PRINCETON UNIVERSITY
SCIENCE OLYMPIAD
INVITATIONAL

2020 Princeton University Invitational Tournament

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 sections **(2 total)**. 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:** 9, 11, 13, 26, 28, 32, 39, 41

Competitors: _____

_____

School Name: _____

Team Number: _____

Rank: _____

Score: _____

Kevin Hao[1], Asher Noel[2], Megan Pramojaney[3]
[1]University of Florida - BS Biology '21, MD '24 kevin@floridascienceolympiad.org
[2]Harvard College – BA Computer Science and Statistics '23 ashernoel@college.harvard.edu
[3]University of North Carolina Chapel Hill – BS Physics '23 pramoj23@live.unc.edu

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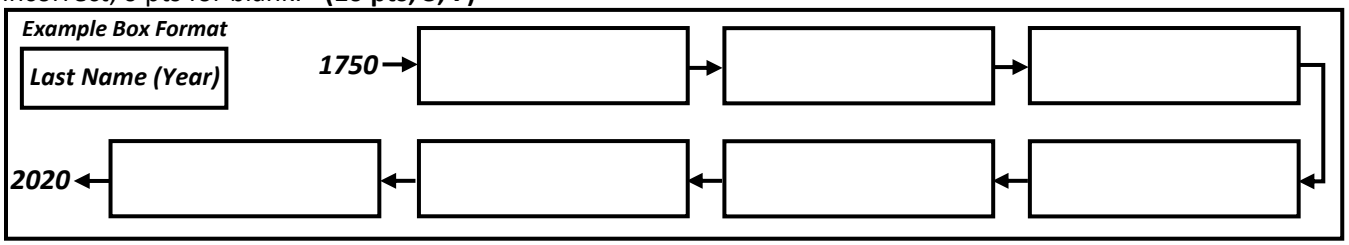
Page Number	Possible Score	Your Score
3	20	
4	24	
5	26	
6	38	
7	20	
8	28	
9	24	
10	28	
LAB 1	36	
LAB 2	40	
Total	284	

1. Part 1: Order the seven scientists in the rules by the ascending date of their crowning contribution to this field.
   Part 2: Write the year of each scientist's crowning contribution next to their name. 1 pt for correct, -1 pt for incorrect, 0 pts for blank. [2] **(10 pts; 3, 7)**



2. Short Response: Who won the War of the Currents: Edison or Tesla? Make a strong claim, support your idea with verifiable evidence and analysis, and write clearly. [2] **(4 pts; 1, 1, 1, 1)**

3. Long Response: Of the scientists listed in the rules, who most deserved to win a Nobel Prize, assuming the Nobel Prize were established in 1700? Make a strong claim, support your idea with verifiable evidence and analysis, and write clearly. [2] **(6 pts; 1, 2, 2, 1)**

____ / 20

4. **[A]** Which could be performed to simplify the circuit? [1] **(2 pts)**

A. Y-to-Δ B. Δ-to-Y
C. Either D. Neither

5. **[A]** Determine V_o. [1] **(2 pts)**

A. 15 V B. 18 V
C. 22 V D. 35 V

6. **[B]** Determine V_x. [1] **(2 pts)**

A. 4 V B. 6 V
C. 7 V D. 8 V

7. **[B]** Determine V_Y. [1] **(2 pts)**

A. 4 V B. 6 V
C. 7 V D. 8 V

8. **[B]** Determine i. [1] **(2 pts)**

A. 0.5 A B. 1.0 A
C. 1.5 A D. 3.0 A

9. **[C]** Determine the resistance of the device. [1] **(2 pts) (TB#1)**

A. 27 Ω B. 27 kΩ
C. 54 Ω D. 54 kΩ

10. **[D]** Determine the resistance of the device. [1] **(2 pts)**

A. 3.6 kΩ B. 4.1 kΩ
C. 4.9 kΩ D. 5.6 kΩ

11. **[E]** Determine the polarities. (Choose all that apply) [1] **(2 pts) (TB#2)**

