1) The figure below shows a semiconductor with the Fermi level located in five different locations. If we use the Landauer expression to compute the current:

\[ I = \left( \frac{2q}{h} \right) \int_{E_i}^{E_f} \mathcal{T}(E) M(E) (f_1 - f_2) dE \]

what are appropriate limits of integration, \( E_1 \) and \( E_2 \), for each case? You may assume room temperature and a bandgap of 1 eV and that \( E_{F1} \approx E_{F2} \approx E_F \).

2) Determine the limits of integration, \( E_1 \) and \( E_2 \), for the integral in the Landauer expression:

\[ I = \left( \frac{2q}{h} \right) \int_{E_i}^{E_f} \mathcal{T}(E) M(E) (f_1 - f_2) dE \]

for the case of \( T = 0 \) K. Assume that contact one is grounded and that a positive voltage (not necessarily small) has been applied to contact 2.
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3) For a 3D diffusive resistor, we relate the current density to the electric field by

\[ E_x = \rho_{3D} J_x \text{ V/m}, \]

where \( E_x \) is the electric field in V/m and \( J_x \) is the current density in A/m\(^2\). Write the corresponding equations in 1D and 2D and determine the units of \( \rho_{1D}, \rho_{2D} = \rho_S \), and \( \rho_{3D} \).

4) In 1D, we express the resistance of a long (diffusive) resistor by \( R_{1D} = (1/\sigma_{1D}) L \). In 2D, we write \( R_{2D} = (1/\sigma_{2D}) L/W \) and in 3D \( R_{3D} = (1/\sigma_{3D}) L/A \). Assuming a degenerate conductor (i.e. \( T = 0 \text{ K} \)), begin with \( G_{\text{ball}} = \frac{2q^2}{h} M(E_F) \) and develop expressions for the 1D, 2D, and 3D “ballistic conductivities.”

5) One can derive a near-equilibrium current equation for a 2D, n-type conductor in the diffusive limit and write it as \( J_n = \sigma_s d(F_n/q)/dx \text{ A/m} \). Derive the corresponding equation for a p-type semiconductor.

6) Begin with \( J_{nx} = \sigma_n d(F_n/q)/dx \) and derive the drift-diffusion equation for a 3D n-type semiconductor with parabolic energy bands. Do not assume Maxwell-Boltzmann statistics.

7) Answer the following questions about resistivity at \( T = 300 \text{K} \). (Note: for the problem, you will need to hunt down the relevant material parameters.)

7a) Compute the resistivity of intrinsic Si, Ge, and GaAs.
7b) Compute the resistivity of n-type Si, Ge, and GaAs doped at \( N_D = 10^{19} \text{ cm}^{-3} \). Assume complete ionization of dopants.

8) You are given a 10 Ohm-cm silicon wafer at 300 K. Answer the following questions.

8a) If it is n-type, What is the electron density?
8b) If it is p-type, what is the hole density?
9) Determine the diffusion coefficient for electrons in Si at $T = 300$ K for the following two conditions.

9a) Intrinsic Si
9b) Si doped at $N_D = 10^{19}$ cm$^{-3}$