EECS2210
Electronic Circuits and devices
W2015

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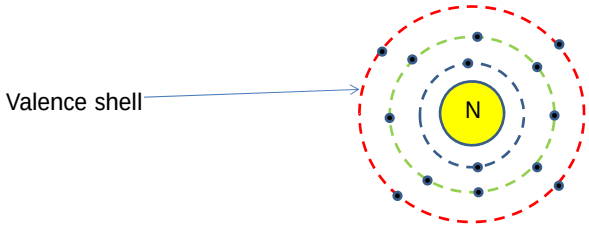
Chapter 3 Diodes

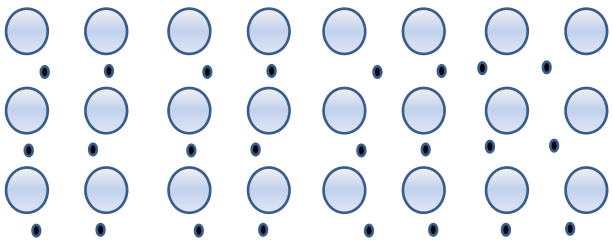
- **Objectives**
- Learn the characteristics of ideal diode and how to analyze and design circuits containing multiple diodes
- Learn the *i-v* characteristic of the junction diode
- Learn a simple model of the diode
- Learn the use of diodes operating in the forward and reverse bias region to provide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

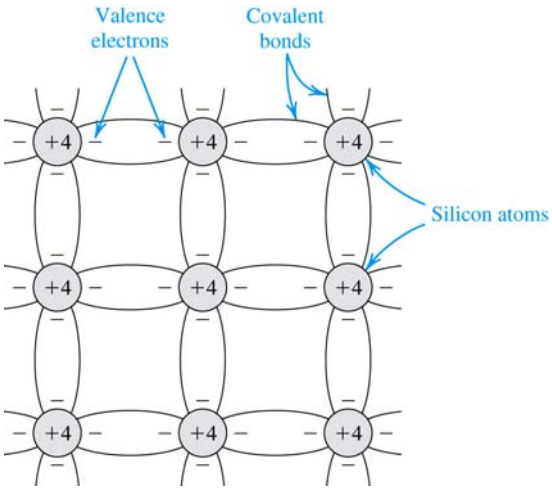
Atoms

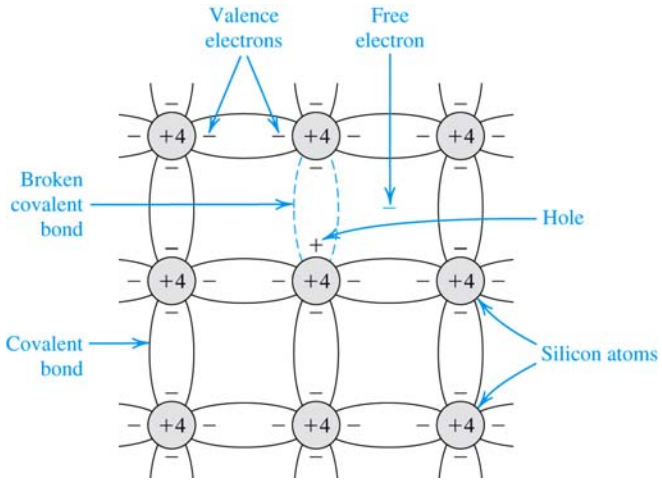
- Atoms consists of a positively charged nucleus and a number of negatively charged electrons rotating around the nucleus.
- Electrons are arranged in shells
- The electrons in the outer shell (<8) are called *valence electrons*.

