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21:35

1. 'The maximum resistivity for a silicon sample can be obtained when the sample is slightly p-type' – prove.

1

At thermal equilibrium, conductivity of a semiconductor is given by-

$$\sigma = nq\mu_n + pq\mu_p$$

$$\Rightarrow = q\left(\frac{n_i^2}{p}\mu_n + p\mu_p\right)$$

For maximum resistivity (or min. conductivity).

$p > n_i$

$$\frac{d\sigma}{dp} = 0.$$

$$\therefore -\frac{n_i^2}{p^2}\mu_n + \mu_p = 0 \rightarrow p = n_i\sqrt{\frac{\mu_n}{\mu_p}}$$

$\mu_n = 1350$ cm²/V·s

$\mu_p = 450$ cm²/V·s

as, $\mu_n > \mu_p$, $p > n_i$

i.e. the sample is slightly p-type.

2. (a) At room temperature calculate the resistivity of intrinsic silicon. (b) Now doped this Si with $N_D = 10^{16}$ cm^{-3}. Calculate the resistivity of this n-type semiconductor. Given, μ_n= 1350 cm^2/V s, μ_p= 480 cm^2/V s and n_i = 1.5x10^{10} cm^2/V s at 300 K.

② At, 300K, n_i of Si is $1.5\times10^{10}\ cm^{-3}$

Electron mobility $(\mu_n) = 1350\ cm^2/V\text{-}s.$

Hole " $(\mu_p) = 480\ cm^2/V\text{-}s.$

So, resistivity of intrinsic Silicon is, $\rho = \dfrac{1}{q n_i(\mu_n+\mu_p)}$

$$\rho = \frac{1}{1.6\times10^{-19}\times1.5\times10^{10}\,(1350+480)} = \boxed{2.3\times10^{5}\ \Omega\text{-}cm.}$$

Doping

Assuming complete ionization,

$n = N_D = 10^{16}\ cm^{-3}$, n-type, $n \gg p$

Resistivity for this case, $\rho = \dfrac{1}{n q \mu_n} = 0.462\ \Omega\text{-}cm.$

So, by adding small amount of impurity (< 1 ppm), resistivity of Si can be changed by many orders.

3. An n-type Si material has a resistivity of $\rho = 0.65\ \Omega$–cm. **(i)** If the electron mobility is $\mu_n = 1250$ cm^2/V–s, what is the concentration of donor atoms? **(ii)** Determine the required electric field to establish a drift current density of $J = 160\ A/cm^2$.

③ Resistivity $(\rho) = 0.65\ \Omega\text{-}cm$

mobility $(\mu_n) = 1250\ cm^2/V\text{-}s.$

$\rho = \dfrac{1}{\sigma} = \dfrac{1}{n q \mu_n} = 0.65$; σ = conductivity

$n = N_D = \dfrac{1}{0.65\times1.6\times10^{-19}\times1250}$; N_D = donor concentration.

$$\boxed{N_D = 7.69\times10^{15}\ cm^{-3}}$$

Drift current density $(J) = n q \mu_n \mathcal{E}$; $\mathcal{E}$ = electric field.

$160 = \dfrac{1}{\rho}\mathcal{E}$

$$\boxed{\mathcal{E} = 160\times0.65 = 104\ V/cm.}$$

p

4. Consider a uniformly doped GaAs pn junction with doping concentrations of $N_A = 5\times10^{18}\ cm^{-3}$ and $N_D = 5\times10^{16}\ cm^{-3}$. **(i)** Find the built-in potential (V_{Bi}). **(ii)** Calculate the change in V_{Bi} if the doping concentration in n-side is increased by 10 times. **Given**, for GaAs bandgap = 1.42 eV and intrinsic carrier concentration = $1.8\times10^6\ cm^{-3}$ at 300 K. Compare this result with Si p-n diode.

n

④ GaAs p-n junction, $N_A = 5\times10^{18}\ cm^{-3}$, $N_D = 5\times10^{16}\ cm^{-3}$; Given, n_i of GaAs $= 1.8\times10^6\ cm^{-3}$ at 300K

Built-in potential, $V_{bi} = V_T \ln\left(\dfrac{N_a N_d}{n_i^2}\right)$; $V_T = 0.026\,V$ at 300K

$$V_{bi} = 0.026 \ln\left[\frac{5\times10^{18}\times5\times10^{16}}{(1.8\times10^{6})^2}\right] = \boxed{1.37\,V. = V_{bi}}$$

5. At what reverse-bias voltage does the reverse-bias current in a silicon pn junction diode reach 90% of its saturation value?

(5)

For diode, $I = I_S\left[\exp\left(\frac{V}{V_T}\right) - 1\right]$; assuming $\eta = 1$.

