2020 Solon High School 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 **20 minutes** to complete each lab section **(2 total)**. A proctor will instruct you when it is your turn. Components may not be replaced between teams, so let us know if you suspect faulty or damaged components and we will be happy to provide replacements.
- **Allowed materials:** 3-ring binder, writing utensils, two calculators, basic multimeter
- **Tie-breaker order:** 9, 16, 21, 23, 35, 39, 41, 44, LAB 2

Competitors: _____

_____

School Name: _____

Team Number: _____

Rank: _____

Score: _____

Kevin Hao[1] and Asher Noel[2]

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This page is for administrative use only. DO NOT WRITE ON THIS PAGE.

Page Number	Possible Score	Your Score
3	26	
4	26	
5	28	
6	32	
7	30	
8	37	
9	30	
10	22	
LAB 1	47	
LAB 2	55	
Total	333	

1. Identify the individual that coined the term for item A. [1] **(2 pts)**

2. Identify the individual that discovered the law demonstrated in item B. [1] **(2 pts)**

3. Identify the individual who is credited with the law demonstrated in item C. [1] **(2 pts)**

4. Identify the individual who is credited with the law demonstrated in item D. [1] **(2 pts)**

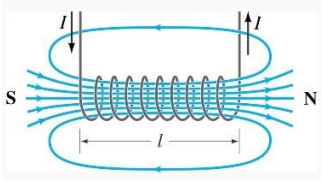
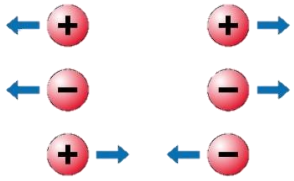
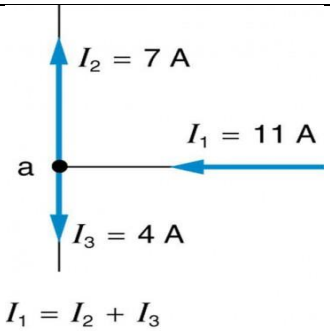
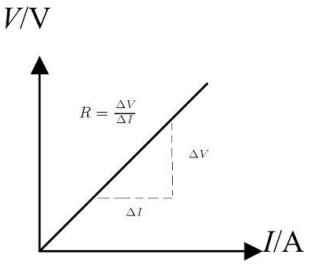
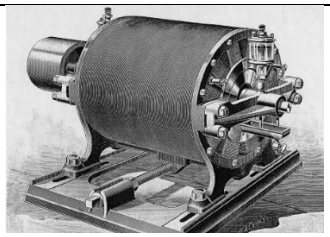
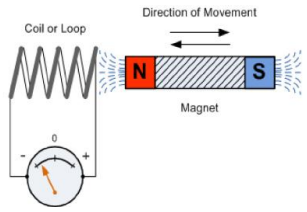
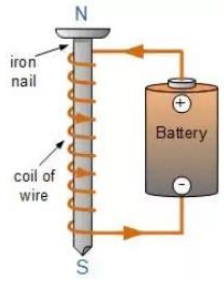
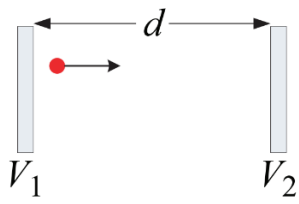
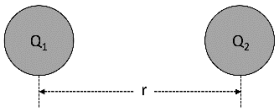
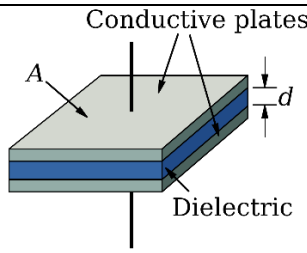
5. Identify the inventor of item E. [1] **(2 pts)**

6. Identify the individual who is credited with the law demonstrated in item F. [1] **(2 pts)**

7. Identify item G. [1] **(2 pts)**

8. A proton is moving rightward between two parallel charged plates separated by distance d = 2.80 cm, as shown in item H. The plate potentials are V_1 = 15.0 V and V_2 = 35.0 V. If the initial speed of the proton at the left plate is 100. km/s, what is its speed just as it reaches the right plate? [1] **(4 pts)**

