ELEC 315

Work Function

$E_{photon} = kE + \Theta$

$h\nu = kE + \Theta$

$h\nu = \Theta + (\text{Applied Voltage})$

where:
$h = 6.626E{-}18\,J$
ν = frequency

photon equation

$\lambda\nu = c \rightarrow \nu = \frac{c}{\lambda}$

Electron Volts

$1eV = e$ (Fundamental charge)

$1eV = 1.602E{-}19\,J$

Energy of a Confined electron

$$E(n_x, n_y, n_z) = \frac{h^2 n_x^2}{8mL_x^2} + \frac{h^2 n_y^2}{8mL_y^2} + \frac{h^2 n_z^2}{8mL_z^2}$$

Momentum

Classical:

$kE = \frac{p^2}{2m}$

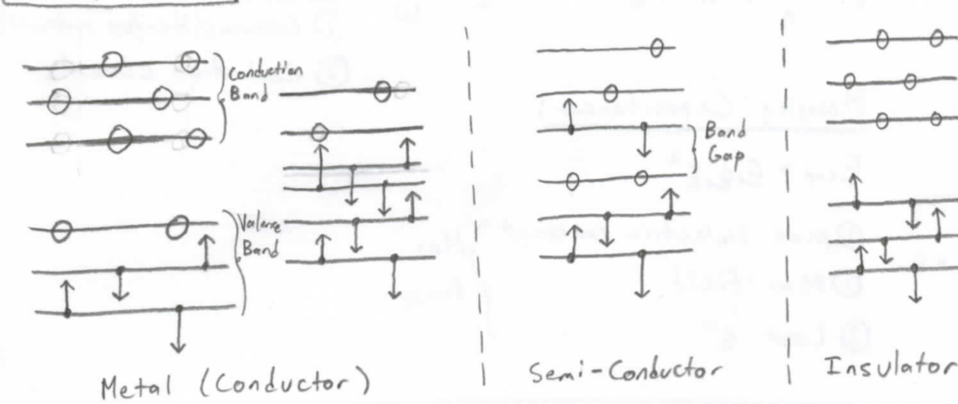
Quantum (Broglie):

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

$\downarrow$

$kE = \frac{h^2}{2m\lambda^2}$

Energy Bands



Counting Electrons

Intrinsic:

$n_i = p_i \rightarrow \boxed{n_i^2 = n_o p_o}$

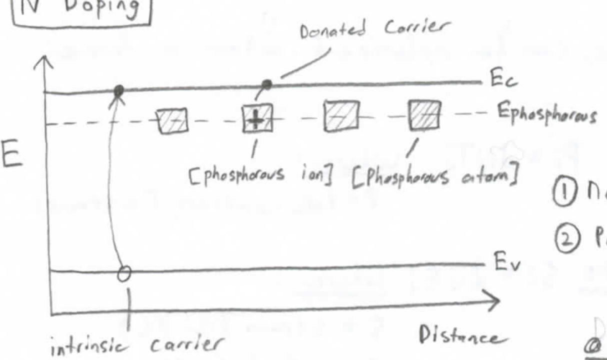
Density of States $\rightarrow g(E)$

Occupancy Probability $\rightarrow f(E)$

$$n_o = \int_{E_c}^{\infty} g(E) f(E)\, dE$$

*Assuming no Simplifications

N Doping



① $n_o > n_i$

② $p_o < p_i$

Counting Holes

$$p_o = \int_{-\infty}^{E_v} g(E)[1 - f(E)]\, dE$$

Dynamic Equilibrium

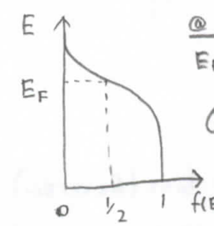
Generation = Recombination

@ Room Temperature:

$n_o = N_D$

$p_o = N_A$

Fermi Level



@ Intrinsic:

$E_F \rightarrow f(E) = \frac{1}{2}$

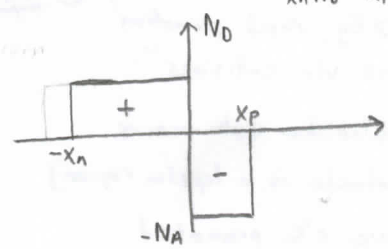
① P-Doping → Pushes E_F down

② N-Doping → Raises E_F UP

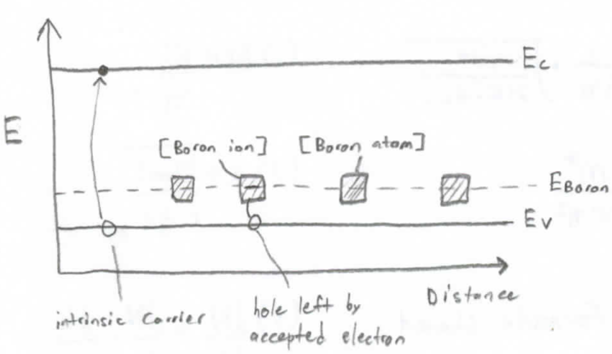
Depletion Region

Charge Balance:

