ELEC 315

Work Function

$E_{photon} = KE + \theta$

$h\nu = KE + \theta$

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

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

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

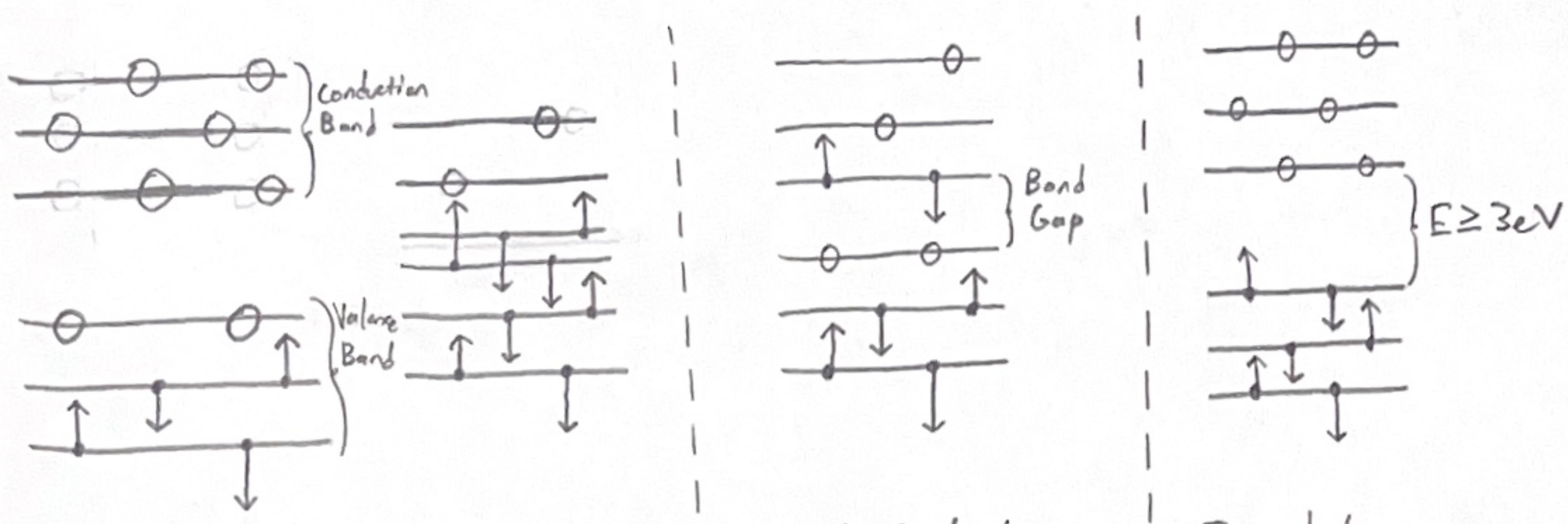
Classical: $KE = \frac{p^2}{2m}$

Quantum (Broglie): $p = \frac{h}{\lambda}$

$\downarrow$

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

Energy Bands



Counting Electrons

Intrinsic:

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

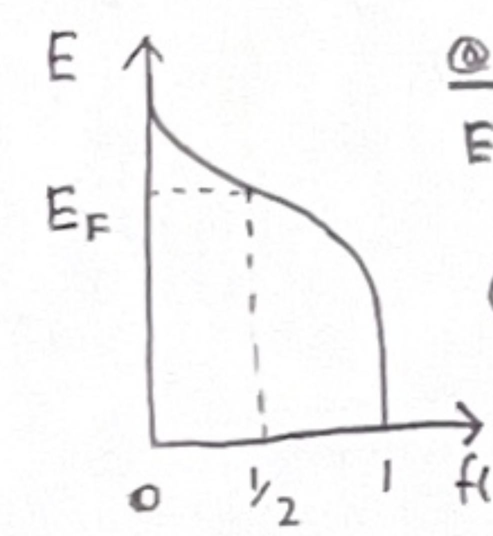
Density of States $\longrightarrow g(E)$

