(Laws for sheet two)

يعني قوانين سكشن ٢

diodes models

1) ideal model

Reverse

$R_r \simeq \infty$ o.C

off

$I_D = 0$

$V_D = V_A - V_K < 0$

forward

$R_f = 0$ S.C

ON

$I_D > 0$

$V_D = 0$

2) Practical model

Picewise linear model

large signal model

Reverse

off

$R_r = 100\,M\Omega$

or

forward

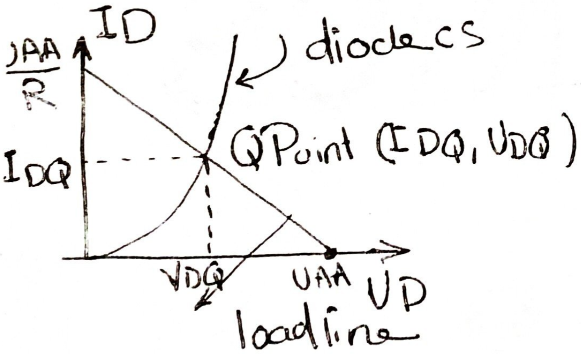
ON

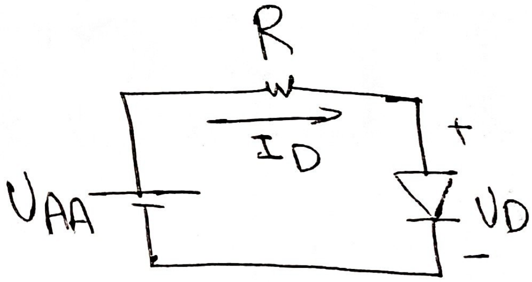
R_f V_γ

$V_D \geq V_\gamma$

$V_A > V_K + V_\gamma$

3) load line model





$V_{AA} - I_D R - V_D = 0$

$I_D = \frac{V_{AA}}{R} - \frac{1}{R} V_D$

when $V_D = 0$

$I_D = \frac{V_{AA}}{R}$

when $I_D = 0$

$V_D = V_{AA}$

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Potential barrier "Contact Voltage"

$$V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$$

remember →

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + P\mu_p)}$$

$$\rho_p = \frac{1}{qP\mu_p} \quad , \quad \rho_n = \frac{1}{qn\mu_n}$$

remember →

$$N_D + P = N_A + n$$

P-Type

$N_D \simeq 0$

$P \gg n$

$P \simeq N_A$

n-Type

$N_A \simeq 0$

$n \gg P$

$n = N_D$

→ diode characteristic equation (relation bet I_D, V_D)

$$I_D = I_S \left(e^{\frac{V_D}{\eta V_T}} - 1 \right)$$

→ effect of temperature on reverse current

$$I_{S2} = I_{S1} * 2^{(T_2 - T_1)/10}$$

°C

→ Diode as a Capacitor law

$$C_j = C_0 \left(1 + \frac{V_{DR}}{V_0}\right)^{-1/2}$$

C_0 → Constant → junction Capacitance at open circuit $V_D = 0$

Sheet two (electronic devices)

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1. (a) The resistivities of two sides of a step-graded germanium diode are 2Ω.cm (p side) and 1Ω.cm (n side). Calculate the value V_o the potential barrier at room temperature.
(b) Repeat part a for a silicon p-n junction.

Sol:-

$\rho_p = 2\ \Omega.cm$

$\rho_n = 1\ \Omega.cm$

$n_i = 2.5 * 10^{13}$ atoms/cm³

$\mu_p = 1800\ cm^2/V.s$

$\mu_n = 3800\ cm^2/V.s$

From table Page 27 in the book

a)

$$\rho = \frac{1}{\sigma} = \frac{1}{q(n\mu_n + P\mu_p)}$$

at P-side $\qquad P = N_A$

$$\rho_p = \frac{1}{q N_A \mu_p}$$

$$\therefore N_A = \frac{1}{q \rho_p \mu_p} = \frac{1}{1.6*10^{-19} * 2 * 1800} = 1.736*10^{15} \text{ atoms/cm}^3$$

at n-side $\qquad n = N_D$

$$\therefore N_D = \frac{1}{q \rho_n \mu_n} = \frac{1}{1.6*10^{-19} * 1 * 3800} = 1.645*10^{15} \text{ atoms/cm}^3$$

