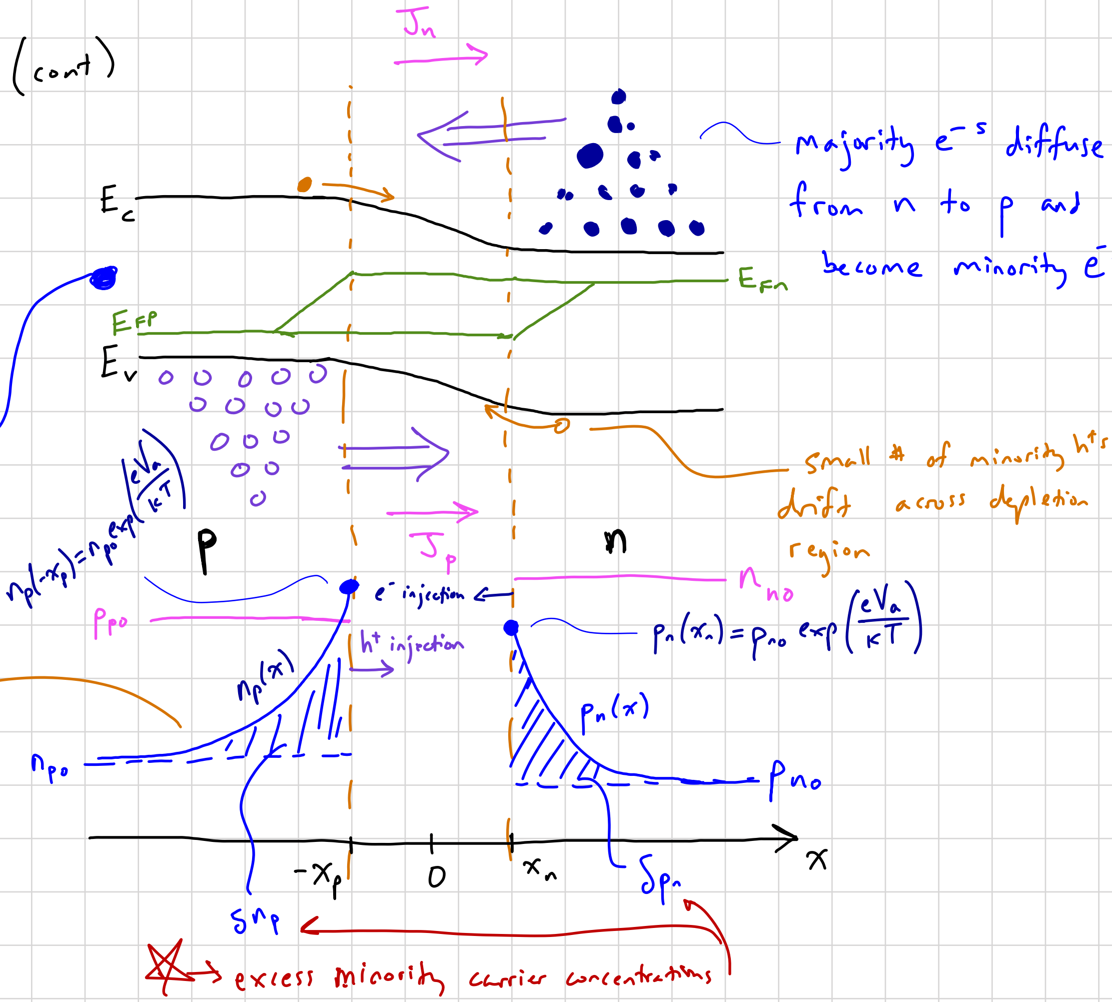
Lecture # 10

pn Junctions under Bias (cont)

