1a) Find \( I_o \) given \( V_{as} = 0.9 \text{V}, V_{ce} = 1 \text{V} \)
\[
I_o = \frac{V}{L_0(1 - kV_B) \left( \frac{4.95 \times 10^{-9} \text{cm}^2}{\text{V} \cdot \text{cm}} \right) e^{V_{as}/V_{th}}}
\]
\[= \left( \frac{0.9}{0.026} \right) \left( \frac{-150 \text{ma}}{1.5 \text{mA}(1 - 0.1(1))} \right) \left( 4.95 \times 10^{-9} \text{cm}^2/\text{V} \cdot \text{cm} \right) e^{0.9/0.026} \]
\[I_o = 41.7 \text{nA} \]

b) Transconductance
\[
g_m = \frac{2I_o}{V_{as}} = \frac{41.7 \text{nA}}{0.026 \text{V}} = 1.6 \text{mS} \]

This is just \( I_o \)

c) Output Resistance
\[
r_o = \left( \frac{\partial I_o}{\partial V_{as}} \right)^{-1} = \frac{1}{g_m} \left[ \frac{1}{V_{th}} \left( \frac{L_0}{V_{th}} \right) \left( \frac{4.95 \times 10^{-9} \text{cm}^2}{\text{V} \cdot \text{cm}} \right) e^{V_{as}/V_{th}} \right] \]
\[= \frac{1}{1 - kV_B} \left( \frac{L_0}{V_{th}} \right) \left( \frac{4.95 \times 10^{-9} \text{cm}^2}{\text{V} \cdot \text{cm}} \right) e^{V_{as}/V_{th}} \]
\[= \frac{2.3 \text{G} \Omega}{0.0191 \text{mA}} = 122 \text{G} \Omega \]

\( r_o \)

d) \( g_m r_o \) product:
\[
g_m = \frac{I_o}{V_{as}} \quad \text{(from part b)}
\]
\[
r_o = \frac{1 - kV_B}{I_o} \quad \text{(from part c)}
\]
\[
g_m r_o = \left( \frac{I_o}{V_{as}} \right) \left( \frac{1 - kV_B}{I_o} \right) = \frac{1 - kV_B}{V_{as}} \quad \text{NOTE THAT THIS PRODUCT IS}
\]
\[
\text{independent of } I_o, \quad \text{stays constant so long as } V_{as} \text{ does} \]

\( \frac{1}{V_{as}} \)

\( 5a \) \( C_u \): the depletion capacitance of the base-collector junction
- It is just a reverse-biased pn junction.
- \( C_u = \frac{2K_{ex}}{x_0} \)
- \( A_u \): area of base-collector junction interface
- \( x_0 \): depletion width of base-collector junction.
- From the cross-section: \( x_w = 0.5 \mu \text{m} \)
- From the layout: \( A_u = (1.5 \mu \text{m} + 0.25 \mu \text{m}) (2 \mu \text{m}) = 3.5 \times 10^{-8} \text{cm}^2 \)
- \( C_u = \frac{(11.7 \times 8.85 \times 10^{-12} \text{F/cm}^2)(3.5 \times 10^{-8} \text{cm}^2)}{0.4 \times 10^{-4} \text{cm}} = 0.604 \text{F} \)

b) By the law of the junction:
\[n_p(x=0) = n_{p0} e^{-V_{be}/V_{th}}, \quad n_{p0} = \text{Concentration of electrons in } p\text{-type base}
\]
\[n_{p0} = \frac{N_{p0}^2}{N_{B0}} \quad \text{(equilibrium concentration of}
\]
\[\text{electrons in } p\text{-type base})
\]
\[n_p(x=0.5) = 0 \quad \text{(since this is at the edge of the reverse-biased base-collector junction)}
\]

And in between, the minority electron concentration falls linearly:
\[n_{p0}(x=0) = 10^9 \quad 10^8 \text{cm}^{-3}
\]
\[n_{p0}(x=0.5) = 10^8 \text{cm}^{-3}
\]

\[n_{p0} = 7.2 \times 10^{10} \text{cm}^{-3}
\]

\[\text{NOTE: This graph shows only the *excess* minority carrier concentration in the base. Therefore, the concentration goes to zero at the base-collector junction.}
\]

A more complete treatment of the minority carrier concentration would have both of these numbers offset by \( n_{ex0} \), but in both cases, the slope of the concentration plot is the same, so for our purposes (calculating the current), it doesn't matter.
3. a) To get \( V_{on} = 0V \) (large signal):
   \[ I_{bs} = \frac{SV - V_{on}}{R_0} = \frac{SV}{10k\Omega} \times 500\mu A \; \text{with} \; I_{bs} = -500\mu A \]

b) To remain in saturation:
   \[ V_{os} \geq V_{os-7\mu A} \; \text{and} \; V_{os} = V_{on} - V_{os} \; \text{but we also know} \; V_{s} = V_{gs} - V_{os} \]
   \[ \text{so} \; V_{os} = V_{on} - (V_{gs} - V_{os}) = V_{on} + V_{os} \quad \text{(since} \; V_{gs} \text{is} \; 0) \]
   \[ = D \; (V_{on} + V_{os}) \geq V_{os-7\mu A} = D \; V_{os} \geq -V_{os} \]
   \[ \text{or} \quad V_{on, min} = -1V \]

c) To find \( R_m \):
   first, we recognize that this is just a common-gate amplifier;
   \[ R_m = \frac{1}{\lambda} \]
   \[ j_{in} = 2 \mu A \times \frac{120\mu A}{100\mu A} = 1200 \mu A \]
   \[ j_{in} = \frac{1}{1200 \mu A} = 1.12 \; mS \]
   \[ R_m = 1.12 \; mS = 0.00112 \; k\Omega \]

d) To find transresistance: start w/ the CG small-signal model:
   \[ \frac{\partial V_s}{\partial I_{in}} = \frac{1}{R_m} \]
   \[ \text{By Thévenin/Norton equivalence:} \; -A_{in}(R_{out}) = R_{min} \]
   \[ R_{out} = -A_{in}R_{min} \]
   \[ \text{But since this is a CG amp, we know} \; A_{in} = 1 \]
   \[ \Rightarrow R_{out} = R_{min} \]

So for a CG amp:
   \[ R_{out} = R_{up} // R_{down} = R_0 // R_0(11\mu A R_s) \]
   \[ R_0 = \frac{1}{\lambda} = \frac{1}{1200 \mu A} = 900 \; k\Omega \]
   \[ R_{out} = 10 \; k\Omega // 900 \; k\Omega = 10k\Omega = R_m \]