In reverse bias current is negative $(-I_S)$ and at that particular voltage

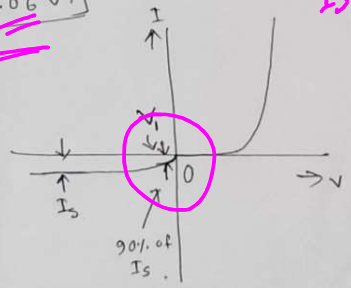
current $= -0.9\, I_S$; (90% of reverse saturation current)

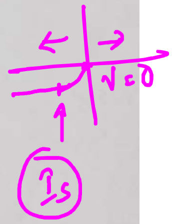
From diode equation, $-0.9\, I_S = I_S\left[\exp\left(\frac{V_1}{V_T}\right) - 1\right]$

$$\therefore \exp\left(\frac{V_1}{V_T}\right) = 0.1$$

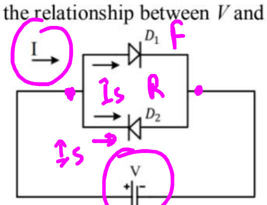
$$V_1 = V_T \ln(0.1)$$

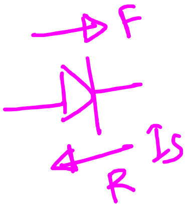
$$\boxed{V_1 = -0.06\,V.}$$





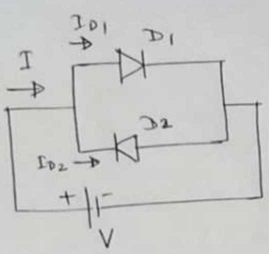
6. In the circuits shown below, find the relationship between V and I.





7. A silicon p-n junction under reverse bias has depletion region of width 10 μm. The relative permittivity of silicon (ε_r) = 11.7 and the free space permittivity (ε_0) = 8.854×10^{-12} F/m. Estimate the depletion capacitance of the diode (in per square meter).

(6)



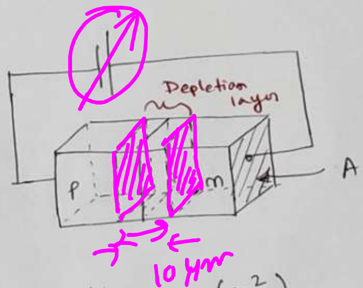
Here, D_1 is forward biased
D_2 is reverse biased.

Total current $I = I_1 + I_2$

$$I = I_S\left[\exp\left(\frac{V}{V_T}\right) - 1\right] + I_S$$

$$I = I_S \exp\left(\frac{V}{V_T}\right)$$

$$\boxed{V = V_T \ln\left(\frac{I}{I_S}\right)}$$



11.7

(7)

$$C = \frac{\epsilon A}{W}$$

C ↕

$$C = \frac{\epsilon_0 \epsilon_r}{W} A.$$

$$= \frac{11.7 \times 8.854 \times 10^{-12}}{10 \times 10^{-6}}$$; A = unit area (m^2).

$= 10.3\ \mu F$

$C = 10.3\ \mu F/m^2$

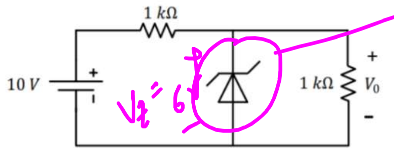
10×10^{-6}

$= 10.3\ \mu F$

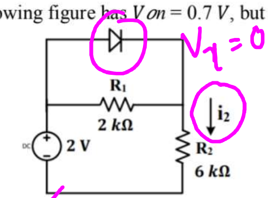
$C = 10.3\ \mu F/m$

8. In the circuit shown below, the Zener diode is ideal and Zener voltage is 6 V. Find out the output voltage V_0.

if the only if the Zener is in breakdown

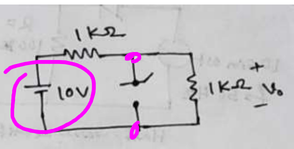


9. Assume that the diode in the following figure has $V_{on} = 0.7\ V$, but is otherwise ideal. Find out i_2.



(8) Given, $V_Z = 6\ V$.

The Zener diode is in reverse bias.



Voltage across the Zener diode is

$$= \frac{1\ k\Omega}{1\ k\Omega + 1\ k\Omega} \times 10\ V$$

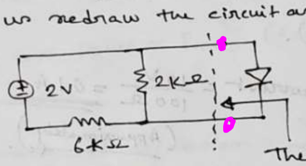
$$= 5\ V, \text{ but, } V_Z = 6\ V.$$

$5V < V_Z$

So, the Zener diode is in reverse bias, but not in breakdown.

So, $V_o = 5\ V$.

(9) Let us redraw the circuit as

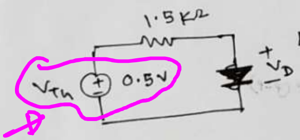


Thevenin equivalent

$$V_{Th} = 2 \times \frac{2}{2+6} = 0.5\ V$$

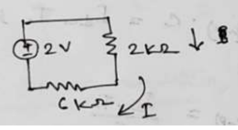
$$R_{Th} = 2\ k\Omega \parallel 6\ k\Omega$$

$$= 1.5\ k\Omega$$



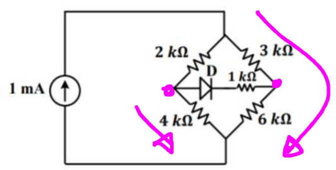
But, as $V_{on} = 0.7V$, the diode is OFF.

