Division C Circuit Lab Test

Team Name: _____

Competitor Names: _____

Created by: Photolithoautotroph

Directions and Information: Throughout the test, point values of individual question parts are indicated in brackets. If an individual question part does not have a point value indicated, then all question parts for that question are of equal point value. Each question or question part has only one correct answer unless otherwise indicated. Partial credit will be given for free response questions but not multiple choice questions. More difficult and longer questions are generally worth more points, but this is not necessarily always the case. Tiebreakers are total free response score, then total multiple choice score, then individual score on each of the free response questions in order.

All values on the test will be given with specified SI units. All answers must be given with SI units and at least four significant figures unless the answer is an exact value (assuming that given values in the problem are exact). Show all work on all free response questions for full credit. For problems where values are given as variables, the final answer should only be given in terms of the given variables.

Do not write in this test booklet. An answer sheet will be provided on which you should only circle your final answer for multiple choice questions, or show all work with your final answer clearly written on the line labeled "Final Answer" or clearly boxed for free response questions. Additionally, scratch paper for any additional work will be provided. Only answers and work written on the answer sheet will be graded.

This test was designed to be taken in 50 minutes.

1 Multiple Choice

30 questions, 50 points.

1. Classify each of the following ideal values as 0 or ∞. [6pt]
   (a) Resistance of an ideal ammeter.
   (b) Resistance of an ideal voltmeter.
   (c) Current through an ideal short circuit.
   (d) Resistance of an ideal insulator.
   (e) Resistance of an ideal conductor.
   (f) Time for an ideal capacitor connected to an ideal voltage source to fully (100%) charge.
2. Which of the following scientists acted as a close advisor to Henrich Hertz during his early studies? [1pt]
   (a) Vilhelm Bjerknes
   (b) Hermann von Helmholtz
   (c) Michael Faraday
   (d) James Clerk Maxwell
3. Which of the following is closest to the approximate current value in low frequency AC required to prevent voluntary muscle movement in men? [1pt]
   (a) 0.6mA
   (b) 4mA
   (c) 16mA
   (d) 40mA
4. Which of the following correctly gives the effective capacitance C_e of a vertically oriented parallel plate capacitor of separation $2d$ with area A that is half filled with a dielectric of constant κ when the dielectric uniformly fills only the bottom half of the volume between the capacitor's plates? Express your answer in terms of the capacitance C of an equivalent capacitor without the dielectric. [3pt]
   (a) $C_e = 2(\kappa + 1)C$
   (b) $C_e = (\kappa + 1)C$
   (c) $C_e = \frac{2\kappa}{\kappa+1}C$
   (d) $C_e = \frac{\kappa}{\kappa+1}C$
5. Which of the following is an accurate qualitative description of the magnitude electric field of a dipole p at a distance much greater than the distance d between the two charges along the axis of the dipole? [2pt]
   (a) Constant.
   (b) Decreasing linearly with distance.
   (c) Decreasing nonlinearly with distance.
   (d) Sinusoidally fluctuating.
6. Which of the following is not a practical application of static electricity? [1pt]
   (a) Electrostatic air filters
   (b) Xerograph printing

(c) High voltage Van de Graaff generators

(d) All of the above are applications of static electricity.

7. Which of the following best describes the function of grounding a circuit? [1pt]

   (a) Grounding controls current levels, preventing fires.

   (b) Grounding prevents power loss.

   (c) Grounding makes part of the circuit safe to touch when standing on the ground.

   (d) Grounding insulates the circuit, making it safer to be around.

