1.a) $\phi_j = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$, $V_T = \frac{KT}{q} = 0.0259\text{ V}$ (given on cover page)

$$= 0.0259 \cdot \ln\left(\frac{(2\times10^{18})\times(10^{19})}{(10^{10})^2}\right) \cong \boxed{1.03\text{ V}}$$

see lecture #8 → b) $I_S = qAn_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right) = qAn_i^2\left(\frac{D_n}{N_A\sqrt{D_n \tau_{np}}} + \frac{D_p}{N_D\sqrt{D_p \tau_{pn}}}\right)$

$$= qAn_i^2\left(\frac{\sqrt{D_n}}{N_A\sqrt{\tau_{np}}} + \frac{\sqrt{D_p}}{N_D\sqrt{\tau_{pn}}}\right)$$

note: $L = \sqrt{D\tau}$, $\frac{D}{\mu} = \frac{KT}{q} = V_T$

Find approx μ_n, μ_p on chart on cover page

$$= qAn_i^2\left(\frac{\sqrt{V_T \mu_n}}{N_A\sqrt{\tau_{np}}} + \frac{\sqrt{V_T \mu_p}}{N_D\sqrt{\tau_{pn}}}\right)$$

$\mu_n \approx 207$
$\mu_p \approx 70$

$$= (1.6\times10^{-19})((50\times10^{-7})\times(100\times10^{-7})((10^{10})^2)\left(\ldots\right.$$
$$\left(\frac{\sqrt{0.0259\times207}}{2\times10^{18}\sqrt{100\times10^{-9}}} + \frac{\sqrt{0.0259\times70}}{10^{19}\sqrt{20\times10^{-9}}}\right)$$

$$\boxed{= 3.69\times10^{-24}\text{ A}}$$

c) $I_D = I_S(e^{V_d/V_T} - 1) \rightarrow \ln\left(\frac{I_D}{I_S} + 1\right)V_T = V_D$

$$\ln\left(\frac{1\times10^{-9}}{3.69\times10^{-24}} + 1\right)0.0259 = \boxed{0.86\text{ V}}$$

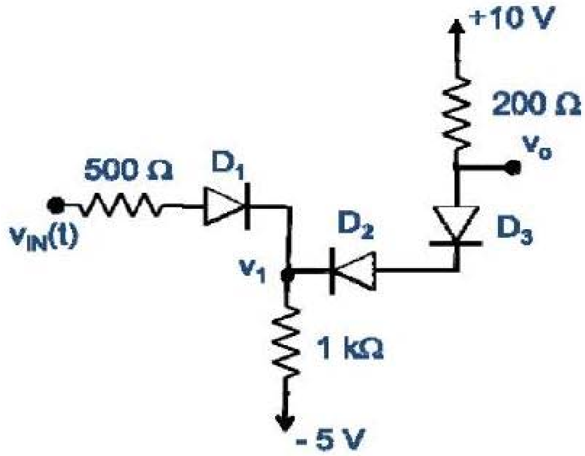
see lecture #6 → d) $C_j = \frac{dQ_D}{dV_D}$, $C_{j0} = \frac{\varepsilon_s A}{x_{d0}} = \frac{11.7\times8.854\times10^{-14}\times50\times10^{-7}\times100\times10^{-7}}{2.83\times10^{-6}} = 1.83\times10^{-17}$

$$x_{d0} = \sqrt{\frac{2\varepsilon_s\phi_j}{q}\left(\frac{1}{N_D} + \frac{1}{N_A}\right)} = \sqrt{\frac{2\times11.7\times8.854\times10^{-14}\times1.03}{1.6\times10^{-19}}\left(\frac{1}{2\times10^{18}} + \frac{1}{10^{19}}\right)}$$
$$= 2.83\times10^{-6}$$

$$C_j = C_{j0}\left(\frac{x_{d0}}{x_0}\right) = C_{j0}\sqrt{\frac{\phi_j}{\phi_j - V_D}} = (1.83\times10^{-17})\sqrt{\frac{1.03}{1.03-0.6}}$$

$$= \boxed{2.83\times10^{-17}\text{ F}}$$

2. In the circuit below, use the constant voltage model for all diodes with a turn-on voltage of 0.6 V and reverse breakdown voltage of -5 V (V_Z = 5 V). (30)



a) What is the minimum value of V_{IN} at which D1 turns on? What is the associated V_O?