The circuit reduces to,

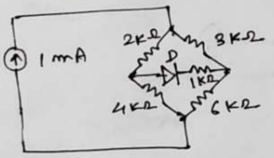


$$I = \frac{2}{2\ k\Omega + 6\ k\Omega} = 0.25\ mA.$$

10. The Si diode in the circuit given below has $V_\gamma = 0.7\ V$ but ideal otherwise. Find out the current in the 4 kΩ resistor.



(10)



This is a bridge circuit and the cross arm product is same

i.e. $2 \times 6 = 3 \times 4$

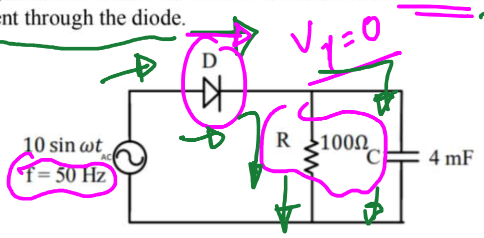
So, the bridge is balanced.

So, no current through the 1 kΩ resistor.

Current through 4 kΩ resistor $= 1\,mA \times \frac{9}{9+6}$

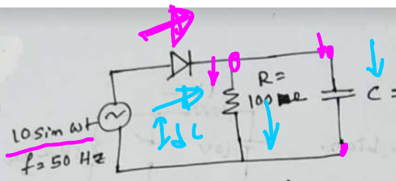
$= 0.6\ mA.$

11. The following figure shows a half-wave rectifier. The diode D is ideal. Calculate the average steady-state current through the diode.



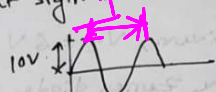
$V_\gamma = 0$

(11)



Half-wave Rectifier.

Input signal = 10 Sin ωt.



Frequency = 50 Hz

Time period $(T) = \frac{1}{50} = 20\ m\,Sec$

RC time const. = RC

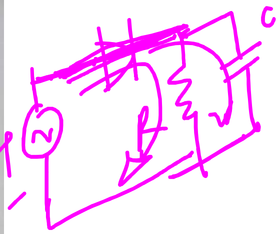
$\cancel{= 100 \times 10^3 \times 4 \times 10^{-3}}$

$= 100 \times 4 \times 10^{-3}$

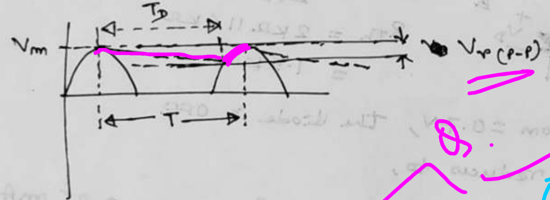
$= 400\ m\,Sec \gg T.$

So, we can say that voltage across the resistor is approximately $\approx 10\ V$ (DC).

So, average Stedy State current $= \frac{10\ V}{100\ \Omega} = 0.1\ A$ (Approximately).



In more details



For half-wave rectifier, $V_{r(p-p)} \cdot C = I_{dc} \cdot T.$; [charge balance]

$\therefore V_{r(p-p)} = \frac{I_{dc} \cdot T}{C}$ (approximated)

$V_{dc} = V_m - \frac{V_{r(p-p)}}{2}$

$\therefore I_{dc} \cdot R = V_m - \frac{I_{dc} \cdot T}{2C}$

$\therefore I_{dc}\left(R + \frac{1}{2fC}\right) = V_m.$

$\therefore I_{dc} = \frac{10}{100 + \frac{1}{2 \times 50 \times 4 \times 10^{-3}}} \approx 0.0976\ A.$

$I_{dc} \cdot T$

$V_r(p-p) \cdot C = I_{dc} T.$

$\therefore I_{dc} = \dfrac{10}{100 + \dfrac{1}{2 \times 50 \times 4 \times 10^{-3}}} \simeq 0.0976\ A.$

12. A diode, whose internal resistance is 30 Ω, is to supply power to a 990 Ω load from a 110 V (rms) source of supply. Calculate (a) the peak load current, (b) the dc load current, (c) the ac load current, (d) the dc load voltage, (e) the total input power to the circuit, and (f) the percentage regulation from no load to the given load.

