# ----ANSWER KEY WITH COMMENTARY----

**C - Circuit Lab C 2020-2021 - BEARSO - 10-24-2020**

Hello Science Olympians! **This is the Division C Circuits Lab Test**.

The test has many questions covering all topics in the Rule Manual and emulating the hands-on lab portion of the event.

Since this test contains more questions than you can solve alone in the allotted time, please chose the questions which you are **most prepared for**, and **most interested in**. The questions are ordered by themes:

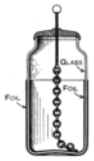
1. History
2. Hands/On Lab Questions
3. Electrostatics
4. Ohms Law
5. Magnetism
6. Digital Logic
7. PN Junctions

[**Important**] The online platform allows us to auto-grade your answers (which saves a lot of time!). Please do us a favor and **follow the answer formatting exactly, when/as requested**. If you make a formatting error but otherwise get the right answer, we will do our best to find the mistake and award you the points.

Enjoy!

**Name that [Device that changed the history of electricity] ! A SciOly Trivia Game Show.**

**Instructions: Match the pictures (indexed by letter) with the corresponding name of the device in the following word bank.**



1

2

3

4

5

6

7

| | |
|---|---|
| A | Van de Graaff Generator |
| B | Voltaic Pile |
| C | Light Bulb |
| D | Tesla Coil |
| E | Leyden Jar |
| F | Wilmschurst Machine |
| G | Faraday's Cage |
| H | Transistor |
| I | Electric Dynamo |
| J | Oudin Coil |

For Questions 1-7, please input the correct letter (capitalized, without spaces, ) to match each picture to it's name. For example, if you think that device 1 is a light bulb, type in "C" into the short answer blank under  question 1. These questions are auto-graded so please try to get it right .

**1. (4.00 pts)** Device 1 is ...

E

**2. (4.00 pts)** Device 2 is ...

A

**3. (4.00 pts)** Device 3 is ...

F

**4. (4.00 pts)** Device 4 is ...

D

**5. (4.00 pts)** Device 5 is...

B

**6. (4.00 pts)** Device 6 is ...

H

**7. (4.00 pts)** Device 7 is ...

C

many teams did not follow formatting guidelines and entered "Leyden Jar" instead of "E" for number 1, etc.

Points were not awarded if the input was not correct.

**8. (30.00 pts)**

**The Resistor Scramble!**

As you and your SciOly team are sailing in a ship, one of your crew members reports that the ship's analog radio, the only means of communication you have available, stopped working. As a Circuit Lab specialist, the entire team is pinning their hopes on you to solve the problem.

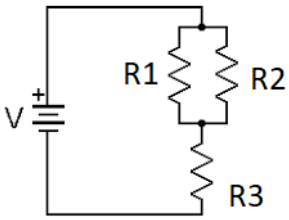
After some investigations, you determined that one of the resistors got fried. Being the super-prepared and well-studied SciOlympian that you are, you came prepared with a toolkit of spare resistors to replace the old one. Your toolkit has the following resistors:

| Resistor Name | Resistor (in ohms) | Quantity | Wattage (in Watts) |
|---|---|---|---|
| R1 | 100 | 1 | 0.75 |
| R2 | 500 | 3 | 0.5 |
| R3 | 750 | 2 | 0.5 |
| R4 | 1000 | 3 | 0.25 |
| R5 | 2000 | 2 | 0.25 |
| R6 | 5000 | 1 | 0.125 |

**If the resistor combination was not possible (for example, R1 was used more than once), 0 points were awarded.

Design a resistor from the components available to you that has a **resistance of 650 Ohms** and can handle **1 Watt of power**. (points for getting close to specified wattage and resistance values will be awarded separately).

