EEE105
“Electronic Devices”

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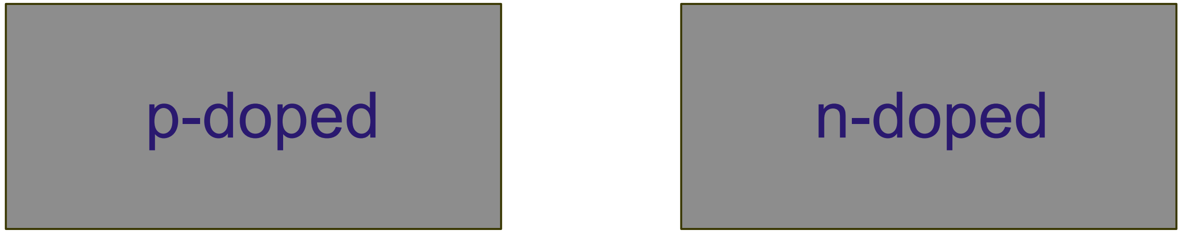
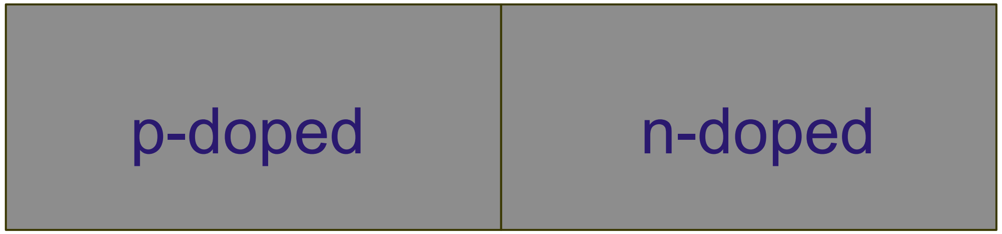
Lecture 12

- p-n Junction
  - Putting two blocks of doped material together...
- Built in Potential
  - Derivation
- Band Structure p-n junction

Two Blocks



2 isolated n and p doped blocks (constant doping) of semiconductor



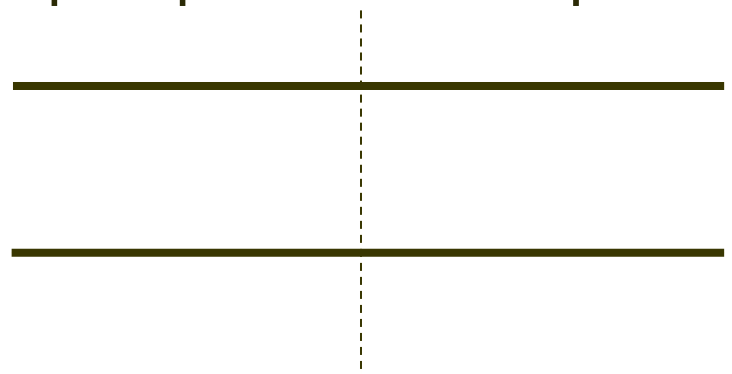
Bring them together – now have a non-uniform carrier concentration at the junction of the two

What happens?

J must be zero….

- An electric field must be generated to create a drift current which is equal and opposite to the diffusion current
- This electric field will appear to be a built-in potential within the junction, V_0
- Here we will try to calculate the magnitude of V_0 and see what factors influence it….

