1. Consider a metal, silicon dioxide, P-type silicon sandwich as shown. Regard the problem as one dimensional.

a) Suppose you apply a negative voltage to the contact A, sketch qualitatively the charge density as a function of depth, $x$, showing the correct sign of the charge.
b) Suppose you apply a small positive voltage, just above flat-band, to the contact A, sketch the charge density as a function of depth, $x$.

![Charge density diagram](image1)


c) Suppose you apply a larger positive voltage, above threshold, to the contact A, sketch the charge density as a function of depth, $x$.

![Charge density diagram](image2)
2. Consider a bipolar junction transistor

a) What are some of the consequences, positive (improving performance) and negative (degrading performance) of making the base thinner and thinner? Explain, don’t just give two word answer.

b) What are some of the consequences, positive and negative, of increasing the base doping?
3. Consider a p-n junction diode that is light-sensitive. It can act both as a light detector and as a solar cell.

a) Sketch the current voltage characteristic of the diode with and without illumination. Clearly identify the curves and make sure they are in correct relation to each other.

b) Sketch a simple circuit with a battery and a resistor that you could use to connect the diode as an effective light detector. Show where you would measure a voltage output.
c) Suppose the I-V characteristic with no light applied is given by \( I = \alpha V^2 \) for \( V > 0 \) and \( I = 0 \) for \( V < 0 \). Assume \( \alpha \) does not change when the diode is illuminated.

If you short circuit the diode with light applied, the current flowing through the diode is \(-I_L\). Given this information calculate the maximum power \( P \) that the diode could deliver to an external circuit as a function of \( \alpha \) and \( I_L \).
(5%) 4. Consider an n-channel MOSFET connected as shown. It has a positive threshold voltage $V_{Th}$

a) Sketch the current $I$ as a function of the voltage $V$ if both resistances are zero, ($R_1 = R_2 = 0$). Make sure your sketch has the correct qualitative features. Locate $V_{Th}$ on the plot.

b) Now suppose $R_1 = R$, and $R_2 = 0$. Indicate how the plot in part a) would change. (e.g. using a dotted line) $R$ has some finite value comparable to the channel resistance.

c) Now suppose $R_1 = 0$, and $R_2 = R$ (same value as in b)). Is the plot the same as in part b)? Qualitatively show the difference if any.
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1. a)

2. a) positive: decreases recombination of minority carriers in base, thereby lowering base defect and increasing beta.

Negative: decreases maximum operating voltage on collector. Depletion region will extend to emitter base junction causing collector current to rise abruptly with no control from the base.

Negative: the Early voltage will decrease, i.e. output impedance will be lowered. The relative base width will decrease faster with collector voltage.

2. b) Positive: increases maximum operating voltage by decreasing depletion width in the base as collector voltage is increased

Positive: increases Early voltage

Negative: increases parasitic base to emitter current, increasing emitter defect and lowering beta

Negative: decreases minority carrier lifetime in base thereby increasing base defect and lowering beta
3.

\[ I \] with illumination

\[ V \]

4.

\[ \mathcal{P} = \sqrt{I} = V(\frac{2}{3}V^2 - I_L) \]
\[ \frac{d\mathcal{P}}{dV} = 3\omega V^2 - 3I_L = 0, \quad V = \sqrt[3]{\frac{3I_L}{\omega}} \]
\[ \mathcal{P} = V\sqrt[3]{\frac{I_L}{3\omega}} = \sqrt[3]{\frac{3I_L}{\omega}}(\frac{2I_L}{3}) \]