Q.1:

Q_2 has $I_{S2} = 4 \times I_{S1}$

$\because$ $I_E, I_C \propto I_S$

$I_{C2} = I_0$ is $4 \times I_{C1}$

So $I_{C1} = 2mA/4 = 0.5$ mA

Similarly, $I_{B2} = 4 I_{B1}$

and so on...

Now: $I_{REF} = I_{C1} + I_{B1} + I_{B2}$

$$I_{REF} = \frac{I_0}{4} + \frac{I_0}{\beta \times 4} + \frac{I_0}{\beta}$$

$\because$ $I_0 = 2mA$, $\beta = 100$

$$I_{REF} = I_0 \left(\frac{1}{4} + \frac{1}{400} + \frac{1}{100} \right)$$

$= 0.525$ mA.

To determine R, we need to know V_B at the base of Q_2 (and Q_1 too).

Assuming $I_{C_2} \approx I_{E2}$

$$= I_{S2} \exp(v_{BE}/V_T)$$

$$v_{BE} = v_B = V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right)$$

$$= .025 \times 2.303 \times \log\left(\frac{2 \times 10^{-3}}{10^{-14}}\right)$$

$$= 0.0576 \times 11.301$$

$$= 0.65 \text{ V}$$

Hence, $R = \frac{5 - .65}{IREF}$

$$= \frac{4.35}{.525} \text{ k}\Omega = 8.28 \text{ k}\Omega$$

Ans: 8.28 kΩ

X

Q. 2: We need to find

$\exp(-v_D/v_T)$

i) $v_D = 30\,mV$

$$\exp\left(-\frac{30}{25}\right) = 0.3012$$

$$\exp\left(\frac{30}{25}\right) = \exp\left(\frac{v_D}{v_T}\right) = 3.32$$

Then, $$\frac{e^{-v_D/v_T}}{1+e^{-v_D/v_T}} = \frac{.3012}{1.3012}$$

$$= 0.2315$$

and $$\longrightarrow \frac{e^{v_D/v_T}}{1+e^{v_D/v_T}}$$

$$= \frac{3.32}{4.32} = 0.768$$

So $$v_{o1} - v_{o2} = 2\times10^{3} \times 2\times10^{-3}$$

$$\times\,(0.2315 - 0.768)$$

$$= -4 \times 0.5370$$

$$= -2.148\ V$$

Voltage gain for $v_D = 30\,mV$ is then $-\dfrac{2.148}{.03} = -71.6$ V/V

(ii) Now $v_D = 2\,mV$

$\exp(-v_D/V_T) = \exp(-\frac{2}{25})$

$= 0.923$

$\exp(v_D/V_T) = 1.083$

Then $\dfrac{e^{-v_D/V_T}}{1+e^{-v_D/V_T}} - \dfrac{e^{v_D/V_T}}{1+e^{v_D/V_T}}$

$= \dfrac{0.923}{1.923} - \dfrac{1.083}{2.083}$

$= -0.0399$

$v_{o1} - v_{o2} = 2\times10^{3} \times 2\times10^{-3} \times (-.0399)$

$= -0.1598$

So, voltage gain $= -\dfrac{.1598}{.002}$

$= -79.89$ v/v

Theoretical small signal gain $= g_m R_c$

Here, $g_m = \frac{1\,mA}{25\,mv} = 0.04$

So $|gain| = 2\times10^3 \times .04$

$= 80$

Comparison:

i) $|Gain| = 71.6 < 80$

ii) $|Gain| = 79.89 \simeq 80$

The gain when vd is << than 25 mv (i.e. VT) is very close to the theoretical small signal gain value.

Q3. The voltage gain is same as the gain of one-half of the circuit, i.e., $-g_{m1} r_{o1} \| r_{o3}$

I_C for each half $\cong 1$ mA

In the given case

$$g_m = \frac{1\,mA}{25\,mV} = 0.04\ \mho$$

$$r_{o1} = \frac{V_A\ (NPN)}{1\,mA} = \frac{25\,V}{1\,mA} = 25\,k\Omega$$

$$r_{o3} = \frac{V_A\ (PNP)}{1\,mA} = \frac{50}{1} = 50\,k\Omega$$

So gain $= -.04 \times 25\,k\Omega \,||\, 50\,k\Omega$

$$= -.04 \times 16.67\,k\Omega$$

$$= -666.8\ V/V$$