

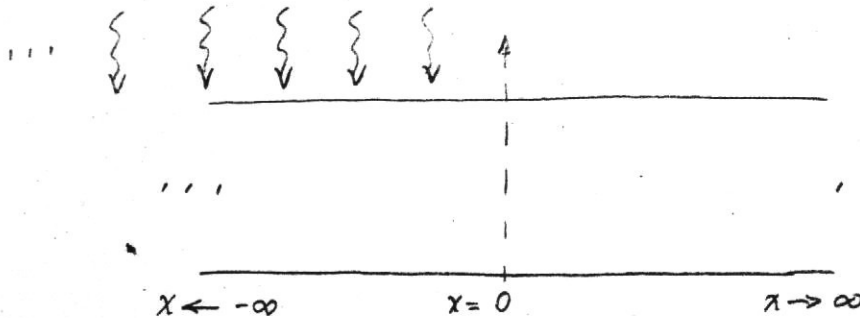
**Başkent University Electrical and Electronics Engineering Department**  
**EEM214**

**QUIZ-2 (4 questions for 50 minutes)**

Equations to remember:

$$\frac{\partial p(x,t)}{\partial t} = \frac{-1}{q} \frac{\partial J_p}{\partial x} - \frac{\delta_p}{\tau_p} + g_{op} \quad \text{where} \quad J_p = -qD_p \frac{\partial p}{\partial x} + qp\mu_p E$$

Q.1.(50pts) As shown below, only the  $x < 0$  portion of an infinite semiconductor bar is uniformly illuminated with light. The light generates  $g_{op} = 10^{15}$  EHPs/cm<sup>3</sup> sec uniformly. This Si bar is uniformly doped with donor atoms  $N_D = 10^{18}$ /cm<sup>3</sup> and there is no electric field inside. Given  $\tau_p = 10^{-6}$  sec,  $n_i = 10^{10}$ /cm<sup>3</sup>,  $D_p = 3$  cm<sup>2</sup>/sec and steady-state conditions are maintained.



- (15pts) Calculate the total minority carrier concentration at minus infinity.
- (25pts) Calculate the total minority carrier concentration as a function of  $x > 0$ .
- (10pts) Plot the the total minority carrier concentration variation along the x-axis.

Q.2. (10pts) Write the charge neutrality equation for a semiconductor which is doped with  $N_A = 10^{18}$ /cm<sup>3</sup> and with  $N_D = 10^{16}$ /cm<sup>3</sup>.

Q.3. (15pts) Si is doped with Boron (from 3<sup>rd</sup> column). Draw energy band diagram and clearly show conduction band, valence band and approximate Fermi levels both for intrinsic case and doped case for this Si.

Q.4. (25pts) For an unbiased diode, p-side and n-side are doped with  $N_A = 10^{18}$ /cm<sup>3</sup> and with  $N_D = 10^{16}$ /cm<sup>3</sup>, respectively. Draw all the approximated majority and minority carrier concentrations along the (x-axis) p and n semiconductors in this diode. Calculate the approximate concentration levels of minority and majority carriers at the edges of the diode. Given  $n_i = 10^{10}$ /cm<sup>3</sup>.

Q.1.

a)  $N_D = 10^{16} / \text{cm}^3$ ,  $N_A = 0$ ,  $g_{op} = 10^{15} \text{ EHPs/cm}^3 \text{sec}$ ,  $\tau_p = 10^{-6} \text{ sec}$ ,  $n_i = 10^{10} / \text{cm}^3$ ,  $D_p = 3 \text{ cm}^2/\text{sec}$

$$p(x) = p_0 + \delta p(x), \quad p(-\infty) = p_0 + \delta p(-\infty), \quad N_D - N_A \gg 2n_i \quad \text{so} \quad p_0 = \frac{n_i^2}{N_D} = \frac{10^{20}}{10^{16}} = 10^4 / \text{cm}^3$$

