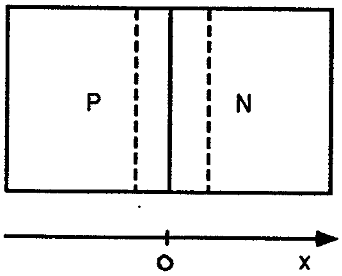
Course: Semiconductor Device Fundamentals
Level: Undergraduate
Module: B
Test: B10
Type: Closed Book, Closed Notes
Note: Available Info/Equation Sheets

Problem Weighting is noted at the beginning of each problem statement.

An abrupt silicon pn junction is under **equilibrium** conditions. Use the information given below to answer questions 1 and 2.



$n_i = 10^{10}$ cm^{-3}
$E_G = 1.12$ eV
kT = 0.026 eV
$K_S = 11.8$
p-side:
  $N_A = 10^{16}$ cm^{-3}
  $\mu_n = 1248$ cm^2/V-sec
  $\mu_p = 437$ cm^2/V-sec
n-side:
  $N_D = 10^{16}$ cm^{-3}
  $\mu_n = 1248$ cm^2/V-sec
  $\mu_p = 437$ cm^2/V-sec

1. (5 points) What is the built-in voltage?

2. (15 points) What is the value of the hole <u>diffusion</u> current density at the metallurgical junction. Make sure you include the sign of the current. (Hint: Calulate the electric field at the metallurgical junction and recall that $E_F = E_i$ at the metallurgical junction)

3. (5 points) The depletion width of a semiconductor pn junction is twice its equilibrium value at an as yet unknown applied voltage. If V_{bi}= 1.0 volts, what is the applied voltage?

