ENG2210
Electronic Circuits

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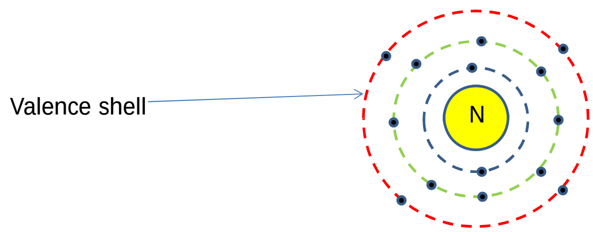
Chapter 3 Diodes

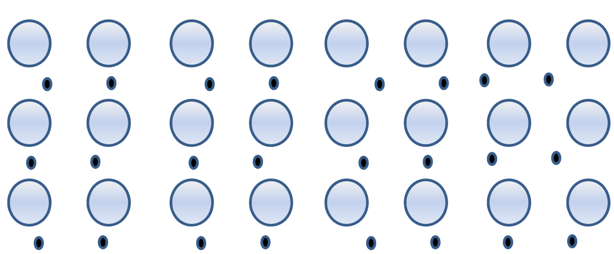
- **Objectives**
- Learn the characteristics of ideal diode and how to analyze and design circuits containing multiple diodes
- Learn the *i-v* characteristic of the junction diode
- Learn a simple model of the diode
- Learn the use of diodes operating in the forward and reverse bias region to provide constant dc voltage.
- Learn application of the diode in the design of rectifier circuits.

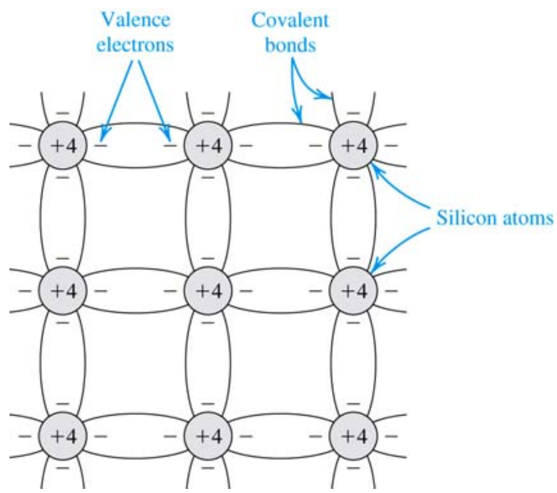
Atoms

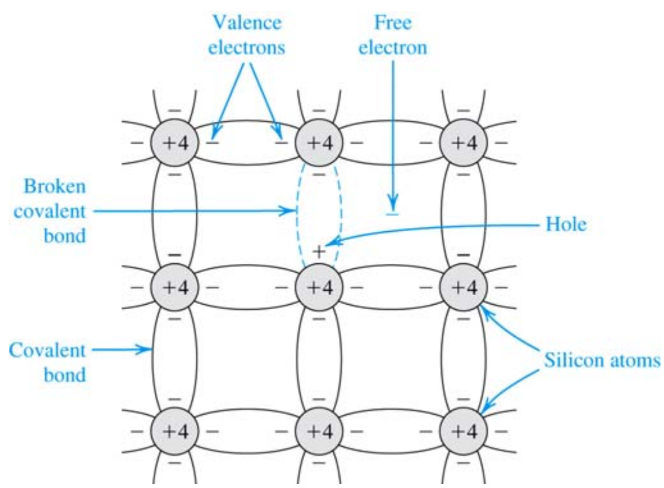
- Atoms consists of a positively charged nucleus and a number of negatively charged electrons rotating around the nucleus.
- Electrons are arranged in shells
- The electrons in the outer shell (<8) are called *valence electrons*.

