PN Junction Physics

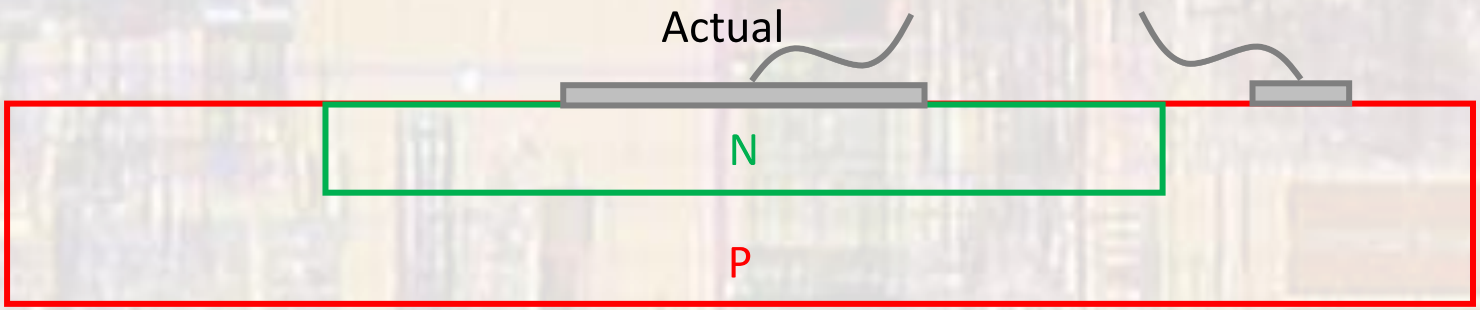
Last updated 2/4/22

PN Junction Physics

- Construction

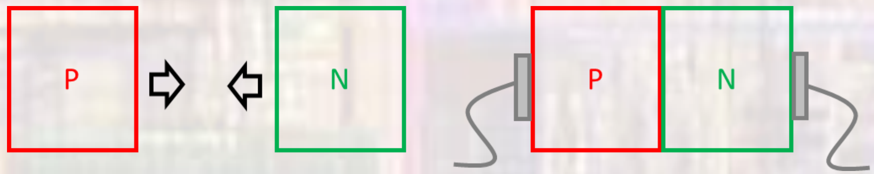
Conceptual

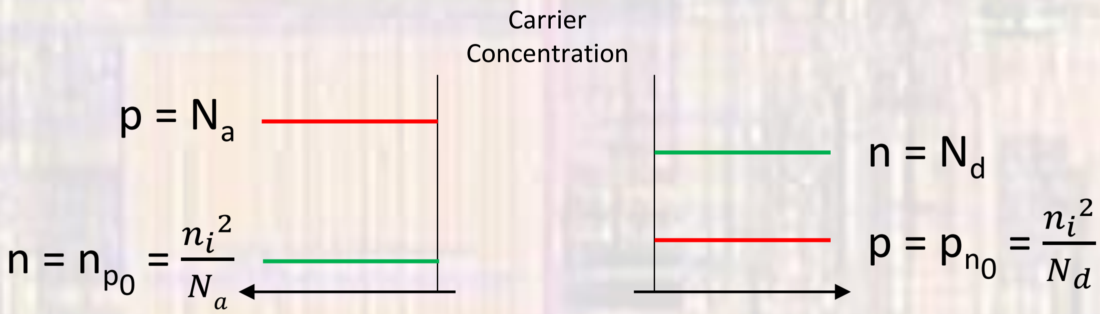
Actual

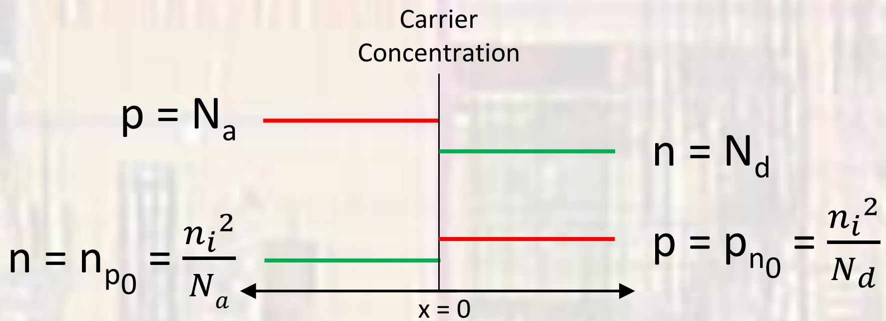


PN Junction Physics

