Electronic Principles &
Devices

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U1 Introduction to Electronics & Semiconductors & Diodes

Basic Circuit elements

Passive Elements

Resistor, Inductor, Capacitor

Resistor: Resists flow of current thru it. Also will have voltage drop when measured across it.

Inductor: Holds charge in form of magnetic field

Capacitor: Holds charge in form of electric field

Active Elements

Voltage Source, Current Source

V-I Characteristics of Resistor

$V \propto I \Rightarrow V = IR$

Ohm's Law

Unit $\Rightarrow \Omega$

$1\Omega = 1 V/A$

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V-I relation in capacitor

$$v \propto \int i\,dt \Rightarrow v = \frac{1}{C}\int_{t_0}^{t_1} i\,dt \Rightarrow \boxed{i = C\frac{dv}{dt}}$$ ☆

Capacitance

SI unit : Farad (F)

V-I relation in Inductor

$$v \propto \frac{di}{dt} \Rightarrow \boxed{V = L\frac{di}{dt}}$$ ☆

$$\Rightarrow i_L = \frac{1}{L}\int_{t_0}^{t_1} v_L\,dt$$

Inductance

SI unit : Henry (H)

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Q. $V = 1.5V$ $I = 0.08A$ $R = ?$

A. $R = \frac{V}{I} = \frac{1.5}{0.08} = \cancel{\frac{150}{8}}$ 18.75Ω

Q. $V = 2.8V$ $I = 1.5A$ $R = ?$

A. $R = \frac{V}{I} = \frac{2.8}{1.5} = \frac{5.6}{3} = 1.867\Omega$

Q. $V = 3.99$ $I = 2.1A$ $R = ?$

A. $R = \frac{V}{I} = \frac{\cancel{3.99}}{\cancel{2.1}}$ $\frac{1.33}{0.7} = \frac{13.3}{7} = 1.9\Omega$

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Q. $i(t) = 3.75e^{-1.2t}$ A ; $v(t) = 4 - 12.5e^{-1.2t}$ V

$C = ?$

$$v(t) = \frac{1}{C}\int_0^t i(t)\,dt + v(t)$$

$$4 - 12.5e^{-1.2t} = \frac{1}{c}\int_0^t 3.75e^{-1.2t}\,dt + v(0)$$

$$= \frac{1}{c} \times \frac{3.75}{(-1.2)} e^{-1.2t}\Big|_0^t + v(0)$$

$$= -\frac{3.125}{c}\left(e^{-1.2t} - 1\right) + v(0)$$

$$\Rightarrow 12.5 = \frac{3.125}{c} \Rightarrow C = 0.25\,F$$

$$= 250\,mF$$

Q. $i(t) = 3 - 4.5e^{-6t}$ A

$L = 2.5H$

$$\boxed{\begin{aligned} v(t) = L\frac{di}{dt} &= 2.5 \times \left(\frac{d}{dt}\left(3 - 4.5e^{-6t}\right)\right) \\ &= 2.5\left(27 \times e^{-6t}\right) = 67.5e^{-6t} \checkmark \end{aligned}}$$

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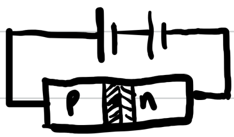
Diode : 2 electrodes

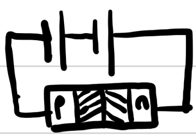
→ p-type & n-type material sandwiched together forming depletion region b/w 2.
Si & Ge can be used

Biasing of 2 diodes

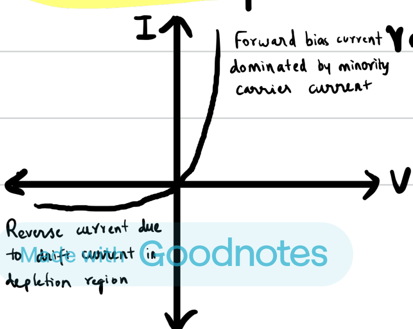
→ Forward Bias - Material type connected to **same** polarity terminal of voltage source

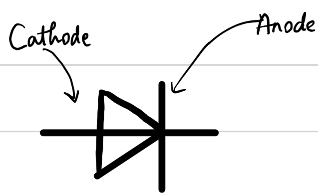


→ Backward Bias - Material type connected to **opposite** polarity terminal of voltage source



