Exploring the World of Science

University of Michigan Science Olympiad
2021 Invitational Tournament

Circuit Lab C

Test length: 50 Minutes

Team name: KEY

Student names: KEY

UMSO Circuit Lab Division C 2021 KEY

Multiple Choice Questions

1. Who suggested that the repulsion between two similarly charged particles is proportional to the square of their separation?

   a. Ampere
   b. Coulomb
   c. Kirchoff
   d. Volta
   e. Tesla
   f. Faraday

2. Who is credited with the invention of an enclosure to block electromagnetic fields?

   a. Ampere
   b. Coulomb
   c. Kirchoff
   d. Volta
   e. Tesla
   f. Faraday

3. Who was most influential in the invention of the Homopolar motor?

   a. Ampere
   b. Coulomb
   c. Kirchoff
   d. Volta
   e. Tesla
   f. Faraday

4. Who first discovered evidence that light and electromagnetism are related?

   a. Ampere

b. Coulomb
c. Kirchoff
d. Volta
e. Tesla
f. Faraday

5. Who is credited with the discovery of the battery?

a. Ampere
b. Coulomb
c. Kirchoff
d. Volta
e. Tesla
f. Faraday

6. Who discovered that two wires (both carrying current) placed next to each other can repel or attract each other?

a. Ampere
b. Coulomb
c. Kirchoff
d. Volta
e. Tesla
f. Faraday

7. Who suggested that the sum of currents entering and leaving a node must be zero?

a. Ampere
b. Coulomb
c. Kirchoff
d. Volta
e. Tesla
f. Faraday

8. What is the unit of conductance?

a. Ampere
b. Coulomb

c. Volt
d. Henry
e. Siemens
f. Watt

9. What is the SI unit for energy?

a. Joule
b. Watt
c. Ohm
d. Henry
e. Tesla
f. Volt

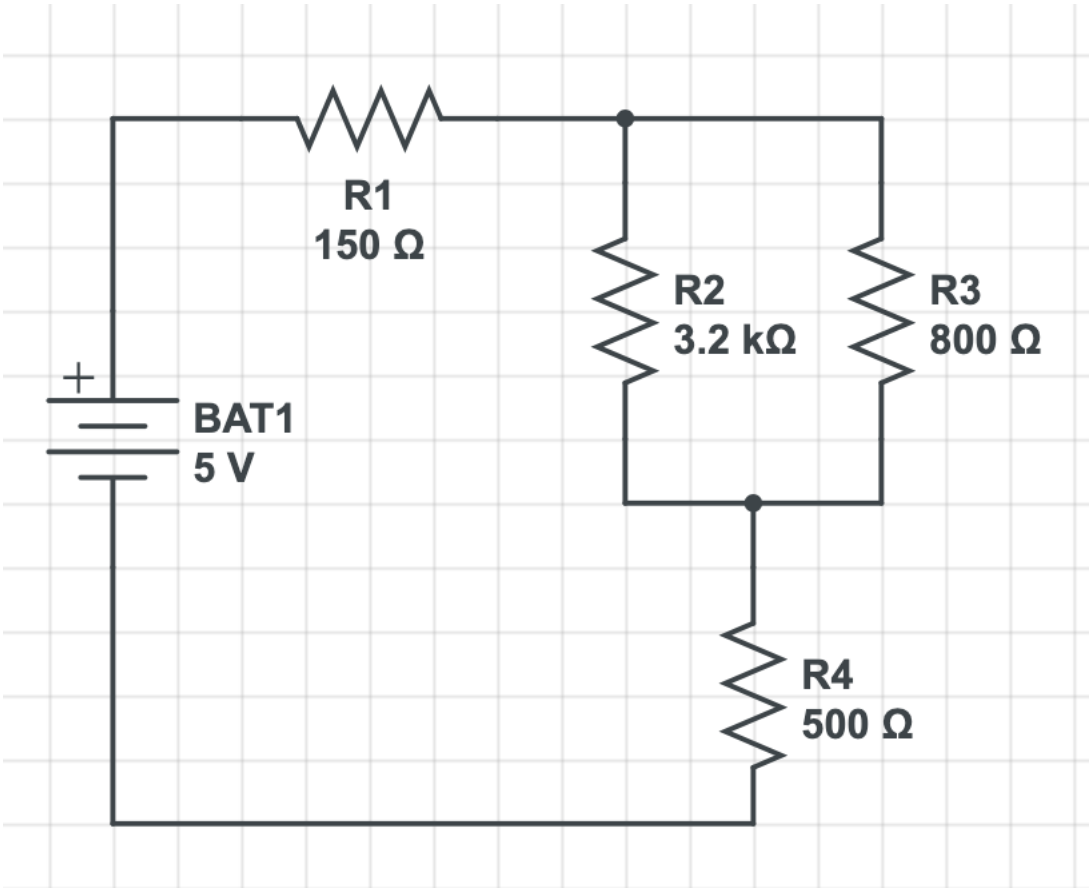
10. What is the SI unit for magnetic field strength?