- Carrier Concentrations, t=0



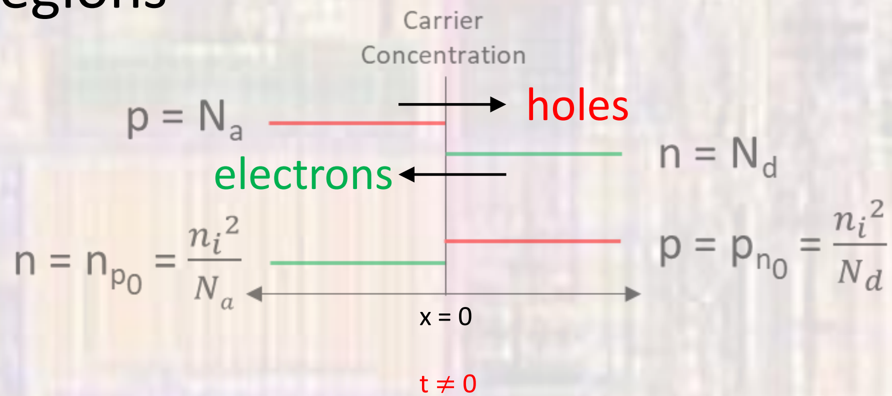


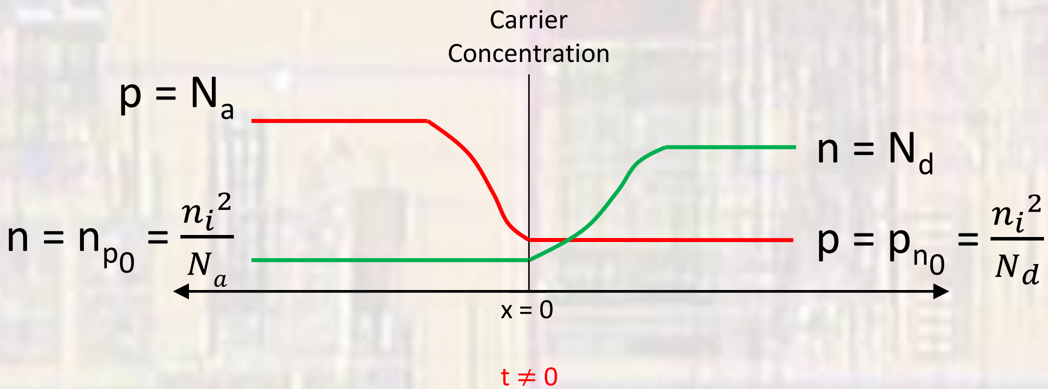


t = 0

PN Junction Physics

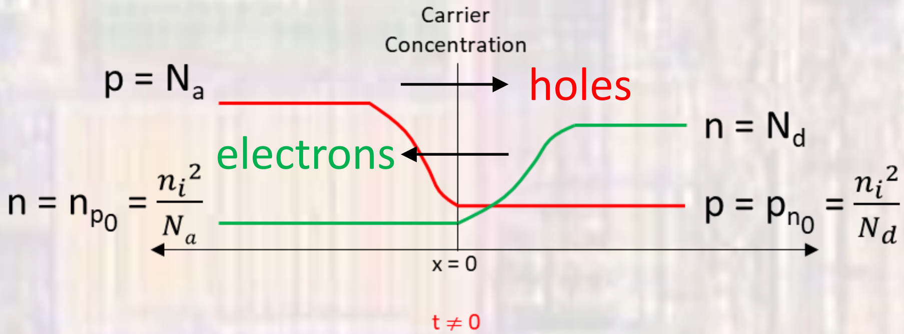
- Carrier Concentrations – diffusion
  - Free carriers move from high density regions to low density regions

