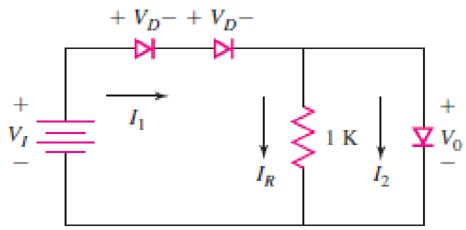
TUTORIAL QUESTIONS AND SOLUTIONS (Introduction to Electronics):

1. If reverse saturation current of the diodes shown below is 2×10^{-13}A and output is 0.6V DC, find the input voltage.



$$I_S = 2\times10^{-13}\ A$$
$$V_0 = 0.60\ \text{V}$$
$$I_2 = I_S \exp\left(\frac{V_0}{V_T}\right) = \left(2\times10^{-13}\right)\exp\left(\frac{0.60}{0.026}\right)$$
$$= 2.105\ \text{mA}$$
$$I_R = \frac{0.6}{1\ \text{K}} = 0.60\ \text{mA}$$
$$I_1 = I_2 + I_R = 2.705\ \text{mA}$$
$$V_D = V_T \ln\left(\frac{I_1}{I_S}\right) = (0.026)\ln\left(\frac{2.705\times10^{-3}}{2\times10^{-13}}\right)$$
$$= 0.6065$$
$$V_I = 2V_D + V_0 \Rightarrow \underline{V_I = 1.81\ \text{V}}$$

2. Consider a Si diode is applied with a forward bias voltage 0.6V. Determine the ratio of diode current at 100°C and 55 °C.

$$\frac{I_S(T)}{I_S(-55)} = 2^{\Delta T/5},\quad \Delta T = 155°\ \text{C}$$
$$\frac{I_S(100)}{I_S(-55)} = 2^{155/5} = 2.147\times10^9$$
$$V_T\ @100°\text{C} \Rightarrow 373°\text{K} \Rightarrow V_T = 0.03220$$
$$V_T\ @-55°\text{C} \Rightarrow 216°\text{K} \Rightarrow V_T = 0.01865$$
$$\frac{I_D(100)}{I_D(-55)} = (2.147\times10^9)\times\frac{\exp\left(\frac{0.6}{0.0322}\right)}{\exp\left(\frac{0.6}{0.01865}\right)}$$
$$= \frac{\left(2.147\times10^9\right)\left(1.237\times10^8\right)}{\left(9.374\times10^{13}\right)}$$
$$\underline{\frac{I_D(100)}{I_D(-55)} = 2.83\times10^3}$$

3. Consider a Si P-N diode with $N_a=10^{18}\text{cm}^{-3}$, $N_d=10^{15}\text{cm}^{-3}$ and C_{jo}=0.25pF. If a 2.2mH inductor is connected in parallel with the PN diode, calculate the resonant frequency f_o for reverse biased voltages of 1 V and 10 V.

$$V_{bi} = (0.026)\ln\left[\frac{\left(10^{18}\right)\left(10^{15}\right)}{\left(1.5\times10^{10}\right)^2}\right] = 0.757\ \text{V}$$

a. $\quad V_R = 1\ \text{V}$

$$C_j = (0.25)\left(1+\frac{1}{0.757}\right)^{-1/2} = 0.164\ \text{pF}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{\left(2.2\times10^{-3}\right)\left(0.164\times10^{-12}\right)}}$$

$$\underline{f_0 = 8.38 \text{ MHz}}$$

b. $V_R = 10$ V

$$C_j = (0.25)\left(1+\frac{10}{0.757}\right)^{-1/2} = 0.0663 \text{ pF}$$

$$f_0 = \frac{1}{2\pi\sqrt{\left(2.2\times10^{-3}\right)\left(0.0663\times10^{-12}\right)}}$$

$$\underline{f_0 = 13.2 \text{ MHz}}$$

4. Hole concentration is expressed as: $p(x)=10^4+10^{15}\, e^{(-x/L_p)}$, for x>=0, for a Si slab. If, D_p=15 cm^2/s and L_p=10 µm, find hole diffusion current density at x=0, 10 µm and 30 µm.

$$J_p = -eD_p\frac{dp}{dx}$$

$$= -eD_p\left(10^{15}\right)\left(\frac{-1}{L_p}\right)\exp\left(\frac{-x}{L_p}\right)$$

$$J_p = \frac{\left(1.6\times10^{-19}\right)(15)\left(10^{15}\right)}{10\times10^{-4}}\exp\left(\frac{-x}{L_p}\right)$$

$$J_p = 2.4\, e^{-x/L_p}$$

(a) $x = 0$ $\quad J_p = 2.4 \text{ A/cm}^2$

(b) $x = 10\ \mu\text{m}$ $\quad J_p = 2.4\, e^{-1} = 0.883 \text{ A/cm}^2$

(c) $x = 30\ \mu\text{m}$ $\quad J_p = 2.4\, e^{-3} = 0.119 \text{ A/cm}^2$

5. Calculate the concentrations of electrons and holes in silicon and germanium if the concentration of acceptor atoms is $10^{16}cm^{-3}$. Also, determine the type of semiconductor.