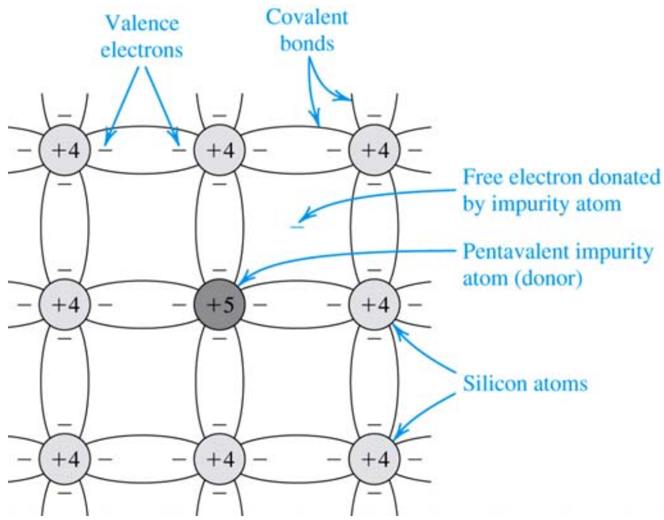


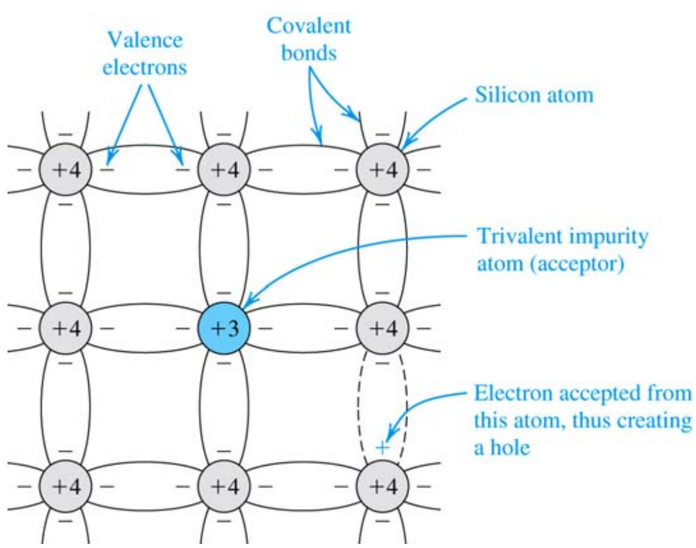
- Conductors: The valence electrons are free to move around.
- When applying an electric field, these electrons starts to move in the opposite direction of the filed (current).




Valence electrons
Covalent bonds
+4
Silicon atoms


Valence electrons
Free electron
Broken covalent bond
Hole
Covalent bond
Silicon atoms
+4


Valence
electrons
Covalent
bonds
+4
+5
Free electron donated
by impurity atom
Pentavalent impurity
atom (donor)
Silicon atoms


Valence
electrons
Covalent
bonds
Silicon atom
+4
+3
Trivalent impurity
atom (acceptor)
Electron accepted from
this atom, thus creating
a hole

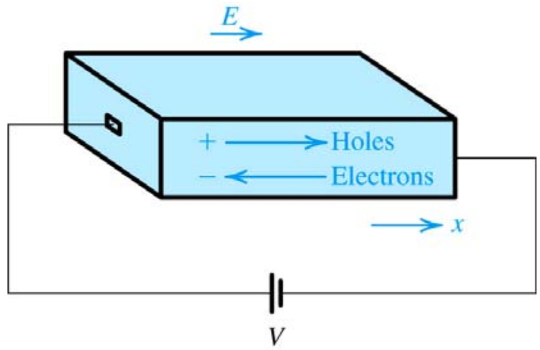
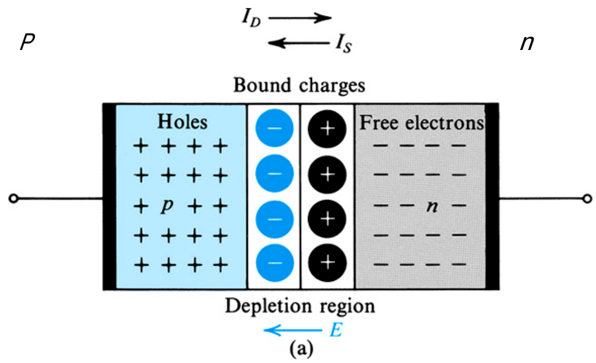
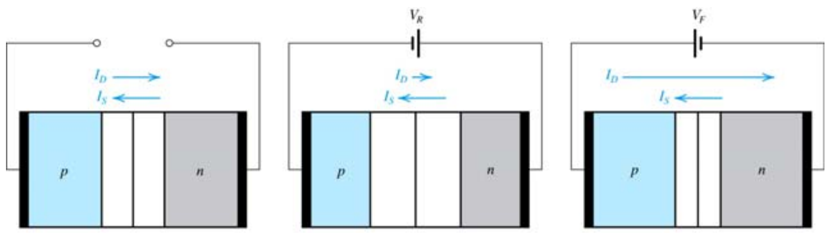