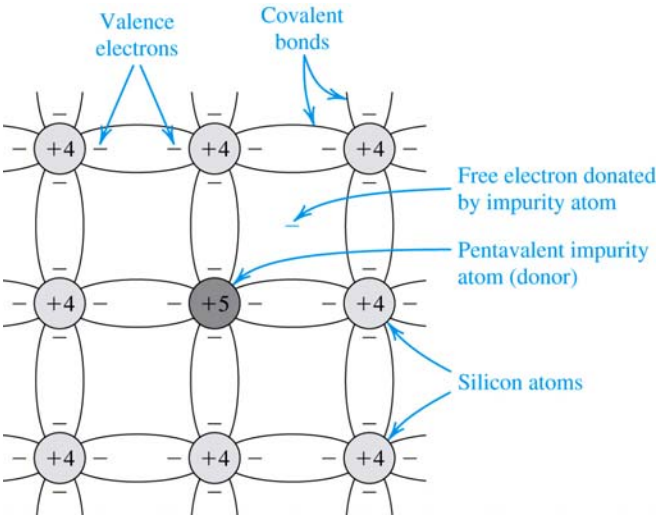


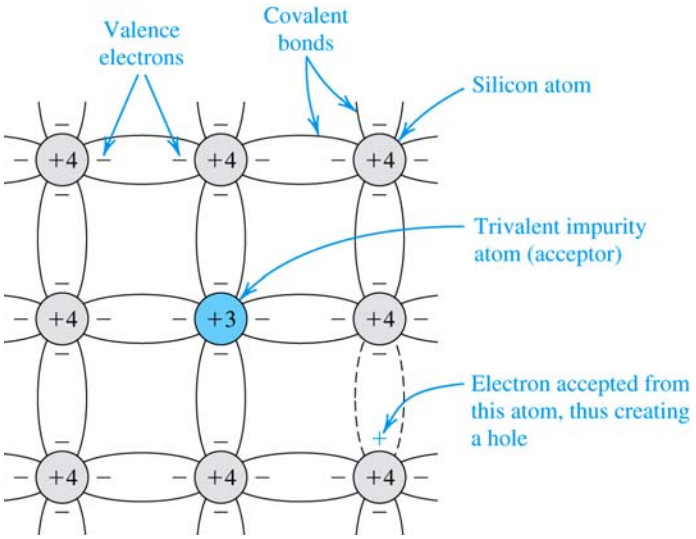
- Conductors: The valence electrons are free to move around.
- When applying an electric field, these electrons starts to move in the opposite direction of the filed (current).




Valence electrons
Covalent bonds
Silicon atoms
+4


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





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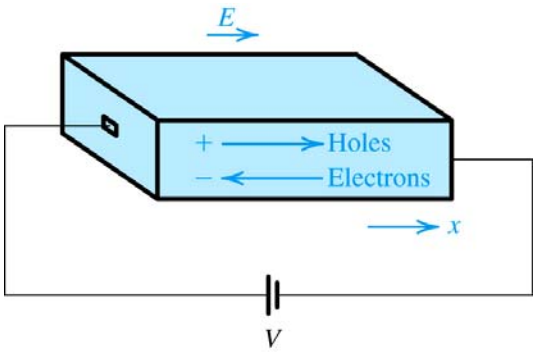
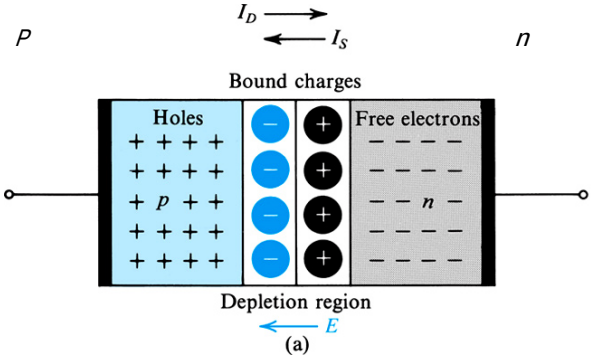
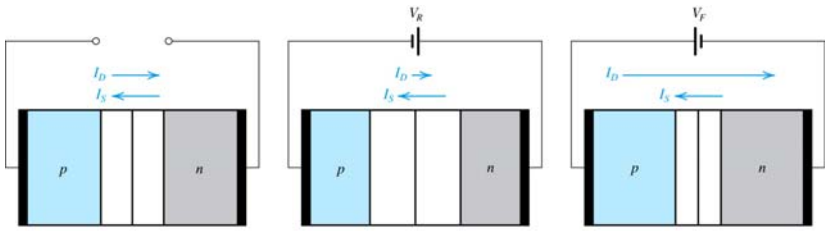


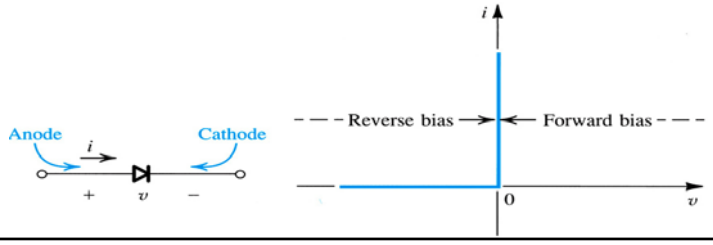
Figure 3.5 An electric field *E* established in a bar of silicon causes the holes to drift in the direction of *E* and the free electrons to drift in the opposite direction. Both the hole and electron drift currents are in the direction of *E*.



