SCIENCE OLYMPIAD
ALUMNI ASSOCIATION

University of Texas at Austin Invitational

Circuit Lab C

Exam Booklet

- DO NOT BEGIN UNTIL GIVEN PERMISSION
- You will have **50 minutes** to complete the exam || You **may** separate the exam
- For calculation questions, it is **not** required that you show your work, however partial credit will be assigned if correct steps are shown with an incorrect answer.
- Answers must be given with appropriate **significant figures** and **units** to receive full credit.
- All final answers must be placed inside the designated box, including multiple choice.
- **Lab:** You will have up to 10 minutes to complete the lab section. A proctor will instruct you when it is your turn. You will not be given any replacement components, so be careful not to damage them.
- **Allowed materials:** 3-ring binder, writing utensils, two calculators, basic multimeter
- **Tie-breaker order:** 38, 45, 48, 28, 27, 24, 23, 16, Chronologically

Competitors: Kevin Hao, Asher Noel
Roger Zhong

School Name: Eyam Icey

Team Number: _____

Rank: _____

Score: _____

Kevin Hao[1], Asher Noel[2], Roger Zhong[3]
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Page Number	Possible Score	Your Score
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11	20	
LAB	44	
Total	294	

Identify the last name of the individual associated with the following epithets for questions 1-10. **(10 pts; 1 pt each)**

1. Rejected a knighthood.[2] **(1 pt)**

   Faraday

2. Contested with a man over frogs.[2] **(1 pt)**

   Volta

3. Regularly got two hours of sleep.[2] **(1 pt)**

   Tesla

4. Fled Paris during the French Revolution.[2] **(1 pt)**

   Coulomb

5. Theorized that sound is perceived as a number of harmonic tones.[2] **(1 pt)**

   Ohm

6. Believed in 'contiguous particles'.[2] **(1 pt)**

   Ohm

7. Showed the sun has sodium.[2] **(1 pt)**

   Kirchoff

8. Won the Nobel prize for helping invent alternating current.[2] **(1 pt)**

   Nobody

9. Published the following: "On Magnetism".[2] **(1 pt)**

   Coulomb

10. Winner of the Berlin Prize.[2] **(1 pt)**

    Nobody

11. What is the voltage of a diesel engine battery?[2] **(2 pts)**

    D

    A. 1.5V B. 9V
    C. 12V D. 24V

12. In a polarized receptable, which prong is "hot", and what does that mean?[2] **(2 pts)**

    B

    A. Shorter, swings (-) B. Shorter, swings (+)
    C. Longer, swings (-) D. Longer, swings (+)

13. How many deaths were due to Corona Discharge from 2005-2015 in the US?[2] **(2 pts)**

    A

    A. 0 B. 550
    C. 1050 D. 16,360

14. Which multiway switching system is notable for its usefulness for long hallways?[2] **(2 pts)**

    A

    A. Alternative B. California
    C. Carter D. Traveler

15. What causes currents to change every half cycle in a motor?[2] **(2 pts)**

    B

    A. Programming B. Commutator
    C. Combinatorics D. Bigfoot

16. What color is associated with an LED that has an ideal voltage drop of 4.15V?[2] **(2 pts) (TB#8)**

    D

    A. Red B. Green
    C. Blue D. White

17. What is the curie temperature of Gadolinium?[2] **(2 pts)**

    B

    A. 192K B. 292K
    C. 392K D. 492K

18. What is the effect of a 200 mA current passing from the left hand to the feet in 20 ms?[2] **(2 pts)**

    B

    A. No effect B. tingling
    C. shaking D. death

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19. What magnetism results from the orbital angular momentum of electrons antiparallel to the external field? [2] **(2 pts)**

B

A. Para magnetism B. diamagnetism
C. ferromagnetism D. antiferromagnetism

20. What is a disadvantage of Eddy Current Brakes used in slow high-speed trains and roller coasters? [1] **(2 pts)**

C

A. Frequent replacement of components B. Temperature-dependent
C. No force when stationary D. Rare metals required

21. Two initially uncharged metal spheres, A and B, are in contact. A negatively charged rod is brought near but does not touch them. With the rod held in place, sphere B is moved to the right, so that the spheres are now separated. Which of the following is now true of sphere B? [3] **(2 pts)**

C

A. It is uncharged B. It is positively charged
C. It is negatively charged D. It is charged, but its sign cannot be predicted

22. High frequency UV light with an energy of 300 eV per photon strikes a metal surface with a work function of 108.57 eV. What is the velocity of the electrons ejected from the material? [3] **(2 pts)**

A

A. 8.21 E6 m/s B. 1.24 E7 m/s
C. 9.28 E6 m/s D. 1.31 E7 m/s

23. Two capacitors are connected in parallel. A voltage V is applied to the pair. What is the ratio of charge stored on C1 to the charge stored on C2, when C1 = 1.5*C2? [3] **(2 pts) (TB#7)**

B

A. 2/3 B. 3/2
C. 1 D. 9/4

24. A simple circuit consists of a battery and a single variable resistor. Data of the current and voltage drop over the variable resistor at 4 different settings is shown to the right. Which value best approximates the internal resistance of the battery? [3] **(2 pts) (TB#6)**