   a) 2 volts

   b) -2 volts

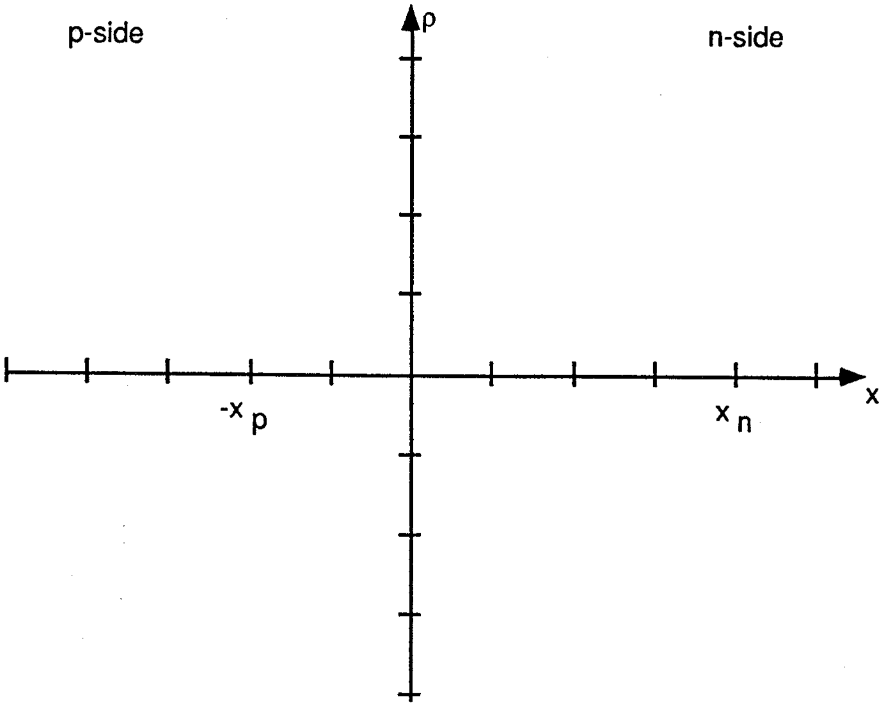
   c) 0.5 volts

   d) -3 volts

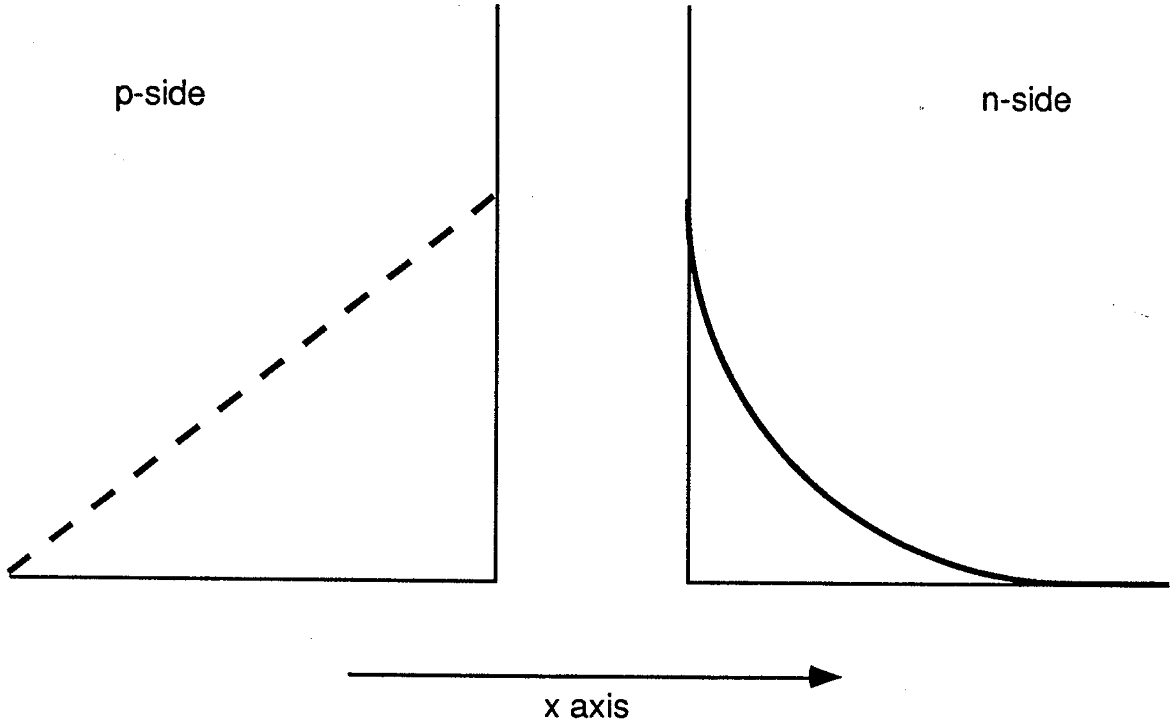
   e) 0.75 volts

   f) -4 volts

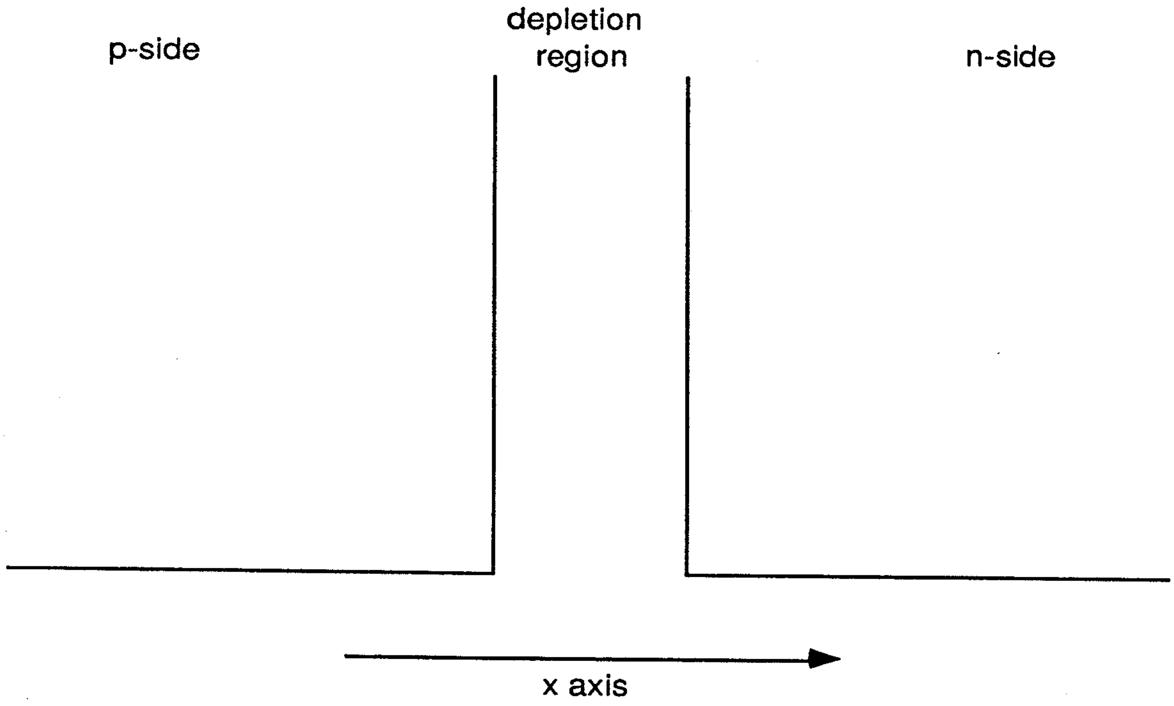
4. (5 points) Assume that the maximum magnitude of the charge density, ρ, is 4 units on