ELECTRONIC PRINCIPLES AND DEVICES

Department of Electronics and Communication Engineering

ELECTRONIC PRINCIPLES AND DEVICES

Course Content

Department of Electronics and Communication.

Course Content

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Unit 1: Semiconductor DIODE

Unit 2: Diode applications

Unit 3: Transistors and Operational Amplifiers

Unit 4: Digital Electronics

- Semiconductor diode under Forward and Reverse bias
- Shockley’s equation
- Zener and Avalanche breakdown
- Temperature effects
- Ideal versus Practical diode
- Diode resistances
- Diode equivalent circuits

- Series diode configurations
- Parallel and Series-Parallel configurations
- Logical operations using diode
- Diode Clippers and Clampers
- **Hardware Lab:** Diode characteristics, Clipper and Clamper circuits.

- Block diagram of regulated power supply
- Half-wave, Full-wave and bridge rectifier, Ripple factor and Peak inverse voltage derivations
- Shunt capacitor filter-working, output waveform and ripple factor equation.
- Zener diode characteristics
- Zener diode voltage regulator

- Transistors: Construction, operation

- Transistor configurations - Common base and common emitter configurations – input and output characteristics.

- Transistor amplifying action.

- Limits of operation, Operating point.

- Biasing circuits: Fixed bias, Emitter bias, Voltage divider bias

- Bias circuit design, Bias stabilization

- Single stage CE Amplifier.

- **Op-Amp:** Introduction, Op-Amp Basics
- Ideal voltage transfer curve
- Op-Amp parameters and its values for Op-Amp 741 – Input and output offset voltages, Input and output resistances, GBW, SR, CMRR (Definitions and significance only), Ideal Op-amp
- Negative feedback.
- Practical Op-Amp circuits: Inverting Amplifier, Non-inverting Amplifier, Voltage follower, Summing Amplifier, Constant Gain Amplifier, Voltage Subtraction, Integrator, Differentiator.
- **Simulation Experiments** on BJT and Op-amp

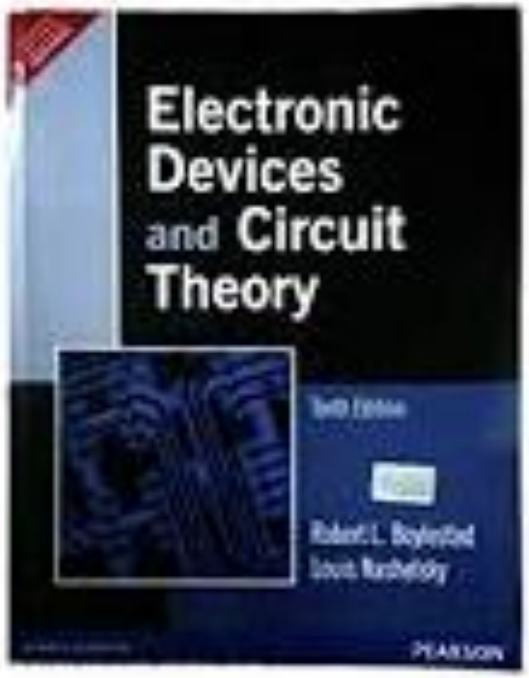
- Number Systems – binary and hexadecimal
- Binary Addition and Subtraction
- 2's complement subtraction
- Boolean Algebra
- Logic gates
- Basic Theorem and Properties of Boolean Algebra
- Boolean Functions

- Canonical and Standard Form
- Other Logical Operations
- Combinational Logic Circuits & Sequential Logic Circuits
- Half Adder and Full adder
- Sequential Circuits: Flip-Flops-RS, D, T, JK
- Registers: SISO
- Counters: 3Bit Synchronous and Asynchronous counter

- Introduction to Embedded Systems: Definition, Block Diagram of Embedded System
- Characteristics of Embedded Systems
- General Purpose and domain specific processors
- Applications of Embedded Systems
- **Hardware Lab using Digital Trainer kit:** TT Verification of Logic Gates, Adders

- Text book for UNIT 1, 2 and 3

http://www.rtna.ac.th/departments/elect/Data/EE306/Electronic%20Devices%20and%20Circuit%20Theory.pdf



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Unit 1 - Introduction to Electronics and Semiconductor Diodes

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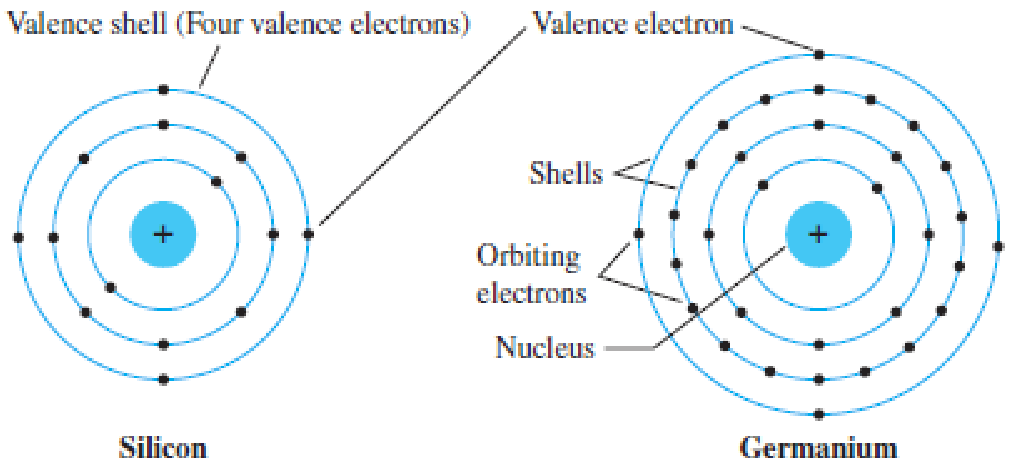
Introduction to Semiconductors

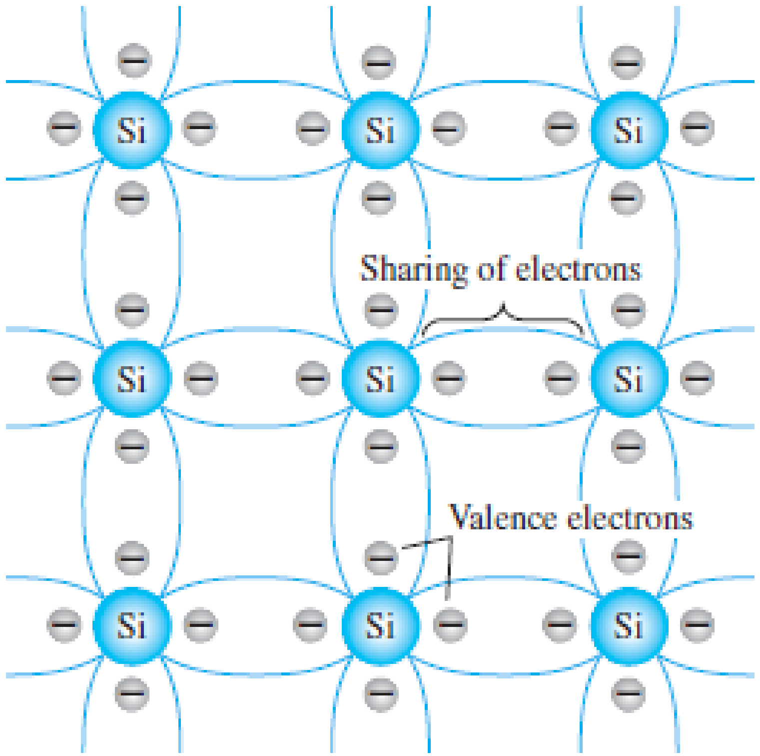


atomic number of silicon=14

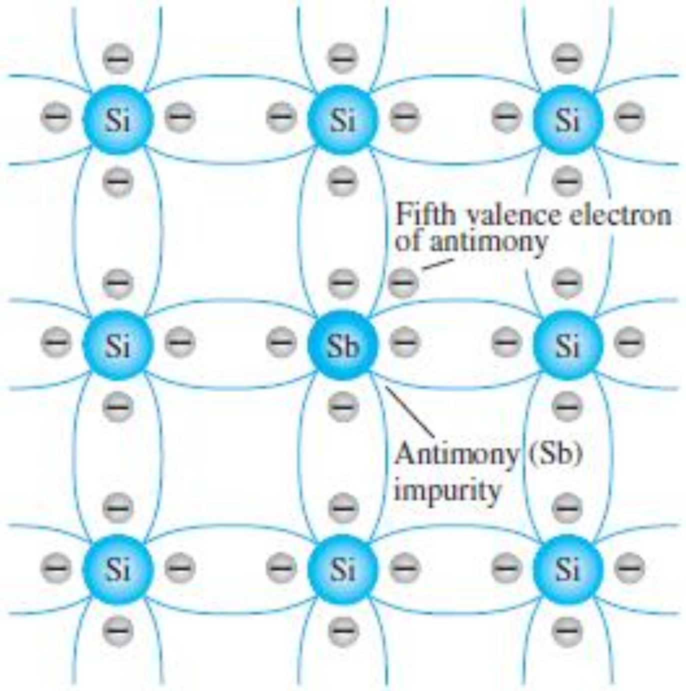
$1s^2 2s^2 2p^6 3s^2 3p^2$

atomic number of germanium=32

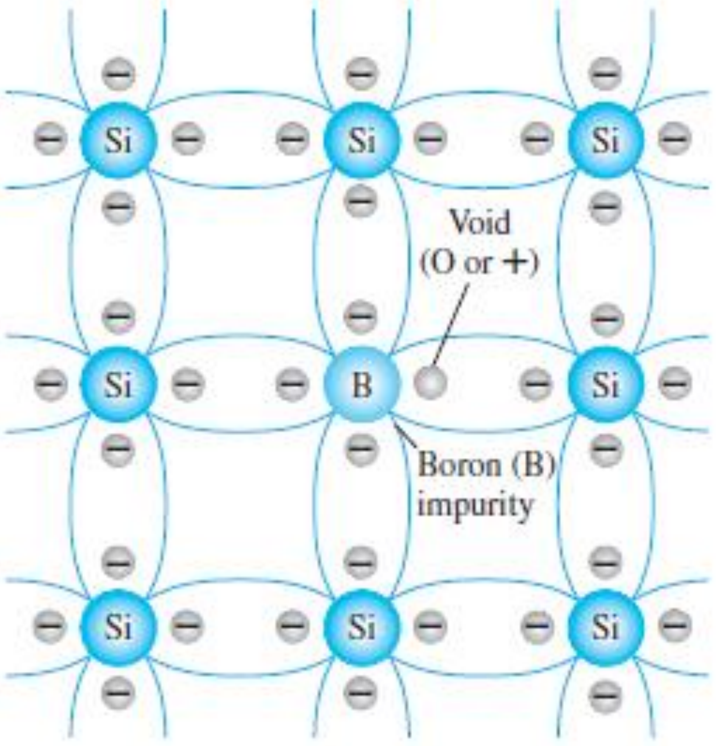
$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$.



Introduction to Semiconductors



An *n -type material is created by introducing impurity elements that* have *five valence electrons (pentavalent), such as antimony , arsenic , and phosphorus.*

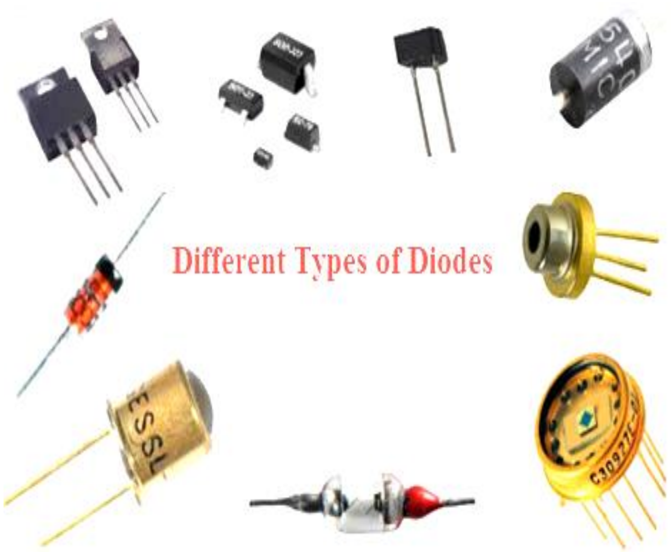


The *p-type material is formed by doping with impurity* atoms having *three valence electrons(trivalent) such as boron , gallium , and indium.*

An Introduction to Semiconductor Diode

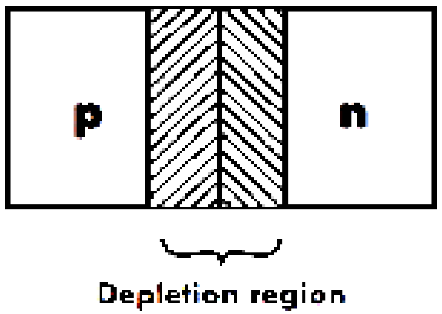
Diode : Two – electrodes

- p-type and n-type material sandwiched together to form a depletion region between the two.
- Semiconductor diode may be either of Silicon or Germanium material

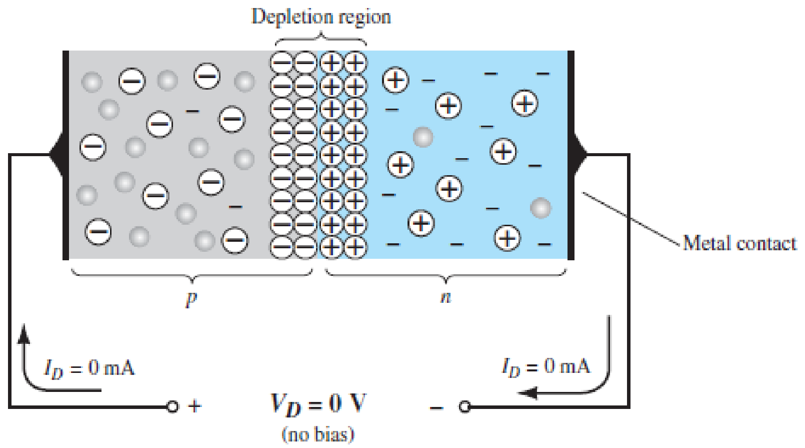


Biasing of diodes :

- Forward Bias: A material type connected to the same polarity terminal of the voltage source
- Reverse Bias: A material type connected to the opposite polarity terminal of the voltage source



Diode under different biasing conditions



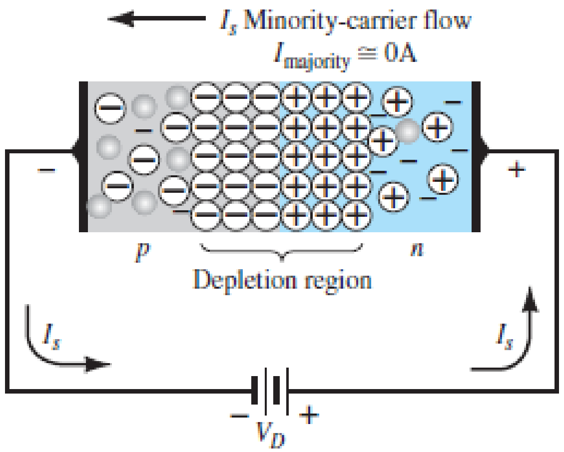
No bias

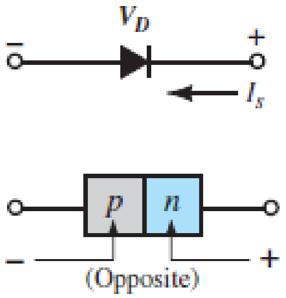
In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

No – bias condition:

- At the instant the two materials are "joined" the electrons and the holes in the region of the junction will combine, resulting in a lack of free carriers in the region near the junction, as shown in Fig.
- Note in Fig. that the only particles displayed in this region are the positive and the negative ions remaining once the free carriers have been absorbed.
- ***This region of uncovered positive and negative ions is called the depletion region due to the "depletion" of free carriers in the region.***

Diode under different biasing conditions





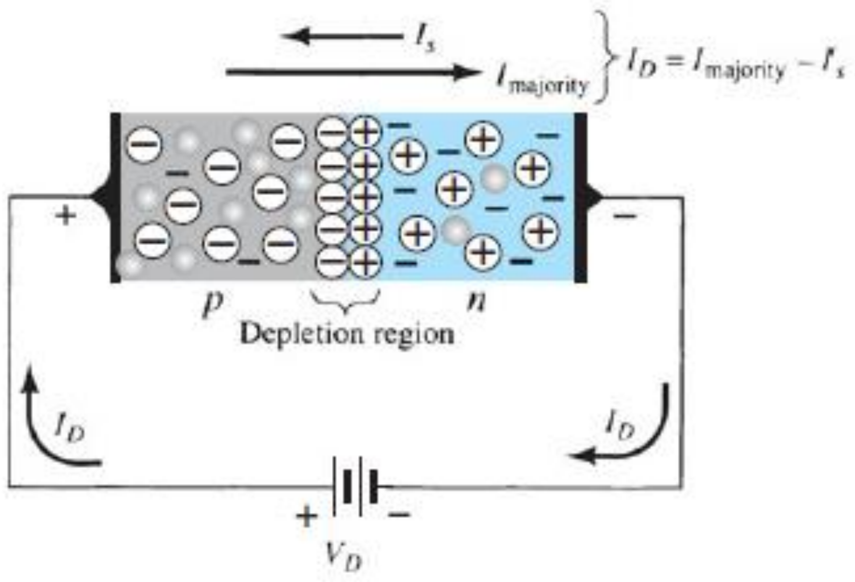
Reverse Bias

The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is.

Reverse – bias condition:

- When a pn junction is reverse-biased as shown in Fig., the number of uncovered positive ions in the depletion region of the *n*-type material will increase due to the large number of free electrons drawn to the positive potential of the applied voltage.
- For similar reasons, the number of uncovered negative ions will increase in the *p*-type material.
- The net effect, therefore, is a widening of the depletion region. This widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero.