I	V
0.1A	14.1V
1.5A	13.3V
3.1A	12.6V
4.6A	11.8V

D

A. 0.38 ohms B. 0.44 ohms
C. 0.47 ohms D. 0.51 ohms

25. In the unlikely event that a high voltage power line hits your car, what is the best method of escape if no one else can help you? [3] **(2 pts)**

A

A. Jump out with both feet together B. Slide out of the window feet first
C. Roll out onto the ground D. Crawl out

26. Which of the following is most related to digital logic? **(2 pts)**

B

A. Spectral Decomposition B. Neural networks
C. Error Propagation D. Fast Fourier Transforms

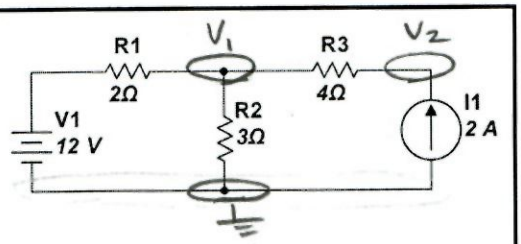
27. Find the voltage drop (V_{R3}) and power dissipated (P_{R2}) over the 3 Ω resistor. Provide your answers to 3 significant figures. [3] **(8 pts; 4, 4) (TB#5)**

$\frac{V_1-12}{2} + \frac{V_1}{3} + \frac{V_1-V_2}{4} = 0$

$\frac{V_2-V_1}{4} - 2 = 0$

$V_1 = 9.6\ V$

$V_2 = 17.6\ V$



$V_{R3} = 17.6 - 9.6 = 8\ V$

$P_{R2} = \frac{9.6^2}{3} = 30.72$

V_{R3} = 8.00 V P_{R3} = 30.7 W

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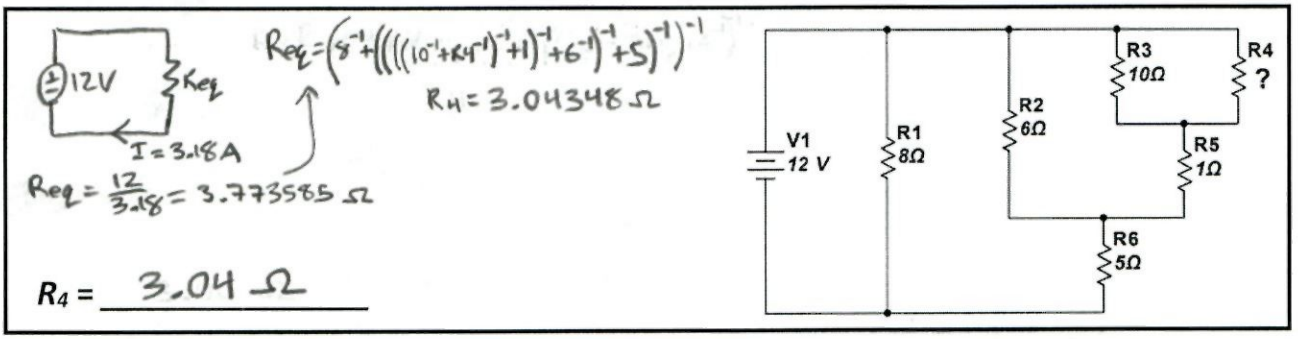
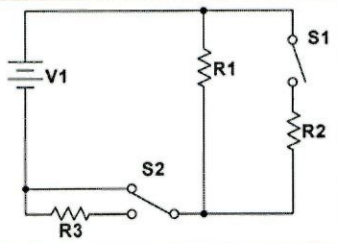
$$8^{-1}+\left(\left(\left((10+R_4)+1\right)^{-1}+6^{-1}\right)^{-1}+5\right)^{-1}$$

28. Find the value of the missing resistor if the total current flowing through the circuit is 3.18 A. Provide your answer to 3 significant figures.[3] **(6 pts) (TB#4)**



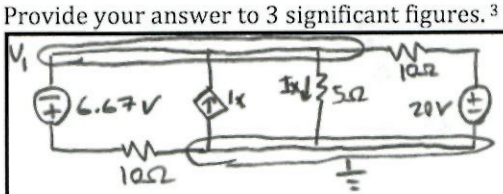
R_4 = 3.04 Ω

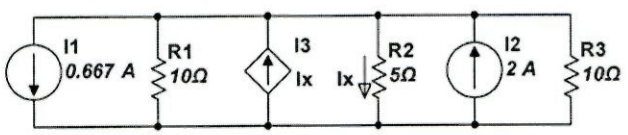
29. Switches S1 and S2 are in the "open" position as shown in the diagram. Note how S2 is able to redirect current. Consider two scenarios where S2 is either open (bypass R3) or closed (connected to R3) and determine if power dissapated over R1 would increase, decrease, or stay the same when S1 moves from open to closed.[3] **(6 pts; 3, 3)**



S2 open = Same **S2 closed** = Decreases

30. Determine the current flowing through the 5 ohm resistor as well as the current controlled current source (Ix). Provide your answer to 3 significant figures.[3] **(8 pts)**