9. What is the net electrostatic force acting on Q_1 and Q_2 in item I? Indicate a repulsive force with a (+) and an attractive force with an (-). [1] **(4 pts) (TB#1)**

A		B	
C		D	
E		F	
G		H	
I	 Q_1 = -3.50 μC Q_2 = +2.00 μC r = 10.0 cm	J	

10. The parallel plate capacitor in item J has an area (A) of 8.2 cm^2 and plate separation (d) of 5.0 mm. If muscovite (Dielectric of 5.4) is used as the dielectric material, what is the capacitance of the capacitor? [1] **(2 pts)**

11. If 125 V is applied across the plates of the capacitor in item J, how much energy is stored by the capacitor? Reference Q10 for additional information. [1] **(2 pts)**

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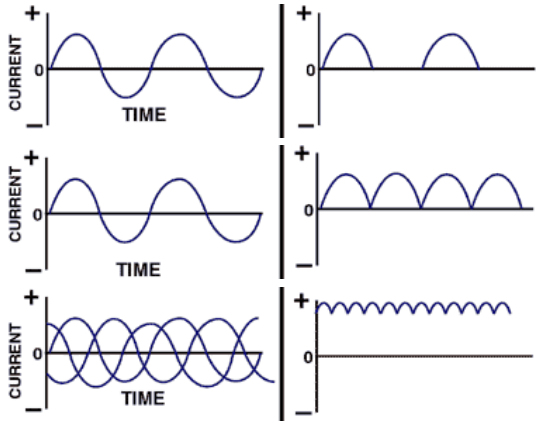
12. Identify the type of rectified AC current shown right. [1] **(2 pts)**



☐ A. Half Wave B. Full Wave C. 3 Phase Half Wave D. 3 Phase Full Wave

13. Identify the type of rectified AC current shown right. [1] **(2 pts)**

☐ A. Half Wave B. Full Wave C. 3 Phase Half Wave D. 3 Phase Full Wave

14. Identify the type of rectified AC current shown right. [1] **(2 pts)**

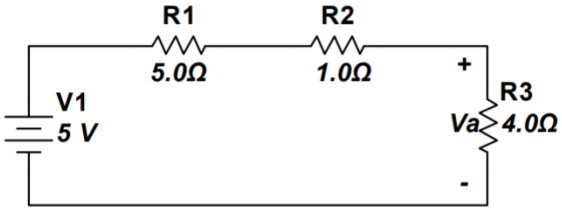
☐ A. Half Wave B. Full Wave C. 3 Phase Half Wave D. 3 Phase Full Wave