Half-wave Rectifier

30Ω r_f

(12) Supply, $V_{rms} = 110\ V$, $V_m = 110 \times \sqrt{2} = 155.56\ V$ — supply

$\therefore I_m = \dfrac{V_m}{R_L + r_f}$; $r_f = 30\ \Omega$, $R_L = 990\ \Omega$

$= \dfrac{155.56}{990 + 30} = 0.152\ A$ peak load current. — (a)

$I_{dc} = \dfrac{I_m}{\pi} = \dfrac{0.152}{\pi} = 48.57\ mA.$ — (b)

$I_{rms} = \dfrac{I_m}{2} = \dfrac{0.152}{2} A = 76\ mA.$ — (c)

$V_{dc} = I_{dc} \cdot R_L = 48.57 \times 990 = 48\ V$ — (d)

Total i/p power $= I_{rms}^2 (R_L + R_f) = (76 \times 10^{-3})^2 \times 1020$

$= 5.89\ W.$ — (e)

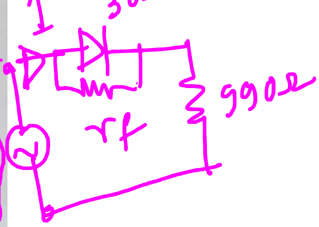
Percentage of regulation $= \dfrac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$

$= \dfrac{V_m/\pi - I_{dc} \cdot R_L}{I_{dc} \cdot R_L}$

$= \dfrac{\frac{155.56}{3.14} - 48.57 \times 10^{-3} \times 990}{48.57 \times 10^{-3} \times 990}$

$= \dfrac{49.54 - 48.08}{48.08} \simeq 3.04\%.$ — (f)

I 30Ω



110V rms

Vm

$V_m \sin \omega t$

$I_{dc} \cdot R_L$

$\dfrac{I_m}{\pi} \cdot R_L$

$\dfrac{V_m R_L}{(R_L + R_f)\pi} = \dfrac{V_m}{\pi} \dfrac{1}{1 + \frac{R_f}{R_L}}$

$= \dfrac{V_m}{\pi}\left(1 + \dfrac{R_f}{R_L}\right)^{-1}$; $\dfrac{R_f}{R_L} \ll 1$

$= \dfrac{V_m}{\pi}\left(1 - \dfrac{R_f}{R_L}\right)$ ← V_{FL}

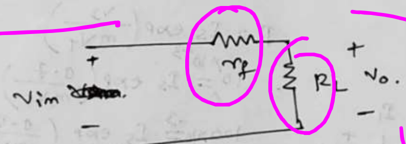
$R_L \to \infty$

$= \dfrac{V_m}{\pi}$ ← V_{NL}

13. Prove that the regulation of both the half-wave and the full-wave rectifier is given by: Percentage regulation = $R_f / R_L \times 100\%$, where, R_f is the diode resistance and R_L is the load resistance.

(13) For, half-wave rectifier, F.W.

$V_{NL} = 2\dfrac{V_m}{\pi}$ and $V_{FL} = 2\dfrac{V_m}{\pi} \dfrac{R_L}{R_L + R_f}$ F.W.



$\therefore$ percentage of regulation, $= \dfrac{V_{NL} - V_{FL}}{V_{FL}} = \dfrac{2\left(\frac{V_m}{\pi} - \frac{V_m}{\pi} \cdot \frac{R_L}{R_L + r_f}\right)}{2\left(\frac{V_m}{\pi} \cdot \frac{R_L}{R_L + R_f}\right)} \times 100\%$

$= \dfrac{R_f}{R_L} \times 100\%.$

For full-wave rectifier, V_{NL} and V_{FL} are double compared

For full-wave rectifier, V_{NL} and V_{FL} are double compared to that of half-wave rectifier. ∴

Hence, % of regulation (full-wave) $= \frac{R_f}{R_L} \times 100\%$.

14. The diode current of a p–n junction diode is 0.5 mA at 340 mV and again 15 mA at 465 mV. Assuming kT/q = 25 mV find out the ideality factor.

(14)

$$I = I_s\left[\exp\left(\frac{V_D}{\eta V_T}\right) - 1\right]$$

Since, $\exp\left(\frac{V_D}{\eta V_T}\right) >> 1$; $\therefore I = I_s \exp\left(\frac{V_D}{\eta V_T}\right)$

So, $$\frac{15\ mA}{0.5\ mA} = \frac{\cancel{I_s} \exp\left(\frac{0.465}{\eta \times 0.025}\right)}{\cancel{I_s} \exp\left(\frac{0.340}{\eta \times 0.025}\right)} = \exp\left(\frac{5}{\eta}\right)$$

$\therefore 30 = \exp\left(\frac{5}{\eta}\right)$

$\therefore \frac{5}{\eta} = 2.303 \log_{10}(30)$

$\therefore \eta = 1.47$

$V_D > 3V_T$

$V_D > 75$ mV.

$\exp\left(\frac{V_D}{\eta KT}\right) >> 1$

$1 \le \eta \le 2$ for Si diode

15. In the circuit shown below, utilizes three identical diodes having $\eta = 1$ and $I_s = 10^{-14}$ A. Find the value of current I required to obtain an output voltage $V_0 = 2$ V. If a current of 1 mA is drawn away from the output terminal by a load, what is the change in output voltage?