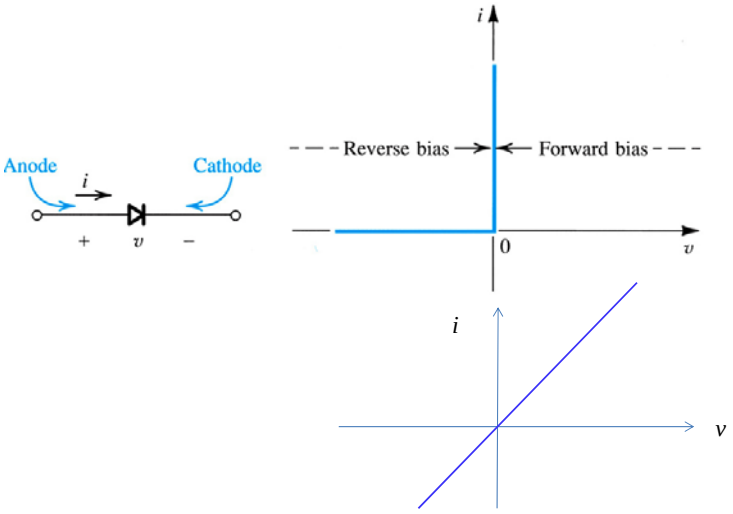


The Ideal Diode

- 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

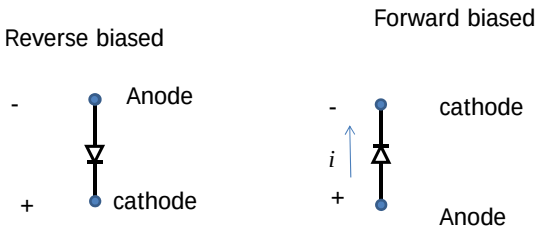


Ideal Diode



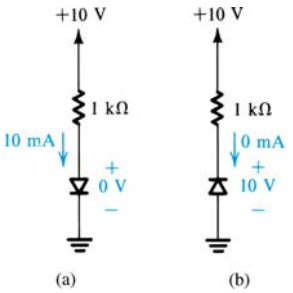
Diodes

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



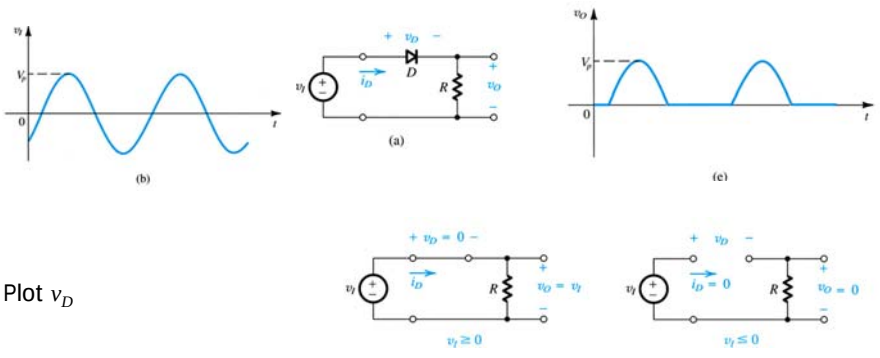
The Ideal Diode

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



Rectifier

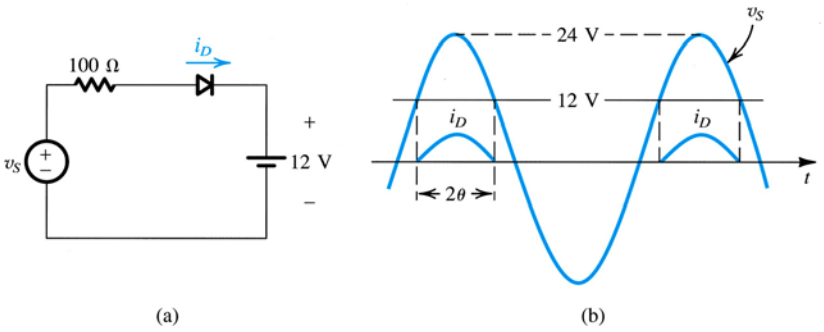
- A fundamental application of the diode is the rectifier.