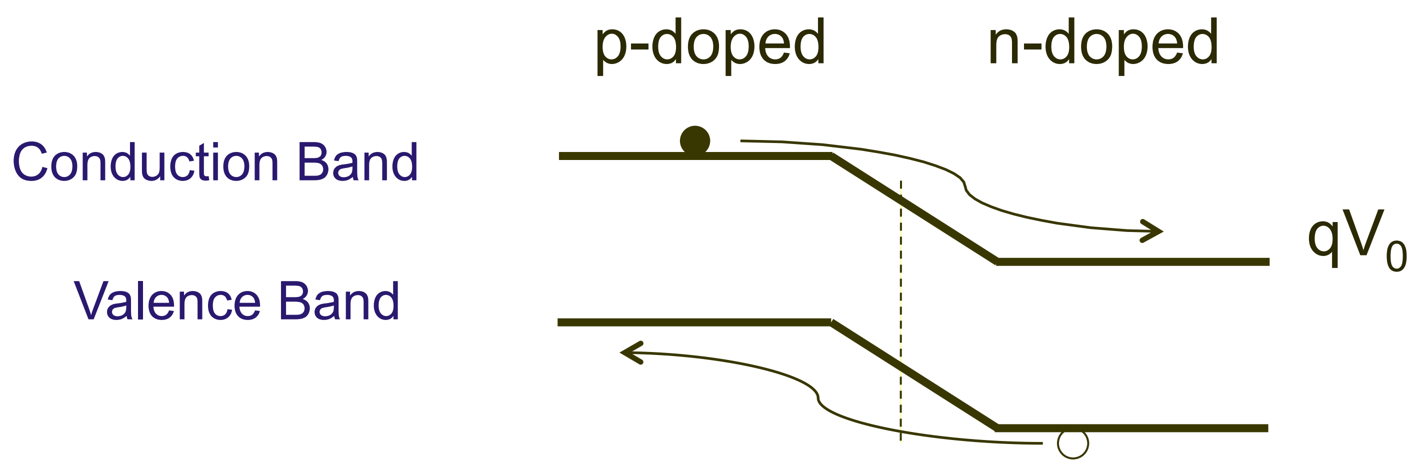
No Internal Field -



$J_h^{diffusion}$ $J_e^{diffusion}$

J_h^{drift} J_e^{drift}

Origin of Drift Current



Minority carriers may “wander” into the region of electric field and be “swept away” contributing to drift current

Thermally generated carriers within diffusion length of E-field

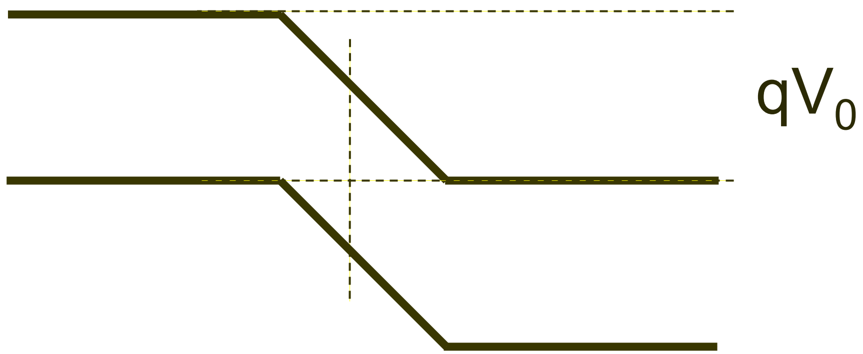
$$L_{e,h} = \left(D_{e,h}\tau_{e,h}\right)^{1/2}$$

