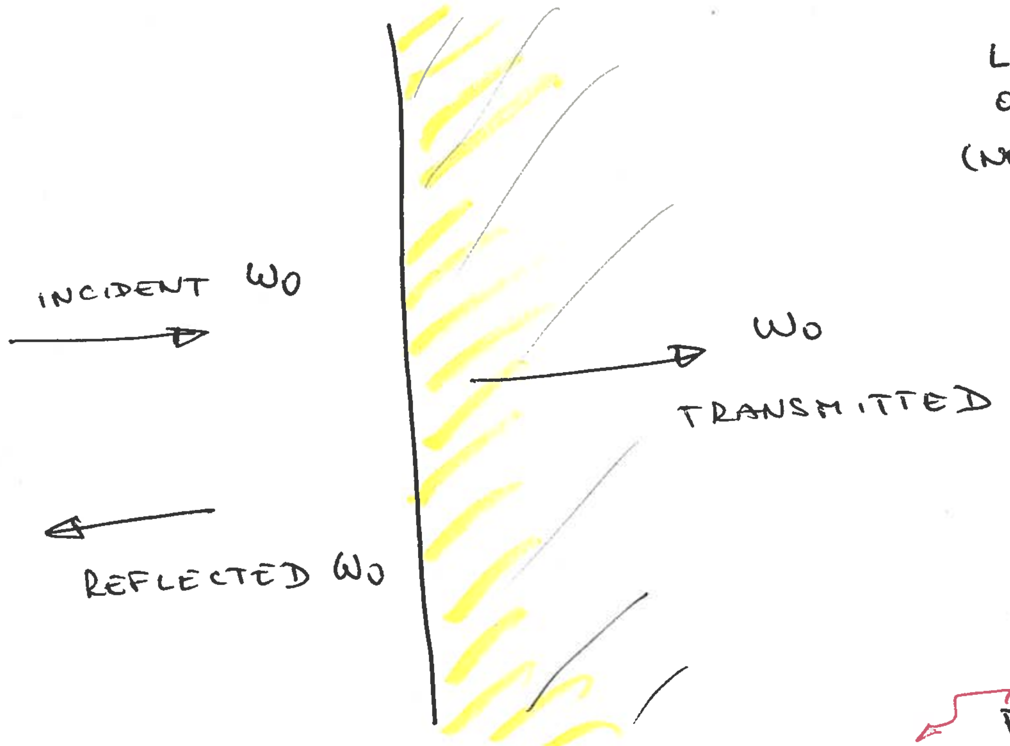
Optical Processes in Solids



LINEAR OPTICS
(NO CHANGE IN FREQUENCY

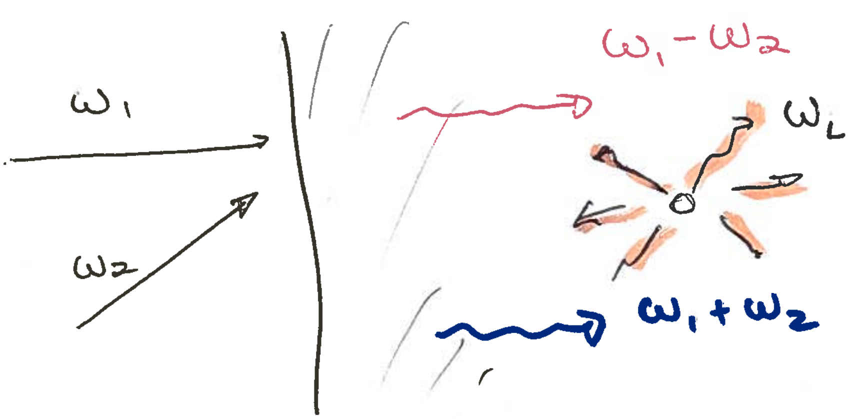
DESCRIBED BY ϵ_{ij} & μ_{ij} PERMEABILITY

TENSORS

PERMITTIVITY
(DIELECTRIC CONSTANT)

.... MORE ON THAT LATTER

OTHER PROCESSES



NONLINEAR OPTICS

HIGHER ORDER SUSCEPTIBILITIES

OR

LUMINESCENCE

ω_L UNRELATED TO EXCITING LIGHT FREQ.

