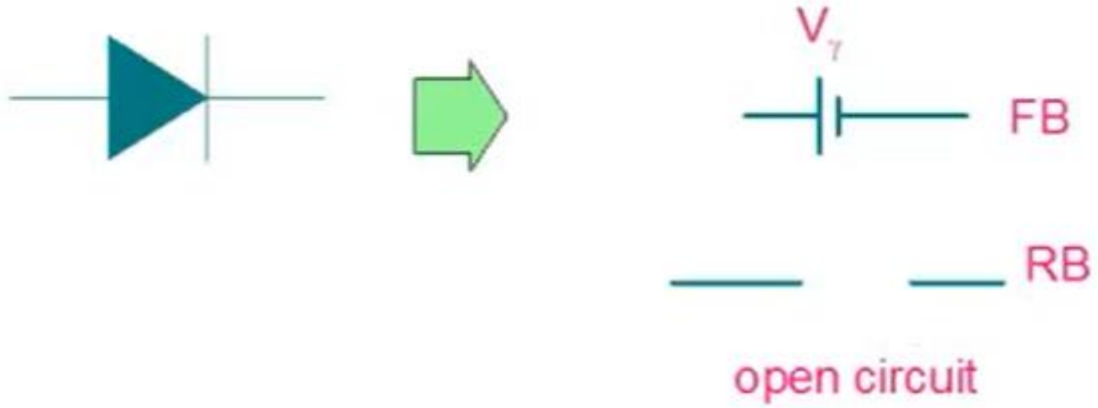
For hand analysis of circuits, we need simpler models!

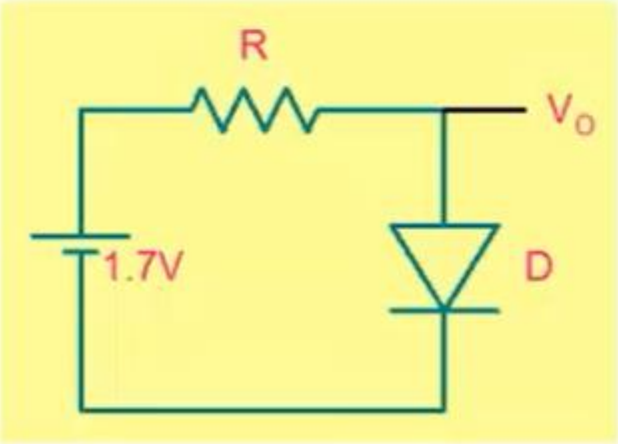
•Analysis using a non-linear diode model is relatively difficult and time consuming.

•It also does not give a symbolic expression that can provide insight and help in the design of the circuit.

Need SIMPLER and LINEAR Device Models



What should we take as diode drop?.....0.7V?



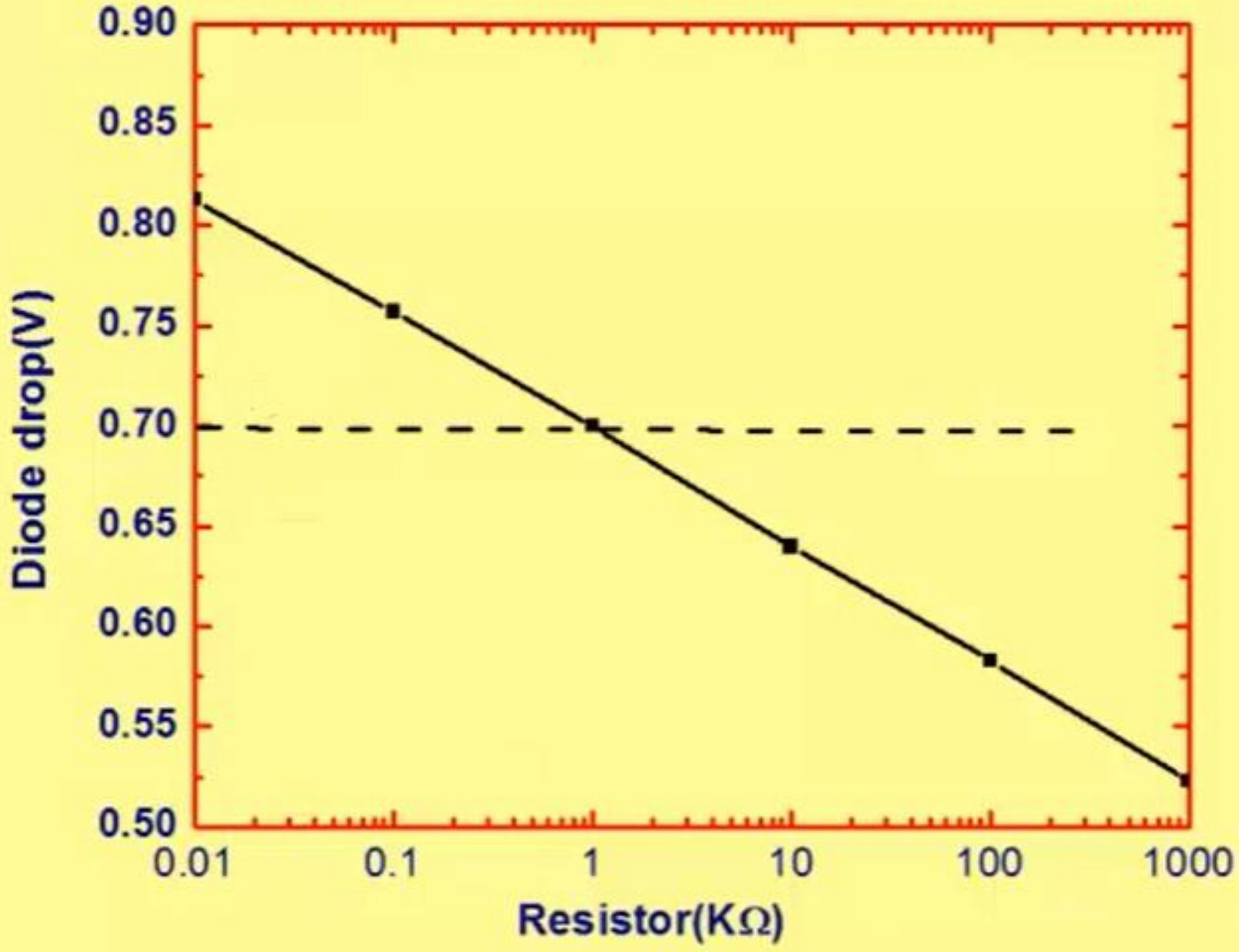
$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15}\ A$$