A. W = North B. X = North
C. Y = North D. Z = South

12. **[F]** Determine the required input (A,B,C) to achieve X=1. [1] **(2 pts)**

A. 1, 0, 1 B. 0, 0, 1
C. 1, 1, 1 D. 0, 1, 1

13. **[G]** Determine the corresponding logic gate. [1] **(2 pts) (TB#3)**

A. AND B. OR
C. XOR D. NOR

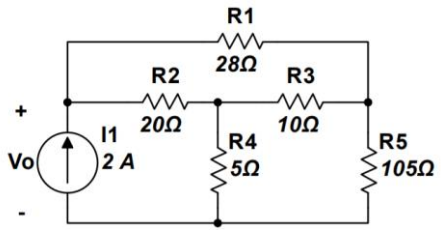
14. All combinational logic functions can be realized by: [1] **(2 pts)**

A. OR only B. XOR only
C. AND only D. NOR only

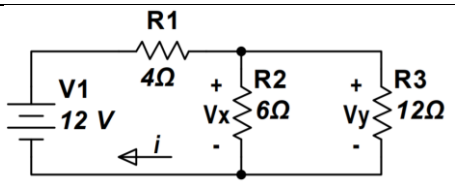
15. A bulb in a staircases has two switches, one switch being at the ground floor and the other one at the first floor. The bulb can be turned ON and also can be turned OFF by one of the switches irrespective of the state of the other switch. The logic of switching of the bulb represents: [1] **(2 pts)**

A. an AND gate B. an XOR gate
C. an OR gate D. an NAND gate

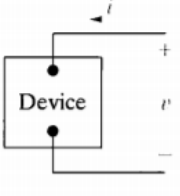
A



B

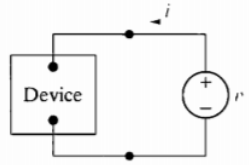


C



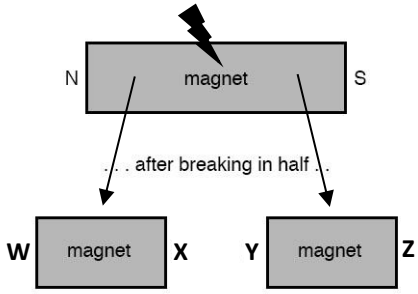
i (mA)	v (V)
−4	−108
−2	−54
2	54
4	108
6	162

D

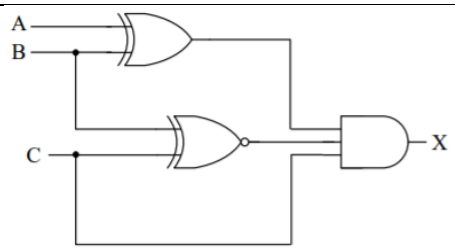


v (V)	p (mW)
−10	17.86
−5	4.46
5	4.46
10	17.86
15	40.18
20	71.43

E



F



G

Input		Output
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

____ / 24

16. **[G]** What is the junction type of the circuit? [3] **(2 pts)**

A. PN B. NP
C. PNP D. NPN

17. **[G]** Name the model used. [3] **(2 pts)**

A. Gummel-Poon B. Ebers-Moll
C. H-parameter D. Hybrid-pi

18. **[H]** Define a function h(x) = \piecewise{1 if Wx + b >= 0 and 0 if Wx + b < 0}. Which of the following logic gates could the following neural network represent, where b = -10, and W1 = W2 = 20? (Choose all that apply)? [2] **(4 pts)**

A. OR B. NOR
C. AND D. NAND

19. **[I]** Calculate the value of i_o. [1] **(2 pts)**

A. 0.5 A B. 1.0 A
C. 2.0 A D. 3.0 A

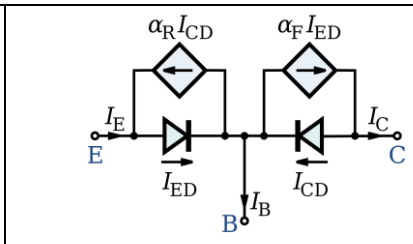
20. **[I]** Calculate the value of i_1. [1] **(2 pts)**