$x_n N_D = x_p N_A$



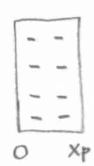
P Doping



① $n_o < n_i$

② $p_o > p_i$

Deriving Parabolic depletion Region Shape



Poisson's Eqn:

$\nabla^2 V = \frac{-\rho_{free}}{\varepsilon_o \varepsilon_r}$

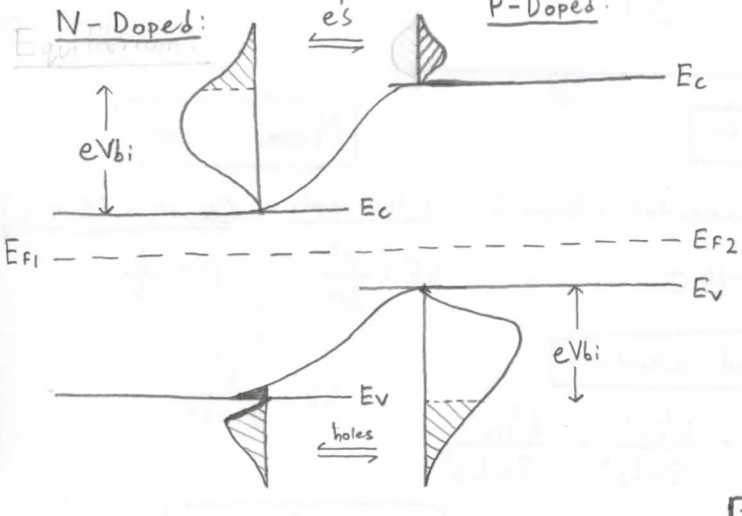
① $\frac{-\rho_{free}}{\varepsilon_o \varepsilon_r} = \frac{eN_A^-}{\varepsilon_r \varepsilon_o} = \frac{d^2V}{dx^2}$

② $V(x) = \frac{eN_A^-}{2\varepsilon_r \varepsilon_o} x^2$

③ $\Delta E = -eV(x)$

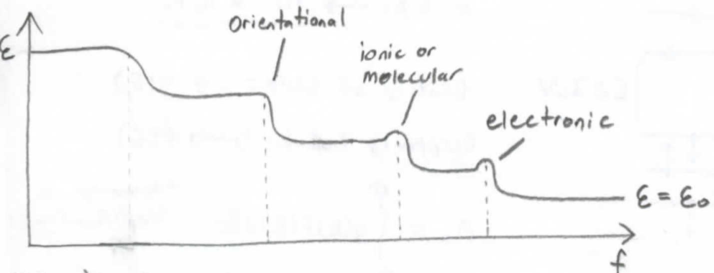
$\therefore \Delta E = \frac{-e^2 N_A^-}{2\varepsilon_r \varepsilon_o} x^2$

PN Junctions



@ Equilibrium

Dielectric Frequency Dependance



"Can't focus x-rays because the field oscillates too fast for the electrons to keep up"

Breakdown

1. <u>Zener</u>: "Extreme bias (Reverse) so that e's in valence band (P side) tunnel through depletion region into conduction band (N side)"
2. <u>Avalanche</u>: "$q(V_{bi} - V_A) >> E_g$, rapid promotion of valence band electrons via collisions"
3. <u>Intrinsic</u>: "Same as Avalanche but occurs across the dielectric" [Avalanche is in depletion region]
4. <u>Thermal</u>: "Heating → more e's promoted → collisions → more e's promoted loop"
5. <u>Discharge</u>: "Applied field ionizes gas pores"

Polarization

$\varepsilon_r = 1 + \chi$

$$\vec{P} = \chi \varepsilon_0 \vec{E}$$

χ — electric susceptibility

1. <u>Ionic Polarization</u>: "Based on the configuration of the material" [Not present in pure Diamond/silicon]
2. <u>Electronic Polarization</u>: "Induced by applied field" [Present in all materials]

Surface Charge density

$$\sigma_{bound} = \vec{P} \cdot \hat{n} \propto P \text{ (for capacitor)}$$

Index of refraction

$v = \frac{c}{n}, \quad n = \sqrt{\varepsilon'}$

Dielectric loss

$\varepsilon_r = \varepsilon' + j\varepsilon''$

$\varepsilon'' = \frac{\sigma}{\omega}$

<u>Causes</u>:
1. Collisions (Heating material)
2. Conduction Currents

<u>Managing Capacitance</u>:

$E_{cap} = \varepsilon_r \varepsilon_0 E^2$

$\left.\begin{array}{l} \text{① max dielectric constant} \\ \text{② Max field} \\ \text{③ Low } \varepsilon'' \end{array}\right\}$ Max Energy

Piezoelectrics and Ferroelectrics

"Non-Centrosymmetric, can be polarized when a force is applied"