Denote parallel combinations of resistors using the | symbol, and series combinations using the + symbol. For example, the circuit below will be represented as **[ [R1 | R2] + R3]**




The following scoring rubric was used:

Resistance:

| | |
|---|---|
| 650 +/- 5 | 30pts |
| +/- 15 | 20pts |
| +/- 50 | 15pts |
| +/- 100 | 12pts |
| +/- 200 | 10pts |
| +/- 500 | 7pts |

else: 0pts

Wattage:

| | |
|---|---|
| 1 +/- 0.1 | 15pts |
| +/- 0.25 | 10pts |
| +/- 0.3 | 7pts |
| +/- 0.5 | 5pts |

else: 0

**Expected Answer:** e.g. [ [R1 | R2] + R3]

**9. (30.00 pts)**
**Design a logic circuit!**

A ball bearing factory has asked you to design a circuit to perform a quality control on the steel balls. You have three sensors, which can output either a 0 or 1 based on the following conditions:

| Sensor # | 1 | 0 |
|---|---|---|
| $S_1$ | Ball is too small | Ball meets size tolerance |
| $S_2$ | Ball is too heavy | Ball is within weight limits |
| $S_3$ | Ball surface is rough | Ball surface is smooth |

points taken off for:
- not simplifying logic expression
- incorrect logic expression

partial credit for:
- some combination of S1, S2, S3 from expression being correct (test cases)

Design a circuit that outputs a one (digital 'high') if at least two of the sensors detect an anomaly (and thus output a 1). Please type in a logic expression using the following conventions:

+ = OR; * = AND; ~ = NOT, ! = NOT, use A, B, C to denote sensors 1- 3, respectively; don't forget to use parentheses to denote order of operations.

If you used different symbols for And, Or, Not, I still gave points as long as it was clear what the expression was. Some of you used A,B,C while others used S1, S2, S3.
Benefit of doubt, however, was not given to confusing answers.

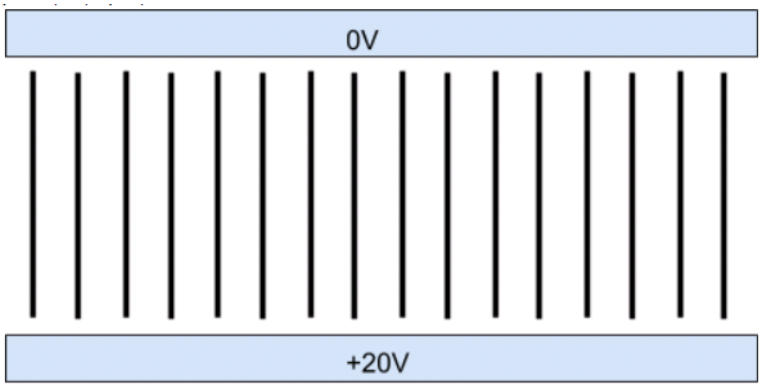
A lot of you answered this correctly...

[If you're curious about how ball bearings are actually manufactured, check this out! https://www.youtube.com/19duYMdiXi0 (https://www.youtube.com/19duYMdiXi0) ]

**Expected Answer:**

Correct answer: (S1*S2)+(S1*S3)+(S2*S3)

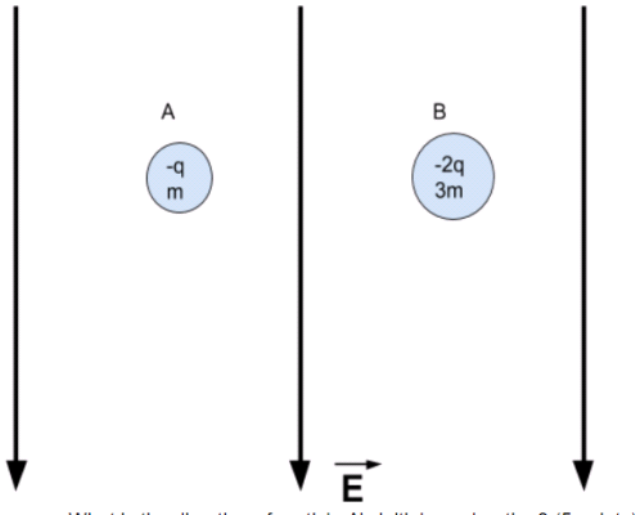
**10. (5.00 pts)**
In the following diagram, the top plate of the capacitor has a voltage of 0V and the bottom plate is at voltage +20V. The electric field lines between the plates are drawn, but the direction arrows have been left out. Is the direction of the electric field up (toward the top plate) or down (toward the bottom plate)?