a. Joule
b. Watt
c. Ohm
d. Henry
e. Volt
f. Tesla

11. Write the unit for current in base SI units (meter, kilogram, second, ampere)

a. $A \cdot s$
b. $(kg \cdot m^2)/(s^2 \cdot A^2)$
c. $(s^4 \cdot A^2)/(kg \cdot m^3)$
d. $kg \cdot m^2/s^2$
e. A
f. $kg \cdot m^2/s^3$

Questions 13-17 refer to the following picture:



12. What is the equivalent resistance of this circuit?

    a. 4650 Ω
    b. 1290 Ω
    c. 2650 Ω
    d. 3550 Ω
    e. 1190 Ω
    f. 2950 Ω

13. What is the voltage drop across R1?

    a. 2.48V
    b. 0.58V
    c. 0.11V
    d. 0.15V
    e. 1.6V
    f. 0.44V

14. What is the voltage drop across R3?

    a. 2.48V
    b. 0.58V
    c. 0.11V
    d. 0.15V
    e. 1.6V
    f. 0.44V

15. How much energy is consumed by the circuit every second?

    a. 0.019J
    b. 0.019W
    c. 0.019V
    d. 0.058J
    e. 0.058W
    f. 0.058V

16. What is the current through R2?

    a. 0.11mA
    b. 0.48mA
    c. 0.16A
    d. 0.77mA
    e. 1.7mA
    f. 7.7mA

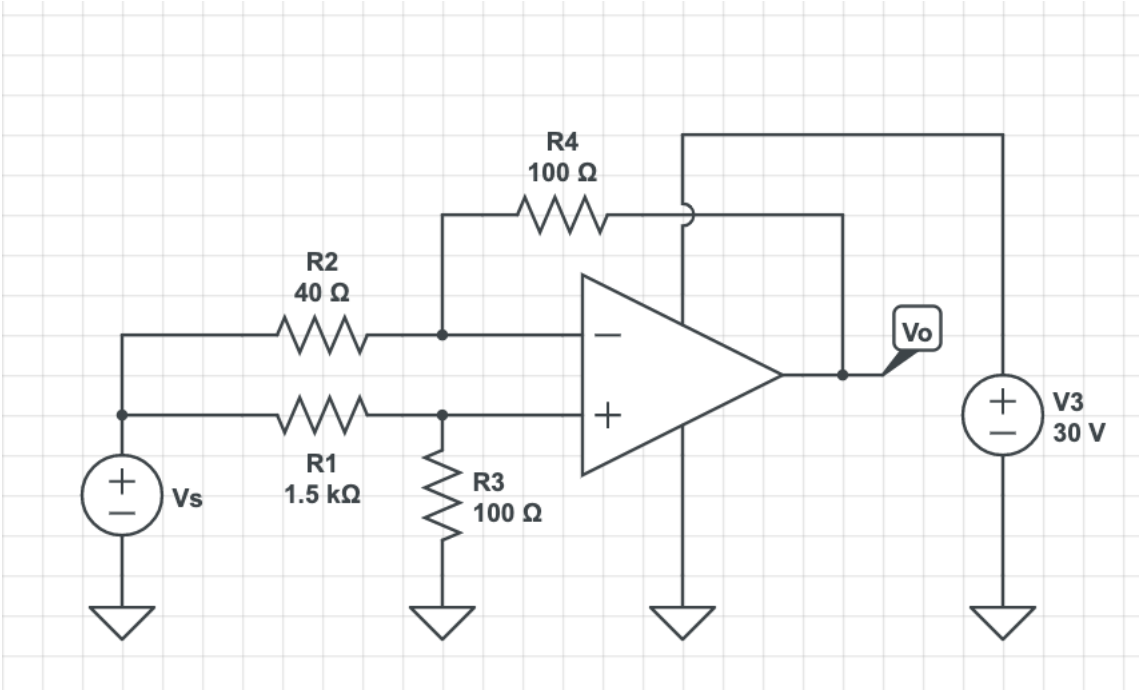
17. What is the direction of the magnetic force on an electron moving directly right through a magnetic field pointing out of the screen??

    a. Up
    b. Down
    c. Left
    d. Right
    e. Into Screen
    f. Out of Screen

Short Answer Questions

For the short answer questions, please explain your thought process (show work) for full points.