Just right – Balance – J=O

p-doped n-doped

Conduction Band

Valence Band



$J_h^{diffusion}$ → → $J_e^{diffusion}$

J_h^{drift} ← ← J_e^{drift}

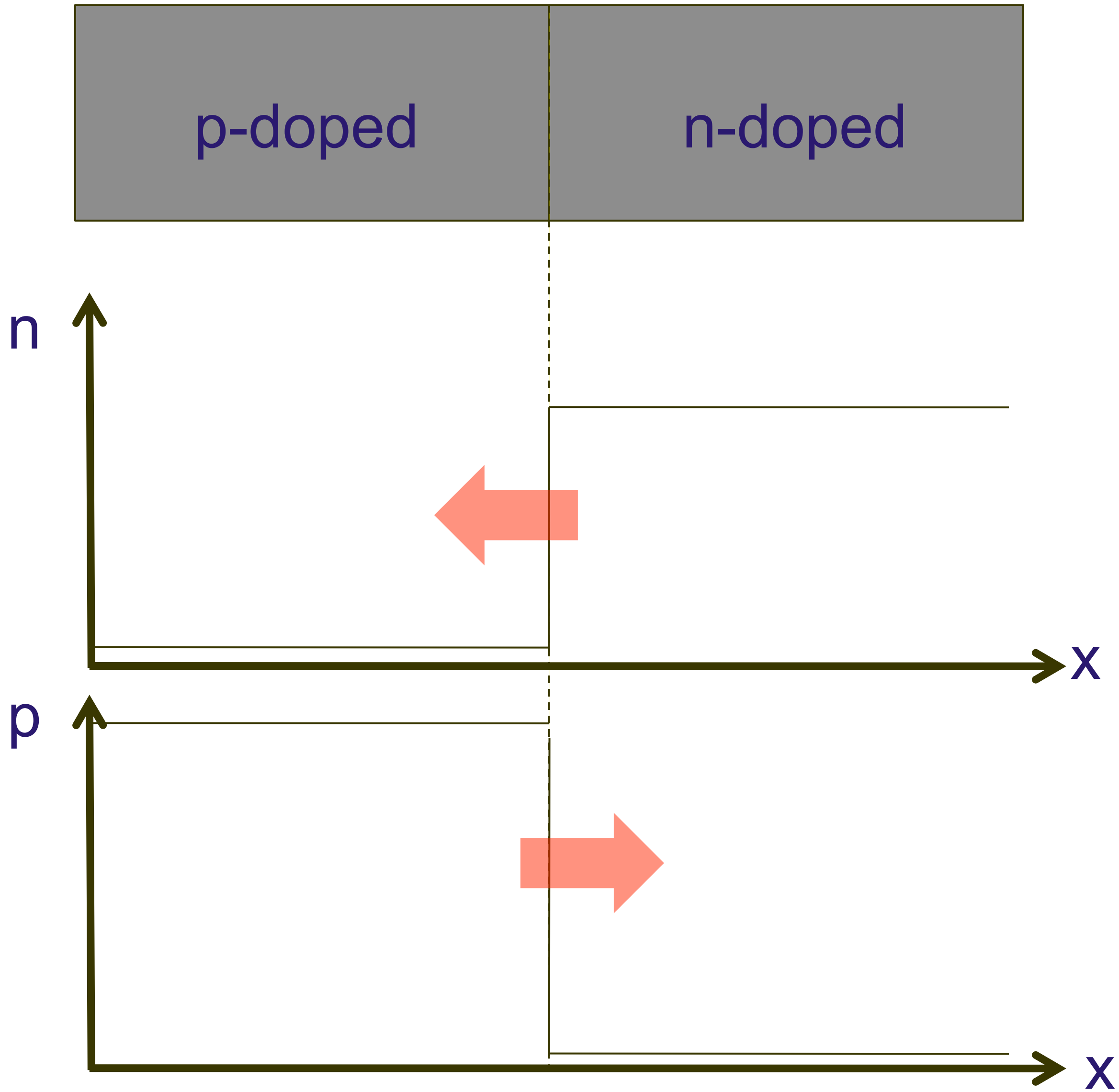
Carriers

(t=0 after connection)

Holes diffuse into n-material where they are minority carriers and recombine with electrons