8. Two resistors R_1 and R_2 have equal length and cross-sectional area, but R_2 has greater conductivity by a factor of k. Which of the following gives the total effective resistance R_e of the two resistors when arranged in series in terms of R_1? [3pt]

   (a) $R_e = \frac{R_1(k+1)}{k}$

   (b) $R_e = \frac{R_1 k}{k+1}$

   (c) $R_e = \frac{R_1}{k+1}$

   (d) $R_e = \frac{R_1(k+1)}{k^2}$

9. Which of the following laws gives the power dissipated in a circuit and who is it sometimes incorrectly credited to? [2pt]

   (a) Ohm's Law, James Prescott Joule

   (b) Coulomb's Law, James Clerk Maxwell

   (c) Faraday's Law, Alessandro Volta

   (d) Joule's Law, Georg Simon Ohm

10. Consider the following image.

    What does this image symbolize in a circuit diagram? [2pt]

    (a) Shockley Diode

    (b) Zener Diode

    (c) Schottky Diode

    (d) Silicon Controlled Rectifier (SCR)

11. Which of the following correctly gives standard AC frequency and voltage in the United States? [1pt]

    (a) 50Hz, 110V

    (b) 50Hz, 120V

    (c) 60Hz, 110V

    (d) 60Hz, 120V

12. Which of the following correctly gives the magnitude and direction of the magnetic field a distance r below a straight wire of length l with current I flowing through it to the left? [2pt]

    (a) $B = \frac{\mu_0 I}{2\pi r}$, out of the page

    (b) $B = \frac{\mu_0 I}{2\pi r}$, into the page

    (c) $B = \frac{\mu_0 Il}{2\pi r^2}$, out of the page

(d) $B = \frac{\mu_0 I l}{2\pi r^2}$, into the page

13. Which of the following best indicates where the energy of a capacitor is stored and in what form? [2pt]

    (a) The electric field, potential energy.
    (b) The magnetic field, potential energy.
    (c) The charge in the plates, potential energy.
    (d) The current, kinetic energy.

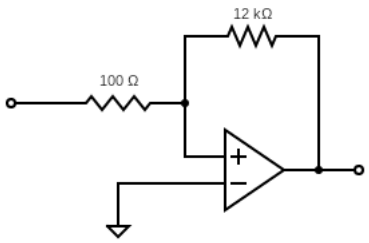
14. Which of the following practices is least practical at preventing shocking of the user of appliances with conductive metal cases containing circuitry? [1pt]

    (a) Using three pronged plugs to ground the case.
    (b) Designing the appliance to minimize contact between the hot wire and the case.
    (c) Using polarized plugs to control which wire is hot.
    (d) Incorporating an insulator in extra space in the case.

15. The most basic form of the tesla coil is essentially a combination of which of the following two devices? [1pt]

    (a) Ruhmkorff Coil, High Speed Alternator
    (b) Dipole Resonator, Ruhmkorff Coil
    (c) Spark Transmitter, Faraday Disk
    (d) High Speed Alternator, Helmholtz Resonator

16. Consider the following operational amplifier circuit.



    Which of the following correctly gives the closed loop gain A, assuming an ideal operational amplifier? [3pt]

    (a) 13
    (b) 121
    (c) 12
    (d) 120

17. Typically, how much larger is the output voltage of a real open loop operational amplifier (relative to ground) than the voltage across its input terminals? [1pt]

    (a) 10^3-10^4 times larger
    (b) 10^4-10^5 times larger
    (c) 10^5-10^6 times larger
    (d) 10^6-10^7 times larger

18. How do light emitting diodes produce light? [2pt]

(a) The electrons in the current ionize the diode molecules, releasing photons.

(b) The internal resistance of the diode causes it to heat up and glow.

(c) The diode slowly undergoes radioactive decay, releasing light and energy.

(d) Electrons in the semiconductor recombine with electron holes, releasing photons.

19. Which of the following best describes the apparatus which Michael Faraday used in his initial discovery of induction? [1pt]

(a) A tightly wound toroidal solenoid held up by a pair of iron bars which could be used to rotate it.

(b) A circular insulated wire held up by iron bars which could be used to rotate the wire loop.

(c) Two parallel insulated wires held together with iron bars.

