USC EE 105 · INTRODUCTION TO ELECTRICAL ENGINEERING · FALL 2026

Practice Midterm B

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.

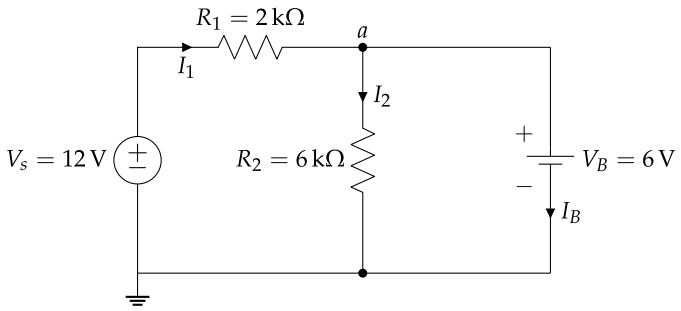
Score

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 12 V source charges a 6 V battery V_B through R_1. R_2 is in parallel with the battery.



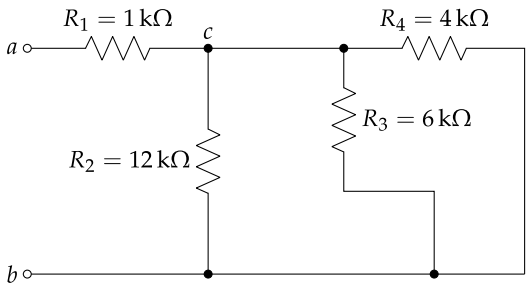
(a) Find the voltage V_a at node a and the current I_1 in R_1. (2 points)

(b) Find the current I_2 in R_2 and the battery current I_B. State whether I_B enters or leaves the "+" terminal of the battery, and whether the battery charges or discharges. (2 points)

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

Problem 2 (6 points)

The resistor network has two terminals, a and b.



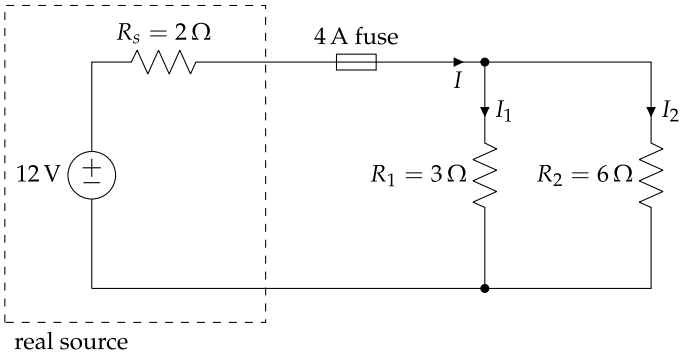
(a) How many distinct nodes does the network have? (Wires that connect form one node.) Which resistors connect the same pair of nodes? (2 points)

(b) Find the equivalent resistance R_{ab}. (3 points)

(c) A 9 V source is connected across a–b, with "+" at a. Find the source current. (1 point)

Problem 3 (6 points)

A real 12 V source has an internal resistance $R_s = 2\ \Omega$. It feeds two loads, $R_1 = 3\ \Omega$ and $R_2 = 6\ \Omega$, through a 4 A fuse.



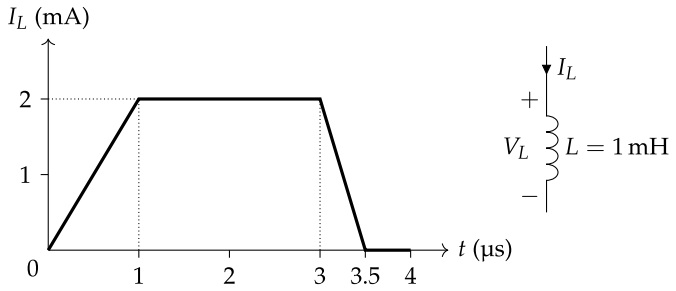
(a) Find the source current I and the voltage across the loads. Does the fuse blow? (2 points)

(b) Use the current divider to find I_1 and I_2. (2 points)

(c) R_2 fails and becomes a short circuit $(0\ \Omega)$. Find the new current I, and state whether the fuse blows. (2 points)

Problem 4 (7 points)

An inductor L = 1 mH carries the current I_L in the graph. I_L enters the "+" terminal of V_L.



