$$\varepsilon_r = 1 + \frac{\omega_p^2}{\omega^2 - \omega_0^2 + i\gamma\omega} = \frac{\vec{P}}{\vec{D}}$$

lorentz model

$$\underset{?}{\frac{1}{\mu}} \nabla \times \vec{B} = \frac{\partial \vec{D}}{\cancel{p}t} + \vec{J}$$

$$\vec{D} = \vec{D}_0 e^{-i\omega t}$$

$$\vec{J} = \sigma \vec{E}$$

$$\nabla \times \frac{\vec{B}}{\mu} = \frac{\partial}{\partial t} \left\{ \varepsilon_0 \underbrace{\left(1 + \chi - \frac{\sigma}{i\omega\varepsilon_0}\right)}_{\varepsilon_r} \vec{E} \right\}$$

Free electron

$$A = \frac{-eE_0/m}{-\omega^2 - i\gamma\omega} \qquad \text{No } \omega_0$$

$$\vec{J} = -ne(-i\omega) A e^{-i\omega t}$$

$$= i\omega \frac{e^2 n_e / m}{\omega^2 + i\gamma\omega} \vec{E}$$

Drude model

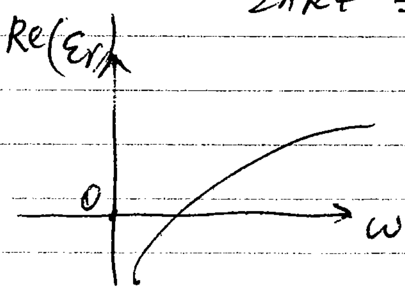
$$\varepsilon_r = 1 - \frac{\omega_p^2}{\omega^2 + i\gamma\omega}$$ due to damping

$$\omega_p^2 = \frac{e^2 n_e}{m \varepsilon_0}$$ — plasma frequency

$$N = n + ik = \sqrt{\varepsilon_r}$$

$$n^2 - k^2 = Re(\varepsilon_r)$$

$$2nk = Im(\varepsilon_r)$$



$\varepsilon_r < 0$

$\omega \uparrow \quad \varepsilon_r \to 1$

$R = 0$

If N is imaginary number

$$R = \left| \frac{N-1}{N+1} \right|^2$$

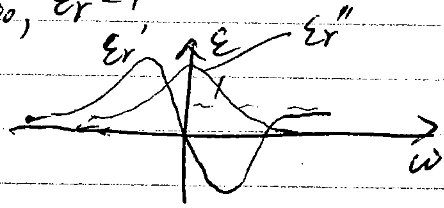
$$= \left| \frac{ai - 1}{ai + 1} \right|^2 = 1$$

for metal

Lorentz model

$\omega \ll \omega_0$, $\varepsilon_r = 1 - \frac{\omega_p^2}{\omega_0^2}$

$\omega \gg \omega_0$, $\varepsilon_r = 1$



Kramer — Krong relation $\varepsilon_r', \varepsilon_r''$

$$\varepsilon_r = 1 + \sum_{j=1}^{N} \frac{\omega_{pj}^2}{\omega^2 - \omega_{0j}^2 + i\gamma_j \omega} - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} = \varepsilon_0 + (\ ) + (\ )$$

?

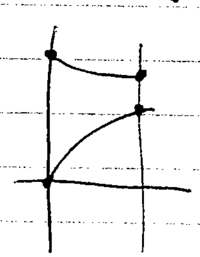
oscillator   free electron

FTIRR

Fourier transform IR

If ω_{01}, ω_{02}, ω_{03} are separated.

Not plasma frequency; $\omega_p = \frac{Ne^2}{\varepsilon_0 m}$ related to N in Lorentz model



$$1 + \frac{\omega_{p1}^2}{\omega^2 - \omega_{01}^2} + \frac{\omega_{p2}^2}{\omega^2 - \omega_{02}^2}$$

$$\parallel$$

$$-\frac{\omega_p^2}{\omega_{01}^2}$$

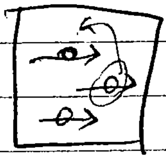
$$\underbrace{\omega \to 0}_{\varepsilon_0 \neq 1}$$

Local field

$$\vec{D} = \varepsilon_0 \vec{E} + \vec{P}$$

$\uparrow$ external

$\vec{E}_{local}$

$\vec{P}$ 

$$\vec{P} \cancel{\propto} \sim \vec{E}_{local}$$

$$\vec{E}_{local} = \vec{E}_{ex} + \vec{E}_{induced}$$

superposition $\quad\uparrow$ other ~~to~~ dipoles

$$\vec{E}_{induce} = \vec{P} / 3\varepsilon_0$$

$\uparrow$ local

$$\vec{E}_{local} = \frac{\varepsilon_0 \varepsilon_r + 2\varepsilon_0}{3\varepsilon_0} \vec{E}_{ex}$$

$\Downarrow$

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{1}{3} \sum_j \frac{\omega_{pj}^2}{\omega^2 - \omega_{0j}^2 + i\gamma_j \omega}$$

Clausius — mosotti relation

Gas properties:

atom $\begin{cases} \text{translation} & kT \sim \hbar\omega_p \\ \text{electronic} & -\dfrac{13.6\,eV}{n^2} \quad (l, m, \underset{\uparrow}{\ }) \end{cases}$ spin

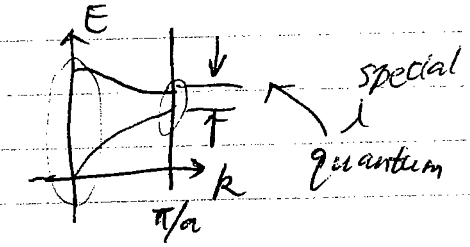
molecules $\begin{cases} \text{vibration} & E_n = \hbar\omega_v (n + \frac{1}{2}), \quad \omega_v = \sqrt{\frac{K}{m}} \\ \text{rotation} & E_l = \frac{\hbar^2}{2I} l(l+1), \quad |m| \le l \end{cases}$

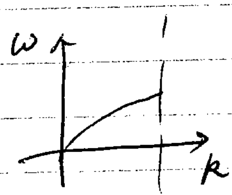
two degrees

two ~~number~~ number

m, l

Solid $\begin{cases} \text{electronic} \\ \text{phonon} \end{cases}$





$p = \frac{h}{\lambda}$

metal, short λ, transparent

x_0

⊕~~⊖

$\vec{E_0 e^{-i\omega t}}$

$$m\frac{d^2x}{dt^2} = -eE - k(x-x_0) - \beta\frac{dx}{dt}$$

ma

sign corrected by itself

$$\Delta x = x - x_0 = Ae^{-i\omega t}$$

substitute

$$\frac{d^2\Delta x}{dt^2} + \gamma\frac{d\Delta x}{dt} + \omega_0^2\Delta x = -\frac{eE_0}{m}e^{-i\omega t}$$

$$A = \frac{-eE_0/m}{-\omega^2+\omega_0^2-i\gamma\omega}$$

$$\vec D = \varepsilon_0\vec E + \vec P = \varepsilon_0\underbrace{(1+\chi)}_{\varepsilon_r}\vec E$$

$$\vec P = e(x-x_0)N = \frac{e^2N/m}{\omega^2-\omega_0^2+i\gamma\omega}\vec E = \varepsilon_0\chi\vec E$$