McGill University
Faculty of Engineering

COURSE: 304-200B – Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee

Associate Examiner: Dr. D. Giannacopoulos

Date: Friday 20 April 2001 **Time:** 14:00 – 17:00

INSTRUCTIONS

(a) *READ* all four exam questions *VERY CAREFULLY!*

(b) Answer *ALL* 4 questions (pp. 2–17) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(c) Individual question values are indicated in the margin at the start of each question. The exam total is 70 marks.

Note: only your 5 worst parts in ques #1 count (4.4 marks each).

Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ______________________________

(22/70) 1. Provide a clear and concise definition for each of the following circuit analysis terms. Also, write a short, direct and specific answer to each associated question that is listed. (You may use diagrams and/or examples to help clarify your responses if you choose.)

(a) **Kirchhoff's current law (KCL).** What conservation law is represented by KCL?

(b) **Kirchhoff's voltage law (KVL).** What conservation law is represented by KVL?

(c) **Lumped-parameter two-terminal device model.** What is a *v-i* characteristic and how are they connected with lumped-parameter two-terminal device models?

(d) **Passive sign convention.** Explain how the passive sign convention is involved in each of the lumped-parameter two-terminal definitions for power and resistance.

(e) **Ideal op-amp model.** What are the assumptions on R_i, R_o and A for this model? Also, what are the typical values for R_i, R_o and A for practical op-amp devices?

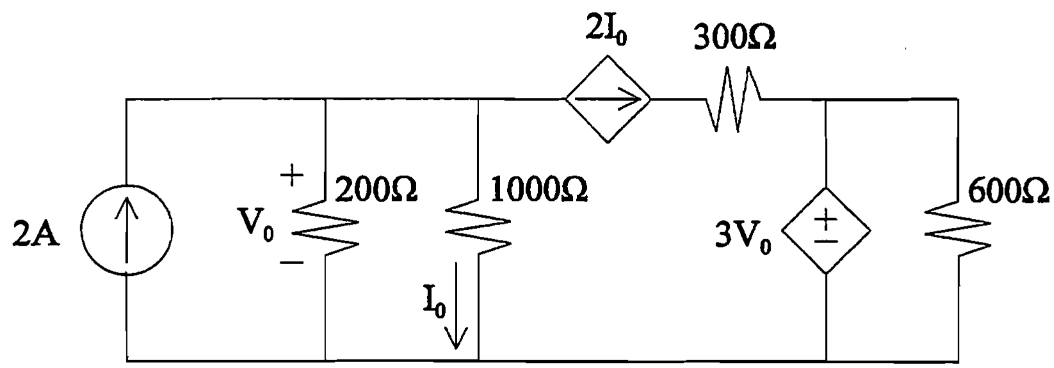
(f) **Ideal ohmmeter.** Describe a model for a ohmmeter (non-ideal) which is based on an ideal ammeter, and explain why the operation of this ohmmeter is not ideal.

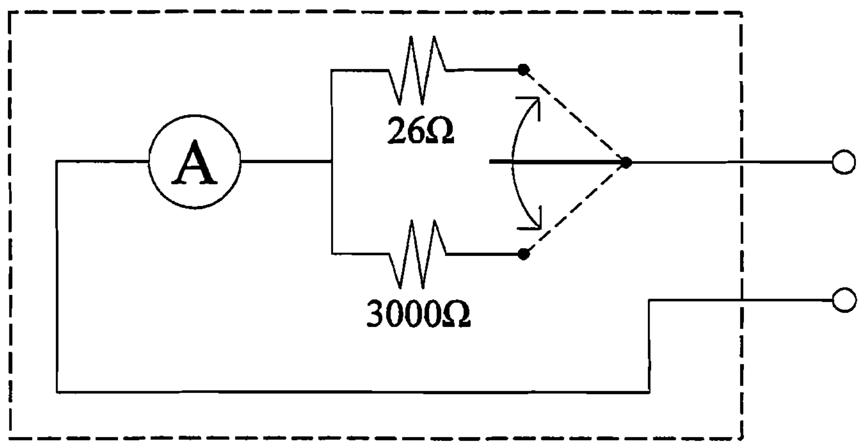
(g) **D.C. steady-state.** What is significant about the operation of ideal capacitors and inductors when they are in D.C. steady-state? What changes if they are non-ideal?

(h) **Capacitance.** What is meant by "dielectric breakdown"; what causes it to occur; and what is the effect on the charge and stored energy of a capacitor when it occurs?

(i) **Inductance.** State (specifically) how voltage, current and power are transformed from the primary to the secondary, according to the ideal A.C. transformer model.

(12/70) 2. Consider the linear circuit and the multimeter illustrated below; answer the following:





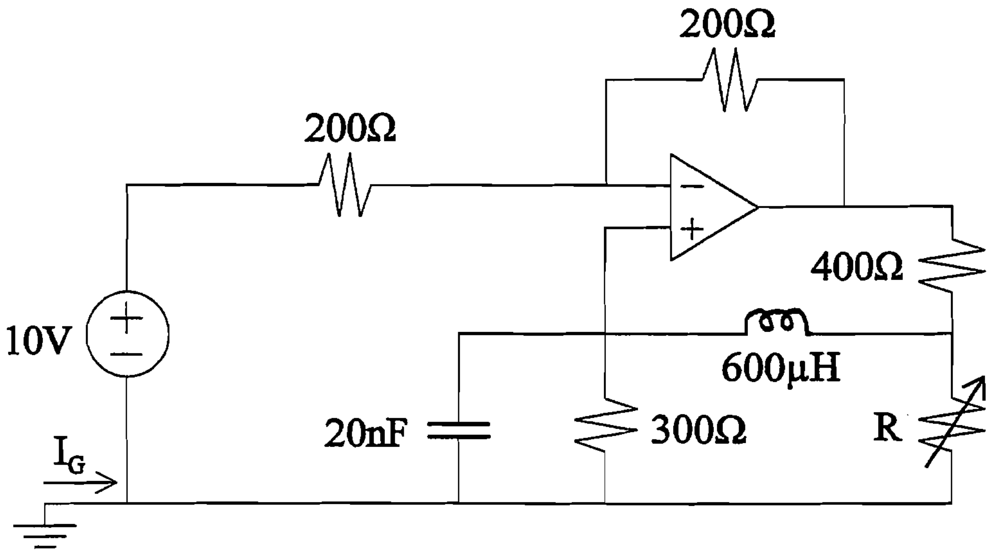
(Switchable resistance multimeter)

(a) Calculate the actual values of the voltage labeled V_0 and the current labeled I_0.

(b) Calculate the values of V_0 and I_0 that you would measure using this multimeter. Assume your measurements must be taken one at a time, exactly where V_0 and I_0 are defined in the circuit. Use the "best" multimeter resistance setting in each case.

(c) Assume the exact values of the four resistors in the circuit were unknown. Explain how you could find the actual values of V_0 and I_0 using the multimeter provided.