(**a**) Find V_L in each interval: 0 to 1 μs, 1 μs to 3 μs, and 3 μs to 3.5 μs. (3 points)

(**b**) Two capacitors, $C_1 = 1$ μF and $C_2 = 3$ μF, start uncharged. They are connected in series across a 4 V source. Find C_{eq} and the voltage across each capacitor. (2 points)

(**c**) Each of these capacitors is rated 6 V. Find the largest source voltage that keeps both capacitors within their ratings. (2 points)

Problem 5 (6 points)

A Si sample is doped with boron, $N_A = 10^{17}$ cm^{-3}. Use $\mu_p = 250$ cm^2/V·s.

(**a**) State whether boron 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 p and n. (2 points)

(**c**) Find the conductivity σ and the resistivity ρ. Explain why you can ignore the electrons. (3 points)

Problem 6 (6 points)

A Si diode has $I_s = 2 \times 10^{-12}$ A and an ideality factor of 1. V is the diode voltage (anode minus cathode), and I is the diode current from anode to cathode.

(**a**) Find I at V = 0.52 V. First write I in the form $I_s \cdot e^{(\cdots)}$. Then use $e^{20} \approx 4.85 \times 10^8$. (2 points)

(**b**) By what factor does I increase when V increases by 60 mV? Find I at V = 0.58 V. (2 points)

(**c**) Find I at V = −3 V. State which terminal is more positive in this case, and explain why the current is so small. (2 points)

Problem 7 (7 points)

A PMOS transistor has $k' = \mu_p C_{ox}(W/L) = 1\ \text{mA/V}^2$ and $V_T = -1$ V. Its source is at $V_{DD} = 5$ V. Use the NMOS current equations with all signs reversed: use V_{SG} for V_{GS}, V_{SD} for V_{DS} and $|V_T|$ for V_T. The current flows from source to drain.

(**a**) Find the range of gate voltages V_G that turn the PMOS on. (2 points)

(**b**) $V_G = 2$ V and $V_D = 4$ V. Find the region and the current. (3 points)

(**c**) $V_G = 2$ V and $V_D = 1$ V. Find the region and the current. (2 points)

Problem 8 (6 points)

An NMOS transistor has $V_T = 1$ V. Its gate is at $V_G = 5$ V, its source is at $V_S = 0$ V, and its drain is at $V_D = 2$ V.

(**a**) Find the voltage across the oxide at the source end and at the drain end of the channel. (2 points)

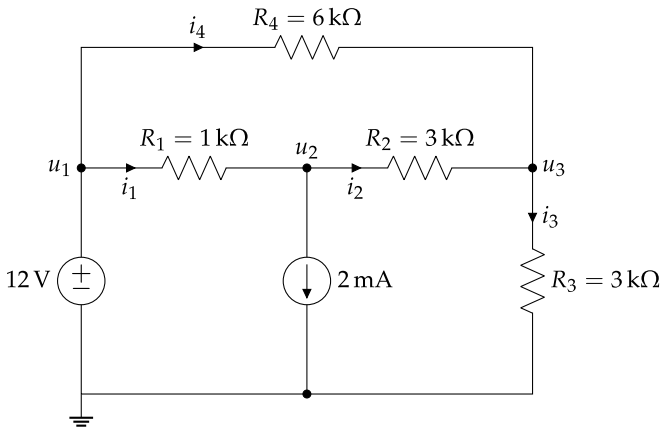
(**b**) The channel charge per unit area is proportional to (oxide voltage $- V_T$). Find the ratio of the charge at the drain end to the charge at the source end. (2 points)

(**c**) At what V_D does the channel pinch off at the drain end? In one or two sentences, explain why I_D stays almost constant when V_D rises above this value. (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)

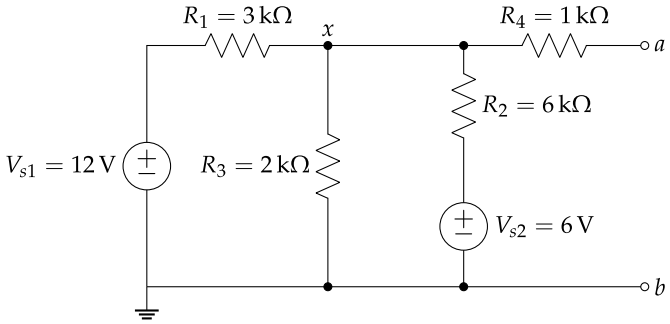
(c) Solve for u_2 and u_3. (3 points)

(d) Find i_1 and i_4. Find the current that the 12 V source delivers. (2 points)

(e) Find the power of the 12 V source and of the 2 mA source. State whether each source absorbs or supplies power. The four resistors absorb 30 mW in total. Show that the powers balance. (3 points)

Problem 10 (12 points)

Two voltage sources drive 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}. (2 points)