Plot v_D

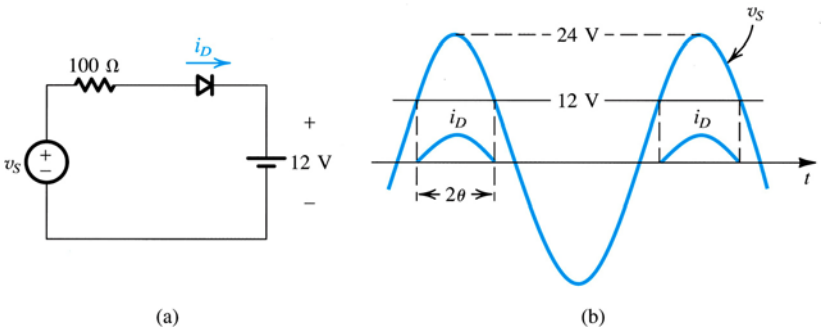
Charger

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

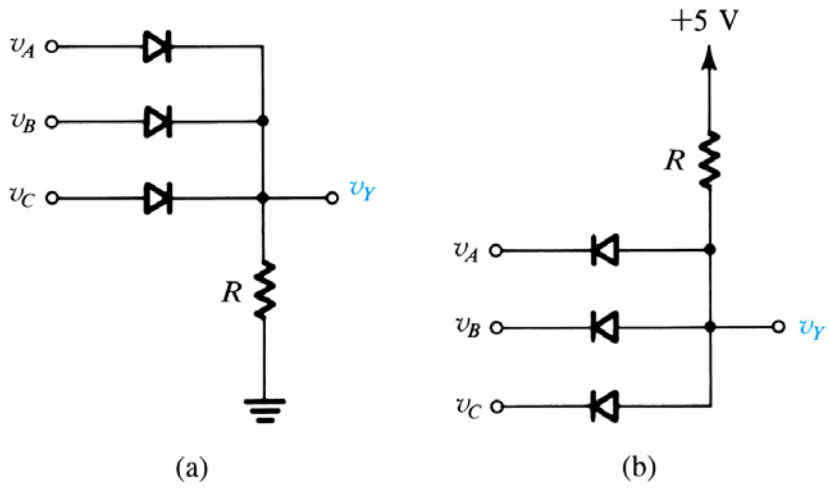


Example

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

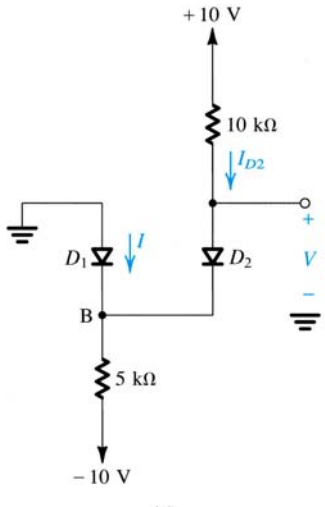


Logic Gates



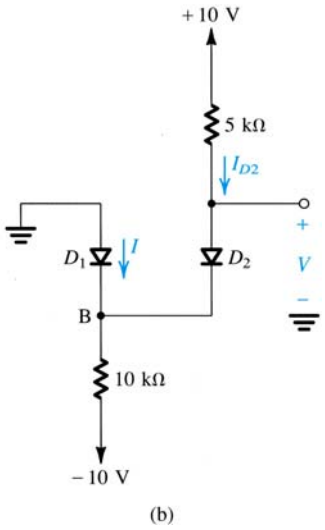
Example

- 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$_T$

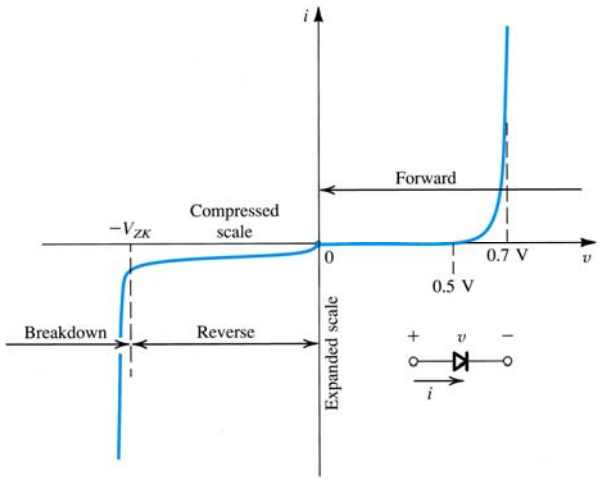
$$i = I_s\left(e^{v/V_T} - 1\right)$$

I_s Saturation current

$V_T = \dfrac{KT}{q}$ Thermal voltage

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

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



At room temperature, V_T = *25.3* mV

Compare this to an ideal diode