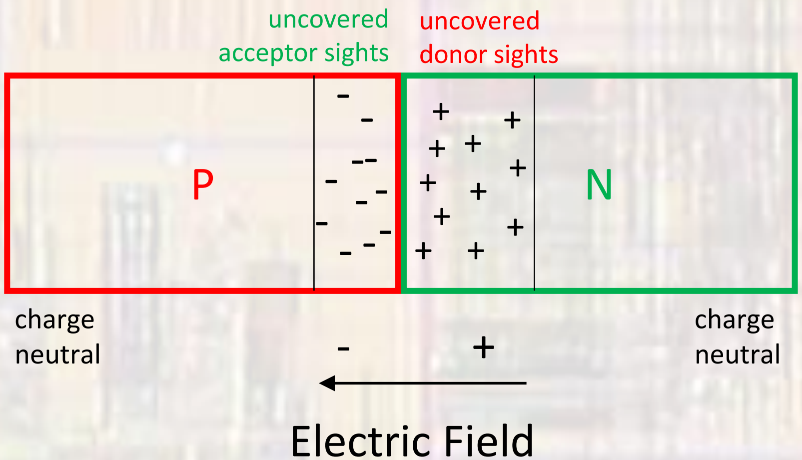




PN Junction Physics

- Carrier Concentrations – Diffusion
  - Diffusing carriers → Uncovered donor and acceptor sites
  - Uncovered donor and acceptor sites → Electric field



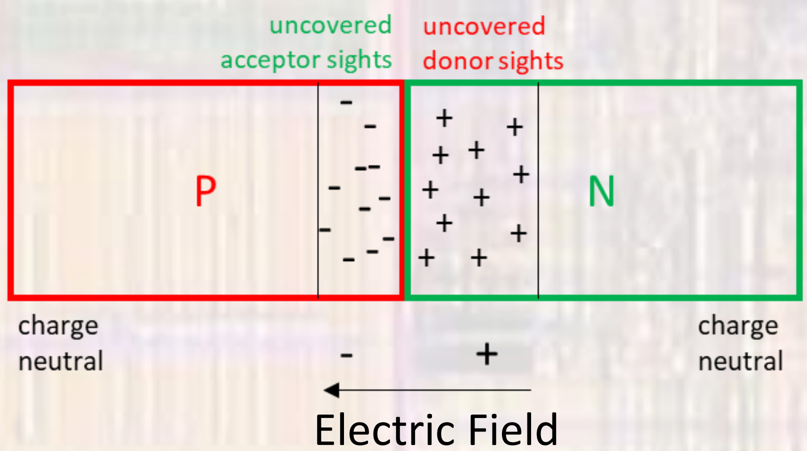


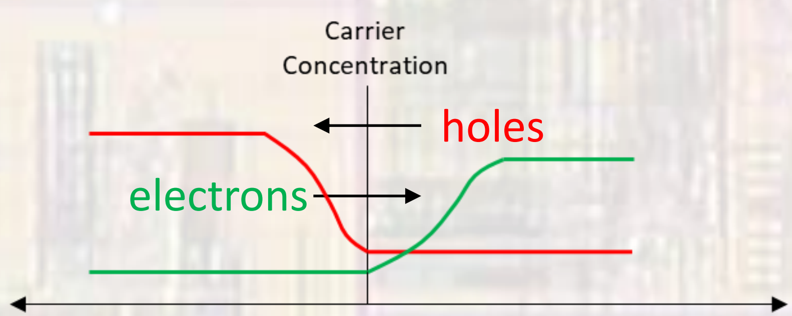
Depletion Region:
The region of uncovered donors and acceptors. There is a depletion of electrons in the N material and a depletion of holes in the P region