15. Which of the following devices converts a direct current (DC) input into alternating current (AC)? [1] **(2 pts)**

☐ A. Rectifier B. Alternator C. Inverter D. Bigfoot

16. What is the value of V_a in Circuit 1? [1] **(2 pts) (TB#2)**

Circuit 1



☐ A. 2.0 V B. 2.5 V C. 5.0 V D. 50 V

17. What is the value of the power supplied in Circuit 1? [1] **(2 pts)**

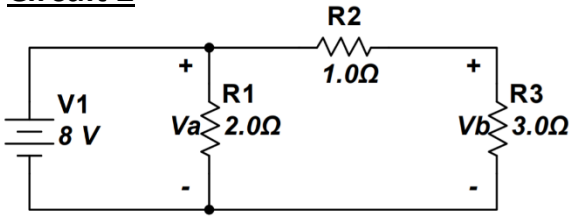
☐ A. 2.0 W B. 2.5 W C. 5.0 W D. 50 W

18. What is the value of the total power dissipated in Circuit 1? [1] **(2 pts)**

☐ A. 2.0 W B. 2.5 W C. 5.0 W D. 50 W

19. What is the value of V_a in Circuit 2? [1] **(2 pts)**

Circuit 2



☐ A. 2.0 V B. 3.0 V C. 6.0 V D. 8.0 V

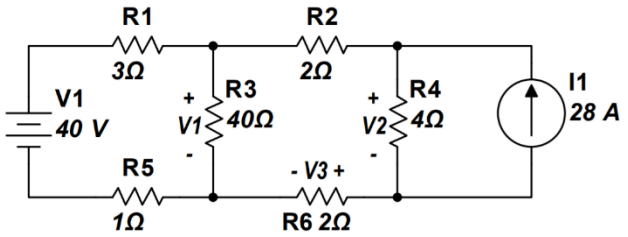
20. What is the value of V_b in Circuit 2? [1] **(2 pts)**

☐ A. 2.0 V B. 3.0 V C. 6.0 V D. 8.0 V

21. What is the value of the current through R1 in Circuit 2? [1] **(2 pts) (TB#3)**

☐ A. 1.3 A B. 4.0 A C. 6.0 A D. 8.9 A

22. Determine the voltages V_1, V_2, and V_3. Provide your answer to 3 significant figures. [1] **(6 pts; 2, 2, 2)**



V_1 = _____ ***V_2 =*** _____ ***V_3 =*** _____

_____ / 26

23. Which of the following is NOT a technique that can be utilized to remove logic redundancy? [1] **(2 pts) (TB#4)**

A. Boolean algebra
B. Karnaugh maps
C. Computational derivation
D. Quine-McCluskey algorithm

24. Which of the following terms describes the number of logic inputs that can be controlled be a single output? [1] **(2 pts)**

A. Reliability
B. Fanout
C. Speed
D. Cost

25. Consider the function *MAJ*: $\{0, 1\}^3$ -> {0,1} that is defined as follows: *MAJ*(x) = \piecewise{1 , $x_0 + x_1 + x_2 >= 2$}{0, otherwise}. Which of the following is a formula involving *AND*, *OR*, and *NOT* to compute *MAJ*? [2] **(3 pts)**

A. OR(AND(x_0, x_1), OR(AND(x_0, x_1), AND(x_0, x_1))))
B. AND(OR(x_0, x_1), AND(OR(x_0, x_1), OR(x_0, x_1)))
C. OR(AND(x_0, x_1), AND(AND(x_0, x_1), AND(x_0, x_1)))
D. AND(AND(x_0, x_1), AND(OR(x_0, x_1), AND(x_0, x_1)))

26. Let *MAJ:* $\{0, 1\}^3$ -> {0,1} be the function that on input *a, b, c* outputs 1 if a + b + c >= 2. What is the *size* of the minimum Boolean circuit composed of *NAND's* for computing *MAJ?* The *size* of a Boolean circuit is the number of gates it contains. Gates in a Boolean circuit have at most 2 inputs and 1 output? [2] **(3 pts)**

A. 8
B. 9
C. 10
D. 11

27. Let XOR_3 : $\{0,1\}^3$ -> {0,1} be the function defined as $XOR_3(a,b,c) = a + b + c$ mod 2. Which equals *1*? [2] **(3 pts)**

A. XOR_3 (*0,1,1*)
B. XOR_3 (1,*0,1*)
C. XOR_3 (*0,1,0*)
D. XOR_3 (*0,0,0*)

28. Define *ALLEQ:* $\{0,1\}^4$ -> {0,1} to the function that on input x \in $\{0,1\}^4$ outputs 1 if $x_0 = x_1 = x_2 = x_3$. What is the *size* of the minimum Boolean circuit composed of *NOT*, *AND*, and *OR* for computing *ALLEQ*? [2] **(3 pts)**

A. 8
B. 9
C. 10
D. 11

29. For every Boolean circuit *C* of *s* gates, there exists a NAND circuit *C'* of at most how many gates that computes the same function as *C*? [2] **(3 pts)**

