USC EE 105 · INTRODUCTION TO ELECTRICAL ENGINEERING · FALL 2026

Practice Midterm A

Modules 1 and 2 · Lectures 5 to 7, 9 and 10

Name _____ **Student ID** _____

Instructions

- Time: 120 minutes. Total: 100 points.
- Part I has 8 short problems (50 points). Plan about 45 minutes for Part I.
- Part II has 4 long problems (50 points). Plan about 65 minutes for Part II. Keep about 10 minutes to check your answers.
- Do not use a calculator. The numbers in each problem need only simple mental arithmetic.
- Show your method for each answer. Give the unit with each numerical answer.
- Where a problem tells you to leave an expression in a given form, do not reduce it further. You can leave a result such as 4/3 mA as a fraction.
- All wires and sources are ideal, unless a problem gives other data.
- Power: an element absorbs P = V·I when its current enters its "+" terminal (passive sign convention). When the current leaves the "+" terminal, the element supplies P = V·I.
- Notation: V_T is the MOSFET threshold voltage. kT/q is the thermal voltage in the diode equation. V_{TH} is a Thevenin voltage. I_s is the reverse saturation current of a diode.
- With resistances in kΩ and voltages in V, currents come out in mA and powers in mW.

Constants

- $q = 1.602 \times 10^{-19}$ C. Use $q \approx 1.6 \times 10^{-19}$ C in hand calculations.
- $n_i = 10^{10}$ cm^{-3} for Si at 300 K, and $n \cdot p = n_i^2$.
- kT/q = 0.026 V at 300 K.
- ln 10 ≈ 2.3, so (kT/q)·ln 10 ≈ 0.06 V.
- Photon energy: E (eV) = 1240 / λ (nm).
- Band gaps (L9-16): Ge 0.67 eV, Si 1.12 eV, GaAs 1.42 eV, GaP 2.25 eV, diamond 6.0 eV.
- Lengths: 1 cm = 10 mm = 10^4 μm.
- Prefixes: f = 10^{-15}, n = 10^{-9}, μ = 10^{-6}, m = 10^{-3}, k = 10^3, M = 10^6.

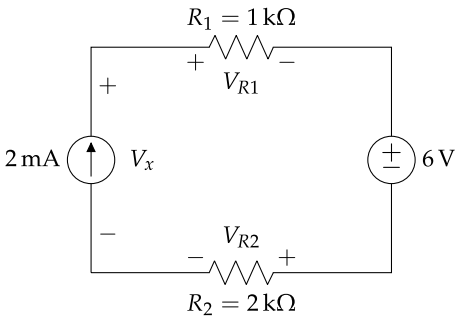
Score

Problem	1	2	3	4	5	6	7	8	Part I	9	10	11	12	Part II	Total
Points	6	6	6	7	6	6	7	6	50	13	12	13	12	50	100
Score															

Part I · Short problems (50 points)

Problem 1 (6 points)

A 2 mA current source, two resistors and a 6 V source form one loop. The figure shows the polarities of V_x, V_{R1} and V_{R2}.



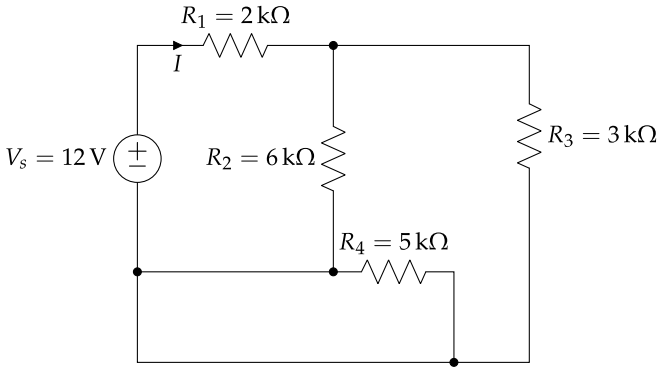
(a) Find the current in R_1 and in R_2. Find V_{R1} and V_{R2}. (2 points)

(b) Use KVL to find the voltage V_x across the current source. (2 points)

(c) Find the power of each source. State whether each source absorbs or supplies power. (2 points)

Problem 2 (6 points)

The circuit has one source and four resistors.