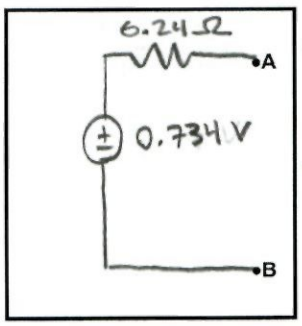
$\frac{V_1+6.67}{10} - I_x + \frac{V_1}{5} + \frac{V_1-20}{10} = 0$ ⟹ $V_1 = 6.665$ V

$I_x = \frac{V_1}{5}$ ⟹ $I_x = 1.333$ A

I_X = 1.33 A

31. Draw the Thévenin equivalent circuit with respect to the terminals A and B in the circuit below. Provide your answers to 3 significant figures.[3] **(8 pts)**

Thévenin

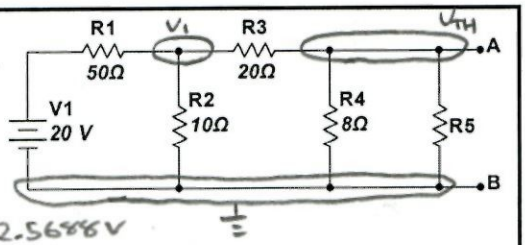


$R_{TH} = 50 \| 10 + 20 \| 8 = 6.24\ \Omega$

$\frac{V_1-20}{50} + \frac{V_1}{10} + \frac{V_1-V_{TH}}{20} = 0$

$\frac{V_{TH}-V_1}{20} + \frac{V_{TH}}{8} = 0$

⟹ $V_1 = 2.5688$ V, $V_{TH} = 0.7339$ V



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32. Part 1: Determine the current thru each of the lightbulbs connected to the battery in series (B). Part 2: Determine the current thru each of the lightbulbs connected to the battery in parallel (A). Provide your answers to 3 significant figures.[1] **(12 pts; 2 pts each)**

A

$P = IV$

$15+35+40 = I(120)$

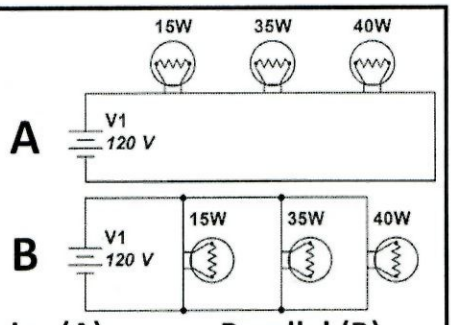
$I_{15W} = I_{35W} = I_{40W} = 0.75\ A$

B

$I_{15W} = \frac{15}{120} = 0.125\ A$

$I_{35W} = \frac{35}{120} = 0.292\ A$

$I_{40W} = \frac{40}{120} = 0.333\ A$



Series (A)	Parallel (B)
I_{15W} = 0.750 A	I_{15W} = 0.125 A
I_{35W} = 0.750 A	I_{35W} = 0.292 A
I_{40W} = 0.750 A	I_{40W} = 0.333 A

33. Determine the current (I_{V1}) thru the battery V1 and the voltage (V_{R2}) across the resistor R2. Provide your answers to 3 significant figures.[1] **(8 pts; 4, 4)**

Need $+V_{R2}-$

$\frac{V_A-22}{8} - 5 + \frac{V_A-V_C}{16} = 0$

$\frac{V_B-22}{3} + 5 + \frac{V_B-V_C}{9} + \frac{V_B}{5} = 0$

$\frac{V_C-V_A}{16} + \frac{V_C-V_B}{9} + \frac{V_C}{2} = 0$

$V_A = 42.946\ V$

$V_B = 5.167\ V$

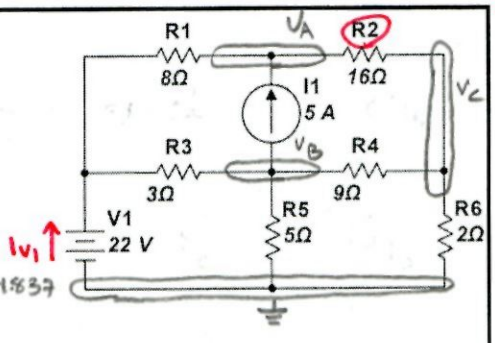
$V_C = 4.837\ V$

$0 = -\frac{42.946-22}{8} + \frac{22-5.167}{3} - I_{V1}$

$I_{V1} = 2.99\ A$

$V_{R2} = V_A - V_C = 42.946 - 4.837$

$V_{R2} = 38.1\ V$



I_{V1} = 2.99 A V_{R2} = 38.1 V

34. Draw the Thévenin equivalent circuit with respect to the terminals A and B in the circuit below. Provide your answers to 3 significant figures.[2] **(10 pts)**

