Dielectrics Examination questions 2005

<u>SHORT QUESTIONS</u> [4 marks for each correct answer]

a) What is the key structural requirement of a material in order to exhibit the piezoelectric effect? Give a simple illustration of a system which would show this effect.

b) Sketch a plot of polarisation against electric field, labelling key points, for a ferroelectric material below and above the Curie temperature.

<u>LONG QUESTION</u>

Given that the frequency dependent relative permittivity of a material is expressed as $\varepsilon^*(\omega)=\varepsilon'(\omega)-i\varepsilon''(\omega)$ write down an expression for the loss tangent ($\tan\delta$) and briefly explain its significance. [3 marks]

For a particular material, up to angular frequencies $\omega \gg \omega_0$, it is found that

$$\varepsilon^*(\omega)=A+\frac{B}{(\omega_0-\omega)+i\gamma\omega},$$

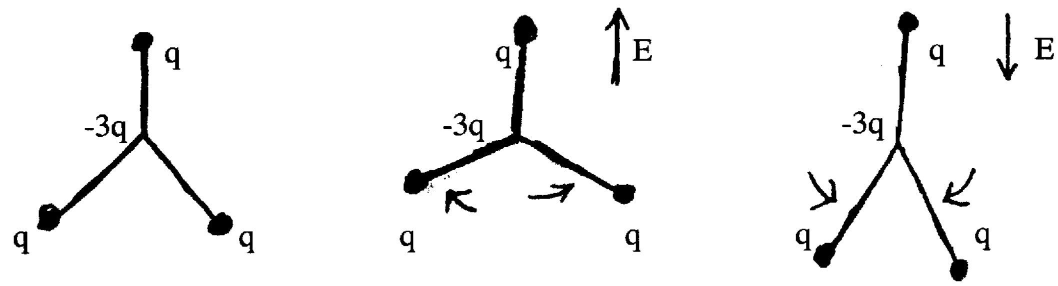
where A, B, ω_0 and γ are positive constants. Sketch the form of the real and imaginary components of $\varepsilon^*(\omega)$ as a function of ω indicating any key values. [9 marks]

If $\omega_0 = 2\times10^{12}\ \mathrm{s}^{-1}$ and $\gamma = 1$ at what frequency is there a maximum in $\varepsilon''(\omega)$? [8 marks]

ANSWERS

SHORT QUESTIONS

a) The key requirement is that the structure must be **non-centrosymmetric,** i.e. not having inversion symmetry. There is no need for a permanent dipole moment. A system built from non-polar "building blocks" such as the molecule below would show the effect.



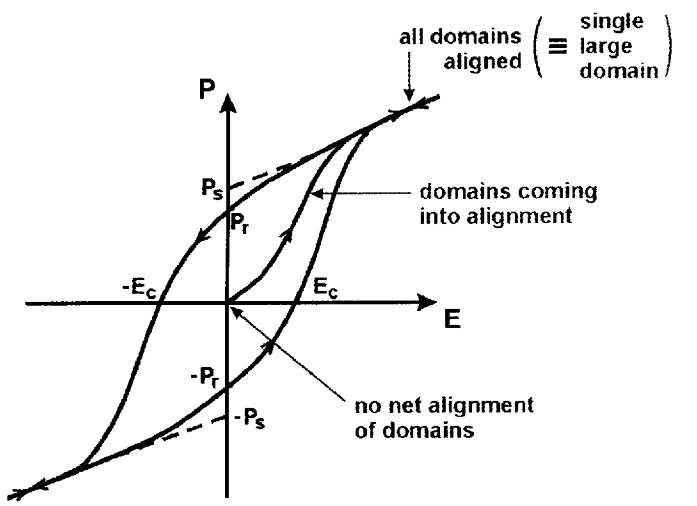
E=0
No dipole moment, p

In compression or with
E-field applied

In tension or with
E-field applied

A dipole moment is induced in direction of E

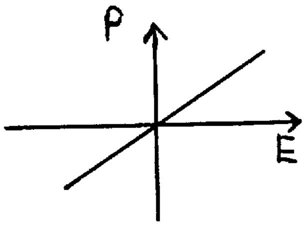
b) Ferroelectric hysteresis diagram



P_s - spontaneous polarisation
P_r - remanent polarisation
E_c - coercive field
(defined as +ve)