→ **Knee Voltage** - Minimum amount of voltage required to conduct the diode





Diode

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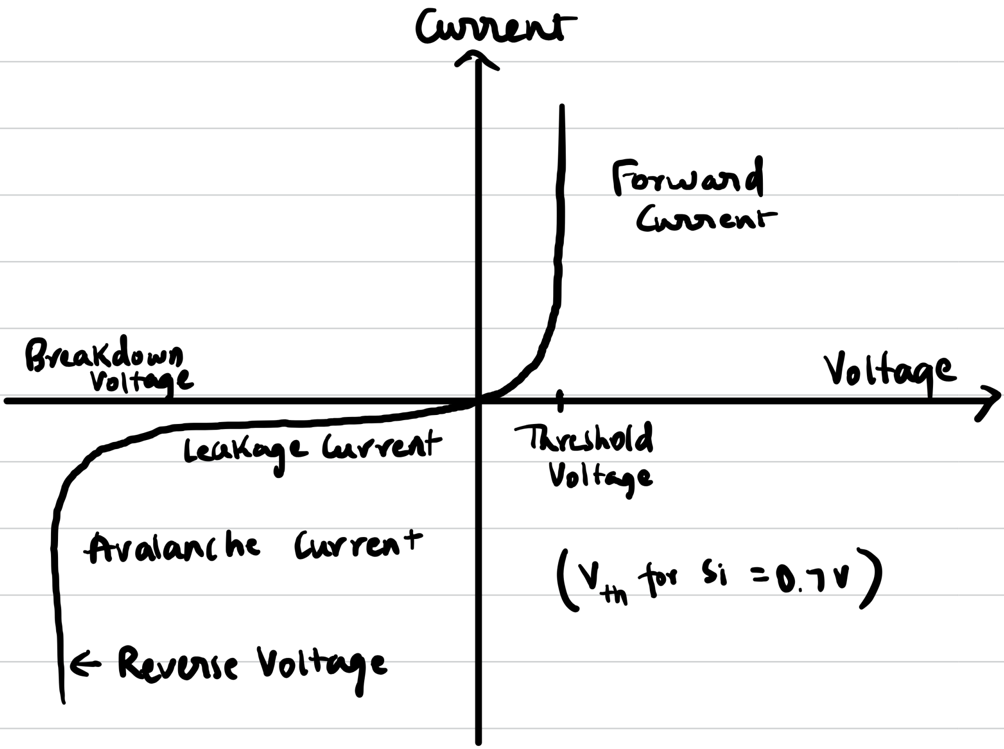
Shockley's Equation

→ $I_D = I_s\left(e^{\frac{qV_d}{nKT}} - 1\right)$ ⇒ Ideal diode eq

I_D ⇒ Diode Current
V_D ⇒ Diode Voltage
q ⇒ charge on $e^- = 1.6 \times 10^{-19}$ C
n ⇒ ideality factor ($n=1$ ⇒ indirect semicond ⇒ Si, Ge, etc., $n=2$ ⇒ direct semicond ⇒ GaAs, InP etc.)
K ⇒ Boltzmann const ($K = 1.38 \times 10^{-23}\ m^2\ Kg\ s^{-2}\ K^{-1}$)



Parameters :

Forward Bias	Reverse Bias
→ Knee Voltage	→ Reverse Saturation Current
→ Forward Current Rating	→ Break down Voltage
→ Max Power dissipation	→ Peak Inverse Voltage Rating