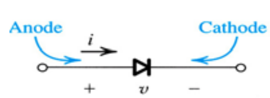
Figure 3.5 An electric field *E* established in a bar of silicon causes the holes to drift in the direction of *E* and the free electrons to drift in the opposite direction. Both the hole and electron drift currents are in the direction of *E*.

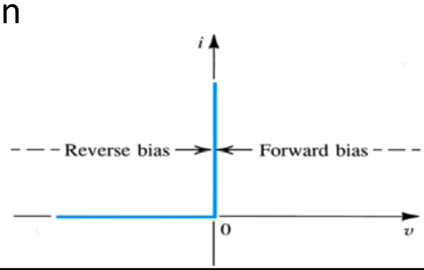




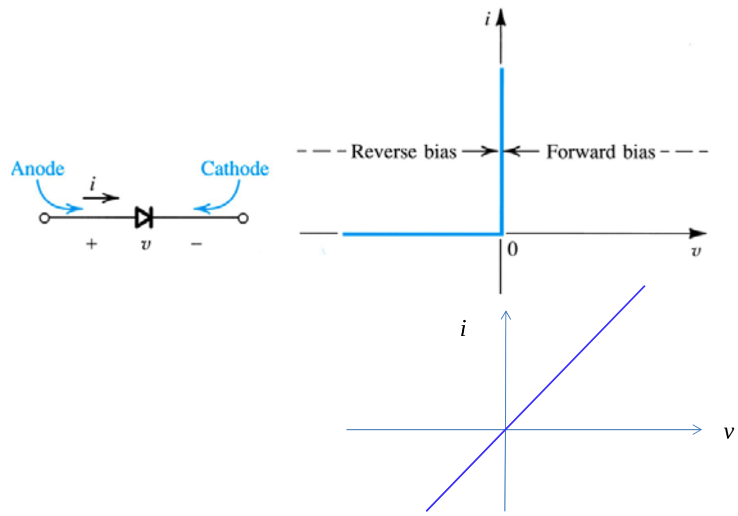
The Ideal Diode

- So far, we are dealing with linear elements.
- An ideal diode allows current to flow in only one direction, it has a resistance of ∞ in the other direction.
- Short circuit in one direction, and open circuit in the other direction



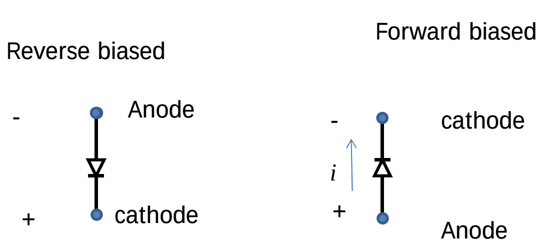


Ideal Diode



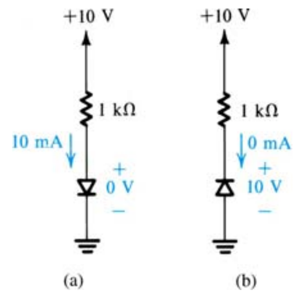
Diodes

- Conducts or not (ON or OFF) based on the relative polarity. Voltage drop across diode not voltage values.