These uncovered charges are not mobile

PN Junction Physics

- Carrier Concentrations – Drift
  - Electric field causes carriers to drift
  - Drift is opposite to diffusion





PN Junction Physics

- Carrier Concentrations – Equilibrium
  - The drift and diffusion currents reach a steady state

$J_{p\text{-diff}} = J_{p\text{-drift}}$

$$J_{p-drift} = qp\mu_p \mathrm{E} = J_{P-diff} = -qD_P\nabla_P$$

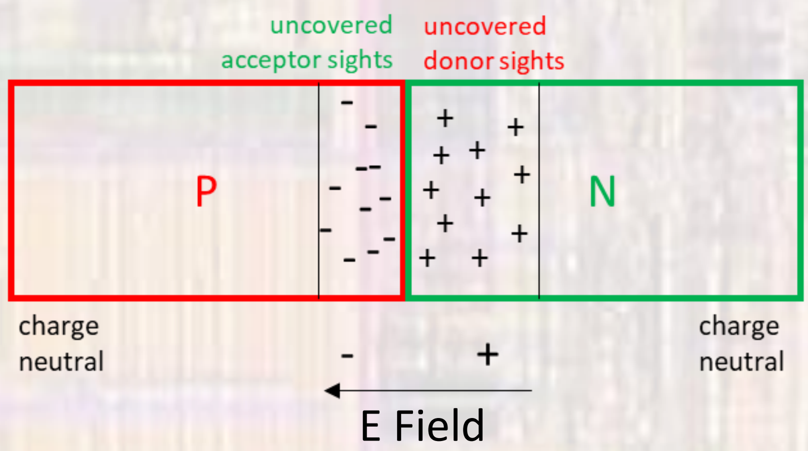
$I_D = 0$

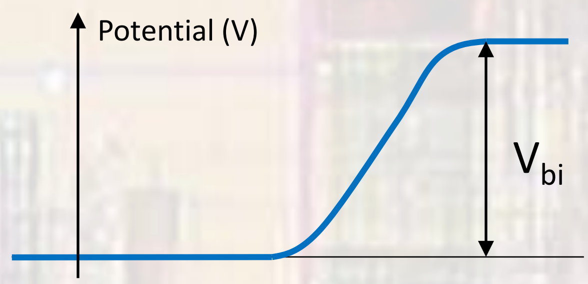
$J_{n\text{-diff}} = J_{n\text{-drift}}$

$$J_{n-drift} = qn\mu_n \mathrm{E} = J_{N-diff} = qD_N\nabla_N$$

PN Junction Physics

- Carrier Concentrations – built-in Potential
  - The steady state E field is called the Built-in Potential



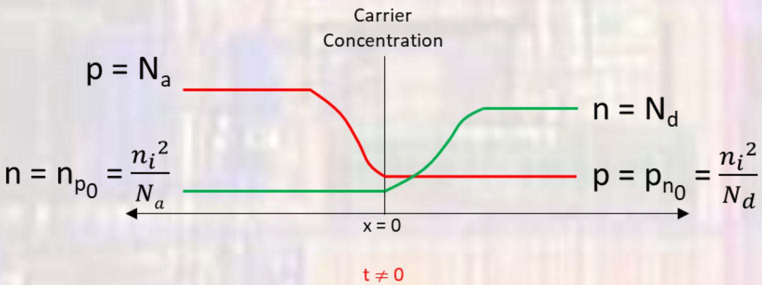


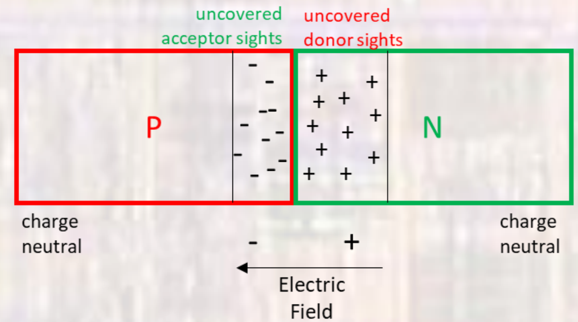
Electric Potential: Amount of work needed to move a unit charge from a reference point to a specific point against an electric field