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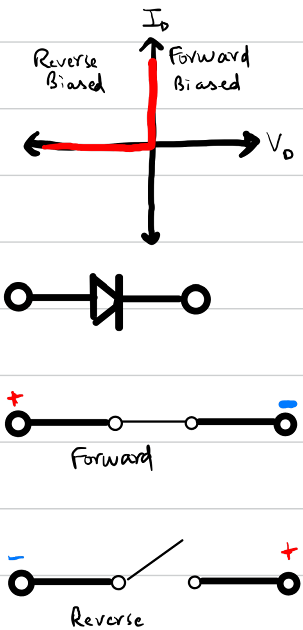
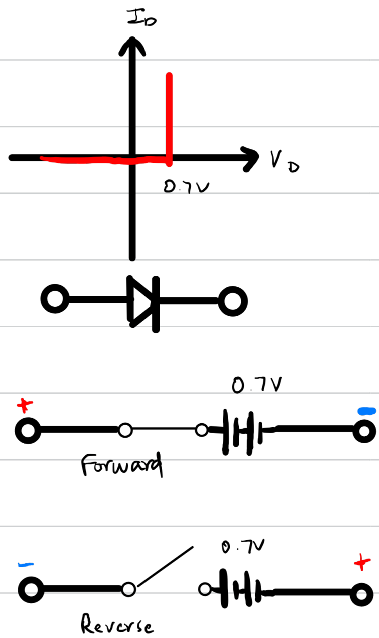
Ideal Diode → Forward bias ⇒ No resistance ⇒ Closed switch
Backward bias ⇒ ∞ 〃 ⇒ open switch

Practical Diode → Forward bias ⇒ Conducts at knee voltage
Reverse bias ⇒ No current (due to majority charges)
Acts like open switch





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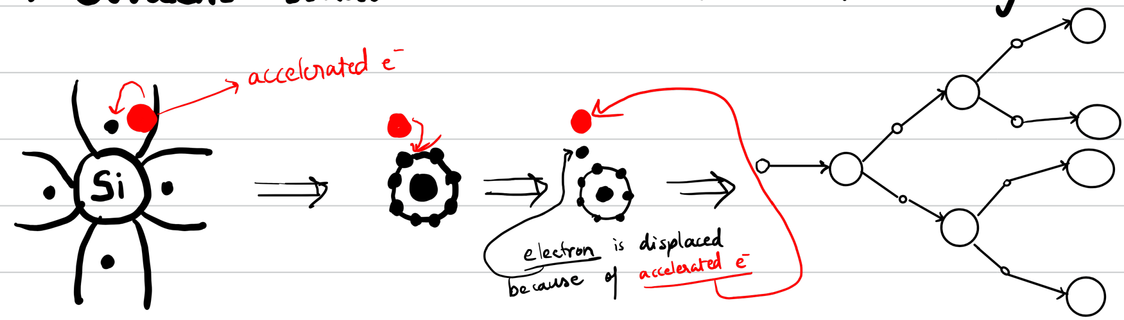
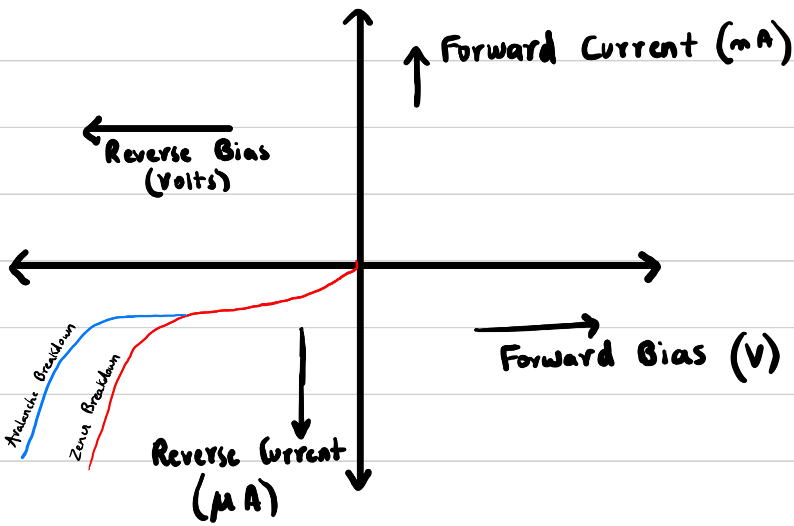
Avalanche Breakdown

→ In Reverse bias condition,
as Voltage increases, free charge carriers obtain velocity & associate K.E & release additional carriers through collision with other atomic structures

