

pn junction under forward bias

day09

1. Review

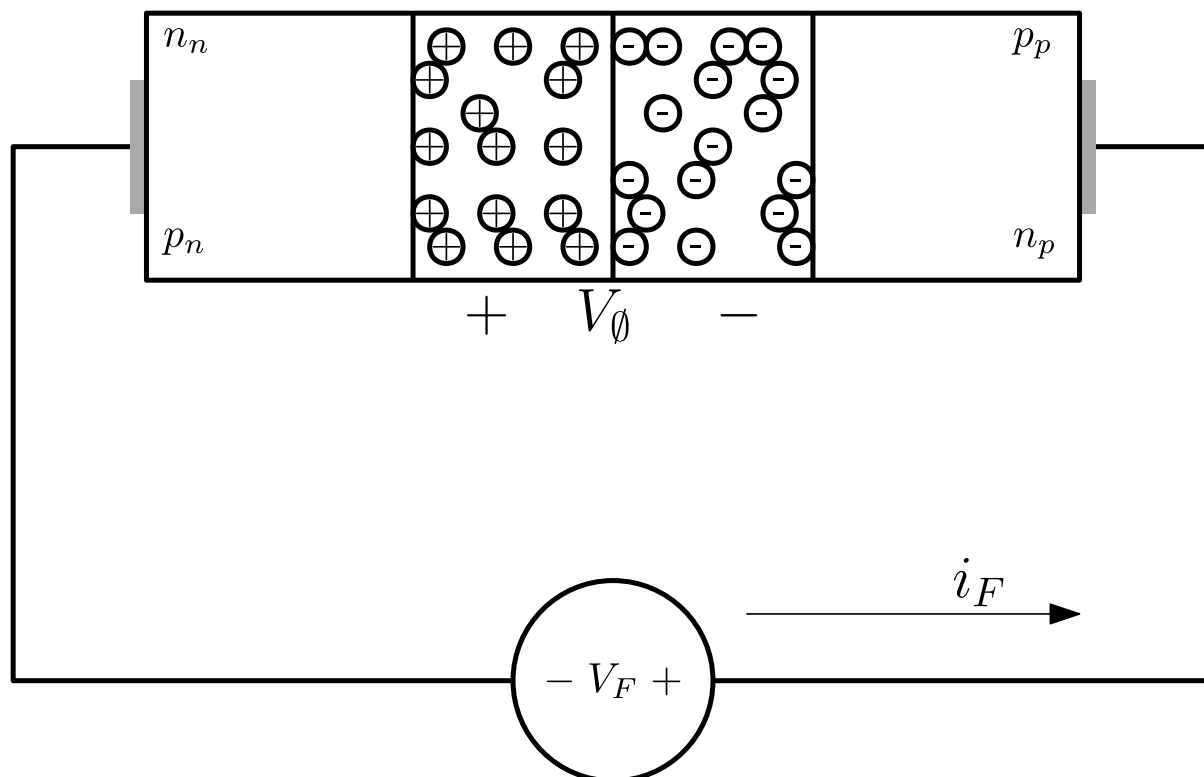
Equilibrium

- Open circuit
- Depletion region forms with separated and fixed-in-place charges, setting up an internal E -field.
- Built-in potential V_0 .

Reverse bias

- **Same direction** as the built-in field and V_0 .
- No real change in current (≈ 0).
- Depletion width increases with more reverse bias.
- Effect is a **voltage-variable capacitance**.

2. Forward bias



Revisit the built-in potential:

$$V_0 = \frac{k_B T}{q} \ln \left(\frac{p_p}{p_n} \right) \quad (1)$$

$$V_0 = V_T \ln \left(\frac{n_n}{n_p} \right). \quad (2)$$

Solve for the *minority* carrier concentrations in equilibrium:

- $p_n(\text{equ}) =$

- $n_p(\text{equ}) =$

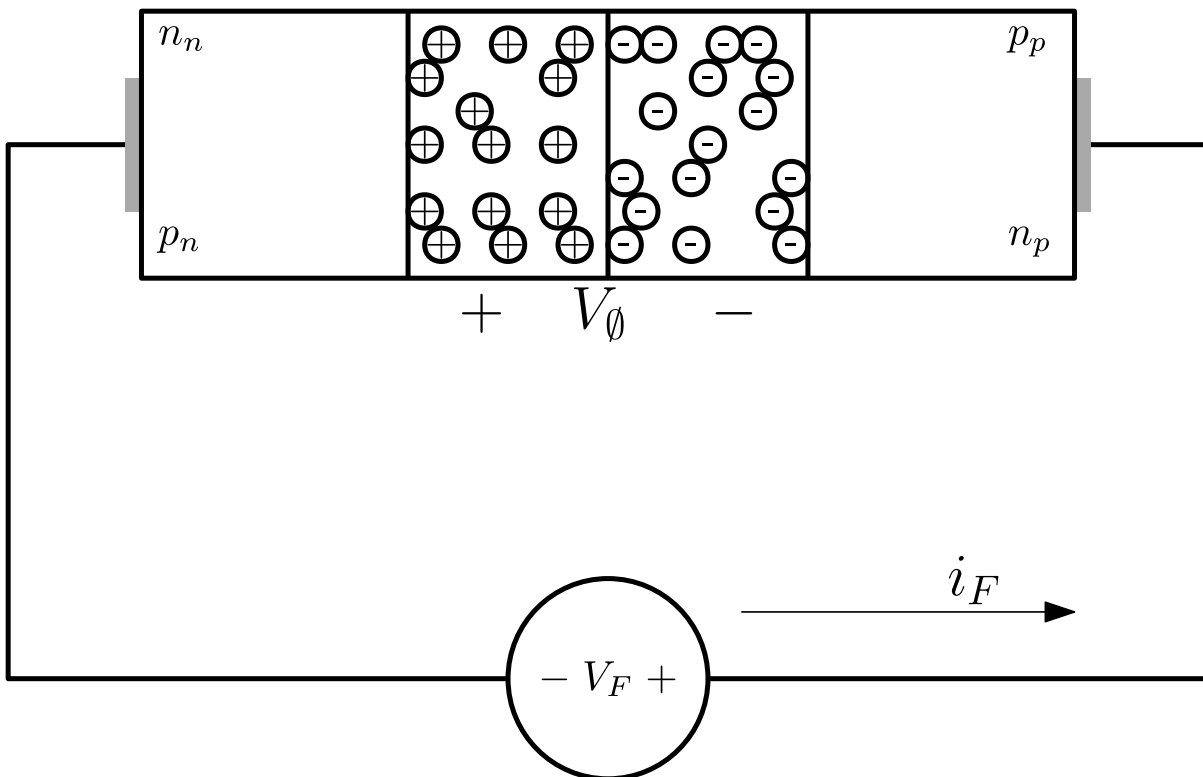


The barrier (V_0) is *reduced* by the external applied voltage V_F since they are in opposite directions.

We can compute the **new** minority carrier concentration by replacing $V_0 \Rightarrow V_0 - V_F$.

- $p_n(\text{fwd}) =$

- $n_p(\text{fwd}) =$



2.1. Towards current flow



ONLY the *minority* carriers are affected.

→ the *pn* junction is a **minority carrier device**.

The *change* in hole concentration is:

$$\Delta p_n = p_{n,\text{fwd}} - p_{n,\text{equ}} \quad (3)$$

$$\Delta p_n = \frac{p_p}{\exp\left(\frac{V_0 - V_F}{V_T}\right)} - \frac{p_p}{\exp\left(\frac{V_0}{V_T}\right)} \quad (4)$$

Collect the terms with V_0

$$\Delta p_n = \frac{1}{\exp\left(\frac{V_0}{V_T}\right)} \left[\right] \quad (5)$$

What we know:

- n_p and p_n increase exponentially lots,
- diffusion currents therefore also increase lots.

{ ... insert another day or so of semiconductor physics ... }

We also know that:

- Total current is proportional to this change in minority carrier concentration,
- $I_{\text{total}} \propto (\Delta p_n + \Delta n_p)$

So:

$$I_{\text{total}}(v_D, T) = \underbrace{A q n_i^2 \left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right)}_{I_S} \left[\exp\left(\frac{v_D}{V_T}\right) - 1 \right] \quad (6)$$

Circle all of the parts where temperature is buried.

2.2. Shockley diode equation

$$i_D = I_S \left[\exp\left(\frac{v_D}{V_T}\right) - 1 \right] \quad (7)$$

The -1 makes things difficult, can it be dropped? Continue here.