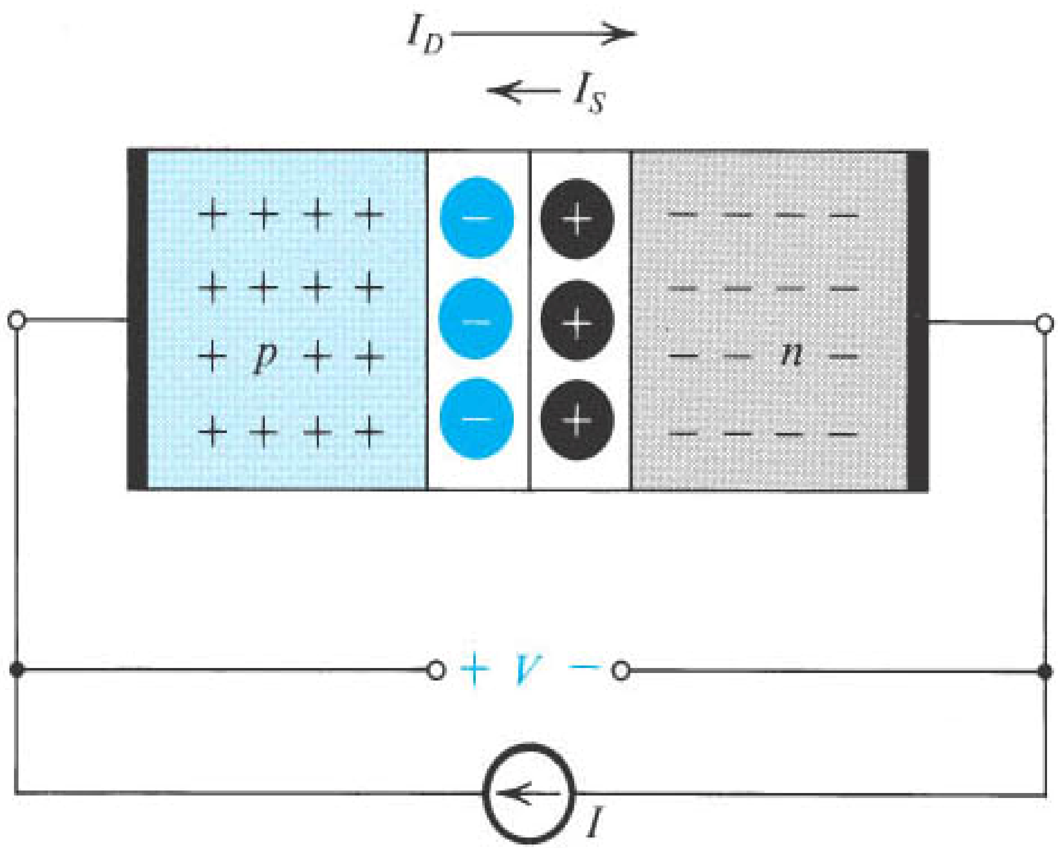
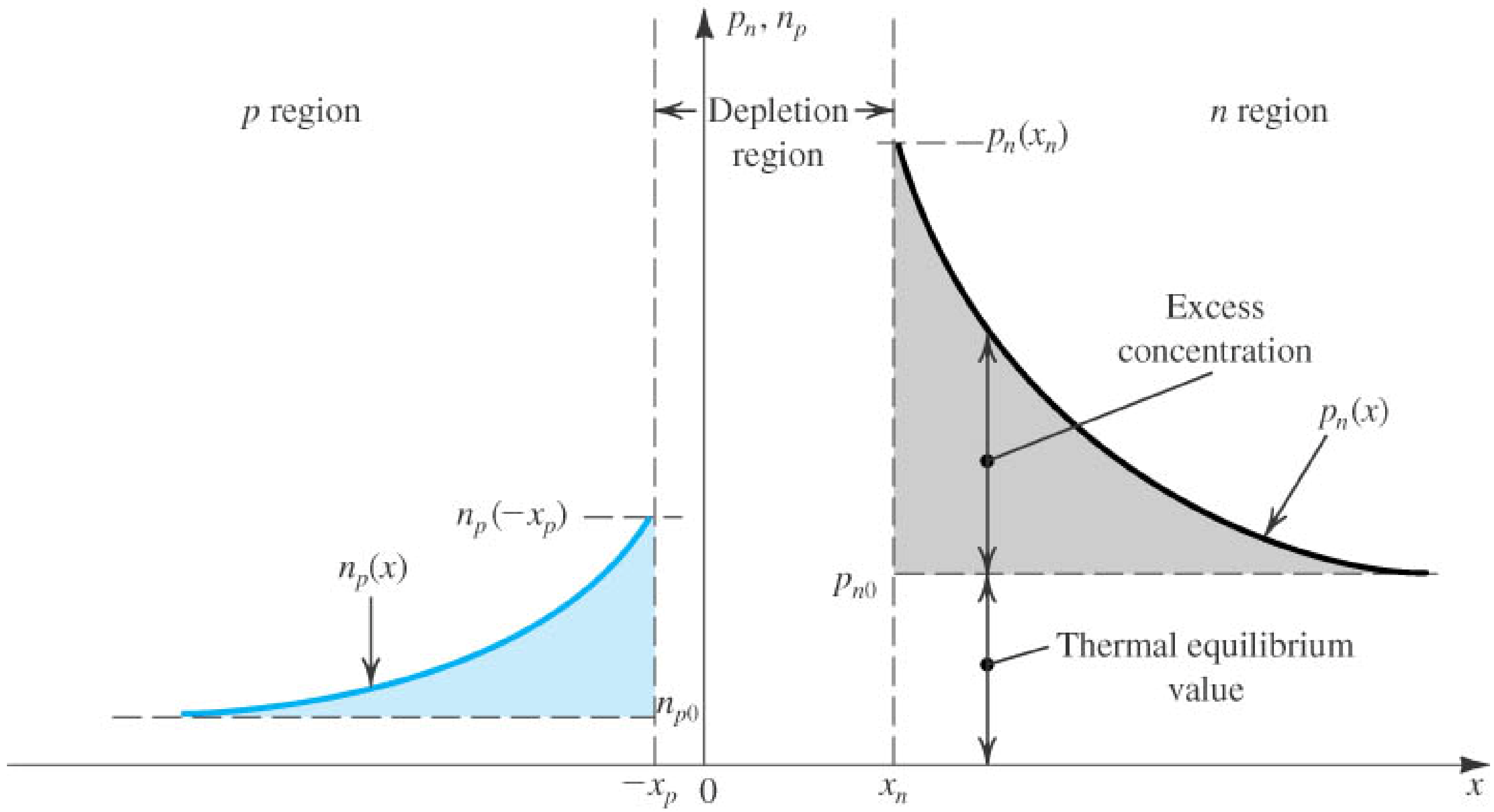
The *pn* Junction Under Bias Conditions