**Expected Answer:**

UP. the top plate has a lower potential, and the convention is to have arrows point from high to low potential (direction of conventional current)

Two negatively charged particles are in a uniform electric field pointing downward. Particle A has a charge of -q and a mass m, while particle B has double the charge (-2q) and three times the mass (3m). Both particles are initially at rest. There is no gravity acting on these objects.




Reference this figure for the following 2 questions.

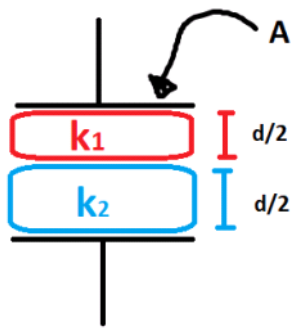
**11. (5.00 pts)** What is the direction of particle A's initial acceleration?

- (●) A) up
- ( ) B) down
- ( ) C) left
- ( ) D) right

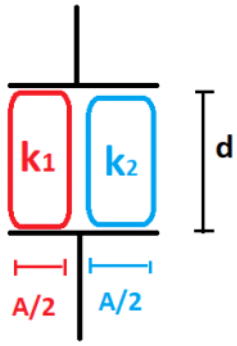
**12. (10.00 pts)** Which particle has a larger magnitude of initial acceleration?

- (●) A) Particle A
- ( ) B) Particle B

Which capacitor has the higher capacitance value, if A = 5cm^2, d = 1mm, k_1 = 3.1 (Mylar) and k_2 = 6.7 (Neoprene)?




Capacitor 1




Capacitor 2

What is the value of the capacitor with the greater capacitance? Report your value in scientific notation to 3 significant figures, with units of Faradays.

For example, you would **report 137.2 microFarads as 1.37E(-4)** .

**Follow this format exactly (no extra spaces as this will be auto-graded)**

**13. (10.00 pts)** The capacitor with the highest value is...

(Mark **ALL** correct answers)

- [ ] A) Capacitor 1
- [x] B) Capacitor 2

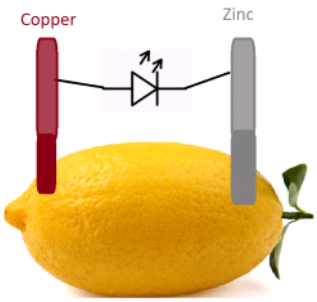
This can be proved without substituting numbers...
But intuitively, capacitors in parallel > capacitors in series.

**14. (10.00 pts)** The value of the capacitor with largest capacitance, in Farads, is...

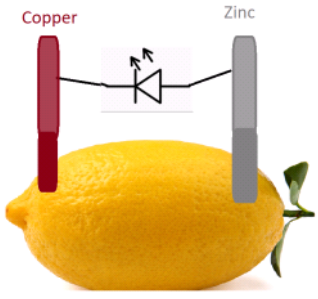
Almost none of you got this answer correct...

1.08E(-10)

**15. (5.00 pts)**
You can build a battery out of a lemon, a copper rod, and a zinc-plated nail. Assuming the battery provides enough voltage, how should you connect an LED for it to glow?




A




B

This can be proved without substituting numbers...
But intuitively, capacitors in parallel > capacitors in series.

- (●) A) Option A

○ B) Option B

Copper has a lower electronegativity than Zinc, and therefore will accept electrons from Zinc. (5pts)
Since electrons will flow from zinc to copper, conventional current flows from copper to zinc. (5pts)
An LED must be forward biased to operate, so the anode (base of triangle) must be connected to copper. (5pts)

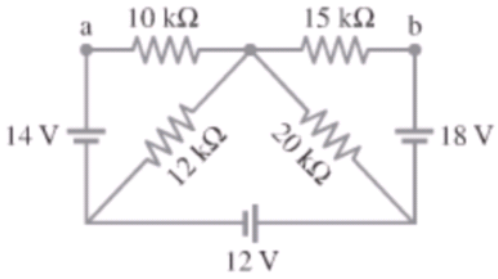
**16. (15.00 pts)** Provide a justification for your answer to the lemon-battery-LED question above.