Diode under different biasing conditions



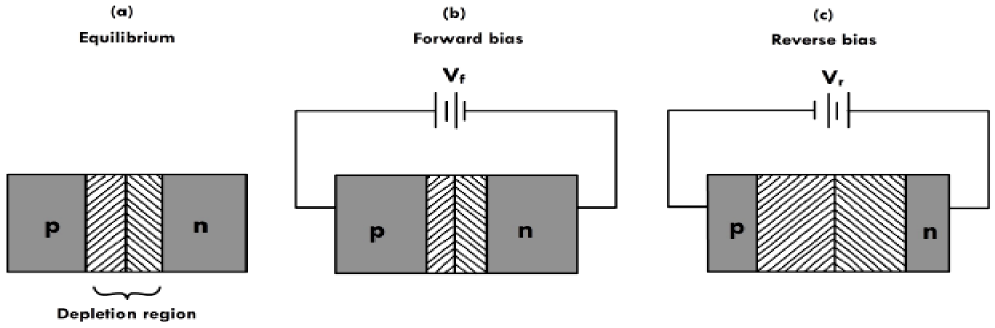
Forward Bias

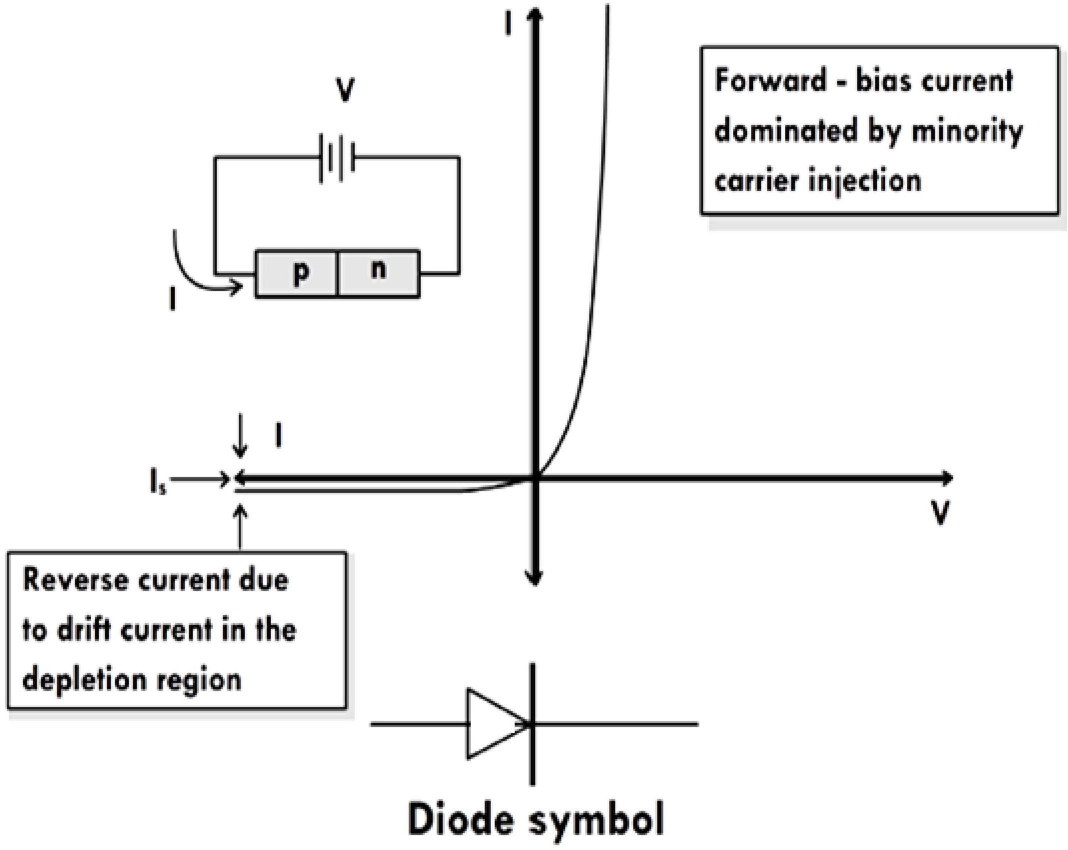
Forward – bias condition

- A *forward-bias* or "on" condition is established by applying the positive potential to the *p*-type material and the negative potential to the *n*-type material as shown in Fig.
- The application of a forward-bias potential V_D will "pressure" electrons in the *n*-type material and holes in the *p*-type material to recombine with the ions near the boundary and reduce the width of the depletion region as shown in Fig.

Semiconductor Diode – Forward & Reverse Characteristics

- **Knee voltage** (Vk) is also known as **cut- in** voltage. The minimum voltage across the diode for it to start conducting is known as knee voltage or cut in voltage.
- The forward voltage at which the current through PN junction starts increasing rapidly is known as knee voltage.





Diode's Current Expression (Shockley's Current Equation)

Shockley's Equation also called the **diode equation** helps us determine the current at a given temperature knowing the diode voltage and saturation current

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

k = 1.380 649 x10^-23 Joule/Kelvin.

q=1.602176634 × 10^{-19} **coulomb**

- When V_D is negative

$$I_D \sim -I_S$$

- When V_D is positive

$$I_D \sim I_S e^{\frac{qV_D}{nkT}}$$

Where

I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor: n = 1 for indirect semiconductors (Si, Ge, etc.)

n = 2 for direct semiconductors (GaAs, InP, etc.)

k is Boltzmann's constant

T is temperature in Kelvin

Diode's Current Expression (Shockley's Current Equation)

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

k = 1.380 649 . 10^-23 Joule/Kelvin.

q=1.602176634 × 10^{-19} coulomb

kT/q is also known as V_{th}, the thermal voltage. At 300K (room temperature),

kT/q = 25.9mV

EXAMPLE 1.1 At a temperature of 27°C (common temperature for components in an enclosed operating system), determine the thermal voltage V_T.

Solution: Substituting into Eq. (1.3), we obtain

$$T = 273 + {}^\circ\mathrm{C} = 273 + 27 = 300\ \mathrm{K}$$

$$V_T = \frac{kT_K}{q} = \frac{(1.38 \times 10^{-23}\ \mathrm{J/K})(30\ \mathrm{K})}{1.6 \times 10^{-19}\ \mathrm{C}}$$

$$= 25.875\ \mathrm{mV} \cong 26\ \mathrm{mV}$$

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Q. No 1 Calculate the thermal voltage when the temperature is 25°C

Solution:

k = 1.380 649 x10^-23 Joule/Kelvin.

Thermal voltage V_T =k T/q

q=1.602176634 × 10^{-19} coulomb

Where k is the Boltzmann constant and q is the charge of electron. This can be reduced to

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

V_T = T/11600   q/k=11600

Therefore, V_T = 298/11600 = 0.0257V

V_T = 25.7mV

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Q.No.2 Calculate the forward bias current of a Si diode when forward bias voltage of 0.4V is applied, the reverse saturation current is 1.17×10^{-9}A and the thermal voltage is 25.2mV.

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

Solution: $I_D = I_s(e^{V_D/nV_T} - 1)$; I_s = reverse saturation current

η = ideality factor, V_T = thermal voltage, V_D = applied voltage

Since in this question ideality factor is not mentioned it can be taken as one.

$I_s = 1.17 \times 10^{-9}$A, $V_T = V_T = kT/q = 0.0252$V, $\eta = 1$, $V_D = 0.4$V

Therefore, $I_D = 1.17\times10^{-9} \times (e^{0.4/0.0252} - 1)$

$I_D = 9.156$mA.

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Q. No 3 Given a diode current of 8 mA and n=1, find the reverse saturation current (Is) if the applied voltage is 0.5 V and the room temperature is 25°C.

Solution: Equation for diode current (Shockley's Equation) $I_D = I_s(e^{V_D/nV_T} - 1)$

Given: I_D = **diode current = 8 mA**, η = ideality factor = 1, V_D = Applied voltage = 0.5V

Find V_T = Thermal voltage and Reverse saturation current Is

$$V_T = \frac{kT_K}{q} = \frac{(1.38\times10^{-23}\ \mathrm{J/K})(25°\mathrm{C} + 273°\mathrm{C})}{1.6\times10^{-19}\ \mathrm{C}}$$

$$= 25.70\ \mathrm{mV}$$

$$8\mathrm{mA} = I_s(e^{(0.5\mathrm{V})/(1)(25.70\ \mathrm{mV})} - 1) = I_s(28\times10^8)$$

$$I_s = \frac{8\ \mathrm{mA}}{2.8\times10^8} = \mathbf{28.57\ pA}$$

Numerical on Diode's Current Equations

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Q. No 4: Calculate the applied voltage V_D, if diode current is 6 mA, Thermal Voltage is 26 mV, Ideality factor is 1, and Reverse saturation current is 1 nA.

Solution: **Given:** I_D = 6 mA, V_T = 26 mV, η = 1, I_S = 1 nA, V_D = Applied voltage = ………V

Equation for diode current (Shockley's Equation)

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

$$6\text{ mA} = 1\text{ nA}(e^{V_D/(1)(26\text{ mV})} - 1)$$

$$6 \times 10^6 = e^{V_D/26\text{ mV}} - 1$$

$$e^{V_D/26\text{ mV}} = 6 \times 10^6 - 1 \cong 6 \times 10^6$$

$$\log_e e^{V_D/26\text{ mV}} = \log_e 6 \times 10^6$$

$$\frac{V_D}{26\text{ mV}} = 15.61$$

$$V_D = 15.61(26\text{ mV}) \cong \mathbf{0.41\ V}$$

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Q. No 5 Consider a silicon diode with η=1.2. Find change in voltage if the current changes from 0.1mA to 10mA.

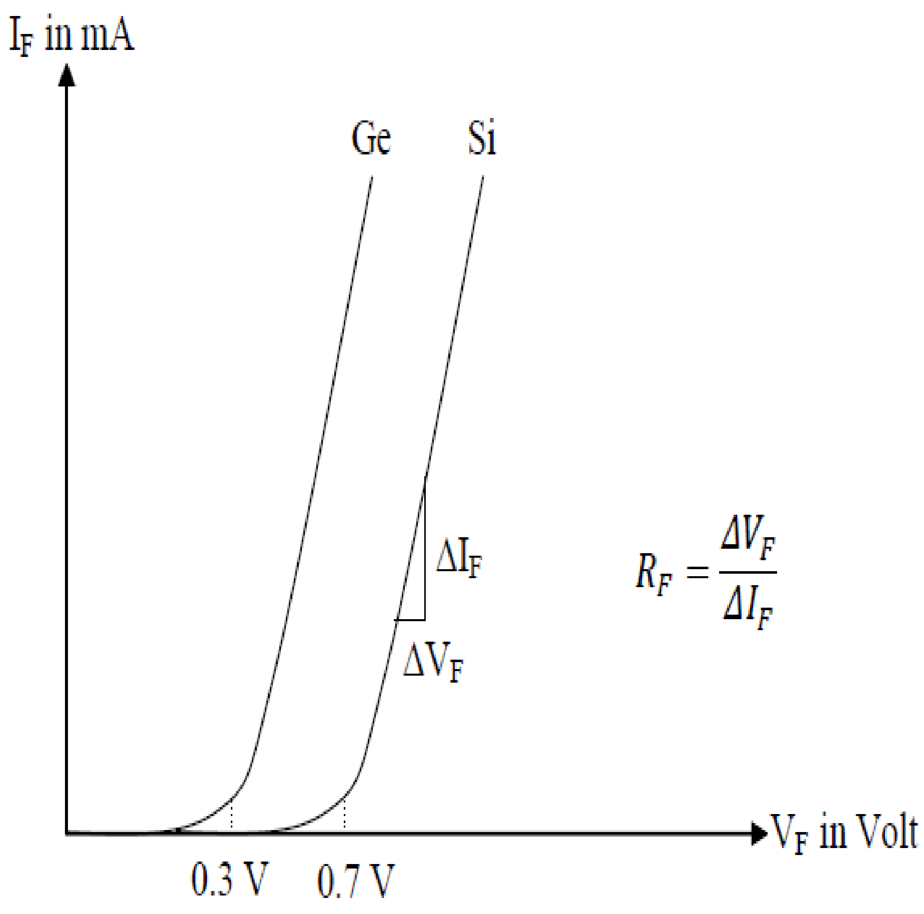
Solution: Equation for diode current $I=I_0\times(e^{(V/\eta V_T)}-1)$

Where I_0 = reverse saturation current, η = ideality factor
V_T = thermal voltage, V = applied voltage

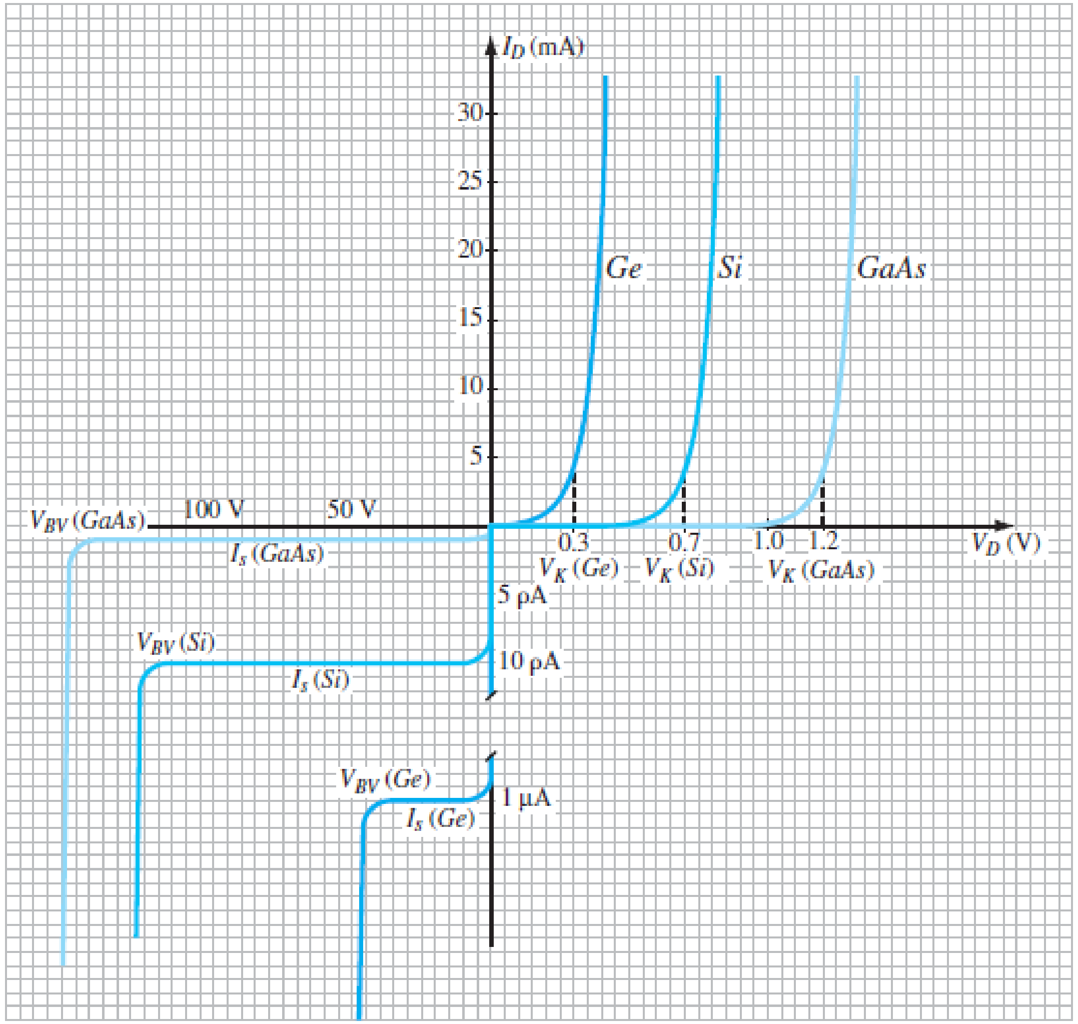
$\eta = 1.2$, $I_2 = 10mA$, $I_1 = 0.1mA$ and take $V_T = 0.026V$

$$\text{Change in voltage } \Delta V = \eta V_T \ln\left(\frac{I_2}{I_1}\right) = 1.2\text{x}0.026\text{x}\ln\left(10 \times \frac{10^{-3}}{0.1\times10^{-3}}\right) = 0.143V$$

Diode's Current Expression (Shockley's Current Equation)



$$R_F = \frac{\Delta V_F}{\Delta I_F}$$



Semiconductor Diode's Characteristics & Parameters

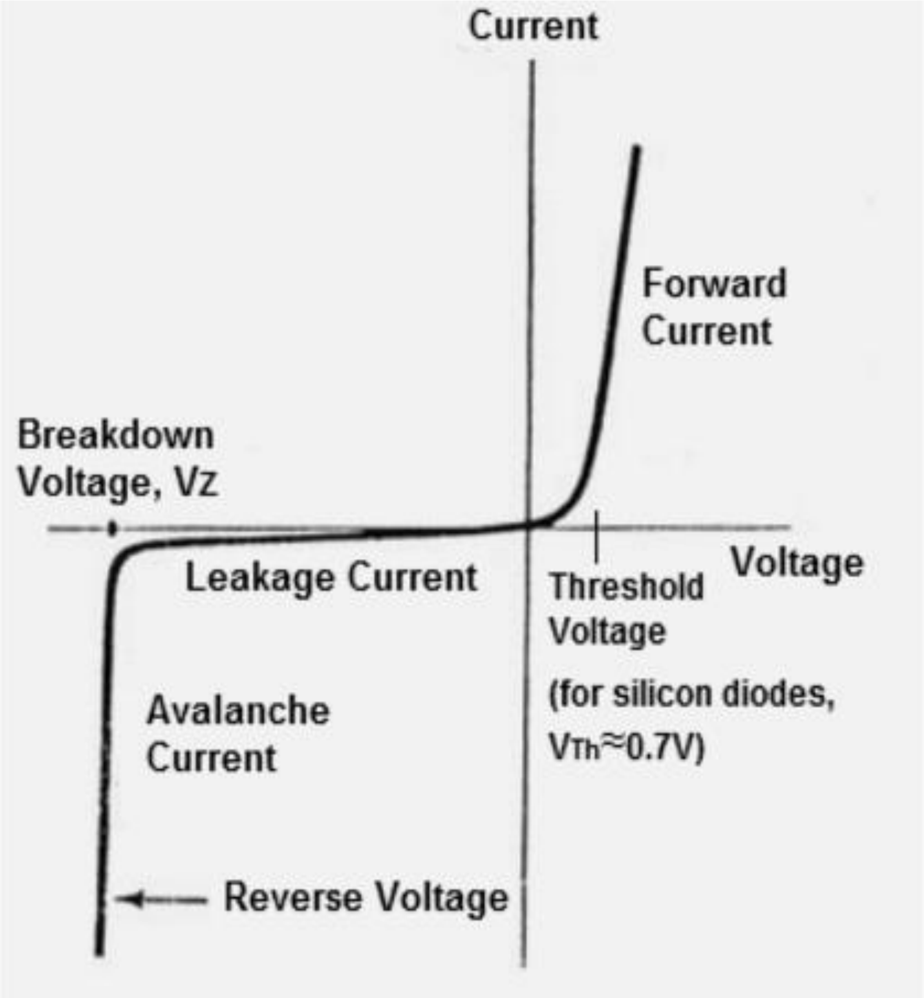
From the characteristics curve of a semiconductor diode the following parameters have been observed under,