→ Covalent bonds are broken & electron-hole is generated





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Diode Equivalent Circuit

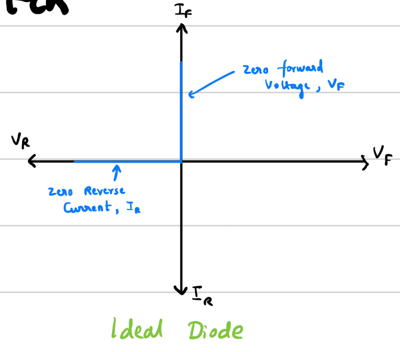
→ Mathematical method to approximate non linear behaviour of real diodes to enable calculations & circuit analysis

→ 3 different equivalent circuits are used to analyse diode circuits :

i) Ideal Equivalent Circuit
ii) Simplified Equivalent Circuit
iii) Piece-wise linear equivalent Circuit

Ideal Equivalent Circuit

→ Considered as
forward bias diode ⇒ Closed switch ⇒ No voltage drop
backward bias diode ⇒ Open Switch



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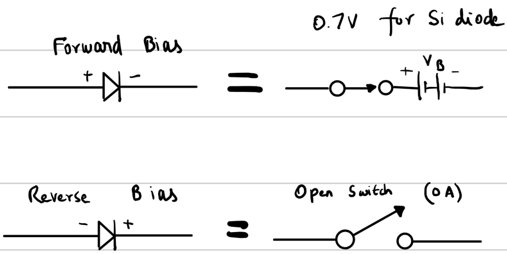
Simplified Equivalent Circuit

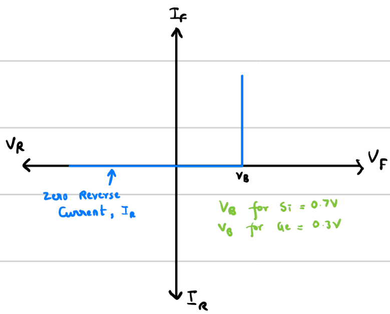
→ Diode is forward-biased diode in series w battery to turn on

For Si diode, $x \geq 0.7V$ required to turn it on.

If less than 0.7V, it won't turn on.

→

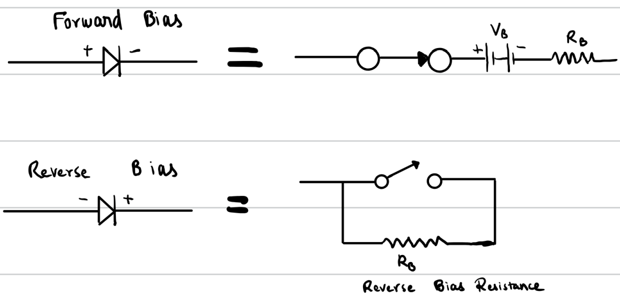


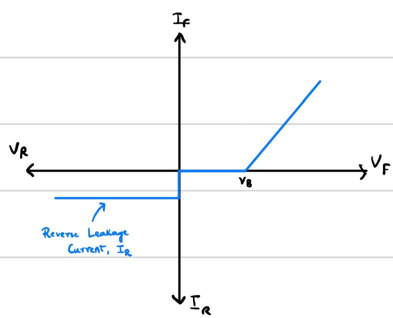


Piece-Wise Linear Equivalent Circuit

→ Includes voltage across diode & voltage across Bulk resistance

→ Voltage Drop, $V_D = 0.7V + I_d \times R_B$





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Temperature Effects on V-I Characteristics Diode

→ Effect of Temp. on diode is observed on both forward & reverse characteristics.

→ Temp ↑ ⇒ No. of e^- hole pair ↑ ⇒ Conductivity ↑ ⇒ Current ↑

→ PN junction diode parameters also depend on temp

i) Reverse Saturation Current

ii) Bias Current

iii) Reverse Breakdown Voltage

iv) Barrier Voltage

→ Temp ↑ ⇒ Carrier conc. ↑ ⇒ Knee Voltage & Breakdown Voltage ↓

Reverse Saturation Current ↑

→ In forward Bias

Barrier Voltage decreases by 2.5mV/1°c for Ge & Si

→ In reverse Bias

Reverse Saturation Current increases by 7%/1°c for Ge & Si

almost doubles for every 10°c increase

en: $T = 20°c \Rightarrow I_s = 0.1 \mu A$

$T = 30°c \Rightarrow I_s = 0.2 \mu A$

$T = 40°c \Rightarrow I_s = 0.4 \mu A$

$T = 50°c \Rightarrow I_s = 0.8 \mu A$

$T = 60°c \Rightarrow I_s = 1.6 \mu A$

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Diode Resistance

→ Actual Diode offers very small resistance ($\neq 0$) in forward biased & called forward resistance