Questions 1 and 2 refer to the following diagram:



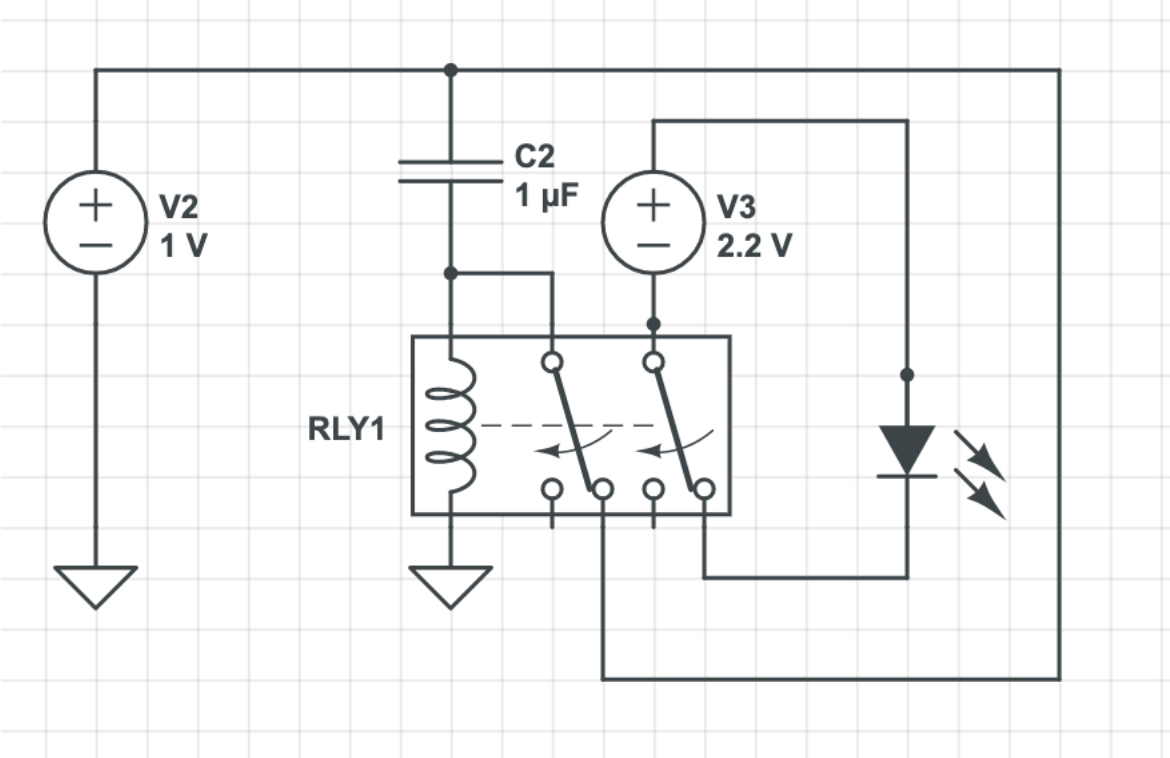
1. What is the gain of the circuit?

