All problems assume temperature $T = 300$ K, and consequently $kT = 0.0259$ eV; $kT/q = 0.0259$ V
Constants: $q = 1.6 \times 10^{-19}$ coulomb; $\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm; $k = 8.617 \times 10^{-5}$ eV/K; $\ln10 = 2.303$

Problem #1 (50 points):
A metal-oxide-semiconductor (MOS) capacitor is made from aluminum ($\Phi_M = 4.1$ V), 15 nm
thick silicon dioxide ($\varepsilon_r = 3.9\varepsilon_0$) and p-doped silicon with $\varepsilon_s = 11.9\varepsilon_0$, $\chi = 4.05$ V, $E_g = 1.12$ eV,
and doping level of $N_a = 10^{17}$ cm$^{-3}$. Assume there is no fixed charge in the oxide or at the oxide-
silicon interface.
1a: (10 points) Calculate the oxide capacitance, $C_{ox}$.
1b: (10 points) What is the semiconductor surface potential, $\phi_S$, when inversion is on-set? What
is the depletion width in silicon, $W_d$, at inversion threshold?
1c: (10 points) Calculate the high frequency capacitance for voltages beyond the onset of
inversion.
1d: (10 points) Calculate the flat band voltage, $V_{FB}$, and threshold voltage, $V_T$.
1e: (10 points) Sketch the capacitance of this MOS-C over a large applied voltage range at low
measurement frequencies. The applied voltage range should be large enough so that you can
clearly mark the threshold voltage, flat band voltage, and mark with reasonable accuracy the
capacitances at the flat band and threshold voltages based on calculations in parts a-d.

Problem #2 (50 points):
An n-channel silicon MOSFET has a threshold voltage $V_T = 1$ V, channel width $W = 5$ µm,
channel length $L = 1$ µm, and oxide thickness $t_{ox} = 10$ nm. The effective mobility is $\mu_n = 288.5$
cm$^2$/N/σ, and the body voltage $V_{BS}$ is set to 0 V. Using square law and assume gate voltage $V_{GS} = 3$ V and drain voltage $V_{DS} = 5$ V, answer the following questions:
2a: (5 points) What regime, e.g. triode, saturation, or sub-threshold, is this device operating at?
2b: (10 points) What is the drain current, $I_D$?
2c: (10 points) Calculate the transconductance, $g_m$.
2d: (10 points) Assume that $V_{GS} = 3$ V but drain voltage is now $V_{DS} = 0$ V. Calculate the drain or
channel conductance, defined as $g_d = \frac{\partial I_D}{\partial V_G}$.
2e: (15 points) If we go beyond the square law, and consider the changes in the depletion width
along the channel, how would the drain current change when compared with the values predicted
by square-law, assuming the same $V_{GS}$ and $V_{DS}$? How would the onset voltage of current
saturation, $V_{Dsat}$, change? Please give quantitative reasoning for your predictions.

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