(14/70) 3. Consider the linear circuit shown below. Assume that the op-amp is ideal, and that the circuit is stable and operating in D.C. steady-state. Answer the following questions:



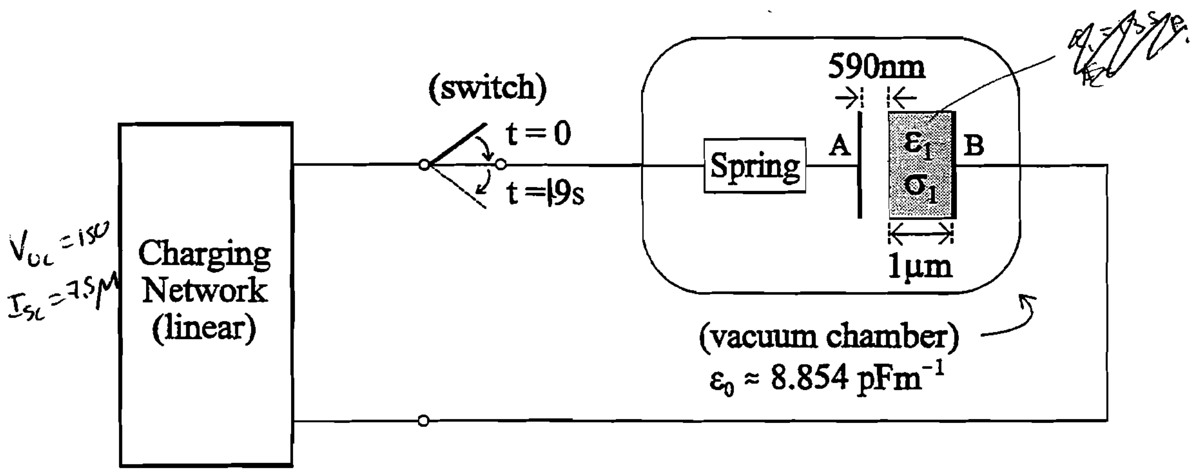
(a) Calculate the power supplied to the circuit by the independent source if R = 600Ω.

(b) Find the value (non-negative) of the variable resistance R that yields I_G = 250mA.

(c) Find the two non-negative values of R that would yield the highest and the lowest stored energy levels for the passive elements of the circuit. Also, find the values of these two steady-state stored energy levels, and briefly explain how they would be affected (increase / decrease / no change) if the 600μH inductor was non-ideal.

(22/70) 4. A specialized electro-mechanical relay system is shown below. The charging network is defined by $V_{OC} = 150V$ and $I_{SC} = 7.5\mu A$. The switch is ideal, and all wires, contacts and electrodes are perfectly conducting. The spring is also perfectly conducting, and yields a constant return force of 84N when stretched (it is at its natural length at t = 0−). The two thin electrodes, labeled "A" and "B", are identical square plates (2cm × 2cm); the dielectric slab (2cm × 2cm × 1μm) is defined by $\varepsilon_1 = 135pFm^{-1}$ and $\sigma_1 = 125pSm^{-1}$; and all three parts are aligned to form the parallel plate capacitor construction pictured.

Note: The capacitor diagram is not drawn to scale. The switch moves twice: it is open for all t < 0; closes at t = 0; then opens again at t = 9s (stays open for all t > 9s).



Assume that the two electrodes are uncharged at t = 0−; neglect all inductance, friction and mass-related effects; neglect all fringing fields; and answer each of the following:

(a) Provide circuit models to represent the charging network and the capacitor device, using only ideal circuit elements and connecting wires. Be sure to state all values.

(b) Find the time t when the spring will first start to stretch (i.e. electrode A will start to move towards the dielectric slab). Also, find the capacitor charge at that time t.

(c) Assume that electrode A will take 9.67 s to move across the 590nm distance, once it starts to move. Find the total time electrode A will stay in contact with the slab.

(d) Find the value of the maximum power dissipated as heat in the slab over all t > 0.

McGill University
Faculty of Engineering

COURSE: 304-200A – Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee *Steve McFee*

Associate Examiner: Dr. D. Giannacopoulos *D. Giannacopoulos*

Date: Thursday 14 December 2000 **Time:** 14:00 - 17:00

INSTRUCTIONS

(a) *READ* all five exam questions *VERY CAREFULLY!*

(b) Answer *ALL* 5 questions (pp. 2–21) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(c) Individual question values are indicated in the margin at the start of each question. The exam total is 70 marks.

Note: only your 6 worst parts in ques #1 count (3 marks each).

Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ______________________________

(18/70) 1. Provide a clear and concise definition for each of the following circuit analysis terms. Also, write a short, direct and specific answer to each associated question that is listed. (You may use diagrams and/or examples to help clarify your responses if you choose.)

(a) **Kirchhoff's current law (KCL).** What conservation law is represented by KCL?

(b) **Kirchhoff's voltage law (KVL).** What conservation law is represented by KVL?

(c) **Equivalent resistance (R_{eq}) of a two-terminal network.** When is R_{eq} physical?

(d) **Power absorbed by a two-terminal network.** What is implied if it is negative?

(e) **Ideal op-amp model.** What are the assumptions on R_i, R_o and A for this model?

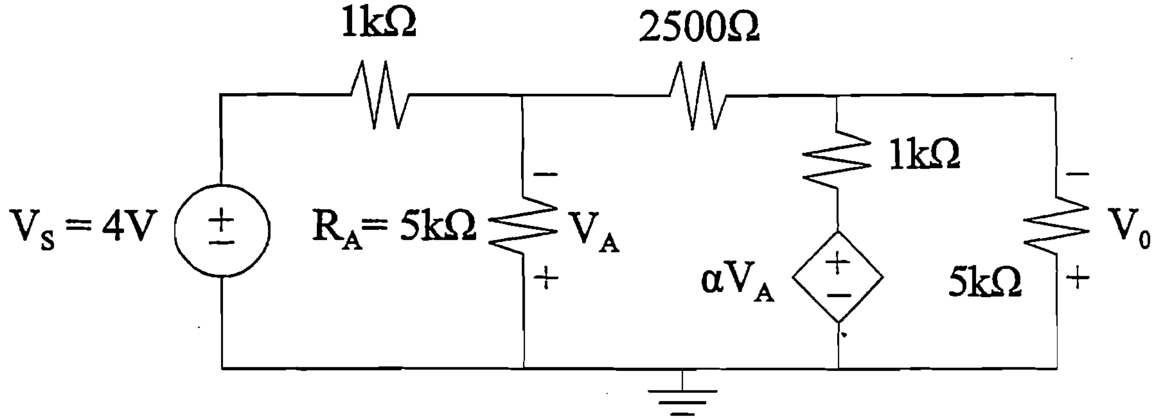
(f) **Ideal source of emf.** What is the two-resistor model for a non-ideal source of emf, and what performance characteristics do the resistors represent in the model?

(g) **Ideal voltmeter.** Describe a model for a voltmeter (non-ideal) which is based on an ideal ammeter, and explain why the operation of this voltmeter is not ideal.

(h) **D.C. steady-state.** What is significant about the performance of capacitors and inductors under D.C. steady-state operation?

(i) **Capacitance.** What is meant by "dielectric breakdown"; what causes it to occur; and what is the effect on the charge and stored energy of a capacitor when it occurs?