Contact Voltage

$$V_o = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$= 0.026 \ln \frac{1.736*10^{15} * 1.645*10^{15}}{(2.5*10^{13})^2}$$

$V_o = 0.22$ Volt

(b) for silicon

$\mu_p = 1500\ cm^2/V\text{-}s$

$\mu_n = 1300\ cm^2/V\text{-}s$

$n_i = 1.5 * 10^{10}$ atoms / cm^3

$\Rightarrow$ at P-side , $P \simeq N_A$

$$\rho_p = \frac{1}{q N_A \mu_p}$$

$$N_A = \frac{1}{q \rho_p \mu_p} = \frac{1}{1.6*10^{-19} * 2 * 1500} = 2.08 * 10^{15} \text{ atoms}/cm^3$$

$\Rightarrow$ at n-side , $n = N_D$

$$N_D = \frac{1}{q \rho_n \mu_n} = \frac{1}{1.6*10^{-19} * 1 * 1300} = 4.8 * 10^{15} \text{ atoms}/cm^3$$

$\Rightarrow$ Contact Voltage

$$V_o = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$= 0.026 \ln \frac{2.08*10^{15} * 4.8*10^{15}}{(1.5*10^{10})^2}$$

$$= 0.637 \text{ Volt}$$

	Ge	Si
μ_n	$3800\ cm^2/V\text{-}s$	$1300\ cm^2/V\text{-}s$
μ_p	$1800\ cm^2/V\text{-}s$	$1500\ cm^2/V\text{-}s$
Concentration	$4.4 * 10^{22}$ atoms/cm^3	$5 * 10^{22}$ atoms/cm^3
n_i	$2.5 * 10^{13}$	$1.5 * 10^{10}$

no. of Germanium atoms / Volume → Concentration

intrinsic Carrier Concentration → n_i

$\eta \rightarrow$ Silicon $= 2$

$\eta \rightarrow$ Germanium $= 1$

3. (a) Consider a step graded germanium p-n junction with $N_D=10^3N_A$, Corresponding to 1 acceptor atom per 10^8 germanium atoms. Calculate the contact difference of potential V_0 at room temperature.
(b) Repeat part (a) for a silicon p-n junction.

Sol:-

Concentration = $4.4 * 10^{22}$ atoms/cm^3

$N_D = 10^3 N_A$

Concentration = $10^8 N_A$

to get NA firstly

$$N_A = \frac{\text{Concentration}}{10^8}$$

$$= \frac{4.4*10^{22}}{10^8} = 4.4*10^{14} \text{ atoms/cm}^3$$

$\therefore N_D = 4.4*10^{14}*10^3 = 4.4*10^{17}$ atoms/cm^3

$$\therefore V_0 = U_T \ln \frac{N_A N_D}{n_i^2}$$

$$= 0.026 \ln \frac{4.4*10^{14} \times 4.4*10^{17}}{(2.5*10^{13})^2} = 0.329 \text{ Volt}$$

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Si P-n junction

$$N_A = \frac{5*10^{22}}{10^8} = 5*10^{14} \text{ atoms} / cm^3$$

$$N_D = 10^3 N_A = 5*10^{17} \text{ atoms} / cm^3$$

$$V_o = 0.026 \ln \frac{5*10^{14} * 5*10^{17}}{(1.5*10^{10})^2}$$

$$= 0.721 \text{ Volt}$$

4. If the reverse saturation current in a p-n junction silicon diode is 1nA, what is the applied voltage for a forward current of 2.5μA?

