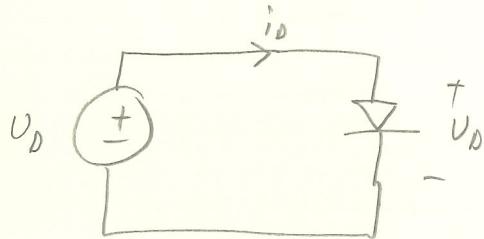


Consider this circuit:



→ Show Fig 3.8

The diode characteristic is clearly nonlinear

for  $V_D < \sim 0.7V$  :  $i_D \approx 0$

for  $V_D > \sim 0.7V$  :  $i_D > 0$

$\sim 0.7V$  → "turn-on" or "cut-in" voltage

→ show Fig 3.9 : close-up plot of the diode i-v curve around the origin

Notice that  $i_D = 0$  only at  $V_D = 0$

For  $V_D < 0$  :  $i_D$  approaches  $-I_s$

→  $I_s$  = reverse saturation current

= saturation current

→ very small :  $\sim 1 \times 10^{-15} A$  in Fig 3.9

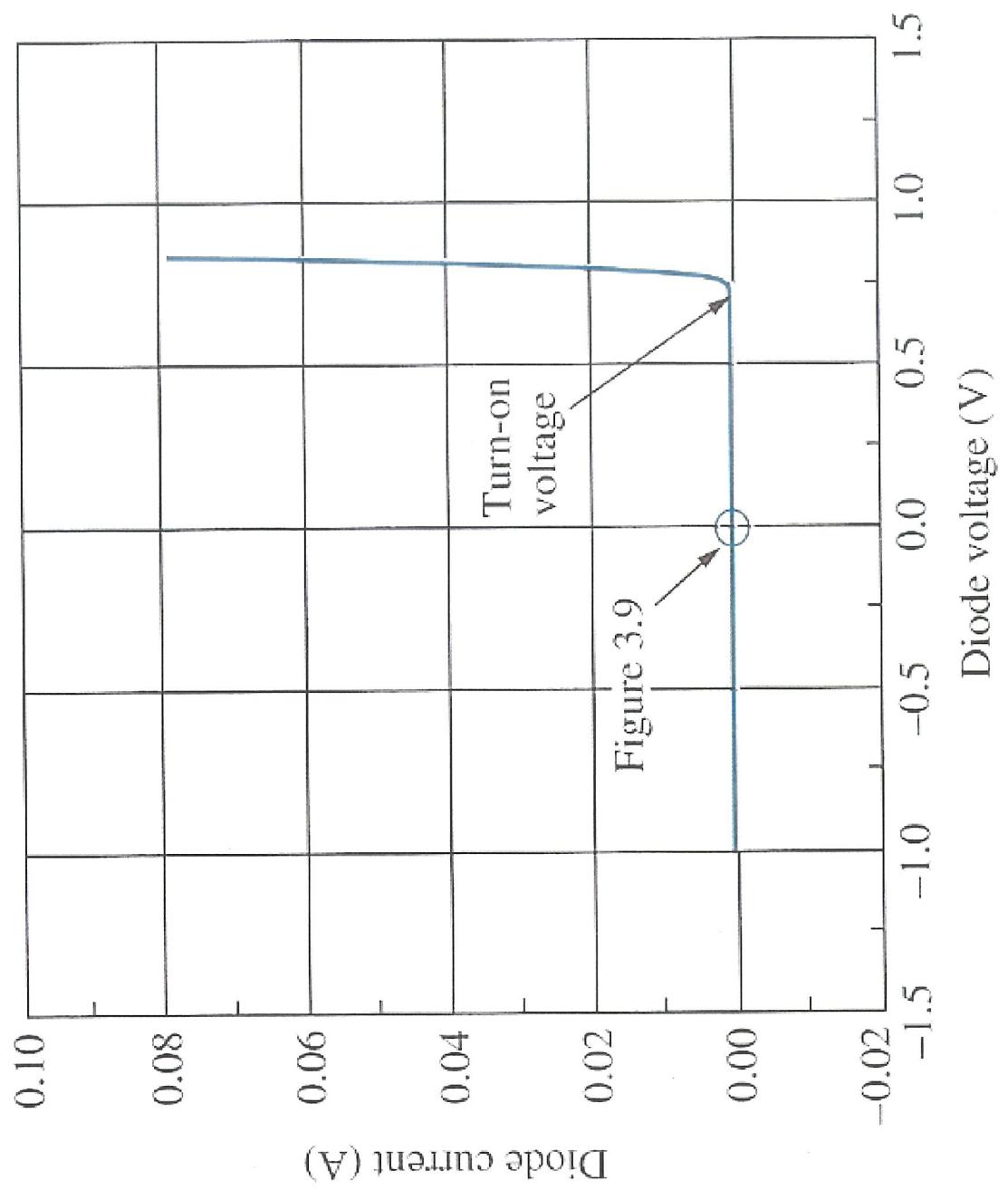


Figure 3.8 Graph of the  $i$ - $v$  characteristics of a  $pn$  junction diode.