**Expected Answer:** your justification here

Answers that repeated the "claim" made previously about which configuration was correct did not receive points. You don't justify things by saying "it is correct".
Points were not awarded that said Zinc has lower electronegativity than copper, or electrons flow from copper to zinc.
Partial points were awarded for including some (but not all) of the 3 critical ideas with varying degrees of clarity ... Some of you mentioned galvanic cells, which was given full credit.

**17. (15.00 pts)**

For the circuit shown in Fig. 19–65, determine (*a*) the current through the 14-V battery and (*b*) the potential difference between points a and b, $V_a - V_b$.



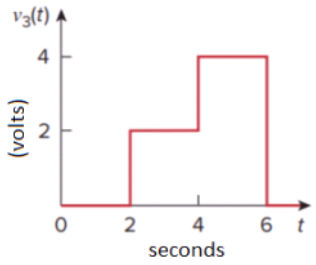

Sorry about this question - it wasn't worth your time to solve an annoying circuit which took me 15 minutes...

And there was confusion about the part (a) and (b)

Report your answer in scientific notation, correct to 2 significant figures. **For example, a value of 31 Volts should be reported as "3.1E(1)", without spaces or quotation marks**

2.0E(1)

**18. (5.00 pts)**




If this alternating-current source has a period of 6 seconds, what is the average, or root-mean-square power delivered by the source?

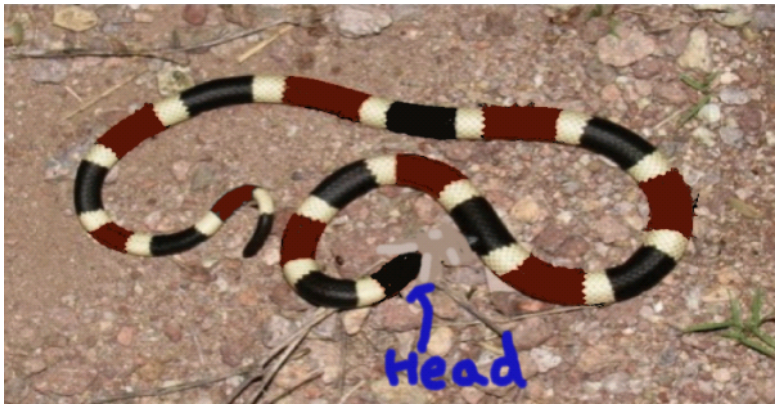
how to solve: Find area under curve, divide by period.
This is also known as the average value.

Report the answer to 2 significant digits in scientific notation, in Volts. **For example, a value of 31 Volts should be reported as "3.1E(1)", without spaces or quotation marks**

2.0E(0)

**Find the resistivity of the snake! (with <3 from your friends in herpetology)**

Just like resistors, some snakes have colored stripes. A stripe is a band of non-white color between that is separated on both sides by white color. Starting with the head and ending at the tail stripe, **calculate the resistivity of the snake**. Note that these snakes do not have tolerances.




Only 1 team solved this correctly

Useful givens: length of snake is 40cm, and is 2cm in diameter throughout its entire length.

Source: [ https://www.desertmuseum.org/books/nhsd_coral_snake.php (https://www.desertmuseum.org/books/nhsd_coral_snake.php) , https://arizonadailyindependent.com/2015/10/31/arizona-coral-snakes-pretty-and-very-venomous/ (https://arizonadailyindependent.com/2015/10/31/arizona-coral-snakes-pretty-and-very-venomous/) ]

**19. (15.00 pts)** Type in the resistivity of the snake in Ohms*meter, to three significant figures using scientific notation.

For example, if your calculator gives resistivity is 0.45773 Ohms*meter, type in **"4.58E(-1)", without spaces or parenthesis**

7.93E(12)

(II) A hair dryer draws 7.5 A when plugged into a 120-V line. (*a*) What is its resistance? (*b*) How much charge passes through it in 15 min? (Assume direct current.)
c) What is the power drawn by the hair dryer?

