) and hcp cobalt (Steinele-Neumann et al., 1999). The reader is invited to refer to the review articles by Sixrud et al. (1998) or Karki et al. (2001).
2. Experimental setup

The development of IXS with meV energy resolution goes back to work at HASYLAB (Germany) in the 1980s (see Burkel et al. (1987) or Dorner et al., 1987). This method allows to study phonons and phonon-like excitations. The theoretical aspect will not be discussed here and the reader is referred to the articles of Schülke (1991) and Burkel (2000). The basic kinematics of the inelastic scattering process is described in Fig. 1. The incident photon of energy $\hbar\omega_1$ and wave vector $\mathbf{k}_1$ is scattered by the sample into a photon characterized by energy $\hbar\omega_2$ and wave vector $\mathbf{k}_2$, a process corresponding to an energy transfer $\hbar\omega = \hbar\omega_1 - \hbar\omega_2$ and the momentum transfer $\hbar \mathbf{Q} = \hbar \mathbf{k}_1 - \hbar \mathbf{k}_2$. In the cases investigated in this study, the energy transfers are of the order of meV, much smaller than the incident photon energy of 15–25 keV, and $\mathbf{Q}$ is only controlled by the scattering angle theta, with the following expression:

$$Q = 2k_1 \sin (\theta/2)$$  \hspace{1cm} (1)

At the ESRF (European Synchrotron Radiation Facility), two beamlines (ID16 and ID28) are dedicated to X-ray inelastic scattering spectroscopy. On ID28, the X-ray beam produced by three undulators is monochromatized by a cryogenically cooled silicon (1 1 1) crystal and a high-energy resolution silicon backscattering monochromator (Verbeni et al., 1996). The backscattered beam is focused by a gold-coated toroidal mirror which provides a focal spot at the sample position of 250 μm (horizontal) by 60 μm (vertical) full-width-half-maximum. The scattered photons are analyzed by five analyzers mounted on a Rowland circle at a distance of 650 cm from the sample (Masciovecchio et al., 1996). The energy-analyzed photons are subsequently detected by a Peltier-cooled five element silicon diode detector positioned near the sample position 3 mm above the incident beam axis. According to Eq. (1), the momentum transfer $Q$ is selected by rotating the spectrometer arm in the horizontal scattering plane around a vertical axis passing through the sample (see Fig. 2). The energy scans are performed by varying the monochromator temperature while the temperature of the analyzers is kept fixed. With a linear thermal expansion of silicon at room temperature $\alpha = 2.58 \times 10^{-6}$ K$^{-1}$ and a conversion to the energy scale according to the relation: $\Delta E/E = \alpha \Delta T$, a temperature scan over a few degrees with mK resolution provides the necessary meV resolution in energy needed to probe phonon excitations. The sample orientation and scattering angle are kept fixed whereas the energy of the beam impinging on the sample is changed by varying the monochromator temperature in steps of 0.005–0.020 K over 1–4 K, corresponding to a scanning range of several 10 meV up to a few 100 meV.

In order to illustrate how data processing is made, a typical IXS spectrum is given in Fig. 3 for polycrystalline bcc iron at ambient conditions. On both sides of the elastic line centered at zero-energy transfer, one can notice two excitations which correspond to the scattering of incident X-ray photons by longitudinal acoustic LA phonons in iron. These Stokes (energy loss) and anti-Stokes (energy gain) inelastic interactions, corresponding to phonon creation and annihilation, respectively, are characterized by an energy transfer at a given momentum transfer $Q$, which corresponds to a particular location in the first Brillouin zone. The energy positions and the widths of the excitations are fitted by using a Lorentzian model function, convoluted with an experimentally determined energy resolution function, by standard $\chi^2$ minimization (shown in Fig. 3).
2.1. The example of iron and its implications for the Earth’s inner core

The knowledge of the elastic constants of the phases of iron, which makes up 70–90 wt.% of planetary cores, is essential for comparison with global velocity models of Earth. The hcp (or ε) high-pressure phase is stable to at least 300 GPa at ambient temperature (Mao et al., 1990) and numerous experiments have been carried out in order to characterize the elastic properties of iron phases, such as XRD (Mao et al., 1998; Mathies et al., 2001), NRIXS (Lubbers et al., 2000; Mao et al., 2001), or INS on the low pressure bcc phase (Klotz and Braden, 2000). As shown in Fiquet et al. (2001), IXS provides a way to derive the acoustic velocity from the dispersion of the longitudinal acoustic phonon energy in iron. The results of this study are used here for illustrating how acoustic velocities are obtained from IXS data collected under high pressure.