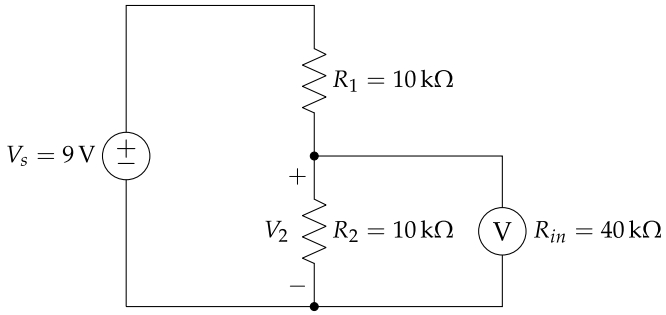
(**a**) How many distinct nodes does the circuit have? (Wires that connect form one node.) (2 points)

(**b**) One resistor carries no current. Name it and explain why. (1 point)

(**c**) Find the equivalent resistance R_{eq} that the source sees and the source current I. Then use the current divider to find the current in R_3. (3 points)

Problem 3 (6 points)

A 9 V source drives R_1 and R_2 in series. A voltmeter measures V_2, the voltage across R_2. The real meter is an ideal meter in parallel with an input resistance $R_{in} = 40\ k\Omega$.



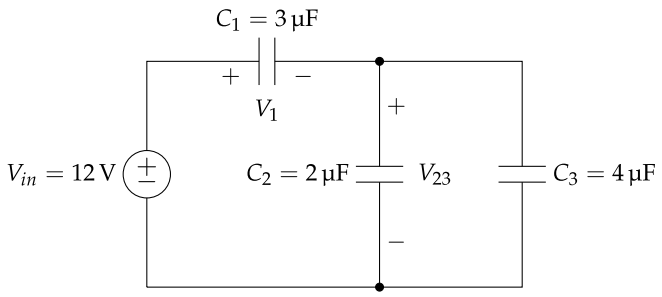
(a) Find V_2 if the meter is ideal ($R_{in} \to \infty$). (2 points)

(b) Find the voltage that the real meter reads. (2 points)

(c) Find the loading error in percent. State whether a meter with $R_{in} = 1\ M\Omega$ gives a larger or a smaller error. (2 points)

Problem 4 (7 points)

$C_1 = 3\ \mu F$ is in series with the parallel pair $C_2 = 2\ \mu F$ and $C_3 = 4\ \mu F$. The source applies $V_{in} = 12$ V. All capacitors start uncharged.



(a) Find the equivalent capacitance C_{eq}. (2 points)

(b) Find the charge Q on C_1 and the voltages V_1 and V_{23}. (3 points)

(c) A separate inductor $L = 2$ mH carries a current I_L that enters the "+" terminal of V_L. I_L rises at a steady rate from 0 to 6 mA in 3 μs. Find V_L during the rise. (2 points)

Problem 5 (6 points)

A Si sample is doped with phosphorus, $N_D = 10^{16}\ cm^{-3}$. Use $\mu_n = 1250\ cm^2/V{\cdot}s$.

(a) State whether phosphorus is a donor or an acceptor in Si. State whether the sample is n-type or p-type. Name the majority carrier. (1 point)

(b) Find n and p. (2 points)

(c) Find the conductivity σ and the resistivity ρ. Ignore the holes. (2 points)

(d) The sample is a bar with a length of 0.5 cm and a cross-section area of $2.5 \times 10^{-3}\ cm^2$. Find its resistance R. (1 point)

Problem 6 (6 points)

A red laser emits light at $\lambda = 620$ nm. A near-infrared laser emits light at $\lambda = 1000$ nm.

(**a**) Find the photon energy of each laser in eV. (2 points)

(**b**) For each laser, state which of Ge, Si, GaAs and GaP absorb its light. (2 points)

(**c**) Use the band model (E_c, E_v and E_g) to explain why GaAs is transparent to the 1000 nm light. (2 points)

Problem 7 (7 points)

An NMOS transistor has $\mu_n C_{ox} = 200\ \mu A/V^2$, $W/L = 20$ and $V_T = 0.5$ V. Its source is at 0 V.