Almost all of you attempted and solved this correctly. I checked each answer manually to make sure points were awarded even with incorrect formatting.

**20. (5.00 pts)** Use the first blank to report the Resistance, in Ohms, to 3 significant figures;

Use the following notation: **report 4500 Coulombs as "4.50E(3)", without spaces and quotation marks**.

1.60E(1)

**21. (5.00 pts)** Use the blank to report the Charge, in Coulombs, to 3 significant figures;

Use the following notation: **report 4500 Coulombs as "4.50E(3)", without spaces and quotation marks**.

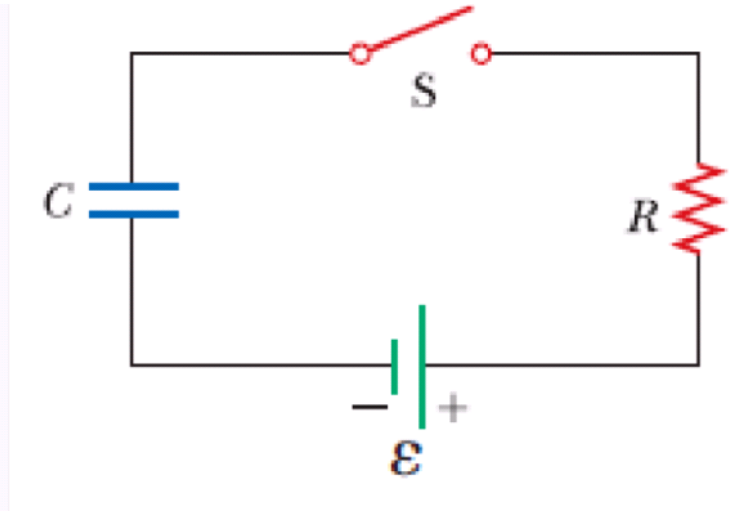
6.75E(3)

**22. (5.00 pts)** Use the blank to report the Power, in Watts, to 3 significant figures.

Use the following notation: **report 4500 Coulombs as "4.50E(3)", without spaces and quotation marks**.

9.00E(2)

**23. (10.00 pts)** Consider this circuit:




If the number was correct but with a wrong exponent, 2 points were awarded.
Otherwise, for all computational questions: an answer within:

10% full credit
20% half credit
30% 1/4 credit
else: no credit

If the capacitance of C is 1.00 microFarad,

the resistance of R is 2.00 MegaOhms

the voltage of battery is 10.0V,

the switch is closed at time t = 0;

Find the voltage on the capacitor after 3 seconds. Report your answer to 3 significant figures in scientific notation, "3.14E(0)"

7.77E(1)

The answer key answer is incorrect: should be 7.77E(0)

The two wires of a 2.0-m-long appliance cord are 3.0mm apart and carry 8.0 A of DC current. Calculate the force one wire exerts on the other. Is the force repulsive or attractive?

**24. (5.00 pts)** The Force between wires is

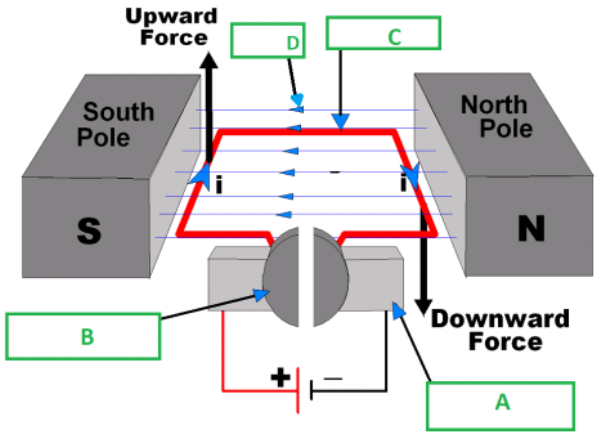
- (●) A) Repulsive
- ( ) B) Attractive

**25. (10.00 pts)** Report the magnitude of Force between the wires, in Newtons, to significant figures using Scientific notation.