a. $N_a = 10^{16} \text{ cm}^{-3} \Rightarrow \underline{p-\text{type}}$

$$\underline{p_0 = N_a = 10^{16} \text{ cm}^{-3}}$$

$$n_0 = \frac{n_i^2}{p_0} = \frac{\left(1.5\times10^{10}\right)^2}{10^{16}} \Rightarrow \underline{n_0 = 2.25\times10^4 \text{ cm}^{-3}}$$

b. Germanium

$N_a = 10^{16} \text{ cm}^{-3} \Rightarrow \underline{p-\text{type}}$

$$\underline{p_0 = N_a = 10^{16} \text{ cm}^{-3}}$$

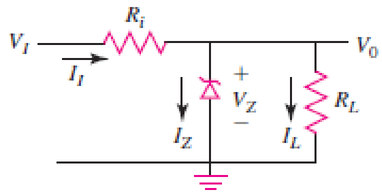
$$n_i = \left(1.66\times10^{15}\right)(300)^{3/2}\exp\left(\frac{-0.66}{2\left(86\times10^{-6}\right)(300)}\right)$$

$$= \left(1.66\times10^{15}\right)(300)^{3/2}\left(2.79\times10^{-6}\right)$$

$$= 2.4\times10^{13} \text{ cm}^{-3}$$

$$n_0 = \frac{n_i^2}{p_0} = \frac{\left(2.4\times10^{13}\right)^2}{10^{16}} \Rightarrow \underline{n_0 = 5.76\times10^{10} \text{ cm}^{-3}}$$

6. In a zener regulator circuit, consider V_i=6.3V, R_i=12 Ω, V_z=4.8V, I_{zmin}=5mA, I_{zmax}=100mA. Determine the ranges for load current and load resistance. Also find the power ratings of the regulator and the load.



a.

$$I_I = \frac{6.3-4.8}{12} \Rightarrow 125 \text{ mA}$$

$$I_L = I_I - I_Z = 125 - I_Z$$

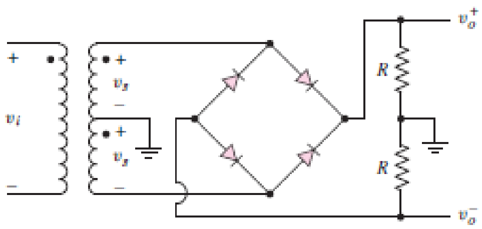
$$\underline{25 \le I_L \le 120 \text{ mA}} \Rightarrow \underline{40 \le R_L \le 192\Omega}$$

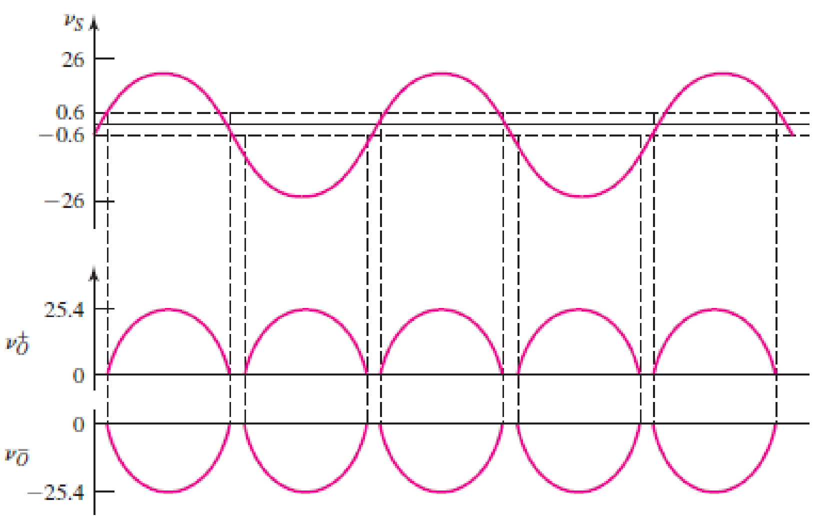
b.

$$P_Z = I_Z V_Z = (100)(4.8) \Rightarrow \underline{P_Z = 480 \text{ mW}}$$

$$P_L = I_L V_0 = (120)(4.8) \Rightarrow \underline{P_L = 576 \text{ mW}}$$

7. <SOLVED Example 2.6 from Neamen book; pg. 84 or equivalent> Line (source) and load regulation for a zener diode based voltage regulator.
8. Draw the output waveforms of the following circuit if v_s=26 sin(2∏60t) V.





9. Consider the figure below and draw the output waveforms if RC time constant is large and cut-in voltage of the diode is 0.