A. 3s
B. 4s
C. $2^s/s$
D. 5s

30. A *classical* system of *n* bits can be modeled by a string s \in $\{0,1\}^n$. Which of the following is logically equivalent to writing the NAND of the 3rd and 5th bits to the 17th bit? [2] **(3 pts)**

A. $s_{17} = 1 - s_3 s_5$
B. $s_{17} = s_3 s_5$
C. $s_{17} = 1 - (s_3 + s_5)$
D. $s_{17} = s_3 + s_5$

31. In quantum computing, the state of an individual bit, called a 'qubit', is modeled by a pair of numbers (α, β) such that $|\alpha|^2 + |\beta|^2 = 1$. Which of the following models the NOT operation with a map $N: \mathbb{R}^2 \rightarrow \mathbb{R}^2$? [2] **(3 pts)**

A. $N(\alpha, \beta) = (\alpha, \beta)$
B. $N(\alpha, \beta) = (\alpha, \alpha)$
C. $N(\alpha, \beta) = (\beta, \alpha)$
D. $N(\alpha, \beta) = (\beta^2, \alpha^2)$

32. A *quantum circuit* is analogous to a Boolean circuit and can be described as a directed acyclic graph. One crucial difference, however, is that all gates must be *reversible* (this ensures that operations can be expressed as unitary matrices). Instead of thinking of *NAND* as a non-reversible map from $\{0,1\}^2$ to {0,1}, how could we think about it as a reversible map on *three* qubits *a, b, c*? [2] **(3 pts)**

A. *a, b, c* to *a, b, c XOR NAND(a, b)* [i.e., this flips the last bit if *NAND* of the first two bits is 1]
B. *a, b, c* to *a, b, c XOR AND(a, b)* [i.e., this flips the last bit if *AND* of the first two bits is 1]
C. *a, b, c* to *a, b, c XOR OR(a, b)* [i.e., this flips the last bit if *OR* of the first two bits is 1]
D. *a, b, c* to *a, b, c XOR NOR(a, b)* [i.e., this flips the last bit if X*OR* of the first two bits is 1]

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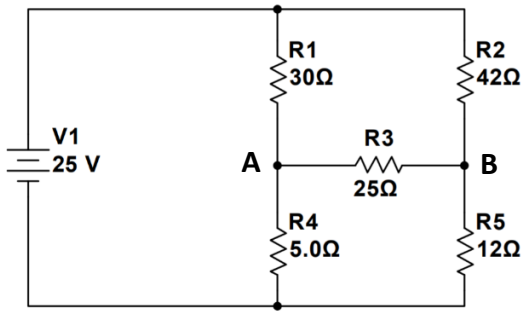
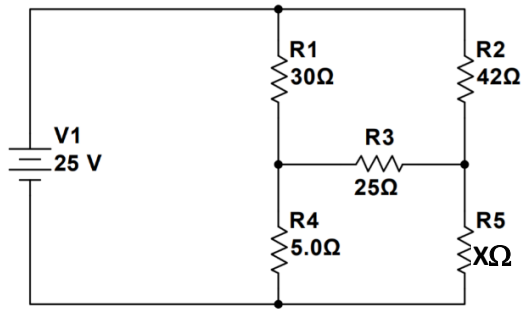
33. Determine the current (I_{AB}) thru the resistor R3 and voltage (V_{AB}) across the resistor R3. Indicate direction with respect to nodes A and B with (+) or (i) sign. Provide your answers to 3 significant figures. [1] **(12 pts; 6, 6)**



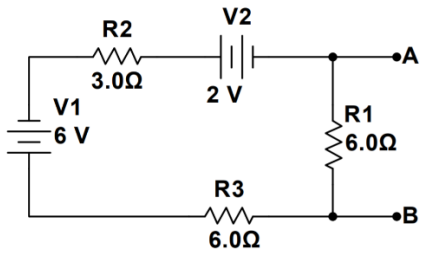
I_{AB} = _____ V_{AB} = _____

34. Determine the value of X, the resistance of R5, so that the voltage across the resistor R3 is zero in the circuit below. What is the name of this configuration? Provide numerical answers to 3 significant figures. [1] **(8 pts; 6, 2)**

