1. a) For the circuit shown draw the small-signal equivalent circuit. (10 points)

![Circuit Diagram]

b) Derive the expression for the small-signal input resistance $R_i$ from (a). (10 points)

\[
v_{be} = v_t
\]

\[
u = g_m v_{be} + \frac{v_{be}}{r_e} = \left( g_m r_e + \frac{1}{r_k} \right) v_{be} = \frac{\beta + 1}{r_k} v_{be} = \frac{\beta + 1}{r_k} v_t
\]

\[
R_i = \frac{v_t}{i_t} = \frac{r_e}{\beta + 1} = r_e \approx \frac{1}{g_m}
\]

c) For the amplifier circuit calculate the small-signal voltage gain $A_v = v_o/v_i$. Assume $g_m = 30mA/V$ and $r_e = 10k\Omega$ at the dc operating point. (20 points)

![Amplifier Circuit Diagram]

\[
\frac{v_o}{v_i} = -g_m R_e = -30 \times 4 = -120
\]

\[
\frac{v_o}{v_i} = \frac{10k\Omega || R_i}{10k\Omega || R_i + 10k\Omega} = \frac{5k\Omega}{5k\Omega + 10k\Omega} = \frac{1}{3}
\]

\[
\frac{v_o}{v_i} = \frac{1}{3} (-120) = -40
\]
2. In the circuit shown below calculate the voltages \( V_A, V_B, V_C, \) and \( V_D \). Assume all transistors are identical, \( \beta = \infty \), and \( |V_{BE(on)}| = 0.7 \text{V} \). (30 points).

\[
\begin{align*}
V_A &= -1 \text{V} \\
V_B &= 6 \text{V} \\
V_C &= 3 \text{V} \\
V_D &= -5 \text{V}
\end{align*}
\]

\[
I_1 = \frac{10.7 - 0.7}{6} \text{mA} = 2 \text{mA}
\]

\[
I_2 = 2 + 2 = 4 \text{mA}
\]

\[
I_3 = 4 \text{mA}
\]

\[
V_A = 5 + 2 \times 2 = -1 \text{V}
\]

\[
V_B = 10 - 4 \times 1 = 6 \text{V}
\]

\[
V_C = V_D + 2 \times 4 = -5 + 8 = 3 \text{V}
\]

\[
V_D = -5 \text{V}
\]
Answer the following questions on MOSFETs. (35 points).

a) Write a C (cutoff), L (linear), or S (saturation) next to each transistor indicating the region of operation. Assume $V_{TN} = |V_{TP}| = 0.7V$.

b) For the circuit shown calculate $V_S$ and $V_{SD}$.

\[
V_D = -5 + 5 \times 0.4 = -3V \Rightarrow \text{transistor in sat since } V_G = 0
\]

\[
V_{SG} = |V_T| + \frac{2I_D}{k'W/L} = 1 + \frac{2 \times 0.4 \times 10^{-3}}{200} = 1 + 2 = 3V
\]

$V_G = 0 \Rightarrow V_S = 3V \Rightarrow V_{SD} = 6V$

\[
V_T = -1V, \quad k' \frac{W}{L} = 200 \mu A/V^2
\]

\[
\lambda = 0
\]

\[
V_T = -1.5V, \quad k' = 25 \mu A/V^2
\]

\[
L = 1 \mu m, \quad \lambda = 0
\]

c) For the circuit shown determine the values of W and R such that $I_D = 100 \mu A$ and $V_{SD} = 2.5V$.

Transistor in sat

\[
V_{SG} = V_{SD} = 2.5V \Rightarrow V_D = 9 - 2.5 = 6.5V
\]

\[
R = \frac{V_D}{I_D} = \frac{6.5V}{0.1mA} = 65k\Omega
\]

\[
\frac{W}{L} = \frac{2I_D}{k'(V_{SG} - 1V_T)^2} = \frac{2 \times 100}{25 (2.5 - 1.5)^2} = 8
\]

\[
L = 1 \mu m \Rightarrow W = 8 \mu m
\]