The *pn* Junction Under Forward-Bias Conditions



- The *pn* junction excited by a constant-current source supplying a current *I* in the forward direction.
- The depletion layer narrows and the barrier voltage decreases by *V* volts, which appears as an external voltage in the forward direction.

The *pn* Junction Under Forward-Bias Conditions



Minority-carrier distribution in a forward-biased *pn* junction. It is assumed that the *p* region is more heavily doped than the *n* region; $N_A >> N_D$.

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Excess minority carrier concentration:

$$p_n(x_n) = p_{n0}e^{v/V_T}$$

$$n_p(-x_p) = n_{p0}e^{v/V_T}$$

- Exponential relationship
- Small voltage incremental give rise to great incremental of excess minority carrier concentration.

The *pn* Junction Under Forward-Bias Conditions

Distribution of excess minority concentration:

$$p_n(x) = p_{no} + [p_n(x_n) - p_{n0}]e^{-(x-x_n)/L_p}$$

$$n_p(x) = n_{p0} + [n_p(-x_p) - n_{p0}]e^{(x+x_p)/L_n}$$

Where

$$L_p = \sqrt{D_p \tau_p}$$

$$L_n = \sqrt{D_n \tau_n}$$

are called excess-minority-carrier lifetime. τ_n, τ_p

The *pn* Junction Under Forward-Bias Conditions

The total current can be obtained by the diffusion current of majority carriers.

$$
\begin{aligned}
I &= I_{pD} + I_{nD} \\
&= A(J_{pD} + J_{nD}) \\
&= A\left(-q \left.\frac{dp(x)}{dx}\right|_{x=x_n} + q \left.\frac{dn(x)}{dx}\right|_{x=-x_p}\right) \\
&= Aq\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)\left(e^{V/V_T} - 1\right)
\end{aligned}
$$

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The saturation current is given by :

$$I_s = qA\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)$$

$$= qAn_i^{\,2}\left(\frac{D_p}{L_p n_D} + \frac{D_n}{L_n n_A}\right)$$

The *pn* Junction Under Forward-Bias Conditions

I-V characteristic equation:

$$i = I_s \left(e^{v / nV_T} - 1 \right)$$

- Exponential relationship, nonlinear.
- I_s is called saturation current, strongly depends on temperature.
- V_T is thermal voltage.