For example, **456N should be entered as "4.6E(2)", without spaces or quotations**.

8.5E(-3)

**26. (15.00 pts)** Label the parts of the DC motor identified by the arrows.




DC Motor Conceptual Diagram

A: brush
B: commutator, slip ring
C: Armature, coil
D: Magnetic field

**Please format your answer as**: (these answers are fake, for example purpose)

A: magnet

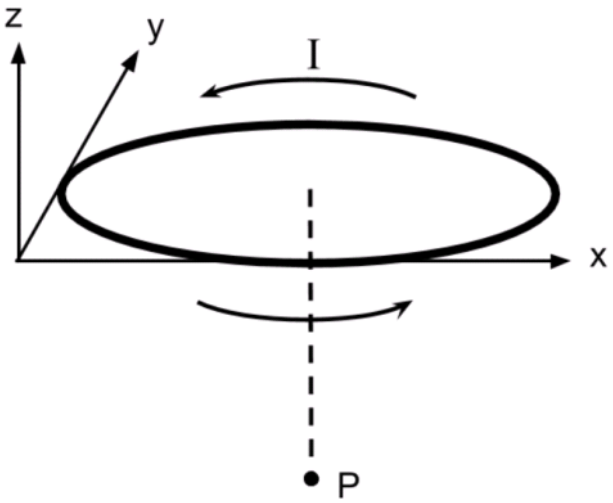
B: wire

C: neutron

D: electrons

**Expected Answer:**

A loop of wire lies in the x-y plane. The arrows in the diagram point in the positive directions for each axis (x, y, and z). The net charge of the wire is 0, but there is a clockwise current of constant magnitude in the wire (when looking downwards). Point P is underneath the center of the current loop.




There is a magnetic field not an electric field... use the right hand rule.

Use this information for the following 3 questions.

**27. (5.00 pts)** What is the direction of the **electric** field at point P?

- A) Up (+z)
- B) Down (-z)
- C) In the +x or +y direction
- D) In the -x or -y direction
- E) The electric field is 0 at point P

**28. (5.00 pts)** What is the direction of the **magnetic** field at point P?

- A) Up (+z)
- B) Down (-z)
- C) In the +x or +y direction
- D) In the -x or -y direction
- E) The magnetic field is 0 at point P

**29. (5.00 pts)** If there was a positively charged particle at rest at point P, which direction would it begin to accelerate in?

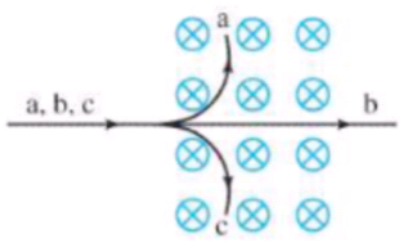
- A) Up (+z)
- B) Down (-z)
- C) In the +x or +y direction
- D) In the -x or -y direction
- E) It would not move

**30. (10.00 pts)**
Did you know that charged particles accelerating in the Earth's magnetic field are the cause of Aurora Borealis? Explain why these effects are most noticeable near the north and south pole.

**Expected Answer:**

Magnetic field lines concentrated near Earth's Magnetic poles --> magnetic field is strongest (3-5 pts)
Charged particles accelerate (3 pts)
Fast moving ions interact with atmosphere gas particles and cause light emission due to excitation. (2-3pts)

