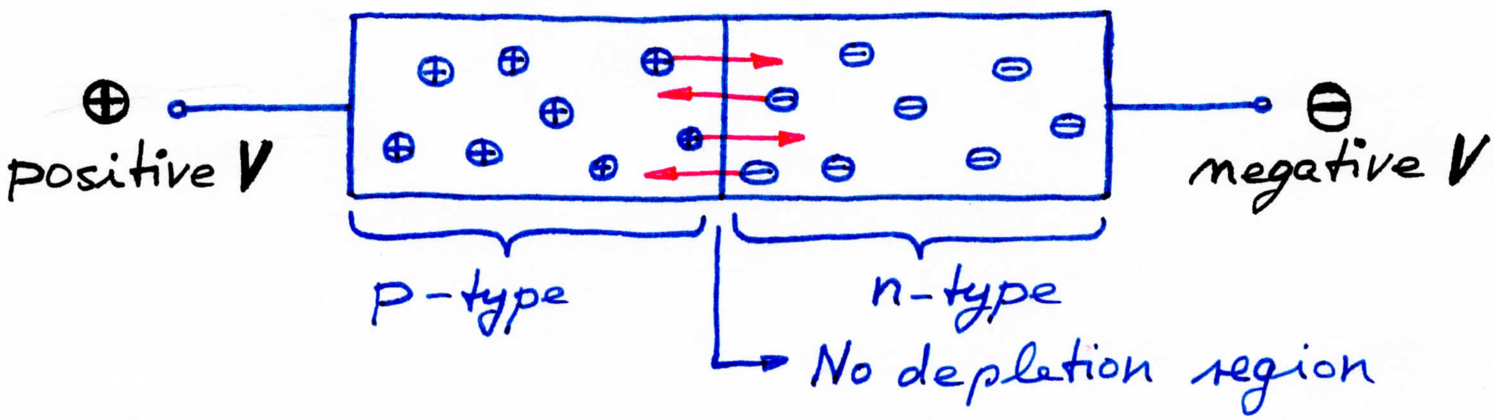
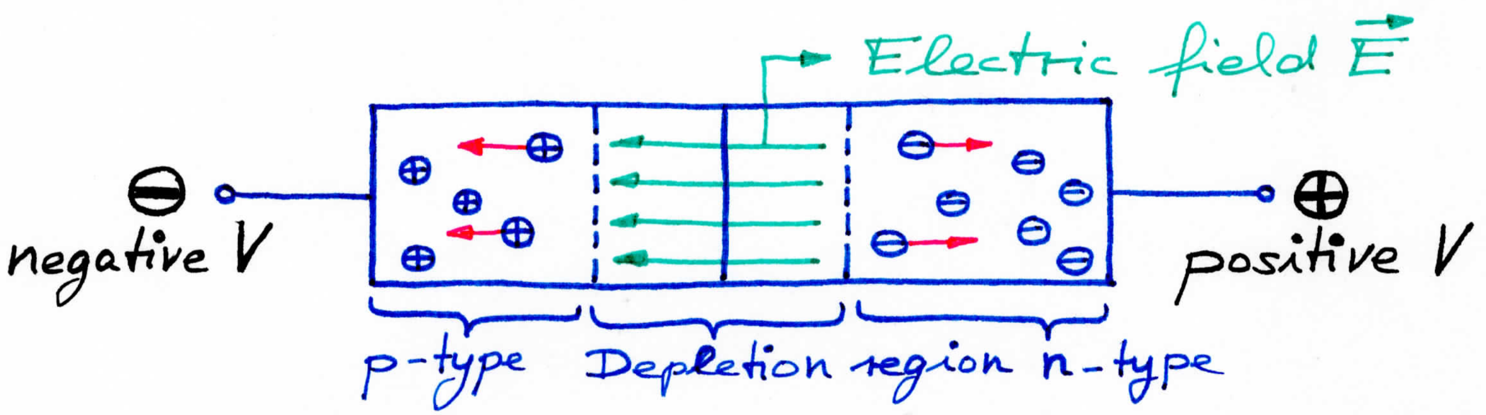
Zener diode

