SSSS Circuit Lab KEY

by Birdmusic

Use appropriate sig figs for all answers.
Include units for all calculations.

Use the following constants:
Coulomb's constant is 9×10^{9} N x m^{2} x C^{-2}
The charge of a single proton is 1.6 x 10^{-19} C
Constants have unlimited sig figs.
Assume everything is ideal unless otherwise stated.

Team Name and Number:
Names:
Score: KEY/69

Here are some things not covered by this test that are pretty common on other tests.

- Thevenin-Norton Theorem (not on rules specifically, but still common on tests)
- Graphs of current/voltage in an RC circuit
- How to make other logic gates using the universal logic gates
- Electrical control devices other than switches

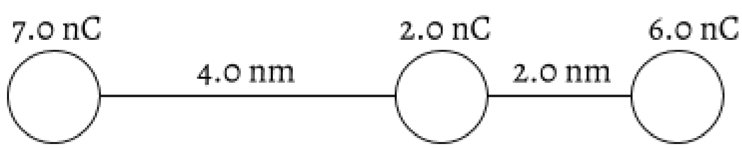
History ___/4

Circle the correct answer in the parentheses.

1. (1 pts) Tesla encouraged the use of (AC/DC) which (is/is not) commonly used today. (0.5 for each part correct)
2. (1 pts) Faraday studied (resistance/electromagnetism).
3. (1 pts) Volta invented the (battery/transformer).
4. (1 pts) Ohm had the unit for (inductance/resistance) named after him.

Electric Charges and Fields ___/6.5

1. (1 pts) 3 point charges are arranged as follows. What is the force exerted on the center charge by the other 2 charges? (The line just means they are all in a straight line) 86 N



$k(\frac{qq_1}{r_1^2})+k(\frac{qq_2}{r_2^2}) = F_{net}$ (Coulomb's Law, force on center by right plus force on center by left is the net force felt by center.)

$$9 * 10^9 * (\frac{7.0nC*2.0nC}{(4.0nm)^2} + \frac{2.0nC*6.0nC}{(2.0nm)^2}) = F_{net}$$

$$9 * 10^9 * (3.5nC/m + 6nC/m) = F_{net}$$

85.5 N without sig figs

86 N

2. (1 pt) What is the electric field felt by the center charge? 43MN/C or 43MV/m

Electric field = force/charge OR solve using electric field equation $k(\frac{q}{r^2}) = E$

(both are the same because the electric field equation is just Coulomb's law with the center charge removed)

85.5N/2nC = 43MN/C or 43MV/m

3. (0.5 pts) What is the unit used for electric fields?

N/C or V/m

4. (2 pts) Spheres A, B, and C are made of a conductive metal. Sphere A has a charge of 6C, Sphere B has a charge of 8C, and Sphere C has a charge of 5C. 2 spheres touch, then one of those spheres touches the third one. (Example: A touches B, then B touches C; another possible scenario: C touches A, then A touches B) What is NOT a possible final charge of A?

a. 6.25C (BCA)
b. 6.5C
c. 6.75C (CAB)

d. 7C (ABC)

When the 2 spheres touch, their combined charge will distribute evenly between them.

1. If A touches B, A and B will have a charge of (6+8)/2 = 7C, then if B touches C, A keeps its charge of 7C, so d is possible. If A then touches C, A will have a charge of (7+5)/2 = 6C (not a listed answer).
2. If C touches B, both B and C will have a charge of (8+5)/2 = 6.5C. If either touches A, A will have (6.5*6)/2 = 6.25C, so a is possible.
3. If C touches A, then A and C will have a charge of (6+5)/2 = 5.5C (not a listed answer). If A then touches B, (5.5+8)/2 = 6.75C, so c is possible.

Only b is not a possible answer.

5. A nucleus has 60 protons in it.

a. **(1 pt) What is the absolute voltage at 10 cm away from the nucleus?**
The absolute voltage from a charge is given by kq/r.
$9 * 10^9 * 50 * 1.6 * 10^{-19}/0.1 \ = \ 7.2 * 10^{-7}$, just $7 * 10^{-7}$ with sig figs

b. **(1 pt) If an electron is placed 10 cm away from it with an initial velocity of 0m/s, what will the speed of the electron when it is 1 cm away from the nucleus? (reminder: kinetic energy is ½ m v^2 and the mass of an electron is $9.109 * 10^{-31}$)**
The potential energy of a charge in voltage is qV. The loss of potential energy would be q(V1-V2), which has to equal 1/2 mv^2 (kinetic energy gained)
$-1.6 * 10^{-19} * ((9 * 10^9 * 50 * 1.6 * 10^{-19}/0.1) - (9 * 10^9 * 50 * 1.6 * 10^{-19}/0.01)) \ = \ 1.03 * 10^{-24}$
$-1.03 * 10^{-24} = ½(9.109 * 10^{-31}) v^2$
V = 1503m/s = about $2 * 10^3 m/s$

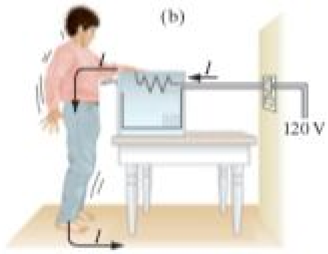
AC and DC ___/5

1. (2 pts) Is AC or DC more dangerous? List 1 reason.