(14/70) 2. Consider the linear circuit shown below and answer each of the following questions:

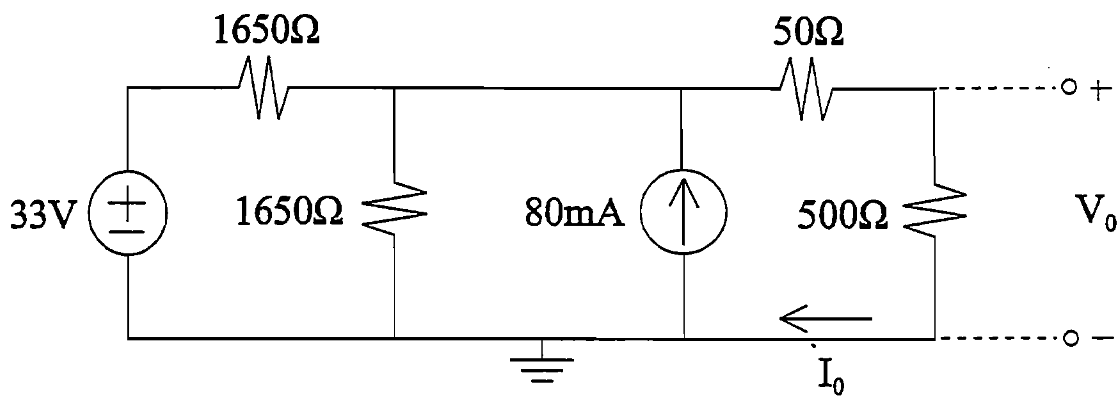


(a) Find the voltage gain of the circuit, defined by V_0 / V_S, in the limit as $\alpha \to \infty$.

(b) Find the power supplied by the controlled source in the limit as $\alpha \to \infty$.

(c) Find the value(s) of α that make the resistance $R_A = 5k\Omega$ absorb $200\mu W$.

(14/70) 3. Consider the linear circuit shown below and answer each of the following questions:



(a) Calculate the exact values of the current labeled I_0 and the voltage labeled V_0.

(b) Calculate the value of I_0 that would be measured if an ammeter with an internal resistance of 50Ω was used. What is the percent error of this measurement?

(c) Calculate the value of V_0 that would be measured if an voltmeter with an internal resistance of 4500Ω was used. What is the percent error of this measurement?

(d) Redo the calculations of parts (b) and (c), assuming that the two measurements are done at the same time (both meters connected to the circuit simultaneously). How do the errors change? Briefly explain why this happens (be specific!).

(14/70) 4. Consider a "leaky", but otherwise ideal parallel-plate capacitor, which is filled with a single dielectric material. The two identical conductor plates are square, and each has an effective area of 5cm^2. The separation between the plates (and dielectric thickness) is 2mm. The (non-ideal) dielectric insulator has a linear permittivity of 3 μF/m and an ohmic conductivity of 20 μS/m. Assume that the capacitor is connected across a linear battery, through an ideal switch, that is set to close the single-loop circuit at time $t = t_0$. The battery is defined below, and all the wires and contacts have negligible resistance. Answer the questions below.

Battery Specifications: open-circuit output voltage = 100 V_{DC} ;
open-circuit internal losses = 50 mW ;
short-circuit output current = 2 mA_{DC} .

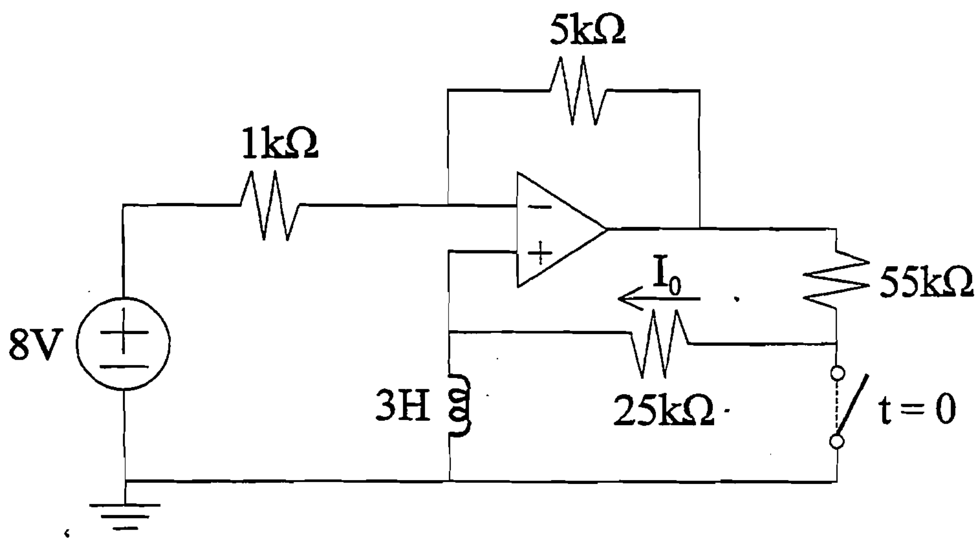
(a) Propose a circuit model to represent the system described above. Be sure to show all the circuit elements required, their specific values, and how they are connected together. (Your circuit model should be fully defined, i.e., ready to be analyzed.)

(b) Find the maximum value for the charge on the capacitor for all time $t > t_0$.

(c) Assume the capacitor is fully charged, then disconnected and open-circuited. Find the minimum time needed for the device to discharge to a negligible energy level.

(d) Assume the non-ideal dielectric material will melt if it is heated to a power density of 400 $\mu\text{W/mm}^3$. Find the maximum allowable operating voltage for the device.

(10/70) 5. Assume the ideal op-amp circuit below is stable, and answer the following questions: (The switch is open for all $t < 0$, then closes at $t = 0$, and remains closed for all $t > 0$.)



(a) Find the value of the energy that is stored by the inductor at time $t = 0^-$.

(b) Determine the current labeled I_0, as a function of time, for all time $t > 0$.

McGill University
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COURSE: 304-200B - Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee Steve McFee.

Associate Examiner: Dr. D. Giannacopoulos D. Giannacopoulos

Date: Tuesday 18 April 2000 **Time:** 14:00 - 17:00

INSTRUCTIONS

(a) *READ* all five exam questions *VERY CAREFULLY!*

(b) Answer *ALL* 5 questions (pp. 2-14) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(c) Individual question values are indicated in the margin at the start of each question. The five questions total 100%.

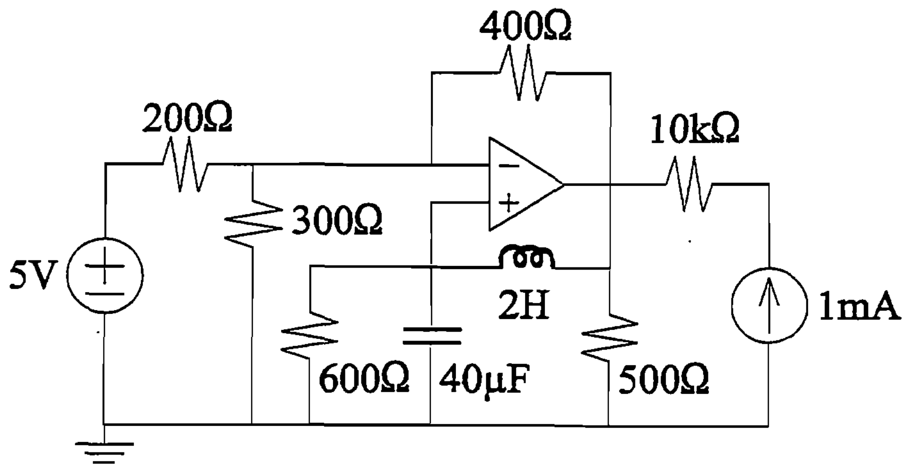
Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ______________________________

(20%) 1. Consider the circuit provided below. Assume that all the elements are linear and ideal, and that the circuit is in stable DC steady-state operation. Answer the questions below:



(a) Calculate the powers supplied by the two sources (two values).