Forward Bias

- Knee Voltage
- Forward Current Rating
- Maximum Power Dissipation

Reverse Bias

- Reverse Saturation Current
- Break down Voltage
- Peak Inverse Voltage Rating



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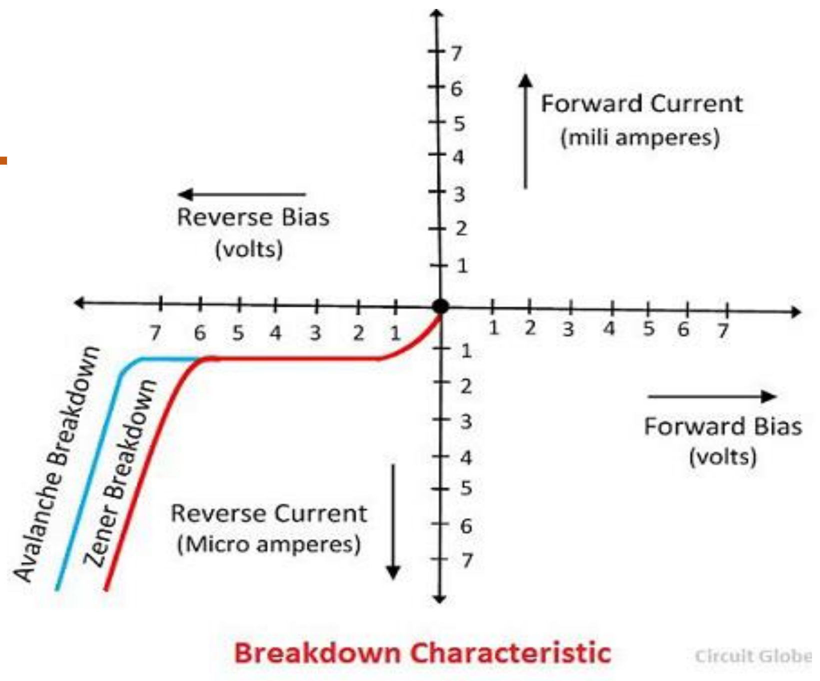
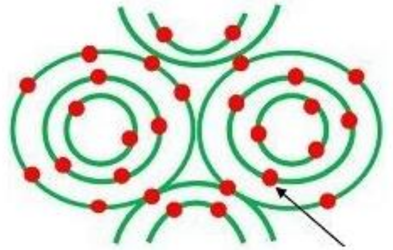
Types of Diode Breakdown

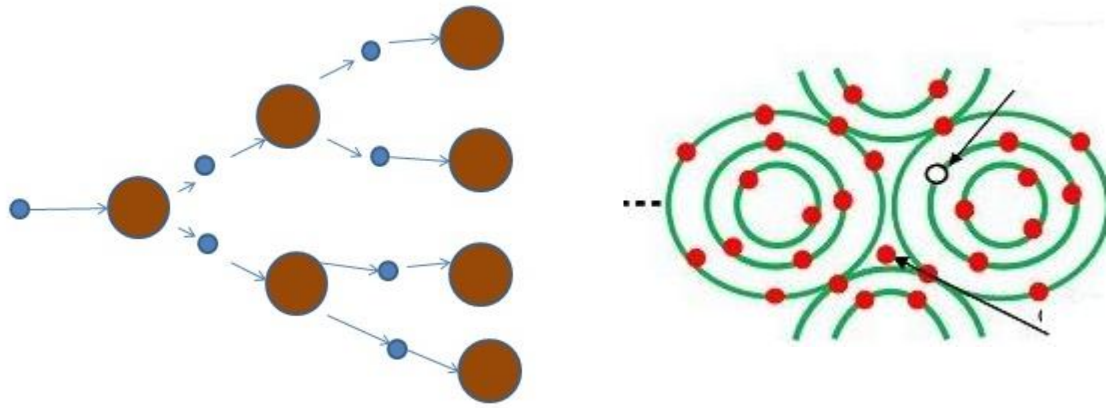
Avalanche breakdown : In the reverse bias condition as the voltage increases the free charge carriers obtain velocity and associated kinetic energy and release additional carriers through collision with other atomic structures.

Hence Covalent bonds are broken and electron–hole are generated.

These charge carriers acquire energy from the applied potential and produce more and more free charge carriers. This cumulative process is called Avalanche multiplication or ionization process.







Carrier Multiplication or avalanche breakdown

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Types of Diode Breakdown

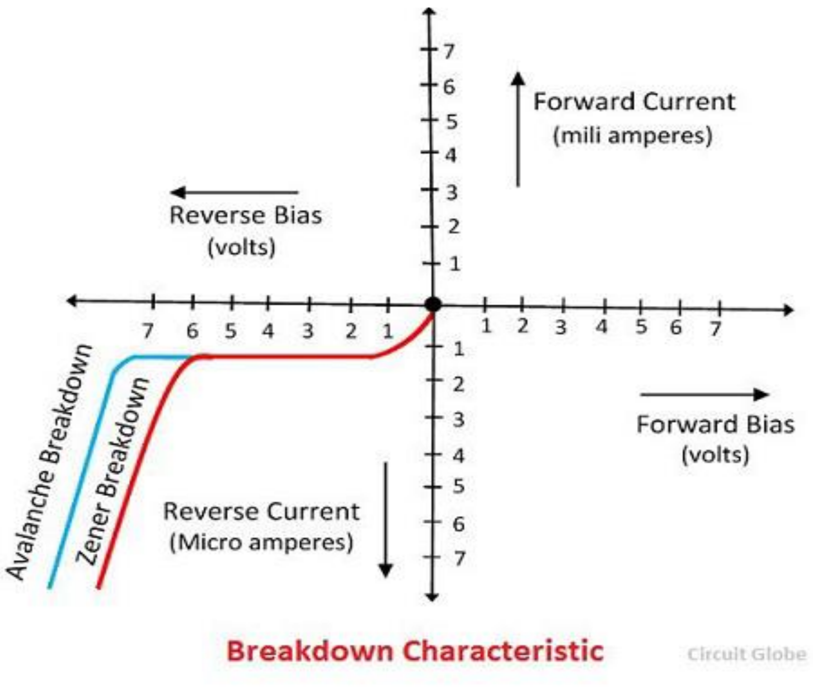
Zener breakdown :

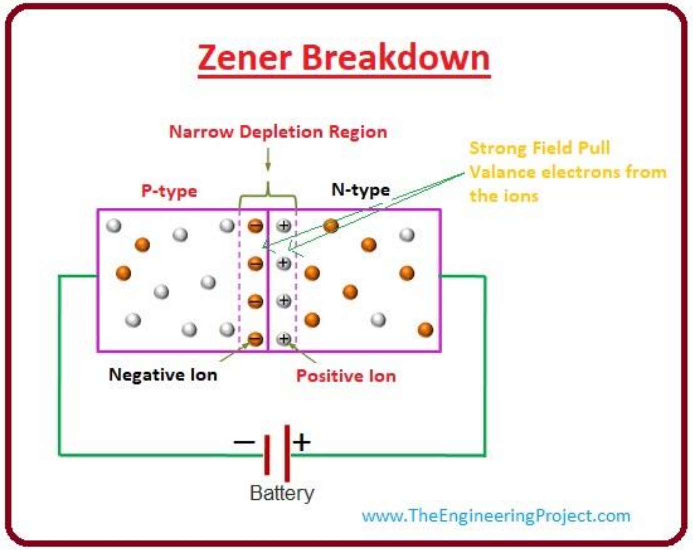
Zener break down occurs when both P and N type material are heavily doped in a semiconductor diode.

Hence the depletion layer region is narrow down.

When a small reverse bias voltage is applied across a diode a very strong electric fied is produced.

Due to this electric field covalent bond breaks and produces large number of free charge carriers.





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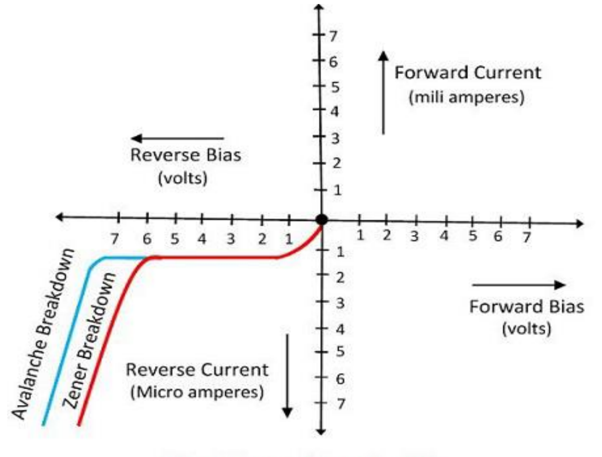
Types of Diode Breakdown

	ZENER BREAKDOWN	AVALANCHE BREAKDOWN
01	The process in which the electrons move across the barrier from the valence band of p-type material to the conduction band of n-type material is known as Zener breakdown.	The process of applying high voltage and increasing the free electrons or electric current in semiconductors and insulating materials is called an avalanche breakdown.
02	This is observed in Zener diodes having a Zener breakdown voltage Vz of 5 to 8 volts.	This is observed in Zener diode having a Zener breakdown voltage Vz greater than 8 volts.
03	The valence electrons are pulled into conduction due to the high electric field in the narrow depletion region.	The valence electrons are pushed to conduction due to the energy imparted by accelerated electrons, which gain their velocity due to their collision with other atoms.
04	The increase in temperature decreases the breakdown voltage.	The increase in temperature increases the breakdown voltage.
05	The VI characteristics of a Zener breakdown has a sharp curve.	The VI characteristic curve of the avalanche breakdown is not as sharp as the Zener breakdown.
06	It occurs in diodes that are highly doped.	It occurs in diodes that are lightly doped.



Breakdown Characteristic

Temperature Effects on V-I Characteristics of a Diode

- The Effect of variation in temperature across a semiconductor diode is observed both in the forward as well as in reverse characteristics.

- Rise in temperature generates more electron-hole pair thus conductivity increases and thus increases in current.

- PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature.

- Increase in the temperature increases carrier concentration. As a result, knee voltage decreases & breakdown voltage increases while reverse saturation current increases.

Temperature Effects on V-I Characteristics of a Diode

Under Forward Bias the Change in Temperature across the diode: Barrier voltage is dependent on temperature hence it decreases by 2.5mV/ °C rise in temperature for both germanium and silicon.

Under Reverse Bias the Change in Temperature across the diode: Reverse saturation current (I_S) of diode increases with increase in the temperature. The rise is 7%/°C for both germanium & silicon and approximately doubles for every 10°C rise in temperature.

Reverse breakdown voltage (V_R) also increases as the temperature increases

Temperature Effects on V-I Characteristics of a Diode

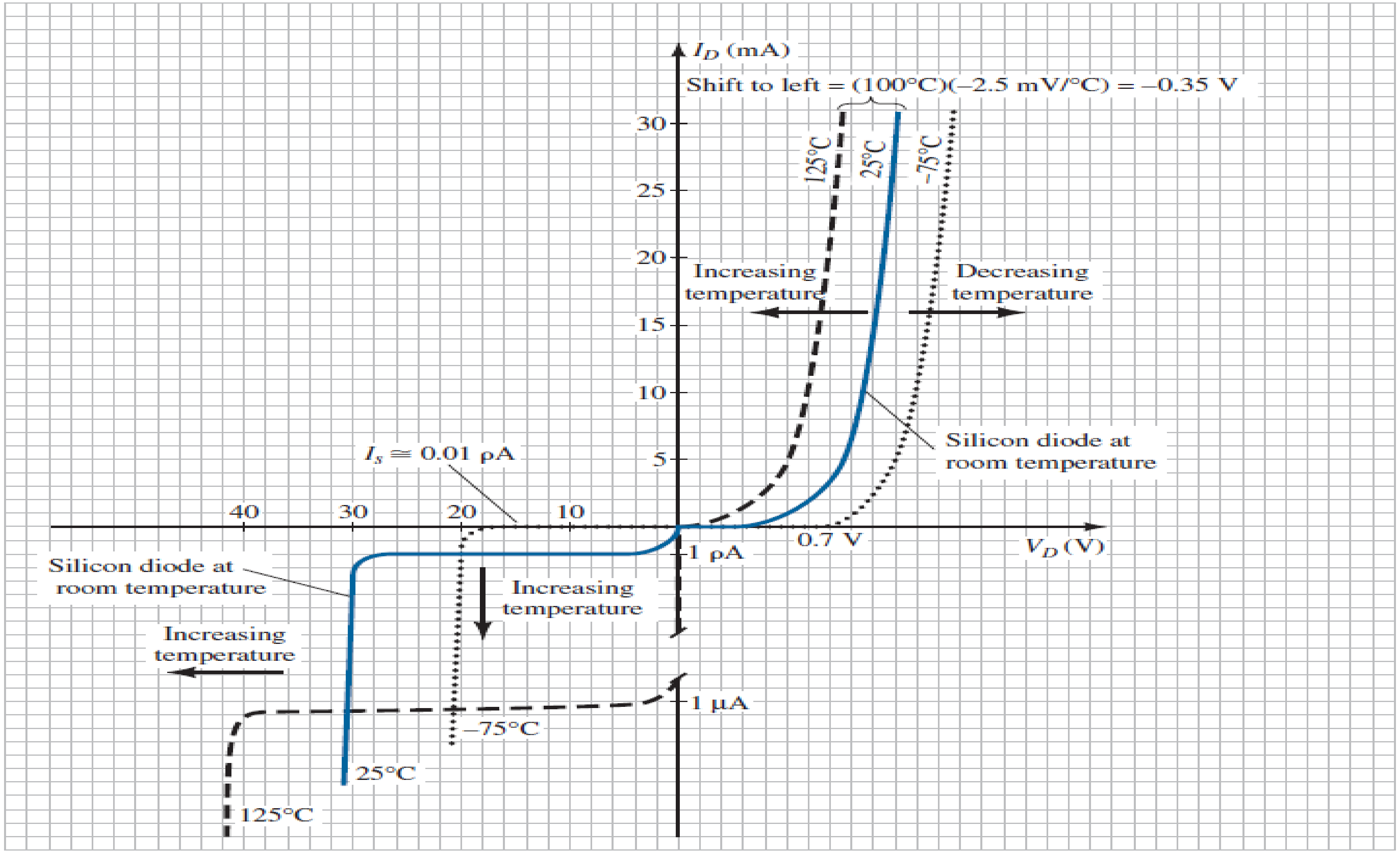


FIG. 19

Variation in Si diode characteristics with temperature change.

An Example - Temperature Effects on A Semiconductor diode

The Reverse saturation current of silicon diode at 20°C is 0.1μA. Determine its value if the temperature is increased by 40 °C .

ANS:

$$Given\ Data\ at\ T = 20^{o}C : I_s = 0.1\mu A$$

$$T = 30^{o}C : I_s = 0.2\mu A$$

$$T = 40^{o}C : I_s = 0.4\mu A$$

$$T = 50^{o}C : I_s = 0.8\mu A$$

$$\mathrm{T} = 60^{o}\mathrm{C} : \mathrm{I_s} = 1.6\mu A$$

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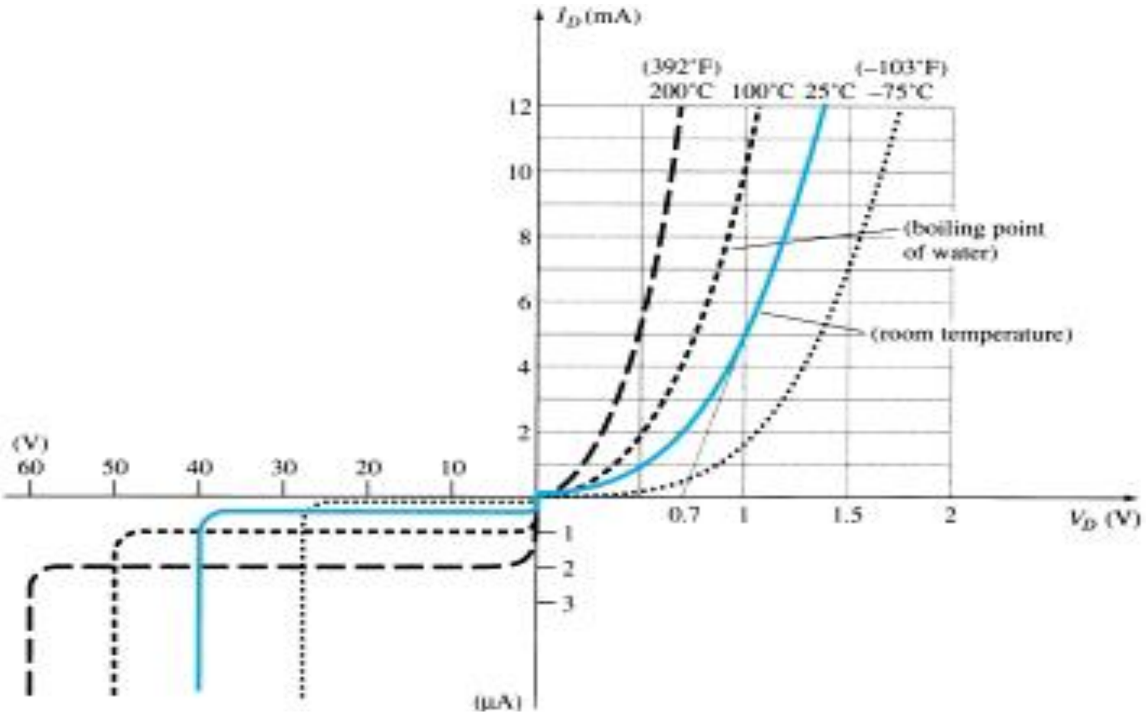
Temperature Effects: Numerical

1. The reverse saturation current Is will double in magnitude for every 10°C increase in temperature.



Reference :ELECTRONIC DEVICES AND CIRCUIT THEORY ROBERT BOYLESTAD LOUIS NASHELSKY

2. The Knee voltage shifts to the left at a rate of 2.5mV per degree centigrade increase in temperature

Temperature Effects: Numerical

1. The knee voltage of a Si diode is 0.7V and its reverse Saturation current is 20nA at 25°C. Determine these values at 40°C.