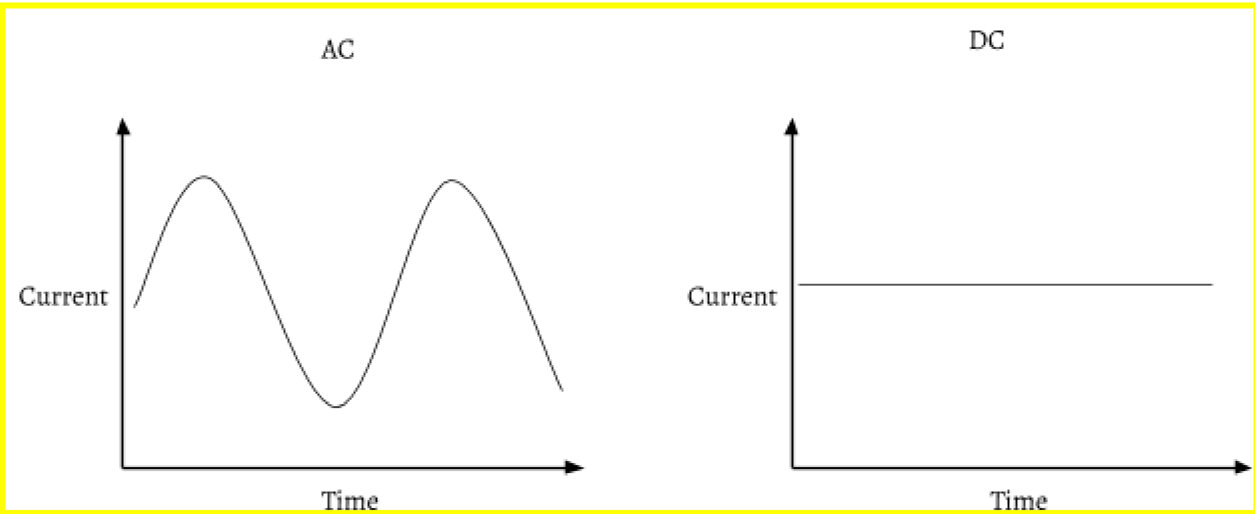
AC is more dangrous.

Anything below is fine for an explanation, and there are more possible explanations but here are the main ones I could find online:

- AC uses the RMS as the voltage, or anything mentioning RMS (an AC current of 5 volts will have a max current of $5 * \sqrt{2} = 7V$ while a DC current of 5V will have a max current of 5V)
- AC is more likely to cause ventricular fibrillation, anything mentioning that AC more likely to cause the heart to malfunction
- AC can enter the body without a closed loop as long as you're touching the ground (diagram from Giancoli textbook)



2. (1 pt) How does the current in an AC circuit differ from that in a DC circuit? Draw a graph (of current vs time) of each. (Do not worry about actual values, just get the general shape down.)



3. (0.5 pts) Name a device that can only use DC.

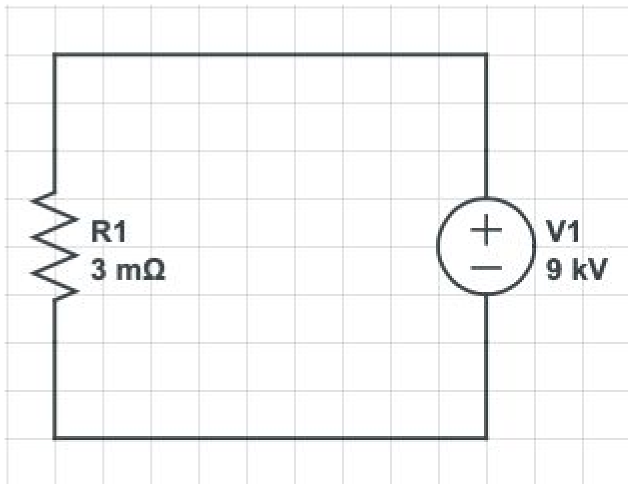
LED, Computer (PC/Laptop), DC motors, accept others

4. (1.5 pts) An AC circuit has an RMS voltage of 2 mV. What is the highest voltage it supplies?

$2 * \sqrt{2} = 3$ (sig figs)

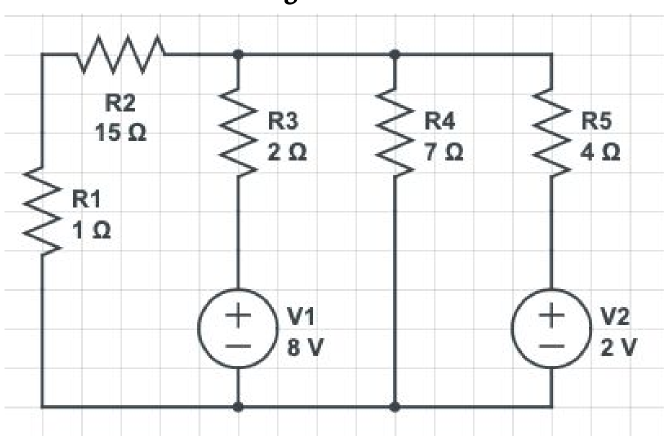
DC Circuits ___/31

1. (0.5 pts) What is the current passing through the R1?