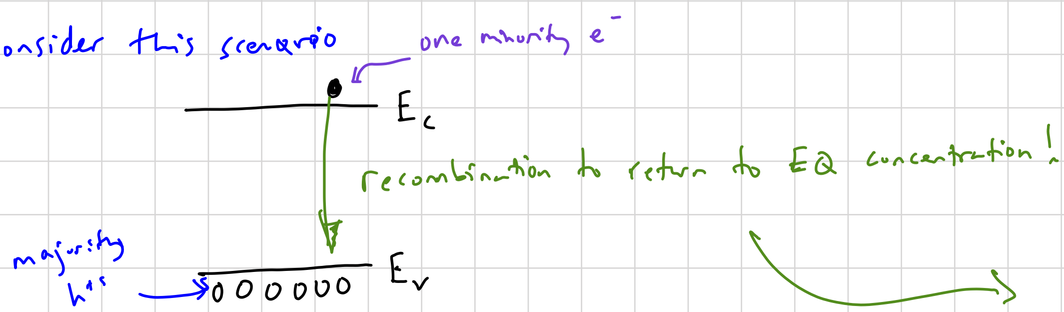
- What is happening in Forward Bias?
  - → steady state: Fixed bias and no longer changing in time

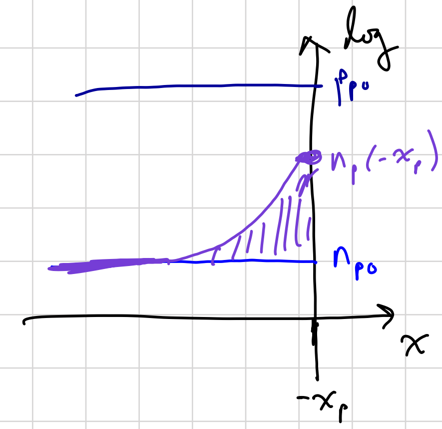


contacts to the diode p- and n- sides "replenish" the lost majority carriers ⟹ current flow

- Why is the minority carrier concentration decaying moving into the "neutral" region?
  - ☆ Recombination

Consider this scenario





- What current is flowing in Forward Bias?
  1. "Ideal" current from ideal diode
     - Key assumptions:
       - → abrupt junctions
       - → Boltzmann approx holds
       - → complete ionization and low-injection
       - ☆→ total current is constant; individual e^-, h^+ currents are continuous functions and constant in depletion region

Derivation for current:

☆ $\mathcal{E} = 0$ at $-x_p$ and x_n, and focus on diffusion current:

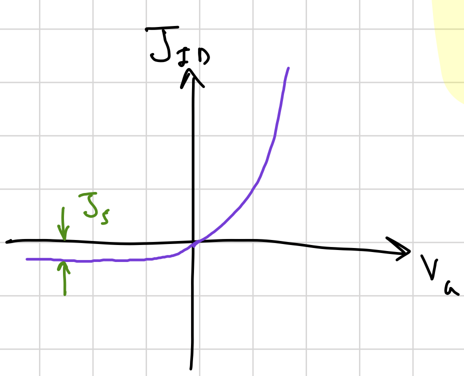
$$J_p(x_n) = -eD_p \left.\frac{dp_n}{dx}\right|_{x=x_n}$$

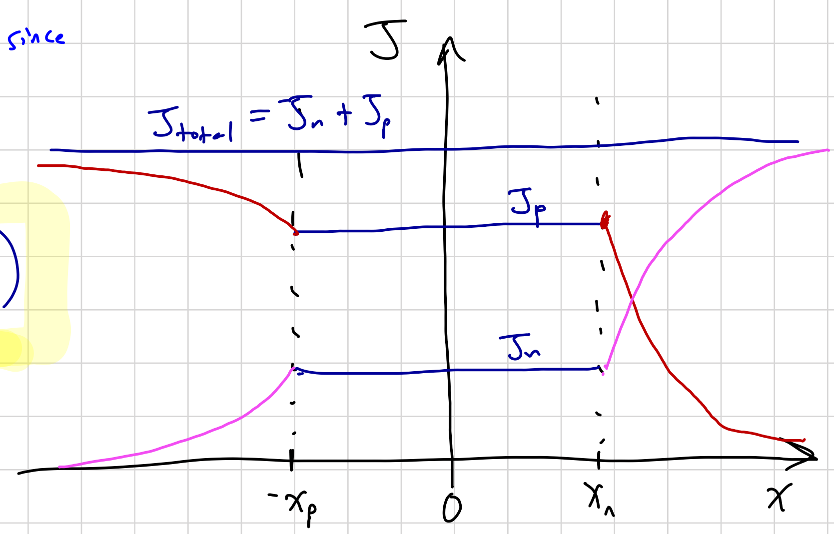
$$J_n(-x_p) = eD_n \left.\frac{dn_p}{dx}\right|_{x=-x_p}$$