   -73/32

2. What are the minimum and maximum Vs that can be supplied so the output is not clipped?

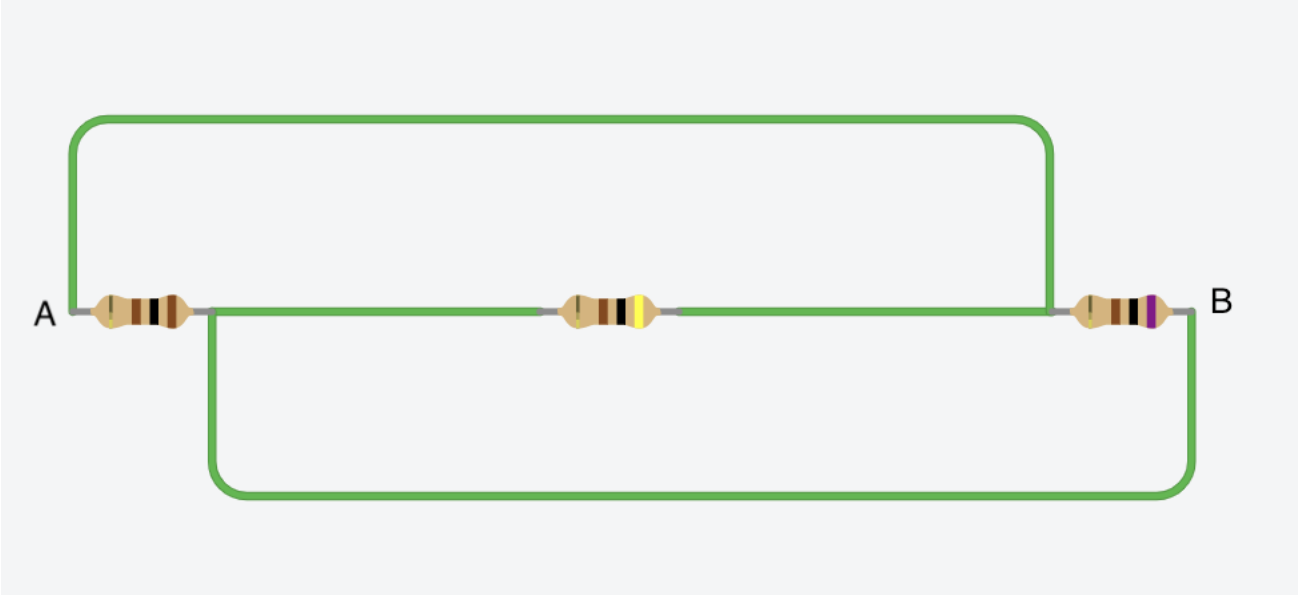
   0V max, -960/73V min

3. What does the following circuit do, and what is it called?



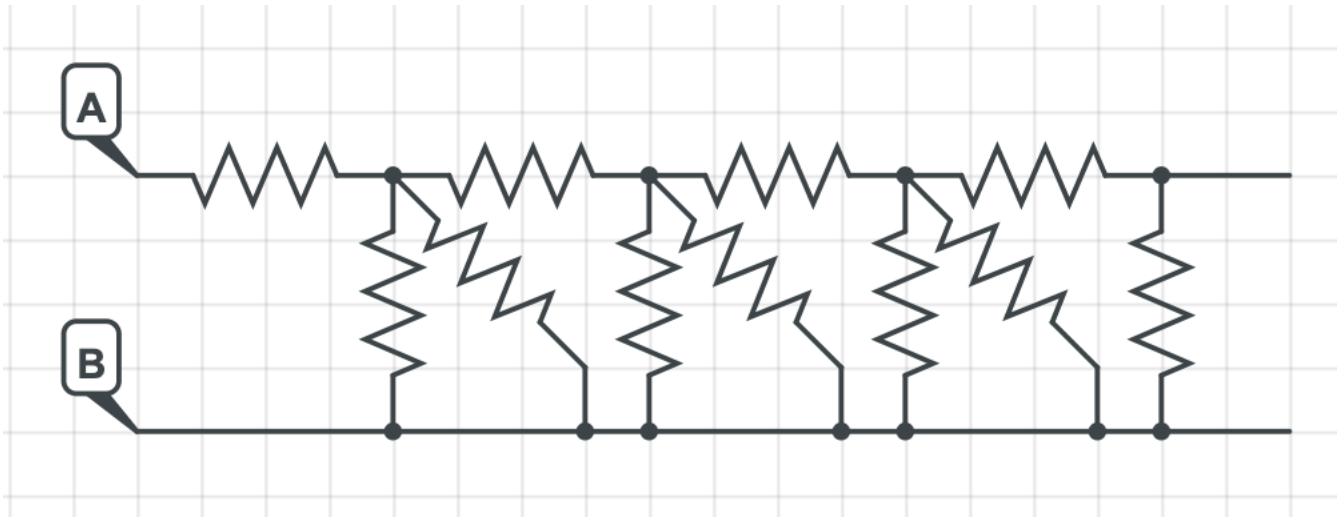
It's a relay oscillator, it will flicker the LED on and off.