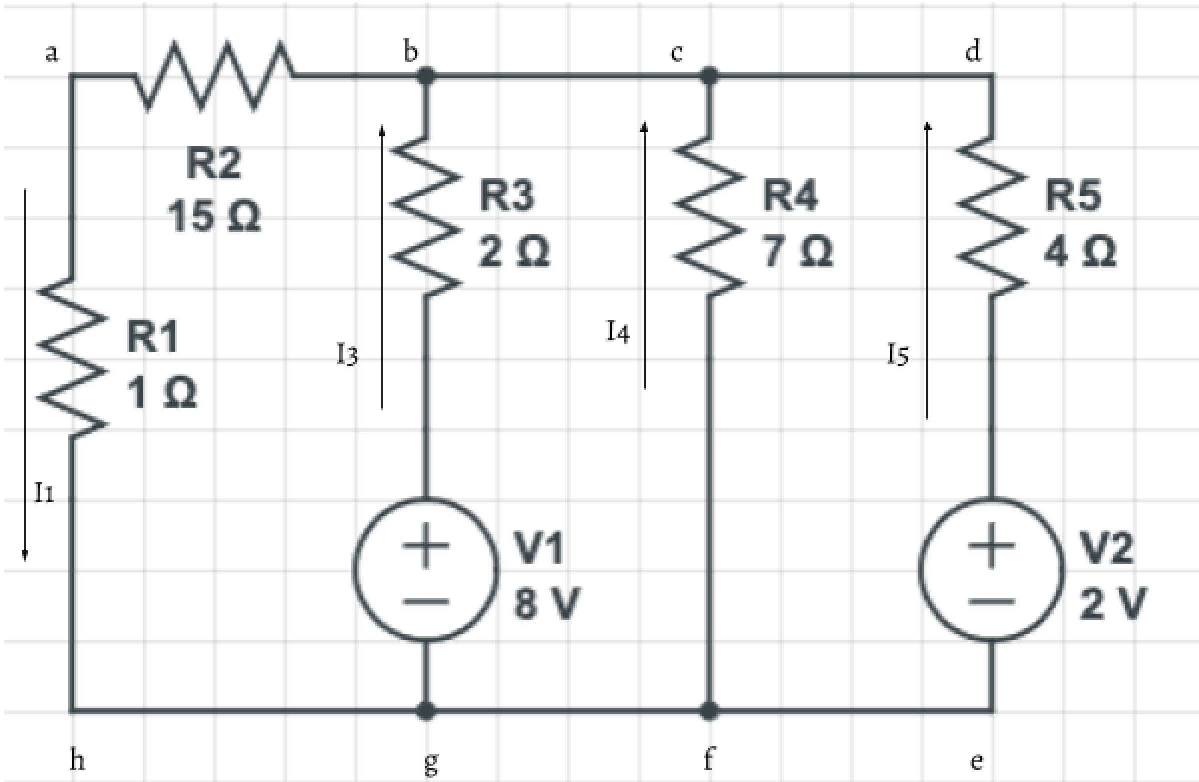


9 KV/3m Ω =3MA

2. For the following circuit: (also assume all numbers on the circuit have 3 sig figs since I can't get them to show up)
a) (3 pts) What is the voltage drop over R3? 3? 3.29V
b) (3 pts) What is the current through R1? Draw its direction as well.
0.294A with an arrow pointing down, OR -0.294A with an arrow pointing up.
-1 for no arrow or wrong arrow.



Explanation Using KCL/KVL:



First, KCL states that $I1 = I3+I4+I5$.

Next, loop BAHGB can be described by the following equation: $V1-R3I3-R2I1-R1I1 = 0$.

Loop DCFED can be described by $V2-R5I5+R4I4 = 0$. Notice the current drawn for I4 is going in the opposite direction of the loop, so it is added rather than subtracted.

Finally, loop BGFG can be described by $V1+R4I4-R3I3=0$.(I4 same scenario as above)

Now, substitute I3+I4+I5 for I1 on equation 2.

$$V1-R3I3-R2(I3+I4+I5)-R1(I3+I4+I5) = 0$$

$$V1 -R3I3-R2I3-R2I4-R2I5-R1I3-R1I4-R1I5 = 0$$

$$V1-(R1+R2+R3)I3-(R1+R2)I4-(R1+R2)I5=0$$

This system of three equations can now be written in a way that can be solved with a calculator. (You could do this with 4 variables too, but I personally like 3)

Move all the constants to the right side of the equations, and then put the variables in order. Replace all Rs and Vs with known values.

Equation #2: $-(R1+R2+R3)I3-(R1+R2)I4-(R1+R2)I5=-V1$

$$-18I3-16I4-16I5 = -8$$

Equation #3: Notice how there's no I3 in equation 4 and I5 was put before I4. This will need to be reformatted before being plugged into a calculator.

$$0I3+R4I4-R5I5 = -V2$$

$0I_3+7I_4-4I_5 = -2$

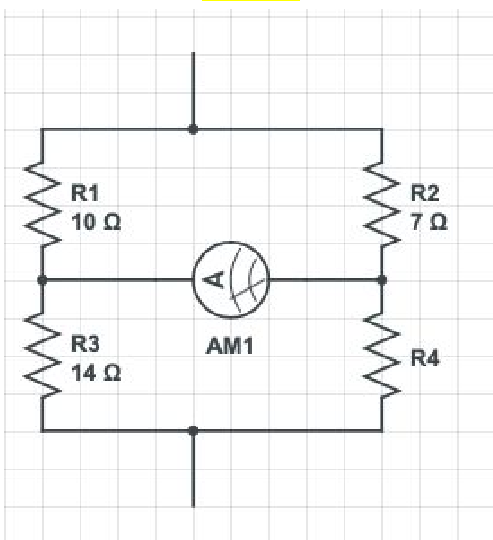
Equation #4: Same situation as 3.

$-R_3I_3+R_4I_4+0I_5 = -V_1$

$-2I_3+7I_4+0I_5 = -8$

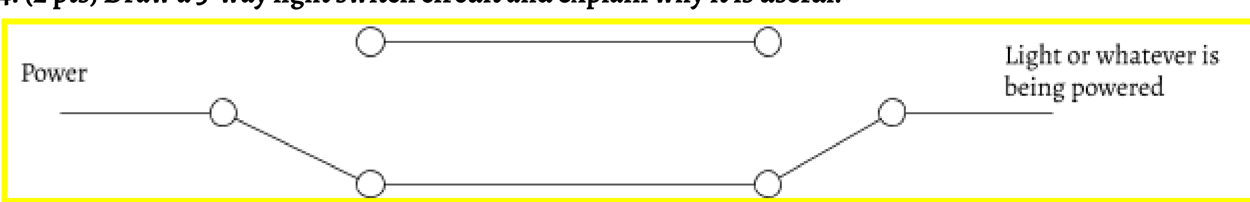
Now you can use the matrix property on a calculator to solve this. Here is a tutorial:
[How to Solve a System of Equations on the TI-84 Plus](https://www.dummies.com/.../graphing-calculators/how-to-solve-a-system-...)
[...https://www.dummies.com/.../graphing-calculators/how-to-solve-a-system-...](https://www.dummies.com/.../graphing-calculators/how-to-solve-a-system-...)
Basically, put all the coefficients into a matrix and multiply the inverse of that matrix by a matrix containing all the constants.
Unfortunately docs refuses to cooperate with me on matrices so I'll skip that.
Anyways, the matrix returns that
$I_3 = 1.645A$
$I_4 = -0.673A$
$I_5 = -0.678A$
Since I_1 is the sum of them, $I_1 = 0.294A$
$R_3*I_3 = 3.29V$

3. (1.5 pts) If no current is going across the ammeter, what is the missing resistance (R4)? (Assume its in a closed circuit.) 10 ohms



This is a wheatstone bridge. $R_1/R_3 = R_2/R_4$, so $R_4 = R_2R_3/R_1=9.8$, with sig figs 10 ohms

4. (2 pts) Draw a 3-way light switch circuit and explain why it is useful.