Occupancy Probability $\longrightarrow f(E)$

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

*Assuming no Simplifications

Fermi Level

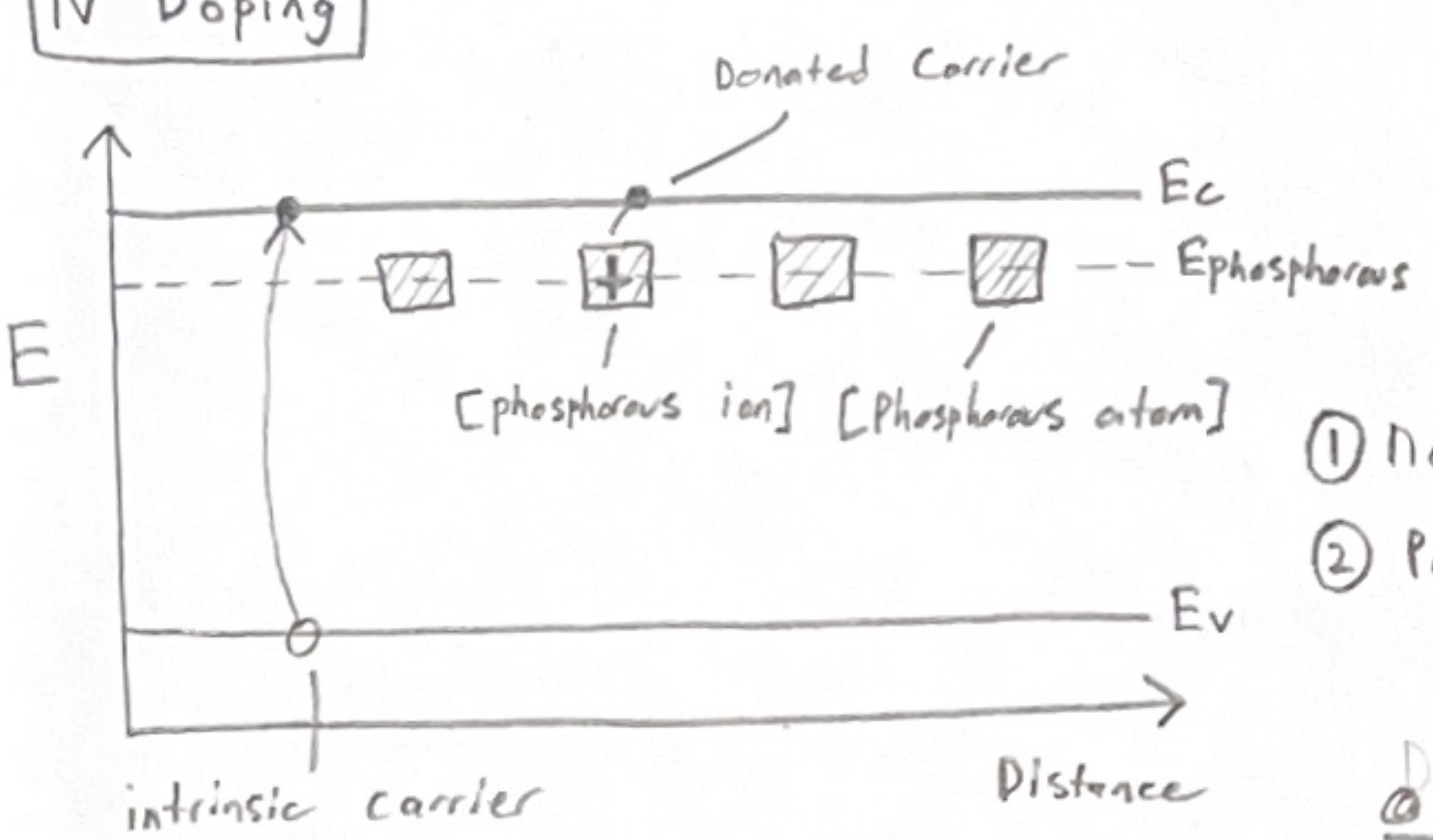


@ Intrinsic:
$E_F \rightarrow f(E) = \frac{1}{2}$

① P-Doping → Pushes E_F down

② N-Doping → Raises E_F UP

N Doping



① $n_o > n_i$

② $p_o < p_i$

@ Room Temperature:

$n_o = N_D$

$p_o = N_A$

Counting Holes

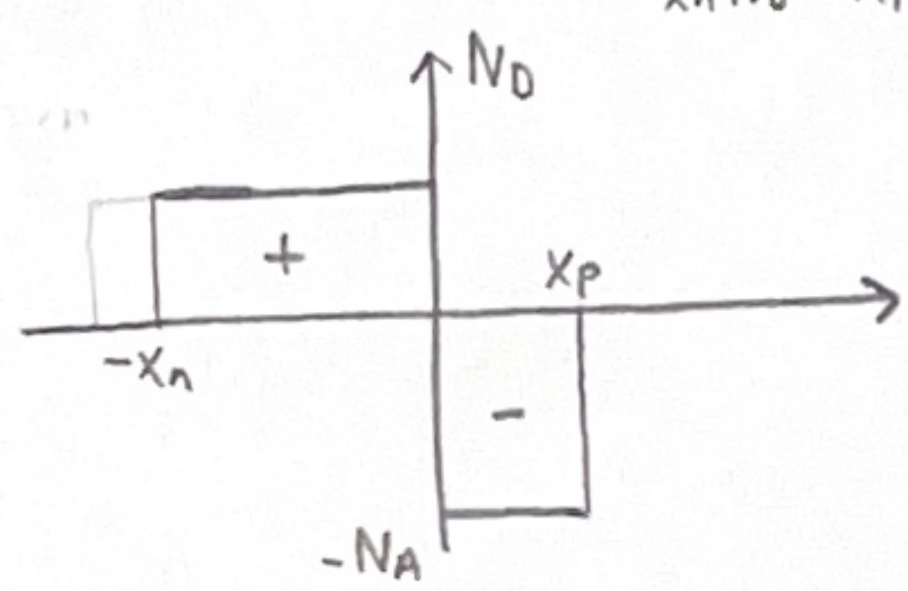
$$p_o = \int_{-\infty}^{E_v} g(E)[1-f(E)]\,dE$$

