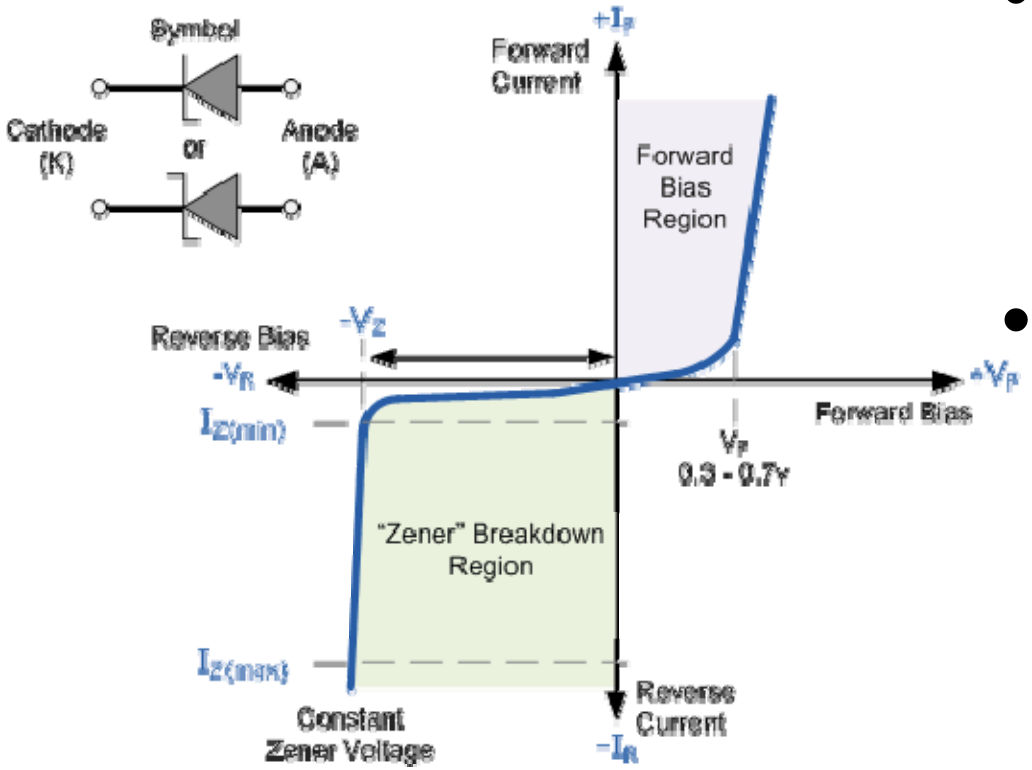
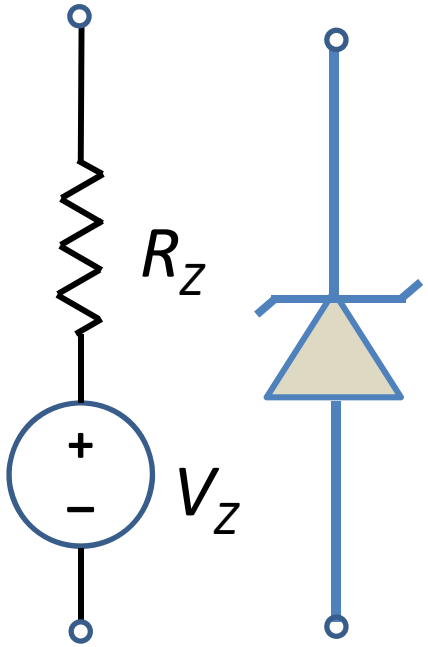
Diode Breakdown