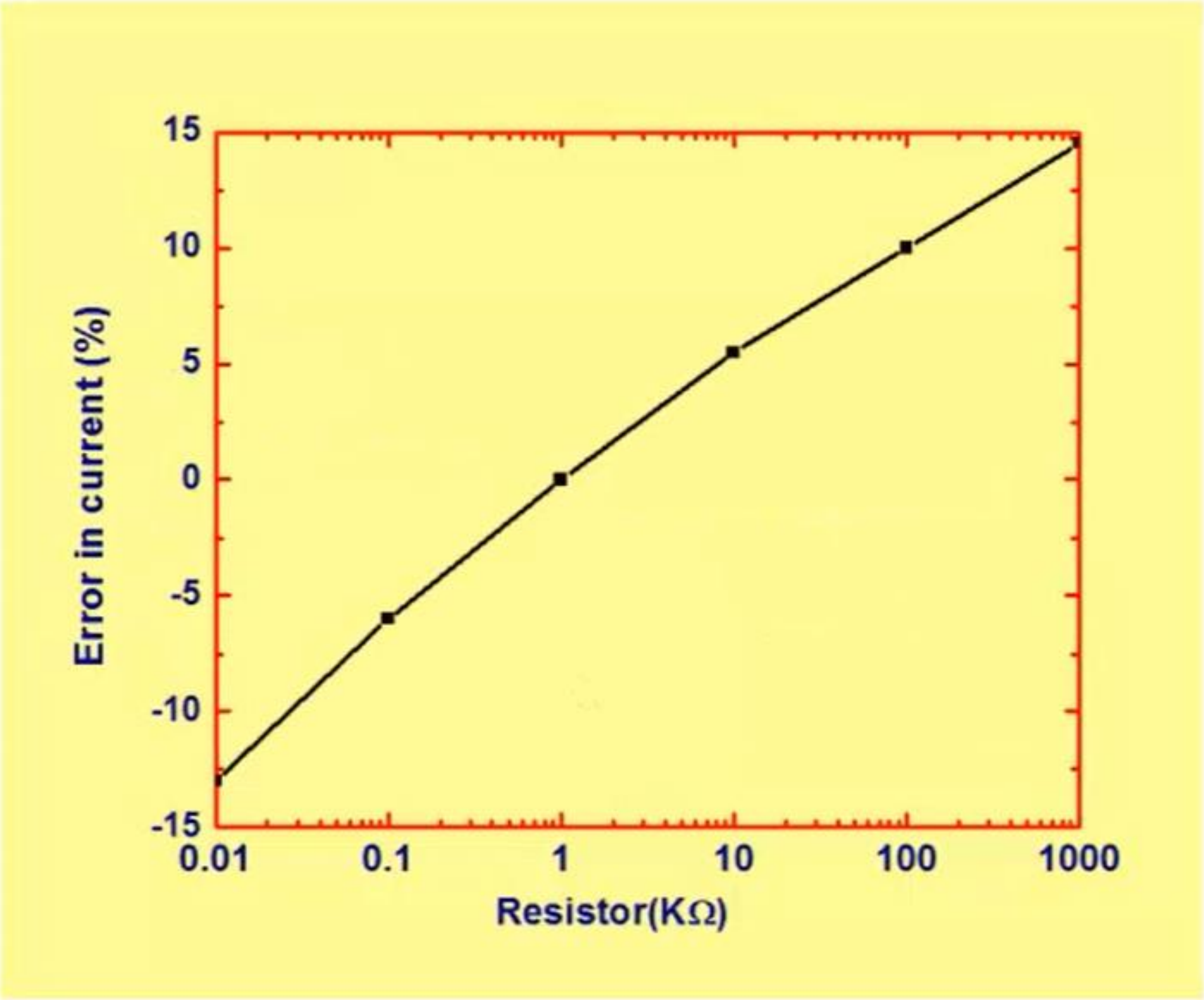
$$V_T = kT / q \cong 26\ mV \text{ at T = 300K}$$

$$R : 10\Omega \rightarrow 1M\Omega$$

Simple 0.7V model would predict: $I = \frac{1}{R}$

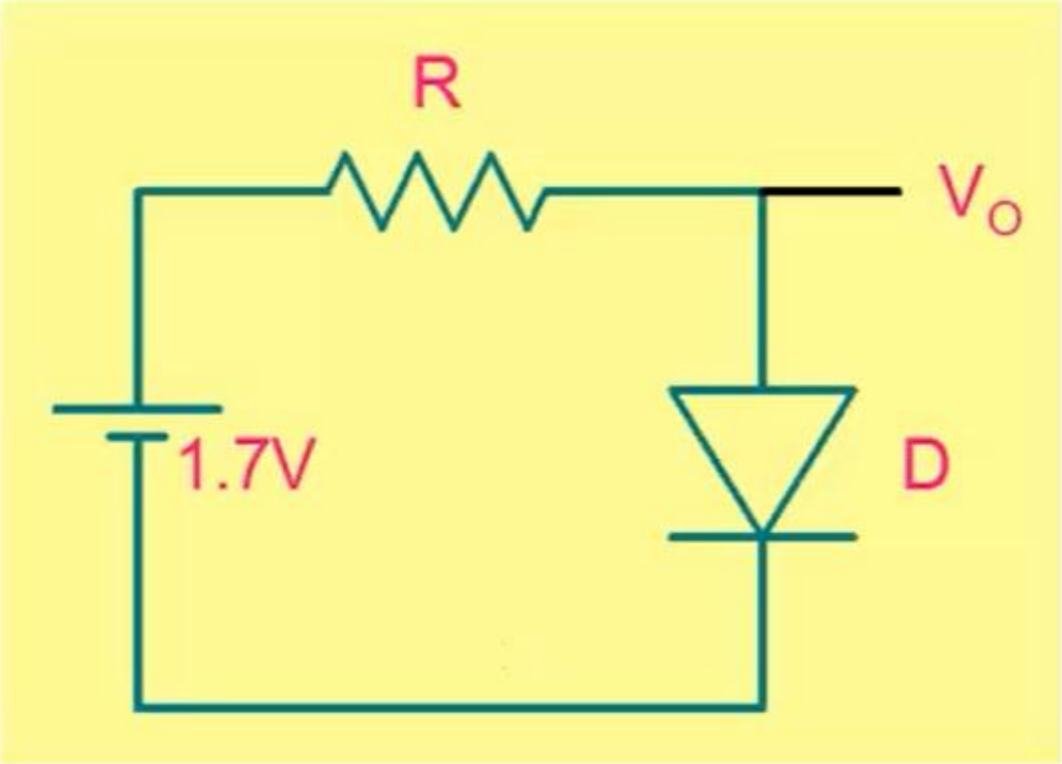


0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
Diode drop(V)
0.01
0.1
1
10
100
1000
Resistor(KΩ)


15
10
5
0
-5
-10
-15
Error in current (%)
0.01
0.1
1
10
100
1000
Resistor(KΩ)