Sol:-

$I_S = 1n\,A$

$I_D = 2.5\,\mu A$

$\eta_{silicon} = 2$

$$I_D = I_S\left(e^{\frac{U_D}{\eta U_T}} - 1\right) \quad A$$

for forward

$$I_D = I_S\, e^{\frac{U_D}{\eta U_T}}$$

$$2.5 * 10^{-6} = 1 * 10^{-9}\, e^{\frac{U_D}{\eta U_T}}$$

$$e^{\frac{U_D}{\eta U_T}} = 2500$$

$$\frac{U_D}{\eta U_T} = Ln\,2500$$

$$\frac{U_D}{2 * 0.026} = Ln\,2500$$

$V_D = 0.407$ Volt

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5. (a) Calculate the factor by which the reverse saturation current of a germanium diode is multiplied when the temperature is increased from 25 to 80°C.
(b) Repeat part (a) for silicon diode over the range 25 to 125°C.

Sol:-

a)
$$I_{S2} = I_{S1} * 2^{(T_2-T_1)/10}$$

$$\frac{I_S(80°C)}{I_S(25°C)} = 2^{(80-25)/10}$$

Germanium

$$= 45.25$$

b)

$$\frac{I_S(125°C)}{I_S(25°C)} = 2^{(125-25)/10}$$

Silicon

$$= 1024$$

6. Reverse biased diodes are frequently employed as electrically controllable variable capacitors. The junction capacitance of an abrupt junction diode is 20pf at 5V compute the decrease in capacitance for 1.0V increase in bias, assuming that potential barrier = 0.65V.

Sol:-

$$C_j\big|_{5V} = 20\ PF = 20 * 10^{-12}\ F$$

$$V_o = 0.65\ V$$

V_R increased from 5V to 6V

$$\cdot\ C_j = C_o\left(1+\frac{V_{DR}}{V_o}\right)^{-1/2}$$

C_o → constant → junction capacitance at open circuit $V_D = 0$

$$\frac{C_{j2}}{C_{j1}} = \frac{\left(1+\frac{V_{D2}}{V_o}\right)^{-1/2}}{\left(1+\frac{V_{D1}}{V_o}\right)^{-1/2}}$$

$$C_{j2} = \frac{\left(1+\frac{V_{D2}}{V_o}\right)^{-1/2}}{\left(1+\frac{V_{D1}}{V_o}\right)^{-1/2}}\ C_{j1}$$

$$= \frac{\left(1+\frac{6}{0.65}\right)^{-1/2}}{\left(1+\frac{5}{0.65}\right)^{-1/2}} * 20*10^{-12}$$

$$C_{j2} = 1.84 * 10^{-11}\ F$$

$$C_{j2} = 18.4\ PF$$

Decrease in capacitance $= 20 - 18.4 = 1.6$ PF

(a) A silicon diode at room temperature conducts 1mA at 0.7V. Given that voltage increase to 0.8V, calculate the diode current. Assume $\eta=2$.
(b) Calculate the reverse saturation current.
(c) Repeat (a) for $\eta=1$.

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Sol:-

$I_{D1} = 1mA = 10^{-3}\,A \rightarrow$ at $U_{D1} = 0.7V$

$I_{D2} = ?$ $\rightarrow$ at $U_{D2} = 0.8V$

$\eta = 2$

a) $I_D = I_s\left(e^{\frac{U_D}{\eta U_T}} - 1\right)$

$$\frac{I_{D2}}{I_{D1}} = \frac{\left(e^{\frac{U_{D2}}{\eta U_T}} - 1\right)}{\left(e^{\frac{U_{D1}}{\eta U_T}} - 1\right)} = \frac{\left(e^{\frac{0.8}{2*0.026}} - 1\right)}{\left(e^{\frac{0.7}{2*0.026}} - 1\right)}$$

$$= \frac{e^{15.38} - 1}{e^{13.46} - 1}$$

$$= 6.82 \text{ mA}$$

b)

