Problem 1:

a) Emitter-base junction, because it is the more heavily doped junction and for two diodes biased at the same voltage, the peak electric field is higher in more heavily doped diode. Consequently, the more heavily doped diode will reach the breakdown field at a lower reverse bias level.

b) Emitter-base junction, because the zero-bias depletion region is narrower, and thus the depletion capacitance is higher, in the more heavily doped junction.

c) (i) Emitter-base junction because the depletion region at that junction extends primarily into the base (the more lightly doped side of that junction), and thus a reverse bias on that junction has a bigger impact on the effective width of the base, than does a reverse bias on the collector-base junction.

   ii) Smaller $|V_A|$, because increased base width modulation is evidenced in the output characteristics as increased slope and decreased Early voltage.

d) Collector-base junction, because the reverse saturation current varies inversely with the doping of the more lightly doped side of the junction, and the collector is the more lightly doped region in this transistor. The fact that the collector is much wider counteracts the impact of its lighter doping, but one would still anticipate that the relative doping level is the dominant factor.

e) No difference, because the transconductance only depends on the bias level of the junction, not the structure of the diode.

f) Proper connection, because the connection with the higher beta (i.e., the proper connection) has the smaller $g_e$ ($=g_m/B$), and therefore the larger $r_e$.

g) Reversed connection, because a large output conductance means a small output resistance, which is the result of large base width modulation (and a correspondingly low Early voltage).

h) Reverse connection, because when the base-collector junction is forward bias there is significant minority carrier injection into the collector and much more QNR charge storage than there is in a properly operated BJT.

Problem 2:

a) i) At the threshold to inversion the charge on the gate is equal in magnitude and opposite in sign to the charge in the depletion region in the silicon under the
gate then the potential charge across the depletion region is \(|2\phi_p|\), and this is
\(qN_A X_{Dr} \sqrt{2e_0 qN_A |2\phi_p|} \). \(\phi_p = -0.66 \log(10^3) = -0.42\) V and thus:
\[
Q_c^* = (2 \times 10^{-12} \times 1.6 \times 10^{-19} \times 10^{17} \times 0.84)^{1/2} = 1.64 \times 10^7 \text{coul/cm}^2
\]

ii) The time, \(t\), required to charge the gate to this level with a current source, \(I = 10\) 
\(\mu\)A, is:
\[
t = W L Q_c^*/I = 10^4 \times 0.5 \times 10^4 \times 1.64 \times 10^{-7}/10^{-5} = 8 \times 10^{-10} \text{s}
\]

iii) Any charge added under the gate oxide must be matched by charge added to the 
gate electrode, so the difference between the new total, \(Q_{tor}^*\), and the previous 
total, \(Q_c^*\), must be the added amount, \(10^7\) Coul/cm²:
\[
Q_{tor}^* - Q_c^* = 10^7 \text{Coul/cm}^2
\]

iv) Above threshold all of the additional charge appears across the gate dielectric and 
the \((v_{gs} - V_d) = (Q_{tor}^* - Q_c^*)/C_{ox}\):
\[
(v_{gs} - V_d) = (Q_{tor}^* - Q_c^*) \frac{t_{ox}}{\varepsilon_{ox}} = 10^7 \times 5 \times 10^{-7}/3.5 \times 10^{-10} = 0.14 \text{ V}
\]

b) i) The structure is biased so the semiconductor is at flat band, meaning there is no 
net charge under the gate in it, and thus the charge balancing \(Q_c^*\) must be on the 
upper gate, \(G_2\):

\[
Q_c^* \begin{array}{c}
\delta(x+t_{ox}) \\
-2t_{ox}
\end{array}
\]

\[
\rho(x)
\]

\[
- Q_c^* \begin{array}{c}
\delta(x+2t_{ox}) \\
-2t_{ox}
\end{array}
\]

ii) The profile is shown below. The details of the profile at the back surface are not 
important to us, but the final value of 0.5 V in the metal, of course, is.