The holes leave behind ionized (-ve) acceptors in p-region

Depletion of free carriers at junction

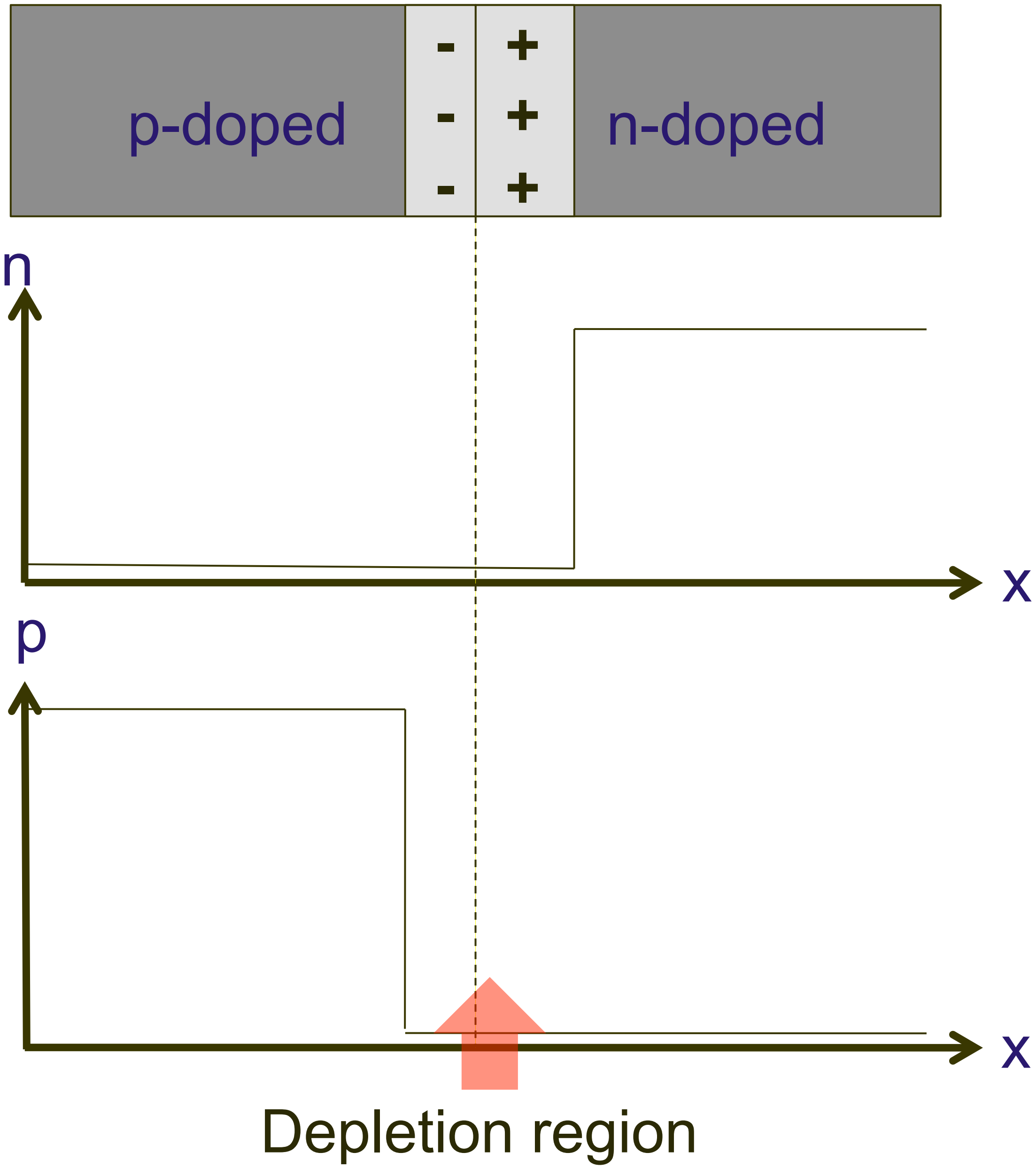


Carriers

Have electron diffusion right to left (current left to right)

Have hole diffusion left to right (current left to right)

At equilibrium there must be no net current so an E-field is generated – Gives potential difference V_0 between n and p regions