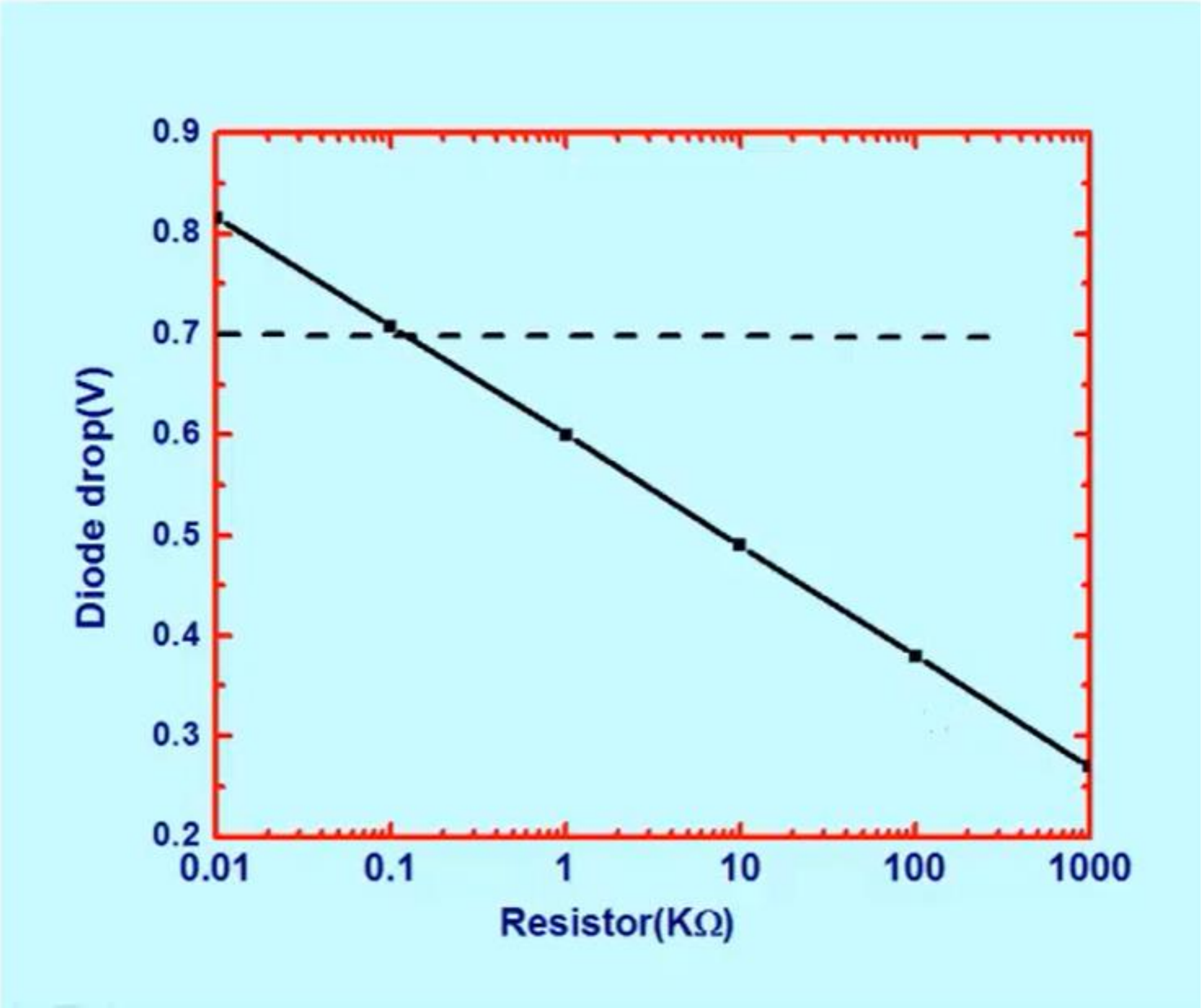
(100mA - 1μA)

Different Diode: ~1N4148

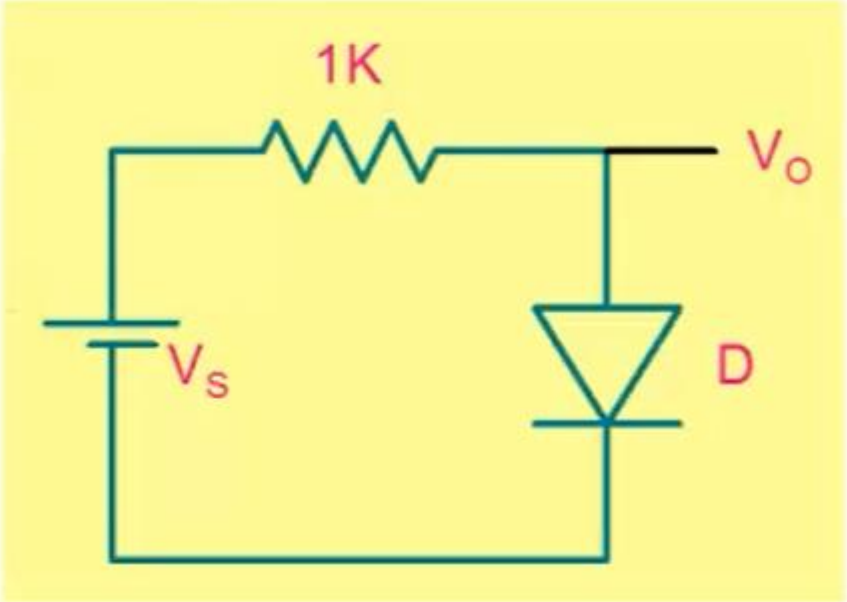


$$I = I_S \times \{\exp(\frac{V}{nV_T}) - 1\}$$

$$I_S = 5.9 \times 10^{-9}\,A\ ;\ n = 1.91$$


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Diode drop(V)
0.01
0.1
1
10
100
1000
Resistor(KΩ)

Constant diode voltage approximation becomes worse as applied voltage approaches the diode drop !