The *pn* Junction Under Forward-Bias Conditions

assuming V_1 at I_1 and V_2 at I_2

then:

$$V_2 - V_1 = nV_T \ln \frac{I_2}{I_1} = 2.3nV_T \lg \frac{I_2}{I_1}$$

** For a decade changes in current, the diode voltage drop changes by 60mv (for n=1) or 120mv (for n=2).*

The *pn* Junction Under Forward-Bias Conditions

- Turn-on voltage

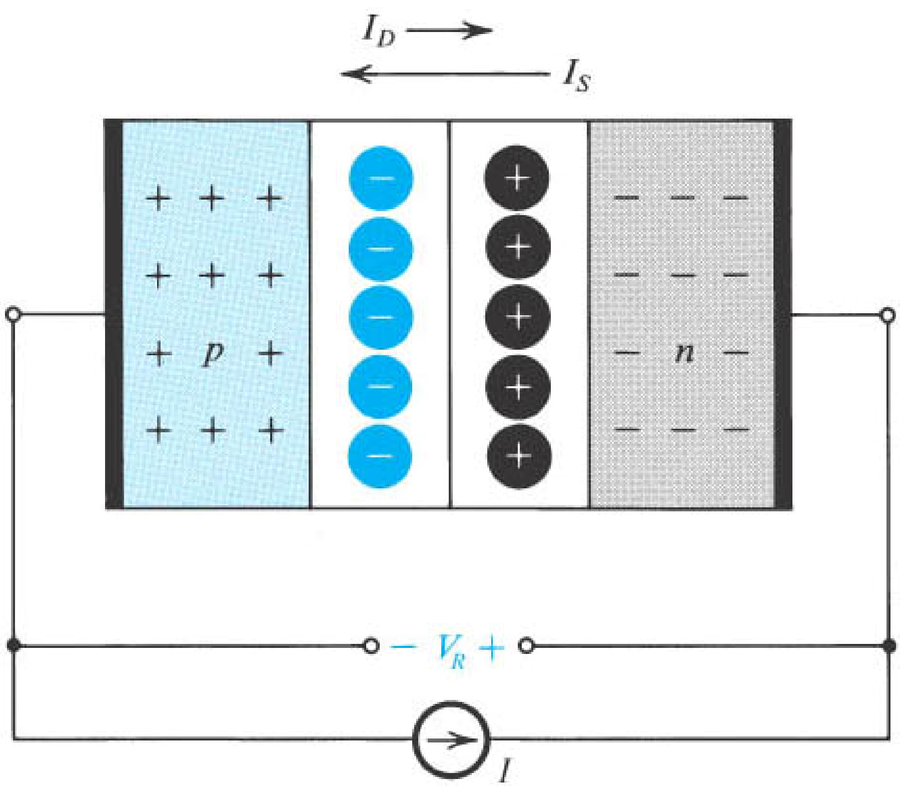
  A conduction diode has approximately a constant voltage drop across it. It's called turn-on voltage.

$$V_{D(on)} = 0.7V$$ For silicon

$$V_{D(on)} = 0.25V$$ For germanium

- Diodes with different current rating will exhibit the turn-on voltage at different currents.
- Negative TC, $TC = -2mv/^{\circ}C$

The *pn* Junction Under Reverse-Bias Conditions



➢The *pn* junction excited by a constant-current source I in the reverse direction.

➢To avoid breakdown, I is kept smaller than I_S.

➢Note that the depletion layer widens and the barrier voltage increases by V_R volts, which appears between the terminals as a reverse voltage.

The *pn* Junction Under Reverse-Bias Conditions

I-V characteristic equation:

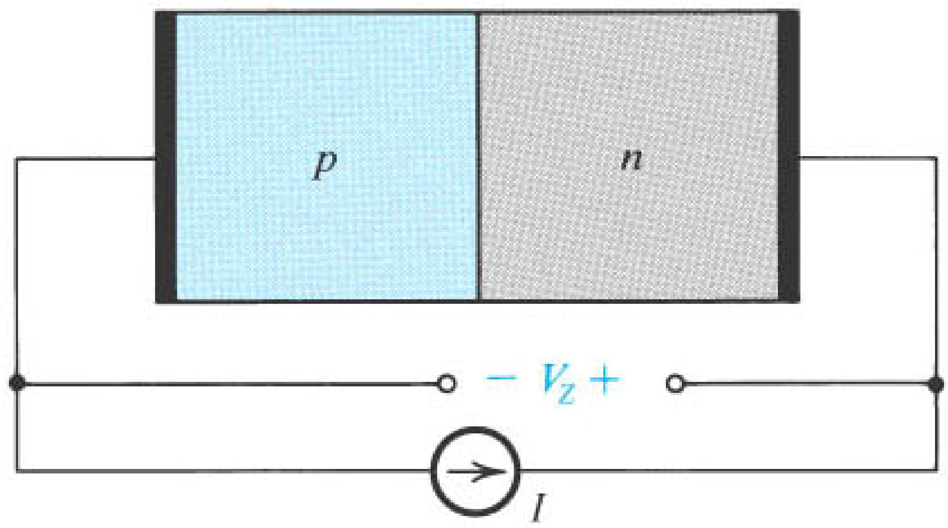
$$i = I_s$$ Independent of voltage。

Where I_s is the saturation current, it is proportional to n_i^2 which is a strong function of temperature.

