1. Give a short answer to each question. No explanation or justification is required.

a. If we could operate circuits at 300 Centigrade (not Kelvin), what’s a rough estimate of the thermal voltage at that temperature?

\[ 26 \text{ mV} \times 2 = 52 \text{ mV} \]

b. How would \( n_i \) for silicon change at that temperature: about the same, a little more/less, a lot more/less?

\[ \text{a lot more} \]

c. If you measure the reverse leakage current of a diode (\(-I_s\)) at room temperature to be 1nA, and then increase the temperature to 85C, will the leakage current increase or decrease, and by roughly what factor chosen from this list: \{a lot less than 2, roughly 2, roughly 10, a lot more than 10\}

\[ \text{increase, a lot more than 10} \]

d. At a particular temperature, you calculate the intrinsic carrier concentration for silicon to be \( 10^{14}/\text{cc} \). At that temperature, in a sample doped with \( 10^{14} \) boron atoms/cc, what are the majority and minority carrier concentrations?

\[ m_{\text{majority}} = 10^{14} \]  
\[ m_{\text{minority}} = n_i^2 / \rho = \frac{10^{14}}{10^{14}} = 1 \text{ } \text{cc} \]

e. At room temperature, you apply 0.7V to a diode and measure a current of 1mA. What voltage is necessary to get a current of 2.7mA? 10mA?

\[ 0.726 \text{ V} \]

f. You have a reverse bias of 5V across a diode, and measure a capacitance of 10fF. What reverse bias should you apply to get 5fF? (accurate to 10%)

\[ \frac{1}{V_{R} + V_{0}} \approx \frac{1}{V_{R}} \quad \text{for } V_{R} \gg V_{0} \quad V_{R} = 4 \times 5 \text{V} = 20 \text{V} \]

g. You have a reverse bias across a diode of \( V_{0} \), the built-in potential of that particular diode, and measure a capacitance of 2pF. What reverse bias should you apply to get a capacitance of 1pF? (accurate to 10%)

\[ \frac{1}{V_{R} + V_{0}} = \frac{1}{V_{R}} \quad V_{R} = 7 \text{ } V_{0} \]

h. The current in the channel of an NMOS transistor is due to (pick one) {drift, diffusion} of (pick one) {valence band holes, conduction band electrons}
2. You have invented a new type of transistor with terminals A, B, and C. In the "active" region, defined by $V_{AC} > 0$, $V_{BC} > 1$, you have determined the formulas for the currents into nodes A and B are:

$$I_A = I_0 \alpha V_{AC}$$

$$I_B = I_0 (\beta V_{AC})^3 (\delta V_{BC})^{1/2}$$

Where $I_0$, $\alpha$, $\beta$, and $\delta$ are process-related parameters.

Draw the DC small-signal model of your transistor. Clearly label the node voltages and currents!

Write down algebraic expressions for the values of the circuit elements of your small signal model. If you want to make a voltage amplifier, which terminal would you make the input, and which would you make the output? Why?

![Image of small signal model]

**Expressions for the values of the circuit elements of your model**

$$g_m = \alpha I_0$$

$$r_{in} = \frac{1}{g_m} = \frac{1}{\alpha I_0}$$

$$g_r = \beta I_0 (\beta V_{AC})^2 (\delta V_{BC})^{1/2} = \frac{3 I_B}{V_{AC}}$$

$$g_o = \delta I_0 (\beta V_{AC})^3 (\delta V_{BC})^{1/2} = \frac{I_B}{V_{AC}}$$

$$r_o = \frac{1}{r_o} = \frac{2 V_{BC}}{I_B}$$

$$f_o = \frac{2 (\delta V_{BC})^{1/2}}{5 I_0 (\beta V_{AC})^3} = \frac{2 (\delta V_{BC})^{1/2}}{5 I_0 (\beta V_{AC})^3}$$

**Input and output node, and why:**

Input is A, because it has a big impact on $I_B$

Output is B, because it has a weak impact on $I_B$
3. In the current mirror below, assume that $\mu_n C_{ox} = 200 \mu A/V^2$, $\lambda = 0.1/V$, and $V_{TN} = 1V$. All transistors have $W/L = 100 \mu m$. Calculate the gate bias voltage $V_{GS1}$ resulting from the input current. Calculate the currents flowing in the drains of the other transistors. All calculations should be accurate to a few percent.

\[ V_{GS1} = 2V \]

\[ I_{D2} = 12mA \]

\[ I_{D3} = 15mA \]

\[ I_{D4} = 0.95mA \]

\[ \frac{\mu_n C_{ox} \cdot W}{L} \cdot \frac{1}{V^2} = 10 \mu A \cdot 100 \cdot \frac{10mA}{V^2} \]

\[ 12mA = I_0 = \frac{10mA}{V^2} (V_{GS} - V_t)^2 (1 + \lambda V_{DS}) \]

\[ V_{GS} = 2 \quad 1.2 \]

\[ I_{D4} = \frac{\mu_n C_{ox} \cdot W}{L} (2 - 1 - \frac{1}{2} 0.1) 0.1 \]

\[ = 20mA \cdot (0.95)(0.1) \]

\[ = 0.98mA \]
4. For the circuit below, find the input $V^*_B$ necessary to make $V^*_C=1V$ and find the operating point currents $I^*_B$ and $I^*_C$. Draw the small signal model for the circuit, and calculate the DC gain. Assume $I_s=10^{-15}A$, $\beta=100$, and $V_A=100V$. Answers should be accurate to 10%.

\[
\begin{array}{|c|c|}
\hline
V^*_B & 780mV \\
\hline
V^*_C & 1V \\
\hline
I^*_C & 10mA \\
\hline
g_m & 0.45 \quad 0.4 \\
r_o & 10K \Omega \\
r_o & 260\Omega \\
I^*_B & 0.1mA \\
-360 & (3) \\
\end{array}
\]

Small signal model for the whole circuit. Label voltages and components.

\[
\begin{align*}
A_v &= -g_m r_o \cdot \beta \\
&= (0.4)(0.7K) = 360
\end{align*}
\]