(15)

1.366 mA

$V_0 = 2$

1 mA

0.366

Three diodes are identical.

So, drop across each diode $= \frac{V_o}{3} = \frac{2}{3}$ V.

$$I = I_s \exp\left(\frac{V}{V_T}\right) = 10^{-14} \exp\left(\frac{2/3}{0.026}\right)$$

$I = 1.366$ mA. — (a)

1 mA current is drawn by a load.

$$\therefore \frac{1.366\ mA}{0.366\ mA} = \frac{\cancel{I_s} \exp\left(\frac{2/3}{0.026}\right)}{\cancel{I_s}\left[\exp\left(\frac{V'}{0.026}\right)\right]} = \exp\left(\frac{0.66 - V'}{0.026}\right)$$

$\therefore 1.317 = \frac{0.66 - V'}{0.026}$

$\therefore$ change in o/p vol $= (0.66 - V') = 0.034$ V $= 34$ mV decrease (b)

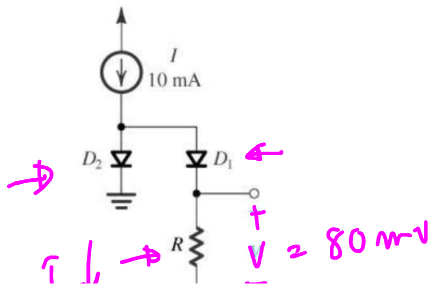
Total reduction.

3 × 34 mV

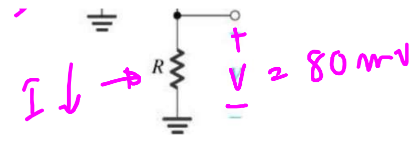
Change in o/p voltage

= 3 × 34 mV

16. For the following circuit both diodes are identical, conducting 10 mA at 0.7 V and 100 mA at 0.8 V. Find the value of R for which V = 80 mV.



$I = I_s \exp\left(\frac{V_D}{\eta V_T}\right)$



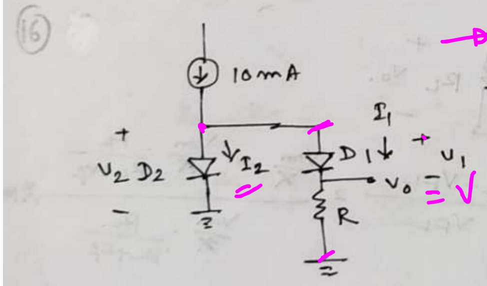
$I = I_s \exp\left(\frac{V_D}{nV_T}\right)$

$\frac{I}{I_s} = \exp\left(\frac{V_D}{nV_T}\right)$

$\ln\left(\frac{I}{I_s}\right) = \frac{V_D}{nV_T}$

$V_D = nV_T \ln\left(\frac{I}{I_s}\right)$

16



$\rightarrow I = I_s \exp\left(\frac{V_D}{nV_T}\right)$

$\therefore 10 \times 10^{-3} = I_s \exp\left(\frac{0.7}{nV_T}\right) \quad — (1)$

$100 \times 10^{-3} = I_s \exp\left(\frac{0.8}{nV_T}\right) \quad — (2)$

$\therefore$ From (1) & (2),

$n = 1.73$

$V_o = V_2 - V_1 = nV_T \ln\left(\frac{I_2}{I_1}\right) = 80\ mV.$

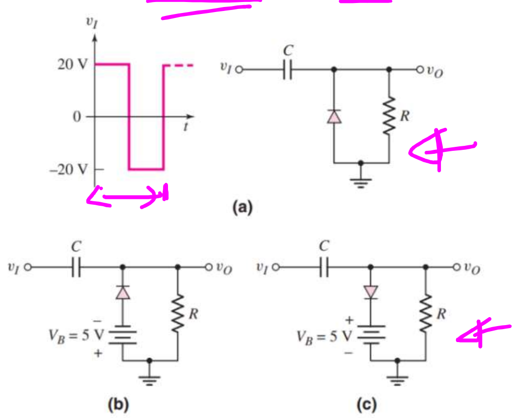
$\therefore 1.73 \times 0.025 \times \ln\left(\frac{I_2}{I_1}\right) = 80 \times 10^{-3}$