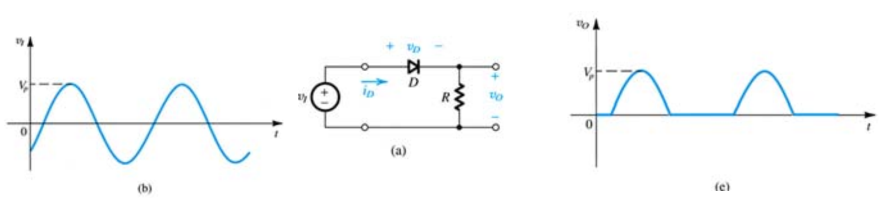
The Ideal Diode

- Forward biased R=0
- Reverse biased R=∞

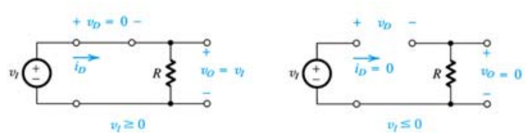


Rectifier

- A fundamental application of the diode is the rectifier.

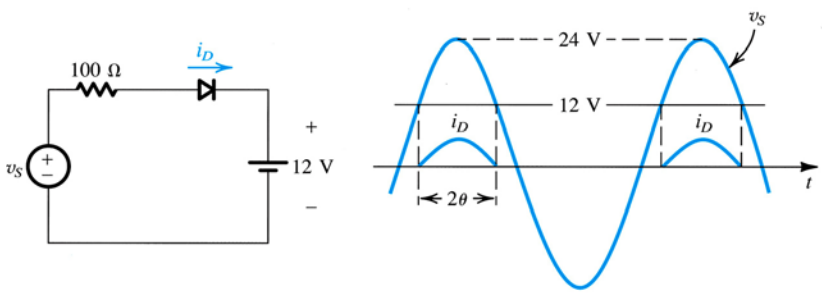


Plot v_D



Charger

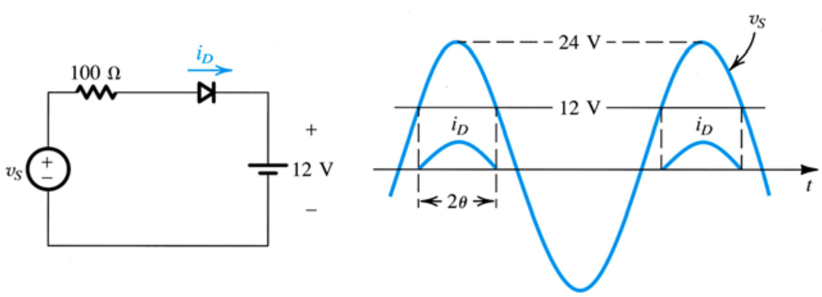
- When the diode is ON
- When the diode is OFF



(a) (b)

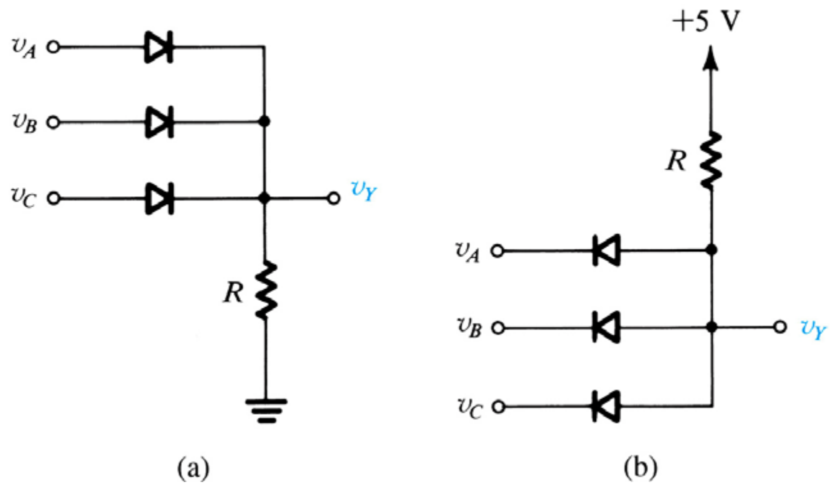
Example

- Find the peak diode current, maximum reverse-bias diode voltage, and the fraction of the cycle over which the diode is conducting