Dynamic Equilibrium

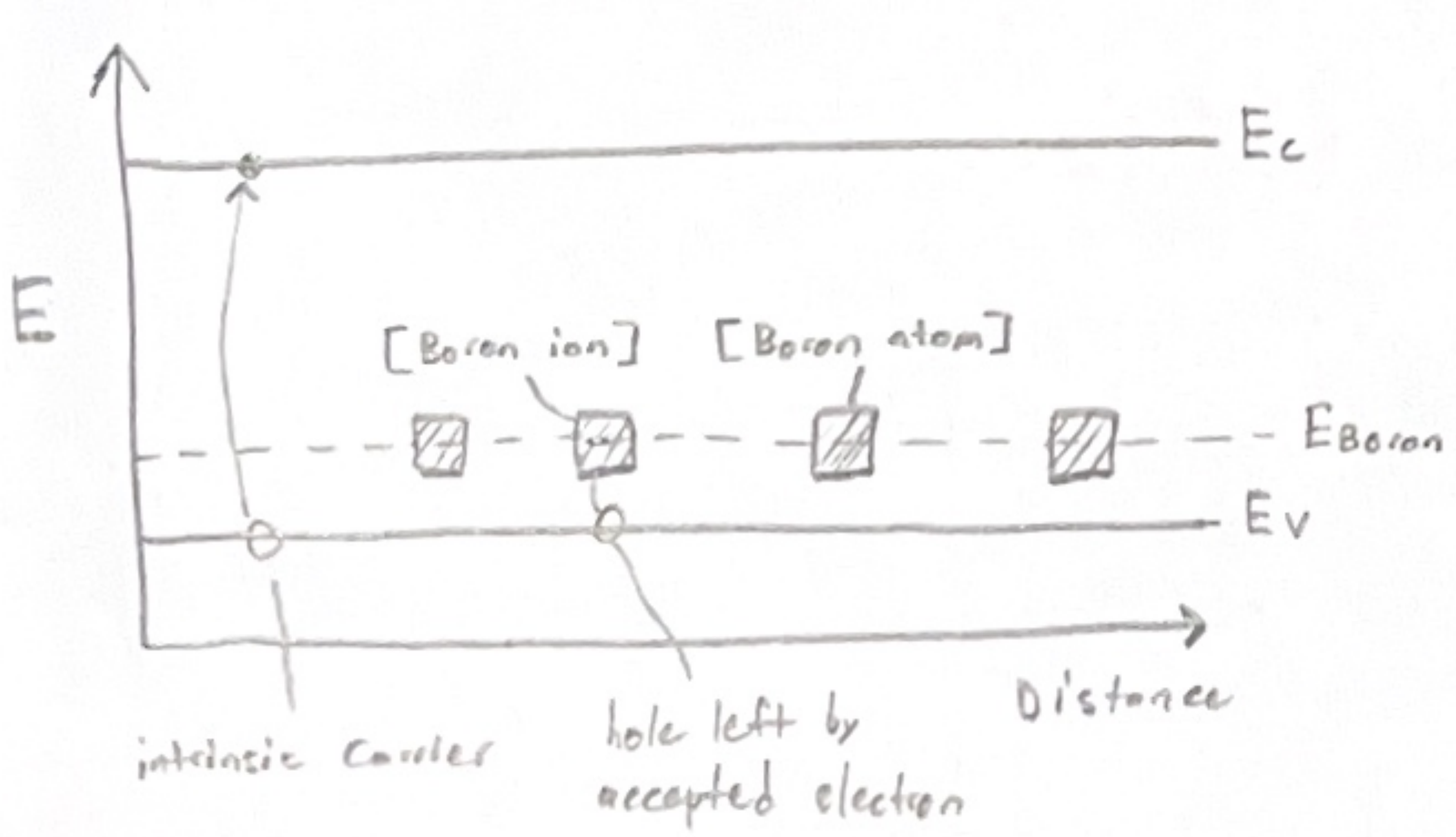
Generation = Recombination

Depletion Region

Charge Balance:
$x_n N_D = x_p N_A$



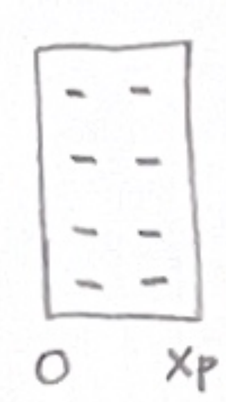
P Doping



① $n_o < n_i$

② $p_o > p_i$

Deriving Parabolic depletion Region shape



Poisson's Eqn:

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

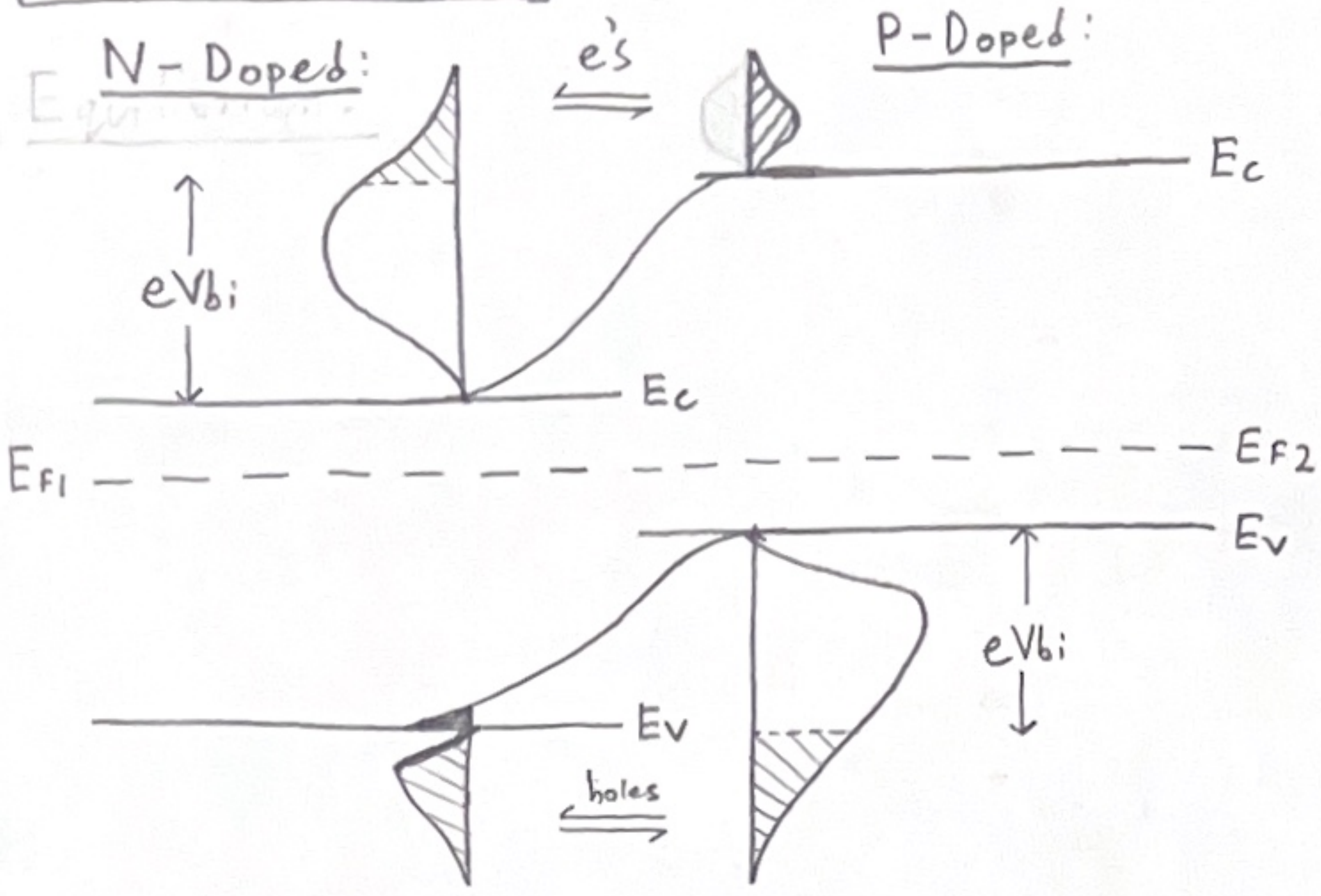
① $\frac{-\rho_{free}}{\varepsilon_o \varepsilon_r} = \frac{eN_A^-}{\varepsilon_r \varepsilon_o} = \frac{d^2V}{dx^2}$