(b) Determine which resistor dissipates the <u>most</u> heat per second, and find the value of the electrical energy absorbed by that resistor in one second.

(c) Determine which resistor dissipates the <u>least</u> heat per second, and find the value of the electrical energy absorbed by that resistor in one second.

(d) Calculate the energies stored by the capacitor and the inductor (two values).

(e) How would the capacitor and inductor energies differ (increase/decrease/same) if the 600Ω resistor was made of a <u>non-ohmic</u> metallic wire. (Briefly explain why.)

(20%) 2. Consider the linear networks provided below; answer each of the following questions:

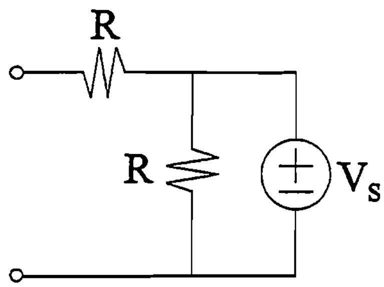


Fig. 1. See (b).

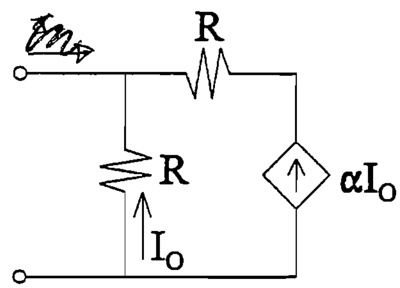


Fig. 2. See (c).

(a) Clearly and concisely state the operational definition of Ohm's Law.

(b) Clearly demonstrate whether the network shown in Fig. 1 is ohmic or non-ohmic. Determine an expression for the equivalent resistance of the network if it is ohmic.

(c) Clearly demonstrate whether the network shown in Fig. 2 is ohmic or non-ohmic. Determine an expression for the equivalent resistance of the network if it is ohmic.

(20%) 3. Clearly explain how to measure an exact Thevenin equivalent circuit representation for a practical battery, using only an ideal ammeter and a 10kΩ resistor. You may assume that the battery is linear and fully charged. Express your solution clearly and concisely in terms of specific current measurements. Please note that you are not allowed to use any other equipment or data in your proposed solution, except for that provided above.

Also: Determine the worst case underestimate and the worst case overestimate for the value of the Thevenin resistance that could be found using your approach, if the 10kΩ resistor had a tolerance of ±10%, and the ammeter was subject to a ±5% error per measurement. Assume $0 < R_{INT} < 95k\Omega$ for this battery, and express your answers in terms of the exact current(s) used to answer the question above.

Note: Please feel free to use circuit diagrams to illustrate and clarify your explanation.

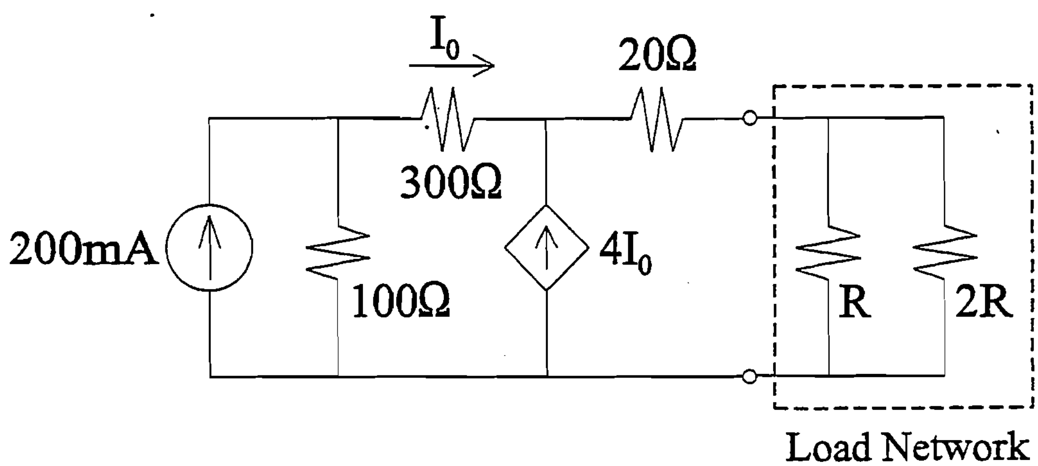
(20%) 4. Consider the linear circuit provided below and answer the following questions:

(a) Determine the value of R that yields <u>maximum</u> power transfer to the <u>load network</u>.

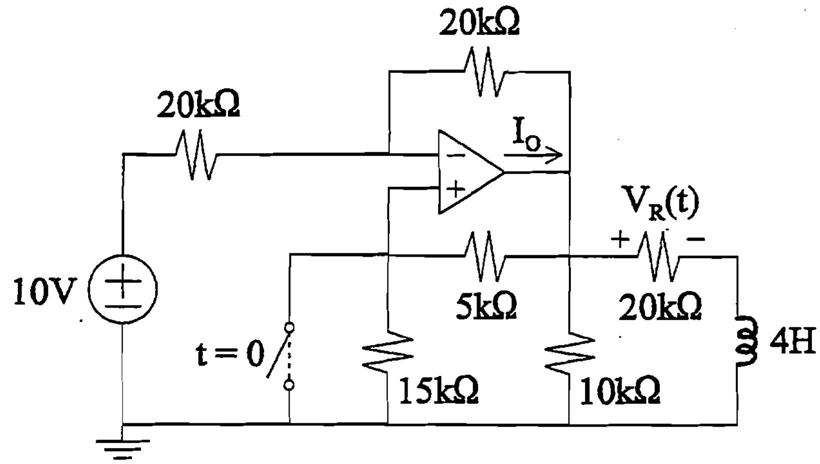
(b) Find the amount of <u>heat loss</u> for the load network <u>per second</u>, for this value of R.

Calculate the power supplied by each source (two values), for this value of R.

(d) Determine the value of R that yields <u>maximum</u> power transfer to the load network, subject to the <u>constraint</u> that the power supplied by the 200mA source to the entire circuit be equal to exactly <u>five times</u> the power supplied by the controlled source.



(20%) 5. Assume the ideal op-amp circuit below is stable, and answer the following questions: (The switch is open for all $t < 0$, then closes at $t = 0$, and remains closed for all $t > 0$.)



(a) Determine the resistor voltage labeled $V_R(t)$ for all time $t > 0$.

(b) Determine the op-amp output current labeled I_O for all time $t > 0$.

(c) Explain qualitatively how and why the individual voltage and current results found in parts (a) and (b) would change (or not change) if the inductor was non-ideal.

McGill University
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COURSE: 304-200A - Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee *Steve McFee.*

Associate Examiner: Dr. D. Giannacopoulos

Date: Monday 20 December 1999 **Time:** 9:00 - 12:00

INSTRUCTIONS

(a) *READ* all five exam questions *VERY CAREFULLY!*

(b) Answer *ALL* 5 questions (pp. 1 - 14) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(c) Individual question values are indicated in the margin at the start of each question. The five questions total 100%.