In this experiment, a polycrystalline sample of iron was loaded into the 120 µm hole of a rhenium gasket and compressed without any pressure transmitting medium between diamond anvils. In the following, only the Stokes part of the spectra has been collected to save time. The peak centered at zero-energy transfer corresponds to the elastic contribution to the signal, whereas two other peaks are visible at higher energy transfer. The knowledge of the phonon dispersion curves of iron (Minkiewicz et al., 1967) and diamond (Warren et al., 1967) allows an unambiguous assignment of these features, which correspond to a LA phonon of iron and a transverse acoustic TA phonon of diamond (see Fig. 4). With the five analyzers located in the horizontal plane at different scattering angles θ, it is possible to map the dispersion curves of acoustic phonons across the first Brillouin zone. Due
Fig. 4. IXS pattern recorded on a powdered iron sample in the hcp phase, at 28 GPa in a diamond–anvil cell. No pressure transmitting medium is used. The momentum transfer $Q$ is 4 nm$^{-1}$. Dashed lines represent the inelastic contributions of the LA phonon branch for iron and from a TA branch from diamond, the thin solid line represents the elastic contribution and the thick continuous line shows the summation of individual contributions.

As shown in Fig. 6 on the dispersion curves resulting from the fitted energy position of the phonon reported as a function of the momentum transfer $Q$. We notice that the high-pressure data are at energies well above those at ambient pressure, implying a significant increase of the sound velocity with increasing pressure, in the bcc phase as well as in the hcp phase of iron. The velocity of longitudinal acoustic velocity ($V_P$) as well as the position of the edge of the first Brillouin zone $Q_{\text{MAX}}$ can be estimated by fitting the dispersion relation with a sine law, and by determining its slope in the $Q = 0$ limit with the following expression:

$$E[\text{meV}] = 4.192 \times 10^{-3} V_P[ \text{ms}^{-1}] \times Q_{\text{MAX}}[\text{ns}^{-1}] \times \sin \left[ \frac{\pi}{2} \frac{Q[\text{ns}^{-1}]}{Q_{\text{MAX}}[\text{ns}^{-1}]} \right]$$

(2)
Fig. 6. Orientationally averaged dispersion curve of the longitudinal acoustic phonon branch of iron. The dashed line corresponds to data recorded in the bcc phase at 0.2 and 7 GPa, solid lines stand for fitted dispersion curves in the hcp phase of iron at pressures of 19, 28, 45, 55, 64 and 110 GPa from bottom to top.

The first Brillouin zone is approximated here by a sphere defined by radius \( Q_{\text{MAX}} \), which has been considered as a free parameter in the fitting procedure. Within uncertainties, the observed values of \( Q_{\text{MAX}} \) calculated from XRD data by equating the volume of the reciprocal unit cell to that of a sphere are in agreement with those obtained during the fit. Data recorded at four to five momentum transfers have been used in each dispersion curve to constrain \( V_P \) within an estimated error of 3%.

Our results for the low-pressure bcc structure agree within 1% with the ultrasonic data collected up to 1 GPa and extrapolated up to 10 GPa (Guinan and Beshers, 1968), thus confirming the reliability of these measurements (see Fig. 7). Results obtained in the hcp phase are given in Table 1 and reported as a function of pressure in Fig. 8, along with previous measurements obtained with other techniques. At low pressures (below 40 GPa), we find an excellent agreement between our longitudinal acoustic velocity \( V_P \) determination and orientationally averaged ultrasonic data (data point at 26.5 GPa in Mao et al., 1998). Up to 100 GPa, our measurements are within error bars in good agreement with radial X-ray diffraction (Mao et al., 1998) or NRIXS data (Mao et al., 2001), whereas theoretical calculations yield much higher velocities (Steinle-Neumann et al., 2001). In Fig. 9, we also show that hcp iron follows a Birch law (see Birch, 1963) for \( V_P \), namely a linear dependence between compressional sound velocity and density, which provides a convenient relationship for extrapolating our measurements to higher pressures. Furthermore, our measurements are in excellent agreement with the Hugo-net shock data of Brown and McQueen (1986) within the frame of the Birch’s plot. These shock data have been collected at high temperature whereas our measurements have been carried out at ambient temperature. The important point is that both experiments yield the same observed acoustic velocity at a same given density, which is indeed the Birch assumption (Birch, 1963). It is striking to note that seismic data (Drzewowski and Anderson, 1981) does not fit the linear extrapolation made from the combination of the two sets of data. This could be interpreted as if Earth’s