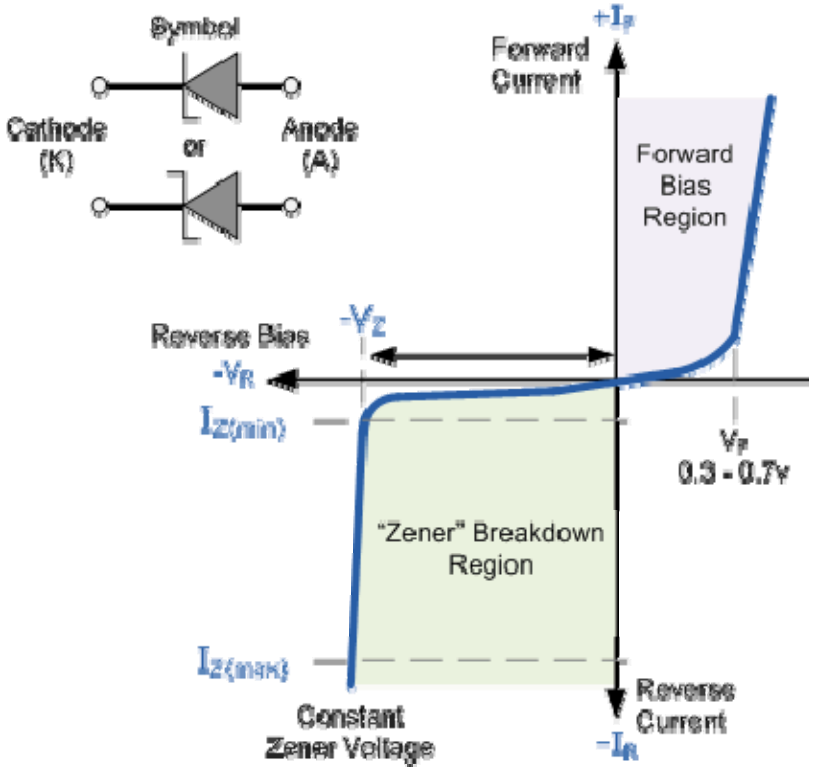


V_Z: breakdown voltage

- Reverse bias increase => E field increases => breakdown
- Two breakdown mechanisms:
  - Avalanche breakdown ("chain reaction")
  - Zener breakdown (carrier tunneling)

Diode Breakdown – Zener Diodes



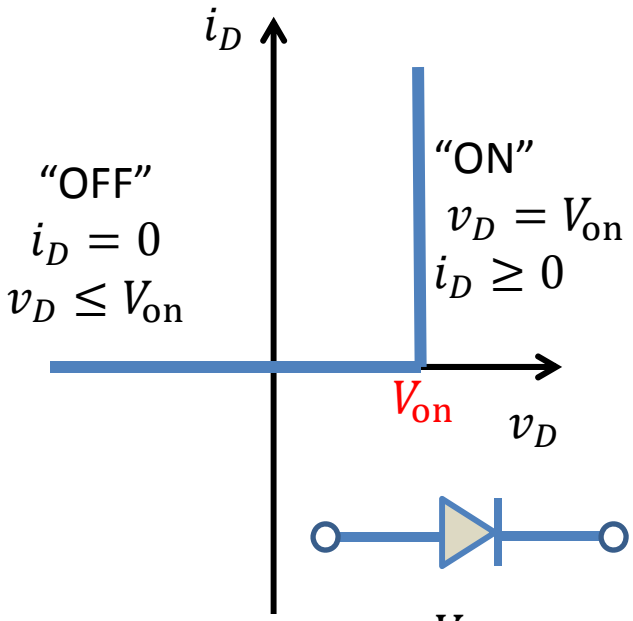


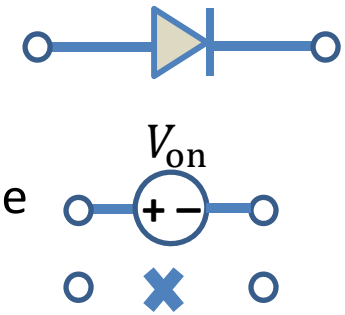
Model for reverse breakdown:

Voltage source in series with a small resistor.

