1. A silicon sample maintained at 300 °K is doped with 1×10^{17} cm^{-3} boron and 1×10^{16} cm^{-3} arsenic. Assuming the intrinsic carrier concentration is 1×10^{10} cm^{-3} at 300 °K.

   (a) **Write down** the charge neutrality condition. (2%)

   (b) **Write down** the mass action law for the product of electron and hole concentration at thermal equilibrium. (Assuming Boltzmann approximation is valid) (2%)

   (c) **What** is the electron concentration n and hole concentration p? (2%)

   (d) **What** is the type (N or P) of this silicon sample? (2%)

   (e) **What** is the electron concentration n and hole concentration p if the silicon sample is doped with 1×10^{5} cm^{-3} boron and 1×10^{6} cm^{-3} arsenic? (2%)

2. The electron mobility in the channel of modern 0.25 μm n-channel MOSFET is around 200 cm^2/V·sec. Assume the channel electric field is around 1000 V/cm and the effective mass of the electron in conduction band is m_0. Assuming the thermal velocity v_{th} is 1×10^7 cm/sec. Answer the following questions.

   (a) **What** is the drift velocity? (5%)

   (b) **What** is the mean free time τ between collisions? (5%)

   (c) **What** is the mean free path ℓ between collisions? (5%)

3. Answer the following question briefly.

   (a) **What** is the dominant leakage current mechanism in reverse biased silicon pn junction diodes maintained at room temperature? (5%)

   (b) **Sketch** the common emitter current gain β as a function of collector current I_c for a bipolar junction transistor and **explain** the behavior of β at low collector current I_c. (5%)

   (c) **Sketch** the transfer characteristics for both n-channel and p-channel enhancement MOSFETs operated in saturation region (5%)

4. Assuming there are negligible interface states, answer the following questions.

(a) **Draw** the energy band diagram for a metal to *n*-type semiconductor junction. Assume that the work function of the metal is larger than that of the semiconductor, that is: $q\phi_m > q\phi_s$. $q\phi_m$ is the work function of metal and $q\phi_s$ is the work function of semiconductor. $q\chi$ is the electron affinity. **Find out** the Schottky barrier height and the contact potential (i.e. the built-in potential). (5%)

(b) Similarly, **draw** the energy band diagram for a metal to *p*-type semiconductor junction. Assume $q\phi_m < q\phi_s$. **Find out** the Schottky barrier height and the contact potential (i.e. the built-in potential). (5%)

5. An *n*-channel MOSFET has the following properties: the gate oxide thickness $t_{ox} = 1000$ Å, the oxide interface charge $Q_i/q = 5 \times 10^{10}$ cm^{-2}, the dielectric constant of oxide ε_{ox} is $3.9\varepsilon_0$, the substrate doping concentration is 1×10^{16} cm^{-3}, *p*-type, the dielectric constant of silicon ε_{Si} is $11.9\varepsilon_0$. The gate electrode is made of heavily doped n^+-doped polysilicon. You can assume that the Fermi level of the n^+-doped polysilicon is located at the bottom of the conduction band of silicon.

(a) **Calculate** the flat band voltage V_{FB}. (10%)

(b) **Calculate** the threshold voltage V_T of this *n*-channel MOS transistor. (10%)

7. (a) **Write** down the ideal diode equation and **explain** the parameters in the equation. (10%)

(b) When the terminal forward bias voltage exceeds the contact potential (i.e. the built-in potential), **what** will the equation become? Please **explain**. (10%)

8. In the design of a bipolar junction transistor (BJT), the determination of base doping level is very important. Please **discuss** the consequences (i.e. good or bad) when

(a) The base doping is lighter. (5%)

(b) The base doping is heavier. (5%)

some physical constant: electronic charge $q = 1.6 \times 10^{-19}$ C, electron rest mass $m_0 = 9 \times 10^{-31}$ kg,
permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m,
thermal energy $kT = 0.0259$ eV @ 300 °K.
the intrinsic carrier concentration $n_i = 1 \times 10^{10}$ cm^{-3} at 300 °K