When D_1 first turns on, $V_{D1} = V_{on}$ = 0.6 V and I_{D1} = 0. Using KCL at V_1 assuming D_2 and D_3 are ON:

$$\frac{10\,V - 2 * 0.6\,V - V_1}{200\,\Omega} = \frac{V_1 - (-5\,V)}{1000\,\Omega}$$

Solving, V_1 = 6.5 V, so $V_{IN} = V_1$ + 0.6 V = 7.1 V and $V_O = V_1$ + 2 * 0.6 V = 7.7 V.

Checking, V_O is less than +10V, so current through D_2 and D_3 is positive, confirming that they are ON.

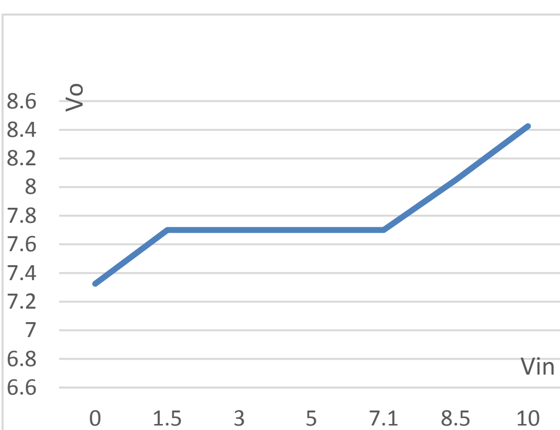
b) If V_{IN} = 10 V, what is the value of V_O? Specify what mode each of the diodes is in and check any assumptions made.

Assume that D_1, D_2 and D_3 are all on. KCL at V_1 gives:

$$\frac{10\,V - 0.6\,V - V_1}{500\,\Omega} + \frac{10\,V - 2 * 0.6\,V - V_1}{200\,\Omega} = \frac{V_1 - (-5\,V)}{1000\,\Omega}$$

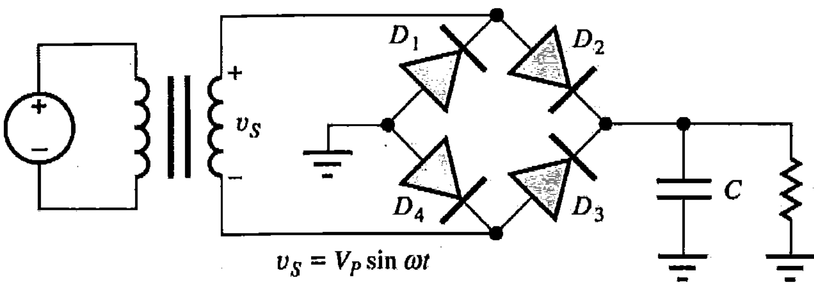
Solving, V_1 = 7.225 V, so $V_O = V_1$ + 2 * 0.6 V = 8.425 V. Checking, V_O is less than +10V, so current through D_2 and D_3 is positive, confirming that they are ON. V_1 + 0.6 V is less than V_{IN}, D_1 is also ON.

c) Sketch plot of the output voltage V_O versus input voltage for 0 V < V_{IN} < 10 V. Specify voltages at inflection points.



For a given mode for all the diodes, the circuit is linear. For V_{IN} < 7.1 V, D_1 turns off, so V_O stay the same (7.7 V). D_1 remains off as V_{IN} is reduced until it breaks down when V_{D1} = -5V, which occurs for $V_{IN} = V_1 - 5$ V = 1.5 V. For V_{IN} = 0 V, can solve KCL at V_1 again using same equation as (b), getting V_1 = 6.125 V and V_O = 7.325 V.

3. For the power supply circuit shown below, the peak value of v_S is 14 V, the operating frequency is 50 Hz, and the on-voltages of the diodes are 0.60 V. State your assumptions clearly and check them if possible. (35)



Solution :

(a) What is the dc output voltage across R if the ripple voltage is small?(8)

$$V_{dc} = V_P - 2V_{on} = 12.8\ V$$

(b) What is the required minimum reverse breakdown voltage for the diodes?(5)

$$PIV = V_P = 14\ V$$

(c) If $R = 2\ k\Omega$, what is the minimum value of capacitance C to ensure that the output voltage remains above 12 V?(12)

$$V_r = 12.8 - 12 = 0.8\ V$$

$$C_{min} = \frac{V_P - 2V_{on}}{V_r}\frac{T}{2R} = \frac{V_P - 2V_{on}}{fV_r}\frac{1}{2R} = 80\ \mu F$$

(d) What fraction of a period is each diode conducting?(10)

$$\Delta T = \frac{1}{\omega}\sqrt{\frac{2V_r}{V_p}} = \frac{0.338}{100\pi} = 1.07\ ms$$

$$T = \frac{1}{50} = 20\ ms$$

$$Fraction\ of\ conducting\ period = \frac{\Delta T}{T} = 0.053$$