Solution:

Knee voltage shift left at a rate of 2.5mV per centigrade degree increase in temperature.

Therefore for a Change in temperature is = 40°C-25°C =15°C

Change in knee voltage will be =2.5mV X 15= 0.0375V

Hence V_K at 40°C = 0.7-0.0375= 0.6625 V,

Reverse Saturation Current doubles for every 10°C rise in Temperature

I_S at 40°C = 2^ (40-25/10) X 20nA = 2.82X20nA = 56.56nA.

Temperature Effects: Numerical

2.The reverse saturation current of a Germanium diode is 200μA at room temperature of 27°C. Calculate the current in forward biased condition, if forward biased voltage is 0.2V at room temperature. If temperature is increased by 30°C, calculate the reverse saturation current and the forward current for the same forward voltage at new temperature.

Solution:

V_T= kT/q= 25.9mV k = 1.380 649 . 10^-23 Joule/Kelvin. q=1.602176634 × 10^{-19} coulomb

$I=I_s\times(e^{(V_D/\eta V_T)}-1)= 200\mu A \times e^{0.2/.0259} = 0.451A$

If the temperature is increased by 30°C New temperature is 27+30= 57°C

Therefore Is= 200μ X2^3= 1600 μA therefore at new V_T at 57°C is 28.4mV

Hence I_D at 57°C = 1.83A.

Temperature Effects: Numerical

3. A Ge diode has a reverse saturation current of 5μA at temperature 300K find diode current at 40°C . When forward bias voltage is 0.27.

Solution:

.

$q=1.602176634 \times 10^{-19}$ coulomb

Given Is at 27°C is 5μA

k = 1.380 649 . 10^-23 Joule/Kelvin.

Therefore, Is at 40°C is = $5\mu \times 2^{(40-27/10)}$

= 5μ X 2.462

=12.31 μ A

Hence V_T at 40°C = kT/q= 26.9mV

Therefore $I=I_s\times(e^{(VD/\eta V_T)}-1)= 12.31\mu A \times e^{(VD/\eta V_T)} = 281.49mA$

Temperature Effects: Numerical

4. The reverse saturation current of a Si diode is 2pA at 27°C. Determine the forward biased voltage across the diode at 57°C, if the forward current through the diode at 57°C is 50mA.

Solution:

Reverse saturation current doubles for every 10°C rise in temperature

Hence at if reverse saturation current at 27°C is 2pA

Then reverse saturation current at 37°C is 4pA

Then reverse saturation current at 47°C is 8pA

Then reverse saturation current at 57°C is 16pA

Therefore V_T 57°C is =k x 330/q= 28.42mV

Hence by using $I_D=I_s\times(e^{(VD/\eta V_T)}-1) = 50mA$

$50/16= e^{VD/\eta V_T}$ → $\ln(50/16)=VD/28.42m$ → $V_D = 0.686V$ at 57°C.

$q=1.602176634 \times 10^{-19}$ coulomb

$k = 1.380\,649 \,.\, 10^{-23}$ Joule/Kelvin.

Temperature Effects: Numerical

5.The reverse saturation current of a Germanium diode is 100μA at room temperature of 28°C. Calculate the current in forward biased condition, if forward biased voltage is 0.3V at room temperature. If temperature is increased by 25°C, calculate the reverse saturation current and the forward current for the same forward voltage at new temperature.

Solution:

V_T= kT/q= 25.9mV   k = 1.380 649 . 10^-23 Joule/Kelvin.   q=1.602176634 × 10^{-19} coulomb

$I=I_s\times(e^{(VD/\eta V_T)}-1)$

If the temperature is increased by 28°C New temperature is 28+25= 53°C

Therefore Is= 100μ X2^2.5= 565.68 μA. Therefore, new V_T at 53°C is 28.117 mV

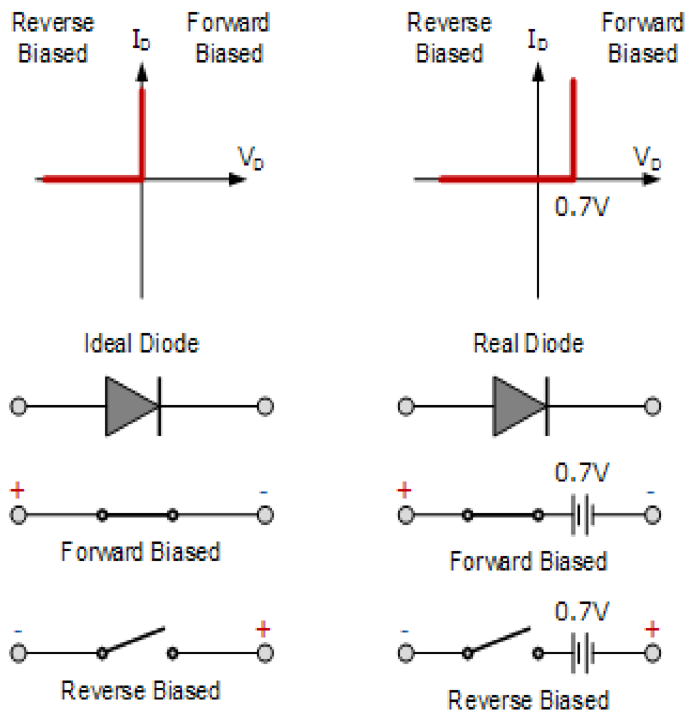
Hence I_D at 53°C = 24.31 A.

ELECTRONIC PRINCIPLES AND DEVICES

Ideal and Practical Diode Characteristics:

Ideal Diode: When an ideal diode is forward biased, it offers no resistance & acts like a closed switch. Likewise, the ideal diode under reverse bias offers infinite resistance hence, it acts like open switch.

Practical Diode: A diode which is said to be forward biased it starts conducting at knee voltage & under reverse bias no current due to majority charges hence a practical diode is considered to be open switch (minority charges current ignored).



Resistance of a Semiconductor Diode

- An actual diode offers a very small resistance (not zero) when forward biased and is called a forward resistance
- Whereas, it offers a very high resistance (not infinite) when reverse biased and is called as a reverse resistance

- Type of applied voltage or signal will define

the following resistance levels

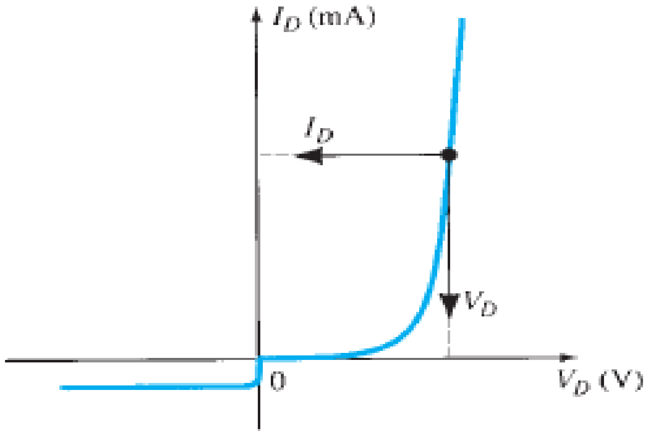
i. DC or Static Resistance

ii. AC or Dynamic Resistance

iii. Average AC Resistance

DC or Static Resistance

- The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the semiconductor diode characteristic curve.
- Finding the corresponding levels of V_D and I_D at particular operating point gives the DC resistance.



$$\boxed{R_D = \frac{V_D}{I_D}}$$

- Typically, the dc resistance of a diode in:

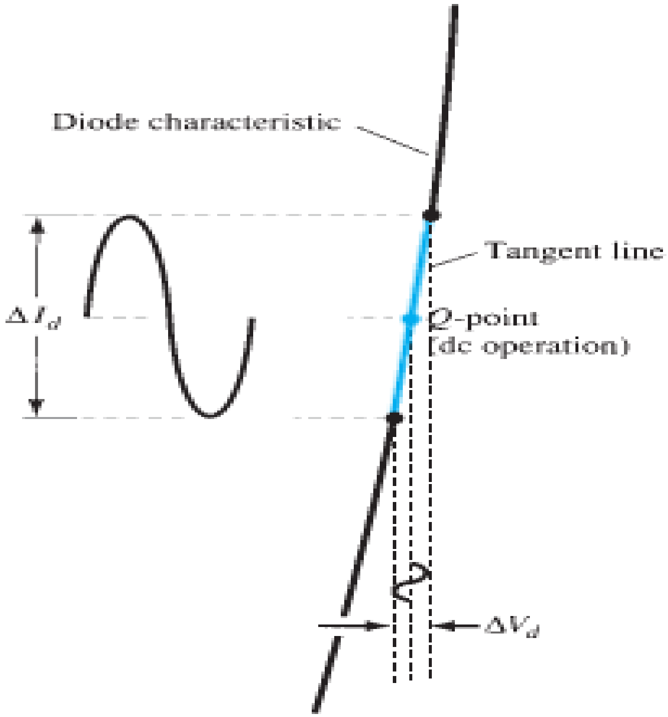
Forward bias : 10 Ω to 80 Ω

Reverse Bias: 10 MΩ

AC or Dynamic Resistance

- The application of a small AC voltage to a circuit containing a semiconductor diode offers AC resistance.
- A straight line drawn tangent to the curve through the Q –point will define a particular change in voltage and current determines the ac or dynamic resistance for this region of the diode characteristics.

$$r_d = \frac{\Delta V_d}{\Delta I_d}$$



AC or Dynamic Resistance

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- Dynamic resistance can be found simply by substituting the quiescent value of the diode current into the equation also

$$\boxed{r_d = \frac{26\text{ mV}}{I_D}}$$

$$\boxed{r'_d = \frac{26\text{ mV}}{I_D} + r_B} \quad \text{ohms}$$

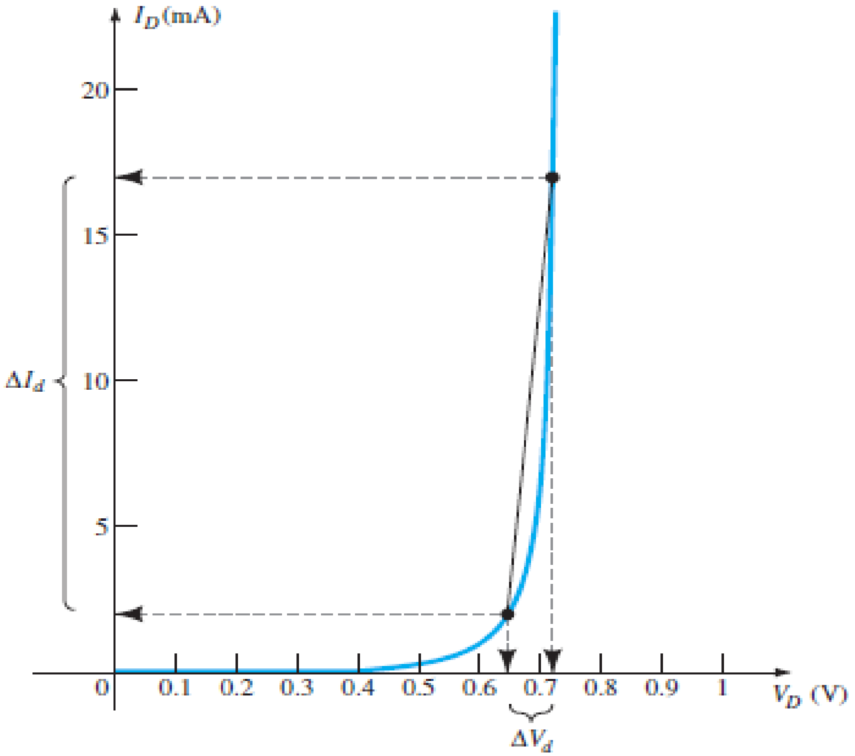
- Where r_B is bulk or body resistance

Typically, the ac resistance of a diode in the active region will range from 1 Ω to 100 Ω.

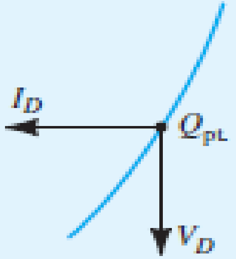
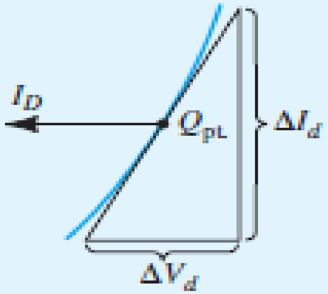
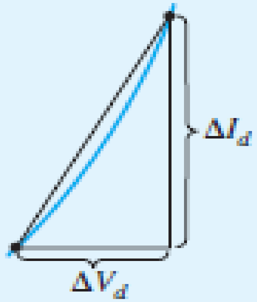
Average AC Resistance

If applied input signal is sufficiently large to produce a broad swing and the resistance determined by a straight line drawn between the two intersections established by the maximum and minimum values of input voltage is called Average AC Resistance

$$r_{av} = \left.\frac{\Delta V_d}{\Delta I_d}\right|_{\text{pt. to pt.}}$$



Summary of Resistances

Type	Equation	Special Characteristics	Graphical Determination
DC or static	$R_D = \dfrac{V_D}{I_D}$	Defined as a point on the characteristics	
AC or dynamic	$r_d = \dfrac{\Delta V_d}{\Delta I_d} = \dfrac{26\text{ mV}}{I_D}$	Defined by a tangent line at the Q-point	
Average ac	$r_{av} = \dfrac{\Delta V_d}{\Delta I_d}\Bigg\vert_{\text{pt. to pt.}}$	Defined by a straight line between limits of operation	

Resistance of a Semiconductor Diode

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- Whereas, it offers a very high resistance (not infinite) when reverse biased and is called as a reverse resistance

- Type of applied voltage or signal will define

the following resistance levels

i. DC or Static Resistance

ii. AC or Dynamic Resistance

iii. Average AC Resistance

Diode Resistance: Numerical

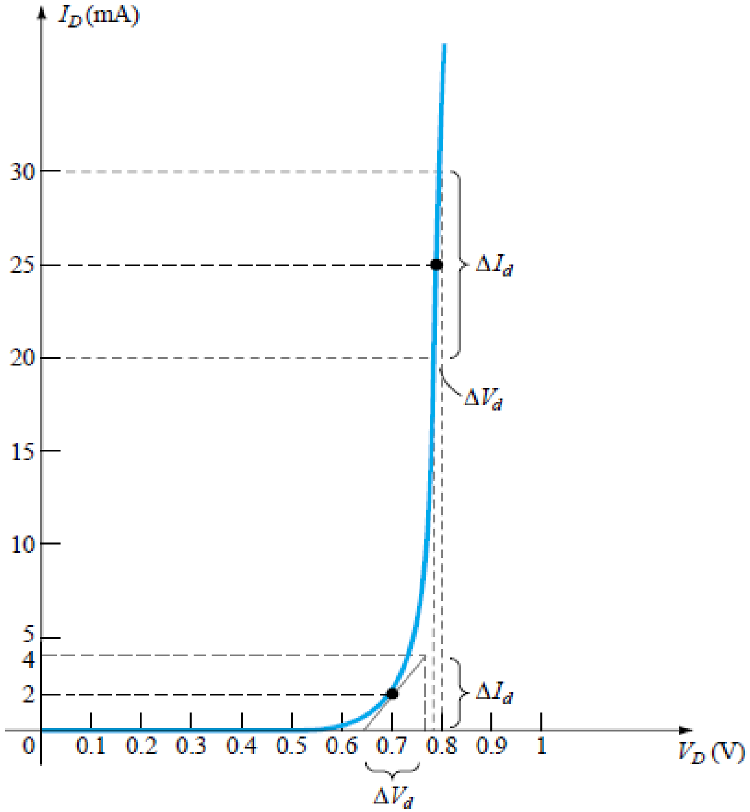
1) For the characteristics of Fig:

(a) Determine the ac resistance at I_D *2 mA.*

(b) Determine the ac resistance at I_D *25 mA.*

(c) Compare the results of parts (a) and (b) to the dc resistances at each current level.

Reference :ELECTRONIC DEVICES AND CIRCUIT THEORY ROBERT BOYLESTAD LOUIS NASHELSKY



a)

$$\Delta I_d = 4\text{ mA} - 0\text{ mA} = 4\text{ mA}$$

$$\Delta V_d = 0.76\text{ V} - 0.65\text{ V} = 0.11\text{ V}$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11\text{ V}}{4\text{ mA}} = \mathbf{27.5\ \Omega}$$

b)

$$\Delta I_d = 30\text{ mA} - 20\text{ mA} = 10\text{ mA}$$

$$\Delta V_d = 0.8\text{ V} - 0.78\text{ V} = 0.02\text{ V}$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02\text{ V}}{10\text{ mA}} = \mathbf{2\ \Omega}$$

c)

$$R_D = \frac{V_D}{I_D} = \frac{0.7\text{ V}}{2\text{ mA}} = \mathbf{350\ \Omega}$$

$$R_D = \frac{V_D}{I_D} = \frac{0.79\text{ V}}{25\text{ mA}} = \mathbf{31.62\ \Omega}$$

Diode Resistance: Numerical

2. AC or Dynamic Resistance: *The derivative of a function at a point is equal to the slope of the tangent line drawn at that point.*

$$k = \frac{11{,}600}{\eta} = \frac{11{,}600}{1} = 11{,}600$$

$$\frac{d}{dV_D}(I_D) = \frac{d}{dV}[I_s(e^{kV_D/T_K} - 1)]$$

$$\frac{dI_D}{dV_D} = \frac{k}{T_K}(I_D + I_s)$$

$$T_K = T_C + 273° = 25° + 273° = 298°$$

$$\frac{k}{T_K} = \frac{11{,}600}{298} \cong 38.93$$

$$\frac{dI_D}{dV_D} = 38.93 I_D$$

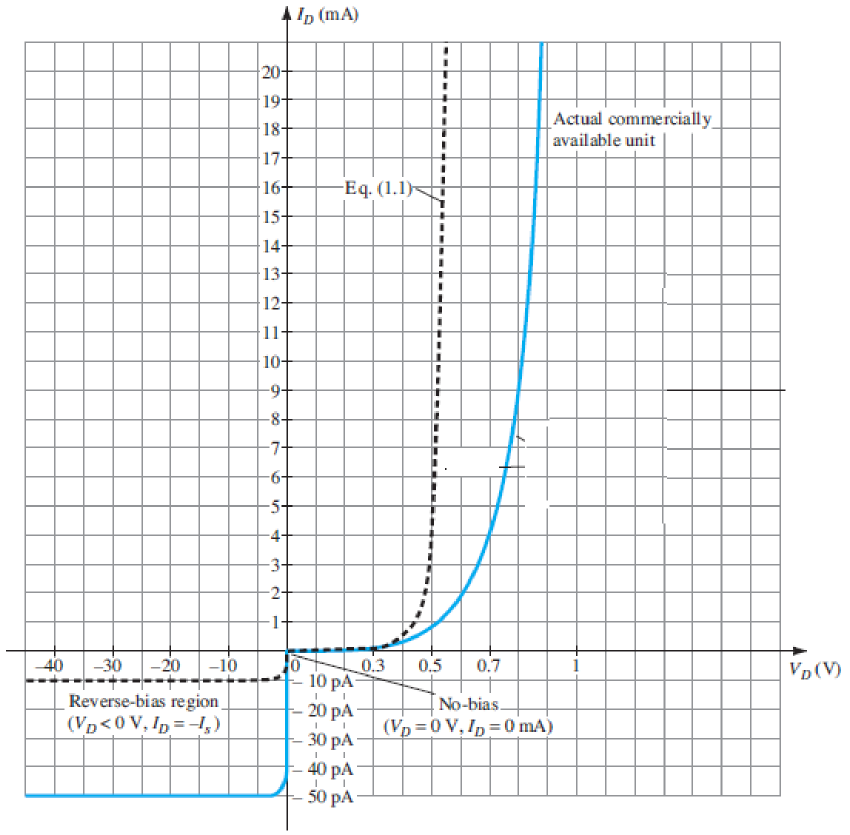
$$\frac{dI_D}{dV_D} \cong \frac{k}{T_K} I_D$$

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

$$\boxed{r_d = \frac{26\text{ mV}}{I_D}}$$ Ge,Si

Diode Resistance: Numerical

3. Calculate the dc and ac resistance for the diode of Fig shown at a forward current of 10 mA and compare their magnitudes.