$-1 + 12(I_1 - I_2) + 2.5(I_1 - I_2) = 0$

$10I_X + 2.5(I_2 - I_1) + 10(I_2 - I_3) = 0$

$6I_3 + 10(I_3 - I_2) + 12(I_3 - I_1) = 0$

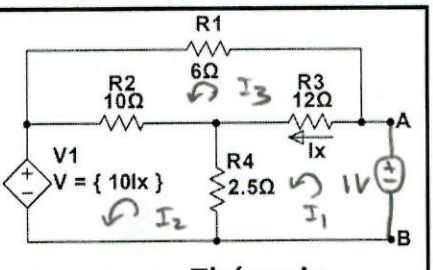
$I_X = I_1 - I_3$

$I_1 = 0.125\ A$

$I_2 = 0.025\ A$

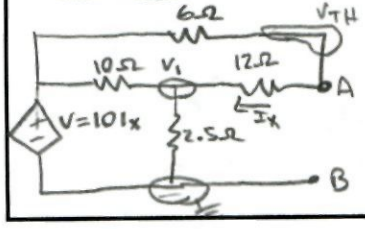
$I_3 = 0.0625\ A$

$I_X = 0.0625\ A$



Thévenin

$R_{TH} = \frac{1}{0.0625} = 16\Omega$



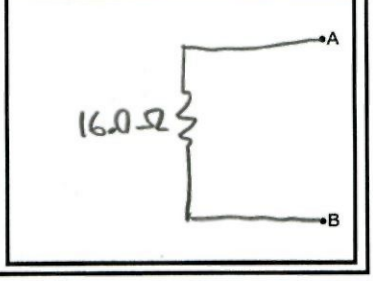
$\frac{V_1 - 10I_X}{10} + \frac{V_1}{2.5} + \frac{V_1 - V_{TH}}{12} = 0$

$\frac{V_{TH} - V_1}{12} + \frac{V_{TH} - 10I_X}{6} = 0$

$I_X = \frac{V_{TH} - V_1}{12}$

$V_1 = 0$

$V_{TH} = 0$



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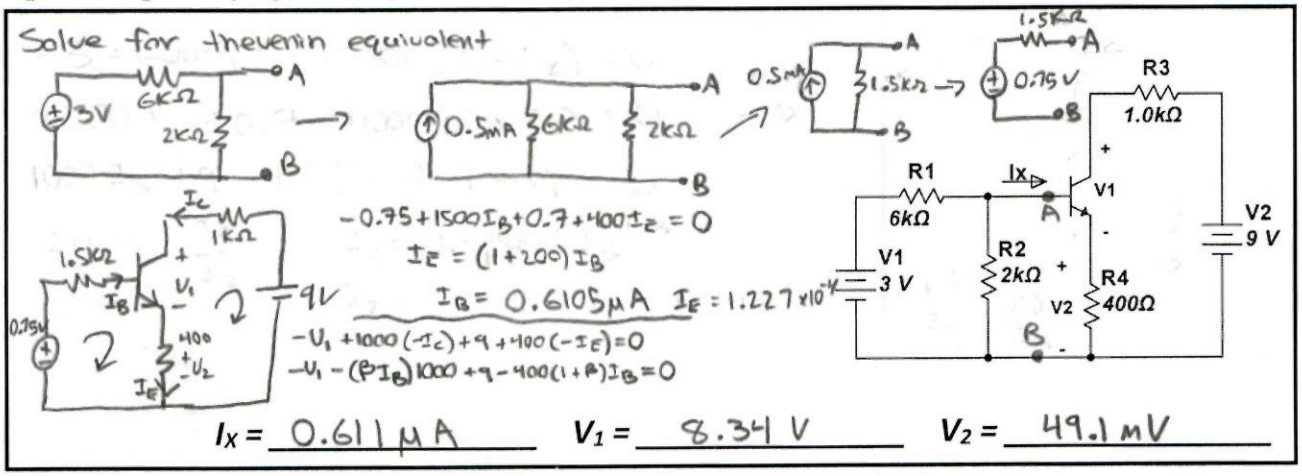
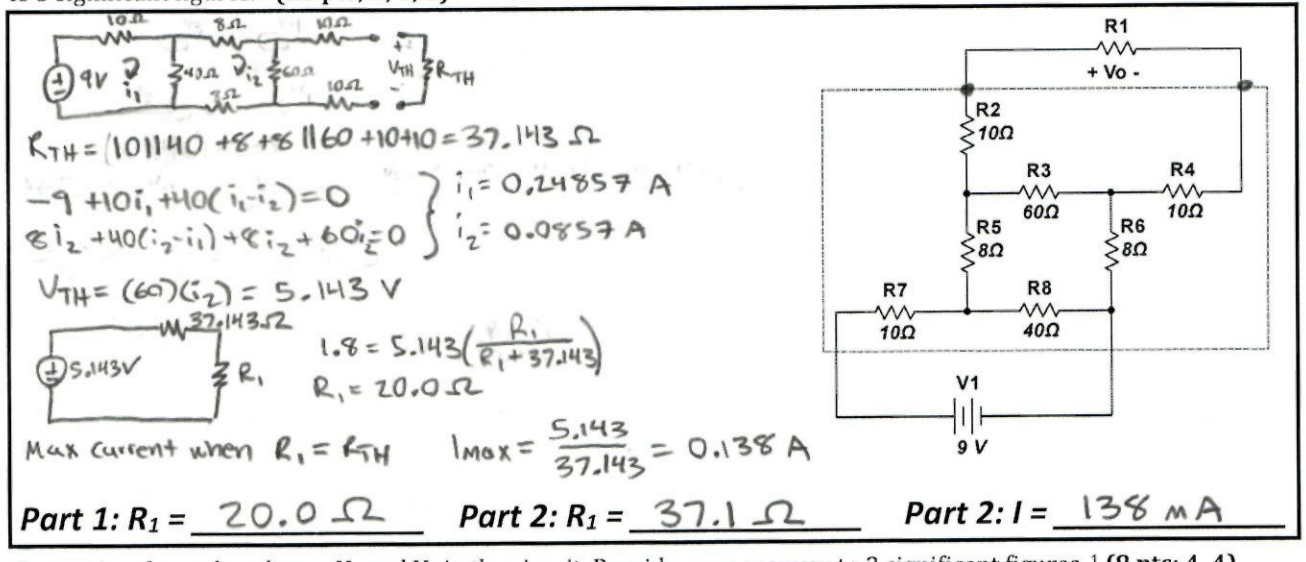
35. Determine the base current (I_X), the voltage across the transistor (V_1), and the voltage across the resistor R4 (V_2) in the circuit below. Take β=200 and the voltage across the base and emitter V_{BE}=0.7 V. Provide your answers to 3 significant figures.[1] **(12 pts; 4, 4, 4)**



