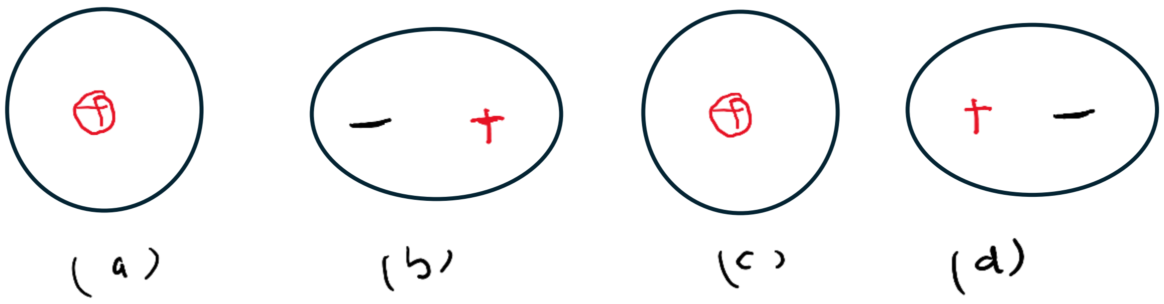
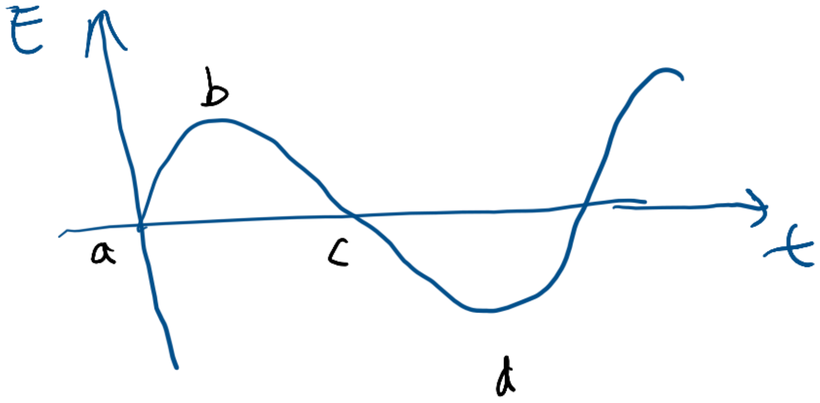
# PYL 102