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

③ $\Delta E = -eV(x)$

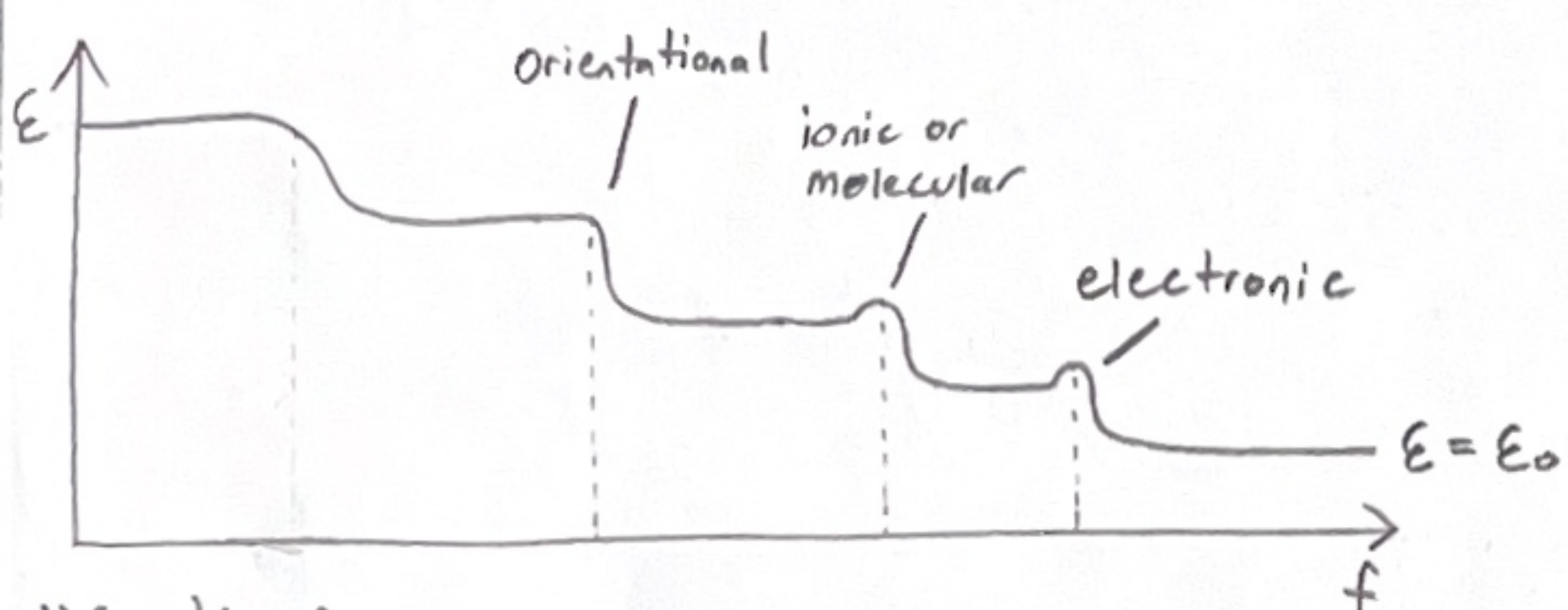
$$\therefore \Delta E = \frac{-e^2 N_A^-}{2\varepsilon_r \varepsilon_o} x^2$$