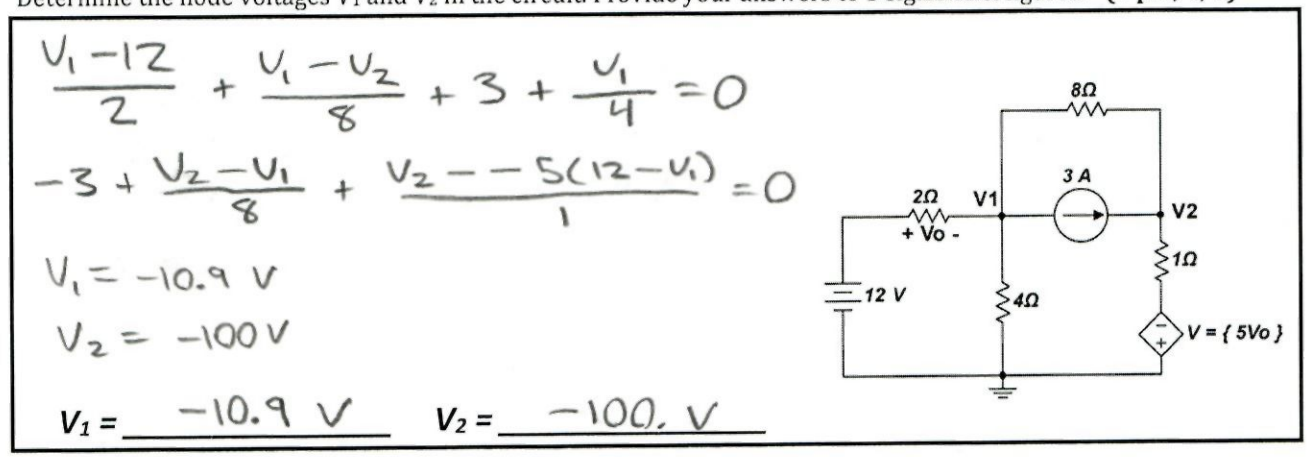
I_X = 0.611 μA V_1 = 8.34 V V_2 = 49.1 mV

36. A resistance array is connected to a load resistor R1 and a voltage source V1. Part 1: Find the value of R1 such that V_o = 1.8 V. Part 2: Determine the value of R1 that will draw the maximum current. State that value. Provide your answers to 3 significant figures.[1] **(18 pts; 6, 6, 6)**



Part 1: R_1 = 20.0 Ω **Part 2: R_1** = 37.1 Ω **Part 2: I** = 138 mA

37. Determine the node voltages V_1 and V_2 in the circuit. Provide your answers to 3 significant figures.[1] **(8 pts; 4, 4)**



V_1 = −10.9 V **V_2** = −100. V

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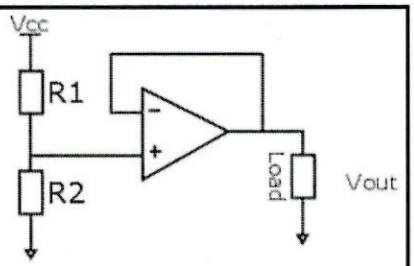
38. Determine the following by referencing the Op-Amp circuit below.[1] **(10 pts; 2, 4, 4)**
    - Gain of the Op-Amp **(2 pts)**
    - An expression for V_{out} in terms of V_{cc}, R1, and R2. **(4 pts)**
    - Explain how the addition of the Op-Amp to this circuit effects the input and output impedance. **(4 pts)**

$V_{out} = V_{cc}\left(\frac{R_2}{R_1+R_2}\right)$



Gain = 1 **V_{out} =** $V_{cc}\left(\frac{R_2}{R_1+R_2}\right)$

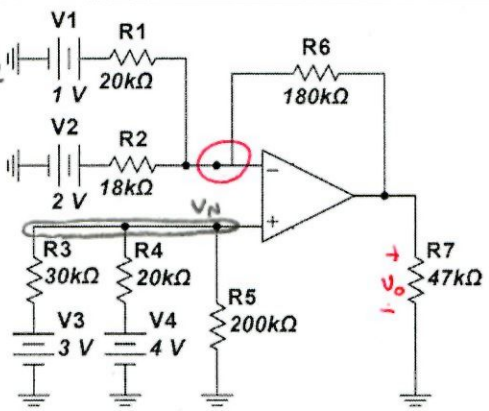
High input impedence and low output impedence