Saturday, Oct. 19, 2024

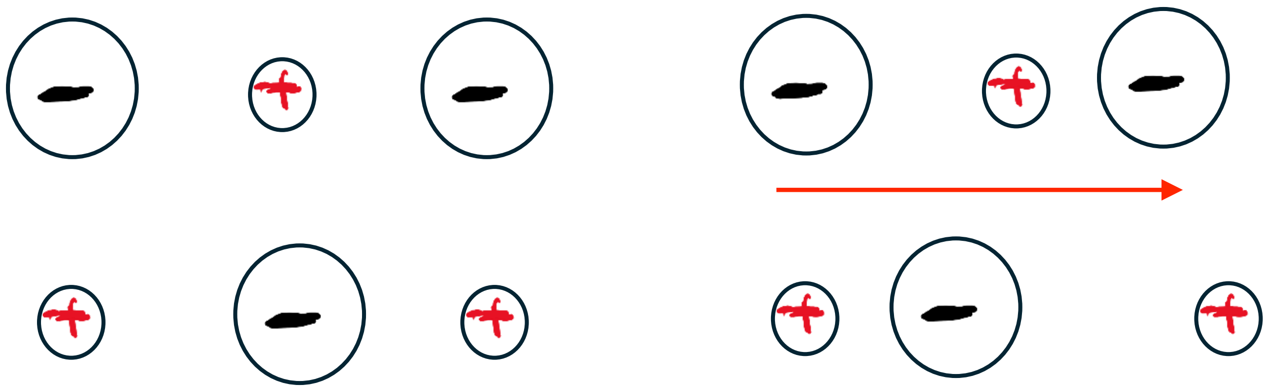
Dielectric Loss

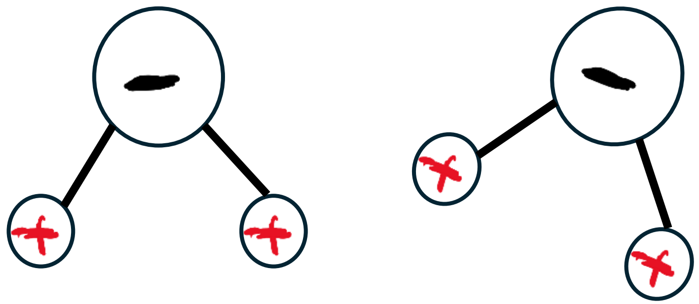
# Dielectric polarization under ac electric field




Under E field (electronic polarization) $p = \alpha_e E$





Under E field (ionic polarization) Under E field (orientational polarization)

The polarization is no longer in phase with the field. Polarization P lags behind E

Why is there phase lag between polarization and ac electric field?
Due to the two factors opposing the immediate alignment of the dipoles with the field i.e. thermal agitation which tries to randomize the dipole orientations and viscous medium by virtue of interaction of molecule with neighbors.

There is a characteristic time involved in each polarization mechanism.

Electronic polarization: optical frequencies (~1012-1015 Hz)
Ionic Polarization: Infrared frequencies (~1010 -1012 Hz)
Orientational polarization: Microwave frequencies (107 -1010 Hz)

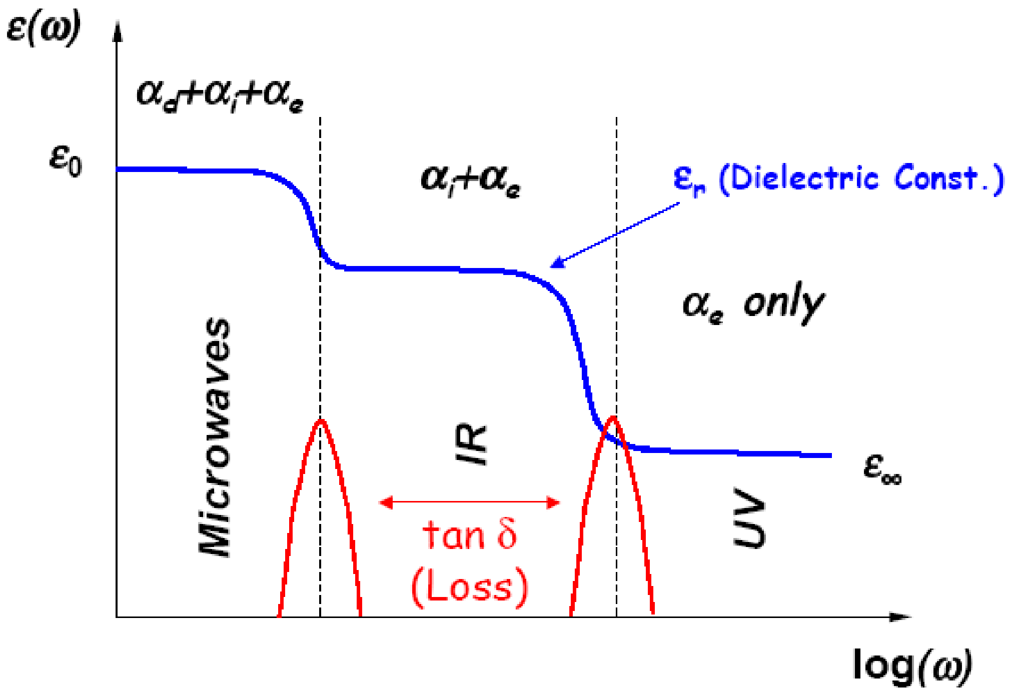
higher. : > 10^17 hz -> no polarization
optical freq. : ~10^12-10^15 Hz -> electronic only
IR freq. : ~10^10-10^12 Hz -> electronic & ionic
Microwave : ~10^7-10^10 Hz -> all 3

Now let us talk about applied electric field frequency. If it's very large (>1017 Hz), material will not polarize. E field changes so fast for material's system to respond. We expect the dielectric constant of the material to attain the same value as for vacuum.