$$I_{D1} = I_s\left(e^{\frac{U_{D1}}{\eta U_T}} - 1\right)$$

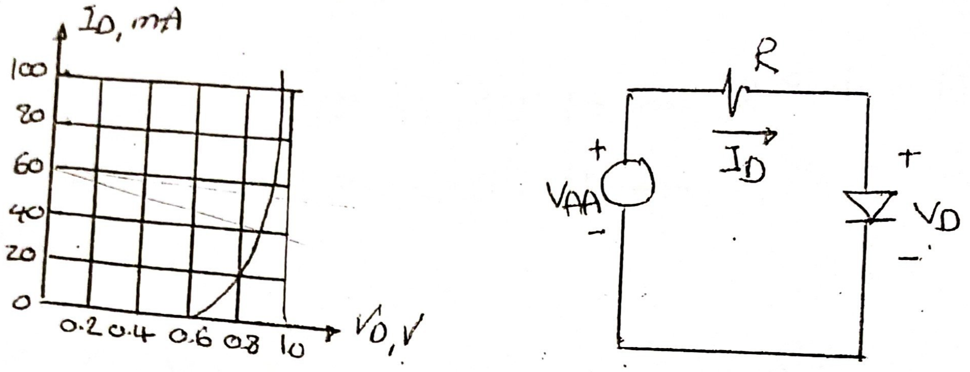
$$10^{-3} = I_s\left(e^{\frac{0.7}{2*0.026}} - 1\right)$$

$$I_s = 1.43 \text{ nA}$$

c) for $\eta = 1$

$$I_{D2} = \frac{\left(e^{\frac{0.8}{0.026}} - 1\right)}{\left(e^{\frac{0.7}{0.026}} - 1\right)} = 46.81 \text{ mA}$$

3. A silicon diode with shown volt-ampere characteristic used in the following circuit with $V_{AA}=6V$ and $R=100\Omega$.
(a) Determine the diode current and voltage.
(b) If V_{AA} is decreased to 3V what must the new value of R be if the diode current is to remain at the value in (a)?



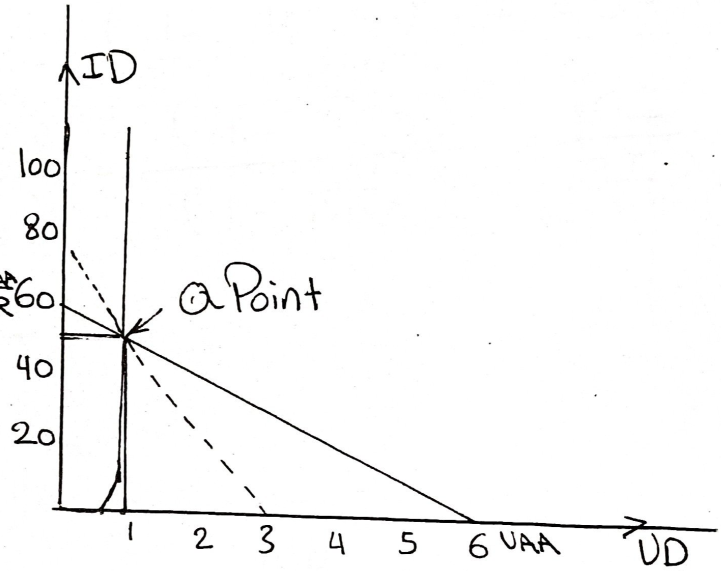
Sol:-

$V_{AA} = 6V$

$R = 100\,\Omega$

a) $V_D = ?$ $\quad I_D = ?$

$I_D = I_s\, e^{\frac{V_D}{\eta V_T}}$
$V_{AA} = I_D R + V_D$
can't be solved together



$I_D R = -V_D + V_{AA}$

$I_D = -\frac{1}{R} V_D + \frac{V_{AA}}{R}$

We have 2 equations but we can't solving the two variables ID, VD so we will use the graphe