$$I = \frac{V_S - V_D}{R}$$

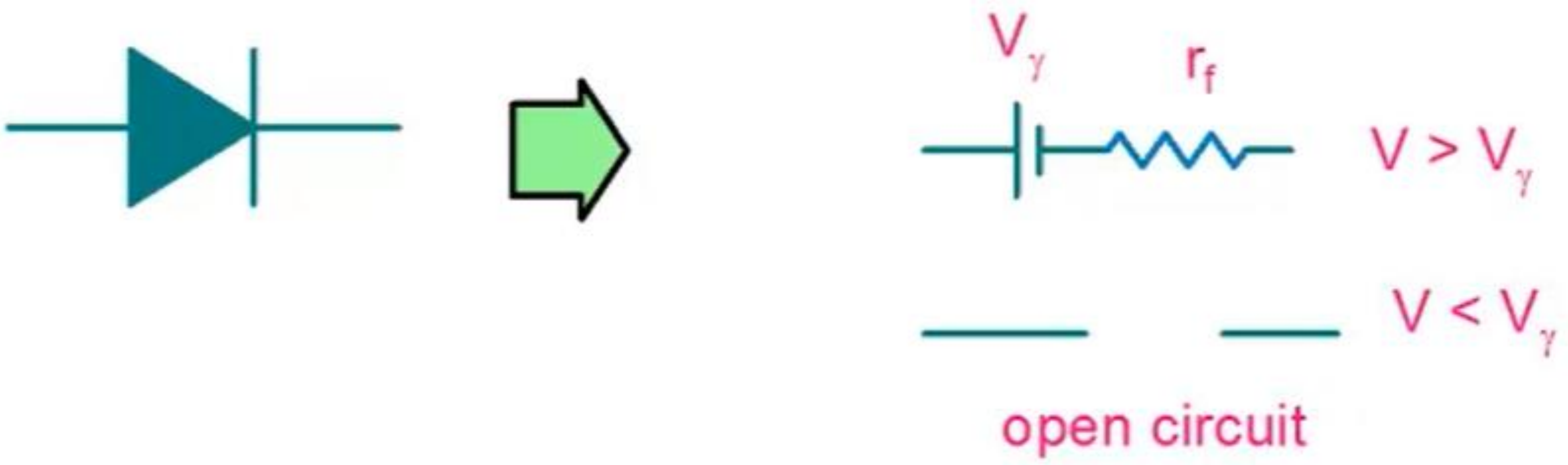
$$\Delta I = -\frac{\Delta V_D}{R}$$

$$\frac{\Delta I}{I} = -\left(\frac{\Delta V_D}{V_S - V_D}\right)$$

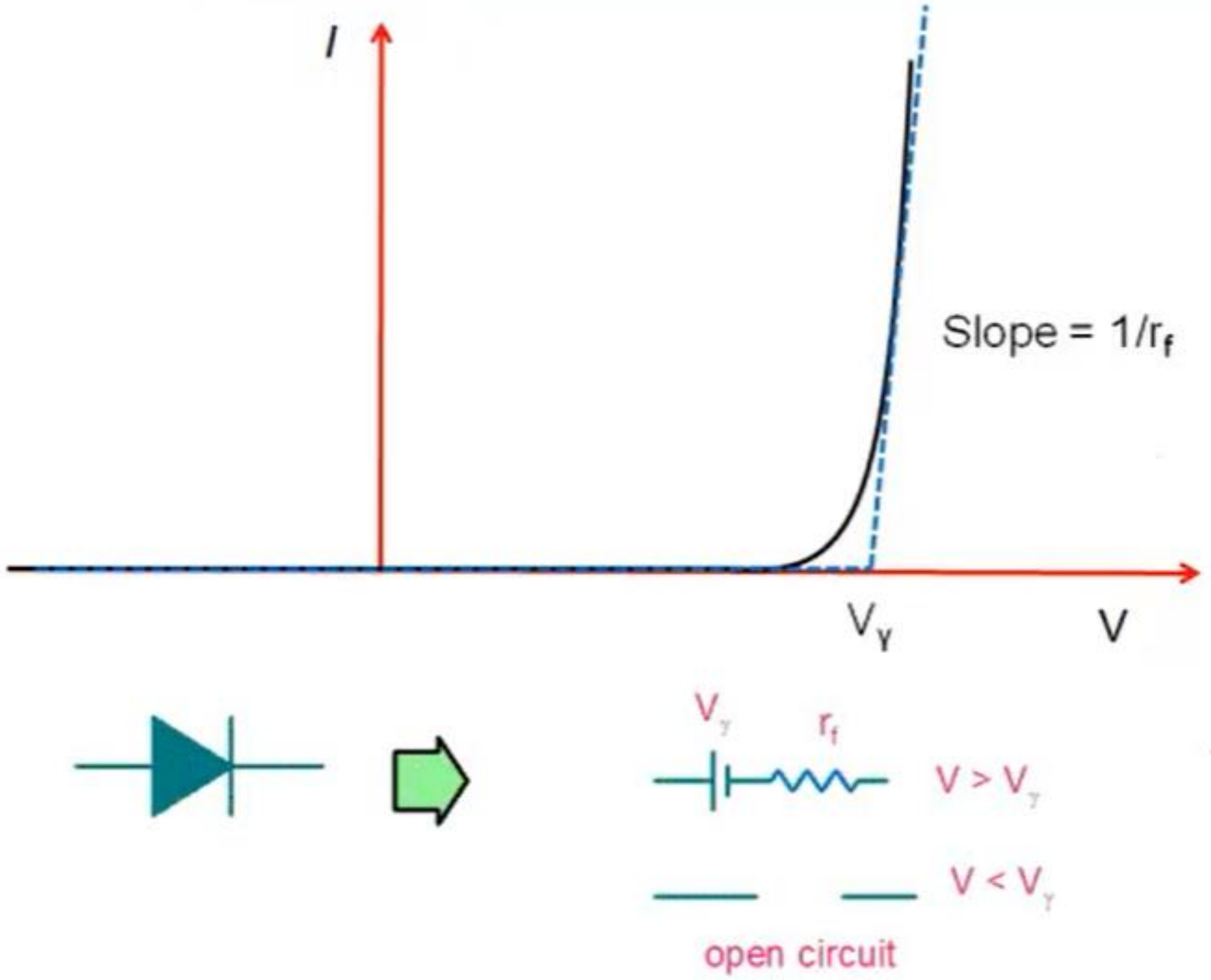
As V_s approaches $V_D \rightarrow \left(\frac{\Delta I}{I}\right)$ increases