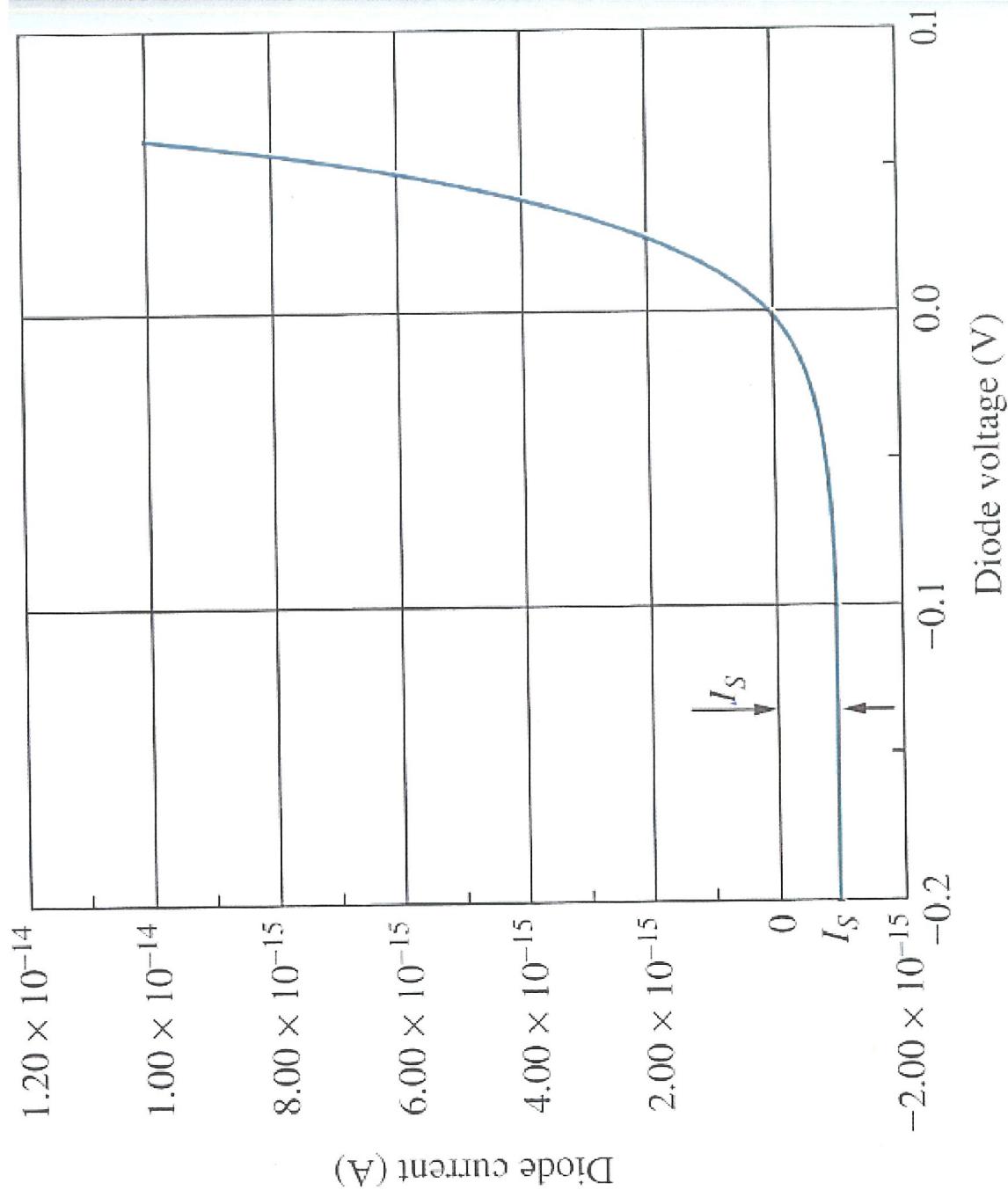
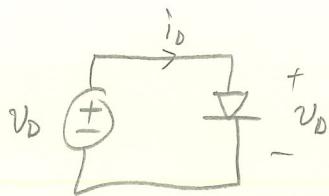


Figure 3.9 Diode behavior near the origin with  $I_S = 10^{-15}$  A and  $n = 1$ .