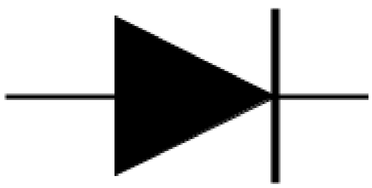
(Can be on or off)

Can control a light from 2 different locations

5. (0.5 pts) Classify the switch below based on the number of throws and poles.

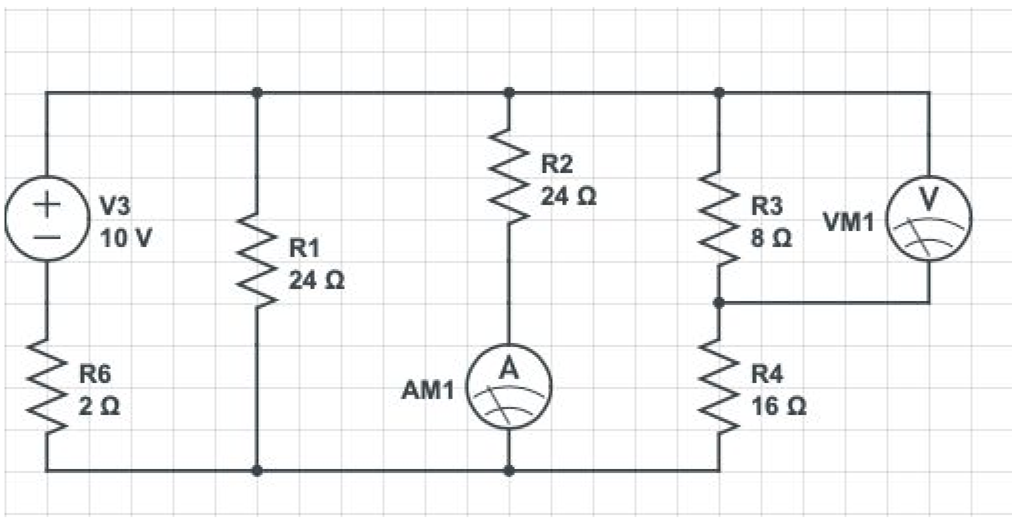
Single Throw Double Pole

6. (1 pt) What circuit component does this represent? Where might you use it in real life?



Diode
Used in: LED, Rectifier Circuits (Only need 1 answer, many other possible answers)

7. (4 pts) In the circuit below, what does the ammeter (AM1) read? What does the voltmeter (VM1) read? (Assume 3 sig figs for all numbers, the upper wire of the voltmeter is the positive one)



Step 1: Circuit analysis using parallel and series resistors

1. R3 and R4 are in series, so they add up to have a resistance of 24 ohms. (Will be referred to as R3+4 from here on out)
2. R1, R2, and R3+4 are in parallel, so their equivalent resistance is 8 ohms. (Will be referred to as R1-4)
   Note: if multiple resistors of the same resistance are in parallel, their equivalent resistance is the resistance divided by the number of resistors. This only works IF the parallel resistors have the same resistance though.
3. R6 and R1-4 are in series and add to have a resistance of 10 ohms. (Will be known as Req)
4. V3/Req = 1 A

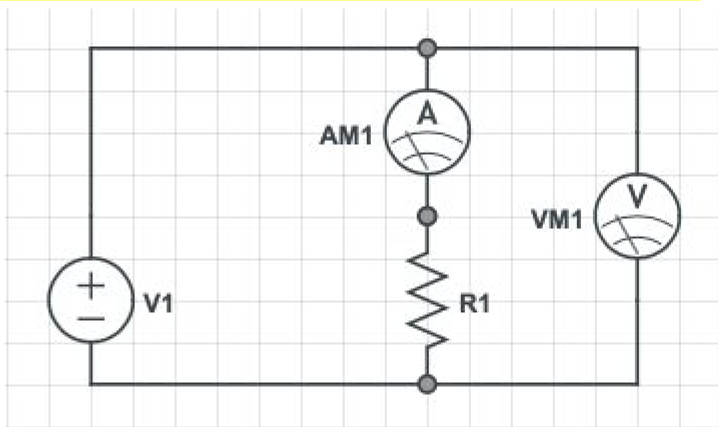
5. Since each branch of parallel part of the circuit has 24 ohms, the current will divide into 3 equal parts. The current going through the ammeter is ⅓ = 0.333A
6. The drop across R3 is R3*current, 8ohms*1/3A = 2.67V

8. (2 pts) What would happen if the ammeter was placed in parallel with the resistor in the diagram below? (ignore voltmeter)

The circuit would short-circuit.

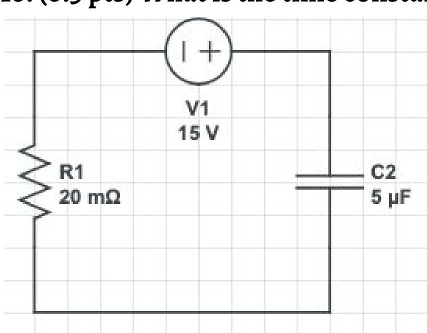
9. (1 pt) What would happen to the voltmeter's reading when it is put in series with the resistor in the below circuit? (ignore ammeter)

The voltmeter would break the circuit, so it would read 0V.



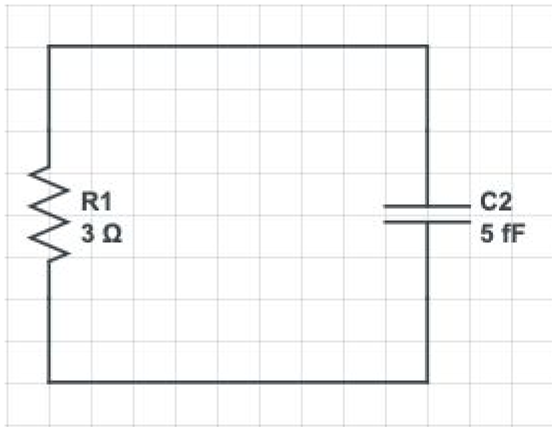
For 8 and 9

10. (0.5 pts) What is the time constant of the circuit below?