If applied E field has frequency in the range of optical one then ionic and orientational polarizability will be zero and only electronic polarizability will be finite. Because at this range of frequencies only electronic system can respond.

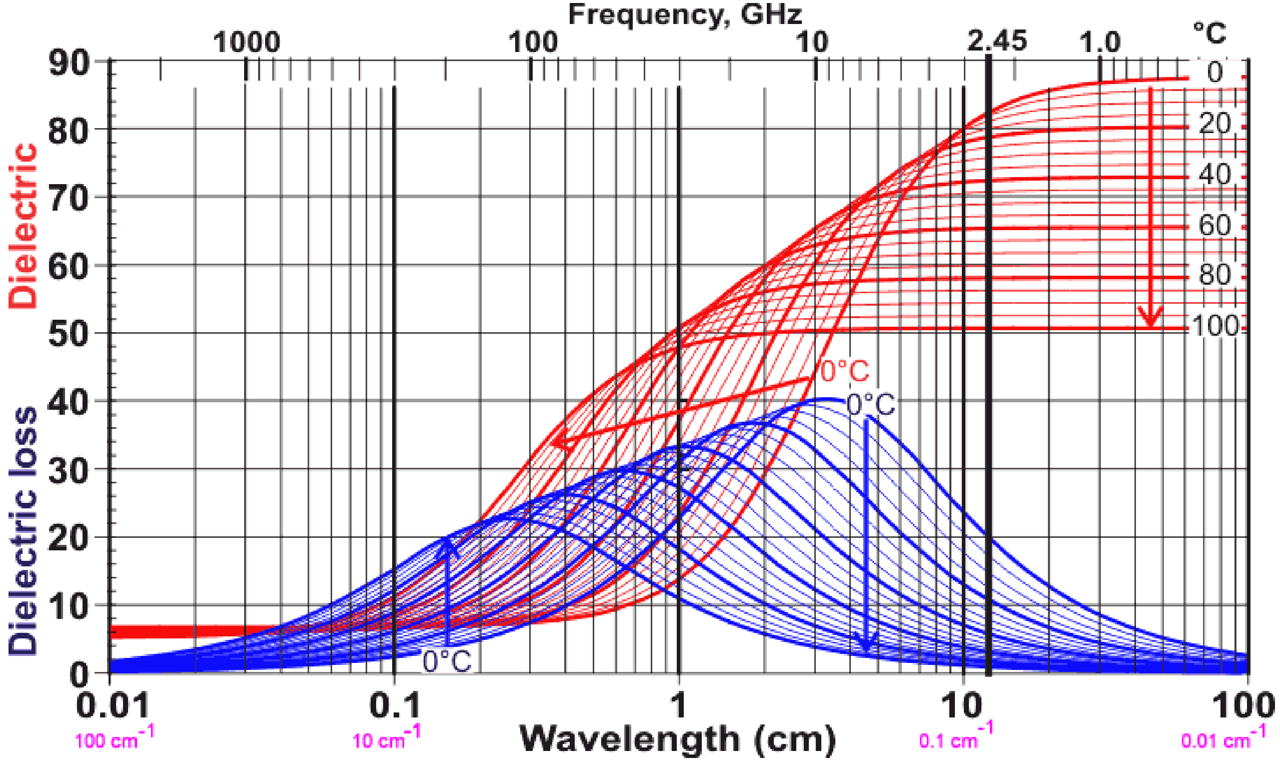
If applied E field has frequency in the range of infrared orientational polarizability will be zero and only ionic and electronic polarizability will be finite.