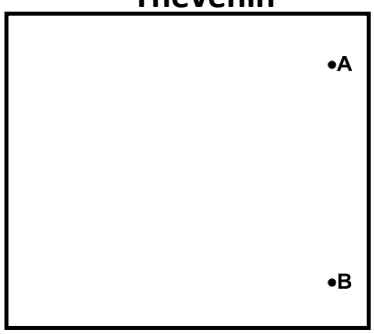


X = _____ Name = _____

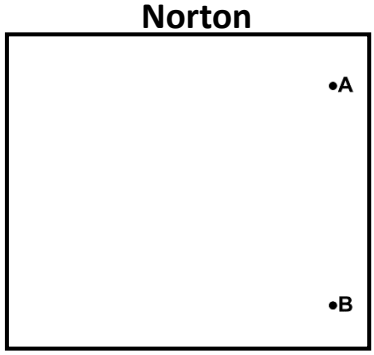
35. Draw the Thévenin and Norton equivalent circuits with respect to the terminals A and B in the circuit below. Provide your answers to 3 significant figures. [1] **(12 pts; 6, 6) (TB#5)**



Thévenin



Norton



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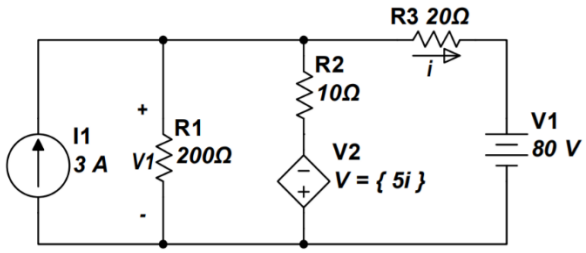
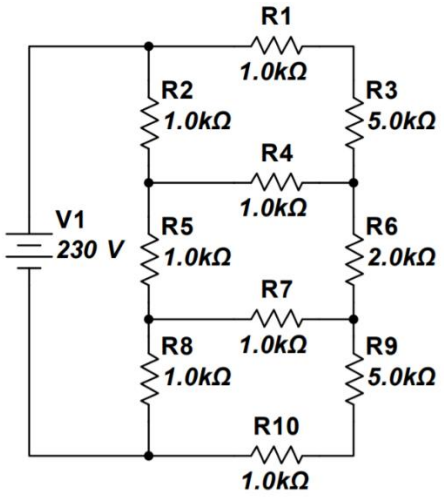
36. Determine the voltage (V_1) across resistor R1 and the current (i) through resistor R3 in the circuit below. Provide your answers to 3 significant figures. [1] **(12 pts; 6, 6)**



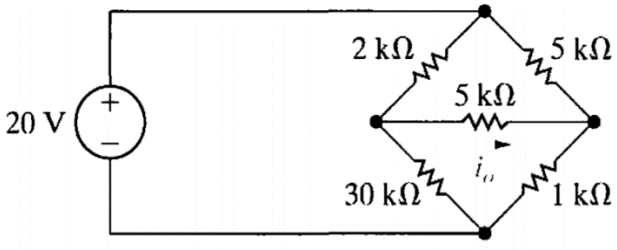
V_1 = _____ i = _____

37. Determine the power dissipated by R6 (P_{R6}) and the power supplied by the source V_1 (P_{V1}). Provide your answers to 3 significant figures. [1] **(12 pts; 6, 6)**



P_{R6} = _____ P_{V1} = _____

38. Determine the current through the center 5 kΩ resistor (i_o) Provide your answer to 3 significant figures. [1] **(6 pts)**



i_o = _____

____ / 30

39. State 4 assumptions of the characteristics an ideal operational amplifier. [1] **(4 pts) (TB#6)**

1. _____

2. _____

3. _____

4. _____

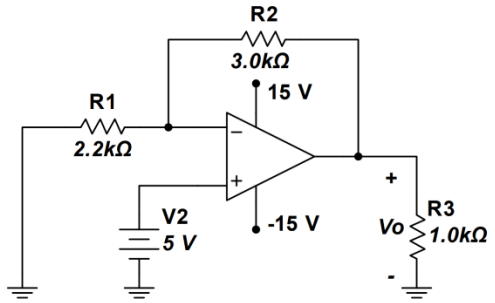
40. What is the measured output voltage of an operational amplifier if the calculated output voltage based on the input voltage and the gain exceeds the supply voltage? [1] **(3 pts)**