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Table 1

Longitudinal acoustic sound velocities (\( \text{m/s} \)) as a function of specific mass (\( \text{kg/m}^3 \)).
inner core were 4–5% lighter than hcp iron, as previously suggested by Jephcoat and Olson (1987). Alternatively, this might indicate the presence of another phase of iron or alloy with different physical properties (e.g. Anderson, 1995). The comparison made with NRIXS data by Mao et al. (2001) shows that the extrapolations of the trends outside of the actual measurement ranges yield different values of $V_P$ at inner core conditions, as well as different conclusions on the possible constitution of the inner core. In NRIXS experiments however, the determination of the average LA velocity is less direct than using IXS. The average Debye phonon velocity has to be extracted from a parabolic fit of the low-energy part of the density of states, and has to be converted into $V_P$ through an averaging scheme using independent determinations of bulk and shear moduli. Alternatively, such a difference between IXS and NRIXS results might originate in the way preferred orientations that develop at high pressure in diamond-anvil cells in iron are taken into account. On a polycrystalline material, every single crystallite contributes to the total average LA dispersion curve. The average position and the width of LA excitation result from both the intrinsic resolution of the spectrometer and the sample texture. If orientation distribution is not random, the average might be biased toward velocities along that preferred orientation. XRD measurements carried out in parallel to our IXS study on the ID30 ESRF beamline indeed show that the $c$ axis of iron is preferentially aligned with the compression axis of the diamond-anvil cell, in accordance with recently reported texture measurements (Wenk et al., 2000). Such measurements proposed in addition a large anisotropy for $V_P$, with $P$-waves travelling 8% faster at 45° from the $c$ axis than either in the $ab$ plane or along the $c$ axis. According to these texture measurements, our IXS experiment probes mainly LA phonons propagating in the $ab$ plane, since the momentum transfer lies approximately perpendicular to the incident X-ray beam and to the $c$ axis. When anisotropy curves are considered however (see Wenk et al., 2000), the orientationally averaged $V_P$ values we obtain from IXS are similar to the values corresponding to a predominant but not complete preferential orientation of the $c$ axis.
In addition, we performed a series of measurements which show the influence of light elements such as sulfur, silicon or oxygen on acoustic sound velocities of iron alloys at high-pressure. The results are presented in Table 1 and reported as a function of specific mass in Fig. 10. One notices that iron silicide, iron oxide as well as pyrite closely follow a Birch’s law, which provides an interesting way to extrapolate data at higher pressure and/or temperature and will therefore bring new constraints to the determination of the light elements content of the Earth’s inner core (Badro et al., in preparation).

2.2. The investigation of the acoustic anisotropy of hcp metals at high-pressure: the example of cobalt

Beyond studies of the bulk properties of the Earth’s core, seismological studies show that the inner core is elastically anisotropic (Woodhouse et al., 1986; Romanowicz et al., 1996; Song, 1997; Garcia and Souriau, 2000). The anisotropy has an axial symmetry and an amplitude of about 3%, with the fast direction oriented parallel to the Earth’s rotation axis. Several hypotheses have been proposed to explain this feature: Jeanloz and Wenk (1988) proposed that the anisotropy might be caused by the lattice preferred orientation of the hcp structure of iron due to plastic deformation, whereas Karato (1993) invokes an interaction of the Earth’s magnetic field with growing magnetically anisotropic iron crystals. However, it is not clear whether hcp iron is highly anisotropic at very high pressure. Some theoretical results show a rather low intrinsic anisotropy, almost requiring a perfect alignment of iron hcp crystals in order to account for the observed seismic anisotropy (Stixrude and Cohen, 1995). More recent theoretical work shows that intrinsic anisotropy in hcp iron is of the order of 12% at inner core conditions and that perfect texturing is not required by the theoretical results (Steinle-Neumann et al., 2001). Texture X-ray diffraction measurements of iron at very high-pressure (Mao et al., 1998; Wenk et al., 2000) indicate a large compressional-wave anisotropy which relieves the “perfect alignment” textural constraint. This is illustrated in Fig. 11 where the longitudinal acoustic wave velocity is shown as a function of the direction of propagation for hcp iron.

The anisotropy proposed by texture measurements (Mao et al., 1998), when compared to calculations (Stixrude and Cohen, 1995), is not only different in magnitude, but as well in direction. Conversely, the direction and magnitude of the anisotropy in another
metal with hcp structure such as cobalt compare well (Guinan and Steinberg, 1974) with iron theoretical values.