Recall : Diode forward direction



Recall : Diode reverse direction

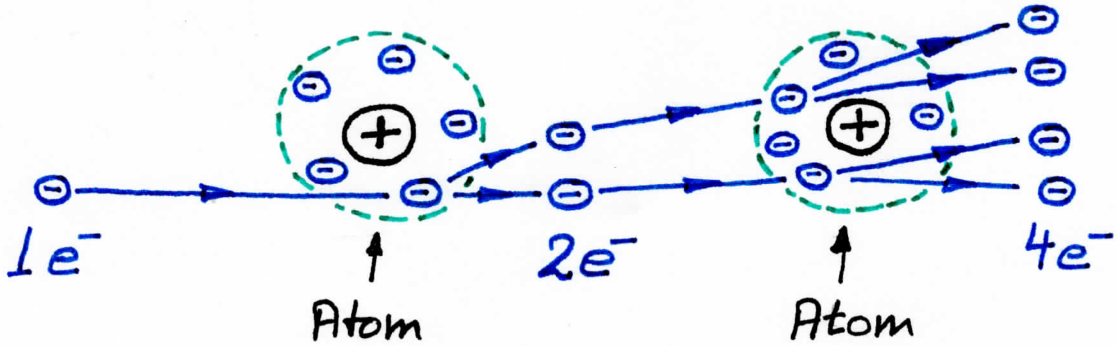


If $V_{Diode} = -10V$, where does the voltage drop across ? $\Rightarrow$ Depletion region $\Rightarrow$ Why?

Every material has a breakdown electric field. For Si $\vec{E}_{breakdown} = 3 \times 10^5 \, V/cm$ $= 30 \, V/\mu m$

What happens if $\vec{E} \geq \vec{E}_{breakdown}$?

$\Rightarrow$ Impact ionization $\Rightarrow$ Avalanche multiplication



$\Rightarrow$ Current increases strongly for $\vec{E} \geq \vec{E}_{breakdown}$

$\Rightarrow$ Is silicon material destroyed during breakdown?

$\Rightarrow$ No! Only electronic processes, no structural changes.

Other techical field: Electrical breakdown in air. What happens? Have you seen such phenomenon?

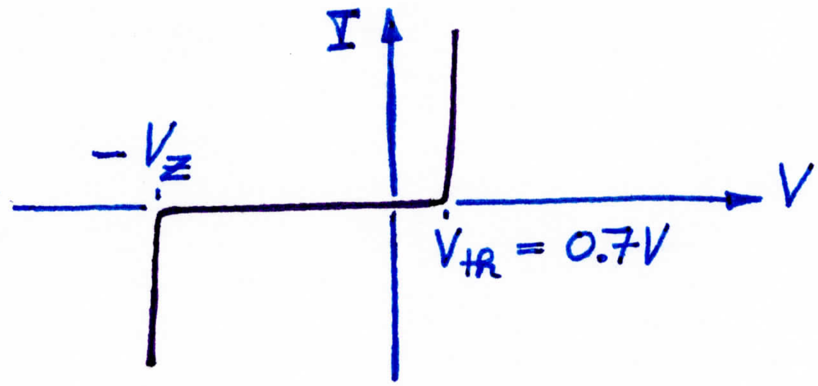
Zener diode: The width of the depletion region can be tuned by doping:

$$W_D = \sqrt{\frac{2\varepsilon}{e}\left(\frac{1}{N_A} + \frac{1}{N_D}\right) V_{bi}}$$

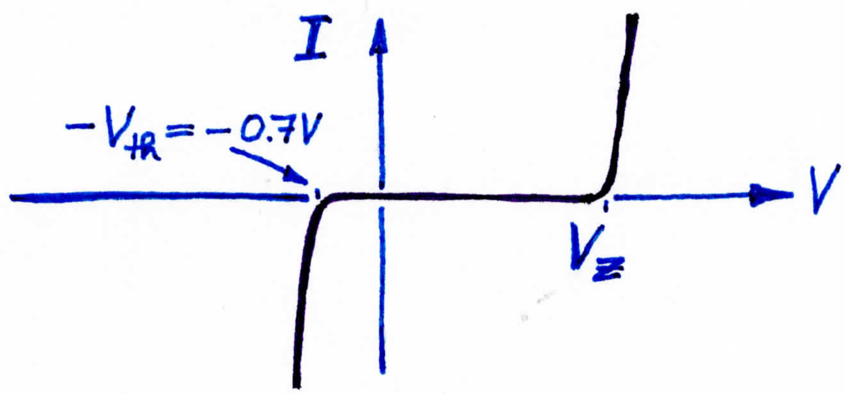
↳ Equation from Microelectronics course.