4. What is the resistance from point A to point B?



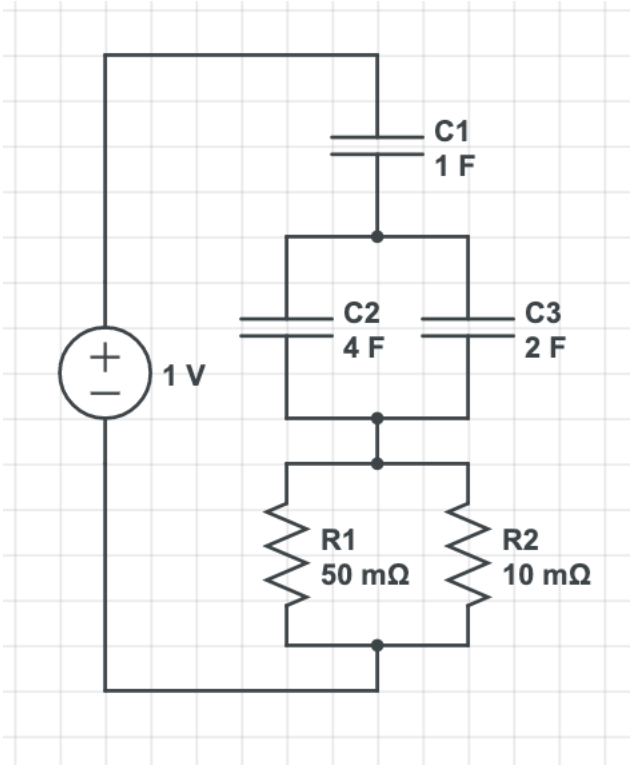
71.8Ω

5. What is the resistance from point A to point B if the pattern continues forever and all resistors have resistance of $R\Omega$? (Your answer should be in terms of R.)



$R \cdot \frac{1+\sqrt{3}}{2} \Omega$

6. What is the time constant of the following circuit?



0.00714s OR 0.05/7 s

7. What are the two types of BJT transistors? List their similarities and differences.

   NPN and PNP.

   Both are made up of both N and P type semiconductors, with three regions each. Both can act as electronic switches with no moving parts.

PNP and NPN are obviously different in the sense of their physical makeup, PNP have an N-type semiconductor between two P-type, and NPN are the opposite, as the names would suggest.PNP transistors use holes as the primary charge carrier, NPN transistors use electrons.

8. What type of semiconductor would result from phosphorus doping of silicon?

   N-type

9. What type of semiconductor would result from boron doping of silicon?

   P-type

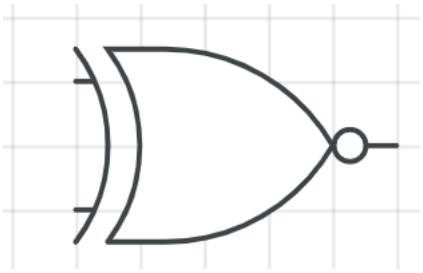
10. Describe a P-N junction, and how it contributes to the function of a diode.

    A P-N junction is a boundary or interface between two types of semiconductor (P-type and N-type). The P-type contains an excess of holes, and the N-type contains an excess of electrons. This junction allows current to flow only one way. When the two semiconductor types overlap, a "depletion region", which does not allow current to cross in one direction forms. This depletion layer is wider when the diode is reverse biased, or when electrons are filling the holes of the p-type. When forward bias is applied, the depletion layer shrinks, and current can flow.

11. Using boolean algebra, show $A\overline{B} + \overline{(A+B)} = \overline{B}$

    $A\overline{B} + \overline{(A+B)} = A\overline{B} + \overline{A}\,\overline{B} = \overline{B}(A + \overline{A}) = \overline{B}$