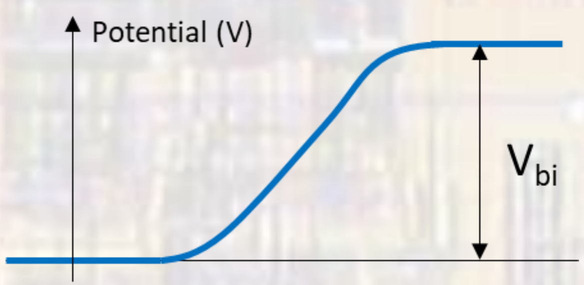
Required voltage to get current to flow from P→N

PN Junction Physics

- Carrier Concentrations – built-in Potential







$$V_{bi} = \frac{kT}{q} ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$V_{bi} = V_T ln\left(\frac{N_a N_d}{n_i^2}\right)$$

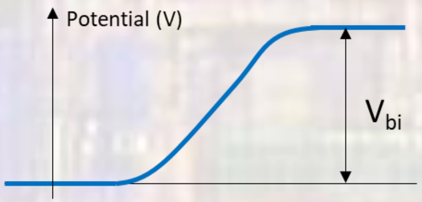
k - Boltzmann's Constant
$k = 1.38 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$

q – electron charge
$q = 1.60 \times 10^{-19}$ coulombs

T – Temperature in Kelvin
70°F → 21°C → 294K
Typically call Room Temp (RT) 300K

PN Junction Physics

- Carrier Concentrations – built-in Potential



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Si diode @RT with $N_a = 10^{17}$, $N_d = 10^{16}$

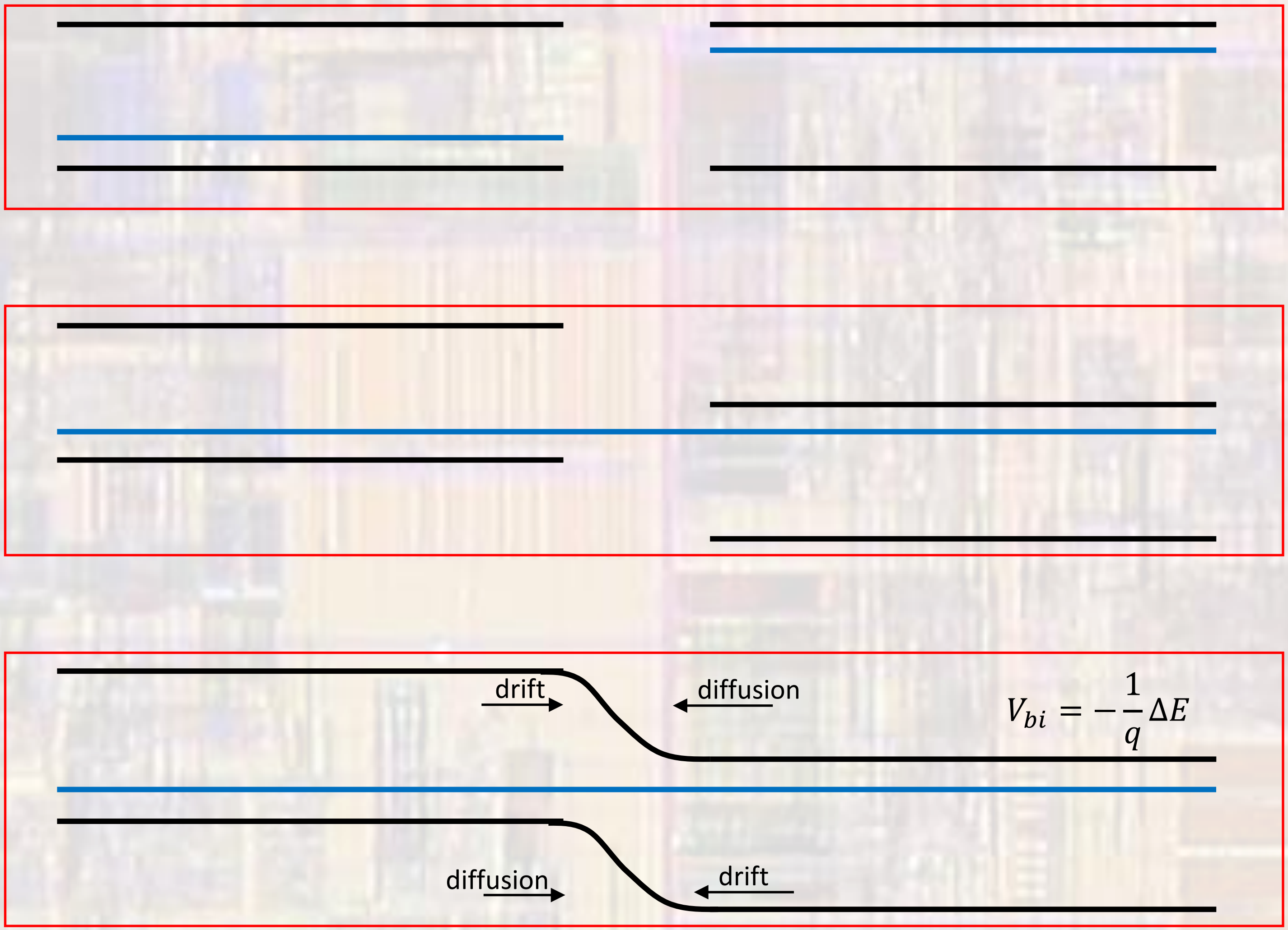
$$V_{bi} = \frac{1.38 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1} \times 300K}{1.60 \times 10^{-19}\ coulombs} ln\left(\frac{10^{17} cm^{-3} \times 10^{16}\ cm^{-3}}{(1.5 \times 10^{10} cm^{-3})^2}\right)$$