(**a**) Find $k' = \mu_n C_{ox}(W/L)$. (1 point)

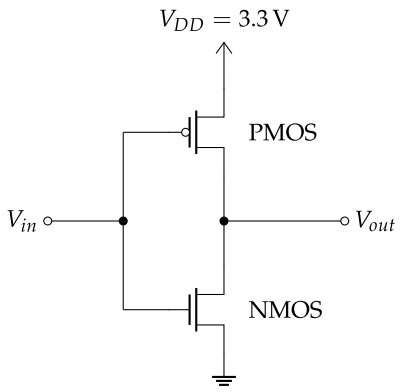
(**b**) $V_{GS} = 0.3$ V and $V_{DS} = 1$ V. Find the region and I_D. (1 point)

(**c**) $V_{GS} = 1.5$ V and $V_{DS} = 0.5$ V. Find the region and I_D. (3 points)

(**d**) $V_{GS} = 1.5$ V and $V_{DS} = 2$ V. Find the region and I_D. (2 points)

Problem 8 (6 points)

A CMOS inverter uses $V_{DD} = 3.3$ V. The NMOS has $V_T = 0.8$ V, and the PMOS has $V_T = -0.8$ V. The NMOS source is at GND, and the PMOS source is at V_{DD}.



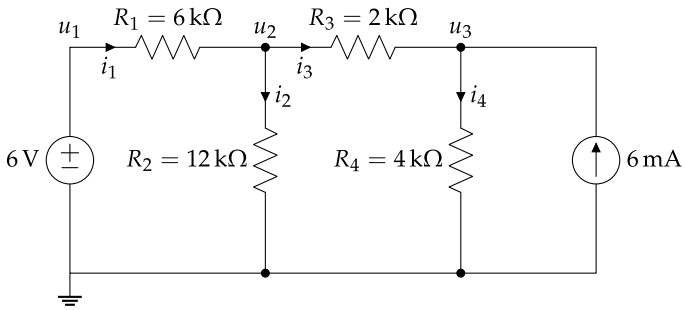
(**a**) Let $V_{in} = 0$ V, and then $V_{in} = 3.3$ V. For each input, find V_{GS} of each transistor. State whether each transistor is on or off. Give V_{out}. (4 points)

(**b**) The input stays at 0 V or at 3.3 V. Explain why the inverter then draws almost no current from V_{DD}. (2 points)

Part II · Long problems (50 points)

Problem 9 (13 points)

Use nodal analysis for this circuit. The bottom node is the reference node (ground). The figure defines the node voltages u_1, u_2 and u_3 and the currents i_1 to i_4.



(a) Which node voltage do you know without a calculation? Give its value and the reason. (1 point)

(b) Write KCL at node u_2 and at node u_3. Use Ohm's law to write each resistor current in terms of the node voltages. (4 points)

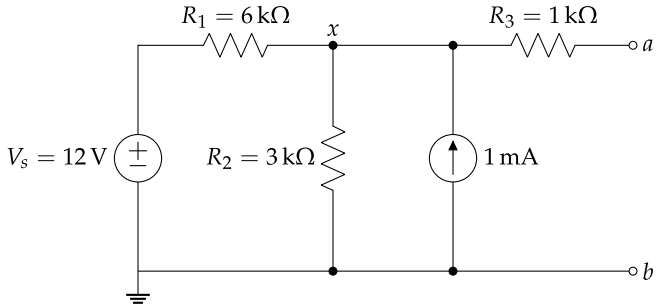
(c) Solve for u_2 and u_3. (3 points)

(d) Find i_1 and i_3. Explain the meaning of a negative value. (2 points)

(e) Find the power of the 6 V source and of the 6 mA source. State whether each source absorbs or supplies power. The four resistors absorb 90 mW in total. Show that the powers balance. (3 points)

Problem 10 (12 points)

The circuit drives the terminals a and b.