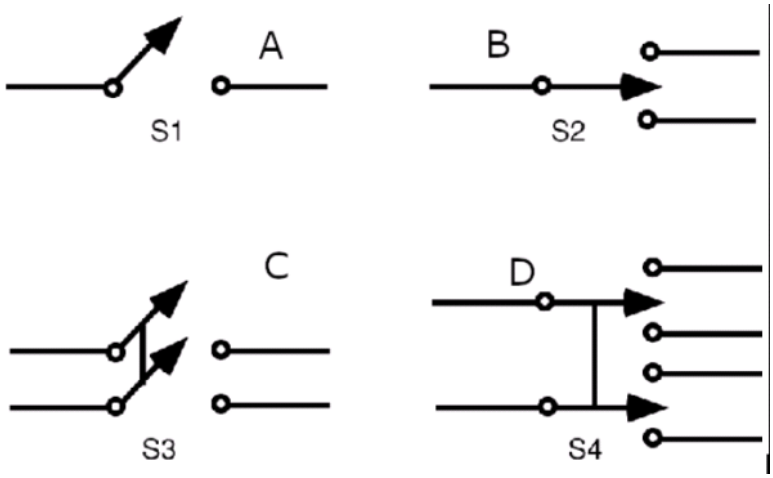
**31. (10.00 pts)** Three particles, a, b, and c, enter a magnetic field as shown in Fig. 20–46. What can you say about the charge on each particle?




Please write the charge of particle A, B, and C in the first, second, and third blank. Don't worry about formatting, we will grade this manually.

negative | neutral | positive

**32. (15.00 pts)** Use the short-answer field to enter the name for each of the 4 switches shown in the picture below:




**Please format your answer as**: (these answers are fake, for example purpose. We will manually grade this. )

A: magnet

B: wire

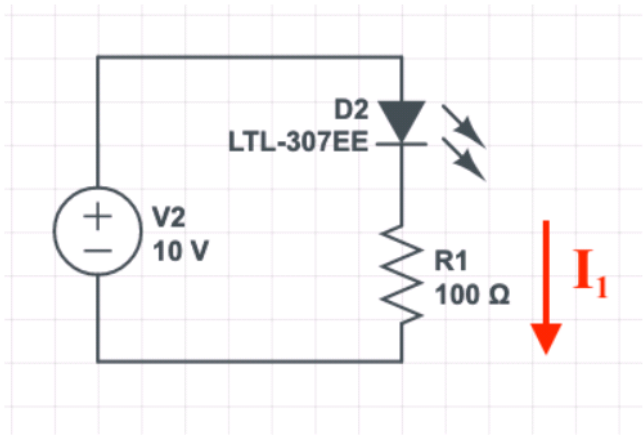
C: neutron

D: electrons

**Expected Answer:**

A. Single Pole Single Throw
B: Single Pole Double Throw
C: Double Pole Single Throw
D. Double Pole Double Throw

**33. (10.00 pts)** Assume that D2 has the characteristics of a real-life red light emitting diode (LED). Which range of currents would I1 through the resistor be?

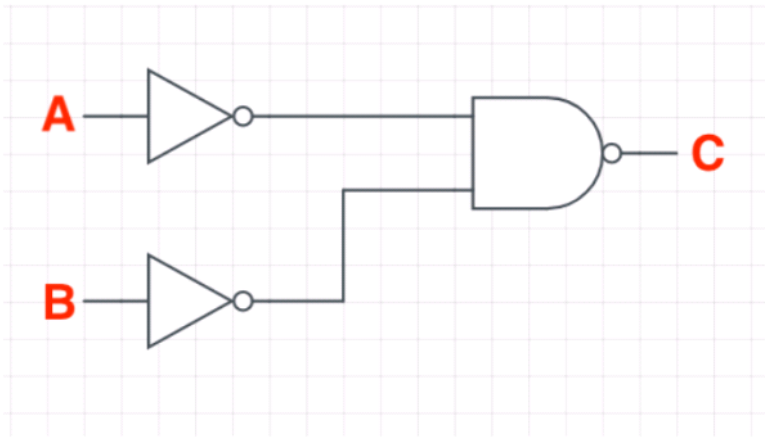



- A) Less than 1 micro-Ampere
- B) Between 1 micro-Ampere and 1milli-Ampere
- C) Between 1 milli-Ampere and 100 milli-Amperes