_____

_____

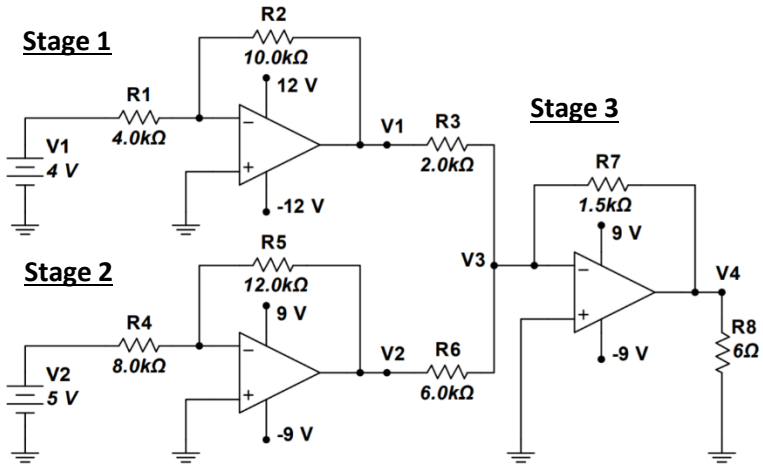
_____

41. Determine the output voltage (V_o) and whether an inverting or non-inverting configuration is used in the circuit below. Assume an ideal operational amplifier. Provide your answer to 3 significant figures. [1] **(8 pts; 6, 2) (TB#7)**



V_o = _____ ***Type =*** _____

42. Determine the gain for each stage and the node voltages (V_1, V_2, V_3, V_4). Assume an ideal operational amplifier. Provide your answers to 3 significant figures. [1] **(22 pts; 3, 3, 4, 4, 4, 4)**

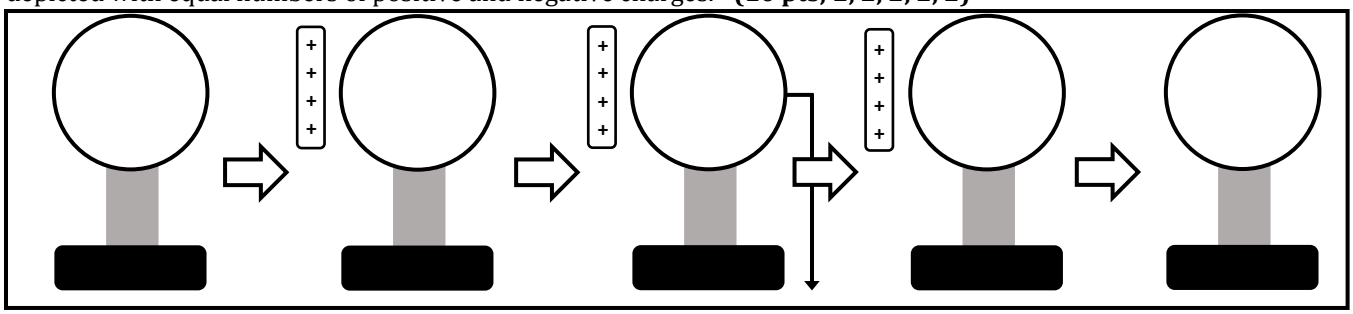


Gain (Stage 1) = _____ ***Gain (Stage 2) =*** _____

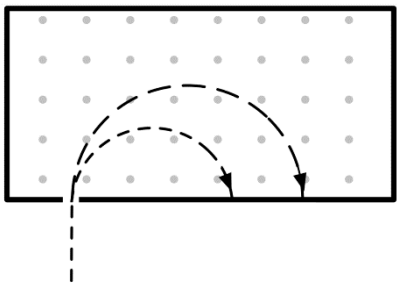
V_1 = _____ ***V_2 =*** _____ ***V_3 =*** _____ ***V_4 =*** _____