use δp_n, δn_p since p_{no} and n_{po} are constant

$$J_{ID} = \left[\frac{eD_p p_{no}}{L_p} + \frac{eD_n n_{po}}{L_n}\right]\left(\exp\left(\frac{eV_a}{kT}\right) - 1\right)$$

$\equiv J_s$ (reverse saturation current)





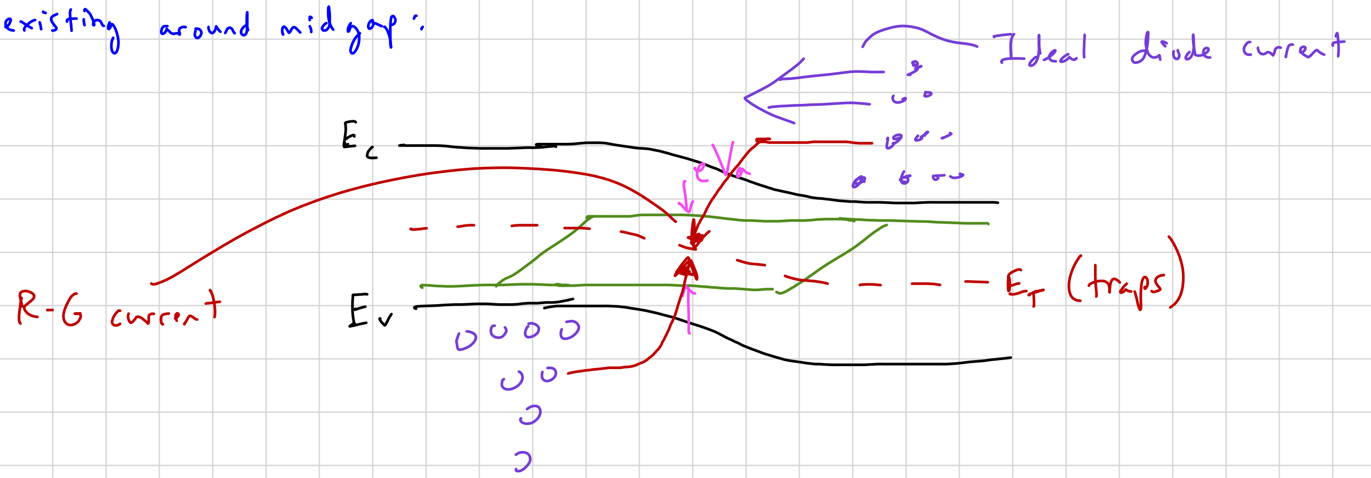
② R-G (Recombination - Generation) current

→ Some e^-s and h^+s crossing the depletion region can recombine at a rate:

$$R = \frac{np - n_i^2}{\tau_{po}(n+n') + \tau_{no}(p+p')} \longrightarrow R\Big|_{max} = \frac{n_i}{2\tau_0}\exp\left(\frac{eV_a}{2kT}\right)$$

avg. e^-, h^+ lifetime

→ This often occurs at a "trap" level created by defects in the crystal lattice and existing around midgap:



☆ It is an added current flow because for every $e^- - h^+$ pair recombined, a new e^- and h^+ flow into the diode from the contacts to replace them

recombination current in F.B. is:

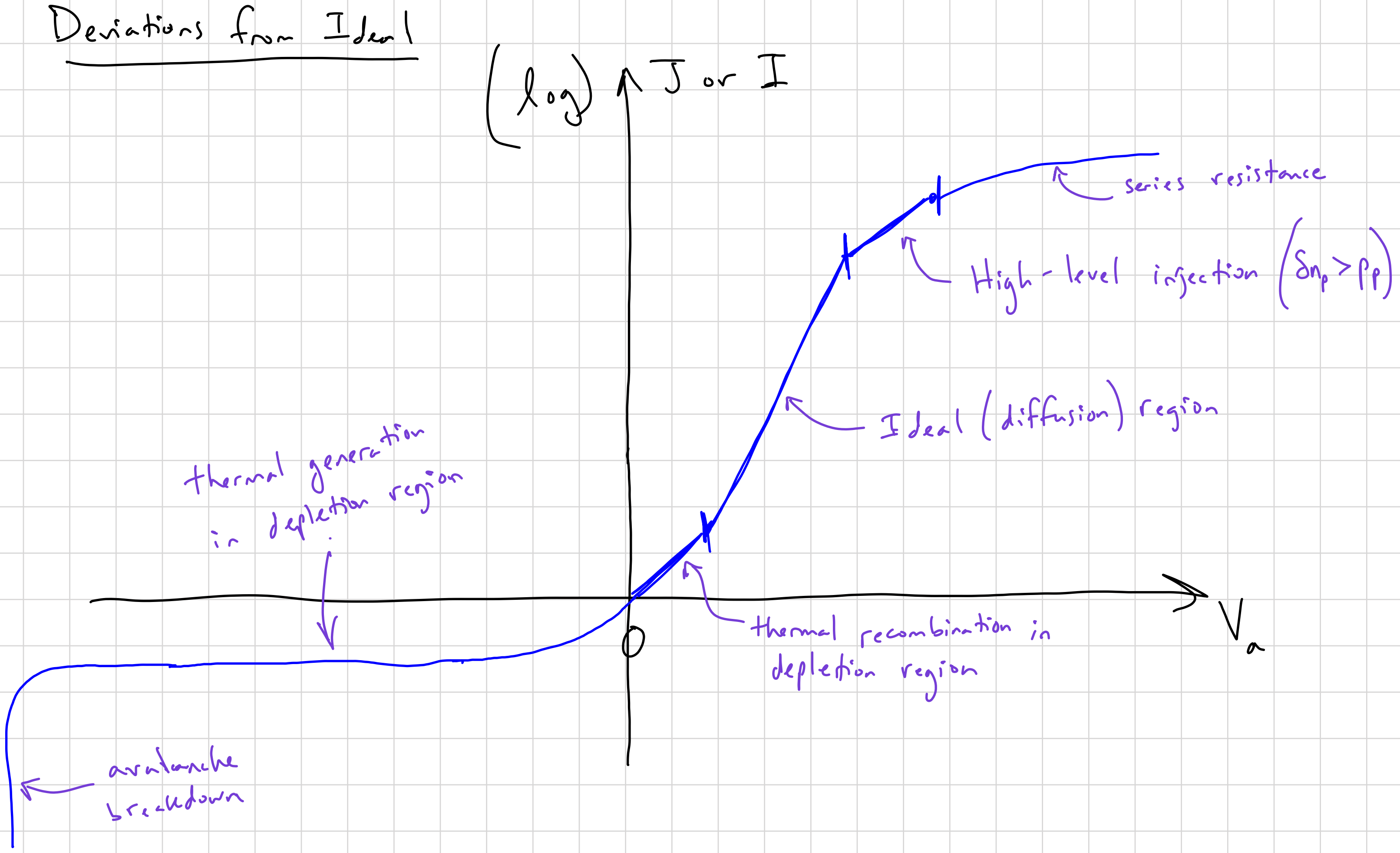
$$J_{rec} = \int_0^W eR\,dx = \boxed{\frac{eWn_i}{2\tau_0}\exp\left(\frac{eV_a}{2kT}\right)}$$