12. What gate is this, what is its truth table, and what is its corresponding boolean algebra expression?



    XNOR, 1 iff inputs are the same, $\overline{A \oplus B}$

13. Which two logic gates are considered "Universal", and why?

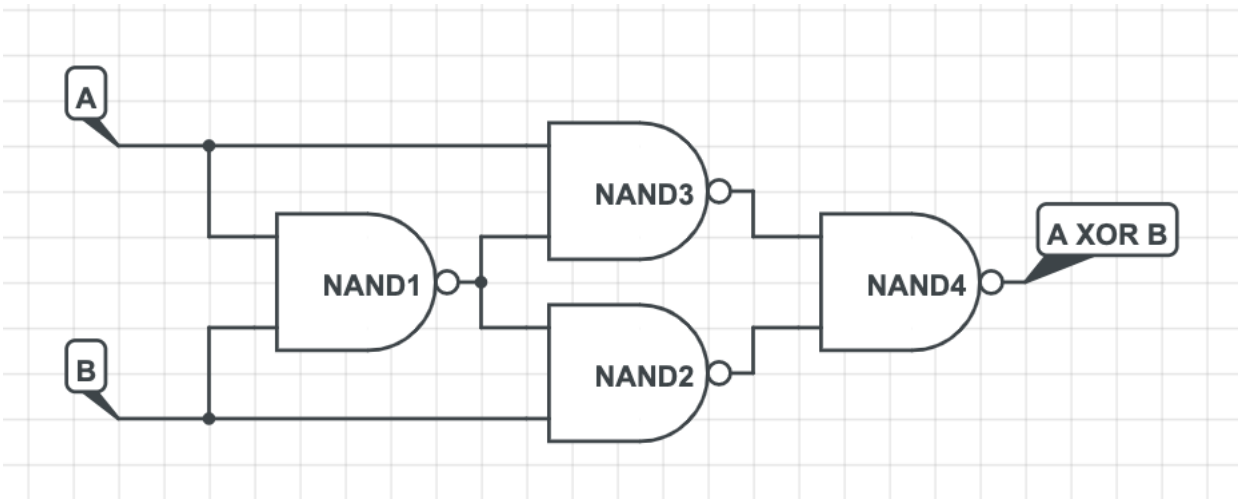
    NOR and NAND, you can make every other gate out of just NOR and NAND gates.

14. Show you can make an XOR gate out of NAND gates.

    Using boolean algebra:

    Boolean expression for XOR: $A \oplus B = \overline{A}B + A\overline{B}$

    My construction using NAND:



Boolean algebra expression:

$$\overline{\overline{\overline{AB} \cdot A} \cdot \overline{\overline{AB} \cdot B}}$$

Transformation of my construction to XOR:

Step	Reasoning
$\overline{\overline{\overline{AB} \cdot A} \cdot \overline{\overline{AB} \cdot B}}$	Given
$\overline{\overline{\overline{AB} \cdot A} + \overline{\overline{AB} \cdot B}}$	De Morgan's law
$\overline{AB} \cdot A + \overline{AB} \cdot B$	Negation Law
$(\overline{A} + \overline{B}) \cdot A + (\overline{A} + \overline{B}) \cdot B$	De Morgan's Law
$\overline{A} \cdot A + \overline{B} \cdot A + \overline{A} \cdot B + \overline{B} \cdot B$	Distributive Law
$\overline{B} \cdot A + \overline{A} \cdot B$	Identity Law
$\overline{A}B + A\overline{B}$	Commutative Law

15. What is a wheatstone bridge, and what is it used for?

    A wheatstone bridge is a circuit containing 4 resistors and a galvanometer, and is used to identify unknown resistor values.

16. What is a three-way switch? Give an application of a three-way switch.

    A three-way switch is a switching mechanism which has two separate SPDT switches. It allows the user to switch something on and off from two separate locations. Application: A hallway light. You want to be able to turn on the hallway light from both sides of the hallway, so you use a three-way switch.

17. What are Kirchoff's laws?

    KCL: The sum of currents entering and leaving a node must equal zero.

    KVL: The sum of voltages in a closed loop must equal zero.

Long(-er) Answer Questions

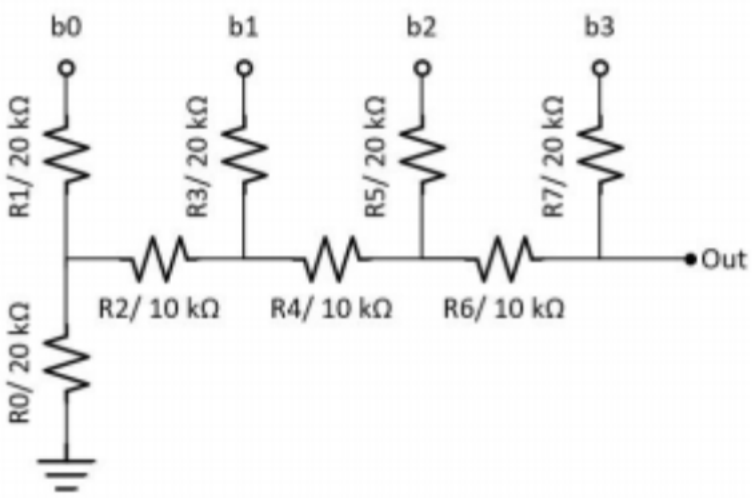
1. Magnetism in Space

   A proton is moving directly right at 44m/s when it encounters a magnetic field with strength 4T. This magnetic field is pointed directly out of the screen (perpendicular to both the ground and the electron's motion), and is 40nm wide. What is the magnitude and direction of the force on the electron from the magnetic field? Where does it exit the magnetic field relative to the entrance point (on what side and how far from the entrance point)?