## 2. Mathematical model of the diode

For :



$$i_D = I_s \left[ e^{\left( \frac{qV_D}{n k T} \right)} - 1 \right] = I_s \left[ e^{\left( \frac{V_D}{n V_T} \right)} - 1 \right]$$

where:  $I_s$  = reverse saturation current, typically:  $10^{-18} \leq I_s \leq 10^{-9}$  A

$V_D$  = voltage applied across the diode (forward bias)

$q$  = electronic charge =  $1.60 \times 10^{-19}$  C

$k$  = Boltzmann's constant =  $1.38 \times 10^{-23}$  J/K

$T$  = absolute temperature (K)

$n$  = nonideality factor (dimensionless)  $\rightarrow$  we will assume that  $n=1$

$V_T = \frac{kT}{q}$  = thermal voltage  $\approx 0.025V$  at room temperature

$\therefore$  use:  $i_D = I_s \left[ e^{\left( \frac{V_D}{V_T} \right)} - 1 \right]$

ex: if  $I_s = 0.1\text{fF}$  at room temp, what is  $V_D$  if  $i_D = 300\mu\text{A}$  ?

solution

$$i_D = I_s \left[ e^{\frac{V_D}{V_T}} - 1 \right]$$

$$\frac{i_D}{I_s} + 1 = e^{\frac{V_D}{V_T}}$$

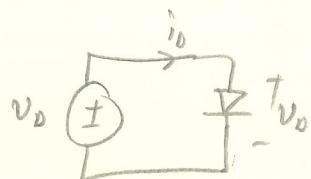
$$\ln \left( \frac{i_D}{I_s} + 1 \right) = \ln \left( e^{\frac{V_D}{V_T}} \right) = \frac{V_D}{V_T}$$

$$V_D = V_T \ln \left( \frac{i_D}{I_s} + 1 \right) = 0.025 \ln \left( \frac{300 \times 10^{-6}}{0.1 \times 10^{-15}} + 1 \right) = 0.718V$$

### 3. Terminology

- A dc voltage applied to an electronic device is called a "bias"
  - Applying the bias to the device is called "biasing" the device
- For a diode : 2 regions of operation : "reverse bias" and "forward bias"

Given :



if  $V_D > 0$  : forward bias region → diode is "on"

if  $V_D < 0$  : reverse bias region → diode is "off"

also : at  $V_D = 0$  : zero bias condition

a) Forward Bias :  $V_D > 0$

suppose that  $V_D \geq 4V_T$

$$\text{at } V_D = 4V_T = 4(0.025) = 0.1V$$

$$e^{\frac{V_D}{V_T}} = e^4 = 54.6 \gg 1$$

$$\therefore i_D = I_S [e^{\frac{V_D}{V_T}} - 1] \approx I_S e^{\frac{V_D}{V_T}}$$

For  $V_D \geq 4V_T \rightarrow$  a 60mV increase in  $V_D$  results in ~ a 10x increase in  $i_D$