(a) Find the Thevenin voltage $V_{TH} = V_{ab}$ with a–b open. (3 points)

(b) Find the Thevenin resistance R_{TH}. Replace the ideal voltage source by a short circuit and the ideal current source by an open circuit. (2 points)

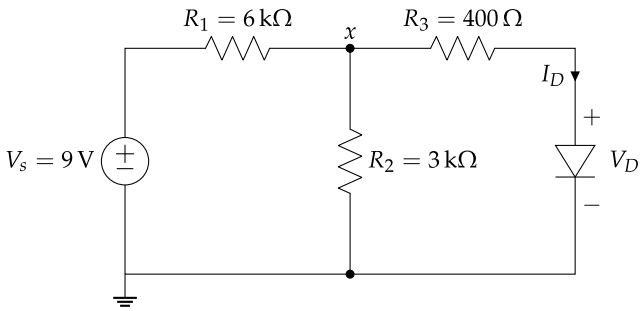
(c) Connect a wire from a to b. Find the Norton current I_N in this wire, and check that $I_N = V_{TH}/R_{TH}$. Then sketch the Thevenin and the Norton equivalent circuits (the sketch is worth 1 of the 3 points). (3 points)

(d) A load $R_L = 3\ \text{k}\Omega$ is connected across a–b. Use the Thevenin equivalent to find the load current I and the load voltage V. (2 points)

(e) A capacitor $C = 2\ \mu\text{F}$ replaces R_L. After a long time, the capacitor voltage no longer changes. Find this voltage and the charge on the capacitor. (2 points)

Problem 11 (13 points)

A voltage divider (V_s, R_1 and R_2) drives a Si diode through R_3. The diode has $I_s = 10^{-13}$ A and an ideality factor of 1. I_D is the diode current, and V_D is the diode voltage (anode minus cathode).



(a) Remove the branch with R_3 and the diode. Find the Thevenin equivalent (V_{TH} and R_{TH}) at node x with respect to ground. (3 points)

(b) Put the branch back. Model the conducting diode as a constant 0.6 V drop. Find I_D. (2 points)

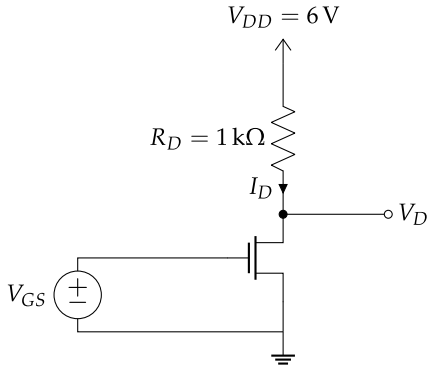
(c) Use the diode equation to find V_D at the current from (b). Use $(kT/q)\cdot\ln 10 \approx 0.06$ V. Does this V_D agree with the 0.6 V model? (3 points)

(d) Use your results to find V_x and the currents in R_1 and R_2 of the original circuit. (3 points)

(e) The diode is turned around, so its cathode faces node x. Find the diode current and the voltage across the diode. (2 points)

Problem 12 (12 points)

An NMOS transistor and a drain resistor $R_D = 1\ \text{k}\Omega$ connect to $V_{DD} = 6$ V. The source is at ground, and a voltage source V_{GS} drives the gate. The transistor has $k' = \mu_n C_{ox}(W/L) = 2\ \text{mA/V}^2$ and $V_T = 1$ V. It is a long-channel device.



(a) Let $V_{GS} = 2$ V. Assume saturation. Find I_D and V_D. Check the assumption. (3 points)

(b) For (a), find the gate-to-drain voltage $V_G - V_D$. Compare it with V_T and explain why the channel is pinched off at the drain end. (2 points)

(c) Let $V_{GS} = 3$ V. Find I_D and V_D. Show that the transistor is exactly at the edge of saturation. (2 points)

(d) Let $V_{GS} = 4$ V. Show that the transistor cannot be in saturation. In the linear region, KVL and the current equation give $V_{DS}^2 - 7 \cdot V_{DS} + 6 = 0$ (V_{DS} in V). Solve this equation, keep the root that meets the region condition, and find I_D. (3 points)

(e) Find V_D for $V_{GS} = 0$ V, and compare it with V_D for $V_{GS} = 4$ V. Explain why this circuit acts as an inverter. (2 points)