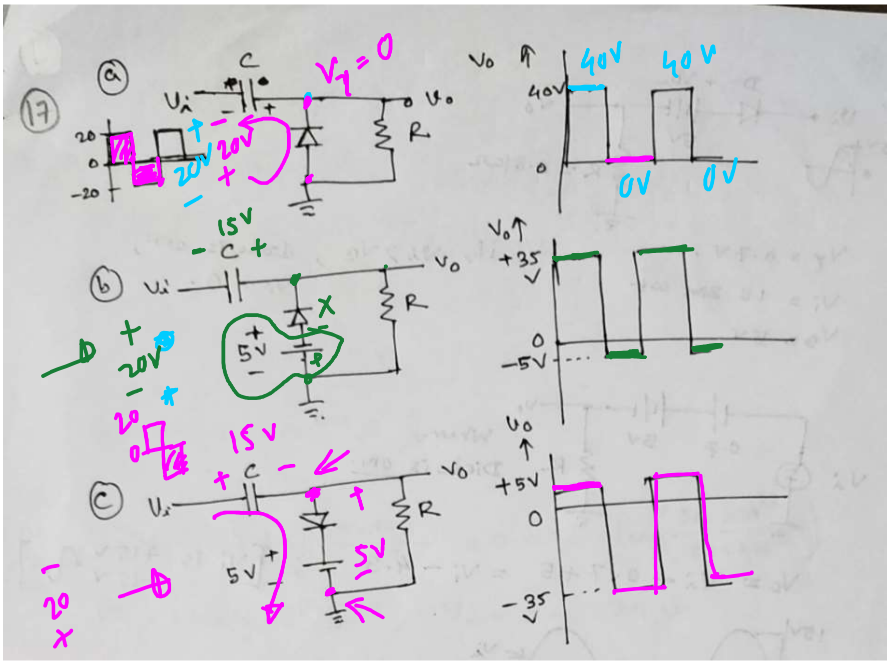
$\rightarrow I_1 + I_2 = 10\ mA = 0.01\ A.$

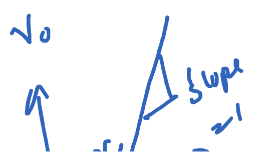
$\therefore I_1 \cong 1.4\ mA$

$\therefore R = \frac{80}{I_1} = 57.1\ \Omega$

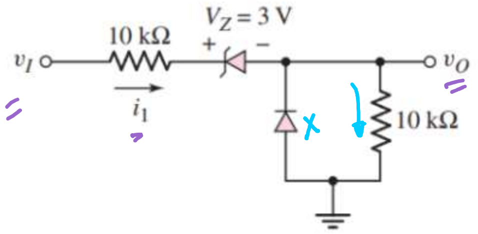
17. Sketch the steady-state output voltage V_O versus time for each circuits in the following figure for the input voltage shown in Figure. Assume $V\gamma = 0$ and the RC time constant is large.

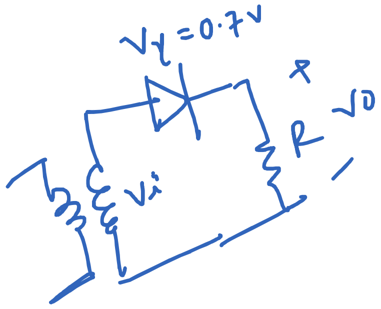


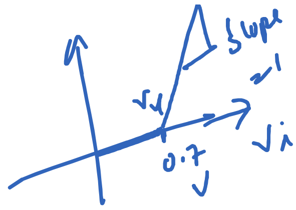




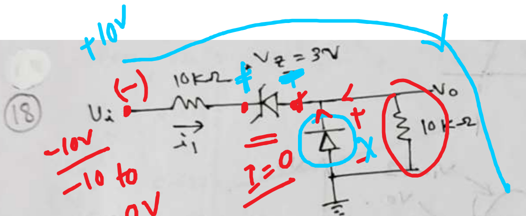
18. For the circuit in the following figure, assume $V\gamma = 0$. (a) Plot v_O versus v_I over the range $-10 \le v_I \le +10$ V. (b) Also plot the i_1 over the same input voltage range.







+10V



−10V

−10 to 0V

I = 0

For $-10 < V_i < 0$ V, both diodes are conducting.

So, $V_o = 0$ V.; (as $V\gamma = 0$)

for $0 < V_i \le 3$ V, Zener diode is not in breakdown. (all voltage drop occurs across Zener and $I = 0$)

So, $V_o = 0$ V.

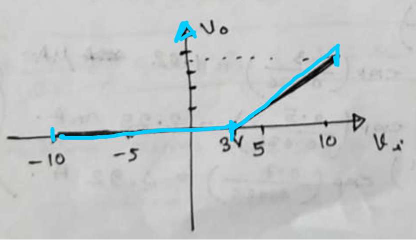
For $V_i > 3$ V, Zener is in breakdown and drop across it is: $V_Z = 3$ V.

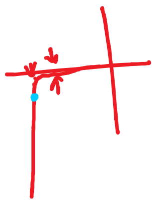
$V_Z = 3V$

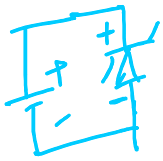
So, $i_1 = \dfrac{V_i - V_Z}{20k\Omega} = \dfrac{V_i - 3}{20}$ mA.

$\therefore V_o = 10\, i_1 = \dfrac{V_i - 3}{2}$ V.

at, $V_i = 10$ V, $V_o = 3.5$ V.

