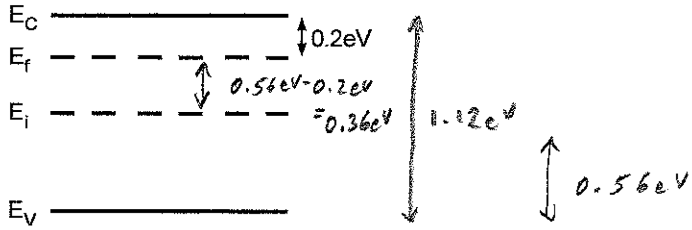
Use the band diagram for silicon for the following parts of this problem.



a. Is this n-type or p-type material? Why?
b. What is the majority carrier and the majority carrier concentration?
c. What is the minority carrier and the minority carrier concentration?
d. What is the resistivity of this material?

a) n-type because the Fermi level is close to the condection band (above E_i)

b) Majority carrier → electrons (n-type material)

$$n = n_i e^{(E_f - E_i)/kT}$$

$$n = (10^{10}\,cm^{-3})\, e^{(0.36eV)/(0.0259eV)} = 1.0877 \times 10^{16}\,cm^{-3}$$

c) Minority carrier → holes

$$p = \frac{n_i^2}{n} = \frac{(10^{10}\,cm^{-3})^2}{1.0877 \times 10^{16}\,cm^{-3}} = 9.1934 \times 10^{3}\,cm^{-3}$$

d) Resistivity

$$\rho = \frac{1}{q(\mu_n n + \mu_p p)} = \frac{1}{(1.602 \times 10^{-19} C)\left[(1360\,cm^2/Vs)(1.0877 \times 10^{16}\,cm^{-3}) + (460\,cm^2/Vs)(9.1934 \times 10^{3}\,cm^{-3})\right]}$$

$$= 0.4220\,\Omega\,cm$$

Also $\rho \approx \frac{1}{q\mu_n n} = 0.4220\,\Omega\,cm$

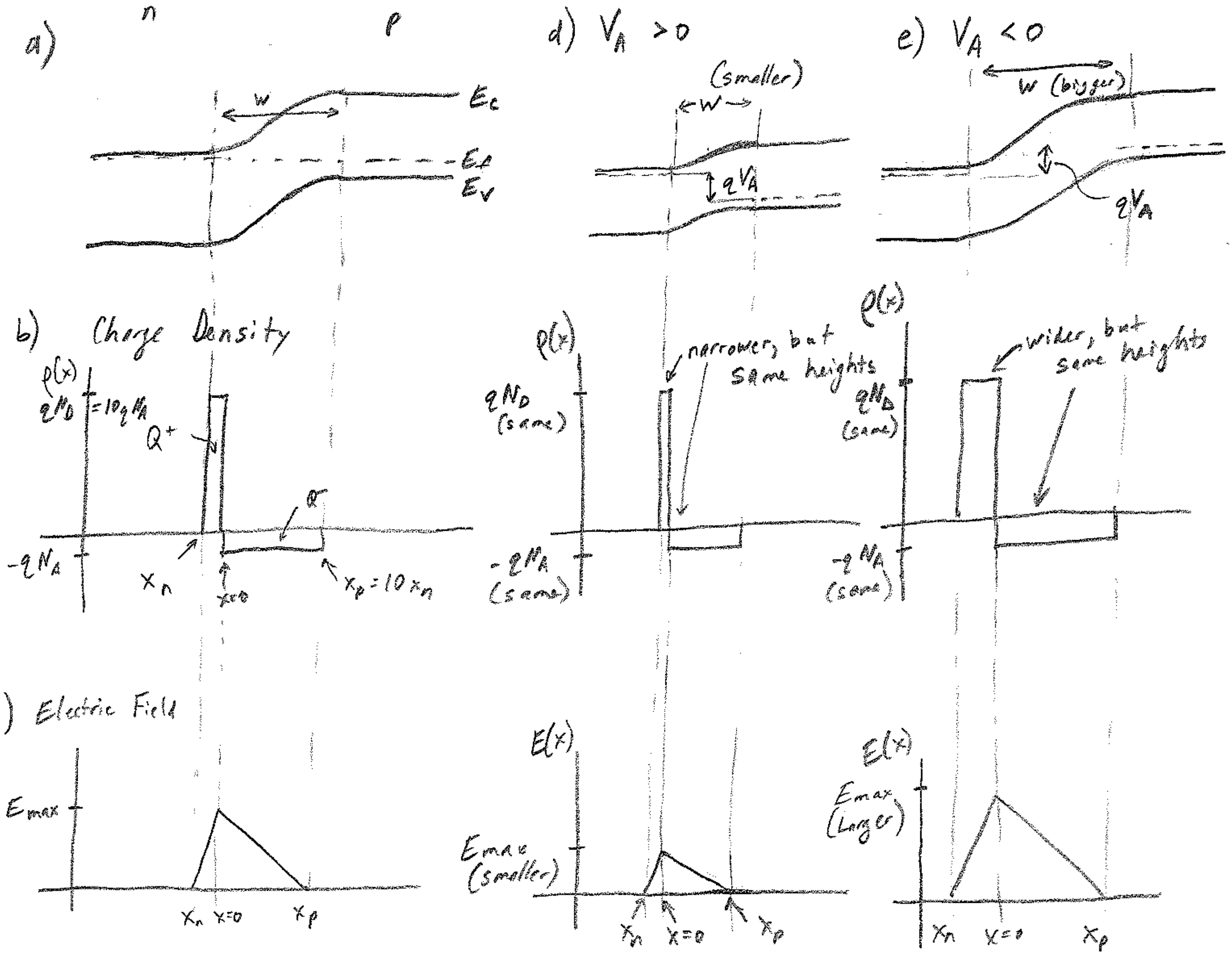
A silicon p-n junction has been doped on the p-type side with $N_A = 10^{17} cm^{-3}$ and on the n-type side with $N_D = 10^{18} cm^{-3}$. Draw the following to scale. Be sure to label all important points and intercepts (exact values are not needed, but expressions are required).