$$p(-\infty) = 10^4 + \delta p(-\infty), \quad \text{No } \vec{E} \text{ field } \quad \vec{E} = 0 \Rightarrow J_p = -q \cdot D_p \cdot \frac{\partial p}{\partial x}$$

$$\frac{\partial p}{\partial t} = \frac{\partial \delta p}{\partial t} = -\frac{1}{q} \frac{\partial J_p}{\partial x} - \frac{\delta p}{\tau_p} + g_{op}; \quad \frac{\partial \delta p}{\partial t} = 0 \text{ at steady state}$$

$$0 = D_p \frac{\partial^2 \delta p}{\partial x^2} - \frac{\delta p}{\tau_p} + g_{op}; \quad \frac{\partial^2 \delta p}{\partial x^2} = 0 \text{ uniform illumination}$$

$$\frac{\delta p}{\tau_p} = g_{op} \Rightarrow \delta p = \tau_p \cdot g_{op} = 10^{-6} \cdot 10^{15} = 10^9 / \text{cm}^3 \quad x \leq 0 \quad \text{so } \delta p(-\infty) = 10^9 / \text{cm}^3$$

$$p(-\infty) = 10^4 + 10^9 \approx 10^9 / \text{cm}^3$$

b) for  $x > 0$ ;  $\delta(0^+) = \Delta p \approx 10^9 / \text{cm}^3$

$\delta p(+\infty) = 0$ ,  $g_{op} = 0$  since there is no optical excitation for  $x > 0$ . Excess carriers will diffuse towards right at  $x = 0$ . As  $x \rightarrow \infty$ , the excess holes are lost to recombination and the excess hole concentration at  $x = \infty$  is zero.

$$\frac{\partial \delta p}{\partial t} = D_p \cdot \frac{\partial^2 \delta p}{\partial x^2} - \frac{\delta p}{\tau_p} = 0 \quad \text{at steady state}$$

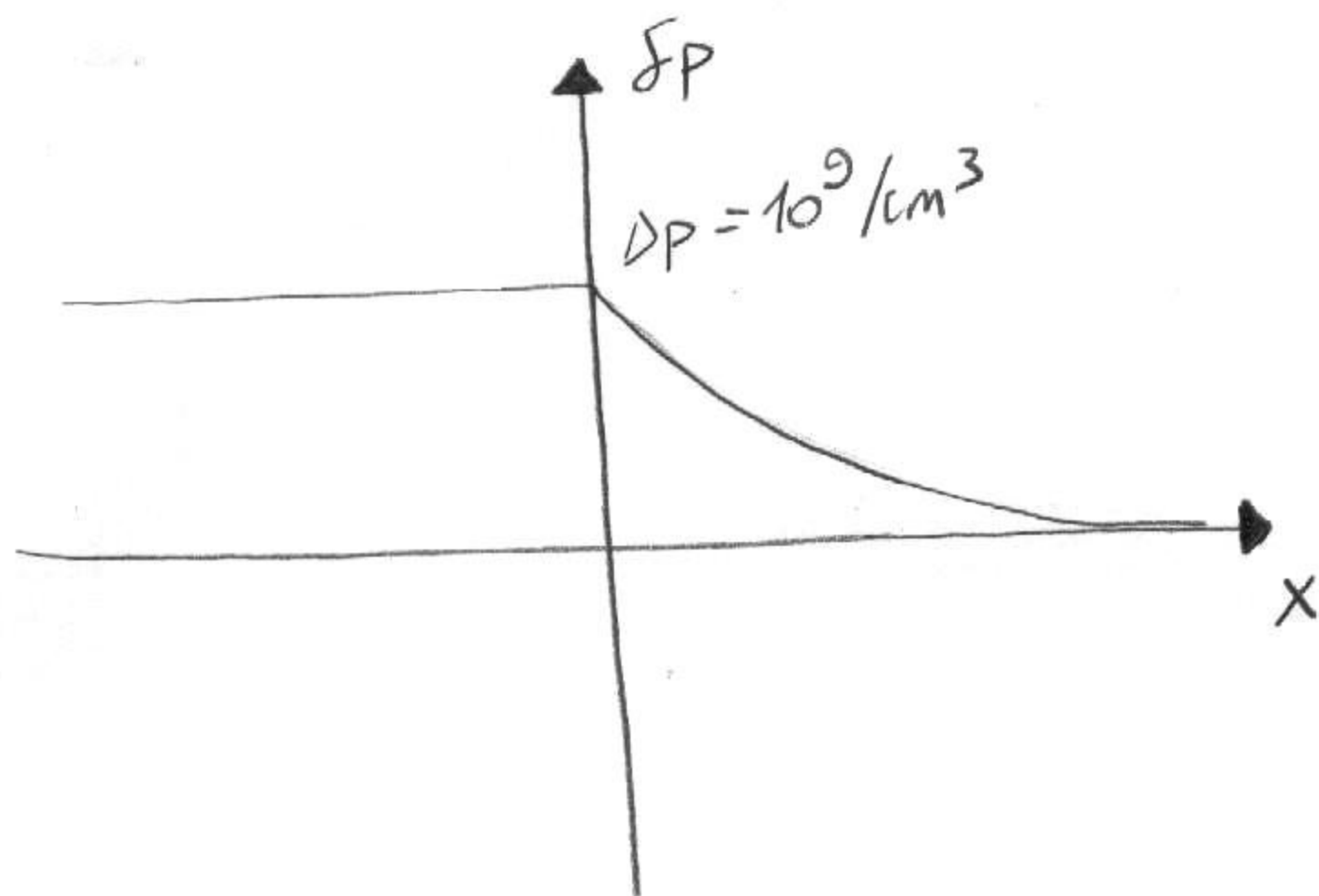
$$\frac{\delta p}{\tau_p} = D_p \cdot \frac{\partial^2 \delta p}{\partial x^2} \Rightarrow \delta p(x) = A e^{x/L_p} + B \cdot e^{-x/L_p}$$