   Always perpendicular to the velocity of the electron and the magnetic field, $2.83184 * 10^{-17}$N.

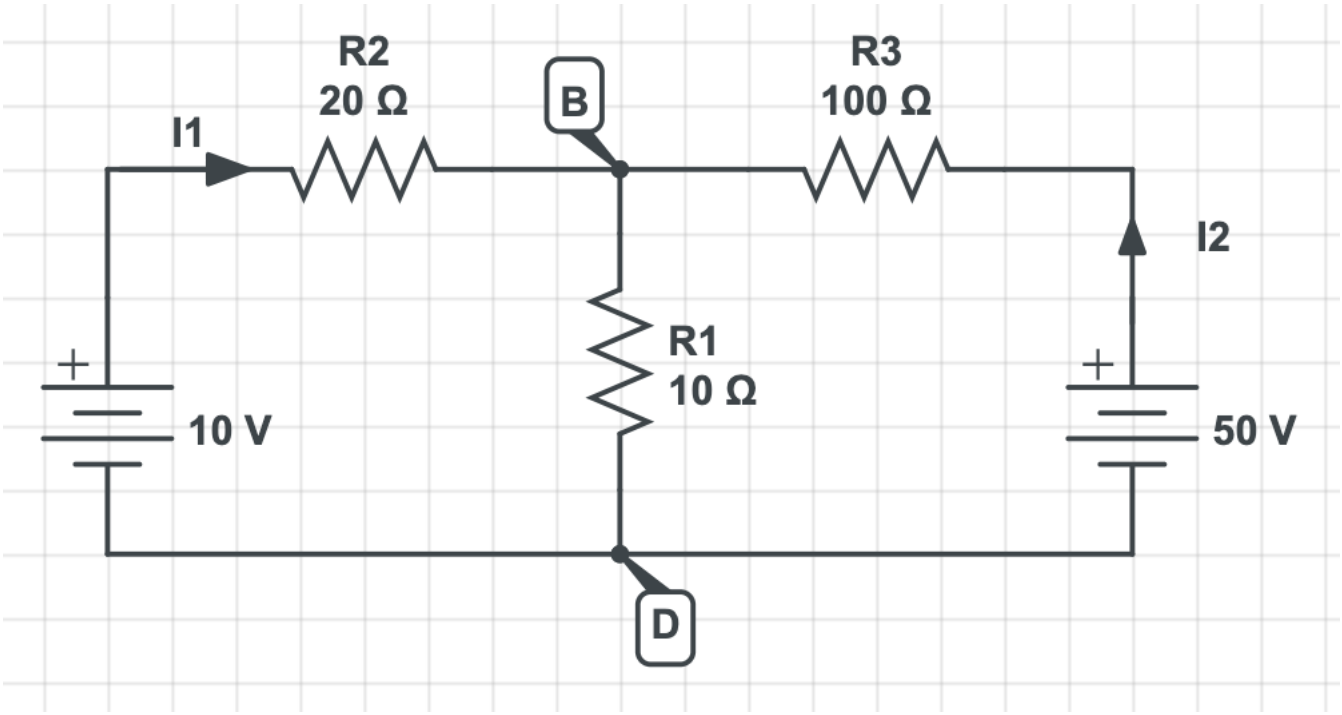
   On the other side, 7.22nm below where it entered.

2. What s the following circuit called? What is it used for?



   This is a digital to analog converter, specifically a 4-bit DAC. It's used to convert digital signals to analog ones.