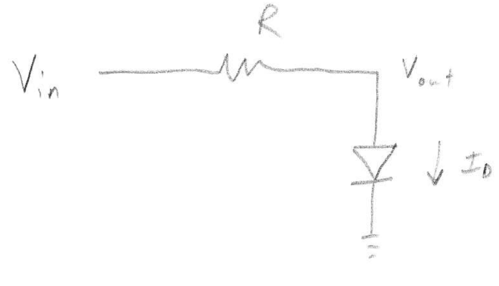
a. Band diagram in equilibrium.
b. Charge density in equilibrium verses position along the p-n junction.
c. Electric field in equilibrium verses position along the p-n junction.
d. Repeat Parts a-c for a forward biased p-n junction. Emphasize the differences from the equilibrium conditions.
e. Repeat Parts a-c for a reverse biased p-n junction. Emphasize the differences from the equilibrium conditions.

$N_D = 10 N_A$ ∴ E_f will be very close to E_c on the n-type side

$$|E_f - E_c|\Big|_{\text{n-type side}} < |E_f - E_v|\Big|_{\text{p-type side}}$$

Draw the band diagrams for each side, and then line up the Fermi levels for equilibrium conditions





Find I_D to three decimal point accuracy

Given $R = 10k\Omega$

$I_o = 0.1pA$

$n = 1$

$U_T = 25mV$

$V_{in} = 10V$

$$I_D = \frac{V_{in} - V_{out}}{R} = I_o\left(e^{V_{out}/nU_T} - 1\right)$$

$$\approx I_o e^{V_{out}/U_T} \quad \leftarrow \text{Forward biased and } n=1$$

Cannot find an analytic expression, so use iterative approach

Guess → $V_{out} = 0.8V$ (the voltage across the diode)

(Note → it is typically better to start with a higher voltage than what you expect)

$$I_{D,guess} = I_o e^{V_{out,guess}/U_T} = 7.8963\ A$$

$$I_D \approx I_o e^{V_{out}/U_T}$$

$$V_{out} = U_T \ln \frac{I_D}{I_o}$$

Therefore

$$I_{D,next} = \frac{V_{in} - V_{out}}{R} = \frac{V_{in} - U_T \ln\left(\frac{I_{D,previous}}{I_o}\right)}{R}$$

$I_{D0} = 7.8963\ A$

$$I_{D1} = \frac{10V - (0.025)\ln\left(\frac{7.8963A}{1pA}\right)}{R} = 9.2000 \times 10^{-4} A$$

$$D_{D2} = \frac{10V - (0.025)\ln\left(\frac{9.2000\times10^{-4}A}{1pA}\right)}{R} = 9.4264 \times 10^{-4} A$$

$D_{D3} = 9.4258 \times 10^{-4} A$

$D_{D4} = 9.\underline{425}8 \times 10^{-4} A$ Converges