(d) An iron ring with two insulated coils of wire wrapped around opposite halves of the ring.

20. Which of the following correctly ranks the charge to mass ratio $\frac{Q}{m}$ of a proton, neutron, and electron? [1pt]

(a) Proton > Neutron > Electron

(b) Proton > Electron > Neutron

(c) Neutron > Proton > Electron

(d) Electron > Neutron > Proton

21. Consider a charged particle with velocity v moving in a uniform magnetic field B. Which of the following provides an accurate qualitative description of the resultant motion of the particle if its velocity has a component directed parallel to and perpendicular to the magnetic field? [2pt]

(a) The particle will undergo uniform circular motion.

(b) The particle's velocity will continue unchanged.

(c) The particle's velocity parallel to the magnetic field will increase while the velocity component perpendicular to the magnetic field remains unchanged.

(d) The particle will spiral around a helix.

22. Which of the following describes the magnetic field lines created by a long, straight wire with current flowing through it? [2pt]

(a) Extending radially outward away from the wire.

(b) Rotating circularly around the wire.

(c) Pointing parallel to the wire in the direction of the current in the wire.

(d) Pointing parallel to the wire opposite the direction of the current in the wire.

23. In which of the following papers was Ohm's Law published? [1pt]

(a) On the attractive force of electric fire

(b) The Galvanic Circuit Investigated Mathematically

(c) Experimental Researches in Electricity

(d) On the Principles and Practicality of Electromagnetism

24. Which of the following processes prepares the silicon used to create a p-n junction? [1pt]

(a) Scoring

(b) Notching

(c) Doping

(d) Electrical Incision

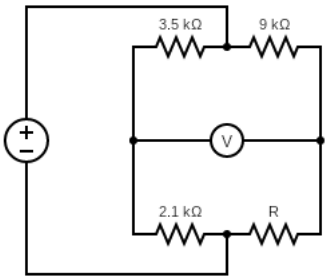
25. Which of the following is not a possible effect of experiencing current flow through the body? [1pt]

    (a) Weakening of muscles in the brain, increasing susceptibility to successive shocking.
    (b) Internal tissue burning due to the electrical resistance of the body.
    (c) Fibrillation of the heart due to shock to the diaphragm muscle.
    (d) Interference from the current with nerve cell communication, causing clenching of muscles.

26. Which of the following correctly gives the function of a diode? [1pt]

    (a) Locks the current in a wire in at a certain value.
    (b) Prevents current flow in a certain direction in a wire.
    (c) Ionizes an insulator, allowing current to flow through it.
    (d) Steps the current up or down by a factor of two.

27. Consider the following Wheatstone Bridge circuit.



    Which of the following gives the correct value of R if the bridge is balanced? [2pt]

    (a) 0.817kΩ
    (b) 15kΩ
    (c) 5.4kΩ
    (d) 1.224kΩ

28. Which of the following gives the correct Boolean expression for the XOR gate? [1pt]

    (a) $A \oplus B = (A + \overline{B})(\overline{A} + B)$
    (b) $A \oplus B = A + \overline{B} + \overline{A} + B$
    (c) $A \oplus B = (A\overline{B})(\overline{A}B)$
    (d) $A \oplus B = A\overline{B} + \overline{A}B$

29. Which of the following describes how the effective resistance R_e of two resistors in parallel compares to the resistances R_a and R_b of each resistor when $R_a \leq R_b$? [1pt]

    (a) $R_e < R_a$
    (b) $R_e \leq R_a$
    (c) $R_a + R_b < R_e < R_a R_b$
    (d) $R_a < R_e < R_b$

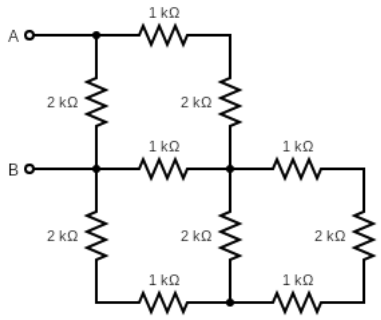
30. Which of the following gives the correct term for the voltage required to convert an insulator into a conductor? [1pt]