Error was ~9% with 1.7 V but 63% with 0.8V supply

A better Diode Model



Piece-Wise Linear Model

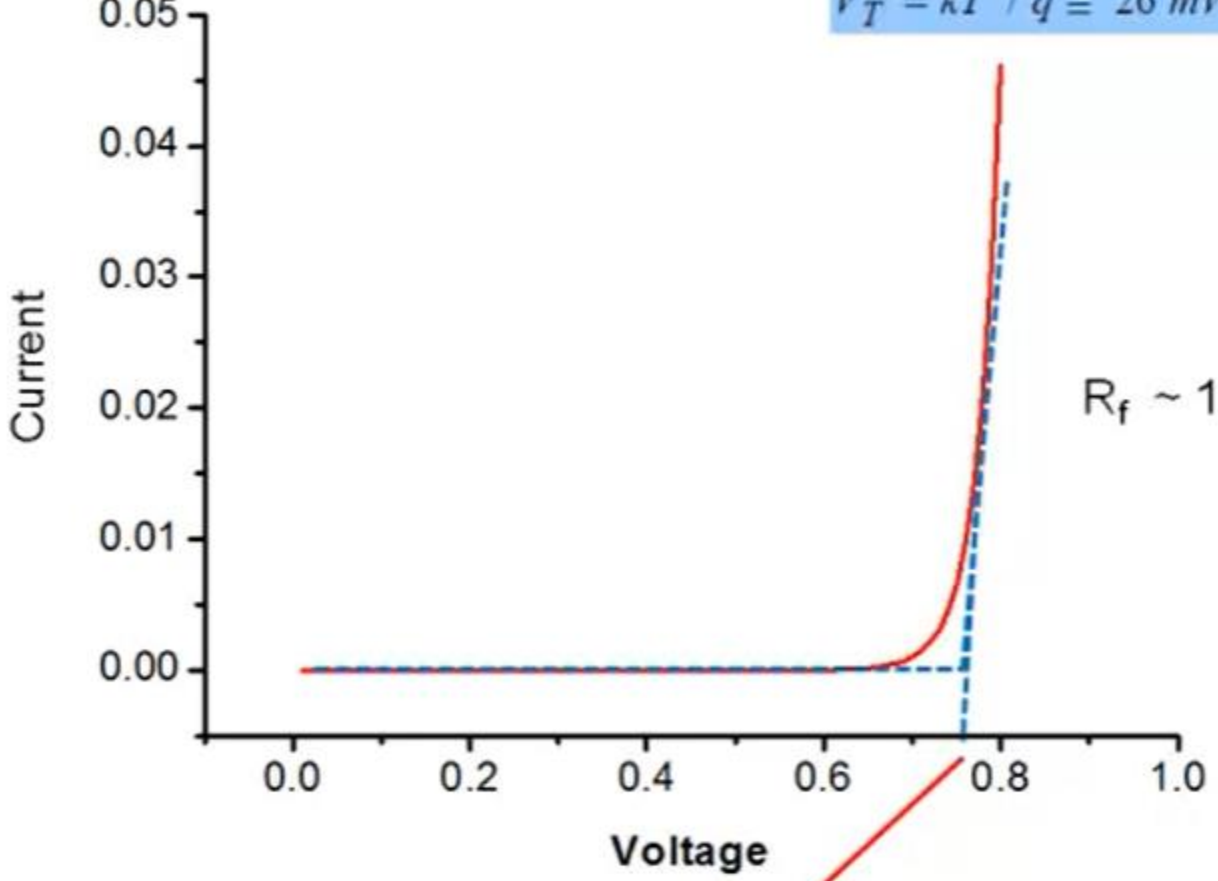


V_γ is called cut-in or turn-on voltage and depends on nature of diode and range of current considered