$$V_{bi} = 753mV$$

Note: @RT, $V_T = \frac{kT}{q}$ = 25.9mV ≈ 26mV
this is a common simplification
V_{bi} = 757mV

PN Junction Physics

- Energy Band / Fermi Level (Equilibrium)



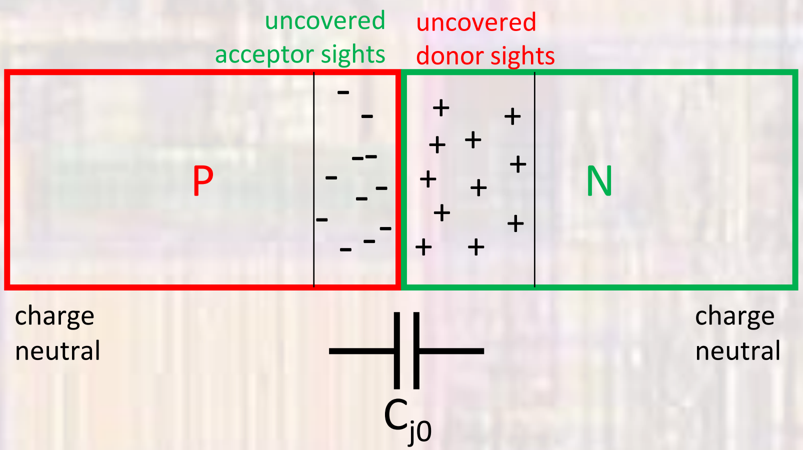
$$V_{bi} = -\frac{1}{q}\Delta E$$

$J_{p\text{-}diff} = J_{p\text{-}drift}$
$J_{n\text{-}diff} = J_{n\text{-}drift}$

$I_D = 0$

PN Junction Physics

- Carrier Concentrations – junction capacitance



- The depletion region acts like an insulator
  - No mobile charge
  - At 0V external bias the capacitance is C_{j0}