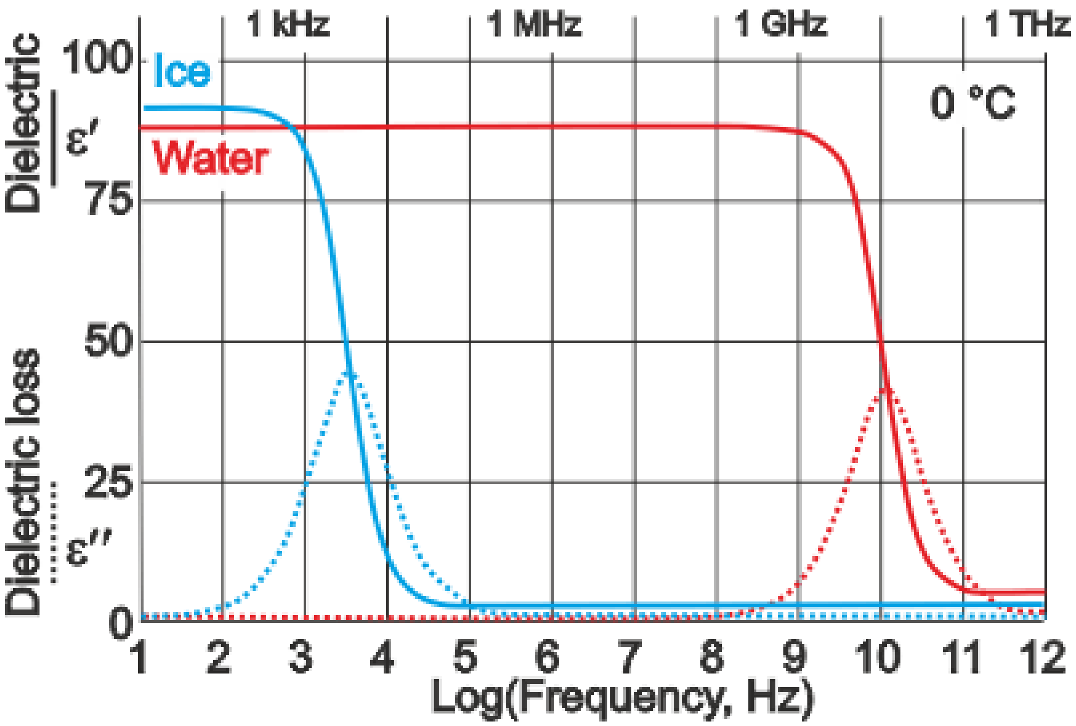
# Frequency Dependence




Source: https://chemistry.osu.edu/~woodward/

The absorption of electrical energy by a dielectric material that is subjected to an alternating electric field is termed *dielectric loss.* This loss may be important at electric field frequencies in the vicinity of the relaxation frequency for each of the operative dipole types for a specific material. A low dielectric loss is desired at the frequency of utilization.




https://water.lsbu.ac.uk/water/microwave_water.html

Dielectric permittivity and dielectric loss of water between 0 °C and 100 °C

Dielectric loss is the mechanism by which microwave ovens heat food. Dielectric heating at high frequencies is used in industrial applications such as heating plastics and drying wood.

A microwave oven generates electromagnetic radiation at about 2.5 GHz. This energy is pretty good at causing H2O molecules to oscillate their orientation (orientational dielectric constant changes greatly). Ice has a low dielectric constant, so not much energy is absorbed by it. Once there is a bit of melted ice, though, then you are really cooking.

# Debye equations

Consider a dipolar dielectric in which there are both orientational and electronic polarizations $\alpha_d$ and $\alpha_e$, respectively contributing to the overall polarizability. Electronic polarization ae will be independent of frequency over the typical frequency range of operation of a dipolar dielectric, well below optical frequencies. At high frequencies, orientational polarization will be too sluggish to respond $\alpha_d = 0$, and $\varepsilon_r = \varepsilon_\infty$

$$\varepsilon_r = 1 + \frac{N_e \alpha_e}{\varepsilon_o} + \frac{N_d \alpha_d}{\varepsilon_o} = \varepsilon_\infty + \frac{N_d \alpha_d}{\varepsilon_o}$$

$$\alpha_d = \frac{\alpha_d(0)}{1 + j\omega\tau}$$

For static field, $\omega$=0

$$\frac{N_d}{\varepsilon_o}\alpha_d(0) = \varepsilon_{rdc} - \varepsilon_\infty$$