SCATTERING

— WHAT IS THIS COURSE ABOUT?

- WE WILL COVER MAJOR OPTICAL EFFECTS & THEIR RELATIONSHIP TO PROPERTIES (ELEMENTARY EXCITATIONS) OF SOLIDS

BROAD FIELD — FOCUS ON BULK — EXCEPT FOR TOPIC #9 (SEMICONDUCTOR STRUCTURES)

- BOOK'S LEVEL < COURSE LEVEL BUT USEFUL AS A GUIDE & INTRO TO BASIC CONCEPTS

  WHEN DISCUSSION EXCEEDS BOOK'S LEVEL, REFS. WILL BE GIVEN.

- REQS: SOLID STATE PHYSICS UG COURSE + QM. EM @ GRIFFITH LEVEL IS USEFUL

  PERTURBATION THEORY (TIME-DEPENDENT)

HOMEWORK + TERM PAPER (GRADING)

NO EXAM

PASS | FAIL

CONSIDER A MEDIUM FOR WHICH
$\rho(\vec{r})$ IS SUCH THAT

$\int \rho(\vec{r})\, e^{i\vec{k}\cdot\vec{r}}\, d^3r$ IS SMOOTH AT LONG WAVELENGTHS

$\Rightarrow$ MEDIUM CAN BE DESCRIBED BY
$\underbrace{\epsilon_{ij} \;\&\; \mu_{ij}}$ MACROSCOPIC PARAMETERS

SIMILAR TO HYDRODINAMICS
(PRESSURE, DENSITY, VISCOSITY...)
ELASTICITY (BULK, SHEAR, ... MODULI, STRESS)
COARSE GRAINING

NECESSARY BUT NOT SUFFICIENT

GASES SUCH AS AIR
SATISFY $\lambda \gg \langle d \rangle$

TYPICAL DENSITIES $\sim 1\text{-}3 \times 10^{19}\ cm^{-3}$
$d \sim 30\text{-}100\ \text{Å}$

OPTICALLY HOMOGENEOUS MEDIA CAN'T SCATTER?

PROBLEM IS SCATTERING
CONDITION THAT MATTERS IS

MANDELSTAM VS RAYLEIGH

$\lambda \gg l_{\text{MEAN FREE PATH}}$

AIR: $\left\{ \begin{array}{l} l \cong 50\,\mu m \quad H > 15\,km \quad d \approx 60\ \text{Å} \\ \text{INCOHERENT EVENTS DOMINATE} \end{array} \right.$

IN SOLIDS

$$\lambda \gg d \quad (3\text{-}5\,\text{Å})$$

AND SCATTERING IS COMPLETELY NEGLIGIBLE
(ELASTIC OR INELASTIC)

SCATTERING IS INTIMATELY ASSOCIATED WITH SPATIAL FLUCTUATIONS
TIME

ROUGH SFCES. SCATTER

MAXWELL EQUATIONS (ISOTROPIC MEDIA)

$$\begin{cases} \vec{D} = \vec{E} + 4\pi\vec{P} = \epsilon\vec{E} \\ \vec{P} = \chi_E \vec{E} \end{cases}$$

PERMITTIVITY

SI UNITS

SUSCEPTIBILITY

NO EXTERNAL SOURCES

$$\epsilon = 1 + 4\pi\chi_E$$

$$\begin{cases} \vec{B} = \vec{H} + 4\pi\vec{M} = \mu\vec{H} \\ \vec{M} = \chi_M \vec{H} \end{cases}$$