$I_D = 51\,mA \qquad V_D \simeq 0.9V$

from graphe = 50mA

b) $V_{AA} = 3V \quad$ at $I_D = 51\,mA$, $V_D \simeq 0.9V$

$R = ?$

$V_{AA} = I_D R + V_D$

$3 = 0.051\,R + 0.9$

$R = \frac{2.1}{0.051} = 41.2\,\Omega \simeq 40\,\Omega$

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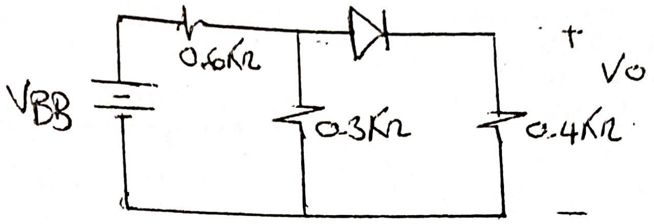
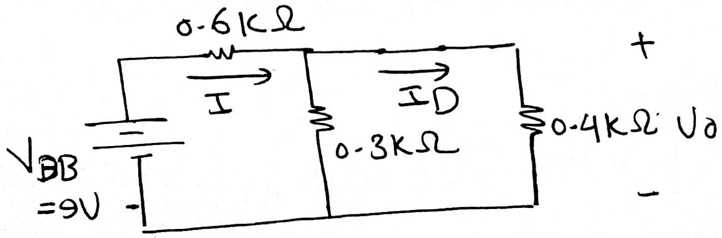
9. The circuit shown uses an ideal diode. Find V_o given V_{BB}=9V.



Sol:-

assume Diode ON



$$R_{total} = 0.6 + \frac{0.3*0.4}{0.3+0.4}$$

$$= 0.77\ k\Omega$$

$$I = \frac{V_{BB}}{R_{total}} = \frac{9}{0.77*10^3} = 11.667\ mA$$

(0.3 ∥ 0.4)

$$I_D = 11.667 * \frac{\frac{6}{35}}{0.4} = 5\ mA$$ +ve assumption true

$$11.667 * \frac{0.3}{0.3+0.4}$$

المقاومة البعيدة

مجموع المقاومتين

$$V_o = 5*10^{-3} * 0.4*10^3 = 2\ V$$

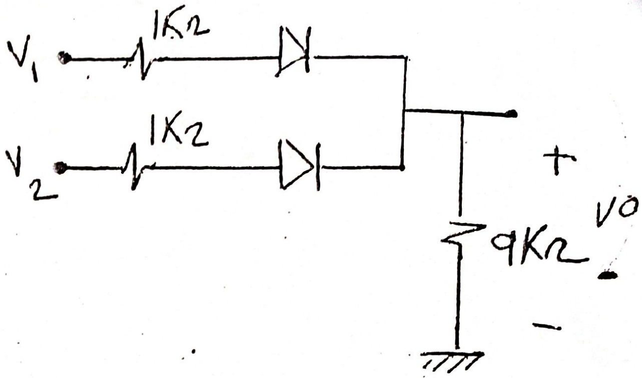
or we can say

$$V_o = I * R(0.3 \parallel 0.4)$$

$$= 11.667 * \frac{0.3*0.4}{0.3+0.4} = 2V$$

10. For the circuit shown, the cut-in voltage of the diode is 0.6V and the drop across a conducting diode is 0.7V. Calculate V_o for the following input voltages and indicate the state of each diode (ON or OFF). Justify your assumptions about the state of each diode.

(a) V1=10V, V2=0V.
(b) V1=5V, V2=0V.
(c) V1=10V, V2=5V.
(d) V1=5V, V2=5V.