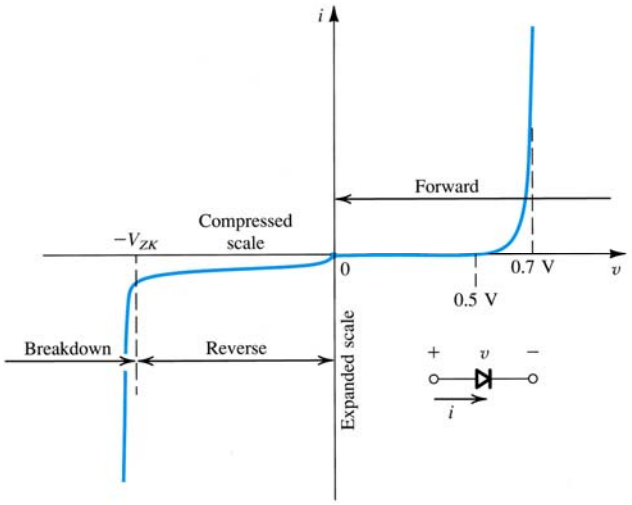


Figure 4.8 The diode i–v relationship with some scales expanded and others compressed in order to reveal details.

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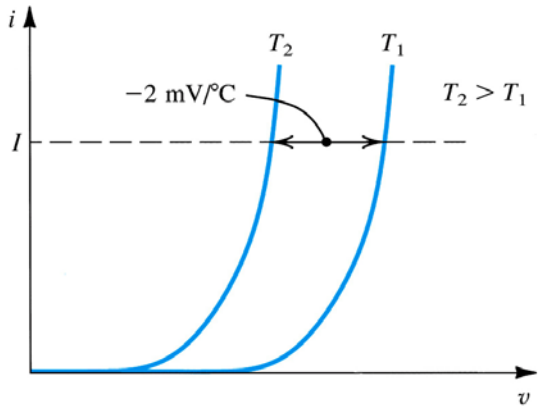

Figure 4.9 Temperature dependence of the diode forward characteristic. At a constant current, the voltage drop decreases by approximately 2 mV for every 1°C increase in temperature.

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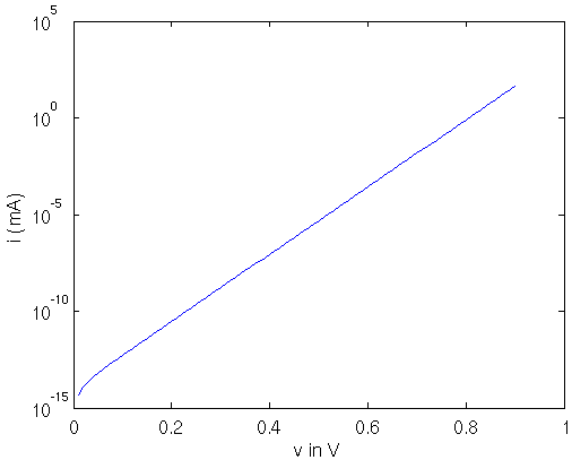
$$i_1 = I_s e^{v_1/V_T}$$

$$i_2 = I_s e^{v2/V_T}$$

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

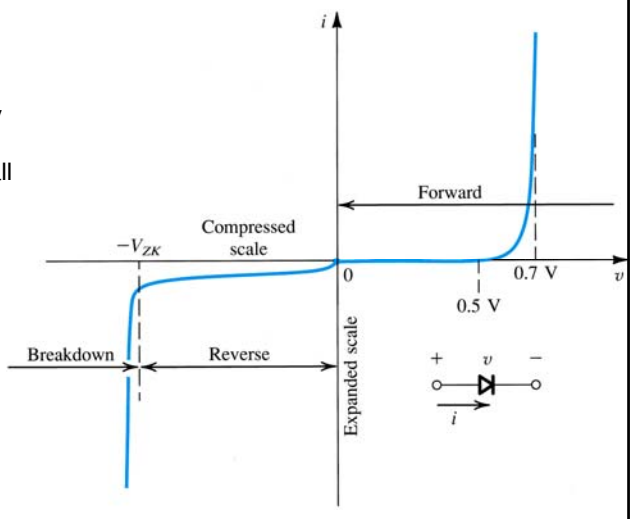
$$\ln\left(\frac{i_2}{i_1}\right) = \frac{v_2 - v_1}{V_T}$$