PERMEABILITY

ϵ, μ FUNCTIONS OF FREQUENCY

IN THIS COURSE, ONE OF THE MAIN GOALS IS TO UNDERSTAND THIS DEPENDENCE

BASIS FOR LINEAR OPTICS ALTHOUGH IT DOESN'T COVER ALL OF IT

IMPORTANT EFFECTS THAT WILL NOT BE COVERED:

- OPTICAL ACTIVITY

$$\epsilon \approx \epsilon_0 + \frac{\partial \epsilon}{\partial k} k$$

DIFFERENT REFRACTIVE INDICES FOR LEFT OR RIGHT CIRCULARLY POLARIZED LIGHT

- MORPHIC EFFECTS

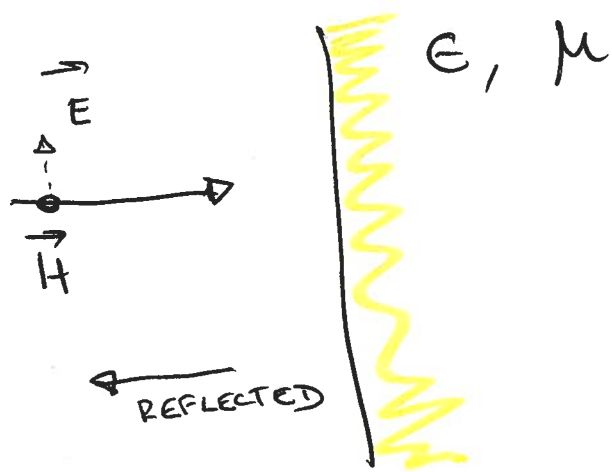
$$\frac{\partial \epsilon}{\partial B_0} \text{ (STATIC)}$$ (FARADAY EFFECT)

$$\frac{\partial \epsilon}{\partial \xi_0} \text{ (STATIC)}$$ (POCKELS EFFECT)

⋮

SINGLE INTERFACE

NORMAL INCIDENCE
PLANE WAVE



BOUNDARY CONDITIONS:

E_t & H_t

D_n & B_n

ARE CONTINUOUS

MAXWELL'S EQS. (NO EXT. SOURCES)

$$\vec{\nabla}\times\vec{H} = \frac{1}{c}\frac{\partial\vec{D}}{\partial t}$$

$$\vec{\nabla}\times\vec{E} = -\frac{1}{c}\frac{\partial\vec{B}}{\partial t}$$

CONTINUITY OF TANG. COMPONENT OF $\vec{H}$ & $\vec{E}$

$$\vec{\nabla}\cdot\vec{D} = 0$$

$$\vec{\nabla}\cdot\vec{B} = 0$$

CONTINUITY OF NORMAL COMPONENT OF $\vec{D}$ & $\vec{B}$

$$\vec{D} = \epsilon\vec{E} \quad \& \quad \vec{B} = \mu\vec{H}$$

CONSTITUTIVE RELATIONS

FOR FIELDS VARYING $\sim e^{-i\omega t}$

$$\vec{\nabla}\times\vec{H} = -\frac{i\omega\epsilon}{c}\vec{E}$$

$$\vec{\nabla}\cdot\vec{E} = \vec{\nabla}\cdot\vec{B} = 0$$

$$\vec{\nabla}\times\vec{E} = \frac{i\omega\mu}{c}\vec{H}$$

INSIDE A MEDIUM

SMALL NOTE

USUALLY, WE HAVE

$$\vec{\nabla}\times\vec{H} = \underbrace{\frac{4\pi}{c}\vec{J}}_{\text{"CURRENT"}} + \underbrace{\frac{1}{c}\frac{\partial\vec{D}}{\partial t}}_{\text{DISPLACEMENT CURRENT}}$$

COMPARE WITH

$$\vec{\nabla}\times\vec{H} = -\frac{i\omega\epsilon}{c}\vec{E}$$

$$\vec{J} = \frac{\partial \vec{P}}{\partial t}$$

"$\vec{J}$" RELATED TO IMAGINARY PART OF ϵ (CONDUCTIVITY)