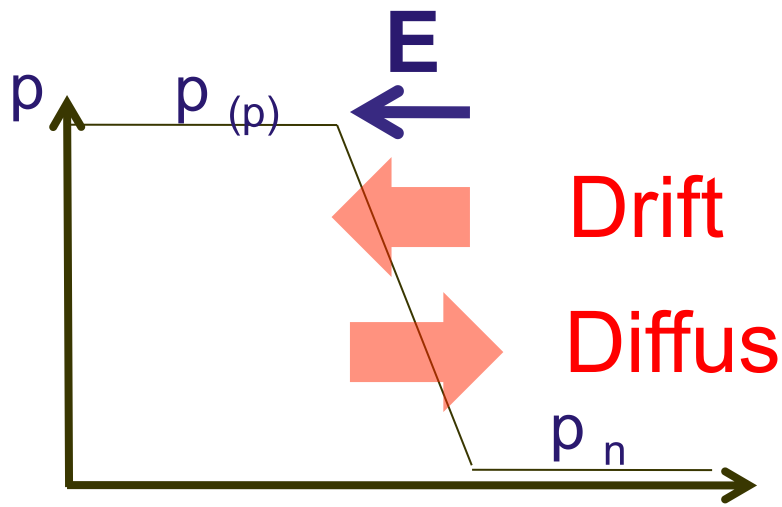
V_0 - Consider holes

From discussion on drift and diffusion

$$J_h^{total}(x) = J_h^{drift} + J_h^{diffusion} = q\mu_h E_x p - qD_h \frac{dp}{dx} = 0$$

Rearranging

$$E_x = \frac{D_h}{\mu_h p} \cdot \frac{dp}{dx}$$



Continued..

Recall Einstein relationship $$D_h = \frac{k_B T}{q}.\mu_h$$

Gives $$E_x = \frac{k_B T}{q}.\frac{1}{p}.\frac{dp}{dx}$$

Remember that $$V = -\int E.dx$$

Combining these gives $$V_0 = -\frac{k_B T}{q}\int_{p_{(p)}}^{p_n}\frac{dp}{p}$$

Integration yields $$V_0 = \frac{k_B T}{q}\ln\left(\frac{p_{(p)}}{p_n}\right)$$

n.b. Same analysis gives similar for electrons $$V_0 = \frac{k_B T}{q}\ln\left(\frac{n_{(n)}}{n_p}\right)$$

Continued (2)..

In terms of minority carrier density isn't helpful....

Remember $$n_i^2 = n_p p_p$$

Gives $$V_0 = \frac{k_B T}{q} \ln\left(\frac{p_{(p)} n_{(n)}}{n_i^2}\right)$$

All are known, or can be calculated

T= Temperature
$p_{(p)}$ = acceptor doping density
$n_{(n)}$ = donor doping density
n_i= intrinsic carrier density

$$n_i = C\ T^{3/2} \exp\left(-\frac{E_g}{2K_B T}\right)$$

Continued (3)..

What is dominant ?