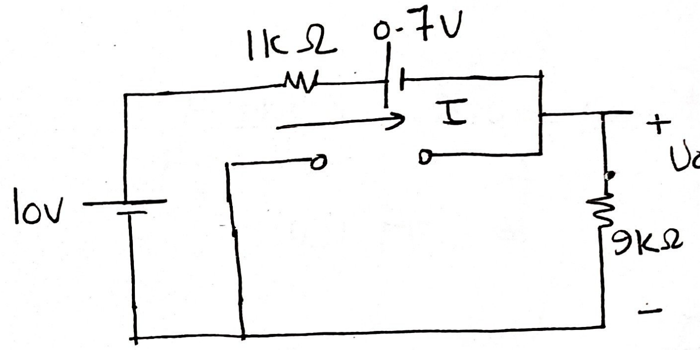
Diode on → $V_D = 0.7V$

Diode off → $V_D < 0.6V$

Sol –

(a) $V_1 = 10V$, $V_2 = 0V$

assume D_1 ON D_2 off



Using KVL

$$10 - 1000 * I - 0.7 - 9000 I = 0$$

$$I = \frac{10 - 0.7}{10000} = 0.93\,mA \quad +ve$$

$$V_o = 0.93 * 9 = 8.37\,V$$

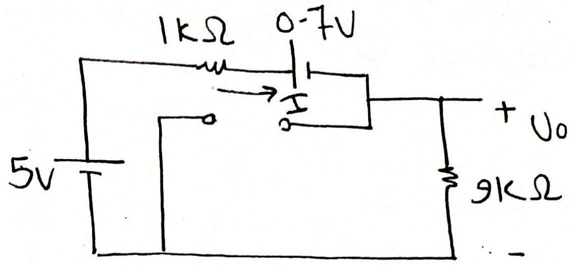
$$\Delta V_1 = 10 - 8.37 = 1.63 > 0.6 \quad D_1 \text{ ON}$$

$$\Delta V_2 = 0 - 8.37 = -8.37 < 0.6 \quad D_2 \text{ off}$$

assumption true

, $V_2 = 0V$

...sume D_1 ON , D_2 off



Using KVL

$$5 - 1000 * I - 0.7 - 9000 I = 0$$

$$I = \frac{5 - 0.7}{10000} = 0.43\ mA$$

$$V_o = 0.43 * 9 = 3.87\ V$$

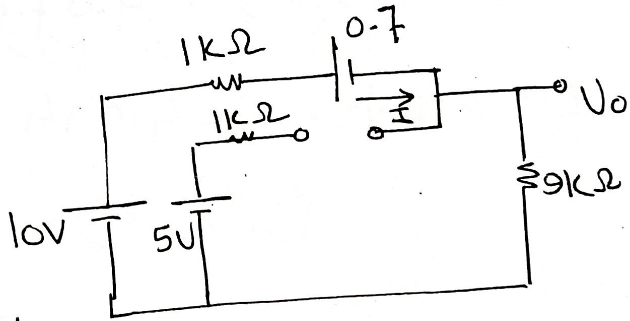
$\Delta V_1 = 5 - 3.87 = 1.13 > 0.6$ D_1 ON

$\Delta V_2 = 0 - 3.87 = -3.87 < 0.6$ D_2 off

assumption true

3) $V_1 = 10V$, $V_2 = 5V$

assume D_1 ON , D_2 off



$$I = \frac{10 - 0.7}{1 + 9} = 0.93\ mA$$

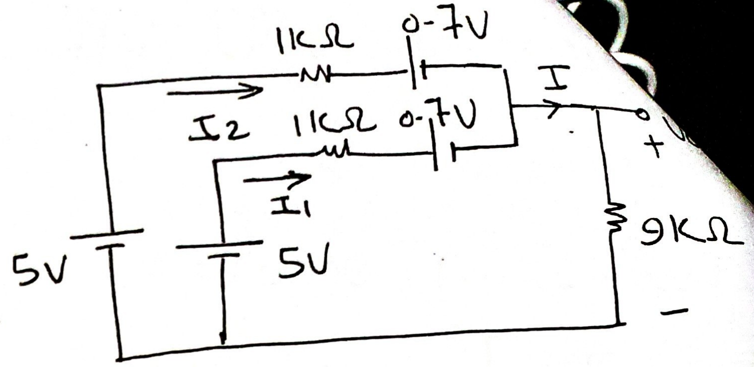
$$V_o = 0.93 * 10^{-3} * 9 * 10^{3} = 8.37V$$