A. 1.54 A B. 1.76 A
C. 1.98 A D. 2.35 A

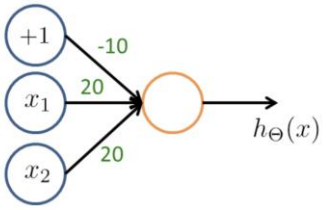
21. **[J]** Identify the op-amp configuration. [1] **(2 pts)**

A. Inverting B. Non-Inverting
C. Summing D. Differentiator

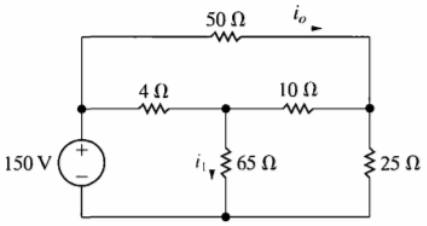
G



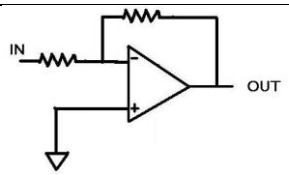
H



I



J



22. Which of the following can help improve the efficiency of a motor? [3] **(2 pts)**

A. Increasing the heat retention of the motor frame
B. Reducing the conductivity of the rotor material
C. Decreasing the mass of the stator winding
D. None of the above

23. In which of the following areas would precautions likely be taken due to the triboelectric effect?(Choose all that apply)? [3] **(4 pts)**

A. Using traction motors for the propulsion of vehicles, such as locomotives
B. Working with CMOS integrated circuits and MOSFET transistors
C. Charging an electric car battery
D. Performing bulk fuel deliveries

24. Rank the conductivity of the following from least to greatest: Lead, Gold, Germanium, Fused quartz. [3] **(2 pts)**

25. An object of charge Q is placed inside an ungrounded Faraday cage. Another identical object of charge Q is held outside the cage. Describe the interaction between the object outside of the cage with the cage. [3] **(2 pts)**

26. Why would you use a flyback diode in a relay circuit? [3] **(2 pts) (TB#4)**

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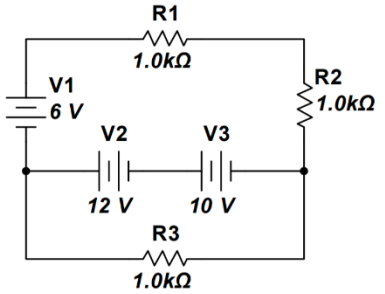
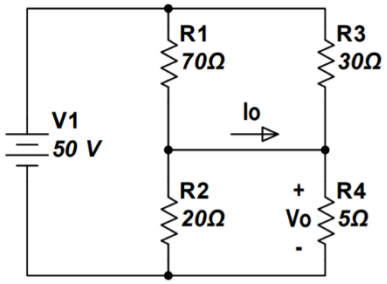
27. Determine the voltage drop across each resistor. Provide your answers to 3 significant figures. [1] **(6 pts; 2, 2, 2)**



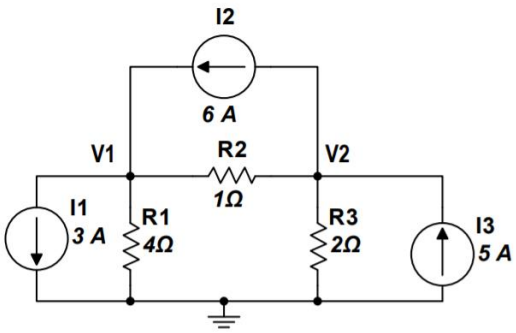
V_{R1} = _____ V_{R2} = _____ V_{R3} = _____

28. Determine the current I_o and the voltage V_o. Provide your answers to 3 significant figures. [1] **(12 pts; 6, 6) (TB#5)**