39. Determine the voltage (V_o) across resistor R7 and the type of Op-Amp configuration shown in the circuit below. Provide your answer to 3 significant figures.[1] **(12 pts; 10, 2)**

$\frac{V_N-3}{30{,}000} + \frac{V_N-4}{20{,}000} + \frac{V_N-0}{200{,}000} = 0 \Rightarrow V_N = 3.3962$

$\frac{3.3962-V_o}{180{,}000} + \frac{3.3962-2}{18{,}000} + \frac{3.3962-1}{20{,}000} = 0$

$V_o = 38.9245\ V$



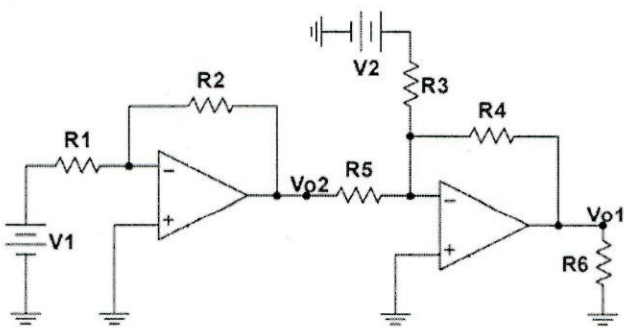
V_o = 38.9 V **Type =** Summing

40. Express the output voltages V_{o2} and V_{o1} in terms of V1, V2, R1, R2, R3, R4, and R5.[1] **(12 pts; 6, 6)**

$\frac{0-V_1}{R_1} + \frac{0-V_{o2}}{R_2} = 0 \Rightarrow V_{o2} = \frac{-R_2 V_1}{R_1}$

$\frac{0-V_{o2}}{R_5} + \frac{0-V_2}{R_3} + \frac{0-V_{o1}}{R_4} = 0$

$V_{o1} = \frac{R_4(R_2R_3V_1 - R_1R_5V_2)}{R_1R_3R_5}$



V_{o2} = $\frac{-R_2 V_1}{R_1}$ **V_{o1} =** $\frac{R_4(R_2R_3V_1 - R_1R_5V_2)}{R_1R_3R_5}$

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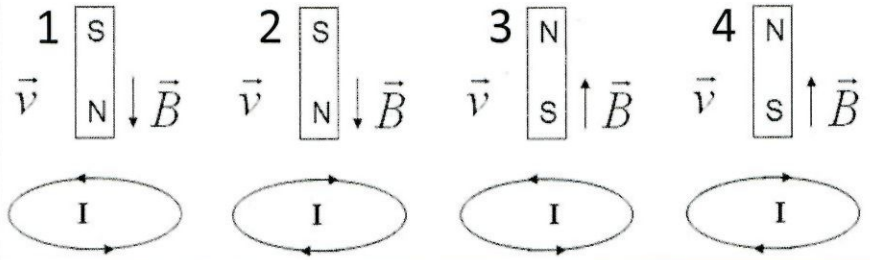
41. Part 1: Indicate the direction the magnet must be moving in order to induce the current in the wire that is shown by circling the arrow for each diagram. Part 2: State the law you used to solve this problem. [1] **(6 pts; 1, 1, 1, 1, 2)**



1	↓ (circled) ↑
2	↓ ↑ (circled)
3	↓ (circled) ↑
4	↓ ↑ (circled)

Law = Lenz's Law

42. Four point charges surround a point P as listed below. Part 1: Find the magnitude and direction (East or West) of the electric field at point P. Part 2: Determine the electric potential at point P. Provide your answers to 3 significant figures. [3] **(6 pts; 2, 2, 2)**
    1. +2 mC 40 meters to the west
    2. -2 mC 30 meters to the west
    3. +2 mC 30 meters to the east
    4. -2 mC 40 meters to the east

$E = \sum \frac{KQ}{r^2}$

$E = 8.99\times10^9 \left(\frac{0.002}{40^2} - \frac{0.002}{30^2} - \frac{0.002}{30^2} + \frac{0.002}{40^2}\right) = 17{,}480.6 \approx 17.5 \text{ kN/C}$

West

Magnitude = 17.5 kN/C ***Direction =*** (E || (W)) ***Potential =*** 0.00 V

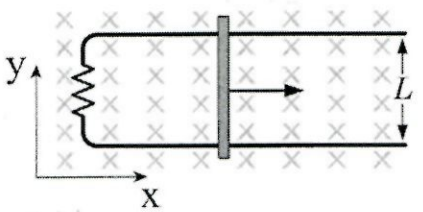
43. In the image below, a rod moves in the +x direction at a constant speed of 2.0 m/s along the horizontal rails, separated by L=12 cm. The rod, rails, and connecting resistor form a conducting loop. The resistor has a resistance of 200 mΩ; the rest of the loop has negligible resistance. The entire apparatus is placed in a uniform 1.2 T magnetic field pointing into the page. Determine the direction (+y or -y) and value of the induced current through the resistor. [1] **(10 pts; 2, 8)**

