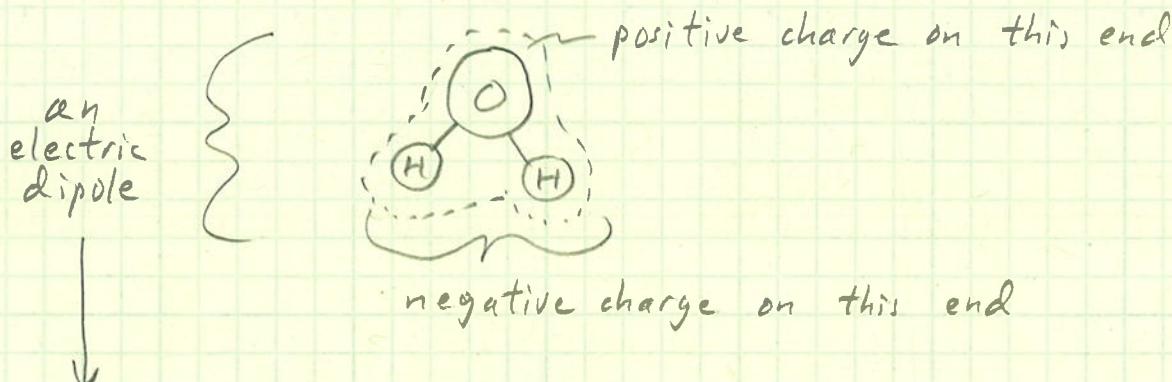


Electromagnetic Properties Sensor : High Frequency Effects

1. Background

a. water is a polar molecule

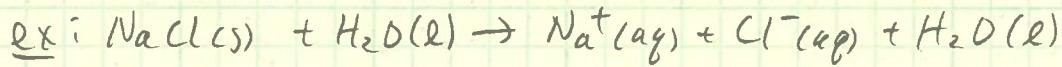


results in dipole-dipole intermolecular forces between molecules

b. Ionic compounds, such as salts

→ readily dissolve in polar liquids, such as water

→ changes the electrical properties of the solution



Na^+ + Cl^- interact with H_2O (dipole) molecules

↳ creates "water shells" or "ionic atmospheres" around the salt ions → process called "self-hydration"

→ Low salt concentration → large diameter water shells

→ high salt concentration → smaller diameter water shells

c. Dipoles and Relaxation

→ Just as SMD systems have a resonant frequency,

dipoles also have an electromechanical resonant frequency

↳ which effects the complex permittivity of the solution

→ called the relaxation or polarization frequency

$$\text{Debye Relaxation: } \hat{\epsilon}(\omega) = \epsilon_{\infty} + \frac{\Delta \epsilon}{1 + j\omega\tau}$$

where: $\epsilon_{\infty} \rightarrow$ permittivity at the high freq. limit

$$\Delta \epsilon = \epsilon_s - \epsilon_{\infty}$$

ϵ_s = static or low frequency permittivity

τ = relaxation time of the material

↳ equivalent to the time constant
in an electrical circuit or a
mechanical system

∴ the circuit element with $\hat{\epsilon}(\omega)$ has a frequency dependent impedance from the material properties

d. Application to salt concentration in water

low salt concentration \rightarrow large water shells \rightarrow relaxation occurs at a lower frequency

high salt concentration \rightarrow small water shells \rightarrow relaxation occurs at a higher frequency

For a conductive salt-water solution:

$$\text{complex permittivity } \epsilon^* = \epsilon_0 \epsilon_r' - j \epsilon_0 \epsilon_r''$$

where ϵ_0 = permittivity of free space

ϵ_r' = real part of the relative permittivity

ϵ_r'' = imaginary part of the relative permittivity
and represents the dielectric losses
(relaxation and conduction) due to
dissipation in the material

$$\text{Also: } \epsilon_r'' = \epsilon_d'' + \frac{\sigma}{\omega \epsilon_0}$$

where ϵ_d'' = relaxation component

σ = electrical conductivity.

Dissolved salts affect ϵ_d'' and σ

$$\therefore \epsilon^* = \epsilon_0 \epsilon_r' - j \epsilon_0 \epsilon_d'' + \frac{\sigma}{j\omega}$$

For an equivalent "pseudo" parallel plate capacitor:

$$C = \frac{A \epsilon^*}{d}$$

$$\therefore \text{Admittance} = j\omega C = Y(j\omega)$$

$$= j\omega \frac{A}{d} \epsilon_0 \epsilon_r' + \omega \frac{A}{d} \epsilon_0 \epsilon_d'' + \frac{A\sigma}{d}$$

$\brace{ \quad }$
affected by salt ion type
and concentration

\therefore sweep the capacitive with a fixed amplitude sinusoid over a wide frequency range and plot $\text{Re}[Y(j\omega)]$ and $\text{Im}[Y(j\omega)]$ vs. frequency

→ from this plot, salt type and concentration can be determined

→ Called "Electrochemical Impedance Spectrometry"