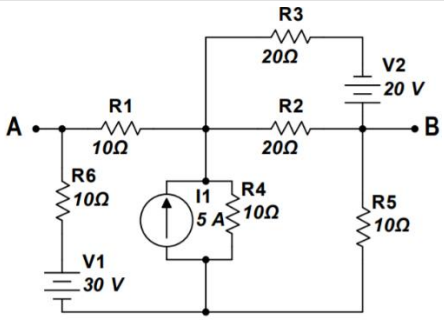
I_o = _____ V_o = _____

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



V_1 = _____ V_2 = _____

30. Find the Thevenin equivalent between nodes A and B. Provide your answers to 3 significant figures. [1] **(12 pts)**



Thévenin

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31. Pictured is an instrument designed to measure current. Answer the following questions: [3] **(10 pts; 4, 1, 1, 4)**
    - Name components A-D in the diagram. **(4 pts)**
    - State the name of the instrument. **(1 pt)**
    - Indicate whether you would connect it to a circuit in series or parallel. **(1 pt)**
    - Consider one of the earliest versions of this type of instrument, where the needle pictured would deflect on the linear scale by an angle **θ** given by $\theta = \tan^{-1}\frac{B}{B_H}$,where B is the magnetic field at the center of the coil in the device and B_H is the horizontal component of the Earth's magnetic field at a given point on earth. Suppose that the needle is deflected 30°. Given that the coil in the device has 350 turns and a radius of 2.5 cm, calculate the current flowing through the coil in terms of BH. Assume B_H is given in its SI base unit(s). **(4 pts)**

A: _____

B: _____

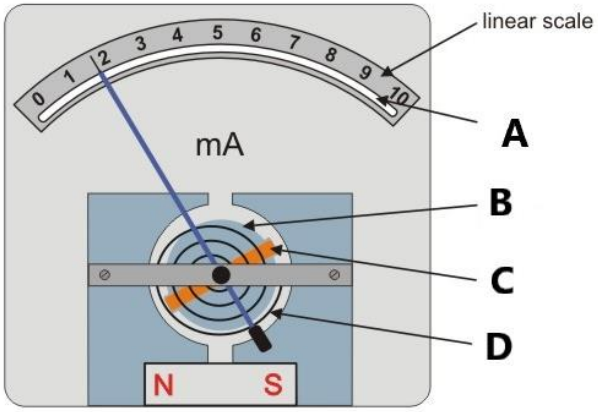
C: _____

D: _____

Name: _____

(Circle one): (Series | Parallel)

I = _____

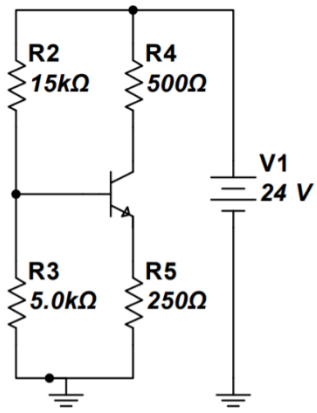


32. Perform the following for the transistor circuit shown below given that the voltage at the base of the transistor is 5.33 V and β = 100. Assume that the transistor has a forward voltage drop of 0.7 V. Provide your answers to 3 significant figures. [3] **(10 pts; 2, 2, 6) (TB#6)**
    - State the junction type of the transistor? **(2 pts)**
    - State the mode the transistor is in. **(2 pts)**
    - Find the Q-point of the transistor by calculating I_{EQ} and V_{CEQ}. **(6 pts; 3, 3)**

Junction type = _____

Transistor Mode = _____

Q-point: _____



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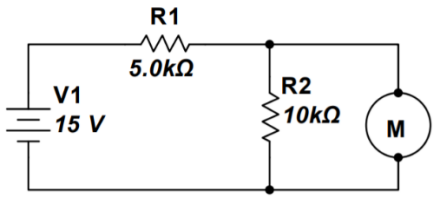
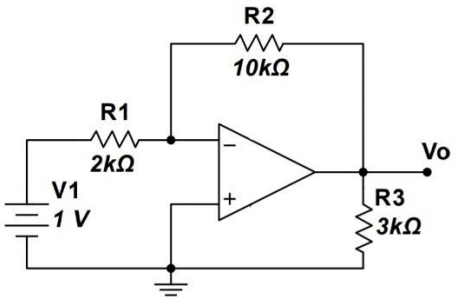
33. Perform the following for the circuit below given that the voltage drop across R1 (V_{R1}) is 5.0 V. [3] **(8 pts; 2, 6)**
    - Determine the power supplied to the motor (P_S). **(2 pts)**
    - Given that the motor M shown has an output torque of 20. N*mm and a shaft angular velocity of 0.050 rad/s calculate the percent efficiency of the motor. **(6 pts)**



