1. For the differential amplifier shown below, find

(a) the voltage gain \( A_v = \frac{v_{out}}{v_{in}} \) when the base of \( Q_2 \) is grounded. (15 points)

(b) the quiescent point collector-to-emitter voltages for \( Q_1 \) and \( Q_2 \). (15 points)
   (HINT: this should be calculated with both bases grounded)

(c) the input resistance. (15 points)

\[ \begin{align*}
(a) & \quad A_v = \frac{1}{2} g_m R_C \quad g_m = \frac{I_C}{V_T} = \frac{1mA}{25mV} = \frac{1}{25} \quad 25 \\
& \quad A_v = \frac{1}{2} \left( \frac{1}{25} \right) (5000) = 100 \\
(b) & \quad v_E = -0.7V \\
& \quad v_C = 10V - 1mA (5k) = 5V \\
& \quad v_{CE} = 5.7V \\
& \quad V_{CE} = 5.7V \\
(c) & \quad R_{in} = 2 \beta R_n = 2 \cdot 100 \cdot 2 \cdot (100) \cdot \frac{1}{2500} = 5k \Omega
\end{align*} \]
2. The circuit shown below will implement the constant current source for the diagram shown in problem 1. Find \( R \) such that \( I_0 = 2\, \text{mA} \). Assume all transistors have equal areas and very large \( \beta \). (15 points)

\[
I_{\text{ref}} = \frac{10\, \text{V} - 1.4\, \text{V}}{R} = \frac{8.6\, \text{V}}{R} = 2\, \text{mA}
\]

\[
R = \frac{8.6\, \text{V}}{2\, \text{mA}} = 4.3\, \text{k}\Omega
\]
3. The circuit shown in problem 1 uses the current mirror shown in problem 2 to implement the constant current source. Find the gain $A_{CM} = \frac{V_{out}}{V_{CM}}$, obtained when a common voltage $V_{CM}$ is applied to both $v_{A}$ and $v_{B}$, if all transistors exhibit an early voltage of 100V. (10 points)

$$A_{CM} = \frac{1}{2} \frac{R_c}{R_{TAIL}}$$

$$R_{TAIL} = R_{0AC} = \frac{V_A}{I_C} = \frac{100V}{2mA} = 50 \, \text{k}\Omega$$

$$A_{CM} = \frac{1}{2} \frac{5k}{50} = 0.05$$
4. The circuit shown below will be connected to the output of the differential stage shown in problem 1. Find

(a) $R_4$ and $R_5$ such that transistor $Q_3$ is biased at approximately 5mA and the quiescent output voltage (when both inputs are grounded) is zero. (10 points)
(b) the overall gain of the amplifier. (10 points)
(c) the approximate output resistance of the amplifier. (10 points)

\[ V_{B3} = V_{C3} = 5V \]
\[ V_{E3} = 5.7V \]
\[ V_{Eq} = 0V \Rightarrow V_{BG} = V_{E3} + 0.7V \Rightarrow V_{BS} = 10.7V \]
\[ R_5 = \frac{10.7}{5mA} = 2.14k\Omega \]
\[ A_{V3} = \frac{2.14k\Omega}{800\Omega} = -2.5 \]
\[ \text{Stage 2 loading on stage 1} = \frac{101(860)}{5k + 101(860)} = 0.95 \]
\[ A_{V4} = 1 \Rightarrow A_{V_{total}} = 100(-2.5)(1) = -238 \]
\[ R_{out} = \frac{5k}{1 + \frac{R_4 + R_5}{5mA}} \]
\[ I_{out} = \frac{10V}{5k} = 2mA \Rightarrow R_m = \frac{100(2.5mV)}{2mA} = 1.25k \]
\[ R_{out} = \frac{5k}{101} \frac{1.25k + 2.14k}{34} = 34.5\Omega \]