5uF*20m Ω = 100 ns or any equivalent values

11. (2 pts) The following RC circuit is charged fully with a charge of 10pC. When the RC circuit below is discharging, at 0.15ps, what is the voltage across the capacitor? (Assume 3 sig figs for all numbers)



0.091V

$V_C = V_S \times e^{-t/RC}$ is the discharging capacitor equation.

Vc is current voltage, Vs is original voltage, t is time and RC is the time constant.

V = q/C so Vs = $10 * 10^{-12}/5 * 10^{-15}$ or $2 * 10^{3}$ V

$Vs = 2000 * e^{-15*10^{-14}/3*5*10^{-15}}$

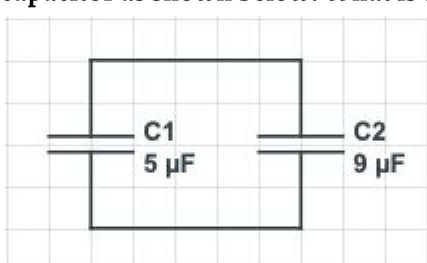
$Vs = 2000 * e^{-10}$

Vs = 0.091V

12. (0.5 pts) What is the equivalent capacitance of two 1 uF capacitors in parallel?

1+1 = 2uF

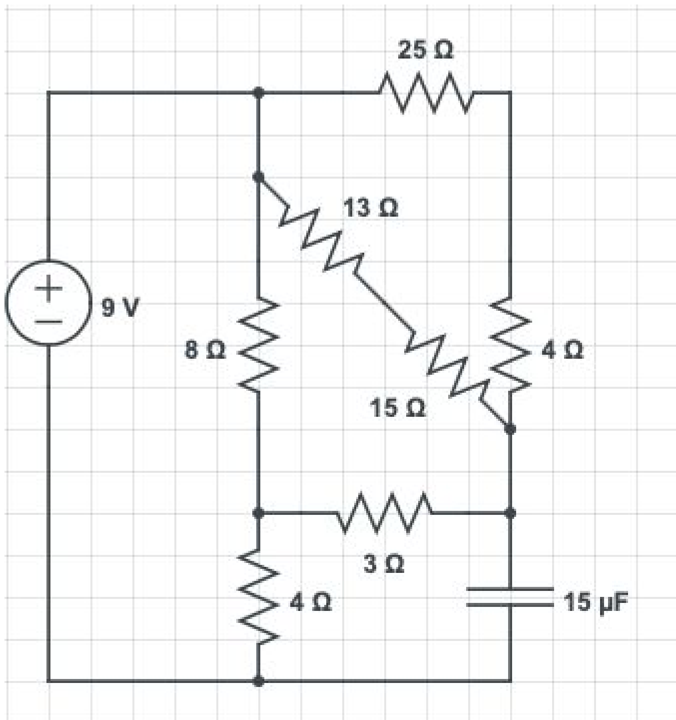
13. (2 pts) The 5uF capacitor is fully charged by a battery of 5V and then connected with the 9uF capacitor as shown below. What is the final charge on each?



5uF: 9uC 9uF: 16uC

1. q = CV, the the final charge on C1 initially is 5uF*5V = 25uC.
2. It is then connected in parallel with C2, making their equivalent capacitance 5+9 = 14uF.
3. The voltage drop across both of them is (V = q/C) 25/14 = 1.79V (charge is conserved from before)
4. To find the final charge on each, just use q = CV again. 1.79V*5uF = 9uC, 1.79V*9uF = 16uC

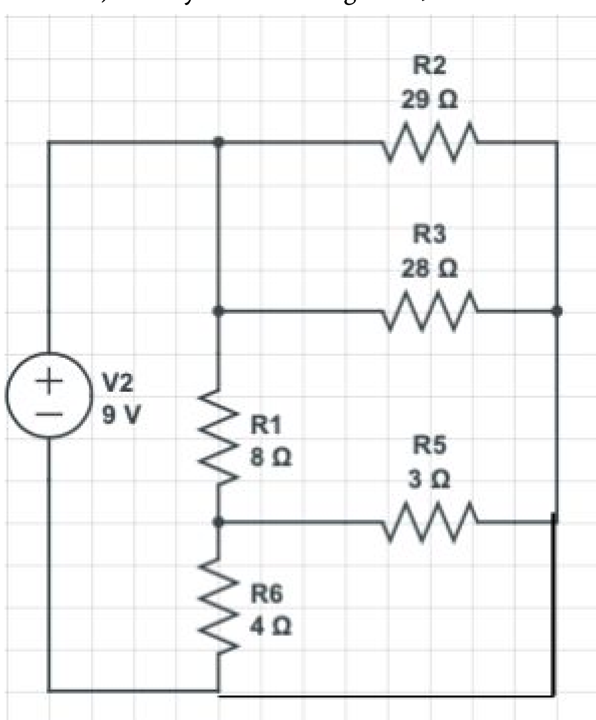
14.a. (3 pts) When the circuit is first connected with the battery (not charged at all), what is the current through the voltage source? (Assume at least 2 sig figs for everything.) 1.6V



Voltage:_______

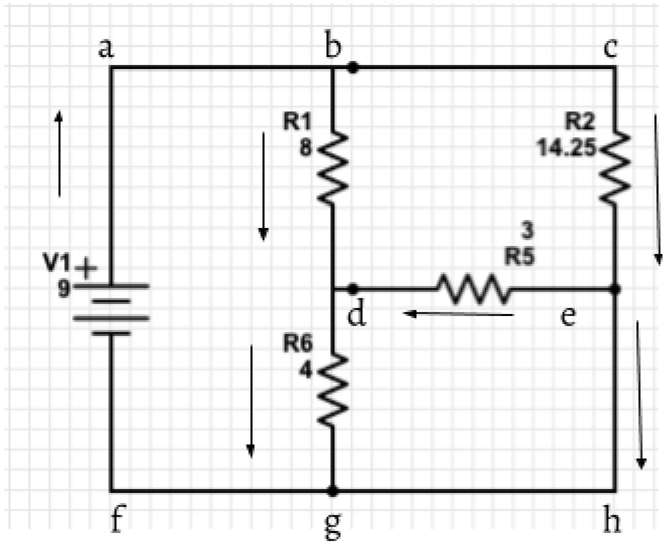
When the capacitor is uncharged, it behaves like a wire.