Piecewise linear model

Constant voltage drop

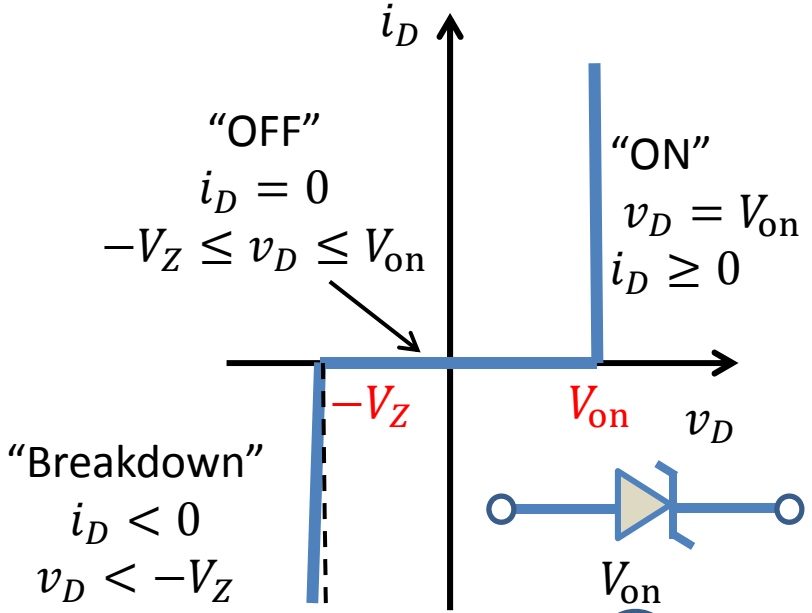


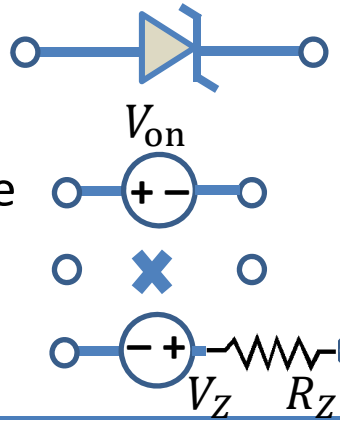


ON: voltage source

OFF: open circuit

Piecewise linear



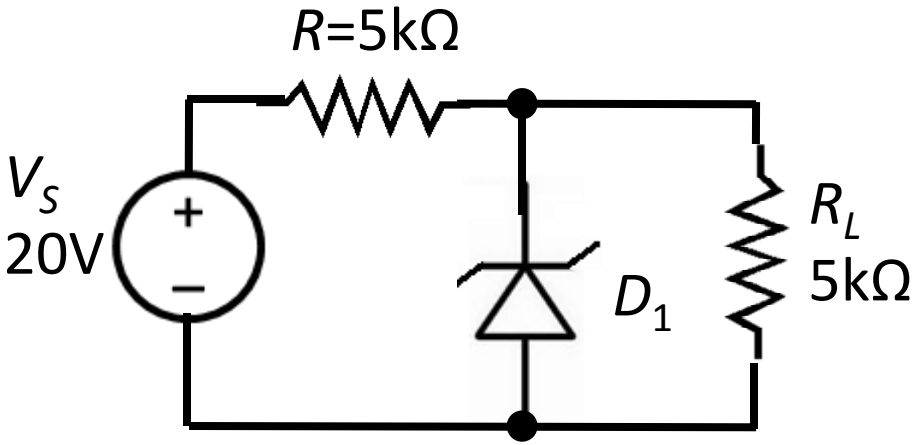


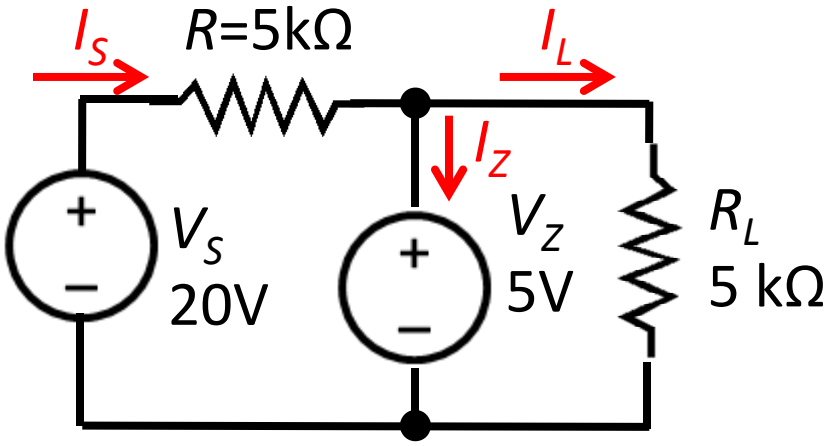
ON: voltage source

OFF: open circuit

Breakdown: linear

Voltage Regulation ($R_Z = 0$)





Guess: Breakdown

$$I_S = \frac{V_S - V_Z}{R} = 3\ \text{mA},\ I_L = \frac{V_Z}{R_L} = 1\ \text{mA}$$