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



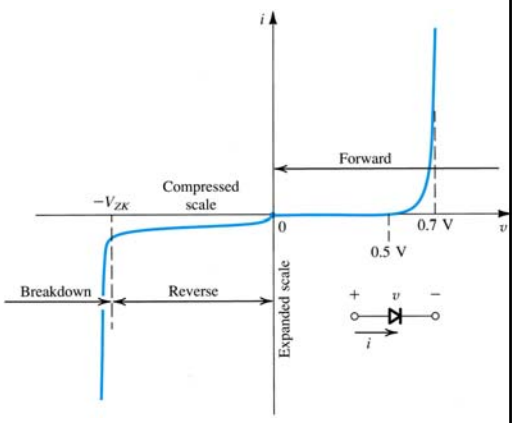
Reverse Bias Region

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



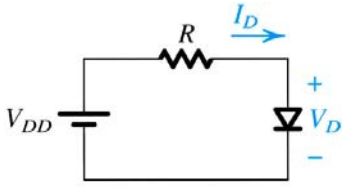
The Breakdown Region

- 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



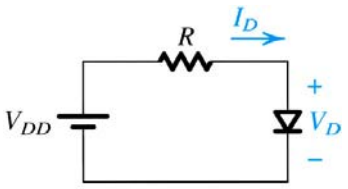
Diode Models

- 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



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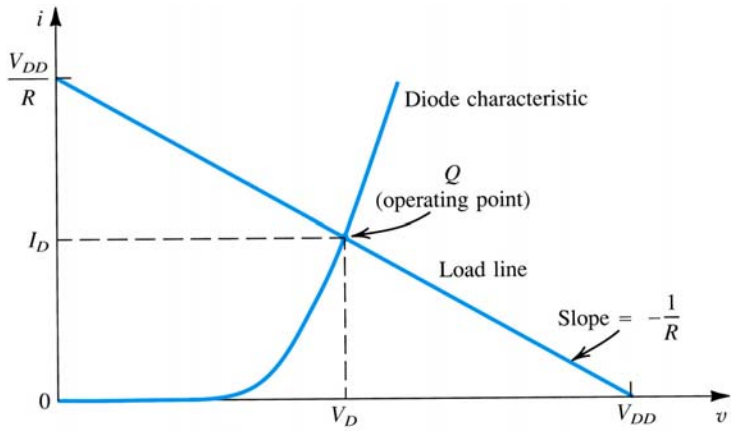

Figure 4.11 Graphical analysis of the circuit in Fig. 4.10 using the exponential diode model.

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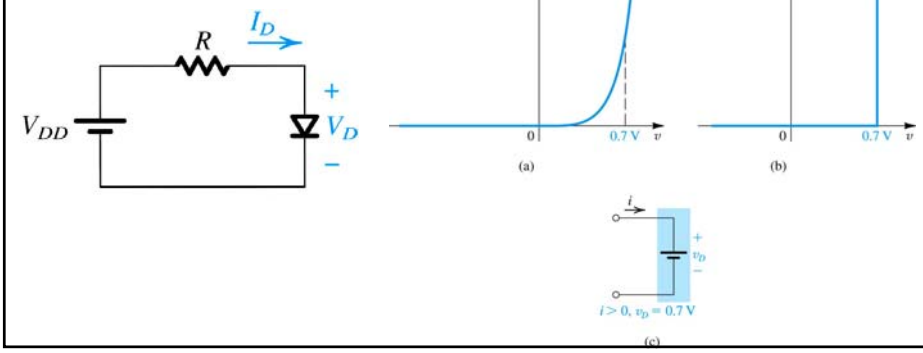
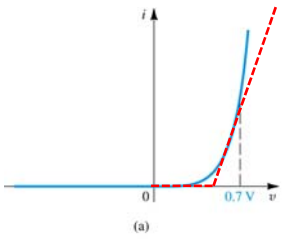
Constant Voltage Drop Model

