3.1 NON-DYNAMIC ORIGIN OF THE ACOUSTIC ATTENUATION AT HIGH FREQUENCY IN GLASSES

One of the most important and still unsettled subjects in the physics of topologically disordered systems regards the mechanisms for the propagation and attenuation of density fluctuations. The propagating nature of acoustic waves, as seen by Ultrasonic and Brillouin Light Scattering (BLS) measurements in the MHz and GHz region respectively, has been shown to persist up to the THz region by the existence of a linear relation between the peak energy, $E$, and the momentum transfer, $Q$, of the inelastic features observed in the dynamic structure factor, $S(Q,E)$, of glasses [1].

This result is the outcome of extensive studies on the shape of $S(Q,E)$ performed using Molecular Dynamics (MD) simulations [2, 3, 4, 5] and the newly developed Inelastic X-rays Scattering (IXS) technique [1, 6, 7, 8]. This latter technique allows to study the $S(Q,E)$ in the “high” $Q$ range ($Q = 1-10$ nm$^{-1}$), thus increasing by about two orders of magnitude the $Q$ values typically investigated by BLS ($Q = 0.01-0.04$ nm$^{-1}$).

In the IXS and MD $Q$-range, beside the persistence of a linear dispersion of the acoustic excitation energies, one also observes a progressive broadening of the inelastic features, which is responsible for their disappearance at a certain $Q_m$ value. Typically $Q_m$ is some tenths of $Q_0$, the position of the first sharp diffraction peak in the static structure factor, $S(Q)$ [1].

The study of the mechanisms leading to this damping, and, therefore, the investigation of the sound waves attenuation at these $Q$-values -characteristic of structural correlations at the interparticle level- is obviously of great interest. The acoustic excitations at frequencies in the THz range, as measured so far in glasses and glass forming liquids by IXS, have a linewidth parameter $\Gamma_0$ which seems to show a $Q^2$ dependence [1]. Moreover, in all the IXS data reported so far, $\Gamma_0/Q^2$ has a negligible temperature dependence in a wide temperature region ranging from values well below the glass transition temperature, $T_g$, up to the liquid phase [1]. At variance with this behavior, as well known, the linewidth of the excitations in the GHz region, measured by BLS, show a relevant temperature dependence, which becomes particularly strong in the limit of very small temperatures [9, 10, 11, 12, 13, 14].

The temperature dependence of the linewidth in the GHz range has motivated many theoretical studies, leading to different hypotheses on the frequency (or $Q$) evolution of the attenuation mechanisms.

In this work we report an IXS study on the low temperature behavior of the excitations linewidth in glassy glycerol, down to $T = 16$ K. Fig. 1 shows spectra obtained at $T = 16$ K and $T = 167$ K and at the indicated $Q$ values. The experiment has been carried out at the new very high energy resolution IXS beamline ID28, at the European Synchrotron Radiation Facility. Specifically, we concentrate on the study of THz excitations in the temperature region where the BLS data in the GHz range show a marked temperature variation.

Fig. 2 shows that, within the error bar, the linewidth measured by IXS is temperature-independent in the whole 0.1 $T_g$ to $T_g$ region, whereas, in this same region, the BLS linewidth increases by more than a factor of ten.

These two opposite behaviors indicate that there are at least two different attenuation mechanisms: i) One of dynamic origin dominant in the low $Q$ (low frequency) region, and ii) A second one, dominant at high $Q$, whose temperature variation is not negligible. This second mechanism is likely to be a coupled quasiharmonic mode, whose linewidth increases with temperature as $Q^2$. The analysis of both the IXS and BLS data lead to the conclusion that the coupled quasiharmonic mode is the main attenuation mechanism at THz frequencies. In fact, the IXS data confirm the BLS results [1] in the $Q$ region of the $S(Q,E)$ shoulder, which is mainly due to this mechanism.
3. Liquid and Disordered Systems

![Graph showing temperature dependence of \( \Gamma_Q / Q^2 \) in glycerol at \( Q = 0.03 \text{ nm}^{-1} \) (open symbols) at \( Q = 2 \text{ nm}^{-1} \) (crossed symbols) and averaged over the \( Q = 2-4 \text{ nm}^{-1} \) (full symbols). The vertical dashed line indicates the glass transition temperature \( T_g = 187 \text{ K} \).]

The glycerol results are confirmed by a similar sound attenuation behavior found in vitreous silica (see Fig. 3), as obtained by the analysis of existing BLS, IXS and MD data.

The observation of two distinct attenuation mechanisms, each one dominant in a different \( Q \) region, implies the existence of a cross-over frequency, which lies in the 100 GHz range for both of the studied glasses.

It also suggests that the frequency dependence of the dynamic contribution to the sound attenuation agrees with the one recently predicted by Fabian and Allen [15].

The hypothesis on a cross-over between the two different attenuation mechanisms considered here [19] call for further studies, where the \( Q \) and \( T \)-dependences of the sound waves is thoroughly investigated using the BLS and IXS technique in a wider number of glass materials.

![Graph showing temperature dependence of \( \Gamma_Q / Q^2 \) in 

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**References**