Technical note

# On the power-law behavior of the AC conductivity of the mixed crystal $(NH_4)_3H(SO_4)_{1.42}(SeO_4)_{0.58}$

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## Abstract

A power law used to describe the AC conductivity from 299 to 393 K of the mixed crystal $(NH_4)_3H(SO_4)_{1.42}(SeO_4)_{0.58}$ led to fractional exponent values ranging from 1.08 to 0.91, depending on structural changes induced on temperature variation [B. Louati, M. Gargouri, K. Guidara and T. Mhiri, J. Phys. Chem. Solids 66 (2005) 762]. In the present note, we suggest that the fractional law exhibits features of lattice relaxation. Despite the structural changes, the parameters of the power law are mutually interconnected to yield a temperature independent phenomenon. Such behavior is probably of general validity and characterizes the universal fractional dispersion of the AC conductivity, as it was also observed in glasses of different composition.
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The role of partial substitution of sulfate by selenate ion in the mixed crystal compound $(NH_4)_3H(SO_4)_{1.42}(SeO_4)_{0.58}$ (NHSSe) was studied recently by AC electrical conductivity measurements from 299 to 393 K [1]. The data were analyzed within the frame of the 'universal' power law [2,3]:

$$\sigma_{ac}(\omega) = A\omega^s \qquad (1)$$

where $\sigma_{ac}$ is the real part of the electrical conductivity, $\omega$ is the angular frequency of the applied field, $A$ and $s$ are fitting parameters, which, in principle, are temperature dependent. The exponent $s$ is related with the interaction of the transferring charge entities with the matrix and $A$ depends on the material.

In a recent publication, it has been shown that, although the parameters $\ln A$ and $s$ that govern the dynamic conductivity in glasses are sensitive to mixed alkali effect in glasses, the *ratio* $-\ln A/s$ is insensitive to glass composition [4,5]. We tried to apply this idea to a different system, i.e. a mixed superionic conductor of constant composition, where the values of the parameters of Eq. (1) are sensitive to structural transitions on increasing

temperature. The ratio $-\ln A/s$ as a function of temperature for $(NH_4)_3H(SO_4)_{1.42}(SeO_4)_{0.58}$ is presented in Fig. 1. We observe that the ratio is practically constant, despite $-\ln A$ and $s$ which change systematicaly with temperature, as can be seen in the inset plot of Fig. 1. The compound undergoes a series of successive structural transitions, which are recorded as six distinct endotherms in DSC thermogram, which affect the hopping transport of protons in this material [6]. As mentioned in Ref. [1], such phase transitions can be traced via the variation of $A$ and $s$ on increasing the temperature (inset of Fig. 1).

A plot of $-\ln A$ against $s$ (Fig. 2) indicates a linear temperature-independent and structure-insensitive correlation between the values of these two parameters. We believe that the constancy of the ratio $-\ln A/s$, which was also observed in non-hopping dynamic conductivity (i.e. the a.c. response due to lattice relaxation) in glasses [4,5], is probably a general feature of the universal power law (Eq. (1)). The latter, which describes the dispersive AC conductivity in various solids and liquids under the empirical constraint for the fractional exponent, i.e. $0.6 \geqq s > 1$ was extended so as to include supra-linear dependencies [5,7,8,1]. Recent numerical calculations suggest that universality if the power law is nothing more than the response of a random 'mixture' of conductors and capacitors [9]. Alternatively, the diffusion cluster

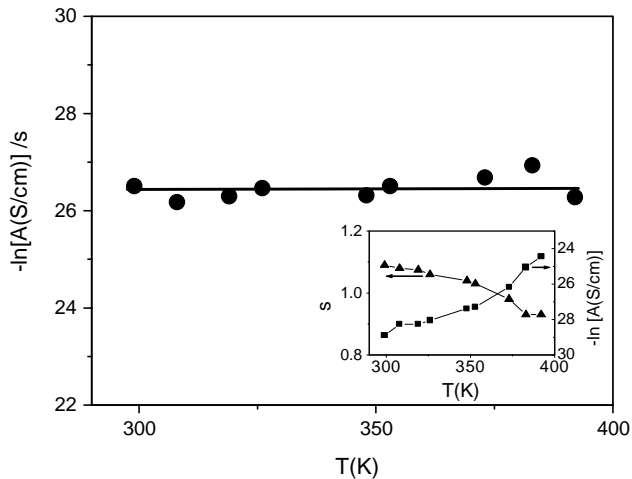* Tel.: +30 1 722 4444; fax: +30 1 934 6840.
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Fig. 1. The ratio $-\ln A/s$ vs temperature of the mixed crystal $(NH_4)_3$-$H(SO_4)_{1.42}(SeO_4)_{0.58}$. In the inset, $-\ln A$ and $s$ are plotted against temperature according to the results reported in Ref. [1].



Fig. 2. Correlation between $-\ln A$ and $s$. The line was best fitted to the experimental data points.

approximation indicates that the exponent is half the fractal dimensionality of a percolation cluster [10]. The observation reported in the present Note can hardly be considered coincidental, as it seems to be applicable in different types of materials and various transport mechanisms [2]. Recalling that the power law is an empirical one and an interconnection of the parameters $A$ and $s$ with microscopic quantities is still lacking, it is difficult to trace the physical meaning of the constancy reported in this paper. However, our observation may help toward a better understanding of the a.c. response of matter. Further check of the temperature independence of the ratio $-\ln A/s$ in different materials at different temperature and frequency ranges is currently carried out to check wether our observation is 'universal' indeed.
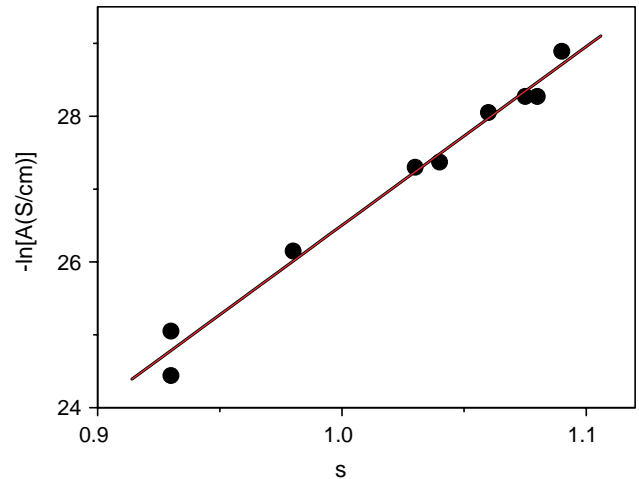
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