$I_D = 10$ mA, $V_D = 0.76$ V

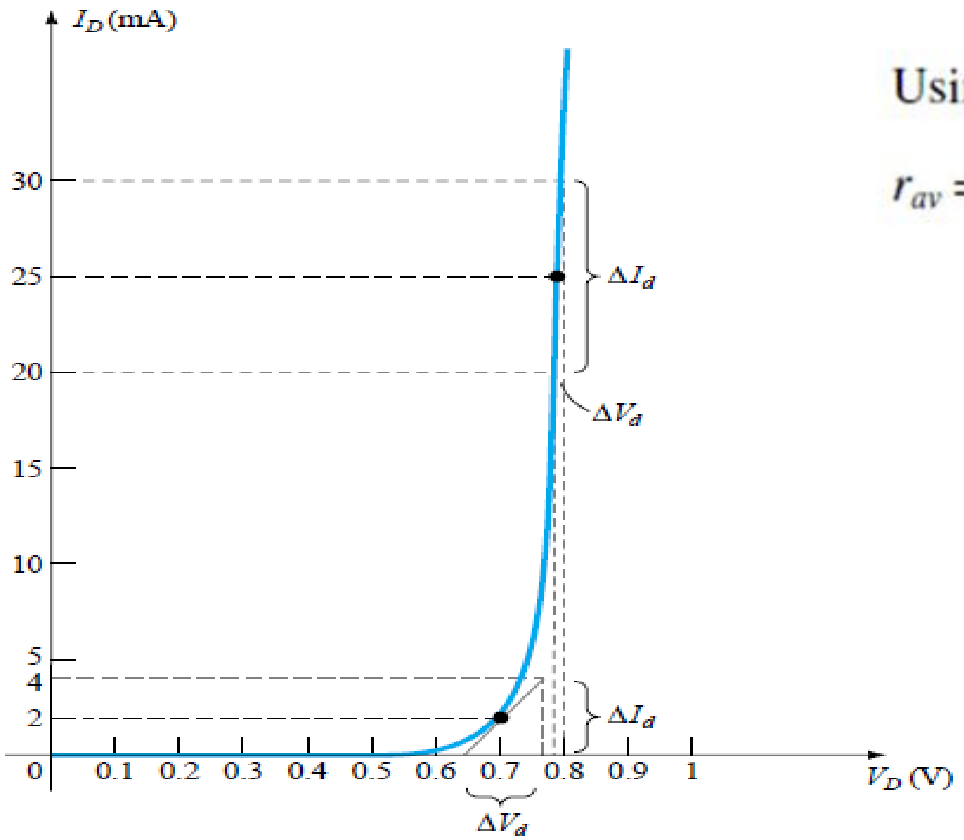
$$R_{DC} = \frac{V_D}{I_D} = \frac{0.76\text{ V}}{10\text{ mA}} = 76\ \Omega$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.85\text{V} - 0.72\text{ V}}{15\text{ mA} - 5\text{ mA}} = \frac{0.13\text{V}}{10\text{ mA}} = 13\ \Omega$$

$R_{DC} >> r_d$

Diode Resistance: Numerical

4. Find the piecewise-linear equivalent circuit for the diode of Fig. Use a straight line segment that intersects the horizontal axis at 0.7 V and Best approximates the curve for the region greater than 0.7 V.

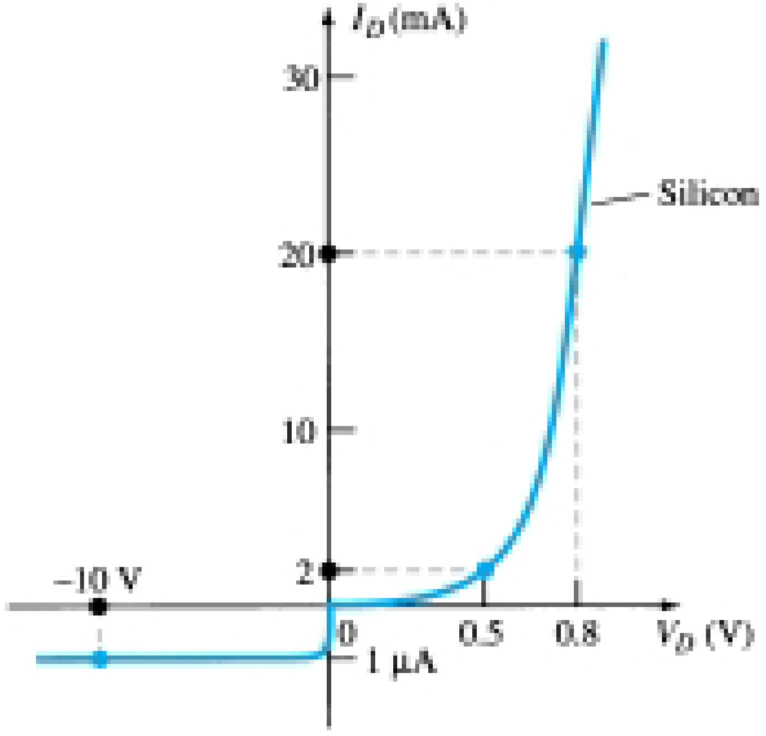


Using the best approximation to the curve beyond $V_D = 0.7$ V:

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} \cong \frac{0.8\text{ V} - 0.7\text{ V}}{25\text{ mA} - 0\text{ mA}} = \frac{0.1\text{ V}}{25\text{ mA}} = 4\ \Omega$$

Diode Resistance: Numerical

5. Determine the dc resistance levels for the diode of Fig.at
(a) I_D =2 mA (b) I_D =20 mA (c) V_D = -10 V



(a) At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

(b) At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

(c) At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

Diode Equivalent Diagrams/Diode Approximations

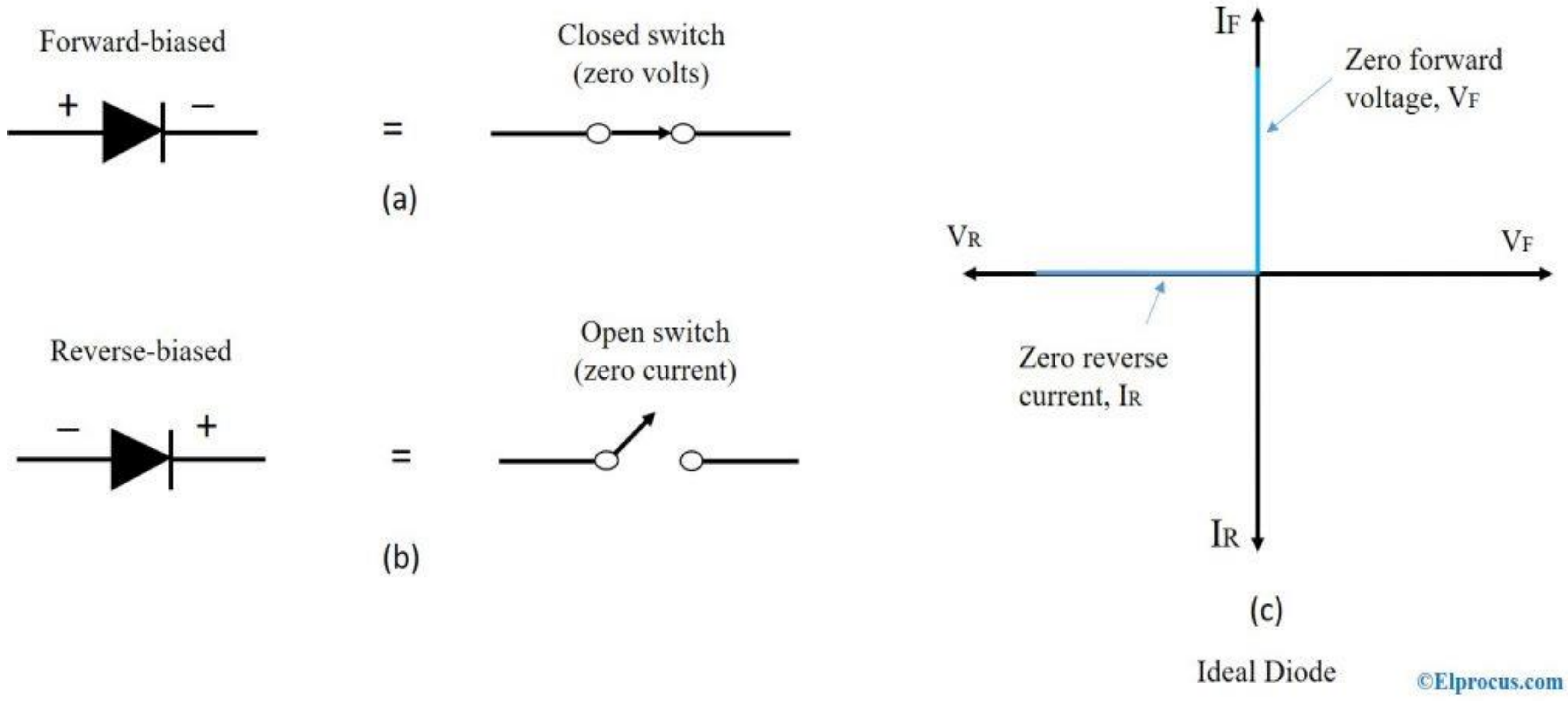
Diode approximation is a mathematical method used to approximate the nonlinear behavior of real diodes to enable calculations and circuit analysis.

There are three different approximations used to analyze the diode circuits, namely

I. First Approximation (Ideal Diode Characteristics)
II. Second Approximation (Simplified Diode Characteristics)
III. Third approximation (Piecewise-linear equivalent Circuit)

First Approximation: Ideal diode Characteristics

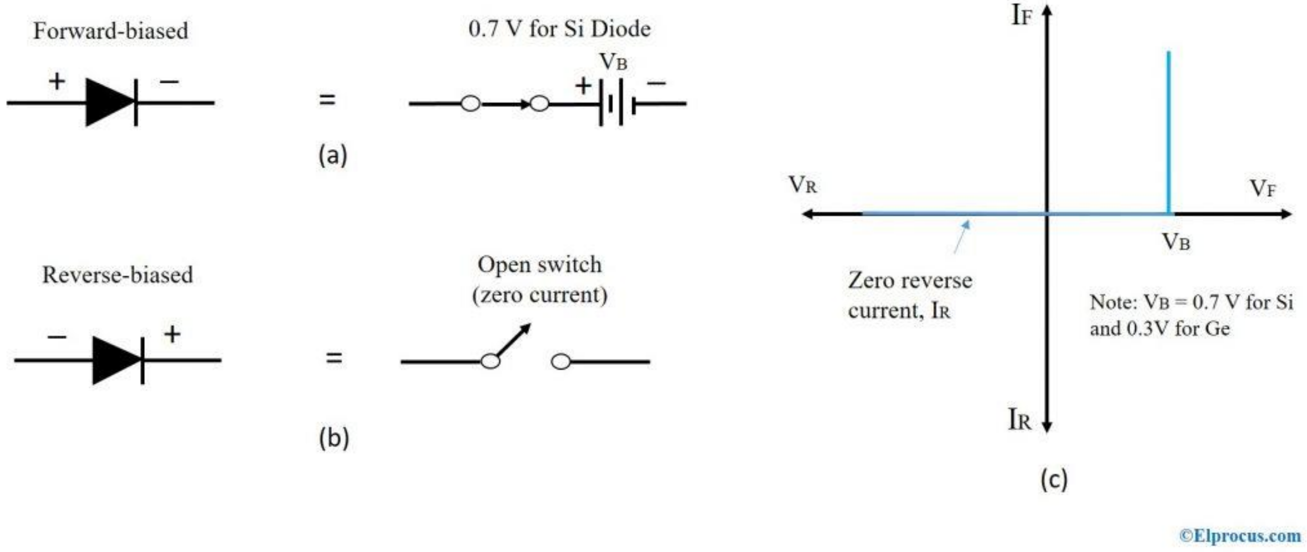
First approximation: The diode is considered as a closed switch with zero voltage drop when forward-biased and as an open switch when reverse biased



Second Approximation: Simplified Diode Characteristics

Second approximation: Under forward-bias, the diode turns ON when a voltage of V_K or V_B is applied across it. It turns off if the voltage is less than V_K. Thus, the diode is represented by a voltage of V_K in series with a closed switch.

Under reverse bias, it is an open switch.



Third Approximation: Piecewise-linear equivalent

Third approximation: Considers the increase in the voltage across the diode when the current through it increases. Here the diode is represented as a closed switch in series with V_K and resistance R_B when forward biased.

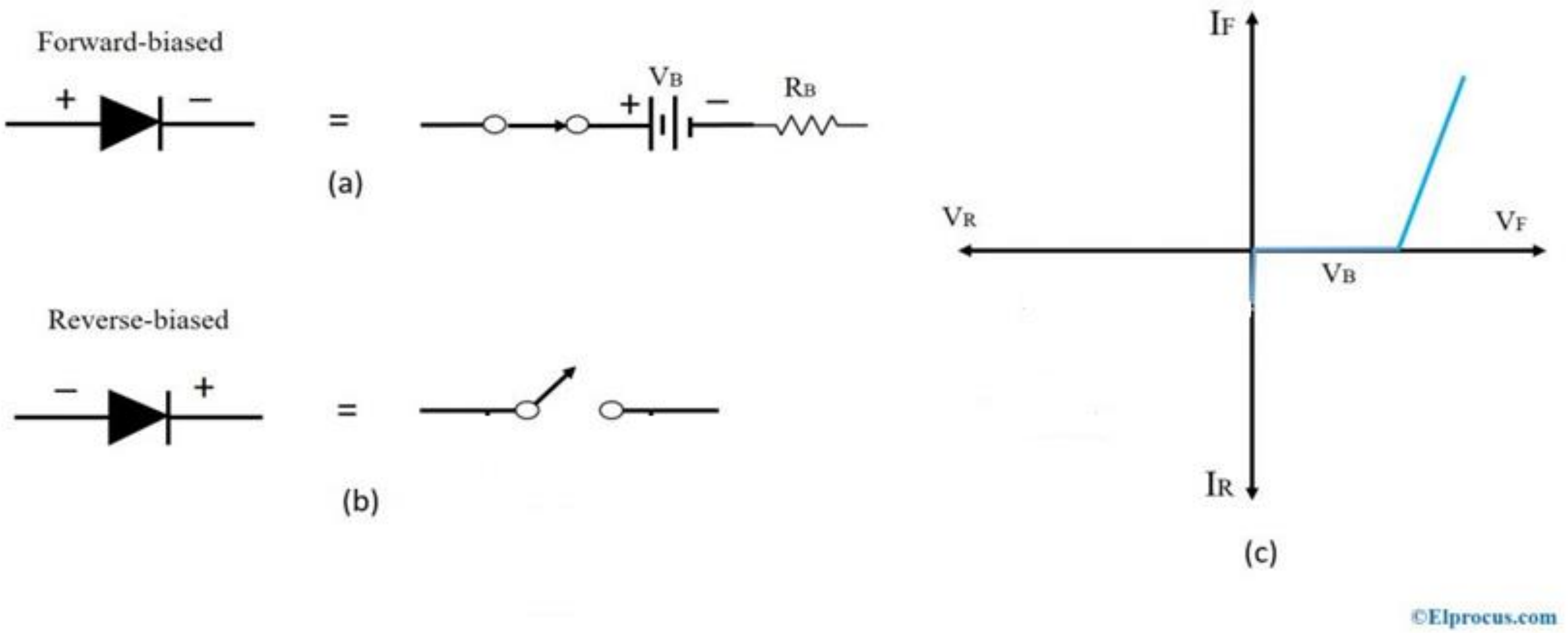
Characteristics resemble closely to that of practical diode.

The voltage drop across the diode is calculated using the formula

$V_d = V_K + I_d * R_B$

Third Approximation: Linear Piece-Wise Diode Characteristics

Under reverse – bias, the diode is an open switch and no current flows through it



Series Diode Configuration with a resistor

- It’s assumed that the forward resistance of the diode is usually so small compared to the other series elements of the network that it can be ignored.
- In general, a diode is in the “on” state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol.