$$I_s = qA\left(\frac{D_p p_{n0}}{L_p} + \frac{D_n n_{p0}}{L_n}\right)$$

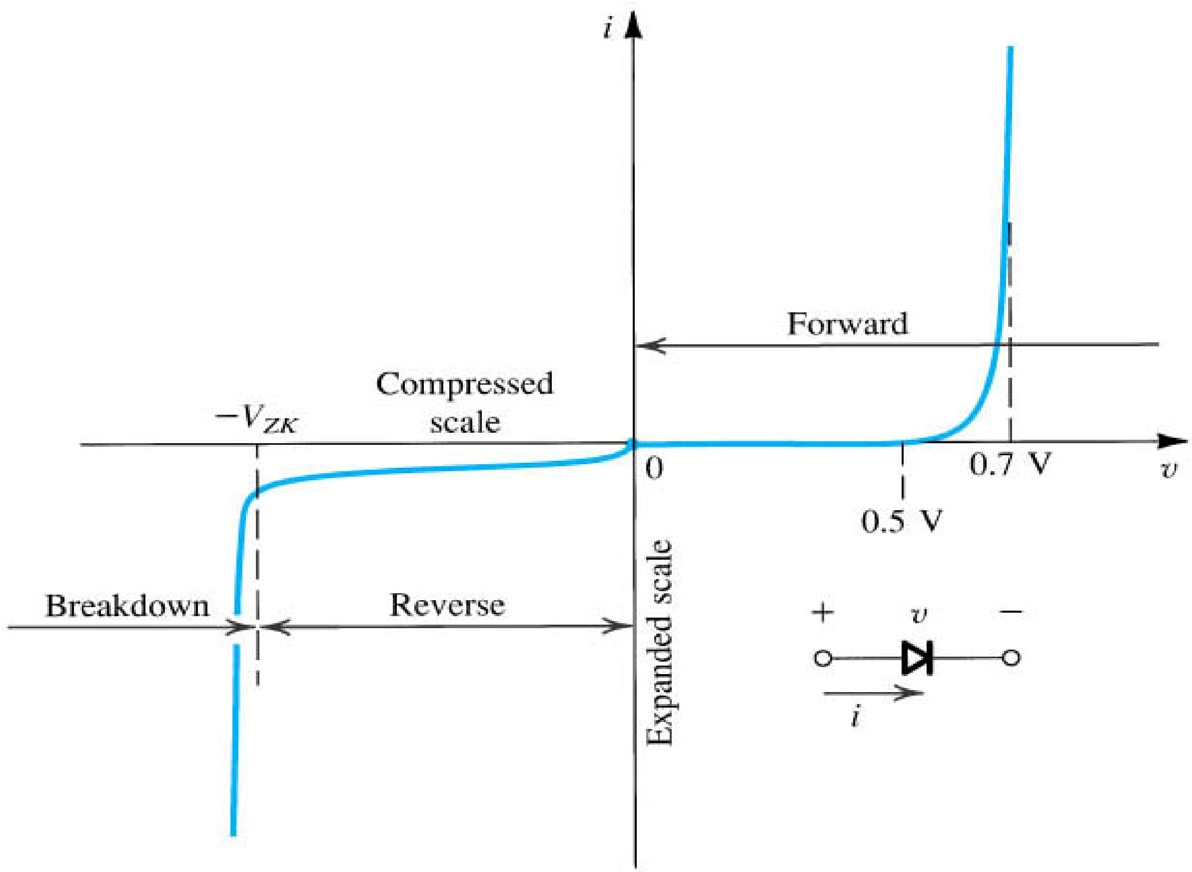
$$= qAn_i^2\left(\frac{D_p}{L_p n_D} + \frac{D_n}{L_n n_A}\right)$$

The *pn* Junction Under Reverse-Bias Conditions



The *pn* junction excited by a reverse-current source *I*, where $I > I_S$. The junction breaks down, and a voltage V_Z, with the polarity indicated, develops across the junction.

I-V Characteristics



The diode *i–v* relationship with some scales expanded and others compressed in order to reveal details