UNIVERSAL FEATURES OF IONIC MOTION IN DISORDERED ION CONDUCTORS

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In the last few decades, ion-conducting materials with quite different kinds of disordered structures have been found to show an unexpected degree of similarity in their broadband conductivity spectra. In particular, two surprising "universalities" have been detected, see Figs. 1 and 2. One of them, the *first universality*, has turned out to be a fingerprint of activated hopping along interconnected sites, while the other, the *second universality*, also known as *Nearly Constant Loss* (NCL) behaviour, reflects non-activated strictly localized movements of the ions. The former is observed at sufficiently high temperatures, while the other is found at sufficiently low ones, e.g., in the cryogenic temperature regime.
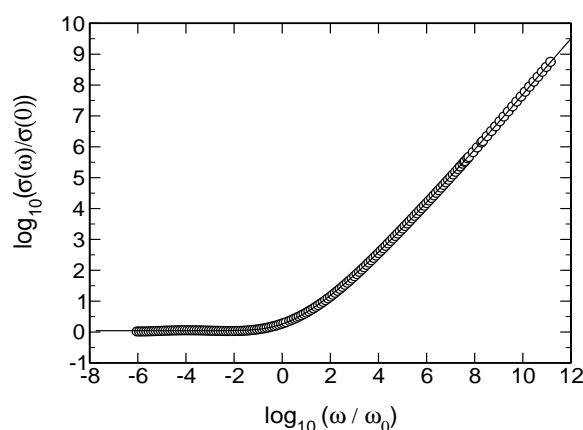

Fig. 1, *First universality*: This scaled representation of experimental and model conductivities (circles and solid line, respectively, with data from 0.45 LiBr $\cdot$ 0.56 Li$_2$O $\cdot$ B$_2$O$_3$ glass) is characteristic of many disordered ion conductors, which largely differ in phase, structure and composition. Note that the slope increases continuously, slowly tending towards unity [1]. The onset of the dispersion is slightly more gradual in mixed alkali glasses, in ion conductors with reduced dimensionality and in materials with low DC conductivities.

The fascination of the two universalities lies in their ubiquity, i.e., in the occurrence of either or both of them in quite different kinds of disordered ion-conducting materials. These include crystalline, glassy and polymer electrolytes, molten salts and ionic liquids. Evidently, the existence of the universalities is not primarily a consequence of phase, structure and composition, but rather of some common laws that govern the many-particle dynamics of the mobile ions.

In experimental conductivity spectra, the two universalities are often found to be superimposed. In these cases, the scaling behaviour of the *first universality* provides an elegant and model-free way to identify and distinguish the two components when plotted versus inverse temperature at constant frequency.
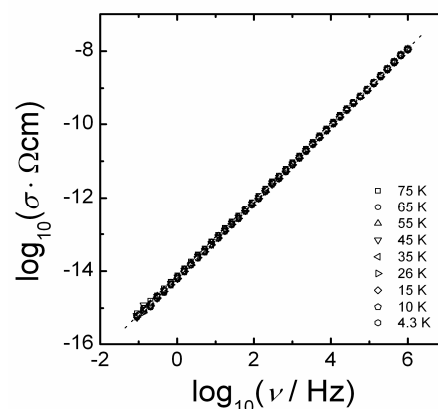

Fig. 2, *Second universality* (*Nearly Constant Loss*), discovered by A.S. Nowick et al. [2]: Low-temperature conductivity isotherms displaying a linear frequency dependence and essentially no temperature dependence (data from 0.3 Na$_2$O $\cdot$ 0.7 B$_2$O$_3$ glass) [1,3].

During the last few years, both universalities have been successfully modelled by considering the changing momentary arrangements and interactions of the mobile ions. Rate equations have thus been found that reproduce the relevant features of the time-dependent ion dynamics as well as the spectra themselves. These equations may, therefore, be regarded as manifestations of the underlying common laws. They also form a sound basis for understanding and visualizing the phenomena in terms of simple physical pictures [1].

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