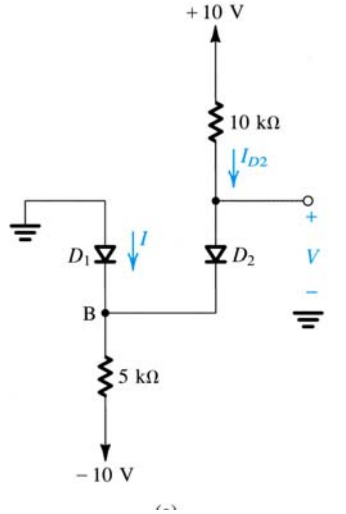
(a) (b)

Logic Gates



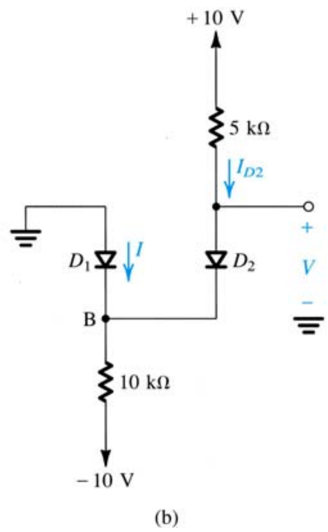
Example

- Make an assumption, then validate your assumption
- Both are ON
- VB=0 =V
- ID2=(10-0)/10K = 1mA
- 1mA+I=(0-(10))/5k
- I=1 mA
- Assumption is O.K.



Example

- Assume both ON
- VB=0=V
- ID2=(10-0)/5k =2mA
- ID2+I=(0- -10)/5=2 mA
- 2+I=10/10K=1mA
- I=-1 mA
- D1 is not ON, invalid assumption
- Try it for D1 OFF