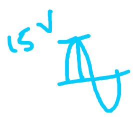


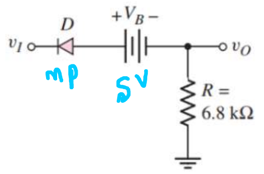




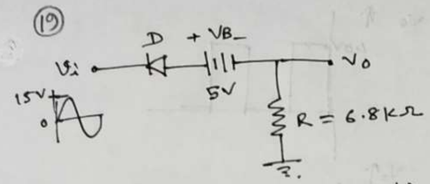
$i_1 = \dfrac{V_i - V_Z}{20\,k\Omega}$

19. In the following circuit the diode cut-in voltage ($V\gamma$) is 0.7 V. The input signal is 15 sin ώt and V_B = 5 V. Sketch v_O verses time.





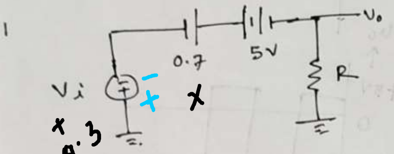
(19)



$V_\gamma = 0.7V.$ if, $V_i > V_B$, diode is off, $V_o = 0.$

$V_i = 15 \sin \omega t$

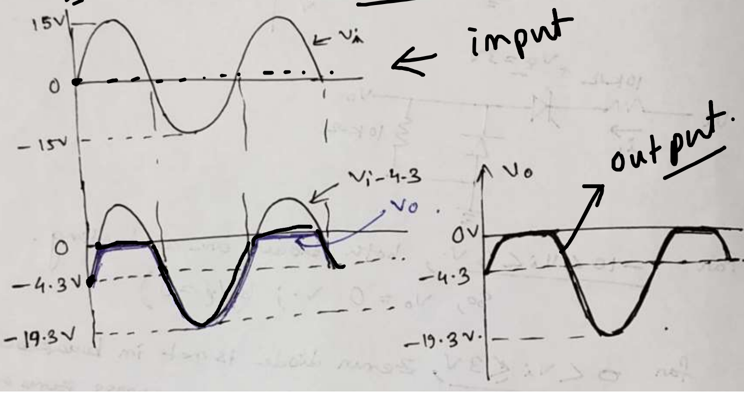
$V_B = 5V.$



When, Diode is ON.

$V_i > 4.3$

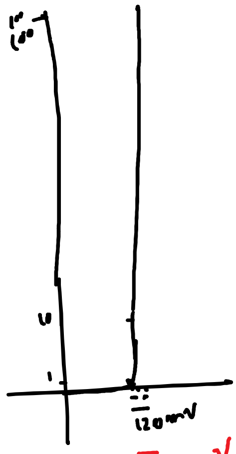
$V_o = V_i - 0.7 + 5 = V_i - 4.3$; [V_i is +15 V −15 V]



20. (a) Consider a silicon pn junction diode operating in the forward-bias region. Determine the increase in forward-bias voltage that will cause a factor of 10 increase in current. (b) Repeat part (a) for a factor of 100 increase in current.

21. The reverse-saturation current of a pn junction diode is $I_S = 10^{-11}$ A. Determine the diode current for diode voltages of 0.3, 0.5, 0.7, −0.02, −0.2, and −2 V. (b) Repeat part (a) for $I_S = 10^{-13}$ A.

$\gg 3V_T$



120mV — 100 times.

(20) $I = I_S \exp\left(\frac{V_D}{V_T}\right)$; $n = 1$

$\therefore 10I = I_S \exp\left(\frac{V_D + \Delta V}{V_T}\right)$

$\therefore \frac{10I}{I} = \frac{\exp\left(\frac{V_D+\Delta V}{V_T}\right)}{\exp\left(\frac{V_D}{V_T}\right)} = \exp\left(\frac{\Delta V}{V_T}\right)$

at Room Temp. 300K = T

$\therefore \Delta V = V_T \ln 10 = 59.86\ mV \approx 60\ mV.$ → 10 times

$\therefore \Delta V = V_T \ln 100 = 119.73\ mV \approx 120\ mV$ → 100 times.

(21) In forward bias,

$I \approx I_S \exp\left(\frac{V_D}{V_T}\right)$

$I(0.3V) = (10^{-11}) \exp\left(\frac{0.3}{0.026}\right) = 1.02\ \mu A.$

$I(0.5V) = (10^{-11}) \exp\left(\frac{0.5}{0.026}\right) = 2.25\ mA.$

$I(0.7V) = (10^{-11}) \exp\left(\frac{0.7}{0.026}\right) = 4.92\ A.$

See the change in current.

In reverse bias..

$I = I_S\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right]$

$I(-0.02V)$ < I_S

So, $I(-0.2\ V) = I_S\left[\exp\left(-\frac{0.2}{0.026}\right) - 1\right]$; $I_S = 10^{-11}$ A.