Forward Bias

Constants

- **Silicon Diode: $V_D = 0.7$ V**
- **Germanium Diode: $V_D = 0.3$ V**

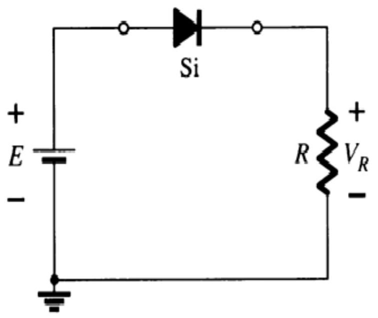
Series Diode Configuration with a resistor

Reverse Bias

Diodes ideally behave as open circuits

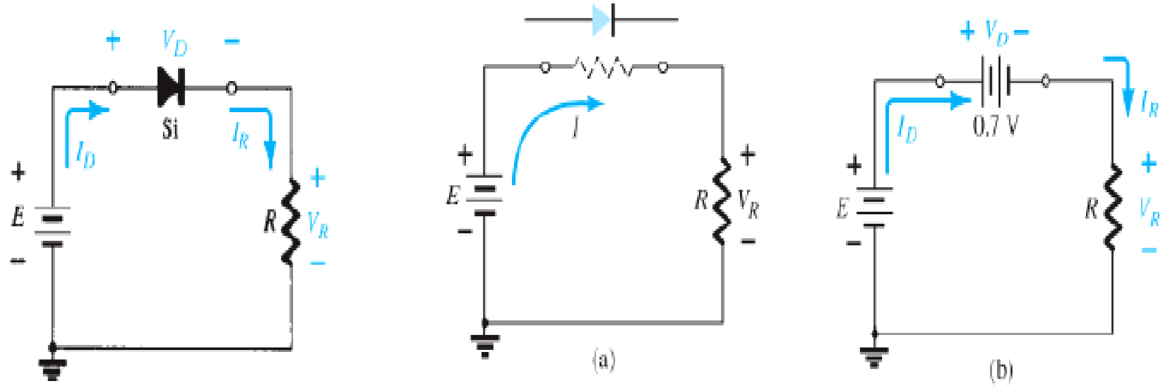
Analysis

$V_D = E;\ V_R = 0\ \text{V}\ \&\ I_D = 0\ \text{A}$



Analysis (for silicon)

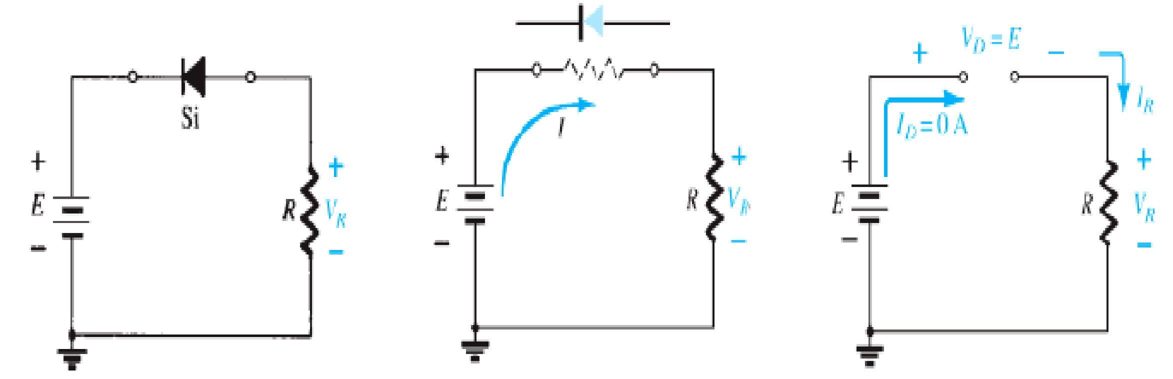
- $V_D = 0.7\ \text{V}$ (or $V_D = E$ if $E < 0.7\ \text{V}$)
- $V_R = E - V_D$
- $I_D = I_R = I_T = V_R / R$



$V_D = V_K$

$V_R = E - V_K$

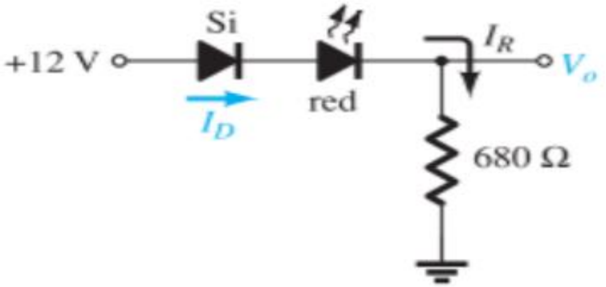
$I_D = I_R = \frac{V_R}{R}$



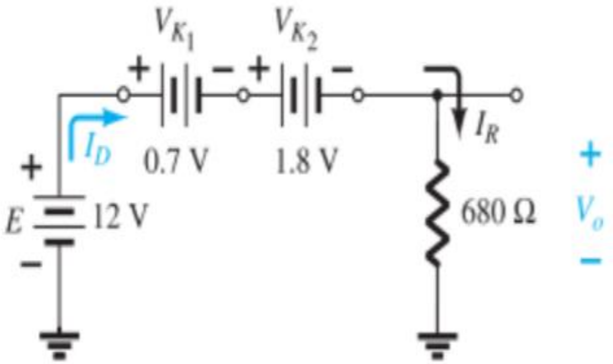
$V_R = I_R R = I_D R = (0\ \text{A})R = 0\ \text{V}$

Series Diode Configuration – A Solved Problem

1. Determine Vout and Id for the given series diode Circuit. Assume the LED Voltage as 1.8 V.



Solution: Re-draw the given circuit based on simplified diode's configuration, we get

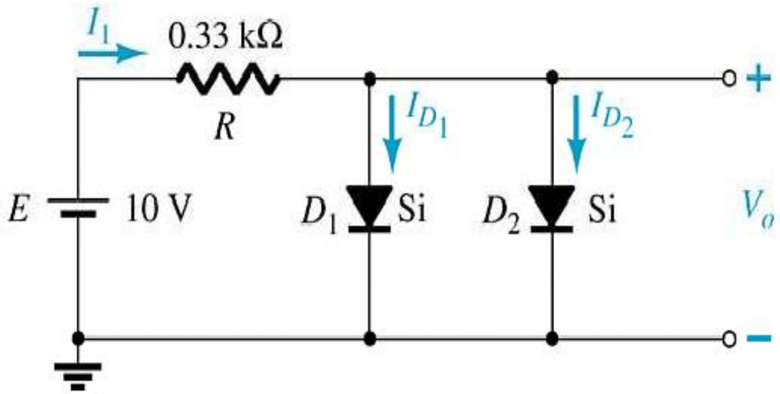


$$V_o = E - V_{K_1} - V_{K_2} = 12\text{ V} - 2.5\text{ V} = \mathbf{9.5\text{ V}}$$

$$I_D = I_R = \frac{V_R}{R} = \frac{V_o}{R} = \frac{9.5\text{ V}}{680\ \Omega} = \mathbf{13.97\text{ mA}}$$

Parallel Diode Configuration - A Solved Problem

2. Determine Vo , I_1 , I_{D1}, and I_{D2} for the parallel diode configuration of Figure below



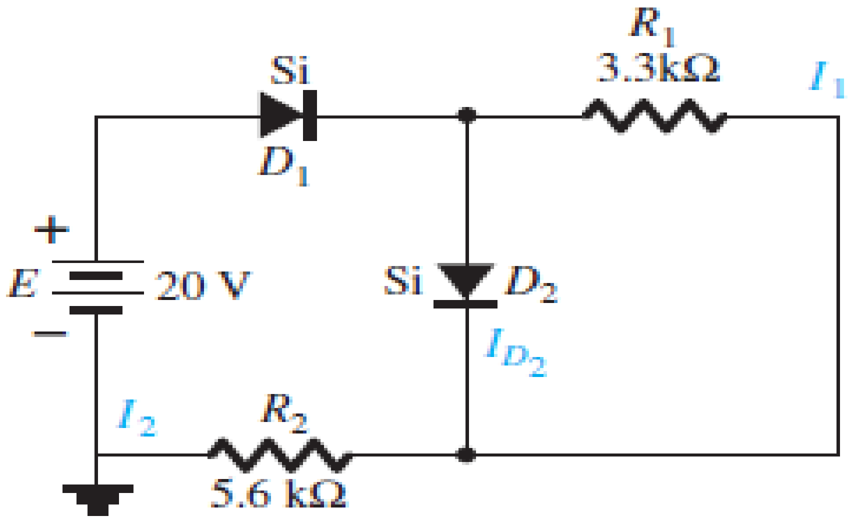
Solution: $V_o = \mathbf{0.7\ V}$

$$I_1 = \frac{V_R}{R} = \frac{E - V_D}{R} = \frac{10\text{ V} - 0.7\text{ V}}{0.33\text{ k}\Omega} = \mathbf{28.18\ mA}$$

$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18\text{ mA}}{2} = \mathbf{14.09\ mA}$$

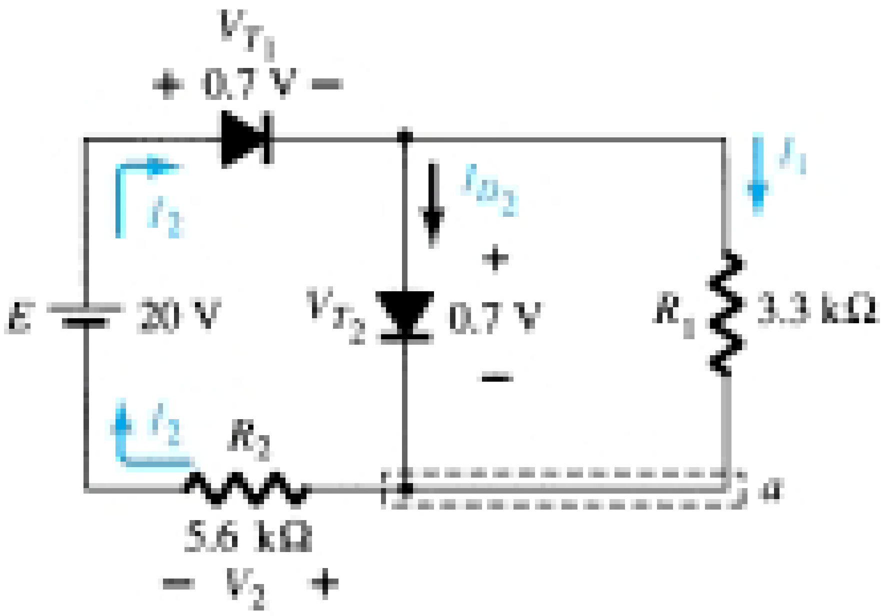
Series-Parallel Diode Configuration

3. Determine I_1, I_2, and I_{D2} for the series- parallel diode configuration of Figure below



ELECTRONIC PRINCIPLES AND DEVICES

Series-Parallel Diode Configuration – An Excise Problem



$$-V_2 + E - V_{T_1} - V_{T_2} = 0$$

$$V_2 = E - V_{T_1} - V_{T_2} = 20\text{ V} - 0.7\text{ V} - 0.7\text{ V} = 18.6\text{ V}$$

$$I_2 = \frac{V_2}{R_2} = \frac{18.6\text{ V}}{5.6\text{ k}\Omega} = \mathbf{3.32\text{ mA}}$$

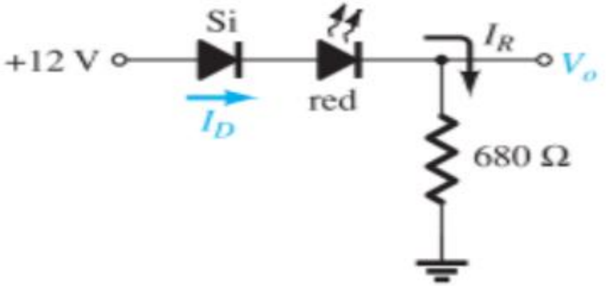
$$I_{D_2} + I_1 = I_2$$

$$I_1 = \frac{V_{T_2}}{R_1} = \frac{0.7\text{ V}}{3.3\text{ k}\Omega} = \mathbf{0.212\text{ mA}}$$

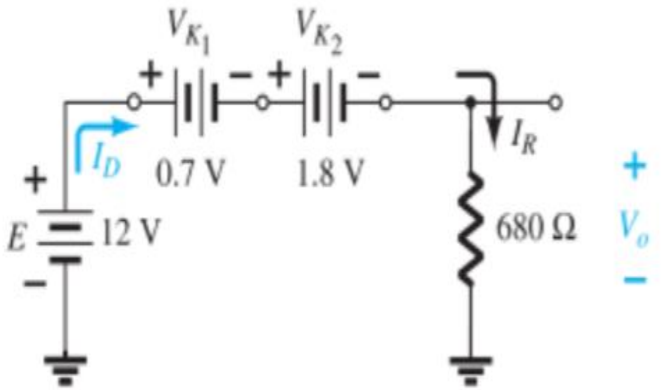
$$I_{D_2} = I_2 - I_1 = 3.32\text{ mA} - 0.212\text{ mA} = \mathbf{3.108\text{ mA}}$$

Series Diode Configuration – A Solved Problem

4. Determine V_{out} and I_d for the given series diode Circuit. Assume the LED Voltage as 1.8 V.



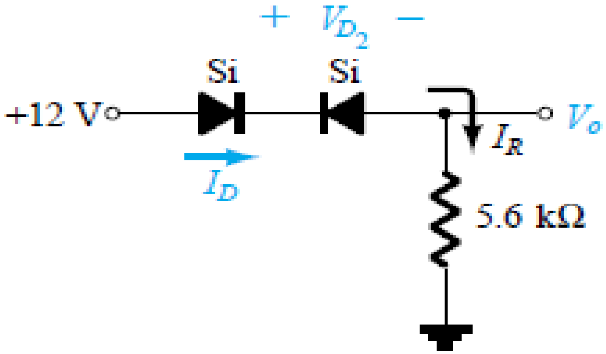
Solution: Re-draw the given circuit based on simplified diode's configuration, we get



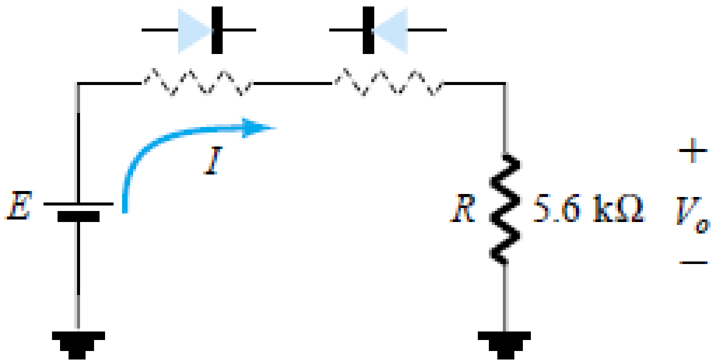
$$V_o = E - V_{K_1} - V_{K_2} = 12\text{ V} - 2.5\text{ V} = \mathbf{9.5\text{ V}}$$

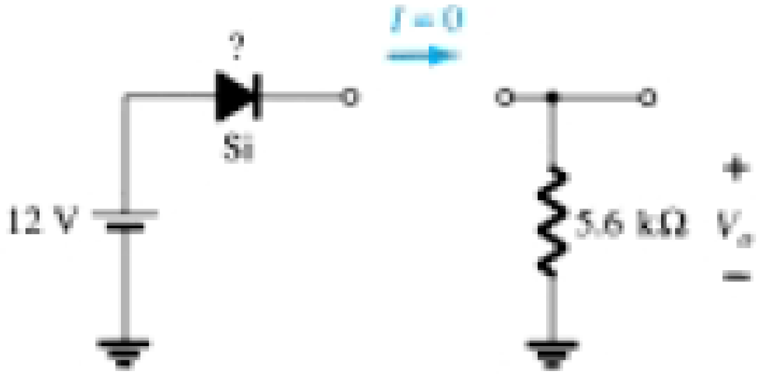
$$I_D = I_R = \frac{V_R}{R} = \frac{V_o}{R} = \frac{9.5\text{ V}}{680\ \Omega} = \mathbf{13.97\text{ mA}}$$

5. Determine I_D, V_{D2} and V_o



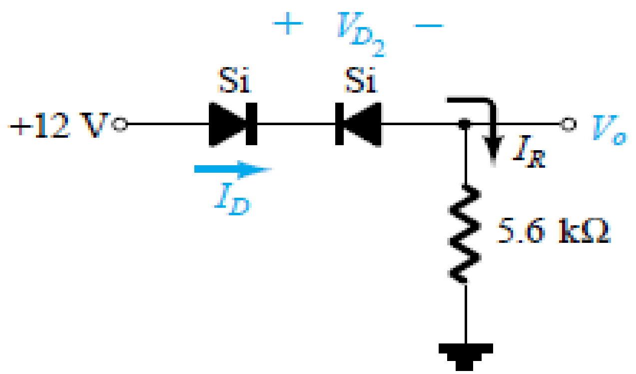
Solution: Re-draw the given circuit based on simplified diode's configuration, we get





Series Diode Configuration

$$V_o = I_R R = I_D R = (0\ \text{A})R = 0\ \text{V}$$



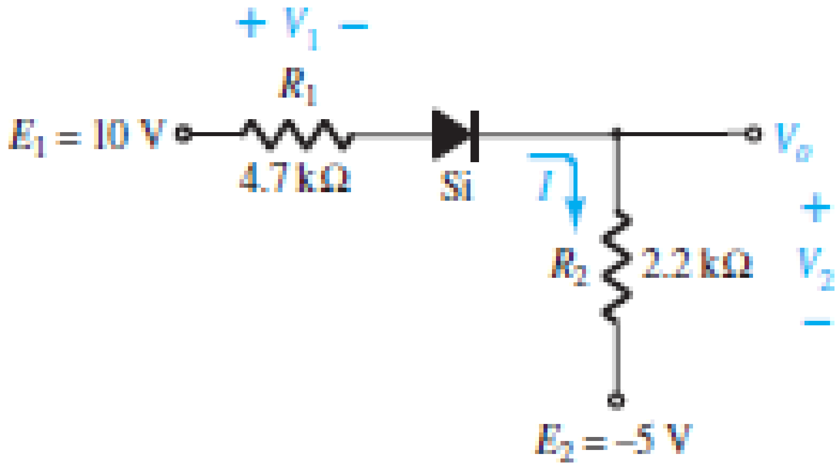
$$E - V_{D_1} - V_{D_2} - V_o = 0$$

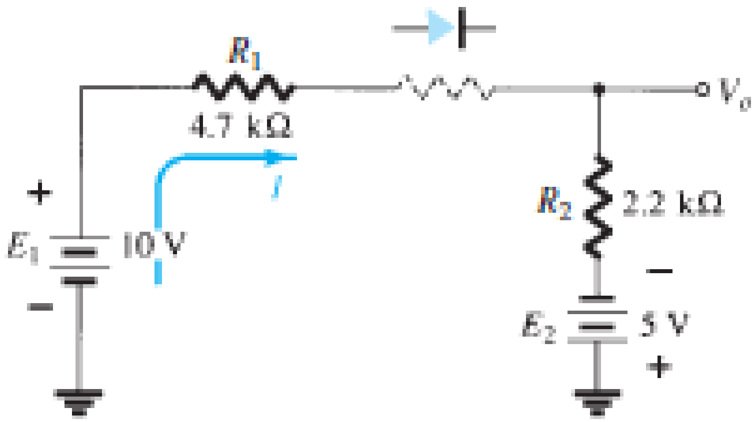
$$V_{D_2} = E - V_{D_1} - V_o = 12\ \text{V} - 0 - 0$$