the vertical scale below. Sketch the charge density as function of position in an abrupt pn junction assuming the depletion approximation.



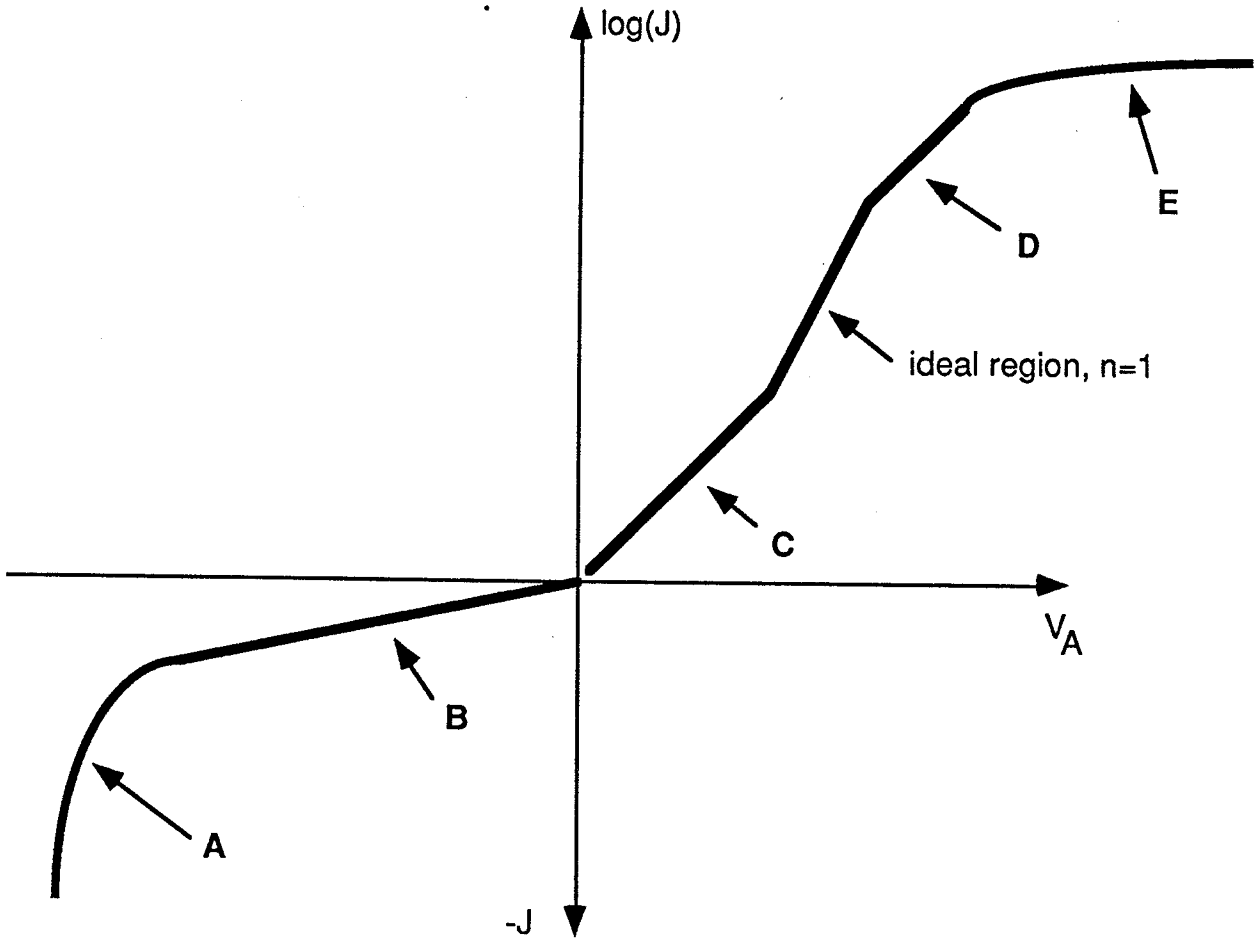
5. (15 points) Below is a sketch of the excess minority carrier concentrations in the quasi-neutral regions of a pn junction.