$\equiv J_{ro}$

total current is now: $J_{total} = J_{rec} + J_{ID}$

$\hookrightarrow J_{DIFF}$

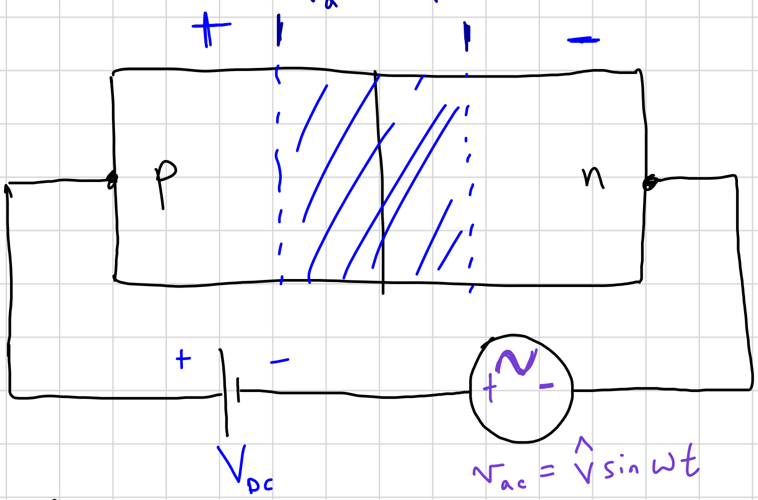
Deviations from Ideal



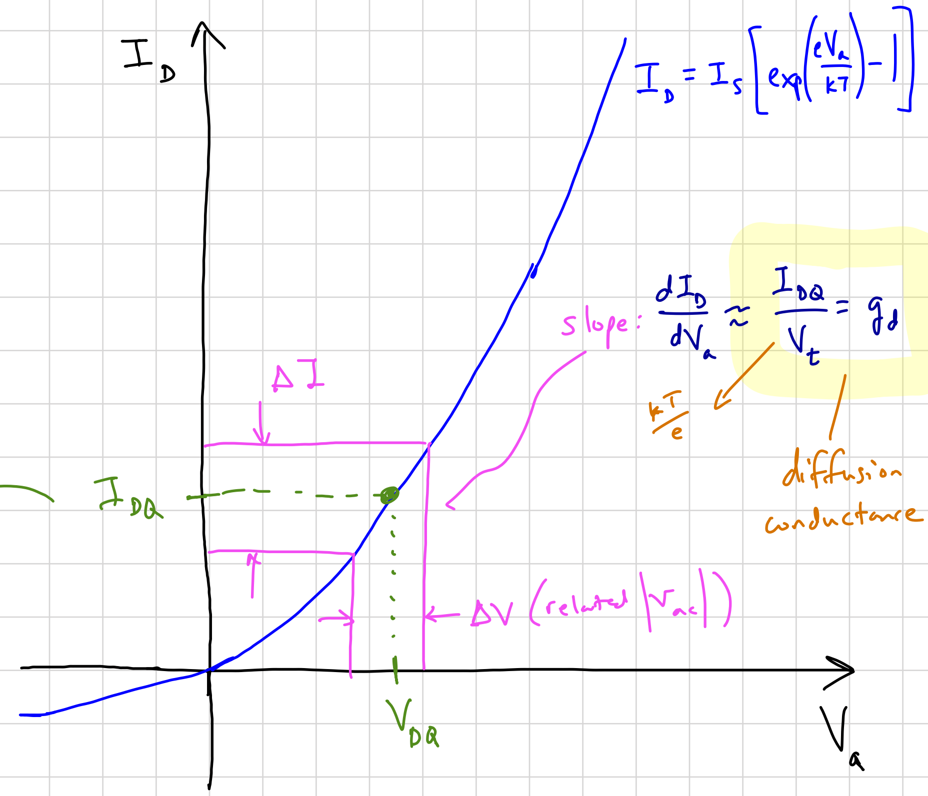
Small Signal Equivalent Circuit for Diode