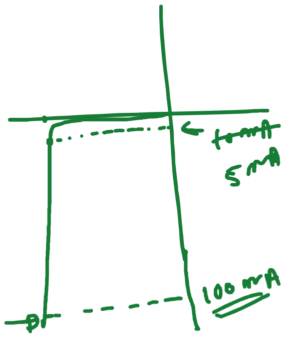
So, $I(-0.2\,V) = I_s\left[\exp\left(-\frac{0.2}{0.026}\right)-1\right]$; $I_s = 10^{-11}$ A.

$I(-0.2V) \simeq -0.999\times 10^{-11}$ A $\approx -I_s$.

$I(-2V) = 10^{-11}\left[\exp\left(-\frac{2}{0.026}\right)-1\right]$

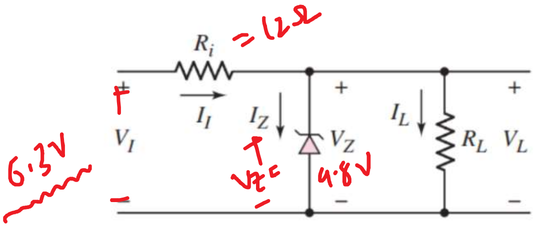
$I(-2V) \cong -10^{-11} \approx -I_s$.

[Do for $I_s = 10^{-13}$ A.]



22. The donor concentration in the n-region of a silicon pn junction is $N_d = 10^{16}$ cm^{-3}. Plot V_{bi} versus N_a over the range $10^{15} \le N_a \le 10^{18}$ cm^{-3} where N_a is the acceptor concentration in the p-region.

23. In the following voltage regulator circuit, let $V_I = 6.3$ V, $R_i = 12$ Ohm and $V_z = 4.8$ V. The Zener diode current is to be limited to the range 5 mA $\le I_z \le$ 100 mA. (a) Determine the range of possible load currents and load resistances. (b) Determine the power rating required for the Zener diode and the load resistor.



5 mA $< I_Z \le$ 100 mA

$< I_L <$

$< R_L <$

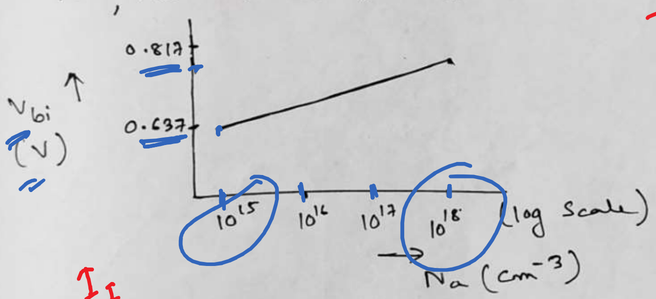
$T = 300$ K

(22) For, $N_a = 10^{15}$ cm^{-3}, $V_{bi} = 0.6374$ V.

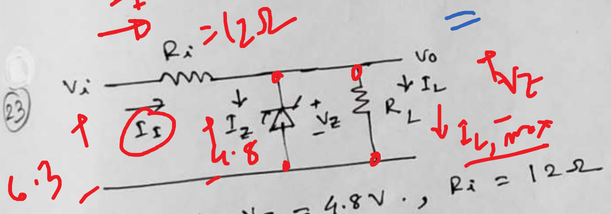
For, $N_a = 10^{18}$ cm^{-3}, $V_{bi} = 0.817$ V.

$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$

26 mV



(23)



$V_i = 6.3$ V, $V_Z = 4.8$ V., $R_i = 12\,\Omega$

$\therefore I_I = \frac{6.3-4.8}{12} = 125$ mA.

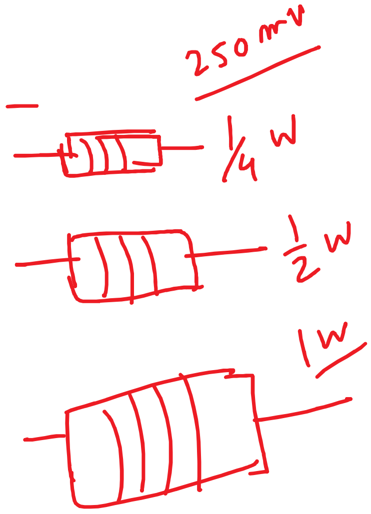
$I_L = I_I - I_Z$, 5 mA $\le I_Z \le$ 100 mA.

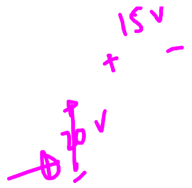
$\therefore$ 25 mA $\le I_L \le$ 120 mA (Range of I_L)

$R_L = \frac{V_Z}{I_L}$; $40\,\Omega \le R_L \le 192\,\Omega$ (Range of R_L) } (a)

Power rating, Zener $= I_{Z\,max} \cdot V_Z = 480$ mW.

Load resistor $= I_{L\,max} \cdot V_Z = 576$ mW. } (b)




15V
+
−
20V
−