CONTINUE

ASSUME THAT FIELDS VARY AS

$$\sim e^{i\vec{k}\cdot\vec{r}}$$ (PLANE WAVE)

$$i\vec{k}\times\vec{H} = -\frac{i\omega\epsilon}{c}\vec{E}$$

$$i\vec{k}\times\vec{E} = \frac{i\omega\mu}{c}\vec{H}$$

IF $\vec{k}\perp\vec{E}$

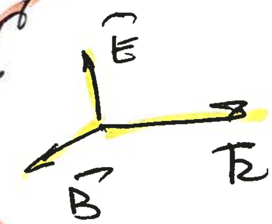
$\vec{k}\perp\vec{B}$

$\Rightarrow \vec{\nabla}\cdot\left\{\begin{matrix}\vec{E}\\ \vec{B}\end{matrix}\right\} =$

$$\cancel{i}kH = +\frac{\cancel{i}\omega\epsilon}{c}E$$

$$\cancel{i}kE = \frac{\cancel{i}\omega\mu}{c}H$$

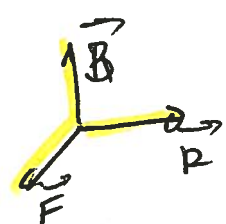
$$\boxed{k^2 = \frac{\omega^2}{c^2}\mu\epsilon}$$



"RIGHT HANDED"

$n>0$

$\epsilon,\mu>0$



$\epsilon,\mu<0$

$n<0$

$$N^2 = \mu \epsilon$$

ON THE OTHER HAND, THE REFLECTION COEFFICIENT IS

$$r = \frac{z-1}{z+1} \qquad \underbrace{Z}_{\text{IMPEDANCE}} = \sqrt{\frac{\mu}{\epsilon}}$$

AMPLITUDE OF REFLECTED BEAM

$$\equiv \frac{1}{Y} \text{ (ADMITTANCE}$$

$R \equiv |r|^2$ IS REFLECTIVITY COEFF. REFLECTANCE ...

IN MOST CASES, AT HIGH FREQS. $\mu \approx 1$

THEN

$$N^2 = \epsilon$$

$$r = \frac{1 - \sqrt{\epsilon}}{1 + \sqrt{\epsilon}}$$

$\epsilon = \epsilon_1 + i\epsilon_2$

$$\Rightarrow R = \frac{(n-1)^2 + K^2}{(n+1)^2 + K^2}$$

$N = n + iK$

n → REFRACTIVE INDEX

K → EXTINCTION COEFFICIENT

$$\sigma = -\frac{i\omega}{4\pi}(\epsilon - 1)$$

σ → CONDUCTIVITY

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

FOR $\omega \to 0$

$\sigma \to 0$ DIELECTRICS

$\sigma \to \sigma_0$ METALS

SINCE $k = \frac{\omega}{c}(n + i\kappa)$

$$E, H \propto e^{i\left[\frac{\omega}{c}(n+i\kappa)z\right]}$$

IT DECAYS LIKE

$e^{-z/\delta}$ BEER'S LAW

SKIN DEPTH $\delta = \frac{c}{\omega\kappa} = \frac{\lambda_0}{2\pi\kappa}$

ABSORPTION COEFFICIENT $\alpha \equiv \frac{1}{\delta}$

ALSO IMPORTANT

$$R = |r|^2 = \frac{(n-1)^2 + \kappa^2}{(n+1)^2 + \kappa^2}$$

LARGE REFLECTIVITY IMPLIES THAT EITHER $n \cong 0$

OR $\left\{\begin{array}{l} \kappa \gg 1 \\ n \gg 1 \end{array}\right.$

GOOD METALS HAVE $\epsilon_1 < 0$

$\epsilon_2 \ll \epsilon_1$

$\Longrightarrow n \approx 0$

HIGHLY ABSORBING SUBSTANCES HAVE $\kappa \gg 1$