$I = \frac{BLv}{R}$

$I = \frac{(1.2)(0.12)(2.0)}{(0.200)}$

$I = 1.44$ A

$B = 1.2$ T
$v = 2.0$ m/s
$R = 200$ mΩ
$L = 12$ cm



Direction = ((+y) || -y) ***I =*** 1.44 A

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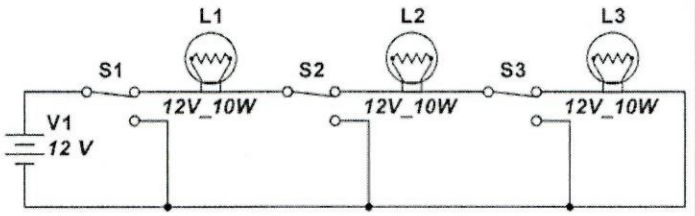
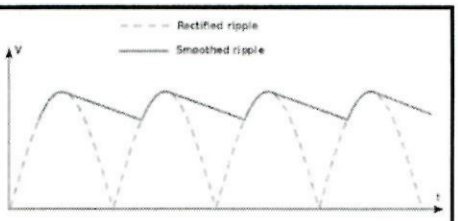
44. Complete the table to show which lamps (L1, L2, L3) will be turned on based on the potition of each of the switches (S1, S2, S3). Assume each switch in the image is "ON", and flipping it would turn it "OFF". [1] **(12 pts; ½ pt each)**

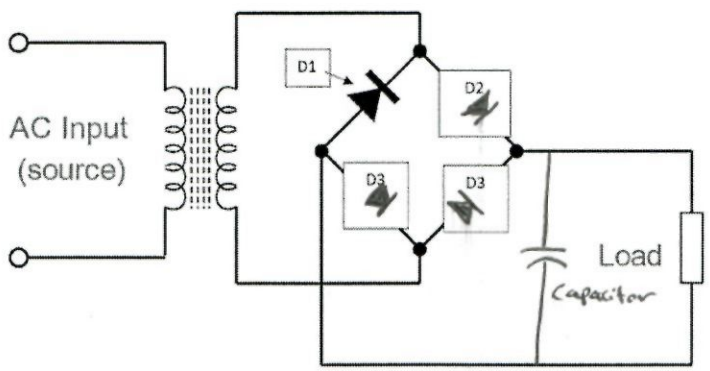
S1	S2	S3	L1	L2	L3
ON	ON	ON	ON	ON	ON
ON	ON	OFF	ON	ON	OFF
ON	OFF	ON	ON	OFF	OFF
OFF	ON	ON	OFF	OFF	OFF
ON	OFF	OFF	ON	OFF	OFF
OFF	ON	OFF	OFF	OFF	OFF
OFF	OFF	ON	OFF	OFF	OFF
OFF	OFF	OFF	OFF	OFF	OFF



45. Part 1: Given that it takes 3 hours to fully charge a battery when using an AC adapter with a full-wave rectifier, determine long it would take to fully charge the same battery with an adapter that uses a half-wave rectifier. Part 2: The full wave rectifier is shown below. The AC input is a standard AC source. Draw the 3 missing diode symbols in the boxes. Direction is important. Part 3: Draw and label a capacitor in the rectifier diagram shown below that would produced the smoothed ripple from the rectified ripple graphed on the voltage vs time graph. You may draw some extra wiring if you wish. [3] **(12 pts; 4, 4, 4)**



Time = 6 hours



46. Part 1: Why don't transformers work with DC? Part 2: In a single ideal transformer, the primary (in) coil A has 10 turns, a current of 10A, and a voltage of 5V. The secondary (out) coil B has 50 turns. What is the current and voltage in coil B? Provide your answers to 3 significant figures. [3] **(6 pts; 3, 3)**

Faraday's law of induction states that only changing magnetic flux can induce an emf in the secondary coil of the transformer.

$I_B = 2.00\,A$

$V_B = 25.0\,V$

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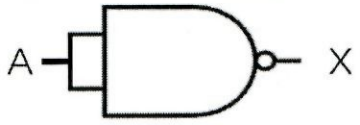
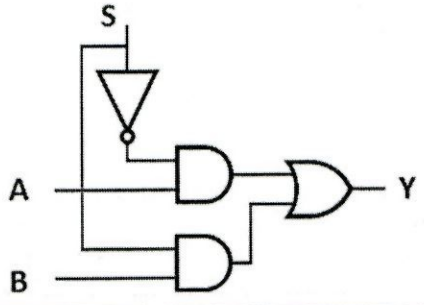
47. Part 1: This NAND gate with a parallel input A is equivalent to which other type of logic gate? Part 2: The NAND gate is functionally complete, which means you can make any other kind of gate using a combination of NAND gates. There is one other type of gate besides the NAND gate that has the same property. Name that gate. **(4 pts; 2, 2)**