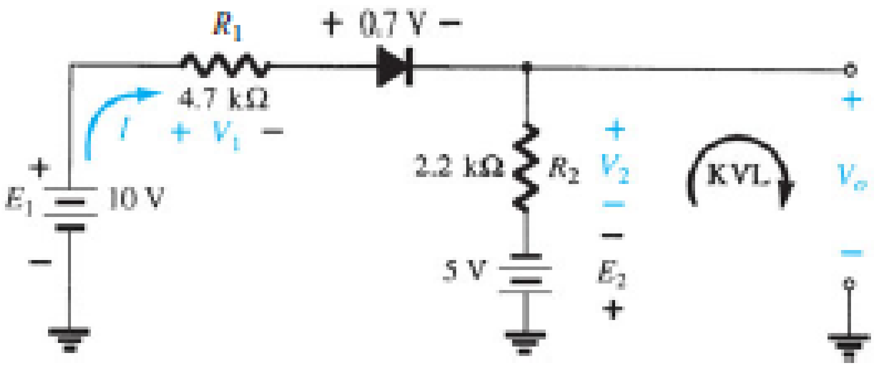
$$= \mathbf{12\ V}$$

$$V_o = \mathbf{0\ V}$$

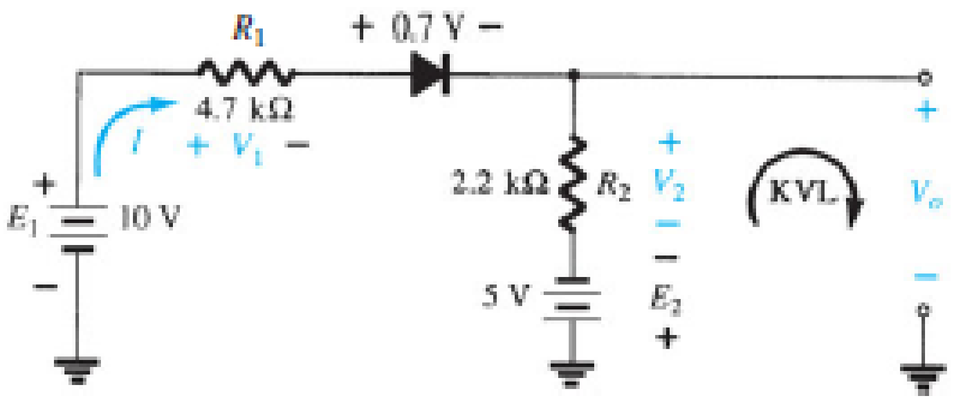
6. Determine I, V_1, V_2 and V_0







Series Diode Configuration

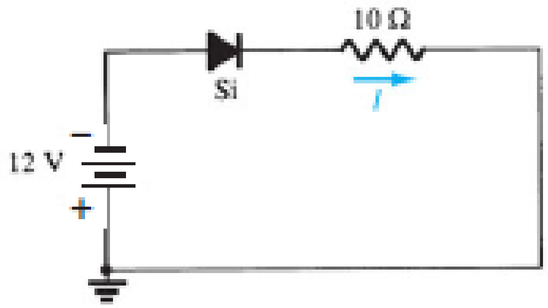


$$I = \frac{E_1 + E_2 - V_D}{R_1 + R_2} = \frac{10\text{ V} + 5\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{14.3\text{ V}}{6.9\text{ k}\Omega}$$
$$\cong \mathbf{2.07\ mA}$$

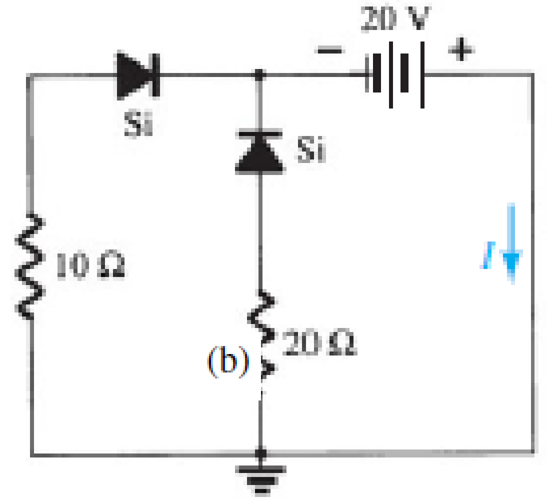
$$V_1 = IR_1 = (2.07\text{ mA})(4.7\text{ k}\Omega) = \mathbf{9.73\ V}$$
$$V_2 = IR_2 = (2.07\text{ mA})(2.2\text{ k}\Omega) = \mathbf{4.55\ V}$$

$$-E_2 + V_2 - V_o = 0$$
$$V_o = V_2 - E_2 = 4.55\text{ V} - 5\text{ V} = \mathbf{-0.45\ V}$$

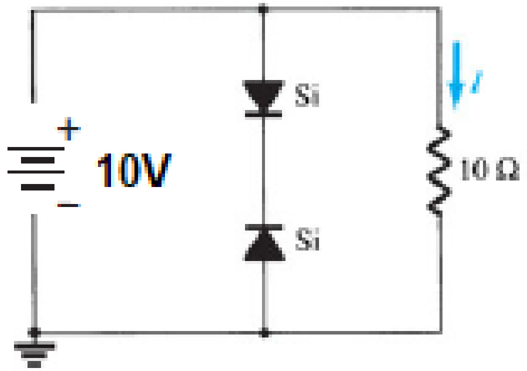
7. Determine the current I for each of the configurations



(a)



(b)



(c)

(a) $I = \mathbf{0\ mA}$; diode reverse-biased.

(b) $V_{20\Omega} = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$ (Kirchhoff's voltage law)

$I(20\ \Omega) = \dfrac{19.3\text{ V}}{20\ \Omega} = 0.965\text{ A}$

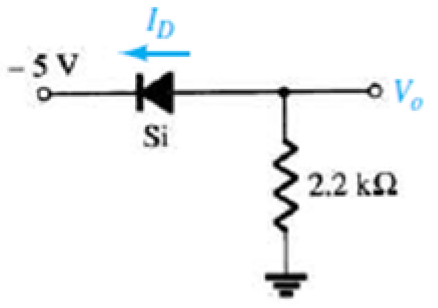
$V(10\ \Omega) = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$

$I(10\ \Omega) = \dfrac{19.3\text{ V}}{10\ \Omega} = 1.93\text{ A}$

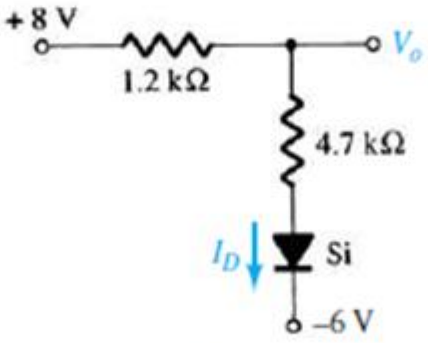
$I = I(10\ \Omega) + I(20\ \Omega)$
$= \mathbf{2.895\ A}$

(c) $I = \dfrac{10\text{ V}}{10\ \Omega} = \mathbf{1\ A}$; center branch open

8. Determine V_0 and I_D for the networks



(a)



(b)

(a) Diode forward-biased,
Kirchhoff's voltage law (CW): $-5\text{ V} + 0.7\text{ V} - V_o = 0$

$$V_o = \mathbf{-4.3\ V}$$

$$I_R = I_D = \frac{|V_o|}{R} = \frac{4.3\text{ V}}{2.2\text{ k}\Omega} = \mathbf{1.955\ mA}$$

(b) Diode forward-biased,

$$I_D = \frac{8\text{ V} + 6\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{2.25\ mA}$$

$$V_o = 8\text{ V} - (2.25\text{ mA})(1.2\text{ k}\Omega) = \mathbf{5.3\ V}$$

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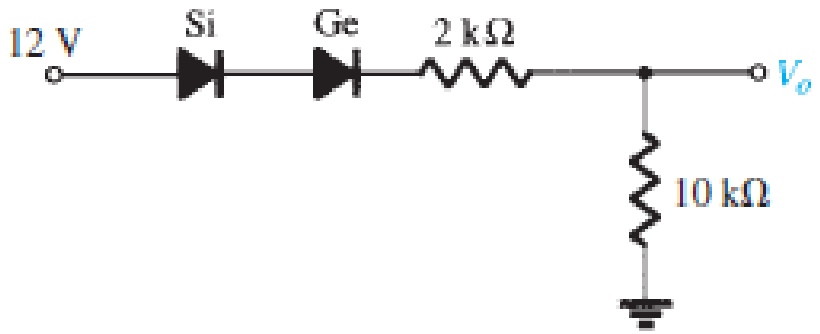
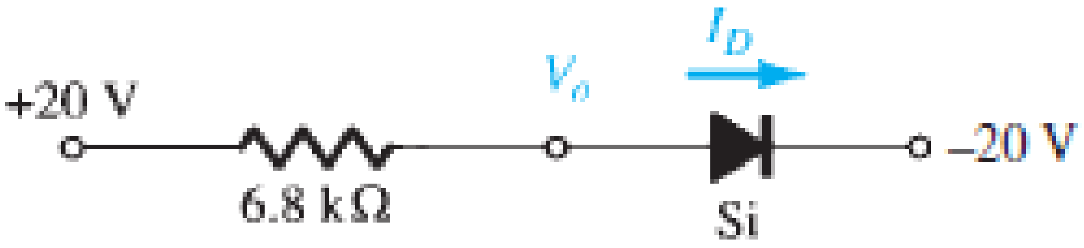
9. Determine the level of V_0 for each network





(a) $V_o = \dfrac{10\ \text{k}\Omega(12\ \text{V} - 0.7\ \text{V} - 0.3\ \text{V})}{2\ \text{k}\Omega + 10\ \text{k}\Omega} = \mathbf{9.17\ V}$

(b) Diode forward-biased

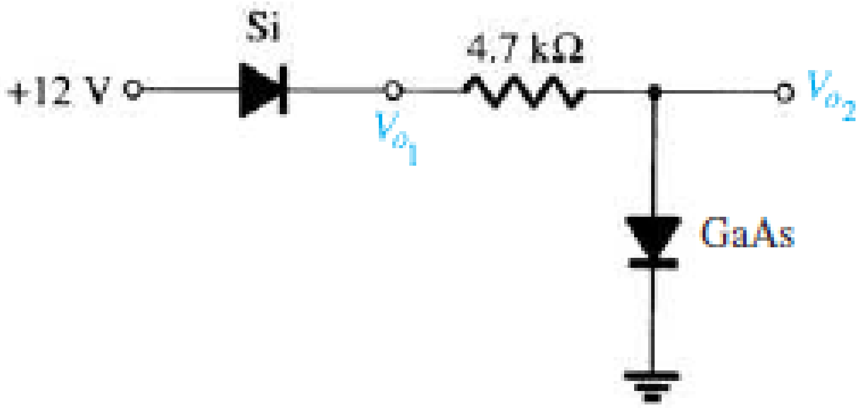
$I_D = \dfrac{20\ \text{V} + 20\ \text{V} - 0.7\ \text{V}}{6.8\ \text{k}\Omega} = \mathbf{5.78\ mA}$

Kirchhoff's voltage law (CW):

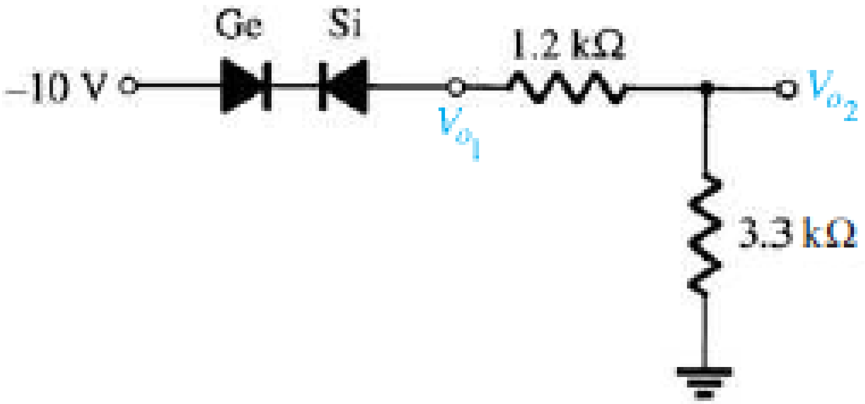
$+V_o - 0.7\ \text{V} + 20\ \text{V} = 0$

$V_o = \mathbf{-19.3\ V}$

10. Determine V_{01} and V_{02} for the circuits



(a)



(b)

(a) $V_{o_1} = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\ V}$

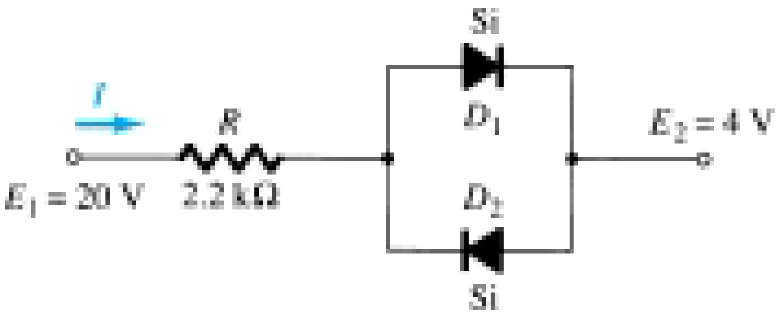
$V_{o_2} = \mathbf{1.2\ V}$

(b) $V_{o_1} = \mathbf{0\ V}$

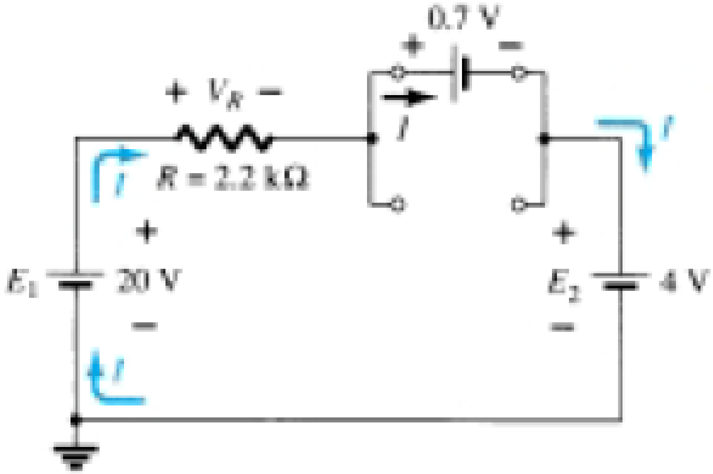
$V_{o_2} = \mathbf{0\ V}$

Parallel Diode Configuration - A Solved Problem

11. Determine I for the parallel diode configuration of Figure below



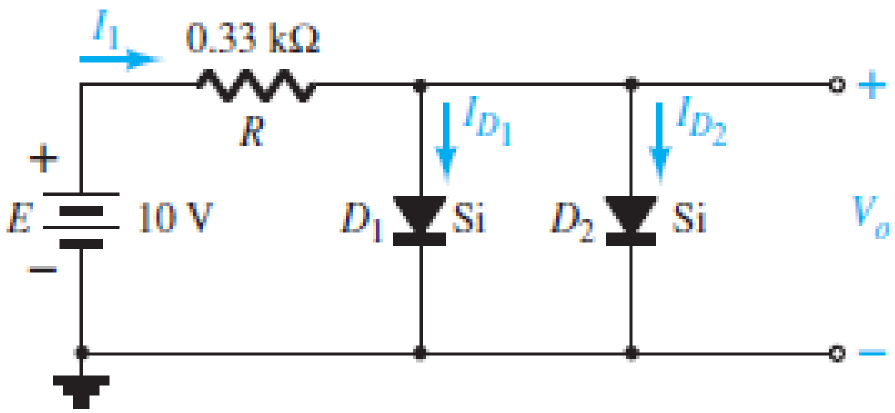
Solution:

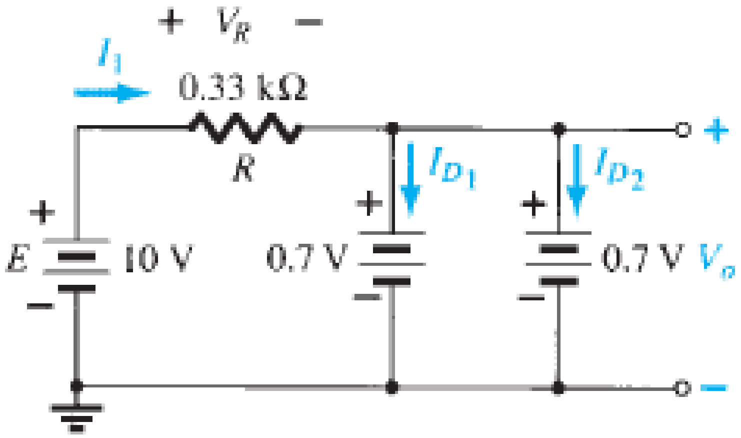


$$I = \frac{E_1 - E_2 - V_D}{R} = \frac{20\text{ V} - 4\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega} \cong \mathbf{6.95\ mA}$$