P_S = _____

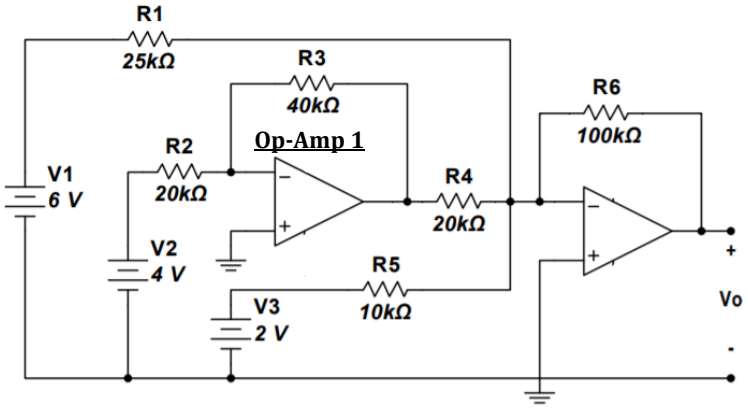
Efficiency = _____

34. Determine the output voltage (V_o) and the current thru resistor R2 (I_{R2}). [1] **(8 pts; 4, 4)**



V_o = _____ I_{R2} = _____

35. Determine the gain of Op-Amp 1 and output voltage (V_o). Provide your answer to 3 significant figures. [1] **(12 pts; 4, 8)**



Gain (Op-Amp 1) = _____ V_o = _____

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36. A charged particle moving through a magnetic field at right angles to the field with a speed of 22.7 m/s experiences a magnetic force of $2.58 \times 10^{-4}\ N$. Determine the magnetic force on an identical particle when it travels through the same magnetic field with a speed of 5.54 m/s at an angle of 27.2°. [1] **(8 pts)**

F = _____

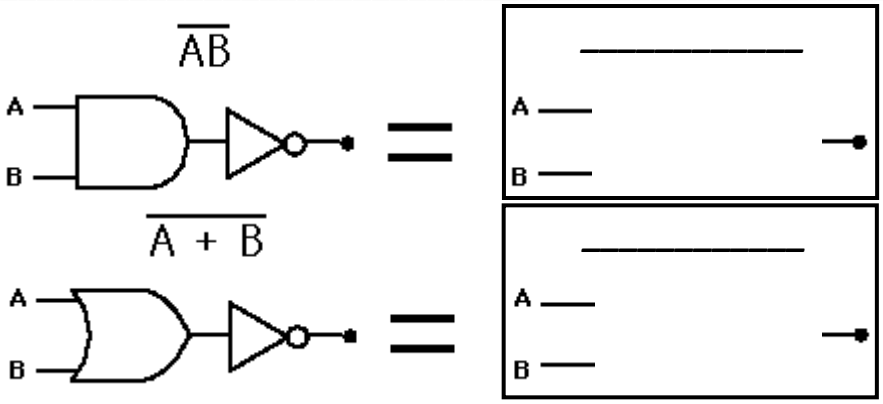
37. State DeMorgan's Theorem. Then apply it to draw the appropriate gates and their Boolean expressions in the spaces provided. [1] **(8 pts; 2, 4, 2)**

_____

_____

_____

_____



38. Draw two possible logic gate diagrams mapping the expression $Z = \bar{A} \cdot \bar{B} \cdot (C + D)$. [1] **(8 pts; 4, 4)**

