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Broadband dielectric spectroscopy from sub-GHz to THz frequency region on hydrated bentonite

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Abstract

Understanding how water molecules interact with one another and with clay under a confined geometry at different temperatures are key information in energy storage applications and nuclear waste disposal. Here we present an investigation of the dielectric response from 100 MHz to 1.8 THz of sodium bentonite at different hydration levels from 233 K to 293 K. Figure 1 shows the complex dielectric spectra of hydrated bentonite. Our previous studies have shown that for hydrated soft matters such as protein [1] and lipid bilayers [2] the dielectric response in the frequency region from sub-GHz to THz are due to the relaxation processes and vibrational processes, which are modeled using a Cole-Cole function and Lorentzian function, respectively, as shown below. The first term is the ion conductivity term, which may be important for conducting materials.

$$\varepsilon^*(\nu) = \frac{\sigma_0}{i2\pi\nu\varepsilon_0} + \sum_{j=1}^n \frac{\Delta\varepsilon_j}{1 + (i2\pi\tau_j)^{\beta_j}} + \sum_{k=1}^m \frac{\Delta\varepsilon_j}{\nu_k^2 - \nu^2 + i\nu\gamma_k} + \varepsilon_\infty$$

We found that two Cole-Cole functions and one Lorentzian function are needed to reproduce both the imaginary and real parts of the complex dielectric spectra at room temperature. There is almost no intensity in the spectra for the dry bentonite ($h=0$) from sub-GHz to sub-THz. However, both the real and imaginary parts of the complex dielectric spectra increased upon hydration. The fast relaxation time at 293 K is close to the bulk water Debye relaxation time of 9.5 ps. This suggests that there are freely moving bulk-like water molecules that may reside outside the interlayer. On the other hand, the major relaxation component has a time constant that is two orders of magnitude slower corresponding to interlayer water. It is suggested that most of the confined water in bentonite is highly restricted in its motion.

Fig. 1: Complex dielectric spectra of hydrated bentonite at 293 K. Here the value of h represents the hydration level; h is the weight of water in gram per one gram of bentonite.

Keywords: broadband dielectric spectra, sodium bentonite, terahertz, confined water

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