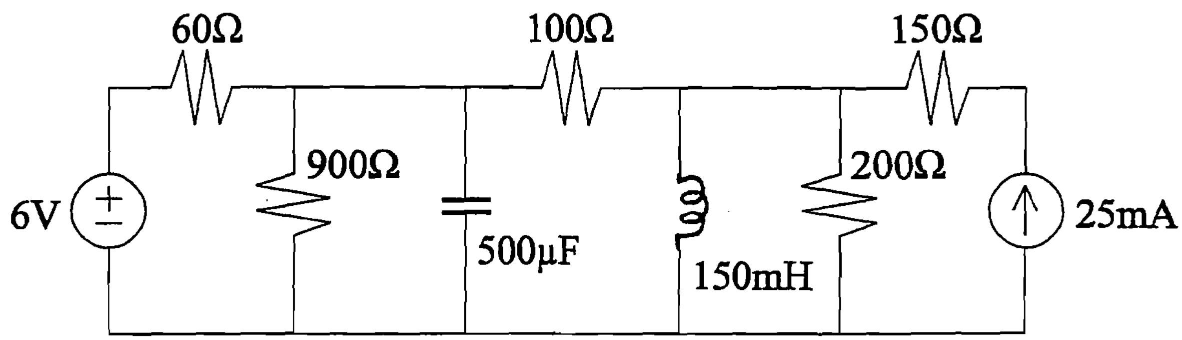
Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ____________________________

(25%) 1. Consider the circuit provided below. Assume that all the elements are linear and ideal, and that the circuit is operating in DC steady-state. Answer the questions listed below:



(a) Calculate the powers supplied by the two sources (two values).

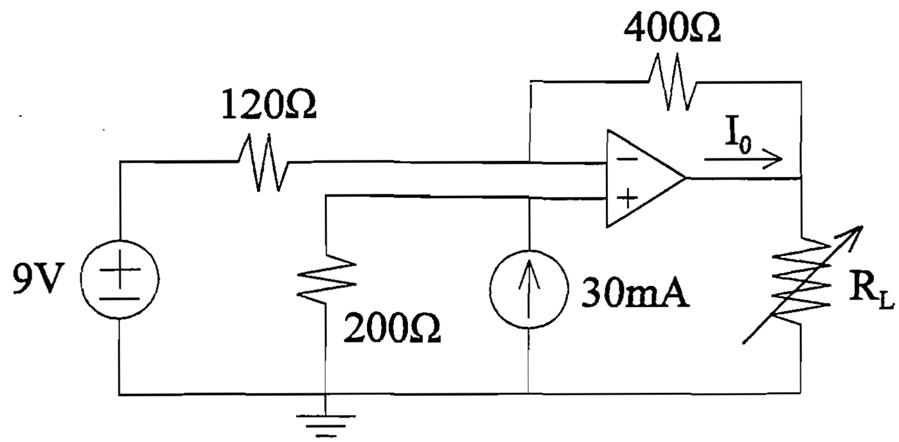
(b) Determine which resistor dissipates the <u>most</u> heat per second, and find the value of the electrical energy absorbed by that resistor in one second.

(c) Determine which resistor dissipates the <u>least</u> heat per second, and find the value of the electrical energy absorbed by that resistor in one second.

(d) Calculate the energies stored by the capacitor and the inductor (two values).

(e) How would the capacitor and inductor energies differ (increase/decrease/same) if the 100Ω resistor was made of a <u>non-ohmic</u> metallic wire. (Briefly explain why.)

(15%) 2. Consider the circuit provided below and answer each of the following questions: (Assume that the ideal op–amp model is valid for each part.)



(a) Find the powers absorbed by each of the three fixed resistances, if $R_L = 520\Omega$.

(b) Find the op-amp output current labelled I_0 if $R_L = 160\Omega$.

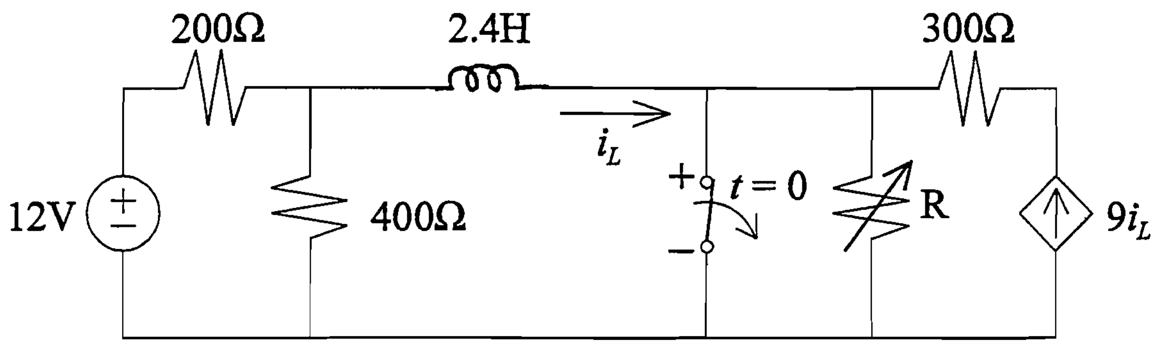
(c) Assume that the op-amp supplies are fused to shutdown if the total op-amp output power demand exceeds 300mW. Find the smallest value of R_L that can be used in this circuit without causing the op-amp power supplies to shutdown. Finally, find the power absorbed by this minimal load resistance.

(15%) 3. Clearly explain how to determine the exact Norton equivalent circuit representation for a practical battery, using only an ideal voltmeter and a 10kΩ resistor. You may assume that the battery is linear and fully charged. Express your solution clearly and concisely in terms of specific voltage measurements. Please note that you are not allowed to use any other equipment or data in your proposed solution, except for that provided above.

Also: Determine the worst case overestimate for the value of the Thevenin resistance that could be found using your approach, if the 10kΩ resistor had a tolerance of ±10%, and the voltmeter was subject to a ±5% error per measurement. Express your answer in terms of the exact voltage(s) used to answer the question above.

Note: Please feel free to use circuit diagrams to illustrate and clarify your explanation.

(?0%) 4. Consider the switched R-L circuit provided below. The switch is set to remain closed until time $t = 0$, at which time it opens and stays open. Assume all the circuit elements are ideal, and answer the questions listed below.



(a) Find the voltage across the open-circuited switch for all time $t > 0$, if R = 50Ω. Assume that the circuit is operating in *dc* steady state just prior to time $t = 0$.

(b) Find the value of R which minimizes the energy stored by the inductor as $t \to \infty$.

(c) Find the value of R which maximizes the energy stored by the inductor as $t \to \infty$.

(25%) 5. Consider an ideal parallel-plate capacitor that is filled with a single dielectric material. The two identical conductor plates are square, and each has an effective area of 4cm^2. The separation between the plates (and thickness of dielectric) is 1mm. The dielectric material has a linear permittivity of 200 nF/m and an ohmic conductivity of 100 μS/m. Assume that this "leaky" capacitor is connected across a linear battery, through an ideal switch, which is set to close the single-loop circuit at time $t = t_0$. The battery is defined below, and all wires/contacts are of negligible resistance. Answer the questions below.

Battery Specifications: open-circuit output voltage = 25 V_{DC} ;
open-circuit internal losses = 80 mW ;
short-circuit output current = 5 mA_{DC} .

(a) Propose a circuit model to represent the system described above. Be sure to show all the circuit elements required, their specific values, and how they are connected together. (Your circuit model should be fully defined, i.e., ready to be analyzed.)

(b) Find the maximum value for the charge on the capacitor for all time $t > t_0 + 10\text{s}$.