_____ / 37

43. Using the template shown below, show the distribution of positive and negative charges in the sphere at each step. Every sphere should contain charges. The number of charges used is irrelevant, but net neutral spheres should be depicted with equal numbers of positive and negative charges. [1] **(10 pts; 2, 2, 2, 2, 2)**

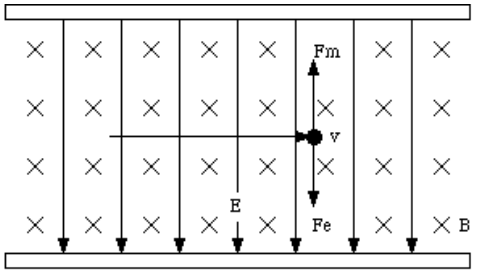


44. The figure shows a mass spectrometer in which charged particles of different masses enter a region through a slit and move perpendicular to a uniform magnetic field permeating the region (the gray dots represent the magnetic field pointing out of the page). For each particle, the detector measures the distance between the entrance point to the place where it strikes the bottom of the region. Assume ^{12}C and ^{16}O singly charged ions are accelerated to the same velocity before entering the spectrometer. If the ^{16}O ions strike the detector 5.0 m from the slit, at what point will the ^{12}C ions hit it? [1] **(8 pts) (TB#8)**



Distance = _____

45. A proton travels through a region with an electric and magnetic force. Name the force being exerted on the proton. If the magnitude of the electric field (E) directed downwards is 4500 N/m and the magnitude of the magnetic field (B) into the page is 2.0 T, determine the velocity (v) that allows the proton to travel in a straight trajectory. [1] **(8 pts; 2, 6)**



Name of Force = _____ v = _____

46. Describe how AC and DC motors differ in terms of their <u>construction</u> and the way <u>speed is controlled</u>. [1] **(4 pts)**