show Fig. 3.11

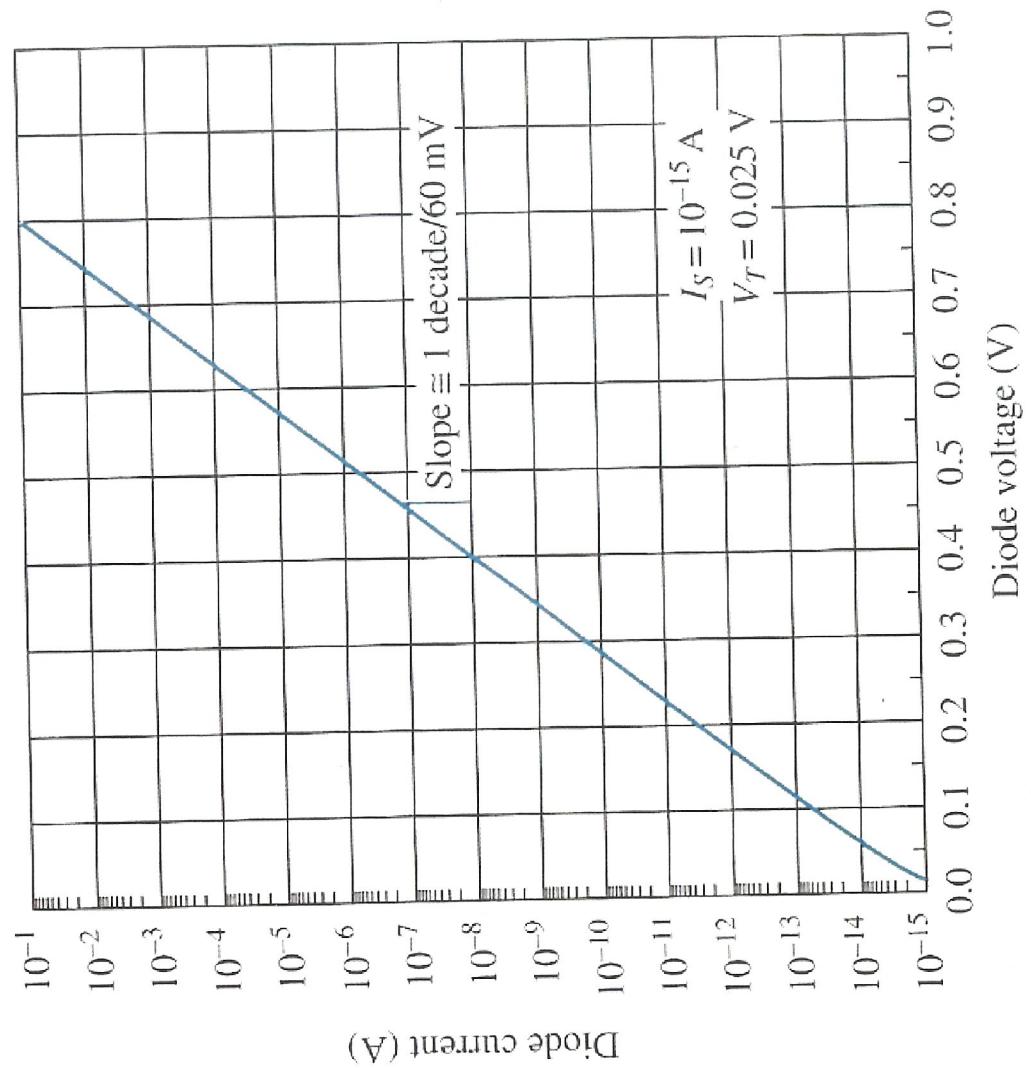


Figure 3.11 Diode  $i$ - $v$  characteristic on semilog scale.

b) Reverse Bias :  $V_D < 0$

suppose that  $V_D = -4V_T = -0.1V$

$$\therefore \frac{V_D}{V_T} = -4$$

$$e^{\frac{V_D}{V_T}} = e^{-4} = 0.0183 \approx 0$$

$$\therefore i_D = I_S [e^{\frac{V_D}{V_T}} - 1] \approx -I_S \text{ for } V_D \leq -4V_T$$

In reality : the reverse leakage current is several orders of magnitude larger than  $I_S$  due to the generation of electron-hole pairs within the depletion region.

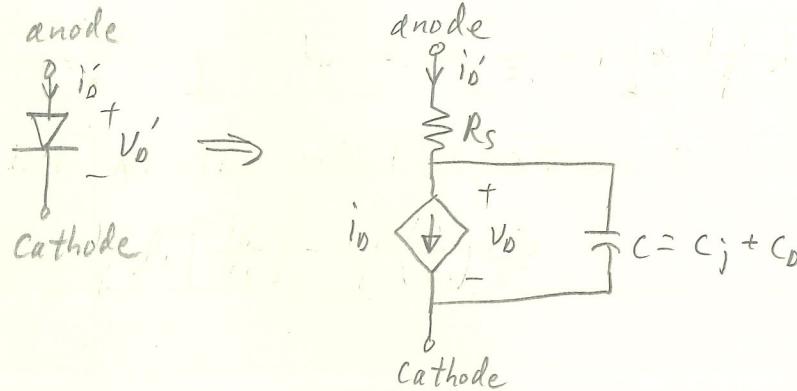
Also,  $|i_D|$  gradually increases as the reverse bias voltage increases.

$\therefore i_D = -I_S$  for  $V_D \leq -4V_T$  is an engineering approximation

c) Zero Bias :  $V_D = 0$

$$i_D = 0 \text{ for } V_D = 0$$

4. Diode SPICE Model (Simplified Version)



$R_s \rightarrow$  series resistance always present in real devices

$$i_D = I_S [e^{\left(\frac{V_D}{N V_T}\right)} - 1]$$

$$C_D = T T \frac{i_D}{N V_T} \text{ for } V_D > 0$$

$$C_j = \frac{C_{JO}}{(1 - \frac{V_D}{V_J})^m} \text{ (RAREA) for } V_D < 0$$

finite switching time

} diode has capacitance associated with it : both in forward bias and reverse bias