→ Actual Diode offers very high resistance ($\neq \infty$) in reverse biased & called reverse resistance

→ 3 Types of Resistance levels based on applied Voltage

i) DC / Static Resistance

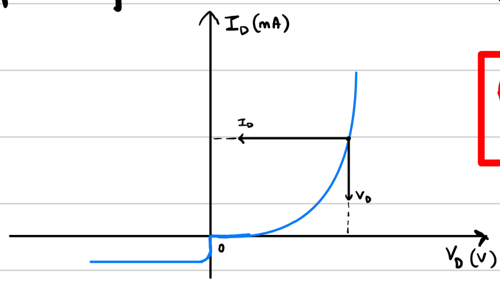
ii) AC / Dynamic Resistance

iii) Average AC Resistance

DC Resistance

→ Application of DC voltage to a circuit containing semiconductor diode will result in an operating point on semiconductor diode characteristic curve.

→ If we find V_D & I_D at operating point gives DC resistance



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

[Typically
forward : 10Ω to 80Ω
reverse : 10 MΩ]

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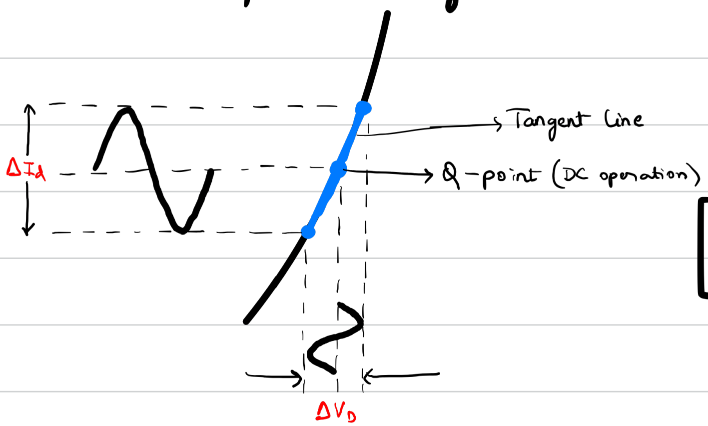
AC Resistance

→ Application of small AC voltage to a circuit containing semiconductor diode offers AC resistance

→ A straight line tangent to curve through Q-point which defines the change in voltage & current to determine AC Resistance for this region $r_d = \frac{\Delta V_d}{\Delta I_d}$



[Typically varies from 1Ω to 100Ω]

→ $I_D = I_s\left(e^{\frac{qV_D}{\eta KT}} - 1\right) \Rightarrow I_D + I_s = I_s e^{\frac{qV_D}{\eta KT}}$

Differentiate wrt V_D

$$\frac{dI_D}{dV_D} = \frac{d}{dV_D}\left(I_s e^{\frac{qV_D}{\eta KT}}\right) = I_s e^{\frac{qV_D}{\eta KT}} \times \frac{q}{\eta KT} = \left(\frac{I_D + I_s}{\eta KT}\right) \times q \simeq \frac{I_D}{\eta KT/q} \quad (I_D >> I_s)$$

