1. (5 points)
   a) (1.5 pts) Suppose you have a sample of silicon at room temperature doped with a density of $4 \times 10^{17}$ arsenic atoms (donors) per cubic centimeter, (i.e. $n = 4 \times 10^{17}$ electrons/cm$^3$). What is the approximate density of holes in the silicon and how do you determine it?

   b) (2 pts) What is the resistivity of the silicon in the case a) ? (To receive full credit, you must give a correct expression and substitute the appropriate numbers from the table below.)

   c) (1.5pts) Now suppose you have a sample of silicon doped with $8 \times 10^{17}$ arsenic atoms (donors) per cubic centimeter, and with $4 \times 10^{17}$ boron atoms (acceptors) per cm$^3$. What is the density of holes in the silicon?
2. (5 points)  a) (2 pts) Suppose you have an n-type Si sample with \( n_o \) electrons/cm\(^3\). Suppose it is uniformly illuminated to create electron-hole pairs at a constant density throughout the sample, such that the electron density becomes \( n_0 + n' \) and the hole density becomes \( p_0 + p' \) where \( n' = p' \). Assume \( n' << n_0 \). Suppose at time \( t = 0 \) the illumination is turned off. Write an expression for the hole concentration, \( p' \), as a function of time.

b) (1.5pts) Now suppose the illumination is more intense and the assumption \( n' << n_0 \) is no longer true, i.e. \( n' \sim n_0 \). When the illumination is turned off, how is the situation different? In particular is the initial decay rate of \( p' \), \( (dp'/dt) \) faster or slower than in part a)? Explain.

c) (1.5 pts) Suppose you are continuously and uniformly illuminating only half of the sample, i.e. for \( x < 0 \) in the drawing. Otherwise the conditions are the same as in part a). Sketch the dependence of \( p' \) on \( x \) throughout the sample. Assume the sample is long, i.e. don’t consider end effects.

### Table A.1

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>Ge</th>
<th>GaAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta E_g (eV) )</td>
<td>1.124</td>
<td>0.67</td>
<td>1.42</td>
</tr>
<tr>
<td>( n_i (\text{cm}^{-3}) )</td>
<td>( 1.08 \times 10^{10} )</td>
<td>( 2.4 \times 10^{13} )</td>
<td>( 9 \times 10^6 )</td>
</tr>
<tr>
<td>( \mu_e (\text{cm}^2/\text{V} \cdot \text{s}) )</td>
<td>1500</td>
<td>3900</td>
<td>8500</td>
</tr>
<tr>
<td>( \mu_h (\text{cm}^2/\text{V} \cdot \text{s}) )</td>
<td>600</td>
<td>1900</td>
<td>400</td>
</tr>
<tr>
<td>( \varepsilon_r (\varepsilon/\varepsilon_0) )</td>
<td>11.7</td>
<td>15.8</td>
<td>13.1</td>
</tr>
</tbody>
</table>
3. **(4 points)** Derive an expression for the resistance (from the end with thickness, a, to the end with thickness, b) of a slab of material of resistivity $\rho$ if the slab is in the shape of a linearly tapered wedge as shown. Assume the electrical contacts are to the entire rectangular faces (a x w and b x w)

![Diagram of a linearly tapered wedge with labels a, w, b, and L.](image)
4. **(6 points)** MOSFETs are usually fabricated using the so-called self aligned process in which the gate electrode is used as a shadow mask for the implantation of the source and drain. For example, for an n-MOS transistor the silicon under the gate electrode remains p-type. The areas not covered by the gate electrode, or the field oxide are implanted and become n+ and serve as the source and drain. Suppose during the fabrication process a break occurs in the gate electrode. Assume the break is large enough so that the action of the gate does not “bridge” the break. Consider the four different cases with horizontal (H) and vertical (V) breaks. *Describe how the transistor operation would be affected.*

Assume an enhancement mode transistor, i.e. no source-drain current flows unless a positive gate-source voltage is applied. Assume the two halves of the gate electrodes in the case (H) are electrically connected.(As they are in case (V)).

![Diagram showing horizontal (H) and vertical (V) breaks in MOSFET gate electrodes.]

a) **(1.5 pts)** geometry H, the break occurred **before** implantation

b) **(1.5 pts)** geometry H, the break occurred **after** implantation.

c) **(1.5 pts)** geometry V, the break occurred **before** implantation.

d) **(1.5 pts)** geometry V, the break occurred **after** implantation.
1. a) \( n_p = n_i^2 \), \( n = 4 \times 10^{17} / \text{cm}^3 \)
   \( p = \frac{(1.08 \times 10^{10} / \text{cm}^3)^2}{4 \times 10^{17} / \text{cm}^3} \sim 3 \times 10^{-2} / \text{cm}^3 \)

b) \( \rho = \frac{1}{\frac{q}{\mu m} n} = \frac{1}{1.6 \times 10^{-19} \text{Coul} \times 1500 \text{cm}^2 / \text{Vsec} \times 4 \times 10^{17} / \text{cm}^3} \)

c) \( n = N_D - N_A = 4 \times 10^{17} \)
   \( \rho = \frac{n_i^2}{n} \) as in part a)

2. a) \( \frac{dp'}{dt} = -\frac{p'}{\tau} \); \( p' = p'(t=0) e^{-\frac{t}{\tau}} \)

b) \( \frac{dp'}{dt} \) at \( t=0 \) will have a larger negative value, i.e. the decay rate will be faster. This is because the excess minority holes, \( p' \), can combine with \( n_0 + n' \) electrons, not just no electrons.

c) \[ \begin{array}{c}
\text{not correct.}
\end{array} \]
4. a) The break will create a short between the source and the drain. The transistor will not operate.

b) The transistor will work. It’s width will be reduced by the width of the break. The source drain current will be smaller compared to a transistor without the break.

c) The transistor will work and will look like two transistors in series.

d) The area of the break will be p-type and there will be an open circuit between the source and the drain regardless of the gate voltage.