Sketch $J_p(x)$, $J_n(x)$, and the total current density, $J(x)$, throughout the device.



6. (15 points) Below is the current-voltage characteristic of a real pn junction diode. Match the possible source of the non-idealities, a-f, to the proper label, A-E.



A ____
B ____
C ____
D ____
E ____

a) low injection

b) tunneling and/or avalanche current

c) recombination in depletion region

d) generation in depletion region

e) series resistance

f) high injection

7. (5 points) The small signal depletion capacitance of a pn junction can be compared to the capacitance of two parallel plates for which the capacitance is given by:

$$C = \frac{\varepsilon A}{d}$$

where ε is the permittivity of the dielectric, A is the area of each plate, and d is the separation of the plates.

i) (2 points) What parameter of a pn junction diode corresponds to d?

ii) (3 points) A small incremental voltage, $v_a > 0$ is applied to the diode. What is the source of the charge on the "plates" of the depletion capacitor?

a) majority carriers at the edges of the depletion region.

b) minority carriers at the edges of the depletion region

c) majority carriers at the metallurgical junction

d) minority carriers at the metallurgical junction

e) ionized dopants at the contacts

8. (5 points) The storage time, t_s, in the turn-off transient of a p^+n diode can be decreased by:

a) increasing τ_p on the n-side and increasing the forward bias voltage on the diode.

b) increasing τ_p on the n-side and decreasing the forward bias voltage on the diode.

c) decreasing τ_p on the n-side and decreasing the forward bias voltage on the diode.

d) decreasing τ_p on the n-side and increasing the forward bias voltage on the diode.

9. (10 points) For a well designed pnp bipolar junction transistor, choose the statement which best explains the role(s) of the current components in the following performance parameters.

i) the base transport factor,

$$\alpha_T = \frac{I_{Cp}}{I_{Ep}}$$

a) $I_{Cp} \approx I_{Ep}$, so that almost all the holes emitted from the Emitter recombine in the Base.

b) $I_{Cp} < I_{Ep}$, so that most of the holes emitted from the Emitter recombine in the Base.

c) $I_{Cp} \approx I_{Ep}$, so that almost all the holes emitted from the Emitter make it into the Collector.

d) $I_{Cp} < I_{Ep}$, so that almost all the holes emitted from the Emitter make it into the Collector.