Part 1 = NOT **Part 2 =** NOR

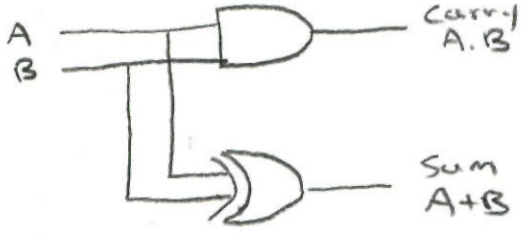


48. In electronics, a multiplexer (or mux) is a device that selects between multiple digital input signals and forwards it to a single output line. A multiplexer of 2^n inputs has n select lines, which are used to select which input line to send to the output. A 2 to 1 multiplexer (shown above) is the simplest kind of mux. A single input line S determines which two input values of A or B are selected. Draw the COMPLETE truth table for a 2 to 1 multiplexer using inputs A, B, S and output Y. Your table needs to have 8 rows. **(8 pts; 1 pt each)**

A	B	S	Y
0	0	0	0
1	0	0	1
0	1	0	0
0	0	1	0
1	1	0	1
1	0	1	0
0	1	1	1
1	1	1	1



49. The half adder is an example of a simple, functional digital circuit built from two logic gates. The half adder adds two one-bit binary numbers (A and B). The output is the sum of the two bits (S) and the carry (C). For example, if we perform 1+0, S will be 1 and C will be 0. If we do 1+1, S will be 1 and C will be 1.
Given two input lines (A and B) and outputs (S and C), draw the complete digital circuit diagram of a half adder. (Hint: for the logic gates, you will need two from AND, OR, XOR). **(8 pts)**



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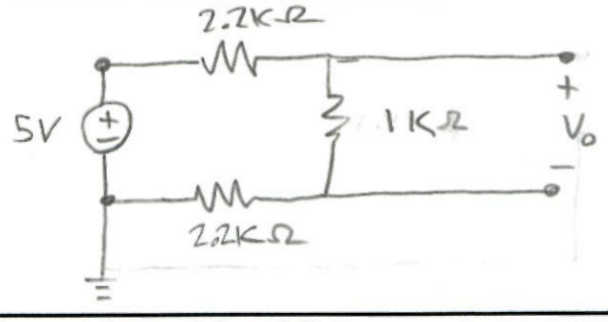
Hands-On Task: For the following questions, your circuit diagrams and calculations MUST be composed of components that are provided (e.g. resistor values used in circuit diagrams should correspond to actual provided values). You will have 15 minutes to work with the physical components to complete the questions in this section.

47. Draw a simple circuit diagram such that its input is ~5 V (battery voltage V_{i1}) and output is ~1 V (~ means within +/- 10%). Calculate its theoretical output voltage (V_{o1}). Provide your answer to 3 significant figures. HINT: Your answer should NOT be 1.00 V.[1] **(10 pts)**



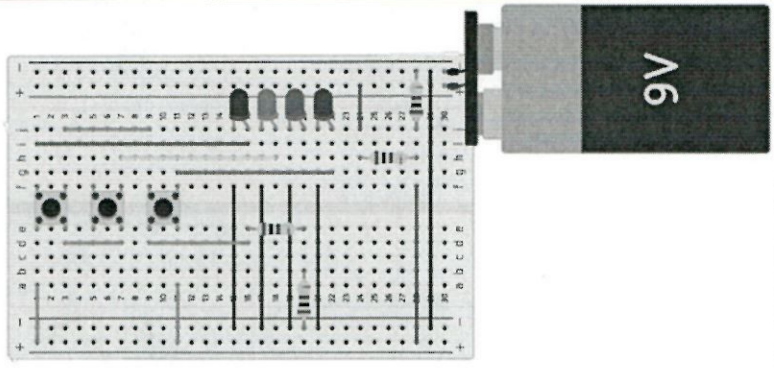
Theoretical V_o = 0.926 V

48. Construct the circuit from Q42. Measure and record the input (V_i) and output (V_o) voltages to 3 significant figures.[1] **(10 pts; 5, 5)**

Measured V_i = Varies ***Measured V_o =*** Varies

49. Study the circuit below and fill out the table to show which LEDs are turned on when each combination of push buttons are pressed. Draw an "X" to indicate the LED is turned on. Determine the theoretical and actual power dissipated by the LEDs when buttons **1 and 2** are pressed. You are provided with the necessary components to build the circuit, but it is NOT required.[1] **(24 pts; ½ pt each box; 5, 5)**

Buttons			LED			
1	2	3	Red	Yellow	Green	Blue
X			X	X		
	X		X			
		X	X	X		
X	X		X	X		
X		X	X	X		
	X	X	X	X		
X	X	X	X	X		



Given LED voltage drops:
Red: 1.63 - 2.03 → AVG: 1.83 V
Yellow: 2.10 - 2.18 → AVG: 2.14 V

→ There is no resistor in series with either the red or yellow LED, thus a theoretical current and power cannot be determined.

→ However, using a voltmeter, measurements to find power experimentally can still be performed.

Red:
Measured V: 1.88 V
Measured I: 3.5 mA

Yellow:
Measured V: 1.79 V
Measured I: 0.28 mA

P = IV + IV
P = 7.08 mW

Theoretical P = N/A ***Actual P =*** 7.08 mW

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