\[ \nabla \times \mathbf{H} = \mathbf{J} + (\frac{\partial \mathbf{D}}{\partial t}) , \quad \mathbf{J} = J_{\text{imp}} + \sigma \mathbf{E} \]

\[ \nabla \times \mathbf{E} = \varepsilon_0 \frac{\partial \mathbf{D}}{\partial t} , \quad \nabla \times \mathbf{E} = -\mu_0 \frac{\partial \mathbf{H}}{\partial t} \]

Electrons and Positrons:
- Electron
- Positron
\[ \nabla \times \vec{H} = \frac{\partial \vec{E}}{\partial t} + \frac{\partial \vec{B}}{\partial t} = \frac{\partial \vec{D}}{\partial t}, \quad \vec{D} = \varepsilon_0 \vec{E} + \vec{P} \]

\[ \vec{P} = \chi \varepsilon_0 \vec{E} \]

\[ \vec{D} = \frac{\varepsilon_0 (1 + \chi)}{\varepsilon_0 + \chi} \vec{E} = \varepsilon \vec{E}, \quad \vec{D} = \vec{E} \cdot \vec{E} \]

**Freq Domain**

\[ e^{-i \omega t} \]

\[ \nabla \times \vec{H} = -i \omega \vec{D} = -i \omega \varepsilon \vec{E} \]

\[ \nabla \times \vec{E} = i \omega \vec{B} = i \omega \mu \vec{H} \]

\[ E, \vec{H}, \vec{D}, \vec{B} \sim e^{ik \cdot r} \]

\[ \vec{k} = \hat{x} k_x + \hat{y} k_y + \hat{z} k_z \]

\[ \vec{r} = x \hat{x} + y \hat{y} + z \hat{z} \]

\[ \vec{E} \cdot \vec{r} = k_x x + k_y y + k_z z \]

\[ e^{i \vec{k} \cdot \vec{r}} = e^{ik_x x + ik_y y + ik_z z} \]

\[ e = e \]

\[ e = e \]
\[ \nabla = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \Rightarrow \hat{x} ik_x + \hat{y} ik_y + \hat{z} ik_z = i \k \]

\[ \nabla \Rightarrow i \k \]

\[ \k \times (i \k \times \hat{t}) = -i \omega \in \tilde{E} \Rightarrow i \k \times \k \times \hat{t} = -i \omega \in \k \times \tilde{E} \]

\[ i \k \times \tilde{E} = i \omega \mu \hat{t} \]

\[ \k \times (\k \times \hat{t}) + \omega^2 \mu \in \tilde{t} = 0 \]

\[ 0 = \k \cdot \tilde{E} \cdot \tilde{t} - k \cdot \k \cdot \tilde{t} + \omega^2 \mu \cdot \tilde{t} = 0 \]

\[ \tilde{A} \times (\tilde{B} \times \tilde{c}) = \tilde{B} (\tilde{A} \cdot \tilde{c}) - \tilde{C} (\tilde{A} \cdot \tilde{B}) \]

\[ \k \cdot \hat{t} = 0, \quad \nabla \cdot \k = 0 \Rightarrow \nabla \cdot \mu \hat{t} = 0 \Rightarrow \nabla \cdot \hat{t} = 0 \Rightarrow i \k \cdot \hat{t} = 0 \]

\[ k^2 = k \cdot k = k_x^2 + k_y^2 + k_z^2 \Rightarrow [-k^2 + \omega^2 \mu \epsilon \cdot \k] \cdot \hat{t} = 0 \]

\[ k^2 = \omega^2 \mu \epsilon, \quad k_x^2 + k_y^2 + k_z^2 = \omega^2 \mu \epsilon \quad \text{Relation,} \]

\[ k = \omega \sqrt{\mu \epsilon} \]
\[ e^{i\mathbf{k} \cdot \mathbf{r}}, \quad \mathbf{E} = \mathbf{E}_0 \ e^{i\mathbf{k} \cdot \mathbf{r}}, \quad \mathbf{H} = \mathbf{H}_0 \ e^{i\mathbf{k} \cdot \mathbf{r}}, \quad \mathbf{\hat{z}}, \ \mathbf{\hat{y}}, \ \mathbf{\hat{z}} \]

\[ \mathbf{k} \times \mathbf{E} = \omega \mathbf{\mu} \mathbf{l}, \quad \mathbf{k} \cdot \mathbf{H} = 0 \]

\[ \mathbf{k} \times \mathbf{H} = -\omega \mathbf{\varepsilon} \mathbf{E}, \quad \mathbf{k} \cdot \mathbf{E} = 0 \]

plane wave

\[ \mathbf{e}^{i\mathbf{k} \cdot \mathbf{r}} \]

\[ \mathbf{e} = \mathbf{e}^{i(k_x x - \omega t)} \]

\[ \mathbf{e} = \mathbf{e}^{i(k_x x - \omega t)} \]

\[ c = \frac{1}{\sqrt{\mu \varepsilon}} \]

\[ \mathbf{f} = \mathbf{f}(\sqrt{\mu \varepsilon} x - t) \]
\[ k_x^2 + k_y^2 + k_z^2 = \omega^2 \mu \]

\[ \nabla \times \mathbf{H} = -i \omega \varepsilon \mathbf{E} + \mathbf{J} \]

\[ = -i \omega \varepsilon \mathbf{E} + \sigma \mathbf{E} \]

\[ = -i \omega \left( \varepsilon + \frac{\sigma}{\omega} \right) \mathbf{E} = -i \omega \varepsilon \mathbf{E} \]

\[ \varepsilon \rightarrow \left[ \varepsilon + \frac{\sigma}{\omega} \right] = \varepsilon', \quad \mathbf{E} \cdot \mathbf{J} = \sigma |\mathbf{E}|^2 \]

\[ \nabla \times \mathbf{H} = -i \omega (\varepsilon_0 \mathbf{E} + \mathbf{P}) , \quad \mathbf{P} = \varepsilon_0 \chi \mathbf{E} \]

\[ = -i \omega \varepsilon_0 (1 + \chi) \mathbf{E} = -i \omega \varepsilon \mathbf{E} , \quad \varepsilon = \varepsilon_0 (1 + \chi) \]

\[ \mathbf{E} \]

\[ \varepsilon_0 \quad \varepsilon_0 \]

\[ \frac{\varepsilon_0}{\varepsilon_0} \]

\[ \frac{\varepsilon_0}{\varepsilon_0} \]

\[ \sigma \varepsilon \mathbf{E} \]

\[ \mathbf{J} = \sigma \mathbf{E} \]
Diatomic case

\[ \frac{m_r}{m_r} \Rightarrow \frac{1}{m_r} \Rightarrow \frac{1}{m_r} = \frac{1}{m_e} + \frac{1}{M} \]

\[ m_r \approx m_e = m_0 \]

\[ \frac{d^2 x}{dt^2} + \frac{m_0}{m} \frac{d x}{dt} + k x = -q E \] \[ \text{spring constant, } E \approx E_0 e^{-i \omega t} \]

\[ -m_0 \omega^2 x - i \omega m_0 x + k x = -q E \]

\[ P = -i \lambda = \frac{q^2 E}{m_0 (-\omega^2 - i \gamma \omega + \omega_0)} \]

\[ P = N P = \frac{N E}{m_0 (-\omega^2 - i \gamma \omega + \omega_0)} \]

\[ \tilde{P} = \varepsilon_0 \chi \tilde{E} \] \[ \chi(\omega) \]