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 Zener: "Extreme bias (Reverse) so that e's in valence band (P side) tunnel through depletion region into conduction band (N side)

② Avalanche: "$q(V_{bi} - V_A) >> E_g$, rapid promotion of valence band electrons via collisions"

③ Intrinsic: "Same as Avalanche but occurs across the dielectric" [Avalanche is in depletion region]

④ Thermal: "Heating → more e's promoted → Collisions → more e's promoted loop"

⑤ Discharge: "Applied field Ionizes gas pores"

Polarization

$\varepsilon_r = 1 + X$

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

X — electric susceptibility

① Ionic Polarization: "Based on the configuration of the material" [Not present in pure Diamond/silicon]

② Electronic Polarization: "Induced by applied field" [Present in all materials]

Surface Charge density

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

Index of refraction

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

Dielectric loss

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

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

Causes:
① Collisions (Heating material)
② Conduction Currents

Managing Capacitance:

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

① max dielectric constant
② Max field
③ Low ε''

} Max Energy

Piezoelectrics and Ferroelectrics

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

① Direct effect: $P_i = d_{ij} T_j$ where: P = Polarization, T = stress

② Indirect effect: $S_i = d_{ij} E_j$ where: 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
② Moving charge
} Can Generate

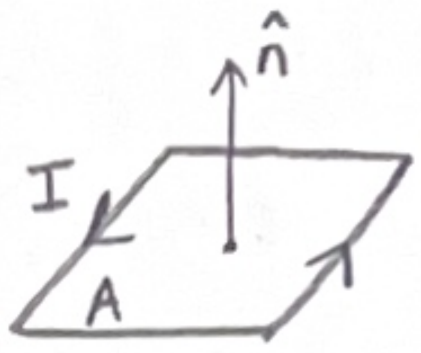
Materials

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



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

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

Magnetization $\vec{M}$

"Polarization for magnetic materials"

Surface Currents:

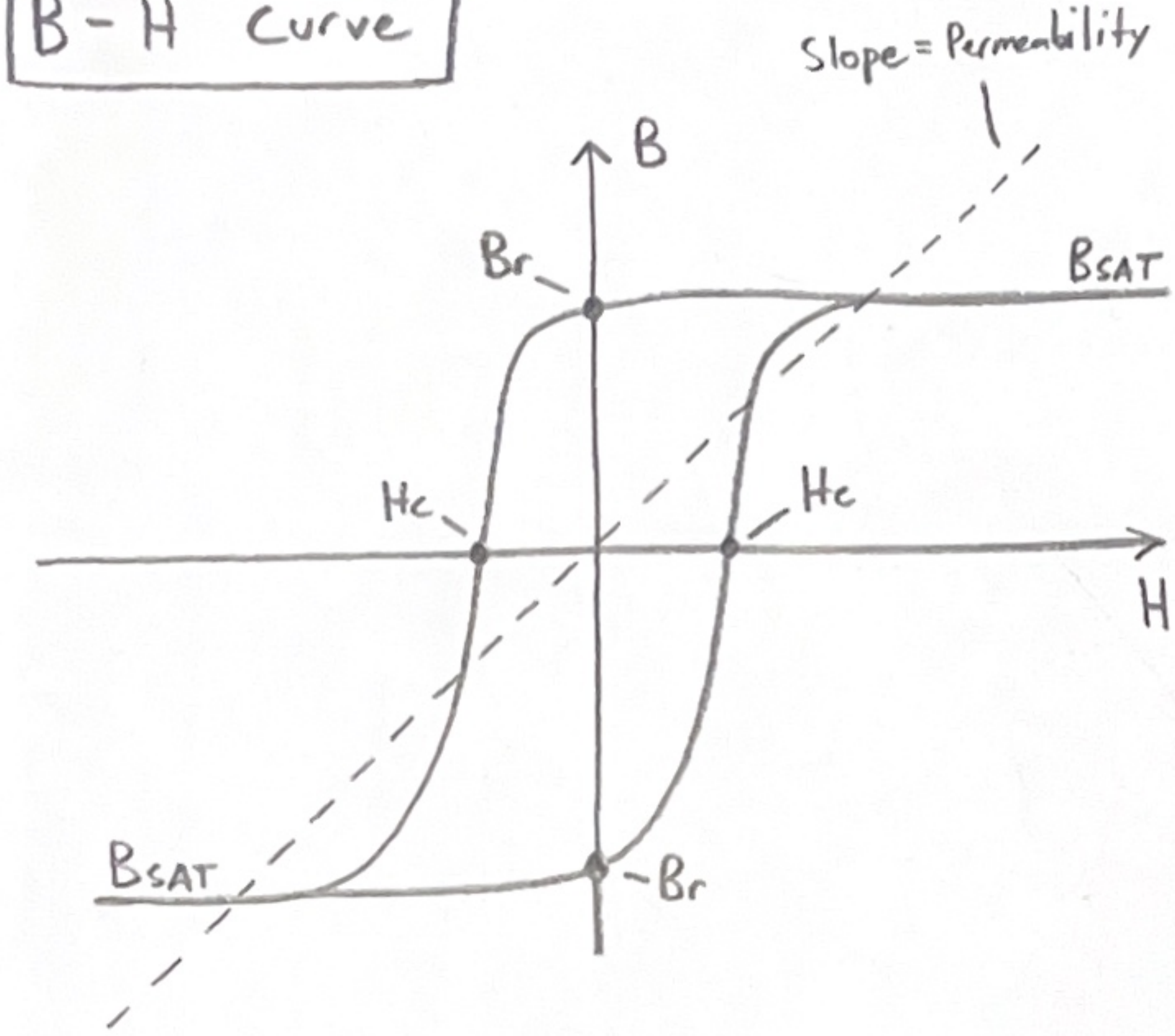
"Caused by alignment of magnetic dipoles"

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

K = current per unit length

M = magnetization

B - H Curve



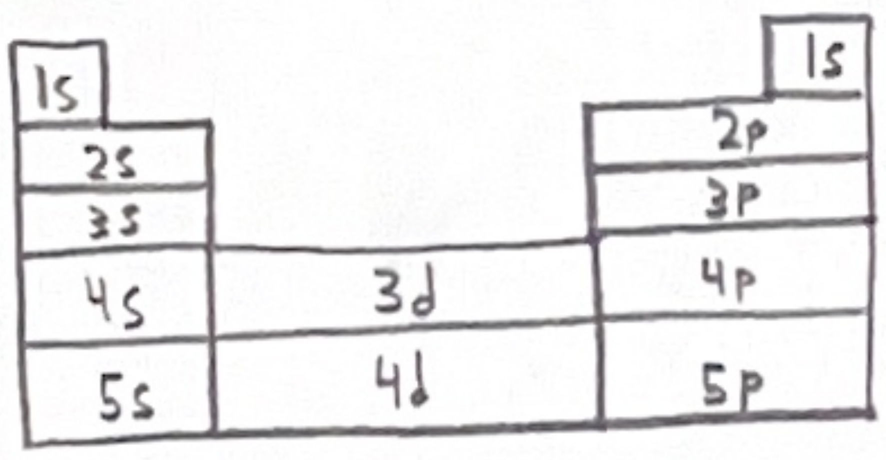
① **BSAT**: "Spins are aligned as much as they can be, max $\vec{B}$ field possible without increasing external field"