The figure on the left shows the situation with T below the Curie temperature. Above the Curie temperature the material reverts to paraelectric form with

$$P = \varepsilon_0 \chi E$$



LONG QUESTION

The definition of the loss tangent is $\tan\delta = \frac{\varepsilon''}{\varepsilon'}$. This is a measure of the energy dissipation (losses) within the material. If $\varepsilon'' = 0$ there will clearly be no losses.

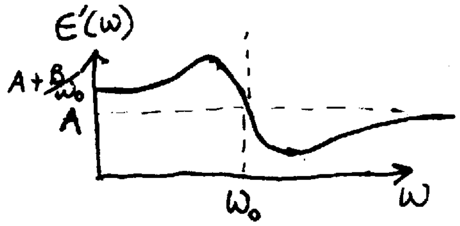
$$\varepsilon^*(\omega) = A + \frac{B}{(\omega_0 - \omega) + i\gamma\omega} = A + \frac{B}{(\omega_0 - \omega) + i\gamma\omega} \times \frac{(\omega_0 - \omega) - i\gamma\omega}{(\omega_0 - \omega) - i\gamma\omega}$$

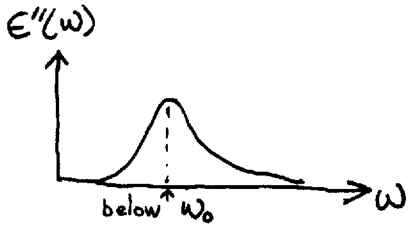
$$= A + \frac{B(\omega_0 - \omega)}{(\omega_0 - \omega)^2 + \gamma^2\omega^2} - i \cdot \frac{B\omega\gamma}{(\omega_0 - \omega)^2 + \gamma^2\omega^2}$$

Thus we have that the real part of $\varepsilon^*(\omega) = \varepsilon'(\omega) = A + \frac{B(\omega_0 - \omega)}{(\omega_0 - \omega)^2 + \gamma^2\omega^2}$ and the imaginary component is $\varepsilon''(\omega) = \frac{B\gamma\omega}{(\omega_0 - \omega)^2 + \gamma^2\omega^2}$.

$\varepsilon'(\omega) = A + \frac{B}{\omega_0}$ when $\omega = 0$, drops to A when $\omega = \omega_0$ and rises up to A again with $\omega \gg \omega_0$.

$\varepsilon''(\omega) \to 0$ at low and high frequencies and has a peak (see later) in between, below ω_0.





$\varepsilon''(\omega)$ peaks when $\frac{d\varepsilon''}{d\omega} = 0 = \frac{B\gamma}{(\omega_0 - \omega)^2 + \gamma^2\omega^2} - \frac{B\gamma\omega\left[-2(\omega_0 - \omega) + 2\gamma^2\omega\right]}{\left[(\omega_0 - \omega)^2 + \gamma^2\omega^2\right]^2}$

$$\Rightarrow 1 = \frac{\omega\left[2\gamma^2\omega - 2(\omega_0 - \omega)\right]}{(\omega_0 - \omega)^2 + \gamma^2\omega^2}$$

$$\Rightarrow \omega_0^2 + \omega^2 - 2\omega_0\omega + \gamma^2\omega^2 = 2\gamma^2\omega^2 - 2\omega\omega_0 + 2\omega^2$$

$$\therefore \omega^2(1 + \gamma^2) = \omega_0^2$$

Thus, $\omega = \omega_0 / \sqrt{2} = 1.414 \times 10^{12}\ \mathrm{s}^{-1}$ at the maximum with $\gamma = 1$.