The 13 and 15 ohm resistors are in series, so they have an equivalent voltage of 28 volts. 25 and 4 are also in series, so they have a voltage of 29V.



The 28 and 29 are in parallel, and they have an equivalent resistance of about 14.25 ohms.

The currents are shown below. The current will be named the same number as their resistor, and the current from f to a will be IV. The current from e to h is IW



KCL and KVL:

1. IV = I1+I2
2. I2 = I5+IW
3. IV=IW+I6
4. I6=Iw+I1
5. Loop ABCGHFA: V1-R2I2 = 0
6. ABGFA: V1-R1I1-R6I6 = 0

Now you can solve with a graphing calculator. Here are the matrices I used:

Coefficients:

I1	I2	I5	I6	IV	IW
1	1	0	0	-1	0
0	1	-1	0	0	-1
0	0	0	1	-1	1
1	0	0	-1	0	1
0	-14.25	0	0	0	0
-8	0	0	0	0	-4

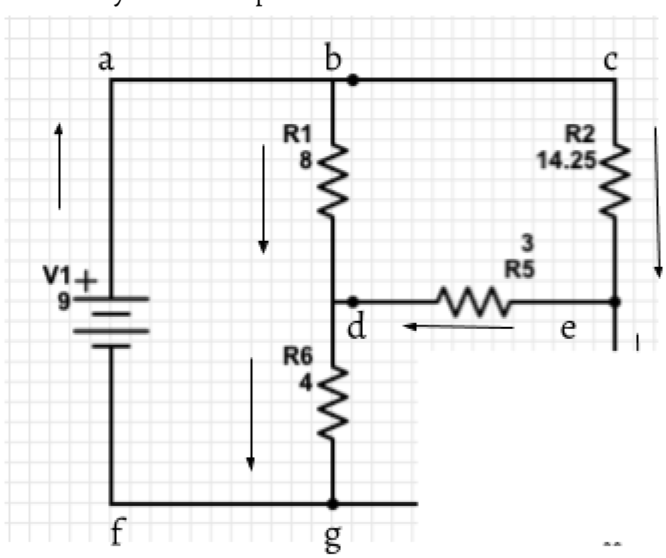
Constants:

0
0
0
0
-9
-9

It returns values of every variable, but IV is 1.27V, 1.3V with sig figs.

b. (2 pts) When the circuit is in a steady state, what is the charge on the capacitor? 86uC

q=CV, so the voltage across the capacitor needs to be known. The difference between nodes e and g would give us this difference, HOWEVER, because the capacitor is now charged, the circuit behaves differently and the capacitor is now a break in the circuit.



This would be the (slighty simplified already) circuit diagram for this scenario.

As you can now see, R2 and R5 are in series. R2+5 = 17.25 ohms
R2+5 is in parallel with R8. R2,5,8 = 5.47 ohms
R2,5,8 is in series with R6. Req = 9.47 ohms
Then, the current going through the main branch is 9/9.47 = 0.95A.
The drop across R6 = 4*0.95 = 3.8V. The drop across R2+5 would be 9-3.8 = 5.2 Volts
5.2/17.25 = 0.3A (current through that branch)

0.3*3 (R5) = 0.9V
0.9+3.8 = 5.7V
5.7*15uF = 86uC

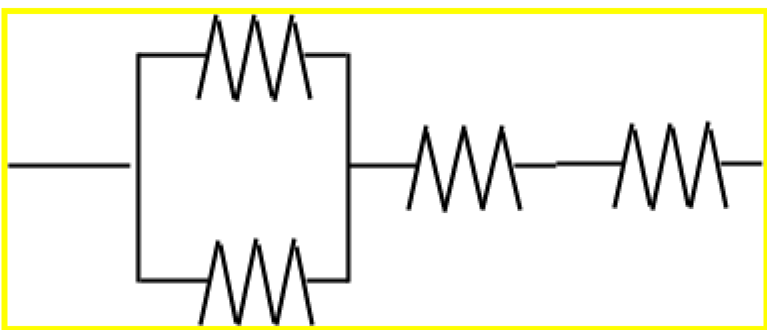
15. (1.5 pts) A section of copper wire has length 1 m and a radius of 0.5 mm. A current of 10 A passes through it. How much power is dissipated by the section?

Resistance = pl/A (resistivity*length/cross-section area)

Resistivity of copper is 1.68*10^-8, so resistance $= \frac{1.68*10^{-8}*1}{(0.5*10^{-3})^2\pi}$

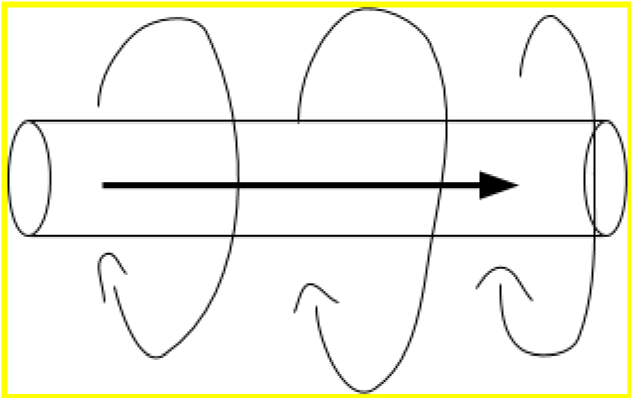
0.0214 ohms is the resistance.
Power = VI, V = IR, so power = I^2R
10*10*0.0214 = 0.02 W

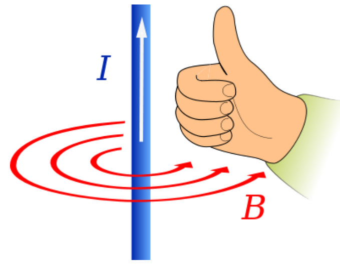
16. (1 pt) How can you connect 5 resistors (all 2 ohms) to have an equivalent resistance of 5 ohms? Draw below.