_____

_____

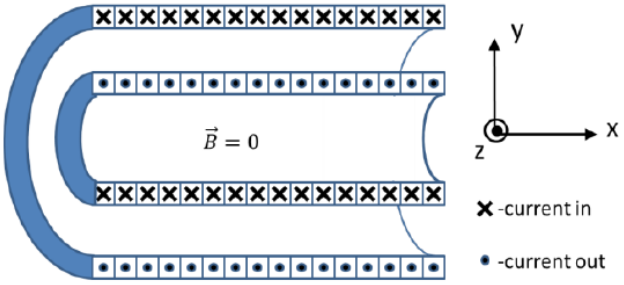
_____

_____

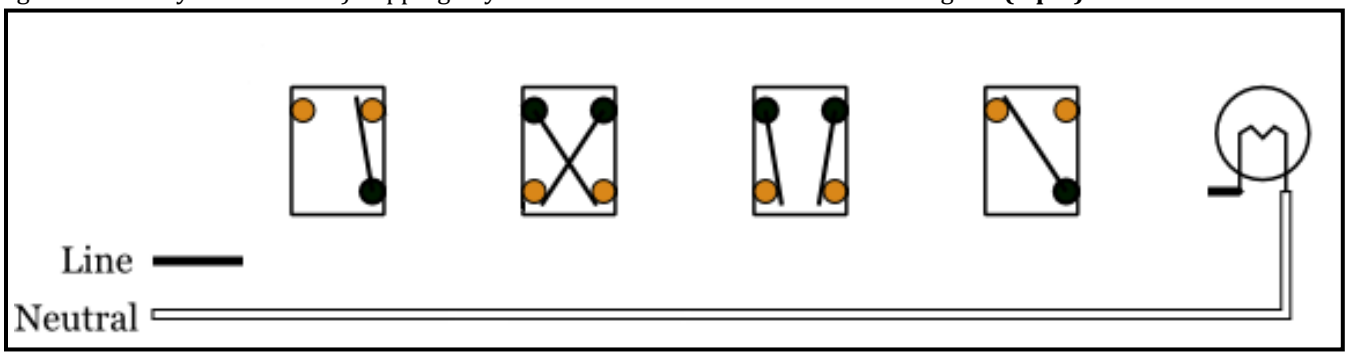
_____

____ / 30

47. Two long solenoids carrying identical current in opposite directions are shown. If there is no magnetic field present inside the inner solenoid, what can you determine about the number of turns per unit length of the inner solenoid and the number of turns per unit length of the outer solenoid? [1] **(4 pts)**



48. Draw wires connecting the round terminals of the switches so that it satisfies the following two conditions: 1.) The light is currently turned off. 2.) Flipping any one of the four switches turns on the light. [1] **(8 pts)**



49. A bank wants to install an alarm system with 3 movement sensors **(S1, S2, S3)**. To prevent false alarms produced by a single sensor activation, the alarm **(Alarm)** will be triggered only when at least 2 sensors activate simultaneously. Draw a logic diagram and provide the simplified Boolean expression. Use the bolded terms above to label your diagram. [1] **(10 pts; 6, 4)**

Alarm = _____

____ / 22

LAB 1 (Circuit Analysis): At this station, you will **analyze** a circuit. Perform the following tasks on the circuit built on the breadboard provided. [1] **(47 pts; 15, 12, 20)**

50. **Draw** the circuit constructed on the breadboard. You may represent the power supply as a battery with a labeled voltage. Represent the potentiometer (trimpot) as a variable resistor. **(15 pts)**

51. **Calculate** the theoretical resistance of the variable resistor needed to balance the circuit such that zero current flows through resistor R_3. **(12 pts)**

52. Part 1: **Measure** the resistance of the variable resistor needed to balance the circuit such that zero current flows through resistor R_3. Part 2: Explain how you manipulated the circuit to make that measurement. **(20 pts; 8; 12)**

Measured R = _____

_____ / 47

LAB 2 (Digital Logic): At this station, you will **draw and construct** a circuit. One way to achieve Digital-to-Analog (D/A) conversion is to build an R-2R ladder. [1] **(55 pts; 30, 25) (TB#9)**

53. Part 1: **Draw** a 3-bit D/A converter circuit using an R-2R ladder that obeys the provided output table. The component values and quantities MUST be representative of the physical components provided. The following criteria should be met:
    - All sources and components include values labeled where appropriate.
    - Three digital inputs representing each bit of data drawn as SPDT switches that provide 5 V or 0 V in the ON and OFF positions, respectively. Label the inputs "B_0, B_1, and B_2".
    - The analog output voltage obeys the output table provided below.

    Part 2: Derive a formula for the analog output (V_{out}) in terms of the digital inputs (B_2, B_1, B_0). **(30 pts; 18, 12)**

Output Table				
B_2	B_1	B_0	Digital	$\mathbf{V_{out}}$
0	0	0	0	0.0 V
0	0	1	1	0.625 V
0	1	0	2	1.25 V
0	1	1	3	1.875 V
1	0	0	4	2.5 V
1	0	1	5	3.125 V
1	1	0	6	3.75 V
1	1	1	7	4.375 V

54. **Construct** a 3-bit D/A converter circuit that uses an R-2R ladder from Q53. The component values and quantities MUST be representative of the physical components provided. When constructed, call over a proctor to demonstrate the circuit. You will only receive credit if the proctor initials below indicating the circuit functions properly. There is NO PARTIAL CREDIT. The following criteria should be met: **(25 pts)**
    - Three digital inputs representing each bit of data are constructed using SPDT switches that provide 5 V or 0 V in the ON and OFF positions, respectively.
    - The analog output obeys the output table given in Q53.

Initials = _____

_____ / 55