(c) Assume the capacitor has zero energy stored at time $t = t_0$. Find the minimum time needed for the capacitor to reach 80% of its maximum charge level, as found in (b).

(d) Assume the capacitor is fully charged, then disconnected and open-circuited. Find the minimum time needed for the device to discharge to a negligible energy level.

(e) Assume the capacitor dielectric material will melt if it is heated to a power density of $100\ \text{mW/mm}^3$. Find the maximum allowable operating voltage for the device.

McGill University
Faculty of Engineering

COURSE: 304-200B – Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee

Associate Examiner: Dr. D. Giannacopoulos

Date: Friday 16 April 1999 **Time:** 14:00 - 17:00

INSTRUCTIONS

(a) *READ* all five exam questions *VERY CAREFULLY!*

(b) Answer *ALL* 5 questions (pp. 1–13) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(c) Individual question values are indicated in the margin at the start of each question. The five questions total 100%.

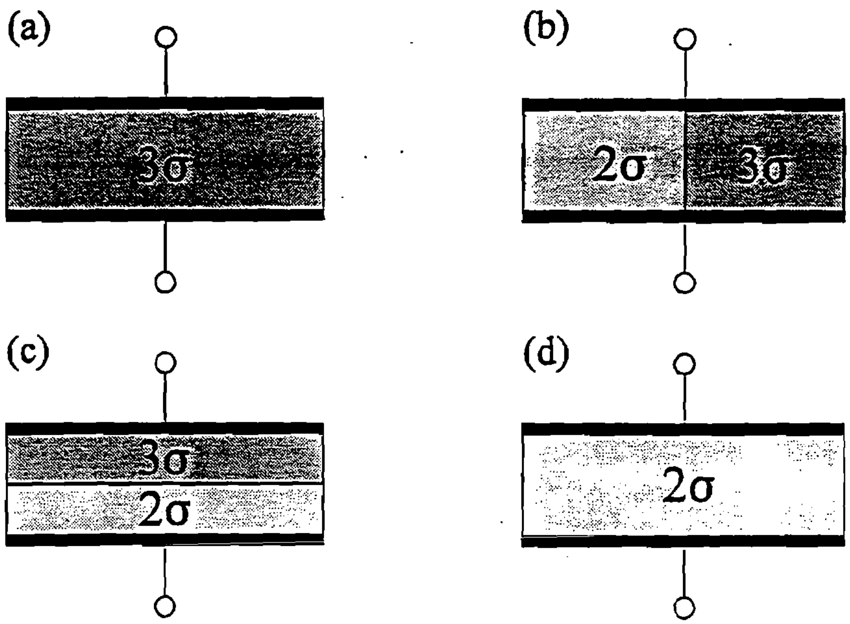
Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ______________________________

(20%) 1. The four parallel-electrode resistor constructions shown below are identical except for the conductive materials between the electrodes. The 2σ material becomes non-ohmic above 3kV/mm and the 3σ material becomes non-ohmic above 2kV/mm.



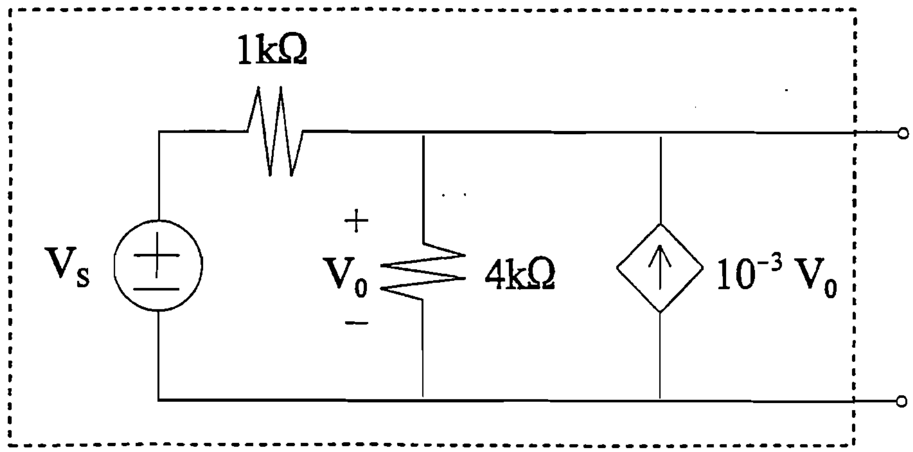
(a) Determine the relative ordering of the ohmic resistance values for the devices. (Mark an "X" in one of the boxes provided below to indicate your answer.)

- ☐ R(a) < R(b) < R(c) < R(d)
- ☐ R(a) < R(c) < R(b) < R(d)
- ☐ R(b) < R(a) < R(c) < R(d)
- ☐ R(c) < R(a) < R(b) < R(d)
- ☐ R(d) < R(b) < R(c) < R(a)
- ☐ R(d) < R(c) < R(b) < R(a)
- ☐ R(b) < R(d) < R(c) < R(a)
- ☐ R(c) < R(d) < R(b) < R(a)

(b) Order the resistors in terms of their maximum ohmic heating output capacities. (Mark an "X" in one of the boxes provided below to indicate your answer.)

- ☐ P(a) < P(b) < P(c) < P(d)
- ☐ P(a) < P(c) < P(b) < P(d)
- ☐ P(b) < P(a) < P(c) < P(d)
- ☐ P(c) < P(a) < P(b) < P(d)
- ☐ P(d) < P(b) < P(c) < P(a)
- ☐ P(d) < P(c) < P(b) < P(a)
- ☐ P(b) < P(d) < P(c) < P(a)
- ☐ P(c) < P(d) < P(b) < P(a)

(20%) 2. Consider the two-terminal linear network contained within the box, illustrated below.

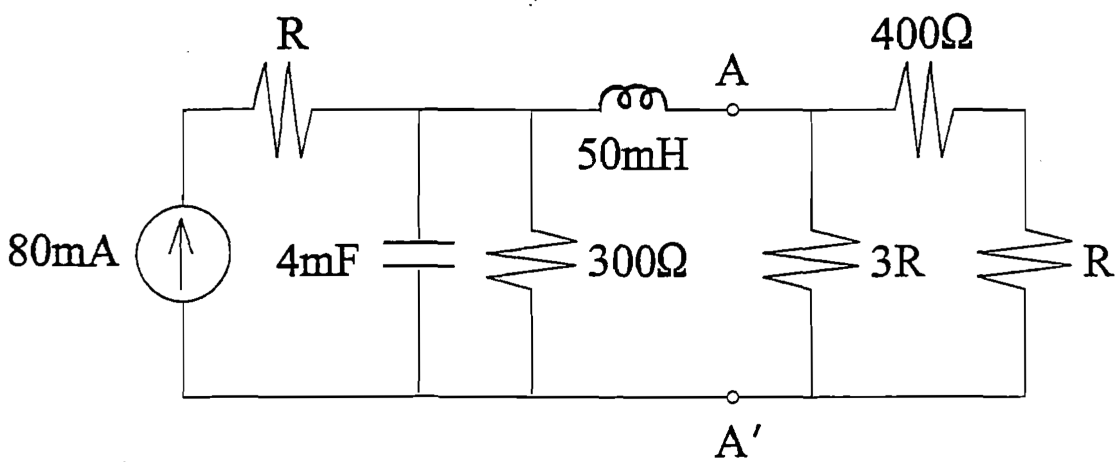


(a) Briefly explain how you could determine the Thevenin resistance for the network by using only a voltmeter and an ammeter to make measurements at the terminals. Also, how would your proposed "measurement approach" be affected if $V_S = 0$? (You may use diagrams to illustrate your explanation if you wish.)