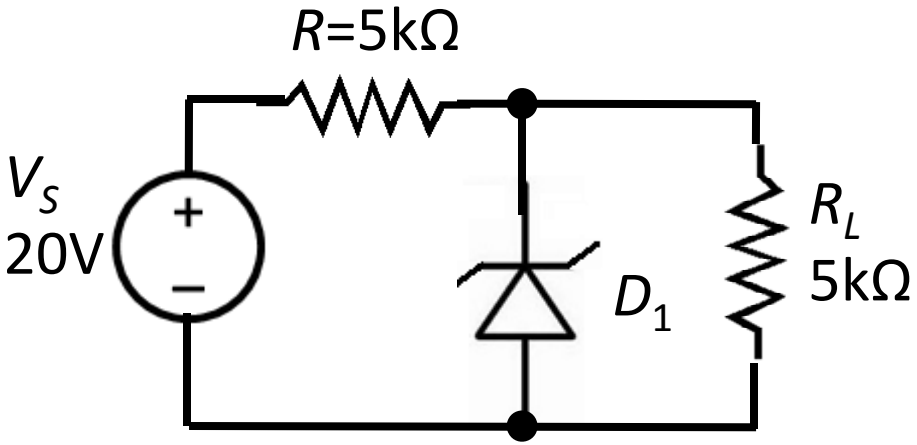
$$I_Z = I_S - I_L = 2\ \text{mA} > 0.$$

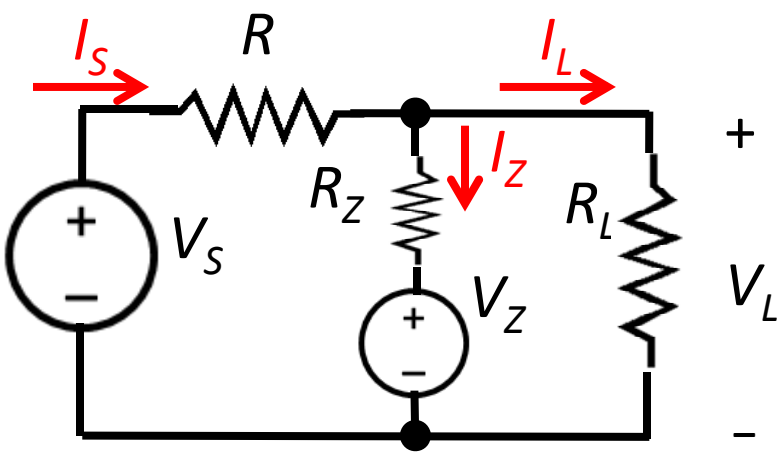
$$I_D = -I_Z < 0.\ \text{Consistent with “breakdown”}$$

$$I_Z = \frac{V_S - V_Z}{R} - \frac{V_Z}{R_L} > 0 \Rightarrow R_L > \frac{R}{\frac{V_S}{V_Z} - 1} = \frac{5\ \text{k}\Omega}{\frac{20\ \text{V}}{5\ \text{V}} - 1} = 1.67\ \text{k}\Omega$$

The minimum load resistance to maintain regulation is $\frac{R}{\frac{V_S}{V_Z} - 1}$

Voltage Regulation ($R_Z \neq 0$)





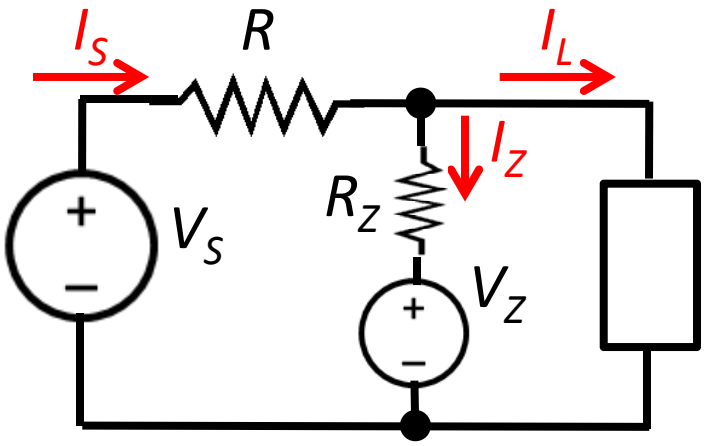
$$I_S = I_Z + I_L \Rightarrow \frac{V_S - V_L}{R} = \frac{V_L - V_Z}{R_Z} + \frac{V_L}{R_L}$$

$$V_L = \left(\frac{V_S}{R} + \frac{V_Z}{R_Z}\right) / \left(\frac{1}{R} + \frac{1}{R_L} + \frac{1}{R_Z}\right)$$

Minimum R_L unchanged (I_Z=0 at threshold).

Voltage Regulation ($R_Z \neq 0$)

If the load sinks a given current I_L, then:



$$I_S = I_Z + I_L \Rightarrow \frac{V_S - V_L}{R} = \frac{V_L - V_Z}{R_Z} + I_L$$

$$V_L = \left(\frac{V_Z}{R_Z} + \frac{V_S}{R} - I_L\right) / \left(\frac{1}{R} + \frac{1}{R_Z}\right)$$

Voltage Regulation (constant I_L)

- $V_L = \left(\frac{V_Z}{R_Z} + \frac{V_S}{R} - I_L\right) / \left(\frac{1}{R} + \frac{1}{R_Z}\right)$
- Line regulation

$$\frac{dV_L}{dV_s} = \frac{R_Z}{R + R_Z}$$

- Load regulation

$$\frac{dV_L}{dI_L} = -\frac{RR_Z}{R + R_Z}$$