\[
\phi(x)
\]

\[
-1.15 \text{ V} -2t_{ox} -t_{on}
\]

\[
-0.42 \text{ V} -0.65 \text{ V} Q_c^* t_{ox}/t_{ox} = 0.23 \text{ V}
\]

\[
0.5 \text{ V}
\]

\[
-2t_{ox} -t_{on}
\]

\[
\text{Back surface}
\]
iii) From the drawing we can see that:
\[ V_{eb} = (\phi_m - \phi_p) - Q_{C1} \cdot t_m / t_m = [0.5 \cdot (0.42)] - 0.23 = -1.15 \text{ V} \]

(iii) Negative, because putting negative charge on \( C_1 \) means that positive charge must be put on \( C_2 \) to counterbalance it, before the voltage on \( C_2 \) can deplete the surface and invert it. This indicates that the threshold voltage will be increased.

Problem 3:

a) \[ i_d(v_{eb}, v_{cb}) = -I_0 \alpha \exp(-qV_{eb}/kT) \cdot \frac{1}{1 - [1 - (1 - \lambda v_{eb})/\beta_{fe}]} \]

b) i) \[ g_m = \frac{dI_e}{dv_{eb}} |_{v_{eb}} = (q/kT) I_e \exp(-qV_{eb}/kT) \approx q I_e / kT \]
   
ii) \[ g_e = \frac{dI_e}{dv_{cb}} |_{v_{cb}} = 0 \]

iii) \[ g_m = \frac{dI_e}{dv_{cb}} |_{v_{cb}} = \alpha \frac{dI_e}{dv_{eb}} \approx \alpha (q/kT) I_e \exp(-qV_{eb}/kT) \approx q I_e / kT \]

iv) \[ g_e = \frac{dI_e}{dv_{cb}} |_{v_{cb}} = \alpha \beta \frac{dI_e}{dv_{eb}} \approx \alpha \beta \frac{dI_e}{dv_{eb}} \approx \alpha \beta \left( \frac{dI_e}{dv_{eb}} \right) \approx \frac{dI_e}{dv_{eb}} \]

The plots only need to be approximate, but for the record, the equations are:

- Connection I: \( i_p = 0 \) for \( v_{ab} < 1 \text{ V} \)
  \[ i_p = \frac{K}{[2]} \left[ V_{ab} \cdot \frac{1}{2} \right] \left[ 1 + v_{ab}/V_A \right] = 0.05\left[ V_{ab} - 1 \right] \left[ 1 + v_{ab}/5 \right] \]
  for \( v_{ab} > 1 \text{ V} \)

- Connection II: \( i_p = 0.1 \left[ 2 - 1 - v_{ab}/2 \right] v_{ab} \) for \( v_{ab} < 1 \text{ V} \)
  \[ i_p = \frac{K}{[2]} \left[ 2 - v_{ab}/5 \right] \left[ 1 + v_{ab}/V_A \right] - 0.05 \left[ 1 \right] \left[ 1 + v_{ab}/5 \right] \]
  for \( v_{ab} > 1 \text{ V} \)

In both cases the linear equivalent circuit is a conductance, as it is with any two-terminal device. The difference is in the value of the conductance:

i) Connection I: \( g_d = g_n + g_m = K \left[ V_{ab} - V_T \right] \left[ 1 + v_{ab}/V_A \right] + \left[ K/2 \right] \left[ V_{ab} - 1 \right] \left[ V_A / V_A \right] \)
   \[ \approx \left[ 2K_{1n} \right] \frac{1}{\left[ \beta_{fe} \right]} + I_0 / V_A \text{ (very approx. given small } V_A \text{ but accepted)} \]

ii) Connection II: \( g_d = g_n = \left[ K/2 \right] \left[ 2 - V_T \right] \left[ 1 + v_{ab}/V_A \right] \)
   \[ \approx I_0 / V_A \text{ (again very approx. given small } V_A \text{ but accepted)} \]