e) $I_{Cp} \approx I_{Ep}$, so that back injection of electrons into the emitter is large.

ii) the emitter injection efficiency,

$$\gamma = \frac{I_{Ep}}{I_{Ep}+I_{En}}$$

a) $I_{En} \approx I_{Ep}$, so that the base current will be large, which will help achieve a large DC gain.

b) $I_{En} \approx I_{Ep}$, so that the base current will be small, which will help achieve a large DC gain.

c) $I_{En} << I_{Ep}$, so that the base current will be large, which will help achieve a large DC gain.

d) $I_{En} << I_{Ep}$, so that the base current will be small, which will help achieve a large DC gain.

e) $I_{En} >> I_{Ep}$, so that the base current will be small, which will help achieve a large DC gain.

10. (5 points) Below is a plot of the minority carrier concentration in the base of a poorly constructed p+np bipolar junction transistor operating in the active region. What condition does the base transport factor satisfy?

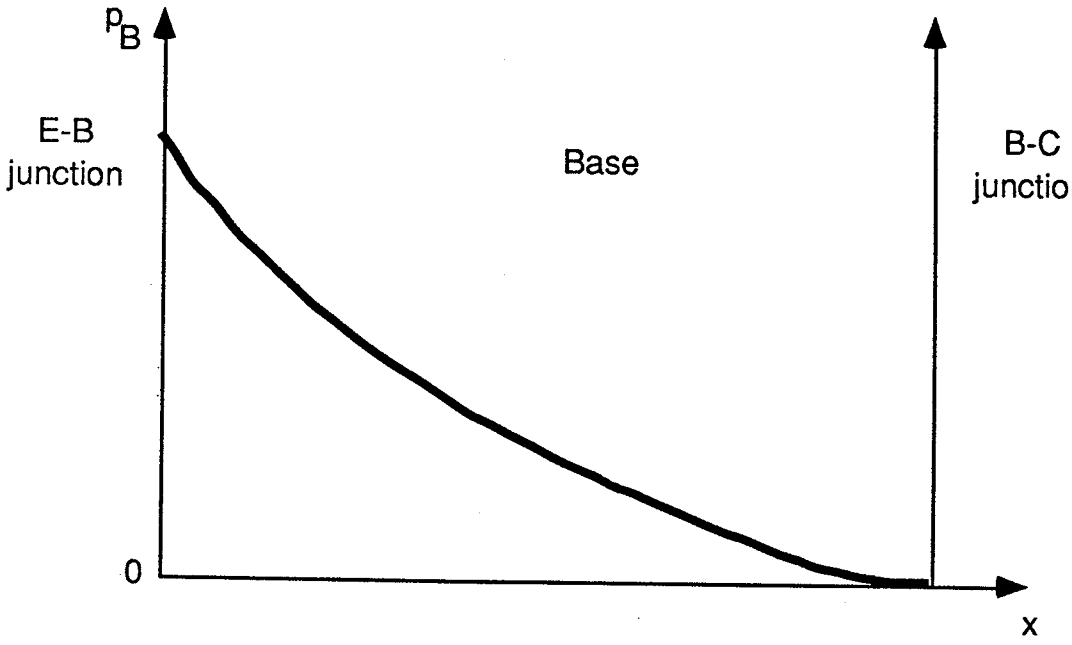
    a) $\alpha_T = 1$

    b) $\alpha_T > 1$

    c) $\alpha_T = 0$

    d) $0 < \alpha_T < 1$

    e) $\alpha_T < 0$



11. (5 points) Use the bipolar transistor DC gain expression (it is on one of your formula sheets) to explain how the base width and the dopings of the base and emitter regions should be chosen to achieve high gain.

12. (10 points) Sketch the minority carrier concentrations in each region (E, B, C) of an ideal p^+np bipolar transistor operating in the **inverted** active region. The dotted horizontal lines are the equilibrium minority carrier concentrations in each region. Plot minority hole concentrations with a solid line and minority electron concentrations with a dashed line.