In order to settle the above outlined discrepancies between the various indirect experimental techniques and theory, a direct experimental determination of the elastic constants of hcp iron and their evolution with pressure and temperature is needed. The key experiments would in fact be the direct comparison of single crystal and polycrystalline data in hcp-Fe. However, obtaining single crystals of hcp-Fe at high pressure is currently not possible. In the next paragraphs, we present preliminary results obtained on cobalt to address the issues of elastic anisotropy. Unlike iron, hcp cobalt is stable at room temperature and ambient pressure to 105 GPa (Yoo et al., 2000). Cobalt is a 3d transition metal located next to iron in the periodic table, and its bulk and thermal properties are close to those of iron. Thus, cobalt makes a good proxy for iron at high-pressure, and single crystals as well as powders can be obtained commercially. The example we present here is focused on the determination of elastic moduli and their pressure derivatives. For the hcp structure there are five independent elastic moduli (C₁₁, C₂₂, C₄₄, C₁₂, C₁₃). These can be derived from the LA and TA phonon dispersion, fitted as shown previously with a sine function where the slope at Q = 0 yields acoustic velocities along main directions chosen by orientating the crystal kept at high-pressure in the diamond-anvil cell. With a single crystal with surface normal to [1 1 0], it is possible to get C₁₁, C₂₂, C₄₄ and C₆₆, which are simply related to LA [1 0 0], LA [0 0 1], TA [1 1 0][0 0 1] and TA [1 1 0][1 0 0], respectively, whereas C₁₂ can be easily obtained from C₆₆ = (1/2)(C₁₁ − C₁₂) and C₁₃ is a linear combi-

![Fig. 12. IXS pattern collected on single crystal hcp cobalt at three different pressures in a diamond-anvil cell. Helium is used as pressure transmitting medium. Squares: 3.3 GPa, circles: 6.5 GPa, triangles: 9.5 GPa. The energy position of the LA phonon is indicated by the arrow. A higher energy phonon can be assigned to an optical mode. Reduced Q setting is 1.1 along [1 0 0] direction in hcp cobalt. The data were taken with an energy resolution of 3 meV.](image1)

![Fig. 13. Top: Dispersion curve of the longitudinal acoustic phonon branch along the [1 0 0] direction in hcp cobalt at 9.5 GPa. Bottom: pressure dependence of C₁₁ elastic modulus (open circles). Ultrasound measurements at room pressure (Landolt-Börnstein, 1966) appear as an open diamond whereas theoretical calculations by Steinle-Neumann et al. (1999) are represented by solid dots. Lines are linear fits to the data. The pressure derivative is 5.3 (4) and the extrapolation to room pressure is C₁₁ = 290 ± 2 GPa.](image2)
nation involving the other four elastic moduli. In order to reach the highest pressure we are aiming at (40–50 GPa), the crystal dimensions compatible with the constraints of the diamond anvil cell are 50 μm in diameter and 15 μm in thickness. These single crystals, which have to be of high quality, have been prepared at the Lawrence Livermore National Laboratory using state-of-the-art polishing and laser cutting techniques, and subsequently loaded in a diamond anvil cell using helium as a pressure transmitting medium. The first set of experiments presented here has been obtained on the ID28 beamline at ESRF using a single crystal with surface normal to [0 0 1]. Typical IXS pattern obtained at pressure up to 9.5 GPa are shown in Fig. 12. It allowed us to obtain the variation of the LA wave velocity along the [1 0 0] direction with increasing pressure. Combining these results with density measurements obtained by XRD, we obtain directly $C_{11}$, and its variation with pressure as shown in Fig. 13, plotted along with recent theoretical determinations (Steinle-Neumann et al., 1999).

These investigations have recently been extended to determine the five elastic constants and their pressure dependences to 42 GPa (Antonangeli et al., in preparation) and will be complemented by measurements on polycrystalline cobalt, in a manner similar to the experiments described above on iron. The sound ve-
Fig. 16. Polycrystalline longitudinal acoustic phonon dispersion and corresponding sine function fit [Eq. (2)] for MgSiO$_3$ perovskite. The resulting mean longitudinal acoustic sound velocity is $10652 \pm 173$ m/s. The value of $Q_{\text{MAX}}$ is a free parameter in this fit ($Q_{\text{MAX}} = 13.82 \pm 0.67$ nm$^{-1}$).

Fig. 17. Experimental measurements plotted along with different simulated dispersion curves calculated using Yegezani-Haeri et al. (1989) elastic constants (with a Voigt-Reuss-Hill average of LA velocity of 10940 m/s) and different averaging processes. The solid line represents a fit with $Q_{\text{MAX}}$ considered as a free parameter; the dashed line is calculated with a spherical first Brillouin zone.