$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

$$I_S = 2 \times 10^{-15} A$$

$$V_T = kT / q \cong 26\ mV \text{ at } T = 300K$$



$R_f \sim 1.4\Omega$

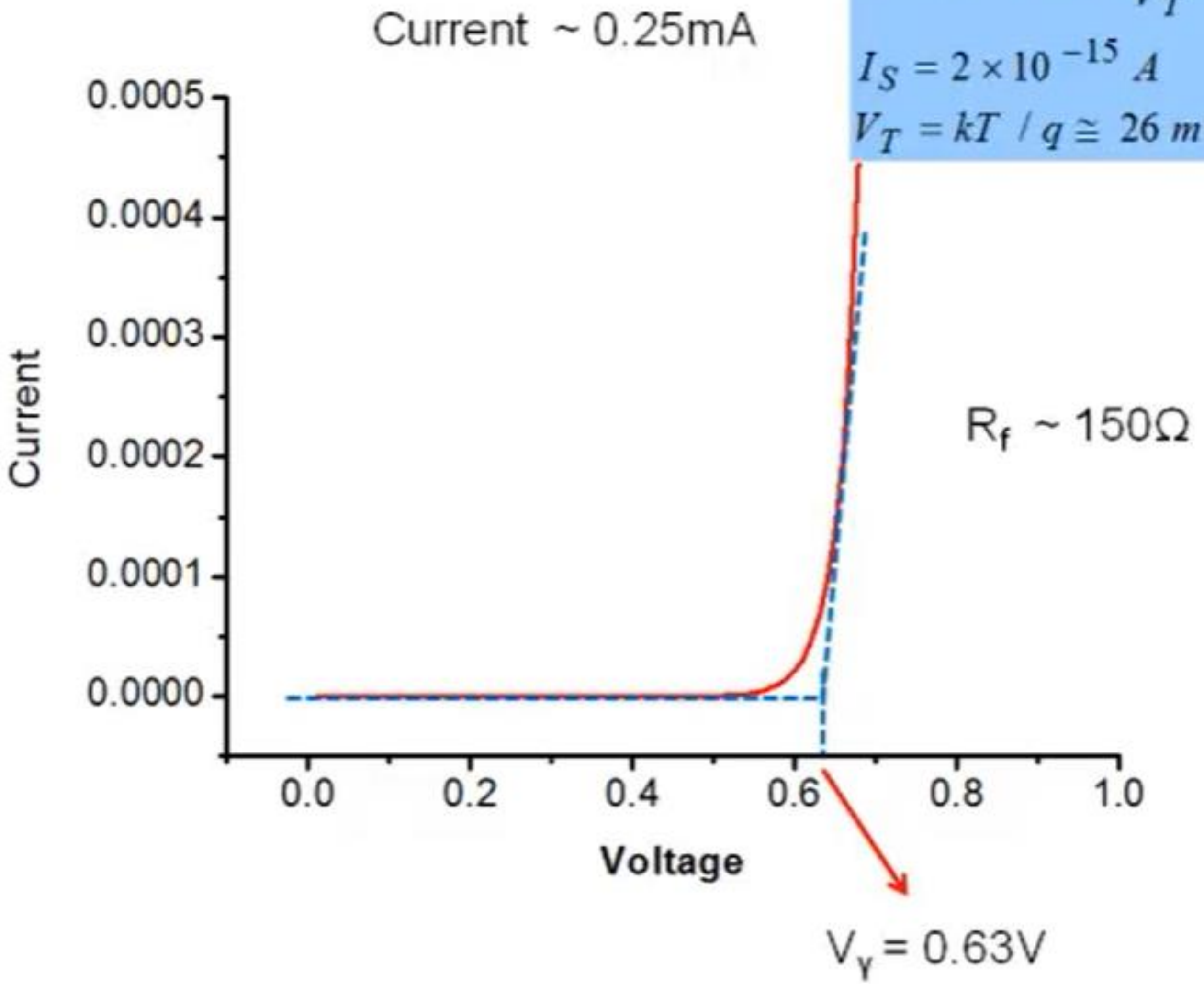
$V_\gamma = 0.75V$

Current ~ 25mA

$$I = I_S \times \{\exp(\frac{V}{V_T}) - 1\}$$

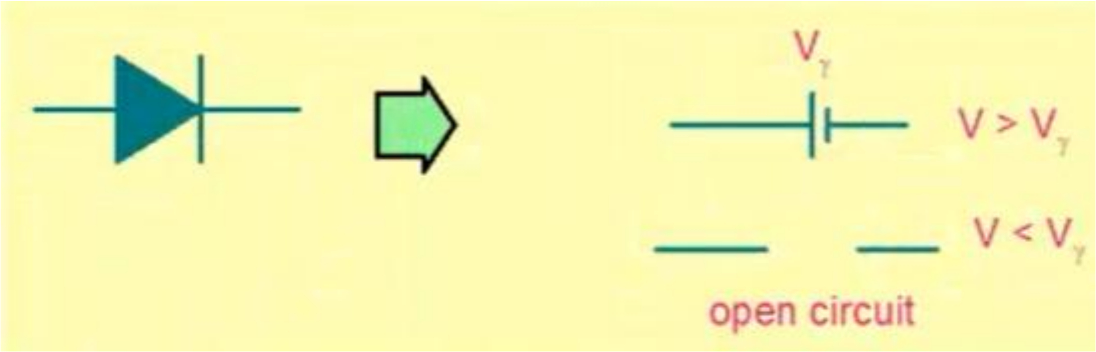
$$I_S = 2 \times 10^{-15}\ A$$

$$V_T = kT / q \cong 26\ mV \text{ at T = 300K}$$

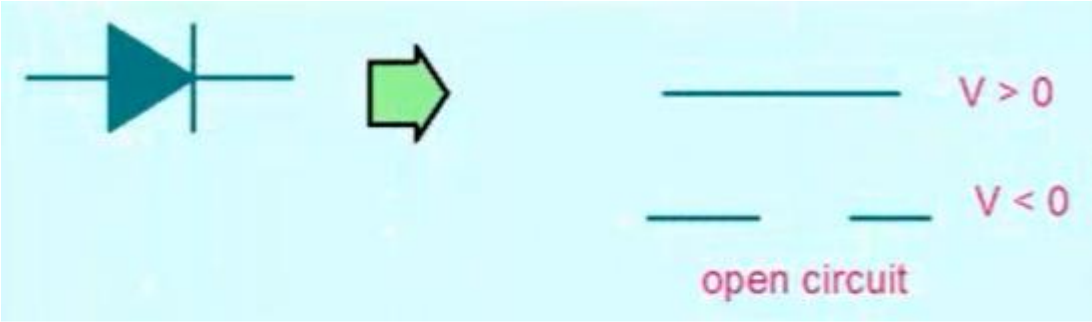


For most of our analysis, we will take $V_\gamma = 0.7V$ and $r_f \sim 10\Omega$

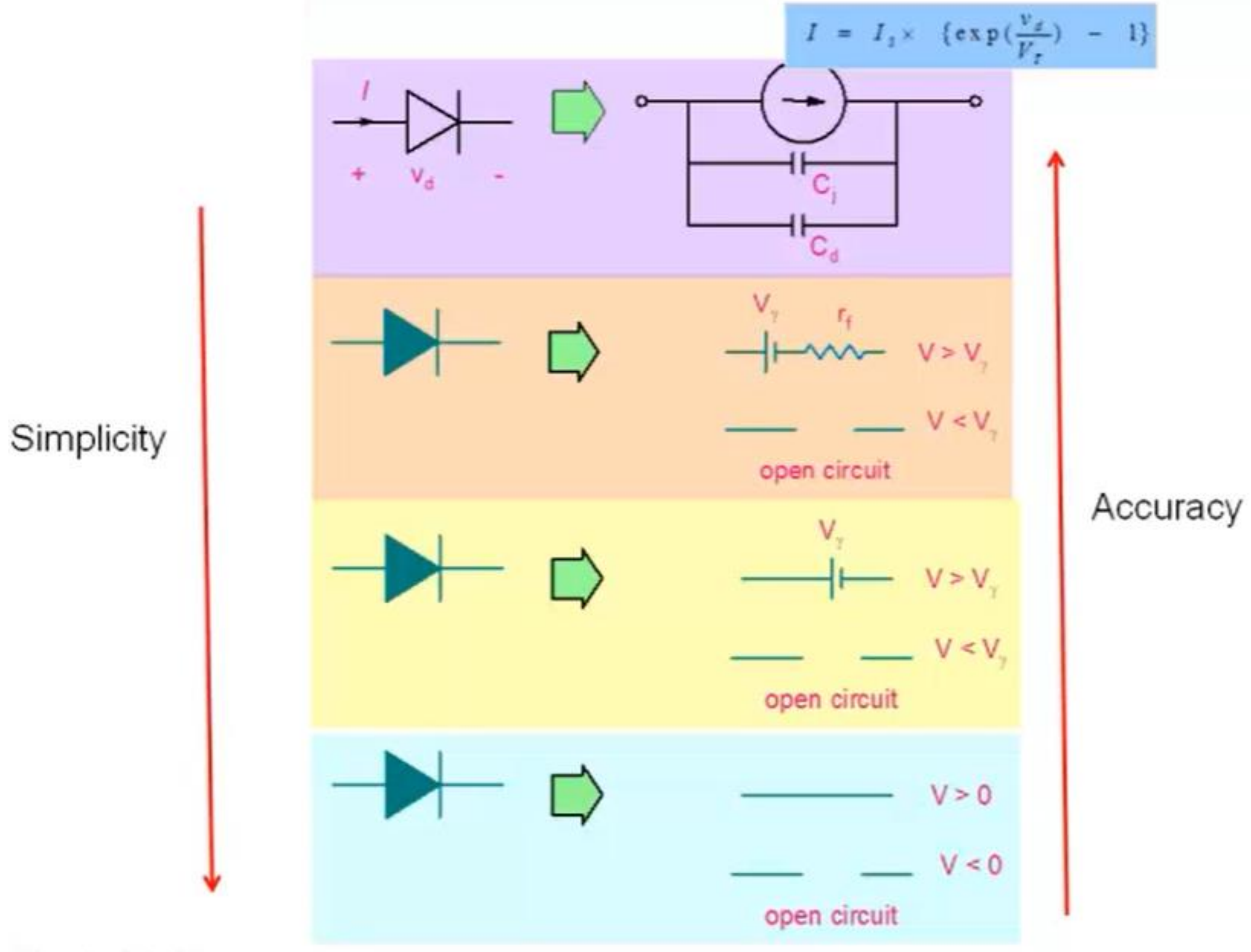
Even Simpler Diode Models



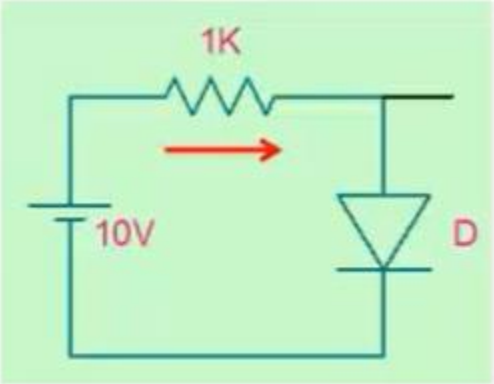
Ideal diode model

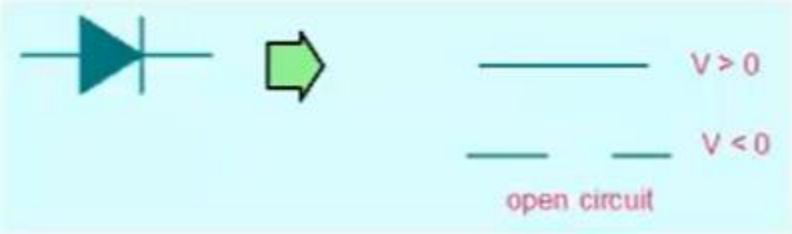


Diode Models



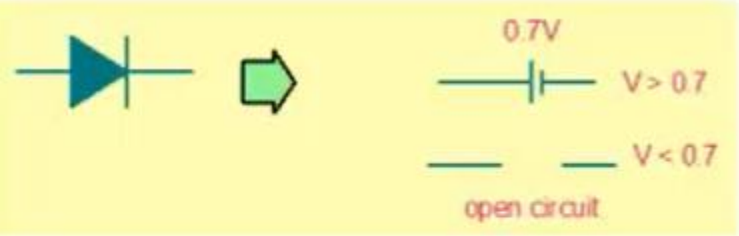