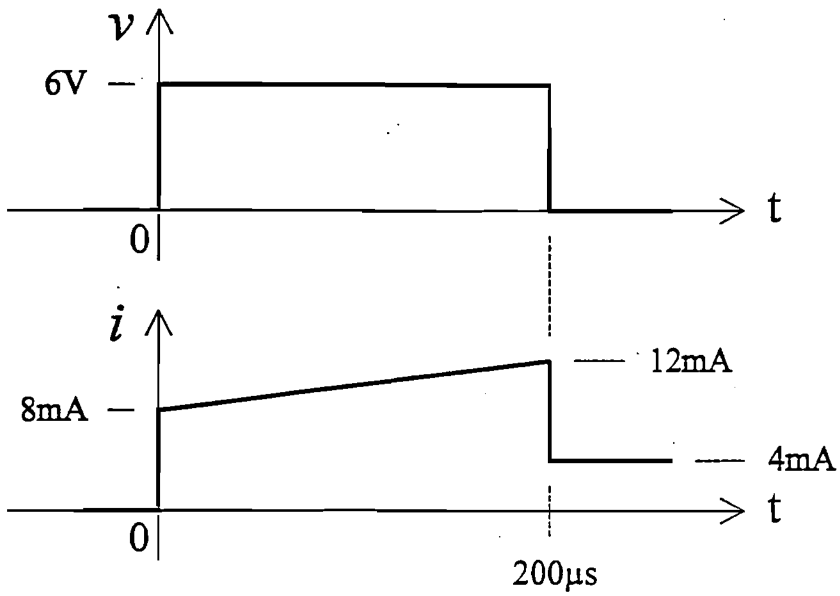
(b) Calculate the value of the Thevenin equivalent resistance you would "measure" if the ammeter has an internal resistance of 200Ω, and the voltmeter has an internal resistance of 10kΩ. Finally, determine the error of this "measured" R_{Th} value.

(20%) 3. Consider the circuit given below. Calculate the value of R that yields maximum power transfer to the two-terminal network connected at the right-hand-side of terminals AA' if the entire circuit is operating in DC steady-state. Also, find the steady-state energies stored by the capacitor and the inductor, for this optimal value of R.

Note: The parameter "R" appears in the definition of three different circuit resistors.



(20%) 4. The following graphs represent the v-i relation for a two-terminal "black box" device that is constructed from one ideal inductor and two <u>identical</u> ideal resistors. <u>Also</u>, it is known that the power dissipated by each resistor is exactly the same for all time $t > 0$.



(a) Draw a circuit diagram to illustrate the internal construction of the device: include all connections between the inductor, the two resistors and the black box terminals. Briefly explain how you determined this circuit from the v-i characteristic graphs.

(b) Calculate the values of the inductor and the two resistors based on the graphs.

McGill University
Faculty of Engineering

COURSE: 304-200A – Fundamentals of Electrical Engineering

FINAL EXAMINATION

Examiner: Professor S. McFee *Steve McFee*

Associate Examiner: Mr. D. Giannacopoulos *D. Giannacopoulos*

Date: Monday 14 December 1998 **Time:** 14:00 - 17:00

INSTRUCTIONS

(1) *READ* all exam questions *VERY CAREFULLY!*

(2) Answer *ALL* 5 questions (pp. 1–11) on this exam paper in the spaces provided (you may also use the back sides of the sheets if needed). Show all solution steps clearly.

(3) Individual question values are indicated in the margin at the start of each question. Total exam value is 99 marks.

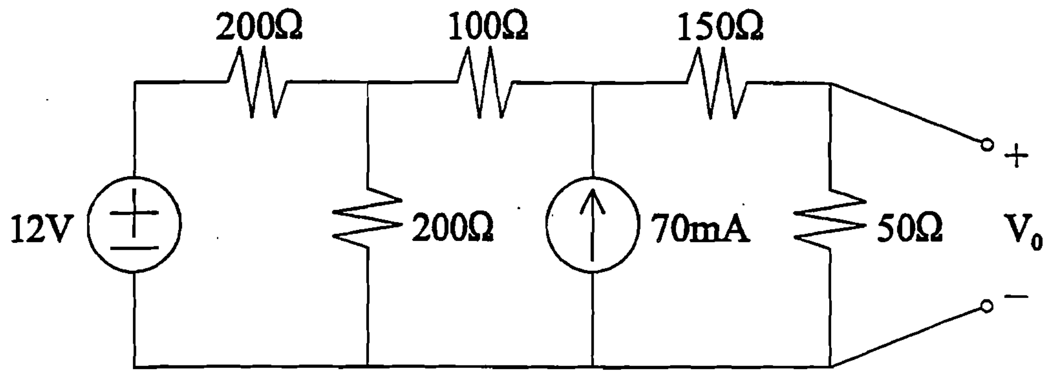
Note: Closed book exam; only the "Faculty Standard" calculators are permitted.

IDENTIFICATION

NAME: ______________________________

ID Number: ___________________________

(11) 1. Consider the circuit provided below.



a) Calculate the value of the voltage V_0.

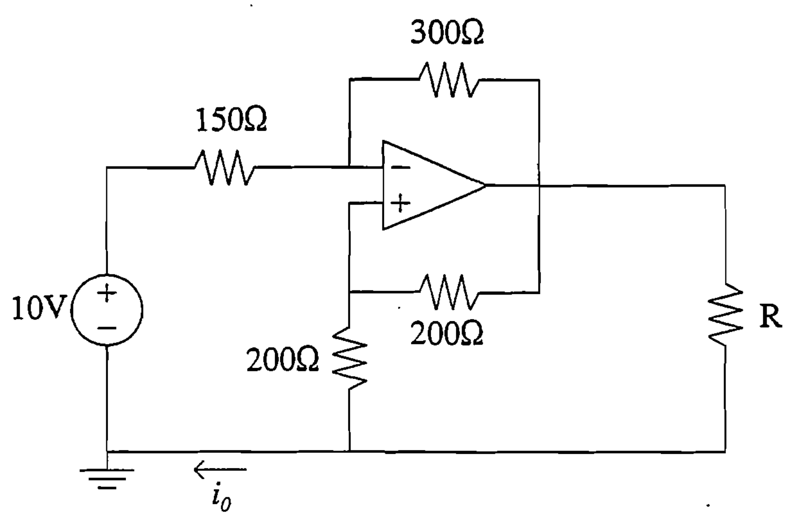
b) Calculate the value of V_0 that would be <u>measured</u> using a passive voltmeter with an internal resistance of 5500Ω. Show your voltmeter model and indicate how it must be connected to the circuit to make this measurement.

(11) 2. Consider the circuit provided below. Use the ideal op-amp model for all calculations.