1. <u>Direct effect</u>: $P_i = d_{ij} T_j$ <u>where</u>: P = Polarization, T = stress
2. <u>Indirect effect</u>: $S_i = d_{ij} E_j$ <u>where</u>: S = Strain ($\Delta L / L$), E = applied field

Density of States Derivation

$\boxed{1D}$ $g(E) = \frac{1}{\hbar \pi} \cdot \sqrt{\frac{m^*}{2(E - E_c)}}$

$\boxed{2D}$ $g(E) = \frac{m^*}{\pi \hbar^2}$

$\boxed{3D}$ Given → Formula sheet

(1) $N = \frac{kL}{\pi}$

(2) $k = \sqrt{\frac{2mE}{\hbar^2}}$

(3) $\frac{dN}{dE} = \frac{dN}{dk} \cdot \frac{dk}{dE}$

Magnetic Field

① Time-varying E field } Can
② Moving charge } Generate

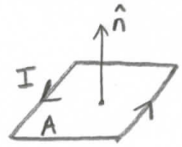
Materials

① **Diamagnetic**: "Applied field causes induced field in opposite direction. Weak, not related to spin"

② **Paramagnetic**: "Applied field causes spins to align equalling stronger field"

③ **Ferromagnets**: "Inherent spin alignment"

Magnetic Moment



$\vec{m} = IA\hat{n}$

$\vec{\Upsilon} = \vec{m} \times \vec{B}$

Magnetization $\vec{M}$

"Polarization for magnetic materials"

Surface Currents:

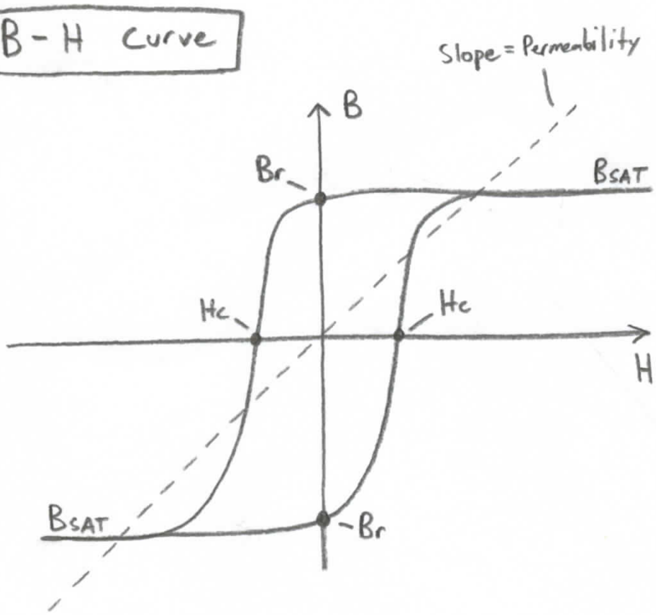
"Caused by alignment of magnetic dipoles"

$\vec{K} = M \times \hat{n}$ where:

K = current per unit length

M = magnetization

B - H Curve



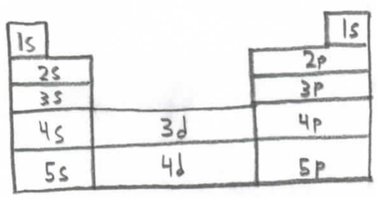
① B_{SAT}: "Spins are aligned as much as they can be, max $\vec{B}$ field possible without increasing external field"

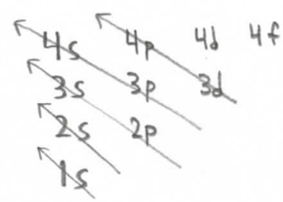
② B_r: "Remanence, The field that remains when the external field = 0"

③ H_c: "Coercive field, external field needed to bring $B = 0$"

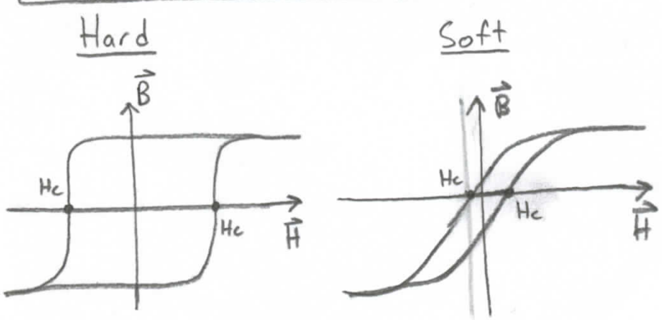
④ **Permeability**: "$B = \mu H$, $B = \mu_0 \mu_r H$"

Filling Orbitals





Hard Vs. Soft Materials



① **Hard Material**: "large H_c, hard to de-magnetize"

② **Soft Material**: "Small H_c, easy to de-magnetize"

Capacitor Model

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

$\varepsilon' =$ Storage

$\varepsilon'' =$ loss