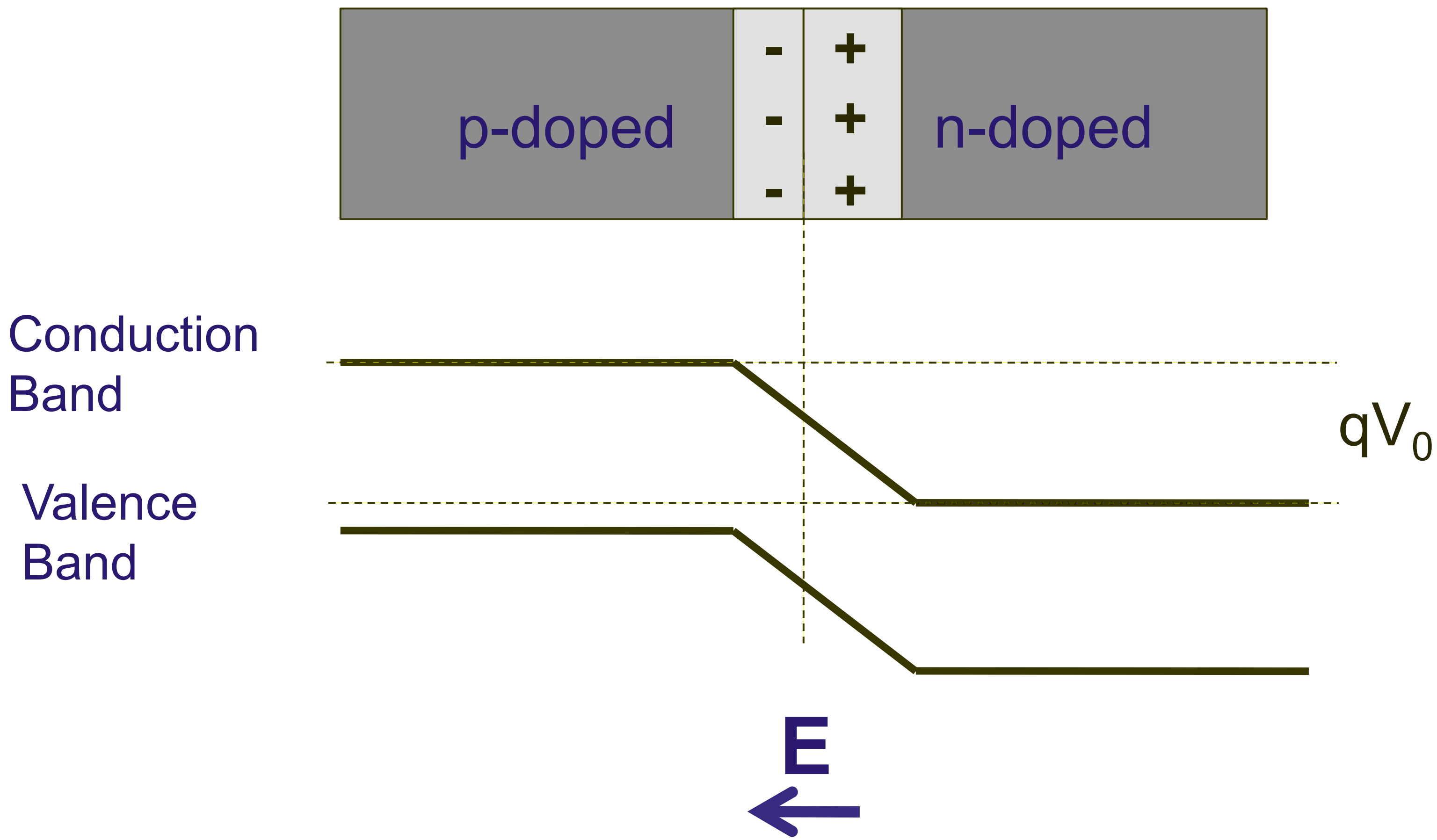
$$V_0 = \frac{k_B T}{q}\left[\ln\left(p_{(p)} n_{(n)}\right) - \ln\left(n_i^{\ 2}\right)\right]$$

Substituting for n_i

$$V_0 = \frac{k_B T}{q}\left[\ln\left(p_{(p)} n_{(n)}\right) - \ln\left(CT^{3/2}\right)^2 + \frac{E_g}{k_B T}\right]$$

$$V_0 = \underbrace{\frac{k_B T}{q}\left[\ln\left(p_{(p)} n_{(n)}\right) - \ln\left(CT^{3/2}\right)^2\right]}_{\text{Small compared to } E_g} + \frac{E_g}{q}$$

Band Structure



Summary

- In a p-n junction electrons and holes will diffuse across the junction and recombine as minority carriers
- The acceptor and donor ions are left behind and cannot move
- In equilibrium the diffusion and drift currents must give no net current
- An E-field is produced to ensure this
- There is a built in voltage in the junction
  - This is an internal barrier to current flow
  - We cannot measure this at the terminals

Summary (2)

- The built in voltage is close to the band-gap
- The temperature dependence of the built in voltage comes from a temperature dependence of the band-gap
- The position of the E-fields with relation to the junction of n and p materials is dependant upon the relative doping concentrations