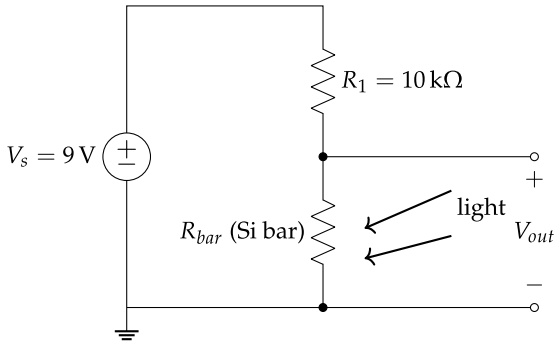
(c) Connect a wire from a to b. Find the Norton current I_N in this wire, and check that $I_N = V_{TH}/R_{TH}$. Then sketch the Thevenin and the Norton equivalent circuits (the sketch is worth 1 of the 3 points). (3 points)

(d) Find the reading of an ideal voltmeter connected between a and b. Then find the reading of a real voltmeter with $R_{in} = 18\ \text{k}\Omega$ between a and b. (2 points)

(e) A load $R_L = 8\ \text{k}\Omega$ is connected across a–b. Find the load current and the load voltage. (2 points)

Problem 11 (13 points)

A bar of lightly doped n-type Si is a light sensor in a voltage divider. The bar has $N_D = 10^{14}$ cm^{-3}, a length of 2 mm and a cross-section of 1 mm × 0.1 mm. Use $\mu_n = 1250$ cm^2/V·s and $\mu_p = 500$ cm^2/V·s. The divider has $V_s = 9$ V and $R_1 = 10$ kΩ. V_{out} is the voltage across the bar.



(a) In the dark, find n and p in the bar. (2 points)

(b) In the dark, find σ, ρ and the bar resistance R_{bar}. Explain why you can ignore the holes. (3 points)

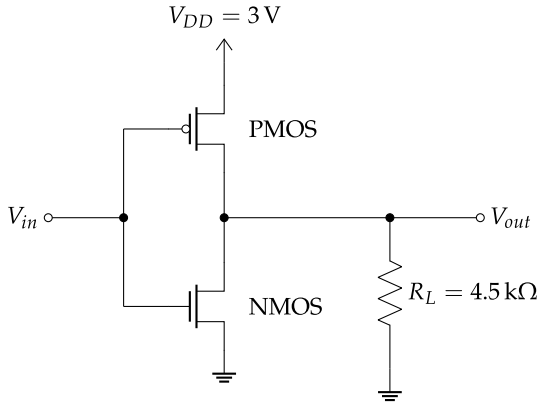
(c) Find V_{out} in the dark. (2 points)

(d) Red light with λ = 620 nm shines on the bar. Show that Si absorbs this light. The light creates $\Delta n = \Delta p = 5 \times 10^{14}$ cm^{-3} in the whole bar. Find the new σ. Use the ratio of the new σ to the dark σ to find the new R_{bar} and V_{out}. (4 points)

(e) Infrared light with λ = 1550 nm replaces the red light. Find V_{out}. Explain. (2 points)

Problem 12 (12 points)

A CMOS inverter uses $V_{DD} = 3$ V. The NMOS has $k'_n = \mu_n C_{ox}(W/L) = 2\ \text{mA/V}^2$ and $V_T = 1$ V. The PMOS has the same W/L, so $k'_p = 1\ \text{mA/V}^2$, because holes have about half the mobility of electrons. The PMOS has $V_T = -1$ V. A transistor that is on, with a small $|V_{DS}|$, acts as a resistor $R_{CH} = 1/[k' \cdot (|V_{GS}| - |V_T|)]$.



(a) For $V_{in} = 0$ V and for $V_{in} = 3$ V, state which transistor is on. Find its R_{CH}. (3 points)

(b) The load $R_L = 4.5\ \text{k}\Omega$ connects the output to GND. For $V_{in} = 0$ V, find V_{out} and the current from V_{DD}. For $V_{in} = 3$ V, find V_{out} and the current from V_{DD}. (4 points)

(c) By what factor must the PMOS W/L change to make its R_{CH} equal to the R_{CH} of the NMOS? (1 point)

(d) Remove R_L. The output now drives only the capacitance C = 20 fF of the next gates. The input falls from 3 V to 0 V, and the output rises from 0 V to 3 V. Find the charge that flows from V_{DD} onto C. The output makes 5×10^8 of these 0-to-1 transitions each second. Find the average current from V_{DD} and the average power $V_{DD} \cdot I$. (4 points)