Use the simplest model that will yield results with desired accuracy





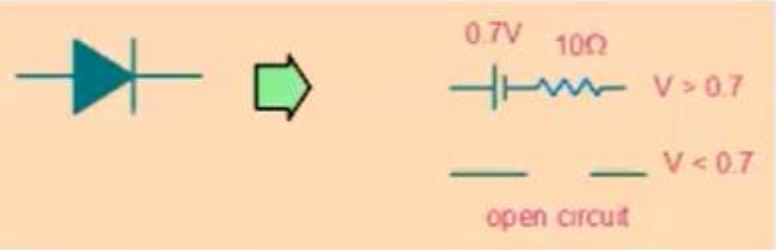
$$I = 10/10^3 = 10\,mA$$

8.2%



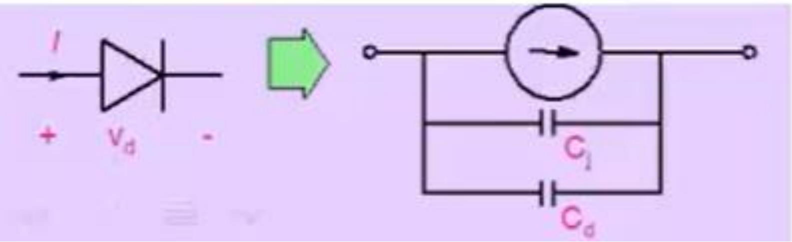
$$I = (10 - 0.7)/10^3 = 9.3\,mA$$

0.65%



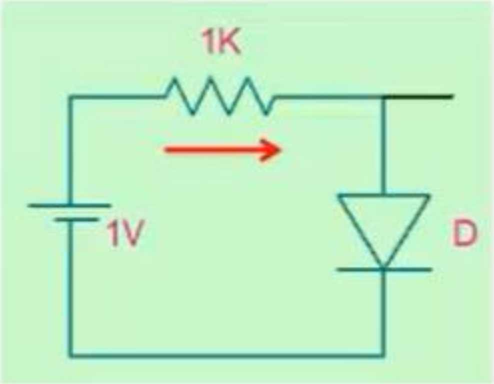
$$I = (10 - 0.7)/(10^3 + 10) = 9.208\,mA$$

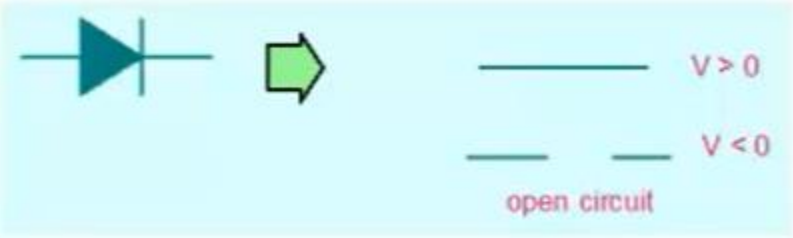
-0.34%



$$I = 9.24\,mA$$

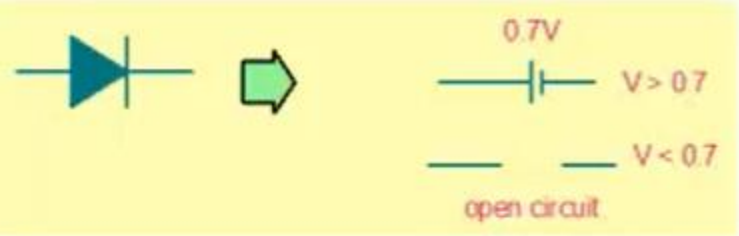
Use the simplest model that will yield results with desired accuracy





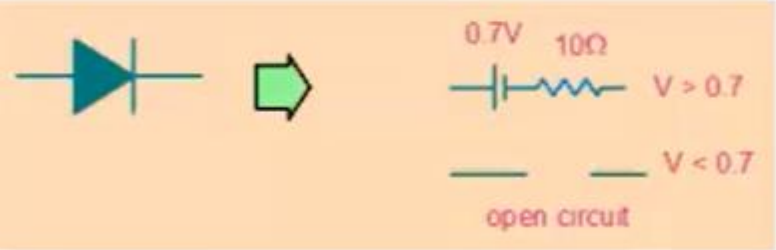
$$I = 1/10^3 = 1mA$$

~200%



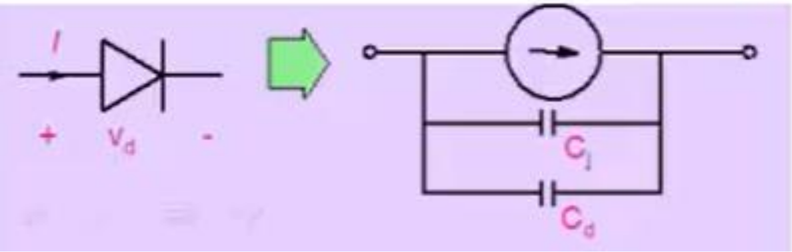
$$I = (1-0.7)/10^3 = 0.3\,mA$$

-8.8%



$$I = (1-0.7)/(10^3+10) = 0.297\,mA$$

-9.7%



$$I = 0.329\,mA$$

Small Signal Model

Diode: Small Signal Model (dc or low frequency)