2.3. Preliminary IXS data on magnesium silicate MgSiO$_3$ perovskite

Physical properties of MgSiO$_3$ with perovskite structure are of interest to better understand both the composition and current state of the Earth’s lower mantle (670 to 2900 km in depth). The knowledge of the elastic constants of this compound, which makes
up to 70–100 wt.% of the lower mantle, is essential for comparison with Earth’s global seismic models, as well as to translate tomographic images into temperature and composition fields. It is also important to understand the lattice dynamics of this phase, which both determines its thermal properties at high pressure and temperature (e.g. Gillet et al., 2000) and which is related to possible phase transitions via soft-mode mechanisms (Hensley and Cohen, 1992; Wang et al., 1992).

In our preliminary experiment, a sintered sample of polycrystalline magnesium silicate perovskite was measured at ambient conditions. Further experiments will be carried out on MgSiO₃ single crystals, but there are some interesting points in proving that working on powders of silicate perovskite is possible. First, it is difficult to keep single crystals at very high pressures whereas powders can be compressed to pressures exceeding the 135 GPa of the core-mantle boundary. Second, IXS on a well sintered powder can still yield information about average acoustic velocities, which can be compared to geophysical models. Our experiments on MgSiO₃ perovskite were performed on a polycrystalline sample synthesized at the mineral physics institute of the State University of New York at Stony Brook. The sample was mounted on a glass fiber and checked by X-ray diffraction using a focused monochromatic radiation and imaging plate (MAR345) detector at the ID09 beamline of ESRF. We confirmed that the sample is a pure MgSiO₃ compound with perovskite structure, and no preferred orientations are detectable from the Rietveld refinement of the XRD pattern presented in Fig. 14. An example of an IXS spectrum is presented in Fig. 15, showing a well resolved LA mode of silicate perovskite. IXS data were collected at eleven different $Q$-settings, which allowed us to obtain the first experimental averaged dispersion curve in silicate perovskite with MgSiO₃ composition. Results are plotted in Fig. 16 along with the fit made using relation [2] in order to retrieve sound velocities. The results are $V_P = 10652 \pm 173$ m/s for the LA acoustic velocity and $Q_{\text{MAX}} = 13.92 \pm 0.67$ nm⁻¹. In Fig. 17, a simulated dispersion curve of orientationally averaged LA mode of silicate perovskite is also reported. The simulation has been made using elastic constants measured by Yeganeh-Haeri et al. (1989), yielding a Voigt-Reuss-Hill average of (LA) velocity of 10940 m/s, and a spherical first Brillouin zone ($Q_{\text{MAX}} = 11.66$ nm⁻¹). As far as acoustic longitudinal velocity determination is concerned, the agreement between experimental and simulated curves is satisfactory. This is not the case for the parameter $Q_{\text{MAX}}$ above $Q = 6$ nm⁻¹, however, the IXS pattern is complicated by the dispersion curves of low frequency optical modes crossing the longitudinal acoustic dispersion curve near the zone edge (see theoretical calculations by Karki et al., 2000 or Parlinski and Kawazoe, 2000). The two curves in Fig. 17 show that the determination of sound velocity is not highly sensitive upon a detailed modeling of $Q_{\text{MAX}}$.

In order to check for elastic anisotropy, simultaneous measurements of longitudinal phonons with 3D structure of the powder, as well as determination of ab initio calculated dispersion curves are needed for refining such determinations of average $V_P$ in silicate perovskite.

3. Conclusions

Inelastic X-ray scattering is a well suited spectroscopic technique for the study of phonon dispersion of materials under high pressure. On both inelastic scattering beamlines of ESRF (ID16 and ID28), specific emphasis was given to high pressure. Moreover, the focusing optics scheme on ID28 is currently upgraded, and a focal spot size of 30 μm $\times$ 60 μm (horizontal $\times$ vertical, FWHM) has been recently accomplished, thus enabling investigations on smaller samples, i.e. higher pressures. This work shows that a large variety of samples (metals or oxides) can be studied, either in a polycrystalline form (powders, sintered samples...) or as single crystals. Inelastic scattering experiments carried out on polycrystalline samples provide direct determination of orientationally averaged longitudinal acoustic sound velocities, whereas investigations on single crystals yield elastic moduli and a view on the dynamics of phase transitions. This technique is thus highly interesting for mineral physicists and offers a great potential in providing essential elastic data and their pressure and/or temperature dependence for most compounds of geophysical interest.
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