$$\left. \begin{array}{l} \text{for } x > 0 \Rightarrow \delta p(0^+) = \Delta p = A + B \\ \text{for } x = +\infty \Rightarrow \delta p(+\infty) = 0 = A \end{array} \right\} B = \Delta p$$

$$\delta p(x) = \Delta p \cdot e^{-x/L_p} = 10^9 e^{-x/L_p} / \text{cm}^3$$

c) for  $x \leq 0$   $\delta p(x) = 10^9 / \text{cm}^3$

for  $x > 0$   $\delta p(x) = \Delta p \cdot e^{-x/L_p} / \text{cm}^3$

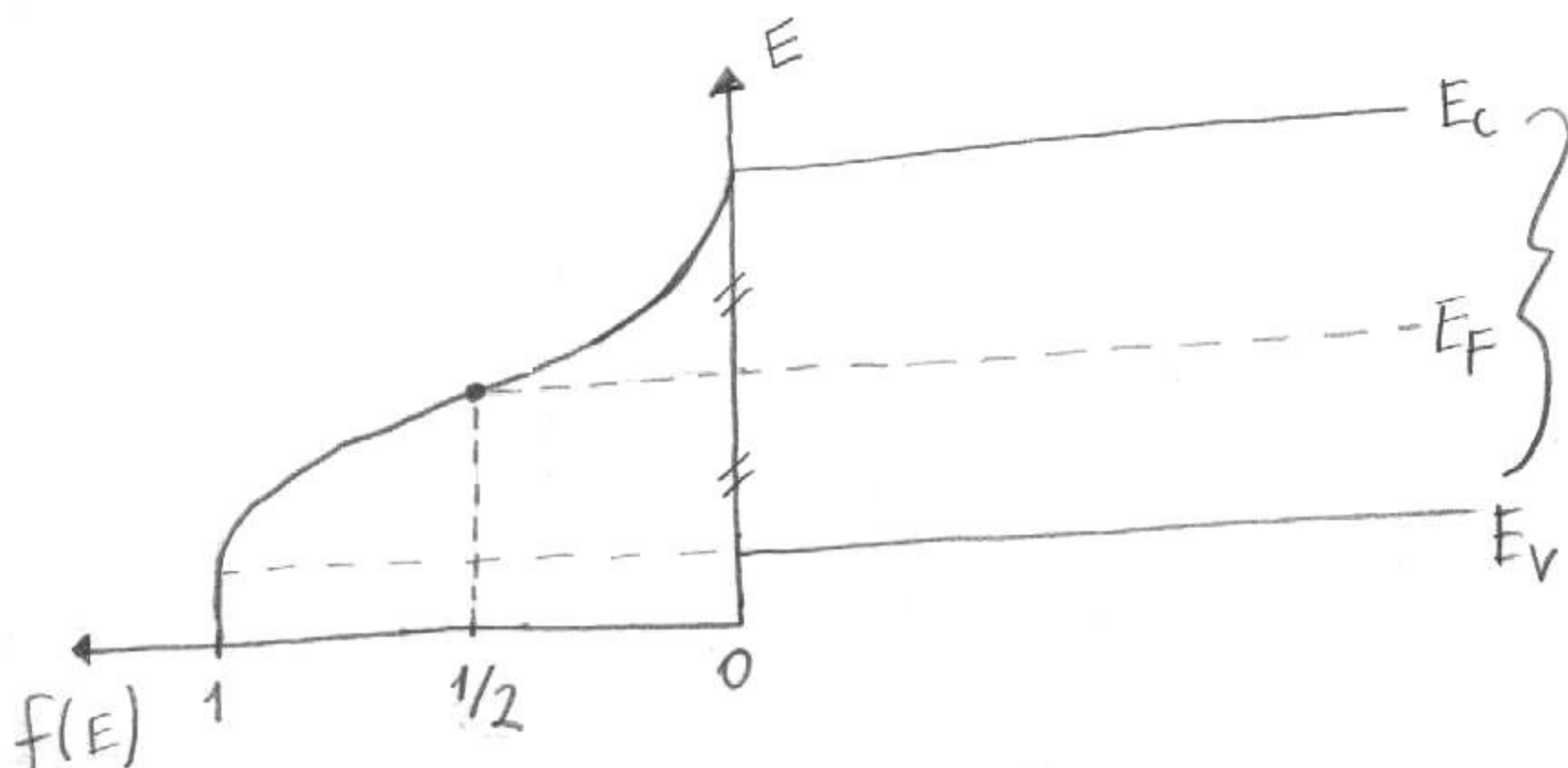


Q.2.  $N_A = 10^{16} / \text{cm}^3$ ,  $N_D = 10^{16} / \text{cm}^3$

$$q(N_D + p - N_A - n) = 0$$

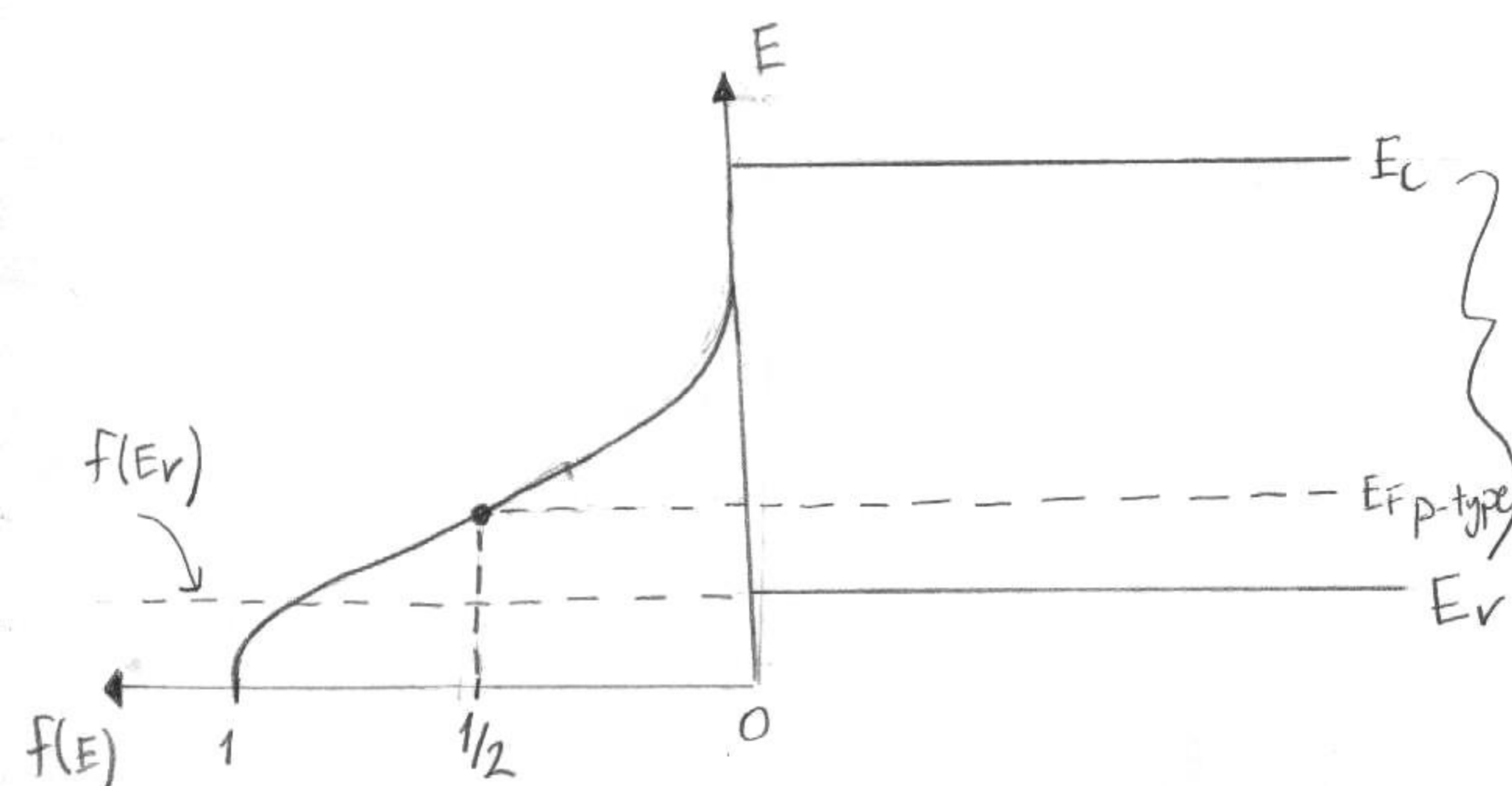
Q.3. Boron is an acceptor atom because from 3<sup>rd</sup> column; semiconductor is p-type

for intrinsic case;



for intrinsic case, there are no energy states available.

for doped case (P-type)



The acceptor atoms introduce energy levels within the bandgap at the acceptor energy level  $E_A$  near the valence band edge

Q.4. For p-type side

$$N_A = 10^{16} / \text{cm}^3, N_D = 0 / \text{cm}^3, n_i = 10^{10} / \text{cm}^3$$

$$N_A - N_D \gg 2n_i \Rightarrow P_p = N_A = 10^{16} / \text{cm}^3$$

$$n_p = \frac{n_i^2}{P_p} = \frac{10^{20} / \text{cm}^3}{10^{16}} = 10^4 / \text{cm}^3$$

For n-type side

$$N_D = 10^{16} / \text{cm}^3, N_A = 0 / \text{cm}^3, n_i = 10^{10} / \text{cm}^3$$

$$N_D - N_A \gg 2n_i \Rightarrow n_n = N_D = 10^{16} / \text{cm}^3$$

$$p_n = \frac{n_i^2}{n_n} = \frac{10^{20} / \text{cm}^3}{10^{16}} = 10^4 / \text{cm}^3$$