    (a) Breakdown Potential
    (b) Ionization Potential
    (c) Electrolytic Potential
    (d) Cleavage Potential

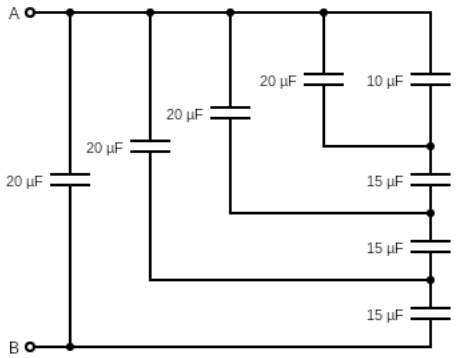
2 Free Response

7 questions, 100 points.

1. (a) Calculate the effective resistance R_e between nodes A and B in the diagram below. [3pt]



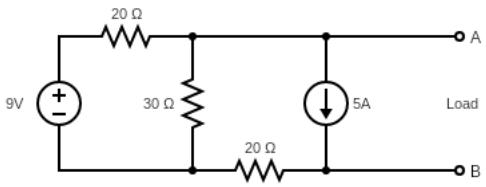
(b) Find the effective capacitance C_e between nodes A and B in the diagram below. [2pt]



(c) Draw a configuration of resistors between two nodes A and B for which the effective resistance between the nodes is $\frac{6}{5}$kΩ. Use only 3kΩ resistors. Extra points will be earned if the total configuration uses only 4 resistors or less. No partial credit will be earned if the effective resistance between the nodes is not correct. [4pt for 4 resistors or less, 2pt for more]

(d) Draw a configuration of capacitors below between two nodes A and B for which the effective capacitance between the nodes is $\frac{8}{7}\mu$F. Use only 2μF capacitors. Extra points will be earned if the total configuration uses only 5 capacitors or less. No partial credit will be earned if the effective capacitance between the nodes is not correct. [4pt for 5 capacitors or less, 2pt for more]

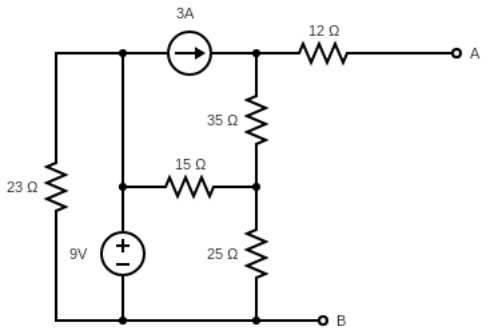
2. Consider the following circuit diagram for parts (a) and (b):



(a) Use source transformations to simplify this circuit to its Norton and Thévenin equivalent circuits. Show at least two intermediate circuits for full credit (between source transformations). [9pt]

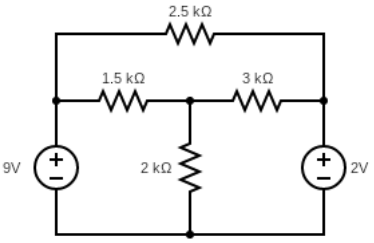
(b) For what load resistor value R_l would the circuit dissipate 460J of energy per second? [3pt]

Now consider the following circuit:



(c) Draw the Thévenin and Norton equivalent circuits for the above circuit. [4pt]

3. Consider the following circuit. All resistors are cylindrical with the same radius and made of the same material.

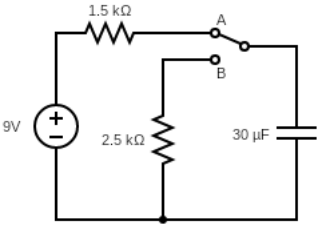


(a) Calculate the three mesh currents in the three loops. Clearly indicate which loop is loop 1, 2, and 3. Redrawing the diagram is the simplest way to do this. Note: direction of the currents does not matter, nor does which current corresponds to which loop. To receive credit, the correct three current values can be in any order as long as each current corresponds to the correct loop. [9pt]