⇒ We can tune W_D, so that breakdown occurs at a desired voltage $V = V_{breakdown} = V_{Zener} = V_Z$

IV characteristic:



We typically operate Zener diode in reverse direction



Circuit symbol

Why this circuit symbol  ?

V_Z can be 5V, 10V, 18V...

$$V < V_Z \Rightarrow r_{Zener} = \frac{dV}{dI} \approx \infty$$

$$V \geq V_Z \Rightarrow r_{Zener} = \frac{dV}{dI} \approx 0$$

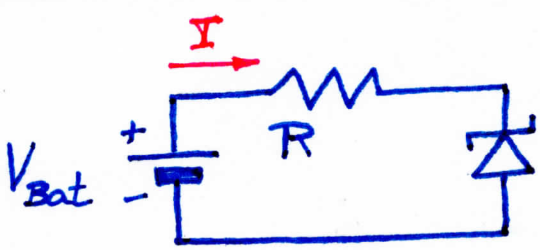
IV characteristic (quantitative)

$$I \approx I_0 \, e^{(V - V_Z)/V_t}$$

↳ regular diode turn-on not included

↳ can be smaller than 26 mV, so turn-on can be very abrupt.

Basic Zener diode circuit



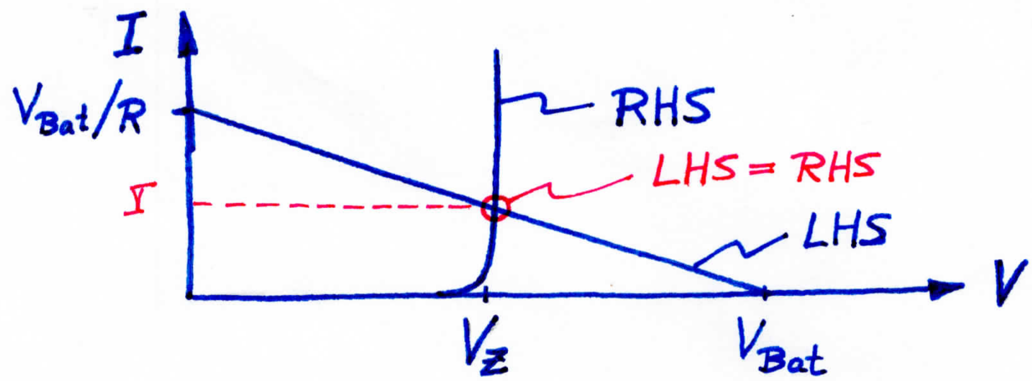
What is current I? Similar to diode discussion, the equation based on **KVL** cannot be solved analytically.

⇒ We need alternative solutions.

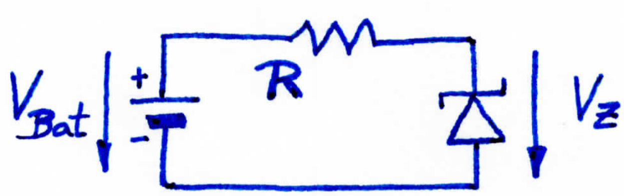
1. Graphical solution based on **load line**

KVL: $$V_{Bat} = IR + V_Z(I)$$

$$\Rightarrow \underbrace{V_{Bat} - IR}_{LHS} = \underbrace{V_Z(I)}_{RHS}$$



2. Approximate analytical solution by assuming $V_Z = \text{constant}$ (e.g. $V_Z = 10V$)



$$V_{Bat} = IR + V_Z$$

$$\Rightarrow I = \frac{V_{Bat} - V_Z}{R}$$

Example: $V_{Bat} = 10V \quad V_Z = 5V \quad R = 1\,k\Omega$

$$\Rightarrow I = \frac{V_{Bat} - V_Z}{R} = \frac{10V - 5V}{1\,k\Omega} = 5\,mA$$