D) 100 mili-Amperes

E) Greater than 100 mili-Amper

**34. (10.00 pts)** Which logic gate is equivalent to the following circuit?




A) NAND

B) AND

C) NOR

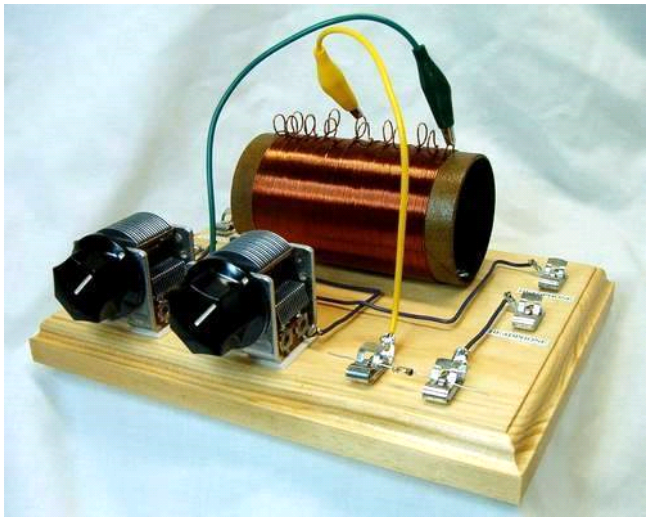
D) OR

E) None of the above

**Radio Communications**:

Transistors: A transistor is a 3 terminal device with one input, one output, and one “control” terminal conventionally called Emitter, Collector, and Base or Source, Drain, and Gate, respectively.

The invention of the transistor revolutionized electronics technology as it enabled us to control electric circuits using purely electrical means more efficiently. One cutting-edge technology that the transistor first enabled was the compact, high quality AM radio receiver.



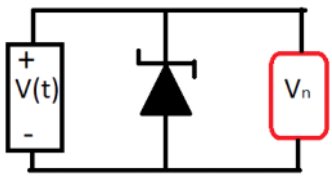
Triode, thermionic tube, Fleming tube was also acceptable.

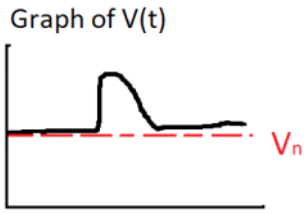
(this is the precursor to the modern radio: a crystal AM radio)

**35. (5.00 pts)** What technology (used in the 1910s - 1940s) was the fore-runner of the transistor? (answer in the blank, don't worry about formatting)

vacuum tube

**36. (10.00 pts)**
Explain how Zener diodes are used in Varactors. How will Zener diodes prevent sudden jolts in input voltage from damaging sensitive electronic components which can't handle more than Vn? (see picture below).



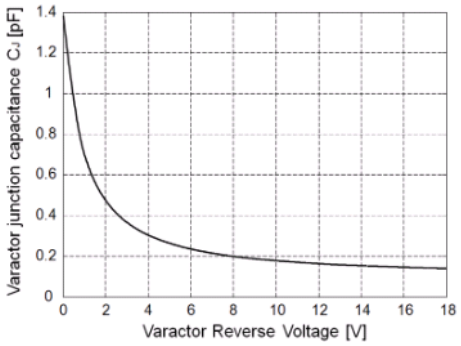




Partial points given for partially correct answers and attempted answers.

**Expected Answer:**

Zener diodes are wired in reverse bias. They break down rapidly when the reverse bias voltage reaches a threshold, acting like a short which saves the sensitive electronic component.

**37. (10.00 pts)**
A Varactor is an electronic component with variable capacitance that is made by reverse-biasing a PN junction. Explain why would a small input voltage result in a large capacitance across the varactor?




Thank you for taking my test!
It is an honor to deliver a SciOly test to so many teams.
Have fun with your SciOly endeavors and all the best wishes for your future tests!
Iliya Shofman.
(Mission San Jose HS (c/o 2019)
University of Toronto, Engineering Science)
email: shofmani@hotmail.com

**Expected Answer:**

The charges on either side of the depletion region in a reverse-biased diode act as capacitor plates. Smaller reverse voltage means small separation, hence larger capacitance. Increasing reverse voltage pulls the charges apart, increasing the distance between plates.

Thank you for taking this test! We will try our hardest to get any questions/ concerns answered. Scores will be released within 1 week.