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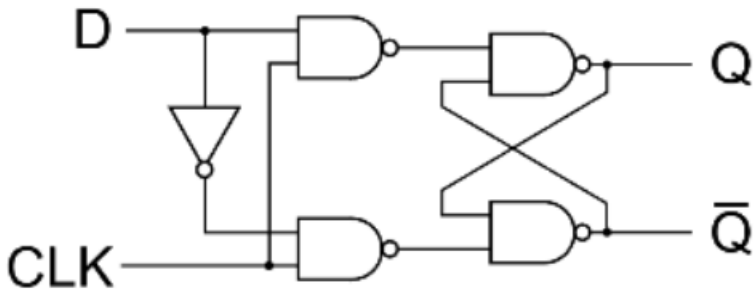
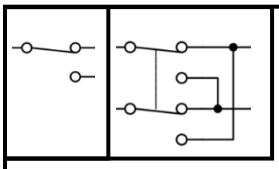
39. Name the circuit and complete the truth table. [1] **(10 pts; 2, 8) (TB#7)**

Clock	D	Q	Q'
↓ >> 0	0		
↑ >> 1	0		
↓ >> 0	1		
↑ >> 1	1		



Logic Gate Configuration: _____

40. Draw an electrical control diagram using three 3-way (SPDT) and one 4-way (DPDT) switches that controls two lights in accordance to the truth table provided. Use a 5V DC light and a 5V DC source. Label the switches (S1, S2, and S3) and light (L1). Examples of SPDT and DPDT switches in the OFF (0) position are provided. [1] **(10 pts)**



S1	S2	S3	**L1**
0	0	0	**1**
1	0	0	**0**
0	1	0	**0**
0	0	1	**0**
1	1	0	**1**
1	0	1	**1**
0	1	1	**1**
1	1	1	**0**

41. Draw magnetic field lines (including arrows) for the pair of magnets shown below. Indicate the direction of motion for each magnet if they were not held in place by drawing an arrow in each box above the magnets. [1] **(8 pts; 6, 2) (TB#8)**

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LAB 1 (Circuit Diagnostics): At this station, you will analyze three circuits, determine the problem with each, and propose a solution to fix them. [1] **(36 pts total)**

42. **Circuit 1** is meant to produce light, but the LED currently connected to the circuit is not turning on. Using your voltmeter to take measurements of voltage only from the labeled leads, determine why the LED is not turning on. Then perform the following: [1] **(20 pts)**
    - **Draw** up to **two unique** solutions to fix the circuit using the additional components provided. Each solution should only have ONE modification. HINT: any color LED is acceptable as long as light is produced. **(12 pts; 6, 6)**
    - **Explain how** each solution fixes the initial problem. **(8 pts; 4, 4)**

_____
_____
_____

_____
_____
_____

43. **Circuit 2** is meant to power all the LEDs with equal brightness, but the LEDs are varying in brightness. Determine the problem with the circuit and then perform the following: [1] **(8 pts)**
    - Redraw Circuit 2 **using the same components**. **(6 pts)**
    - E**xplain how** your new schematic fixes the initial problem. **(2 pts)**

_____
_____
_____
_____
_____
_____
_____
_____

44. **Circuit 3** is a DC gain op-amp circuit that is supposed to produce a 10V output voltage, but only 5V is being measured. Determine the problem with the circuit and then perform the following: [1] **(8 pts)**
    - **Explain** the problem with the circuit. **(6 pts)**
    - Determine if it is possible to fix the circuit to achieve the desired output using the provided components. **(2 pts)**

_____
_____
_____

Possible to fix? (Circle one): (Yes | No)

_____ / 36

LAB 2 (Digital Logic): At this station, you will first **analyze** a circuit. On the breadboard provided, there is a pre-built logic gate circuit. [1] **(40 pts total)**

45. **[Analysis]** Perform the following for the circuit constructed on the breadboard: [1] **(40 pts)**
    - Complete a truth table for the circuit using the template provided. **(4 pts)**
    - Draw a logic gate diagram. Each gate constructed in the circuit should be included. Label each gate. **(12 pts)**
    - Draw a circuit diagram. Include component values where appropriate. You may represent the inputs constructed using press buttons on the breadboard as SPST or SPDT switches. Label A, B, C, and Q. **(24 pts)**

Logic Diagram

A	B	C	**Q**
0	0	0	
1	0	0	
0	1	0	
0	0	1	
1	1	0	
0	1	1	
1	0	1	
1	1	1	

Circuit Diagram

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