$$r_d = \frac{dV_D}{dI_D} = \frac{\eta KT/q}{I_D}$$

At 300K $\Rightarrow \eta KT/q = 26mV$

So $\boxed{r_d = \frac{26mV}{I_D}}$ & $\boxed{r_d' = \frac{26mV}{I_D} + r_B}$

Body Resistance

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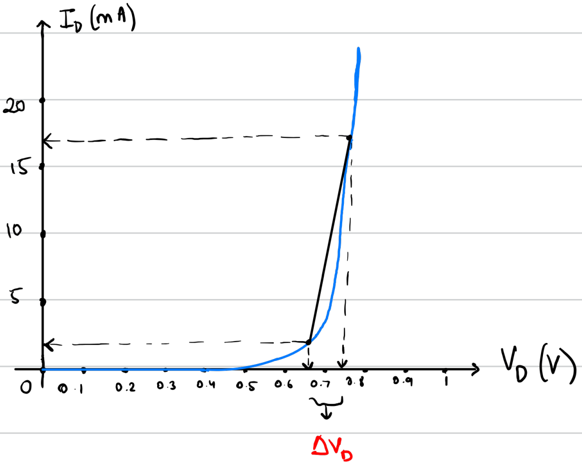
Average AC Resistance

→ If applied input voltage is sufficiently large to produce a broad swing & resistance determined by straight line drawn b/w 2 intersections established by max & min values of input voltage



Q. Determine the dc resistance levels for the diode of Fig. 1.26 at
(a) $I_D = 2$ mA
(b) $I_D = 20$ mA
(c) $V_D = -10$ V

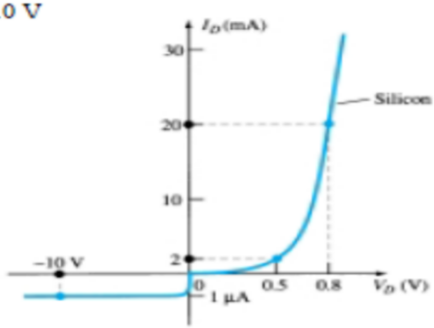


Figure 1.26 Example 1.1

A. i) at 2mA $\Rightarrow$ R = 0.5V

$$R = \frac{V}{I} = \frac{0.5}{2 \times 10^{-3}} = 250\,\Omega$$

ii) at 20mA $\Rightarrow$ R = 0.8 V

$$R = \frac{V}{I} = \frac{0.8}{20 \times 10^{-3}} = 40\,\Omega$$

iii) at $V_D = -10V \Rightarrow I_D = 1\mu A$

$$R = \frac{V}{I} = \frac{10}{10^{-6}} = 10^{7}\,\Omega$$

$$= 10\,M\Omega$$

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Series diode Configurations

→ It is assumed that forward resistance of diode is usually so small compared to other series of elements that it is ignored.

→ It is in 'on' state if current flows that it matches the direction of arrow in diode.

Forward Bias

- $(V_D)_{Si} = 0.7V$
- $(V_D)_{Ge} = 0.3V$

Analysis (For Si)

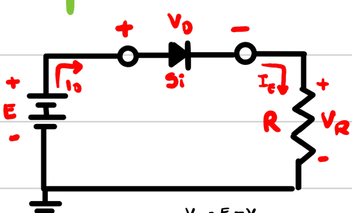
- $V_D = 0.7\,V$ (or) $V_D = E$ if $E < 0.7$
- $V_R = E - V_D$
- $I_D = I_R = I_T = V_R / R$

Reverse Bias

- Diodes behave as open circuits

Analysis

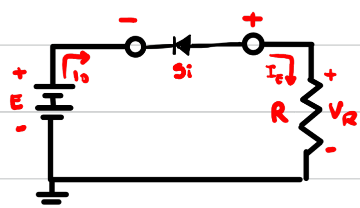
- $V_D = E$; $V_R = 0\,V$; $I_D = 0A$



$V_D = V_K$

$V_R = E - V_K$

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



$V_R = I_R R = I_D R = (0A)R = 0V$

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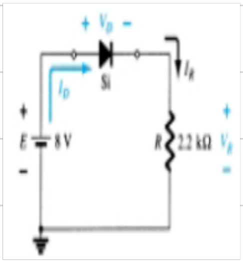
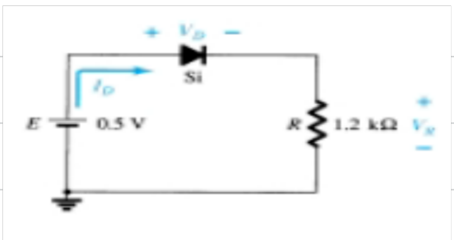
Q. 

