Q 1:

1.1

$$J_n = en\mu_n E + eD_n \nabla n2 \qquad J_p = ep\mu_p E + eD_p \nabla p$$

$$\frac{\partial n}{\partial t} = -\frac{\partial F_n^-}{\partial x} + g_n - \frac{n}{\tau_{nt}} \qquad \frac{\partial p}{\partial t} = -\frac{\partial F_p^+}{\partial x} + g_p - \frac{p}{\tau_{nt}}$$

$$\nabla \cdot E_{int} = \frac{e\left(\delta p - \delta n\right)}{\epsilon_s} = \frac{\partial E_{int}}{\partial x}$$

1.2

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

1.3

$$\Delta V = -\int E \cdot ds$$

1.4

$$\Delta U_{energy} = q\Delta V_{voltage}$$

1.5

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{k_B T}{e}$$

1.6

Photons are energy quanta in the form of EM radiation.

$$p = \frac{h}{\lambda} = \frac{kh}{2\pi} = k\hbar$$

1.7

Phonons are energy quanta in the form of heat.

$$p = \frac{h}{\lambda} = \frac{kh}{2\pi} = k\hbar$$

2

From this equation:

$$E_x = -\frac{k_B T}{e}\frac{1}{N_d(x)}\frac{dN_d(x)}{dx}$$

We can say that the electric field is going to be in opposite direction of $\frac{dN_d(x)}{dx}$

3

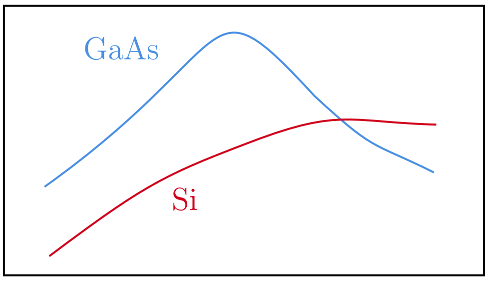
Because the hall voltage depends on the drift velocity which has opposite signs for n-type and p-type semiconductors

4

They will decrease its mobility.

5

The difference is due the difference in the effective mass, affecting the mobility.



Q2

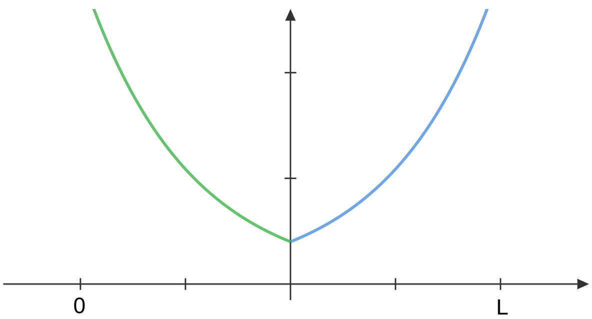
$$V_H = E \times W \implies V_H = -16.5 \times 5 \times 10^{-2} = -0.825\ mV$$

Since V_H is negative, this implies that we have an n-type semiconductor.

$$n = -\frac{I_x B_z}{edV_H} \implies n = -\frac{0.5 \times 10^{-3} * 6.5 \times 10^{-2}}{1.6 \times 10^{-19} * 5 \times 10^{-5} * -0.825 \times 10^{-3}} = 4.9 \times 10^{21} m^{-3} = 4.9 \times 10^{15} cm^{-3}$$

$$\mu_n = \frac{I_x L}{enV_x W d} \implies \mu_n = \frac{0.5 \times 10^{-3} * 0.5 \times 10^{-2}}{1.6 \times 10^{-19} * 4.9 \times 10^{21} * 1.25 * 5 \times 10^{-4} * 5 \times 10^{-5}} = \frac{5}{49}\, m^2/V{\cdot}s \approx 0.102\, m^2/V{\cdot}s$$

Q3



low-level injection prevails because $\delta p = \gamma N_D << N_D$ since $\gamma = 10^{-3}$.

$$D_p \frac{\partial^2 \delta p}{\partial x^2} + g_p - \frac{p}{\tau_{pt}} = 0$$

The solution will have this form:

$$\delta p(x) = \frac{x^2 (p - g_p \tau_{pt})}{2 D_p \tau_{pt}} + c_1 x + c_2$$

$$\delta p(0) = \delta p(L) = \gamma N_D$$

$$J_P = -eD_p \frac{\partial (p_0 + \delta p)}{\partial x}|_{x=0} = -eD_p c_1$$

Q5

$$n_0 = n_i \exp\left(\frac{E_F - E_{Fi}}{k_B T}\right); \quad p_0 = \frac{n_i^2}{n_0} = n_i \exp\left(\frac{E_{Fi} - E_F}{k_B T}\right)$$

$$n_i << N_d \implies n_0 = N_d = 10^{15}\ cm^{-3}; \quad p_0 = \frac{\left(1.5 \times 10^{10}\right)^2}{10^{15}} = 2.25 \times 10^5\ cm^{-3}$$

$$n_0 = n_i \exp\left(\frac{E_F - E_{Fi}}{k_B T}\right) \implies E_F - E_{Fi} = k_B T \ln\frac{n_0}{n_i} = 0.35\ eV$$

$$p_0 = n_i \exp\left(\frac{E_F - E_{Fi}}{k_B T}\right) \implies E_F - E_{Fi} = k_B T \ln\frac{n_i}{p_0} = 0.29\ eV$$

$$\delta p = \delta n = 10^{12}$$

$$n_0 + \delta n = n_i \exp\left(\frac{E_F - E_{Fi}}{k_B T}\right); \quad p_0 + \delta p = n_i \exp\left(\frac{E_{Fi} - E_F}{k_B T}\right)$$

$$E_{Fn} - E_{Fin} = k_B T \ln\frac{n_0 + \delta n}{n_i} = 0.35\ eV$$

$$E_{Fp} - E_{Fip} = k_B T \ln\frac{n_i}{p_0 + \delta p} = 0.109\ eV$$

$$\delta p = \delta n = 10^{18}$$

$$E_{Fn} - E_{Fin} = k_B T \ln\frac{n_0 + \delta n}{n_i} = 0.466\ eV$$

$$E_{Fp} - E_{Fip} = k_B T \ln\frac{n_i}{p_0 + \delta p} = 0.466\ eV$$