(b) Calculate the powers P_2 and P_3 dissipated by the 2kΩ resistor and the 3kΩ resistor, respectively. [4pt]

(c) If the 2kΩ resistor has radius 0.25mm and is 0.5cm long, calculate the conductivity σ of the material and find the length l of the 3kΩ resistor (assuming the same radius and material). [4pt]

4. Consider the following RC circuit. The switch is initially set to position A and the circuit is allowed to reach equilibrium.



(a) Calculate the magnitude of the charge Q on the capacitor after a long time and the initial current I_0 through the 1.5kΩ resistor. [4pt]

(b) Which plate of the capacitor is positively charged (top/bottom) in the diagram? Explain. [3pt]

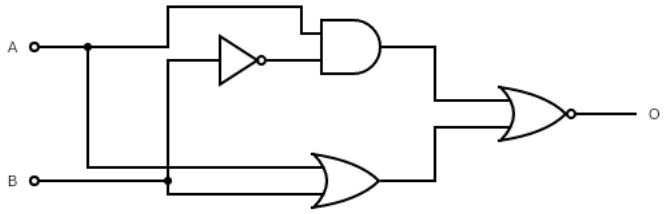
(c) Calculate the time t required for the charge on the capacitor to reach 99% of the value found in (a). [2pt]

After a long time, the switch is set to position B and the circuit is allowed to come to equilibrium.

(d) Calculate the total energy E dissipated by the 2.5kΩ resistor. [2pt]

(e) Suppose the 2.5kΩ resistor was replaced by another capacitor of capacitance 70μF. What would the final charge q on the 70μF capacitor be? [5pt]

5. (a) Write a Boolean expression for the output O of the following digital logic gate. Write a truth table for the logic gate. [3pt]



(b) Simplify the Boolean expression $O = \overline{A + \overline{B * \overline{\overline{C} + A}}}$ until it has no more or gates. Draw a logic gate represented by this expression in its unsimplified form. [5pt]

6. A spherical conductor of radius r_1 with net charge $+q_0$ is a very large distance from another conductor of radius $r_2 = \beta r_1$ with net charge 0.

(a) Calculate the electric potentials V_1 and V_2 on the surface of each sphere. [3pt]

(b) The spheres are now connected with a conducting wire. Calculate the final charges Q_1 and Q_2 on each sphere after the system reaches equilibrium. [5pt]

(c) Explain why your final result for part (b) would be different if the conducting spheres were close together. [2pt]

Now consider two nonconducting spheres otherwise identical to the two conducting spheres described above, with the exception that sphere 2 now has a charge $+2q_0$. Their centers are now a distance d apart.

(d) If the two spheres are both in equilibrium when a third point charge is placed between them, what is the charge Q of that point charge and how far (a distance x is it from the charge $+2q_0$)? [5pt] Note: solving for the position of the point charge before finding the charge is somewhat easier.

7. Consider a wire of length L and radius R with constant current density J.

(a) Calculate the total current I in the wire. [2pt]

(b) Calculate the magnitude of the magnetic field B as a function of distance r from the center of the wire for $r \ll L$. Note: your answer should be different for r less than and greater than R. [6pt]

(c) An electron is moving parallel to the wire with initial velocity v a distance $d = 2R$ directly above the wire. Calculate the magnitude of the magnetic force F_b on the electron and specify the direction of the force if the current in the wire flows to the right while the electron moves left. Denote elementary charge as e in your answer. [4pt]

(d) Using a voltmeter, you measure a voltage V across the two ends of the wire. Determine the resistivity ρ of the wire. [3pt]