Electromagnetics, Transformers, Motors/Generators ___/7

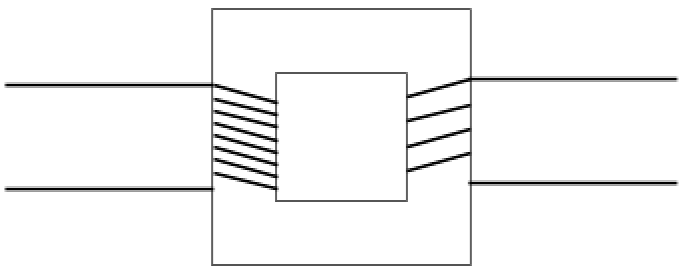
1. (1 pt) Draw the electric field around this wire if the current is going in the direction the arrow is pointing.





(right hand rule)

2. (2 pts) If the difference between the 2 wires of the left side is 10V, what is the difference between the wires of the right side?



8/4 = 10/x, x=5V

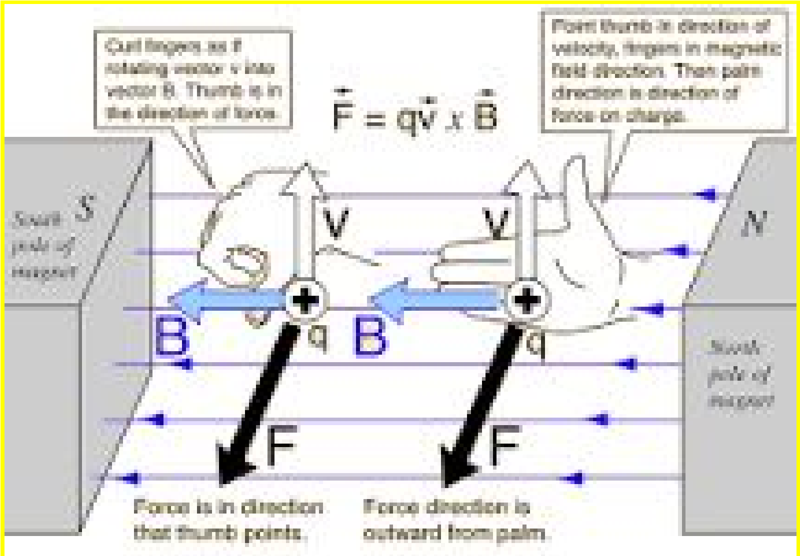
3. (1 pt) What does a motor do? What prevents it from being ideal in real life?

Motors convert electrical energy into mechanical energy.

In real life, friction prevents them from being ideal. (0.5 points for each)

4. Determine the force on an electron in a magnetic field of 4T moving out of the page. (The heads of the vector are pointing at you.)

a) **(1 pt) The electron is not moving.**



The equation has v has one of the variables, so if the velocity of the electron is 0, the force on it is 0N.

b) (2 pts) The electron is moving to the right of the page at a speed of 5 m/s.

5m/s*4T*-1.6* $10^{-19}C$ = $-3*10^{-19}$ N

Using the 2nd right hand rule in the pic:

Put your right hand thumb 90 degrees away from your other fingers. Since the electron is moving right, point your right hand thumb right. Then, since the field is moving out of the page, point all your other fingers towards you. Your palm is pushing down, so the possible answers are:

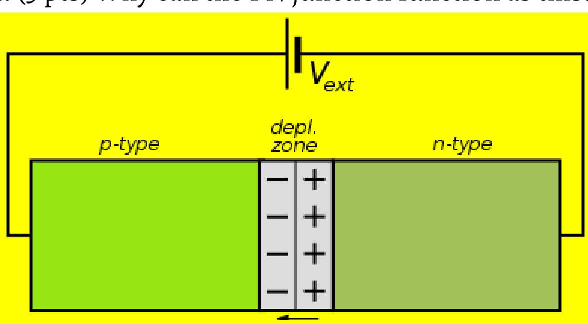
$-3*10^{-19}$ N downwards OR $3*10^{-19}$ N upwards

LEDs and PN Junctions ___/6.5

1. (1 pt) What electrical component does a PN junction function as?

Diode

2. (3 pts) Why can the PN junction function as this? Draw, label, and explain a diagram to demonstrate.

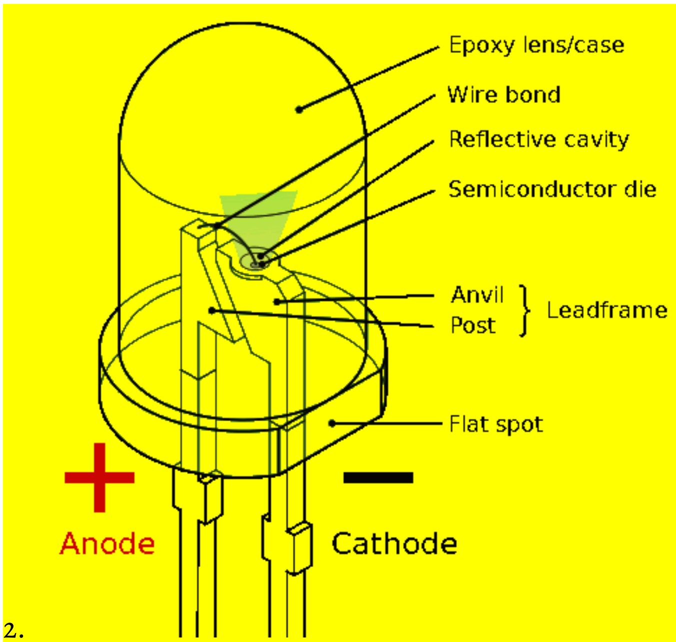


(V ext does not need to be in the diagram, just p, n and depletion zone) (1 pt)

The p-type side has “holes” and it wants the holes to be filled by the n-type side (which has excess electrons) but the depletion zone (gray) prevents the 2 sides from crossing into each other. (1 pt)

- When it is forward biased (shown above, positive terminal connected to p-type and negative connected to n-type) the battery pushes the holes and electrons into the depletion zone, reducing it until the current can flow through the diode.
- When it is reverse biased (when connected the wrong way) the holes are attracted to the negative end and the electrons are attracted to the positive end, so the depletion zone gets larger (1 pt)