- Assume that if the diode is ON, it has a constant voltage drop (0.7V)



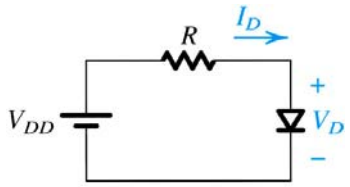
Piecewise Linear Model

- Constant voltage up to ~0.5V then resistor

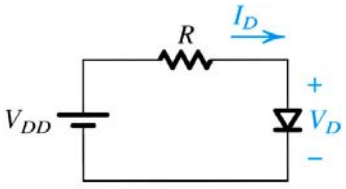


Ideal Diode Model

- Similar to constant voltage drop, but the voltage drop is 0 V



Find ID and VD for VDD = 5V, R=1KΩ
Assume 0.7 V at 1-mA Use iteration



Design a circuit to provide output voltage of 2.4V
(0.7 V at 1 mA)

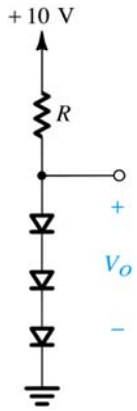


Figure E4.11

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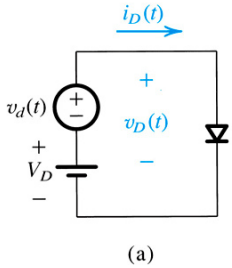
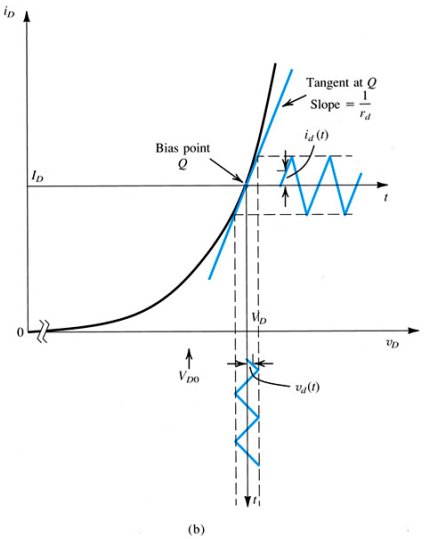
Small Signal Model



(a)



(b)

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Solve

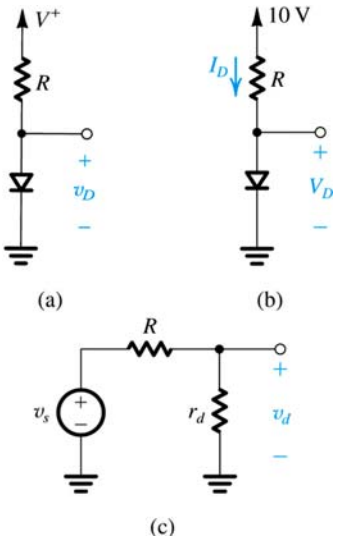

Figure 4.14 (a) Circuit for Example 4.5. (b) Circuit for calculating the dc operating point. (c) Small-signal equivalent circuit.

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Voltage Regulator (forward bias)

- A voltage regulator is a circuit that provides a constant DC voltage even with the changes of the load resistance or the source resistance.
- Since the diode in the forward bias region have a constant voltage with relatively large changes in current, it could be used as a voltage regulator

Solve

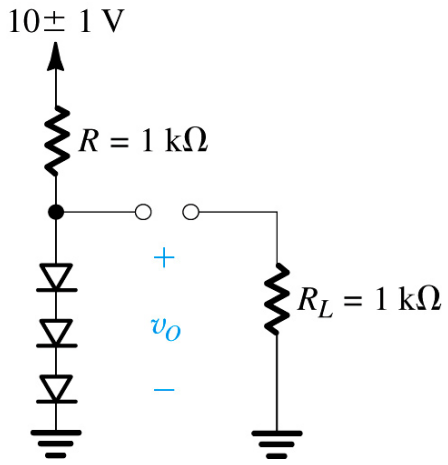

Figure 4.15 Circuit for Example 4.6.

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Solve

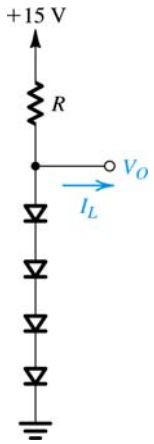

Figure E4.15

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