Terminal Characteristics

Changes with temp

Sometimes v/nV_T

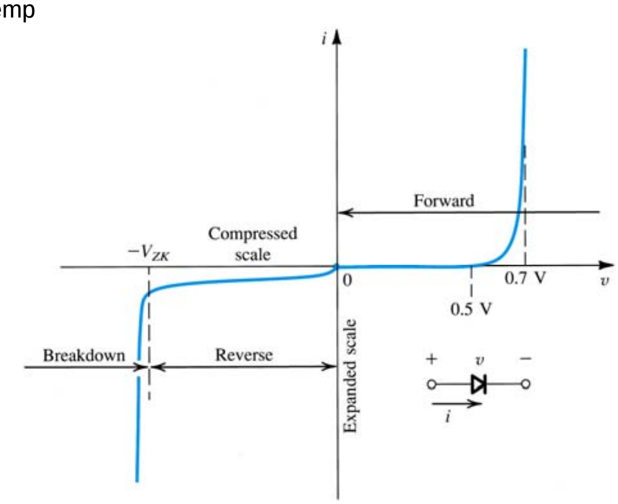
$$i = I_s\left(e^{v/V_T} - 1\right)$$

I_s Saturation current

$$V_T = \frac{KT}{q} \text{ Thermal voltage}$$

$$\text{if } v >> V_T, \quad i = I_s e^{v/V_T}$$

$$v = V_T \ln\frac{i}{I_s}$$



Compare this to an ideal diode

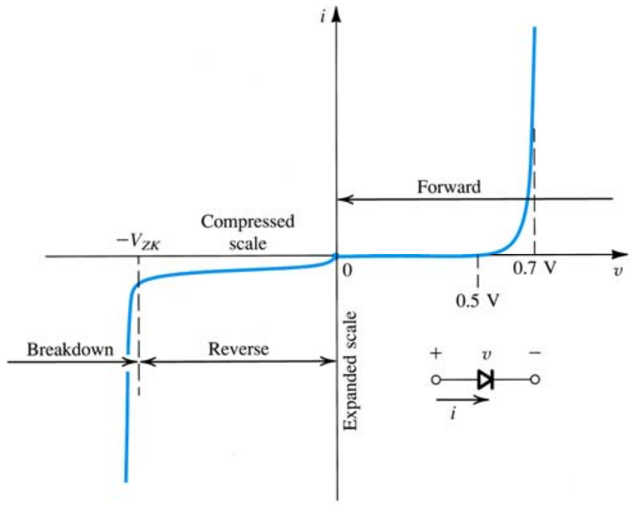


Figure 4.8 The diode i–v relationship with some scales expanded and others compressed in order to reveal details.

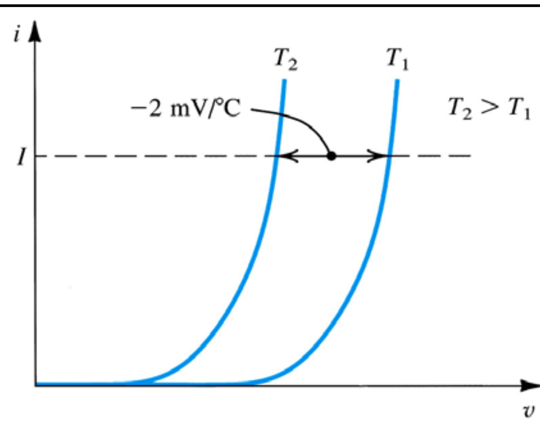


Figure 4.9 Temperature dependence of the diode forward characteristic. At a constant current, the voltage drop decreases by approximately 2 mV for every 1°C increase in temperature.

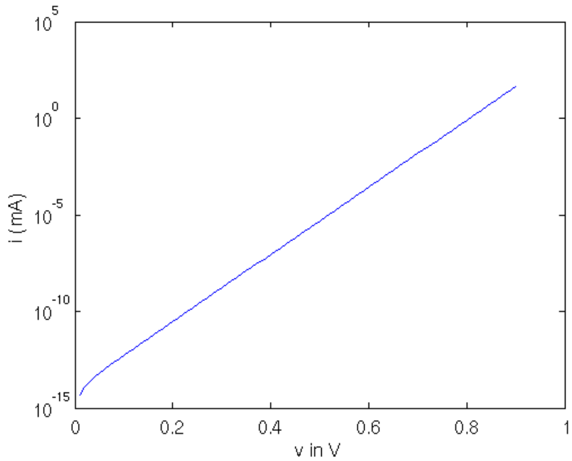
$$i_1 = I_s e^{v_1/V_T}$$

$$i_2 = I_s e^{v_1/V_T}$$

$$\frac{i_2}{i_1} = \frac{e^{v_2/V_T}}{e^{v_1/V_T}} = e^{\frac{v_2 - v_1}{V_T}}$$

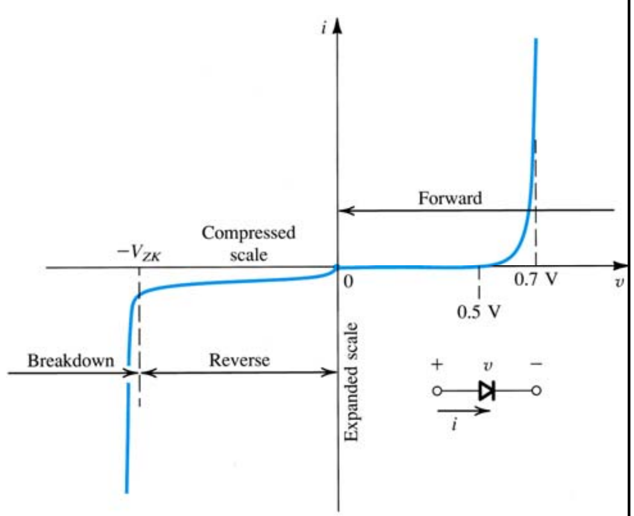
$$\ln\left(\frac{i_2}{i_1}\right) = \frac{v_2 - v_1}{V_T}$$