Find V_D, V_R & I_D

A. $V_D = 0.7V$

$V_R = 8 - 0.7 = 7.3V$

$I_D = I_R = \frac{7.3}{2200} = 3.32\ mA$

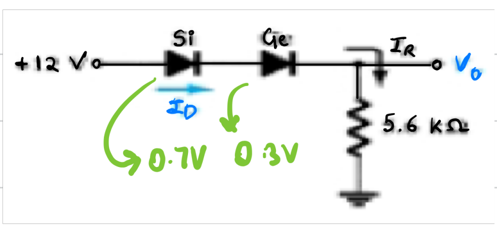
Q 

Find V_D, V_R, I_D

A. $V_D = 0.5V$

Not of enough Voltage is Supplied to turn on the silicon diode

$V_R = 0V$; $I_D = 0A$

Q 

Find V_o & I_D

A. $V_o = E - V_{Si} - V_{Ge}$

$= 12 - 0.7 - 0.3$

$= 11V$

$I_D = I_R = \frac{V_R}{R} = \frac{11}{5600} = 1.96\ mA$

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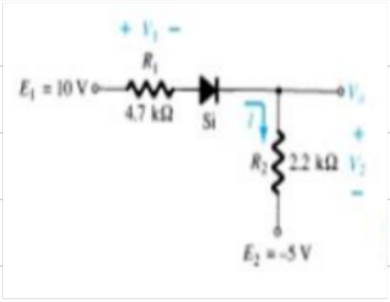
Q.

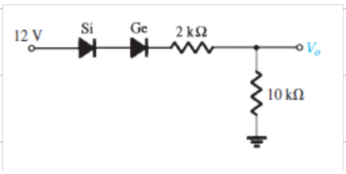


A. $$I = \frac{E_1 - E_2 - (Si)}{R_1 + R_2}$$

$$= \frac{10 + 5 - 0.7}{(4.7 + 2.2) \times 10^3}$$

$$= \frac{14.3}{6.9} \times 10^{-3} = 2.07\,mA$$

Q

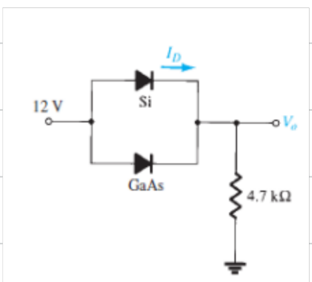


Find V_o

A. $$V_o = \frac{(12 - 0.7 - 0.3) \times 10 \times 10^3}{(10 + 2) \times 10^3}$$

$$= 9.17\,V$$

Q



Find I_D & V_D

A. $$I_R = \frac{12 - 0.7}{4.7 \times 10^3} = \frac{11.3}{4.7} \times 10^{-3}$$

$$= 2.4\,mA$$

$$I_D = I_R = 2.4\,mA$$

$$V_D = 12 - 0.7 = 11.3\,V$$

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BJT Transistor

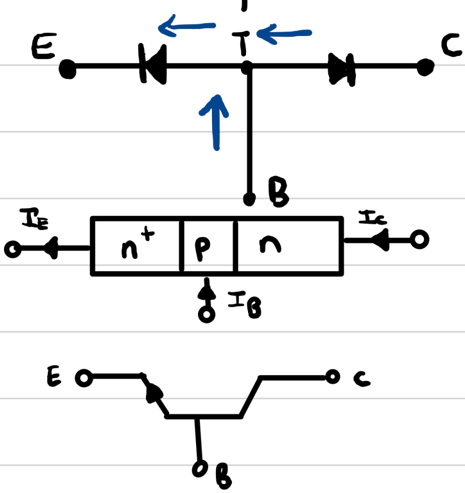
→ A 3 Terminal device with p-type/n-type semiconductor sandwiched by the other