3. What are I1, I2, the voltage at point B, and the voltage at point D?

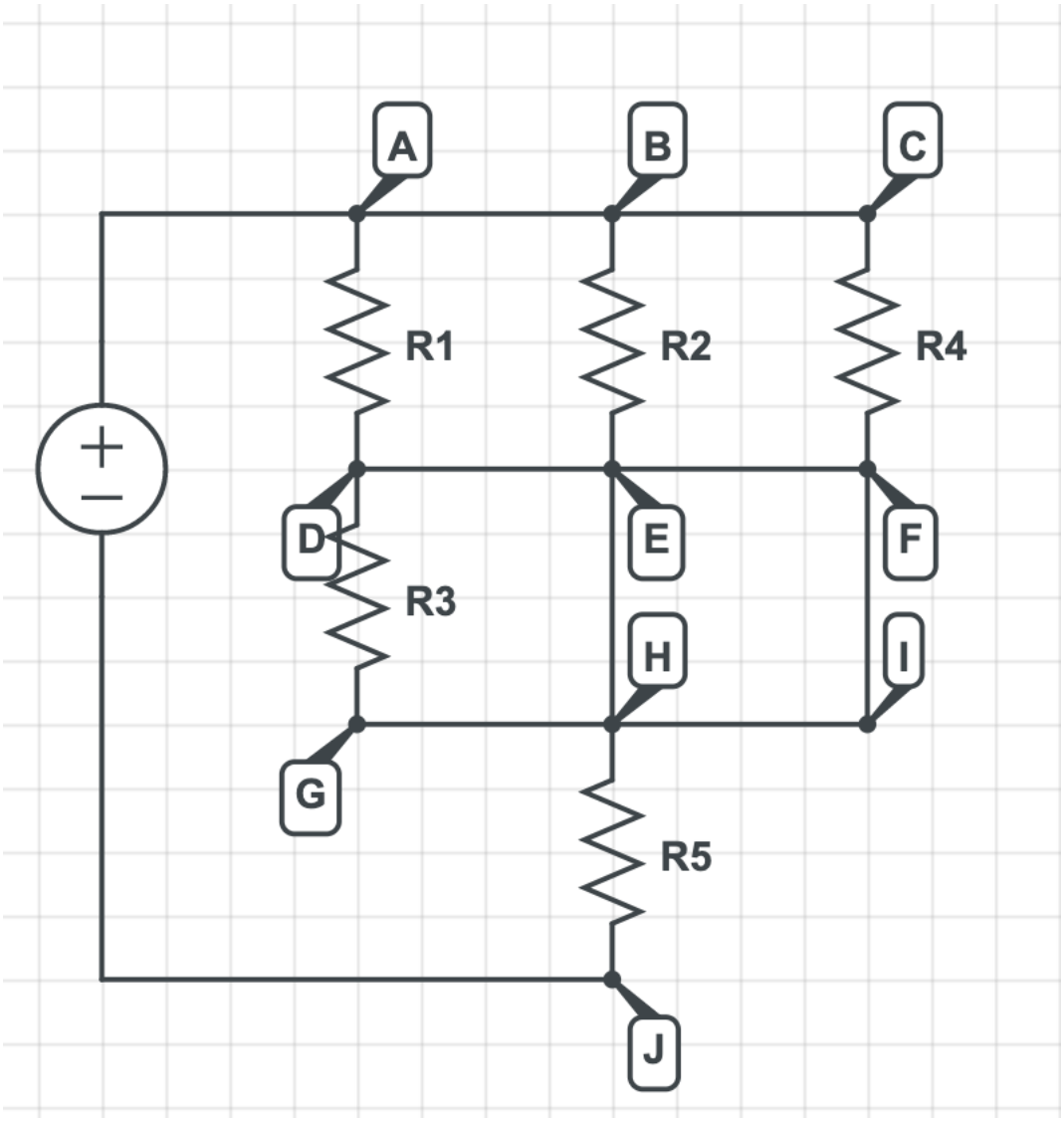


I1 = 9/48A, I2 = 7/16A, B = 6.25V, D = 0V

Lab

Will be making a tutorial video for autodesk tinkercad, hopefully there is a way to distribute it to participants. Obviously banning microcontrollers.

Questions 1 and 2 refer to the following image:



1. If you wanted to measure the current through R3, what tool would you use and where would you place its leads? (Feel free to use the provided node labeling, or qualitatively explain where to place the leads)

   An ammeter, break the circuit just before or just after R3, and measure at the two broken points.

2. If you wanted to measure the voltage drop across R5, what tool would you use and where would you place its leads? (Feel free to use the provided node labeling, or qualitatively explain where to place the leads)

   A voltmeter, simply measure around R5

3. Build a circuit using only SPST switches, a DC motor, and a power supply so you can change the direction of the motor only using the switches. (This should be completed

in Autodesk Tinkercad)

An h-bridge

4. Build an adjustable comparator circuit (using an opamp) to trigger an LED. Make sure to keep the LED safe. That is, do not use too high current, which would damage the LED. (This should be completed in Autodesk Tinkercad)