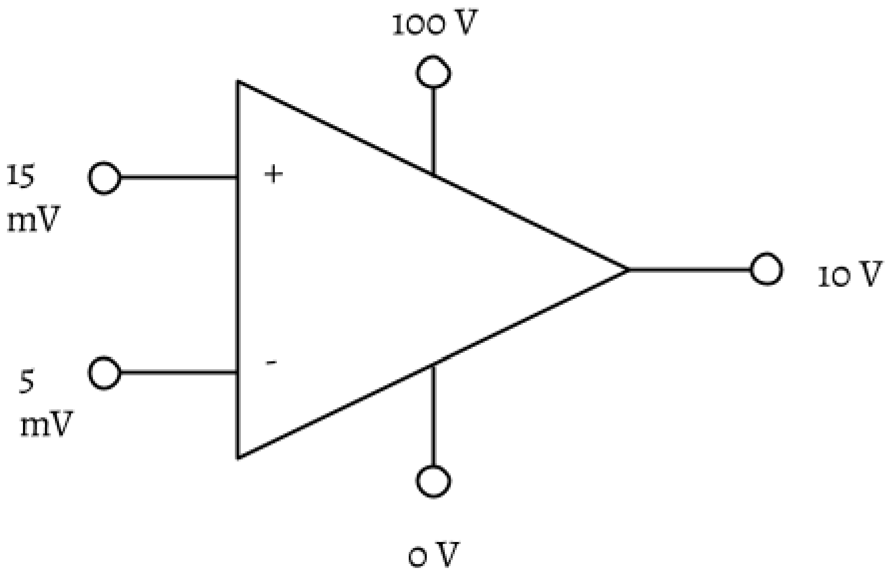
3. (2 pts) What are 2 ways to identify the positive and negative ends of an LED without testing it in a circuit?

1. The negative end has a shorter wire.
2. 

   The negative end has a flat spot, flat cap, etc. (shown above)
   (0.5 pts for each answer)

4. (0.5 pt) In a circuit, an ideal LED provides zero or no resistance.

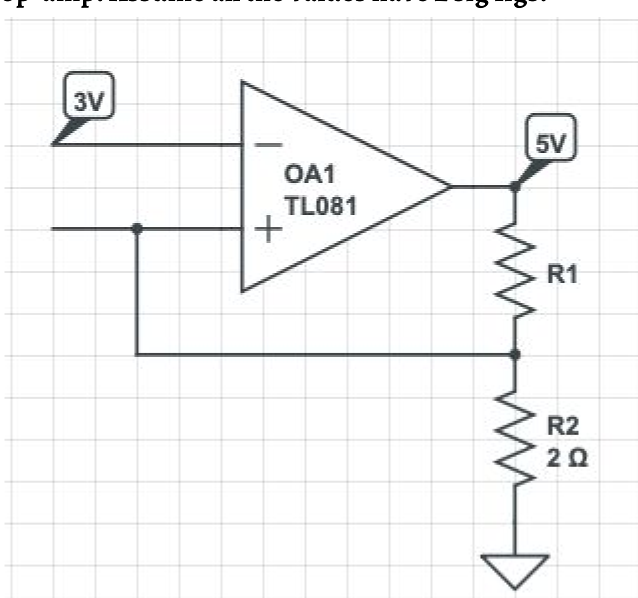
Op-Amps ___/4



a. **(0.5 pts) Find the gain of this Op-Amp.** 500
10V/(15+5mV) = 10V/20mV = 0.5*10^3 = 500 (No units, this is just a number. Minus 0.25 points if a unit is included.)

b. **(0.5 pts) If the plus terminal was at 10V and the negative terminal was at 5V, what would the output be?** 100V (the largest possible output would be the difference between the two terminals sticking up and down.)

2. (2.5 pts) For the following ideal op-amp circuit, what is the value of R1? Ignore the name on the op-amp. Assume all the values have 2 sig figs.



1. The positive and negative terminals will be at the same voltage and will have no current going into them in an ideal op-amp.
2. Therefore, the node between R1 and R2 is at 3V.

3. The drop over R2 is 3V, and the resistance is 2ohms, so the current going through R1 and R2 is 3/2 = 1.5A (No current goes into the other branch, so R1 would have the same current as R2)
4. Since the drop over R1 is 5-3= 2V and the current is 1.5A, 2/1.5 = 1.3 ohms

3. (0.5 pts) What is the basic purpose of an op-amp?

To amplify the input voltage, usually by a very large number.

Digital Logic ___/5

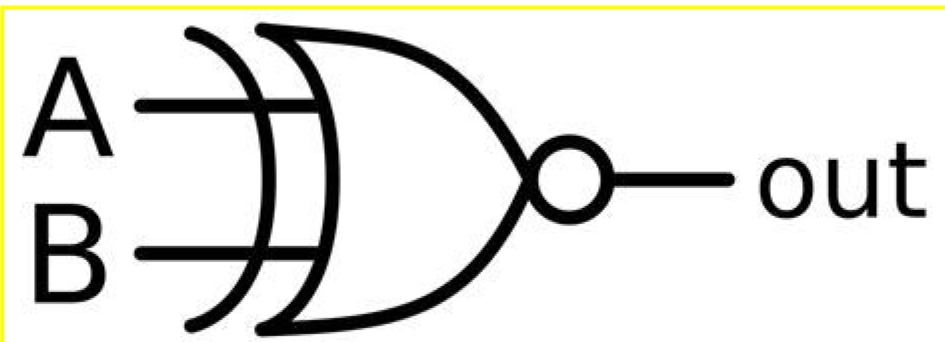
1. (2 pts) Make a truth table for the following logic gates. (A NAND B) XOR C

A	B	C	Output
0	0	0	1
1	0	0	1
1	1	0	0
1	1	1	1

A	B	C	Output
0	1	0	1
0	1	1	0
0	0	1	0
1	0	1	0

2. (1 pt) Draw the logic gate represented in this truth table.

A	B	Output
0	0	1
1	0	0
0	1	0
1	1	1



XNOR logic gate

Also acceptable to link other logic gates together (ie XOR and NOT) to create the same result

3. (1 pts) What are 2 universal logic gates?

NAND and NOR

4. (1 pt) What does universal logic gate mean?

A universal logic gate can be connected with itself and form NOT/AND/OR gates, allowing it to form every other logic gate.