Forward Bias

$$I_d = I_s e^{\frac{V_d}{nV_T}}$$

$$I_D + i_d = I_s e^{\frac{V_D + v_d}{nV_T}}$$

$$i_d = I_D \left(e^{\frac{v_d}{nV_T}} - 1 \right)$$

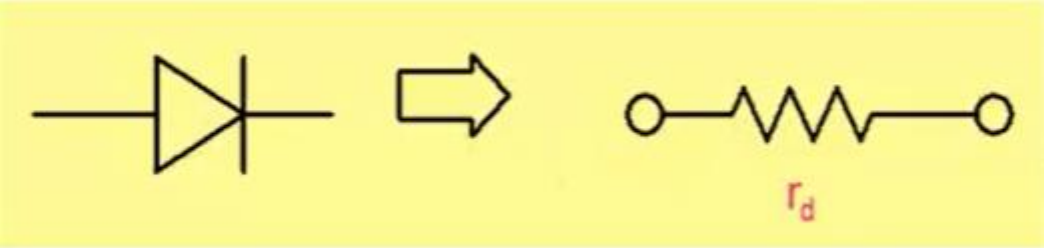
$$i_d = I_D \left(\frac{v_d}{nV_T} + \frac{v_d^{\,2}}{2\left(nV_T\right)^2} + \ldots\ldots\ldots \right)$$

$$\text{Small signal approx}: \frac{v_d}{\mathrm{n}\mathrm{V}_\mathrm{T}} << 1$$

$$i_d = I_D\left(\frac{v_d}{nV_T} + \frac{v_d^{\,2}}{2(nV_T)^2} + \dots\dots\dots\right)$$

$$i_d \cong \left(\frac{I_D}{nV_T}\right)v_d$$

$$i_d = \frac{v_d}{r_d}\ ;\ r_d = \frac{nV_T}{\mathrm{I}_D}$$



Temperature dependence of diode characteristics

$$I_D = I_S \times \{\exp(\frac{V_d}{V_T}) - 1\}$$

$$V_T = \frac{kT}{q}$$

$$I_S \propto n_i^2 \propto e^{-\frac{E_g}{kT}}$$

Reverse saturation current increases with temperature. For forward bias, even though V_T increases, current still increases because of greater influence of I_S

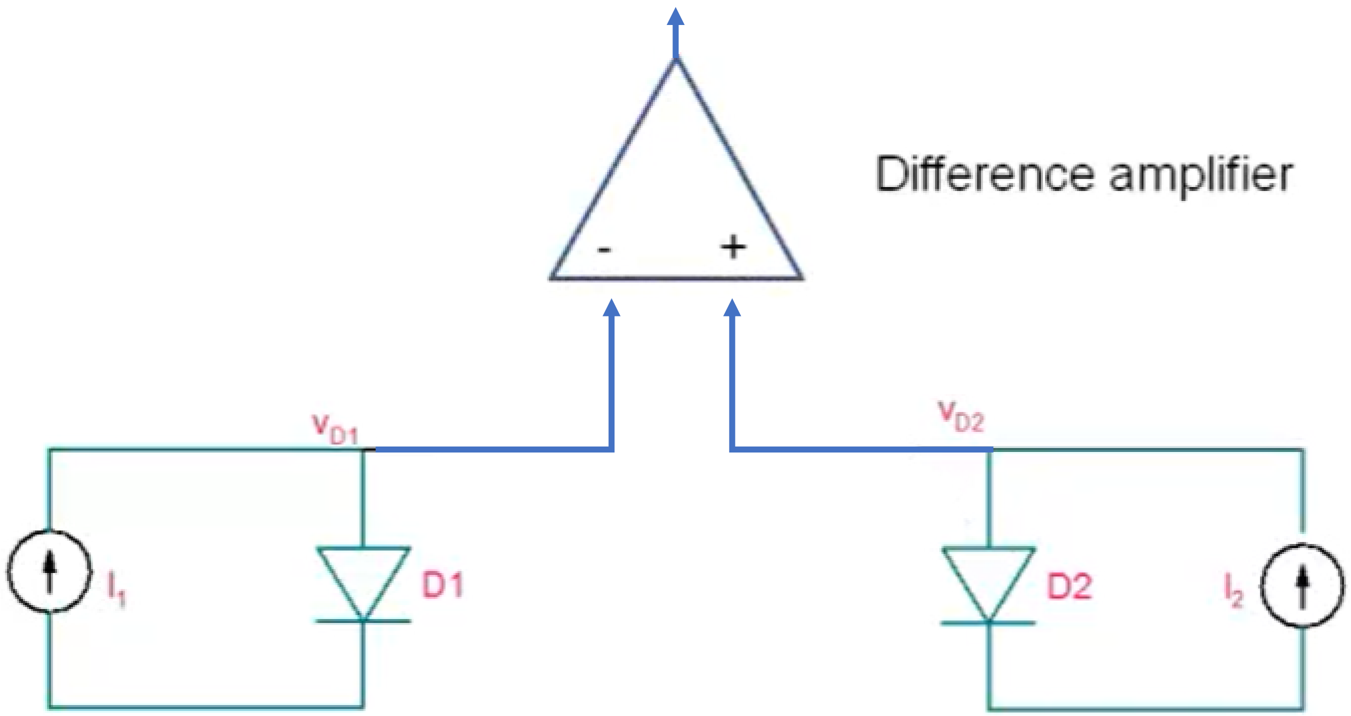
For a diode in forward bias at a fixed current I_O : $v_D = V_T \times \ln(I_O/I_S + 1)$

For Silicon diodes, v_D decreases at the rate of ~ -2mV/°C

If the diode voltage is 0.7 at 27°C, then at 100°C it would be only :

$$0.7 - 2\times10^{-3} \times (100-27) = 0.554V$$

Measurement of temperature using a pn junction diode



$$v_{D1} = V_T \times \ln(I_1/I_S + 1)$$

$$v_{D2} = V_T \times \ln(I_2/I_S + 1)$$

$$v_O = C \times (v_{D2} - v_{D1})$$

$$v_O = (C \times \frac{k}{q} \times \ln(\frac{I_2}{I_1})) \times T$$