Parallel Diode Configuration - A Solved Problem

12. Determine V_0, I_1, I_2 in the diode circuit





$$V_o = 0.7\text{ V}$$

The current is

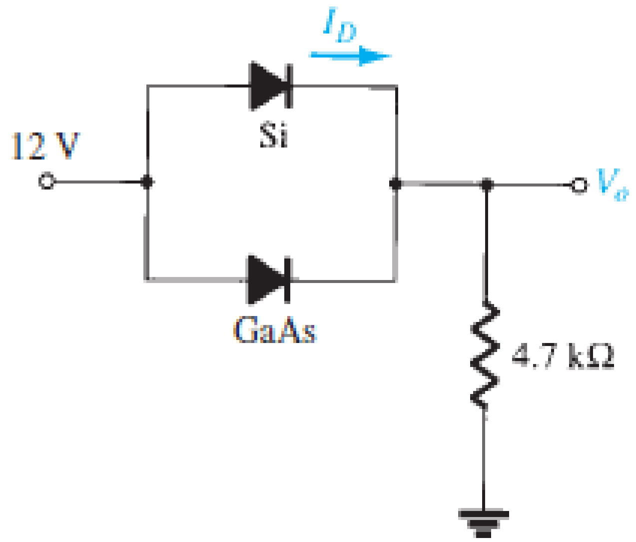
$$I_1 = \frac{V_R}{R} = \frac{E - V_D}{R} = \frac{10\text{ V} - 0.7\text{ V}}{0.33\text{ k}\Omega} = 28.18\text{ mA}$$

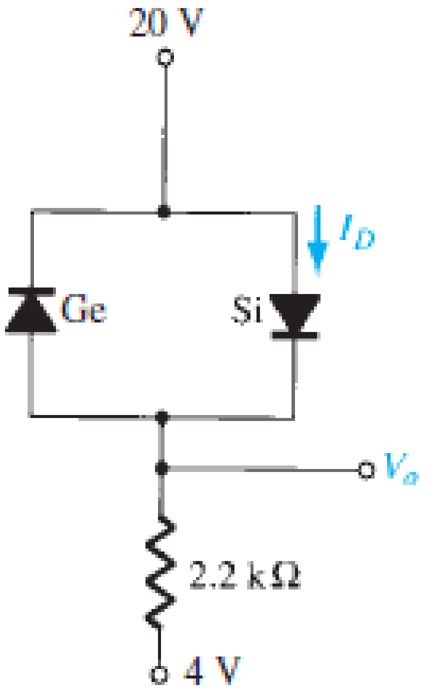
Assuming diodes of similar characteristics, we have

$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18\text{ mA}}{2} = 14.09\text{ mA}$$

Parallel Diode Configuration - A Solved Problem

13. Determine I_D and V_0 for the circuits shown





(a) Both diodes forward-biased
Si diode turns on first and locks in 0.7 V drop.

$$I_R = \frac{12\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega} = 2.4\text{ mA}$$

$$I_D = I_R = \mathbf{2.4\text{ mA}}$$

$$V_o = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\text{ V}}$$

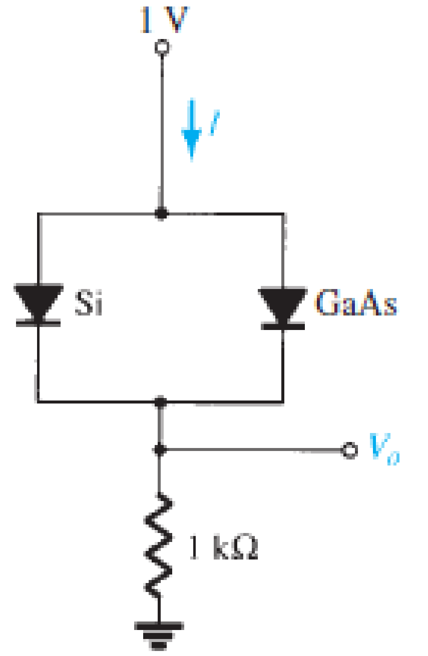
(b) Right diode forward-biased:

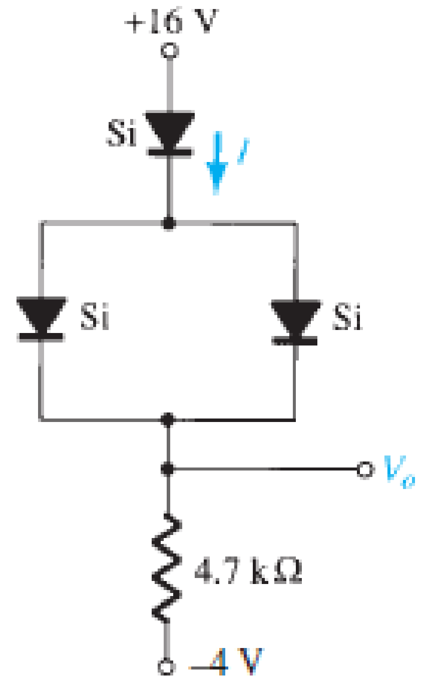
$$I_D = \frac{20\text{ V} + 4\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega} = \mathbf{10.59\text{ mA}}$$

$$V_o = 20\text{ V} - 0.7\text{ V} = \mathbf{19.3\text{ V}}$$

Parallel Diode Configuration - A Solved Problem

14. Determine I and V_0 for the circuits shown





Si diode "on" preventing GaAs diode from turning "on":

$$I = \frac{1\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{0.3\text{ V}}{1\text{ k}\Omega} = \mathbf{0.3\text{ mA}}$$

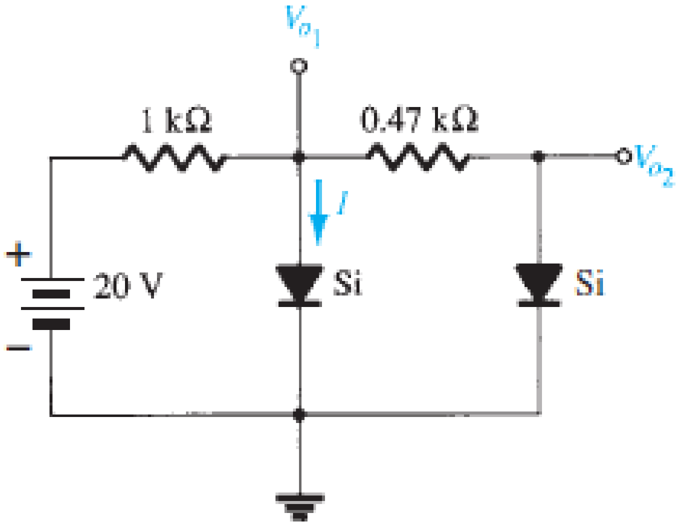
$$V_o = 1\text{ V} - 0.7\text{ V} = \mathbf{0.3\text{ V}}$$

$$I = \frac{16\text{ V} - 0.7\text{ V} - 0.7\text{ V} + 4\text{ V}}{4.7\text{ k}\Omega} = \frac{18.6\text{ V}}{4.7\text{ k}\Omega} = \mathbf{3.96\text{ mA}}$$

$$V_o = 16\text{ V} - 0.7\text{ V} - 0.7\text{ V} = \mathbf{14.6\text{ V}}$$

Parallel Diode Configuration - A Solved Problem

15. Determine I, V_{01} and V_{02}



Both diodes forward-biased:

$V_{o_1} = \mathbf{0.7\ V}$, $V_{o_2} = \mathbf{0.7\ V}$

$$I_{1\,k\Omega} = \frac{20\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{19.3\text{ V}}{1\text{ k}\Omega} = 19.3\text{ mA}$$

$I_{0.47\,k\Omega} = 0\text{ mA}$

$I = I_{1\,k\Omega} - I_{0.47\,k\Omega} = 19.3\text{ mA} - 0\text{ mA}$

$= \mathbf{19.3\ mA}$

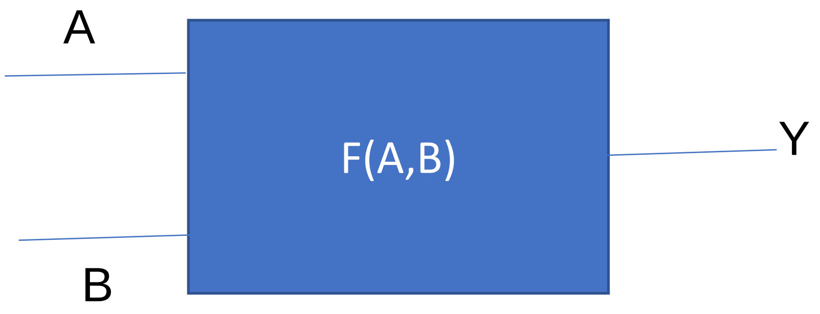
Logical operation:

It is an Operation that acts on binary numbers to produce a result according to the Laws of Boolean Logic.

A Logic Gate is a basic building block of Digital circuits.

Logic gate is considered as a device that has the ability to produce one output level with the combinations of input levels.

Example : AND,OR and NOT functions



Logical operations:

Logic gates are implemented by using diodes, transistors, and by other several devices.

Hence logic gates can also be considered as electronic circuits.

The logic gates obtained by Diode is called Diode Resistor Logic.

Inputs and outputs of logic gates are in two levels which are termed as HIGH and LOW, or TRUE and FALSE, or ON and OFF, or simply 1 and 0.

Logical Operations

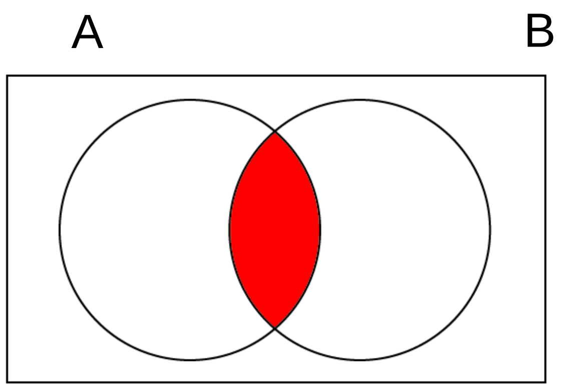
For all logic gates a Table with all combinations is listed out.

The combination of the input variables and the corresponding output is termed as “TRUTH TABLE”.

It explains how the logic circuit output responds to various combinations of logic levels at the inputs.

AND Operation is explained by the following Truth Table

A	B	Y=A.B
0	0	0
0	1	0
1	0	0
1	1	1



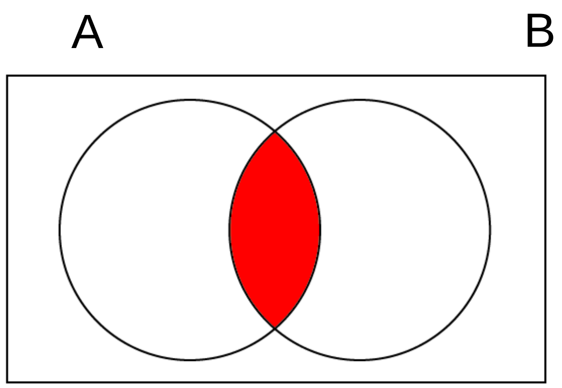
Logical Operations

An AND / OR gate may also have two or more inputs but produces only one output.

AND gate produces an output of logic 1 state when all of its inputs is in logic 1 state and produces an output of logic 0 state if any of its inputs are in logic 0 state.

AND Operation is explained by the following Truth Table

A	B	Y=A.B
0	0	0
0	1	0
1	0	0
1	1	1



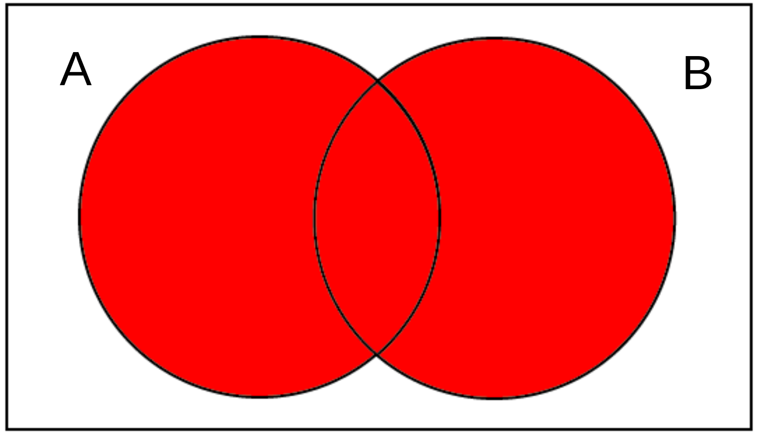
Logical Operations

An AND / OR gate may also have two or more inputs but produces only one output.

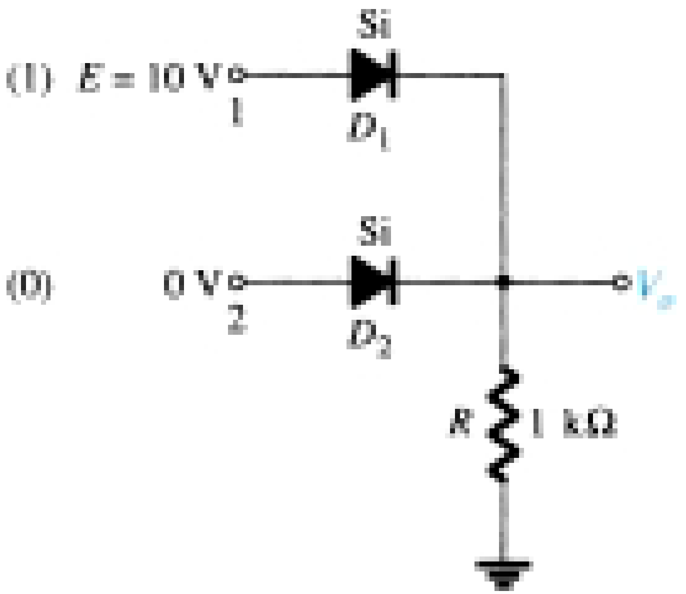
OR gate produces an output of logic 1 state even if any of its inputs is in logic 1 state and produces an output of logic 0 state if all of its inputs are in logic 0 state.

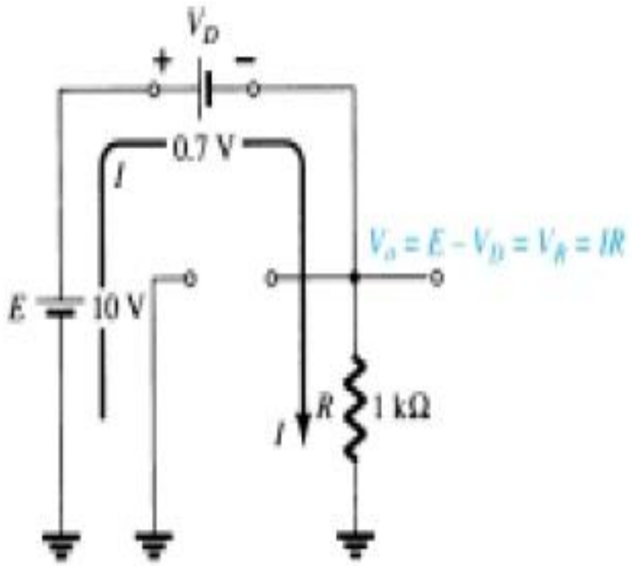
OR Operation is explained by the following Truth Table

A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1



OR Operation Illustrated using Diode





A (V1)	B(V2)	Y (Vo)
0	0	0
0	10 V	9.3 V
10 V	0	9.3 V
10 V	10 V	9.3V

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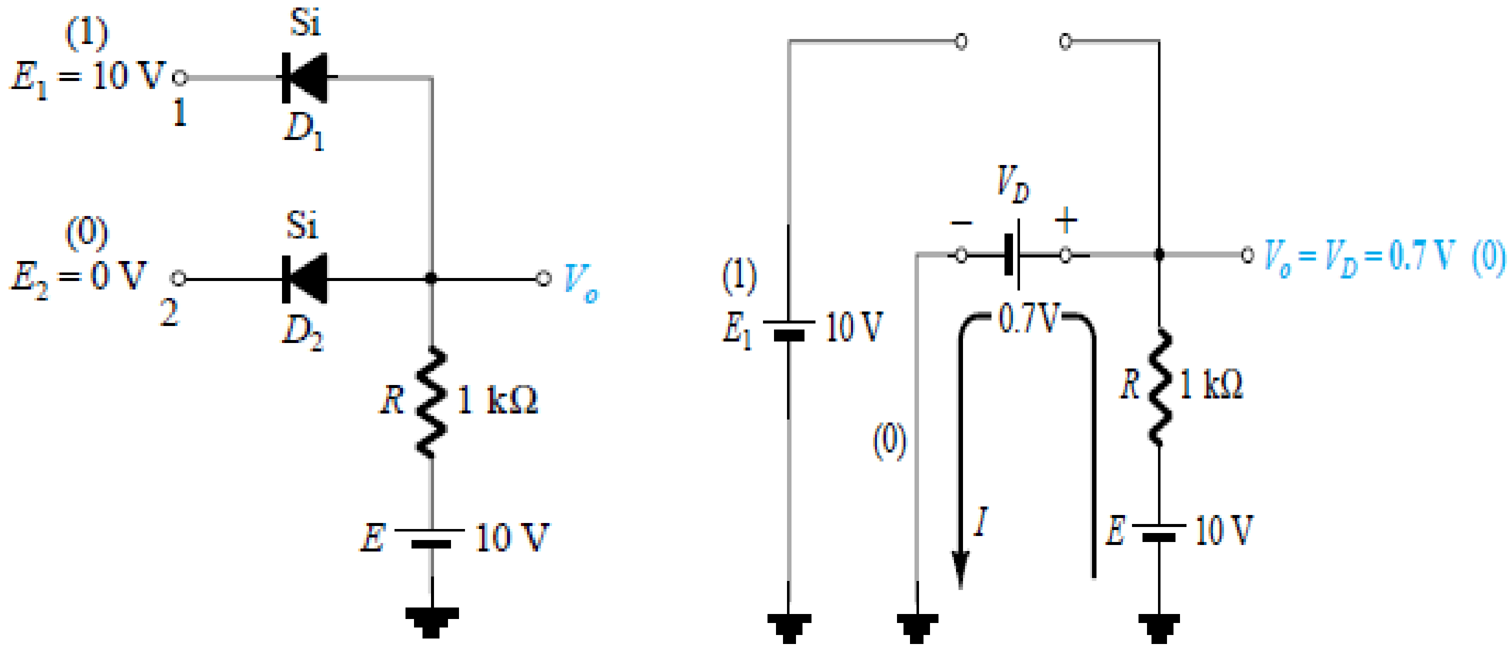
AND Operation Illustrated using Diode



A (V1)	B(V2)	Y(Vo)
0	0	0.7 V
0	10 V	0.7V
10 V	0	0.7V
10 V	10 V	10V

THANK YOU

Department of Electronics and Communication