"Small signal" model → small magnitude, low frequency AC

$V_a = V_{DC} + v_{ac}$



→ dc quiescent diode current



slope: $\frac{dI_D}{dV_a} \approx \boxed{\frac{I_{DQ}}{V_t} = g_d}$ ← diffusion conductance

$V_t = \frac{kT}{e}$

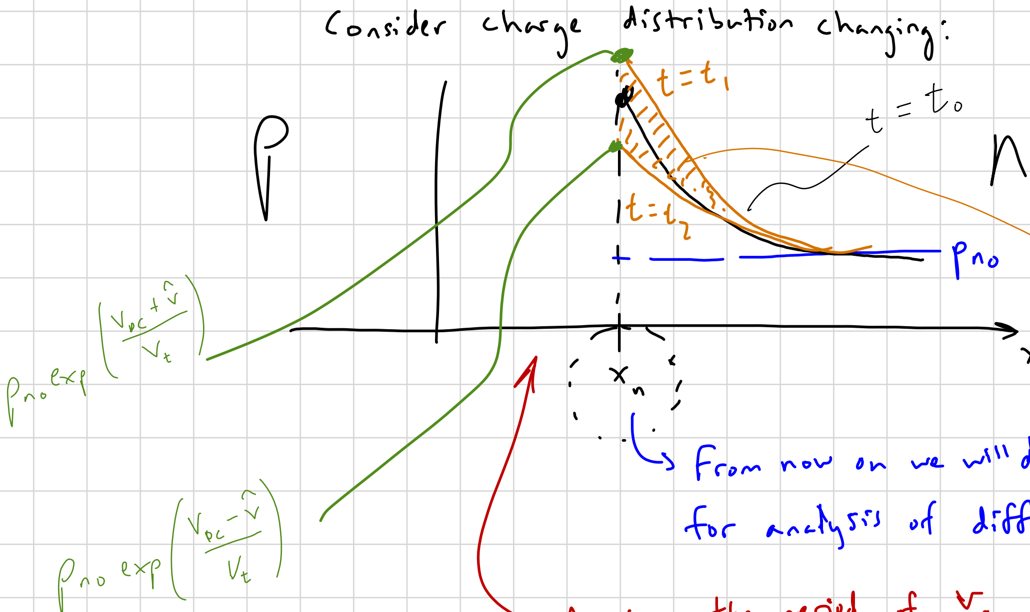
∴ Diffusion resistance is the small-signal incremental resistance: $\boxed{r_d = \frac{1}{g_d} = \frac{V_t}{I_{DQ}}}$

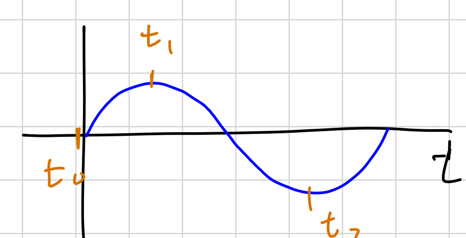
Diffusion Capacitance

→ part of the small-signal admittance (impedance) of a forward biased pn diode

→ different from junction capacitance as this comes from the applied small-signal:

Consider charge distribution changing:





ΔQ is charge changing during v_{ac} cycle

→ From now on we will define $x_p \equiv x = 0$ for analysis of diff. cap.

Assume the period of v_{ac} is large compared to time for carriers to diffuse into n-region

→ Same thing occurs on p-side with minority carrier e^-'s : n_{po}

→ Leads to capacitance since $C = \frac{\Delta Q}{\Delta V} \equiv$ diffusion capacitance

→ magnitude of diff. cap. typically > than junction cap.

See book for derivation > Assumptions use: → homogeneous semiconductor

→ $\omega \tau_{po} << 1$, $\omega \tau_{no} << 1$ ← low freq. ac signal, exponential curves maintained entire time!