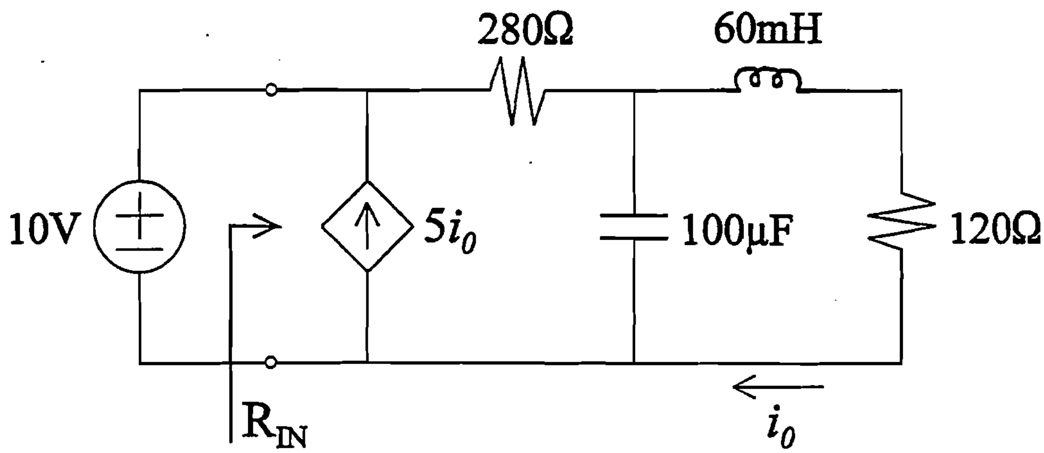
a) Calculate the value of the current i_0 if R = 1000Ω.

b) Find the total power supplied to the circuit through the op-amp with R = 1000Ω.

c) Find the value of R that causes the total power dissipated as heat within the circuit to equal exactly 10 times the power <u>absorbed</u> by the 10V source.



(11) 3. Assume that the circuit shown below is operating under *d.c. steady-state* conditions for the purpose of answering the following questions.



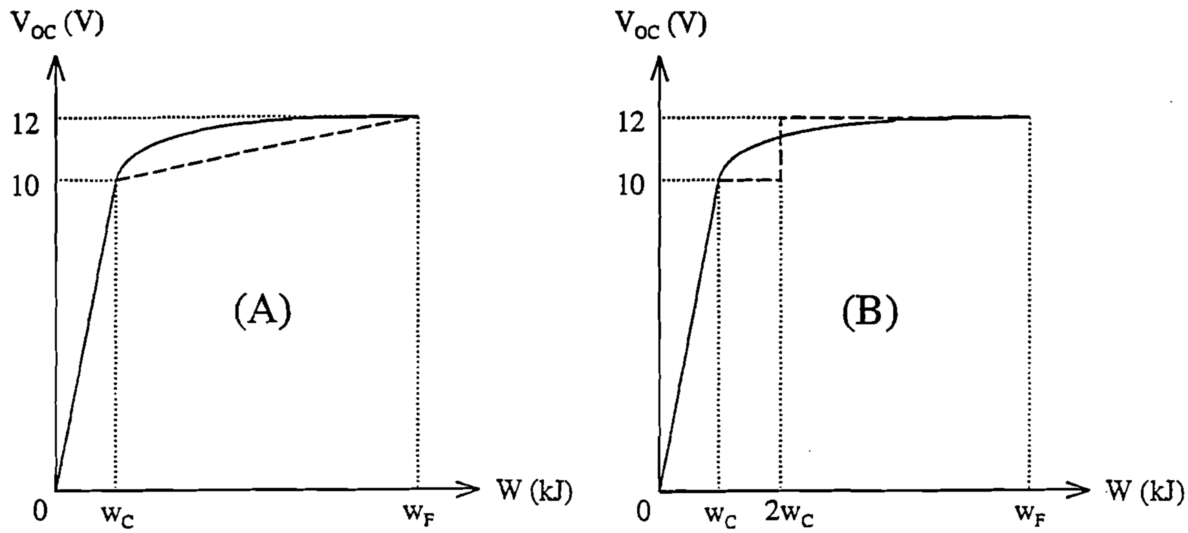
a) Calculate the steady-state power supplied by the current source.

b) Calculate the steady-state input resistance seen by the voltage source.

c) Calculate the steady-state energies stored by the capacitor and the inductor.

(33) 4. Consider a *lossless* battery which is governed by the *open-circuit* voltage versus stored energy characteristics given below. In each plot, the solid-line curve describes the true performance of the battery; and the dashed-line curve represents an approximate model for the rated voltage level (10V to 12V) operation of the device. Graph (A) provides a *linear* model for the W-V_{OC} characteristic; and (B) defines a *piecewise constant* model.

Assume that the battery is initially energized to $W_F = 6kJ$ and then discharged across a 4Ω load for the purpose of answering the following: [parts (a), (b), (c) and (d)]



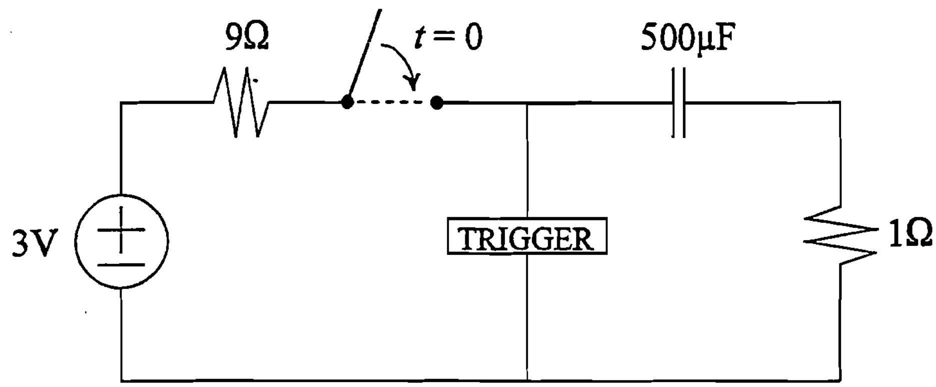
a) According to the *true* performance curve in graph (B), at what stored energy level does the battery deliver maximum power to the load? Briefly explain your answer.

b) Does the *linear* model described in graph (A) accurately approximate the total time required to discharge the battery from W_F to W_C? Briefly explain your answer.

c) Calculate the *time-average* power and the *total* charge delivered to the 4Ω load over the duration of the discharge from $W_F = 6kJ$ to $W_C = 1kJ$ according to the *piecewise constant* model provided in graph (B).

d) Calculate the *total* charge delivered to the 4Ω load over the discharge from $W_F = 6kJ$ to $W_C = 1kJ$ according to the *linear* model provided in graph (A).

(33) 5. Consider the switched *RC* circuit shown below. This system represents a simple strobe light designed to flash on and off repeatedly, after it is activated by closing the switch at time $t = 0$. The electronic flash bulb is modeled by the 1Ω resistor, and the "TRIGGER" mechanism operates like a binary switch: it acts like an *open-circuit* when it is OFF, and a *short-circuit* when it is ON. The trigger can *only* be turned ON by raising the voltage across the device to 2.98V; once ON, the trigger can *only* be turned OFF by reducing the current through the device to 0.4A. The electronic bulb will provide uninterrupted light as long as it absorbs 160mW or more, but at lower power levels no light is generated.



At $t = 0^-$, the capacitor is uncharged, the trigger is OFF and the circuit is in steady-state.

a) Calculate the time t at which the bulb will first <u>start</u> to output light, for $t = 0$ switch.

b) Calculate how long (elapsed time) the bulb will produce light during the first flash.

c) Calculate the energy that will be absorbed by the bulb during the first flash of light.