$$v_2 - v_1 = V_T \ln\left(\frac{i_2}{i_1}\right)$$



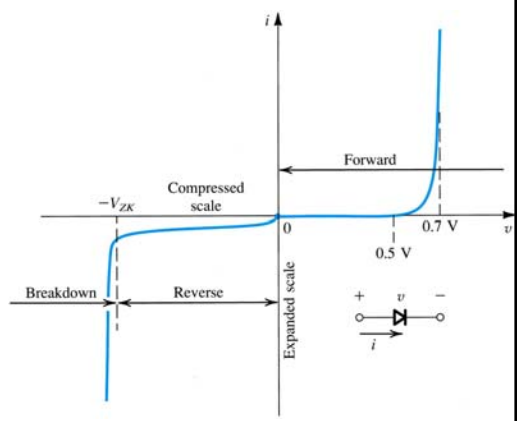
Reverse Bias Region

- In the reverse bias region, v << $-v_T$, the current is I_s
- In reality, the current is small but much bigger than $I_{reverse}$ (1 nA), I_s = 10^{-14}
- The current also increases (slightly) with decreasing v
- Increases with temperature (doubles every 10 rise)



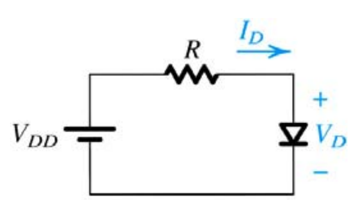
The Breakdown Region

- The current I increases rapidly with almost no change in voltage drop
- It is normally not destructive if the power dissipation is limited
- This is useful for voltage regulation



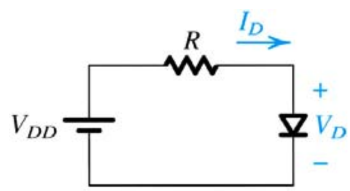
Diode Models

- Diode can be modeled in different ways depends on the application (and the required accuracy).
  - Exponential model
  - Constant voltage drop model
  - Ideal diode model
  - Piecewise Linear Model
  - Small signal model



The exponential Model

- Most accurate, but highly nonlinear
- Assume diode voltage greater than 0.5V
- The diode current is $I_D = I_s e^{V_D/V_T}$
- Also, the diode current is $I_D = \frac{V_{DD} - V_D}{R}$
- Solve these 2 equations



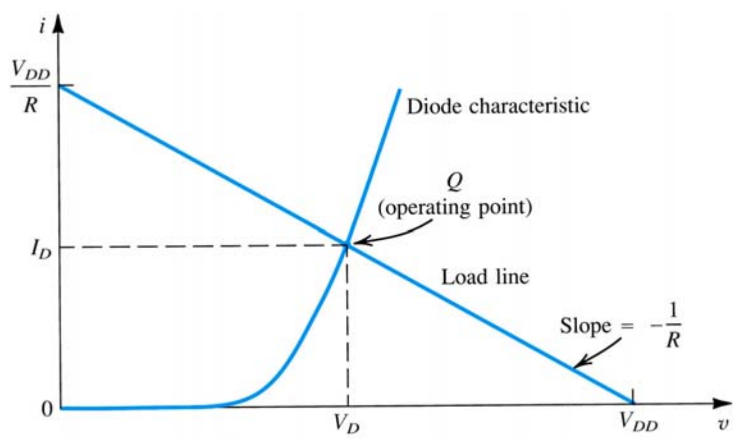


Figure 4.11 Graphical analysis of the circuit in Fig. 4.10 using the exponential diode model.

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