$\Delta V_1 = 10 - 8.37 > 0.6$ D_1 ON

$\Delta V_2 = 5 - 8.37 < 0.6$ D_2 off

(d) $V_1 = 5V$ $V_2 = 5V$

assume D_1, D_2 on



$I = I_1 + I_2$

$I_1 = I_2$ from symmetry

$I_1 = I_2 = I/2$

$5 - I_2 * 1000 - 0.7 - I * 9000 = 0$

$5 - \frac{I}{2} * 1000 - 0.7 - I * 9000 = 0$ $*2$.

$10 - I * 1000 - 1.4 - 2I * 9000 = 0$

$\therefore I = \frac{10 - 1.4}{19000} = 0.453\,mA$

$V_o = 0.453 * 9 = 4.074\,V$

$\Delta V_1 = \Delta V_2 = 5 - 4.074 = 0.926 > 0.6$

D_1 & D_2 ON

assumption true

11. In the shown circuit, the diode D_1 is germanium with offset voltages 0.3V and an incremental resistance 30 ohms whereas D_2 is silicon with offset voltage 0.6V and incremental resistance 18 ohms. Find the diode current if R=10 k-ohms.

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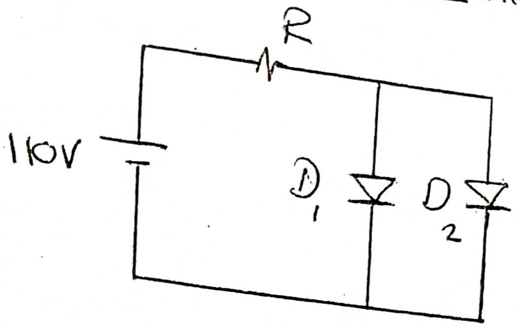
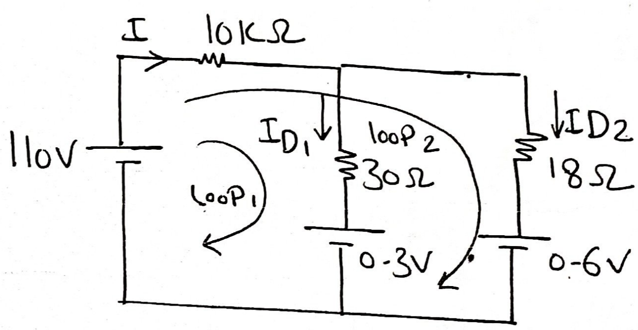
(14)



assume D_1 , D_2 on



$I = I_{D1} + I_{D2}$

loop (1)

$110 - 10*10^3 I - 30 I_{D2} - 0.3 = 0$

$110 - 0.3 = 10*10^3 I + 30 I_{D2}$

$109.7 = 10*10^3 (I_{D1} + I_{D2}) + 30 I_{D2}$

$109.7 = 10030 I_{D1} + 10000 I_{D2} \longrightarrow (1)$

oop (2)

$110 - 0.6 = 10*10^3 I + 18 I_{D2}$

$109.4 = 10000 I_{D1} + 10018 I_{D2} \longrightarrow (2)$

Solving (1) and (2)

$I_{D1} = 0.01094 - 1.0018 I_{D2} \longrightarrow (3)$

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From 3 in 1

$100\ 30\ (0.01094 - 1.0018\ I_{D2}) + 10000\ I_{D2} = 109.7$

$-0.0282 = -48.054\ I_{D2}$

$I_{D2} = 0.587\ mA$ +ve

$\therefore\ I_{D_1} = 10.352\ mA$ +ve

$I = 10.939$

$\Delta V_1 = 110 - 10000 * 10.939 = 0.61 > 0.6$

$\Delta V_2 = 0.61 > 0.6$

D_1 , D_2 ON

assumption true

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