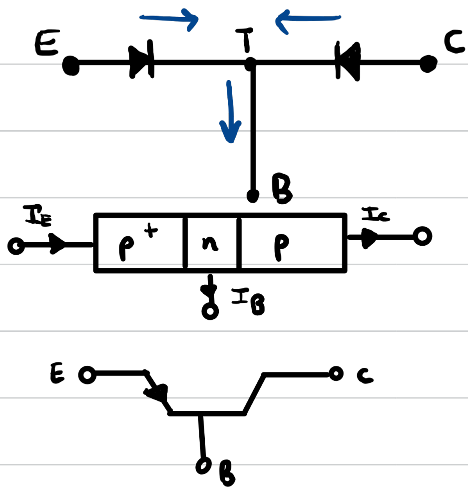
→ Has 2 p-n junctions

→ It requires active participation of both majority & minority carriers

→

Transfer + Resistor = Transistor





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Emitter	Collector	Base
→ Heavily doped	→ Medium doping	→ Minimum doping
→ Moderate size	→ Largest size	→ Smallest size

→ 2 p-n junctions

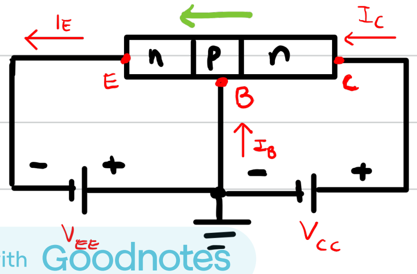
i) Emitter – Base ⟶ Forward

ii) Collector – Base ⟶ Reverse

Regions of Operation	E-B Junction	C-B Junction	Application
Active Region	Forward	Reverse	Works as amplifier
Saturation Region	Forward	Forward	Works as ON switch
Cut-off Region	Reverse	Reverse	Works as OFF switch
Inverse active region	Reverse	Forward	Works as Attenuator

→ In a transistor,

$I_E = I_C + I_B$

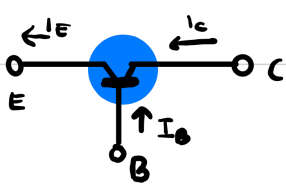


→ Can be :

i) Common Base Config

ii) Common Emitter Config

iii) Common Collector Config



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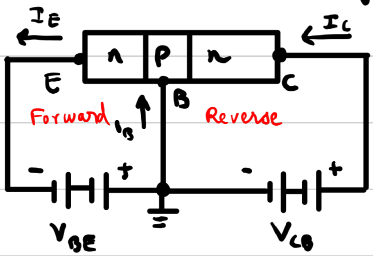
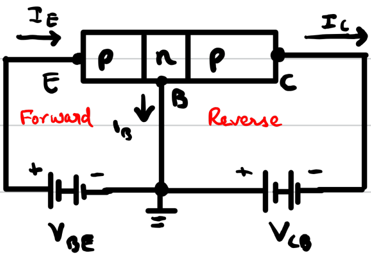
Common Base Configuration



→ Requires 2 voltage sources V_{BE} & V_{BC} in npn

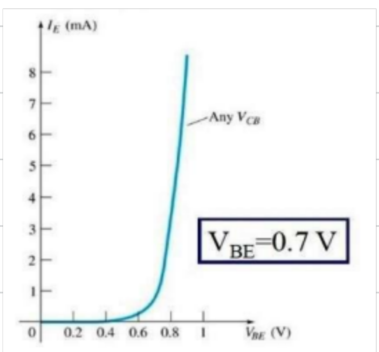
↳ not pointing in



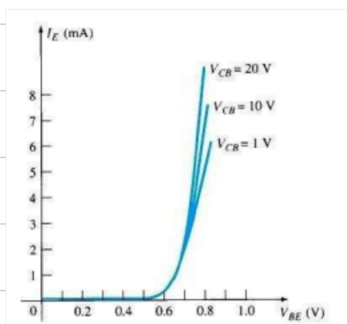
→ Requires 2 voltage sources V_{BE} & V_{BC} in pnp

↳ pointing in permanently

Input Characteristics of BJT



I_E v/s V_{BE} | For fixed V_{CB}



I_E v/s V_{BE} | For Variable V_{CB}

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Base Width Modulation / Early Effect

→ BE junction is unchanged cuz V_{BE} is same ($= 0.7V$)

→ Greater reverse bias across CB Junction increases CB depletion width.

There is variation in width of base in BJT cuz of variable V_{BC}

Causes 2 things:

i) lesser recombination in smaller base

ii) Charge gradient increased across base & current of minority carriers across CB - junction increases called I_{CBO}

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