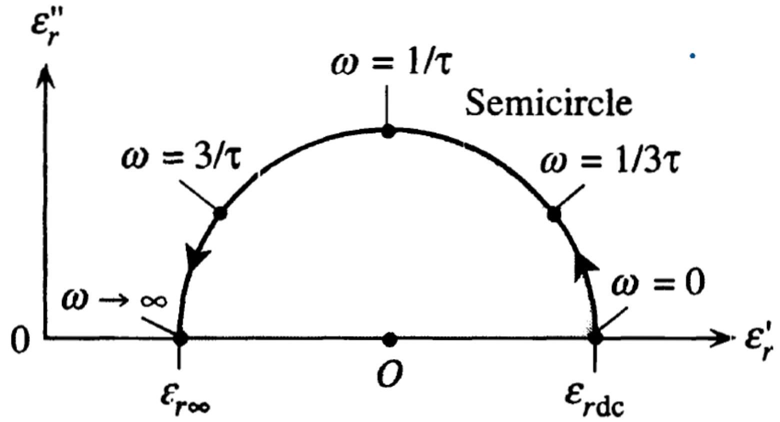
$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$$

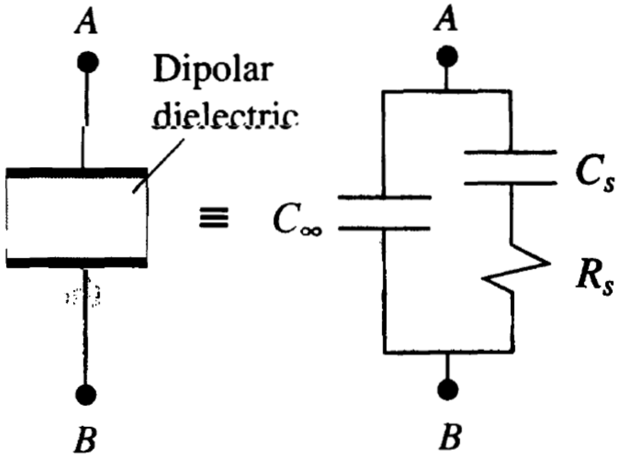
$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' = \varepsilon_\infty + \frac{\varepsilon_{rdc} - \varepsilon_\infty}{1 + j\omega\tau} \Rightarrow$$

$$\boxed{\left.\begin{aligned} \varepsilon_r' &= \varepsilon_\infty + \frac{\varepsilon_{rdc} - \varepsilon_\infty}{1 + \omega^2\tau^2} \\ \varepsilon_r'' &= \frac{(\varepsilon_{rdc} - \varepsilon_\infty)\,\omega\tau}{1 + \omega^2\tau^2} \end{aligned}\right] \text{Debye eqns.}}$$

$$\boxed{\varepsilon_r'' = \frac{\varepsilon_{rdc} - \varepsilon_{\infty}}{1+\omega^2\tau^2}\,\omega\tau}$$

Equations reflect the behavior of $\varepsilon_r''$ as a function of frequency. The imaginary part $\varepsilon_r''$ that represents the dielectric loss exhibits a peak at $\omega = 1 / \tau$ which is called a Debye loss peak. Many dipolar gases and some liquids with dipolar molecules exhibit this type of behavior.




A capacitor with a dielectric and its equivalent circuit

In dielectric studies of materials, it is quite common to find a plot of the imaginary part ($\varepsilon_r''$) versus the real part ($\varepsilon_r'$ ) as a function of frequency $\omega$. Such plots are called Cole-Cole plots.

Piezoelectricity

Certain crystals, for example, quartz (crystalline Si02) and BaTiOs, become polarized when they are mechanically stressed. Charges appear on the surfaces of the crystal, as depicted in Figure 7.38a and b. Appearance of suface charges leads to a voltage difference between the two sufaces of the crystal. The same crystals also exhibit mechanical strain or distortion when they experience an electric field,