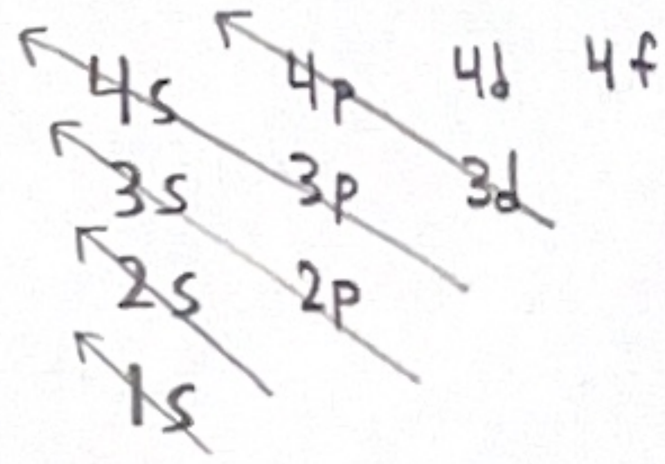
② **Br**: "Remanence, The field that remains when the external field = 0

③ **Hc**: "Coercive field, external field needed to bring B = 0

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

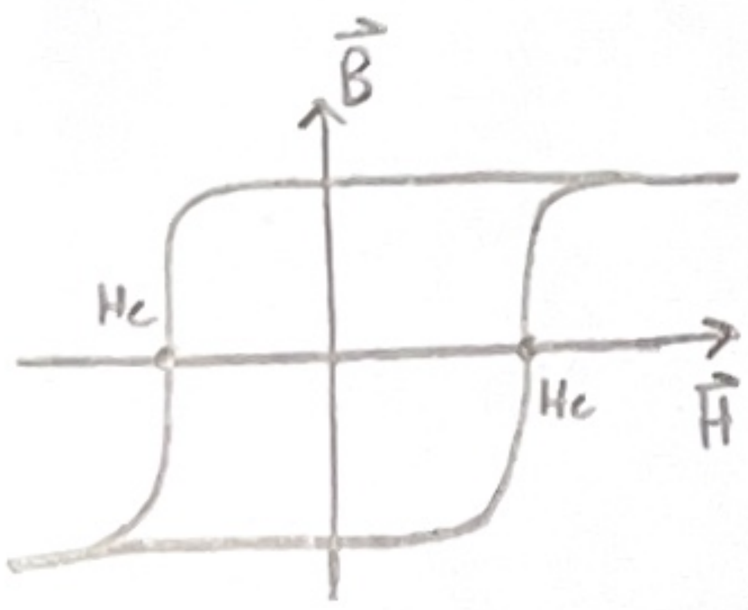
Filling Orbitals



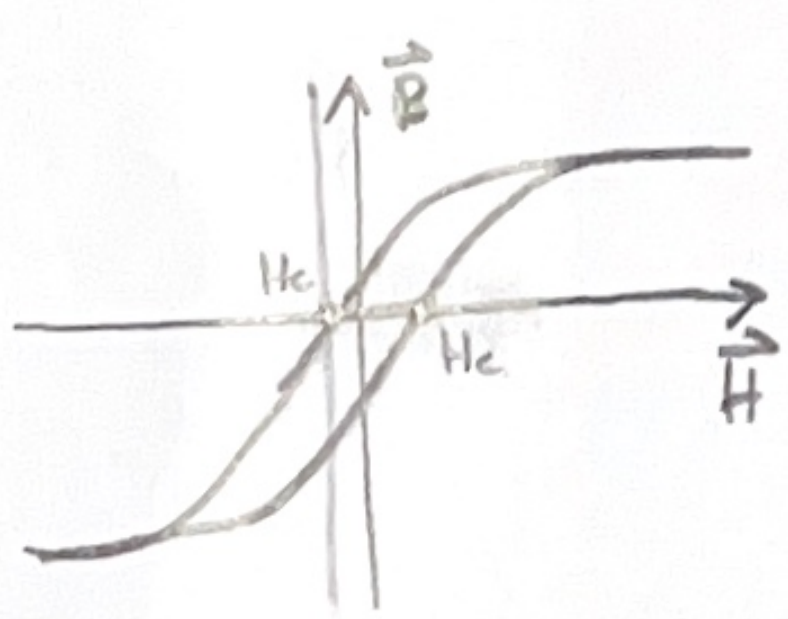


Hard Vs. Soft Materials

Hard



Soft



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

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

Capacitor Model

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

$\varepsilon' =$ Storage

$\varepsilon'' =$ loss