Key

Physics 214/224, Quiz 2

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03/01/2019

For grading purposes	
Problem 1	
Problem 2	
Problem 3	
Problem 4	
Studio	
Total:	

WID:______________________________ NAME:____

Instructions. Print and sign your name on this quiz and on your scantron card. In doing so, you are acknowledging the KSU Honor Code: "On my honor as a student I have neither given nor received unauthorized aid on this academic work."

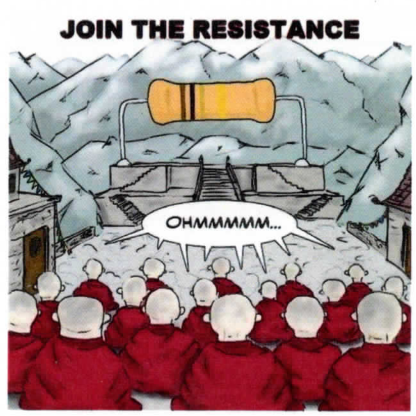
For two quick points, circle your studio instructor:

Smith (TU 7:30) Lohman (TU 9:30) Maravin (TU 11:30)

Maravin (TU 1:30) Smith (TU 3:30)

Weliweriya (WF 9:30) Weliweriya (WF 11:30) Smith (WF 1:30)

Work alone and answer all questions. Part I questions must be answered on the Scantron cards. Put your name on your card. Color in the correct box completely for every answer with a pencil. If you make a mistake, erase thoroughly. **Don't forget to color in the boxes for your WID. If we have to correct this by hand we may take off five points from your score!** Part II must be answered in the space provided on the test. The last page is a detachable equation sheet. You may use a calculator. You may ask the proctors questions of clarification. Show your work in a clear and organized manner. You may receive partial credit for partial solutions. Solutions lacking supporting calculations will receive no points.



Part I: All questions to be answered on your Scantron card (48 points total)

1. (3 points) Consisting of one or more pieces of conductor, separated in space, and used for charge and energy storage applications, this device is

   (a) a resistor

   (b) a battery

   (c) a switch

   (d) a capacitor

2. (3 points) Its essential elements are two different metals, spatially separated and sometimes immersed in an acidic solution. This is

   (a) a resistor

   (b) a battery

   (c) a switch

   (d) a capacitor

3. (3 points) To protect the circuit, how would you connect the fuse?

   (a) in series with the circuit in question

   (b) in parallel with the circuit in question

   (c) fuse does not have to be connected to the circuit, just placing it in the vicinity is sufficient

4. (3 points) If 1000 J of work is required to carry 25 C charge from one point to another, the potential difference between these two points is

   (a) 25,000 V

   (b) 40 V

   (c) 25 mV

   (d) depends on the path

   (e) none of these

5. (3 points) A 60W light bulb carries a current of 0.5 A. The total charge passing through it in one hour is

   (a) 3600 C

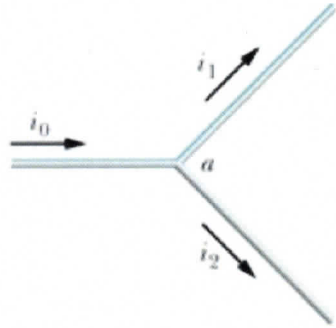
   (b) 2400 C

   (c) 1800 C

   (d) 900 C

   (e) 120 C

6. (3 points) The figure below shows a junction. What is true of the currents?



$i_0 = i_1 + i_2$

$i_1 = i_0 - i_2$

(a) $i_1 = i_0 + i_2$
(b) $i_2 = i_0 + i_1$
(c) $i_0 = i_1 - i_2$
(d) $i_1 = i_0 - i_2$
(e) $i_0 = i_2 - i_1$

7. (3 points) For a cylindrical resistor that obeys Ohm's Law the resistance does NOT depend on:

(a) the current
(b) the length
(c) the cross-sectional area
(d) the resistivity
(e) the electron drift velocity

8. (3 points) Pulling the plates of an isolated charged capacitor apart:

(a) increases the capacitance
(b) increases the potential difference
(c) does not affect the potential difference
(d) decreases the potential difference
(e) does not affect the capacitance

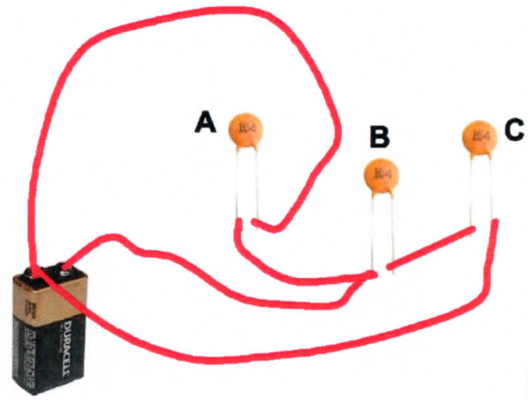
9. (3 points) "The sum of the emf's potential differences around a closed loop equals zero," is a consequence of

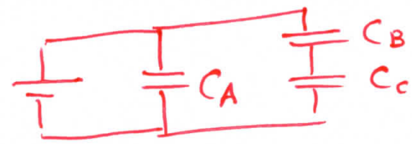
(a) Newton's third law
(b) Ohm's law
(c) Newton's second law
(d) Maravin's law
(e) conservation of energy

10. (3 points) An ideal battery has an emf of 12 V. If it is connected to a circuit and creates a current of 4.0 A, what is the power?

(a) 0.3 W
(b) 3.0 W
(c) 36 W
(d) 48 W
(e) cannot tell without knowing the resistance of the circuit

The next two questions refer to the following figure below. The solid lines in the figure above represent high conductivity copper wire. The three capacitors shown each have $C = 0.1\ \mu$F, and the battery establishes a voltage difference $V = 9$ V between its terminals.



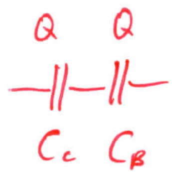


11. (3 points) Which statement is most correct?

    (a) A, B, and C are in series
    (b) A, B, and C are in parallel
    (c) A is in parallel with the series combination of B and C
    (d) A is in series with the parallel combination of B and C

12. (3 points) Which relationship is most correct concerning the charges stored on the capacitors?

    (a) $Q_A = Q_B > Q_C$
    (b) $Q_A = Q_C > Q_B$
    (c) $Q_B = Q_C > Q_A$
    (d) $Q_A > Q_B = Q_C$



$Q_B = Q_c$

This is the correct answer (d)

13. (3 points) In the context of the loop and junctions rules for electrical circuits, a junction is

    (a) where a wire is connected to a resistor
    (b) where a wire is connected to a battery
    (c) where a wire is bent
    (d) where three or more wires are joined
    (e) where only two wires are joined

14. (3 points) A certain capacitor, in series with a 720 Ω resistor is being charged. At the end of 10 ms, its charge is half the final value. The capacitance is about

    (a) 9.6 μF
    (b) 14 μF
    (c) 20 μF
    (d) 7.2 F
    (e) 10 F

$$Q(t) = Q_{final}\left(1 - e^{-\frac{t}{RC}}\right)$$

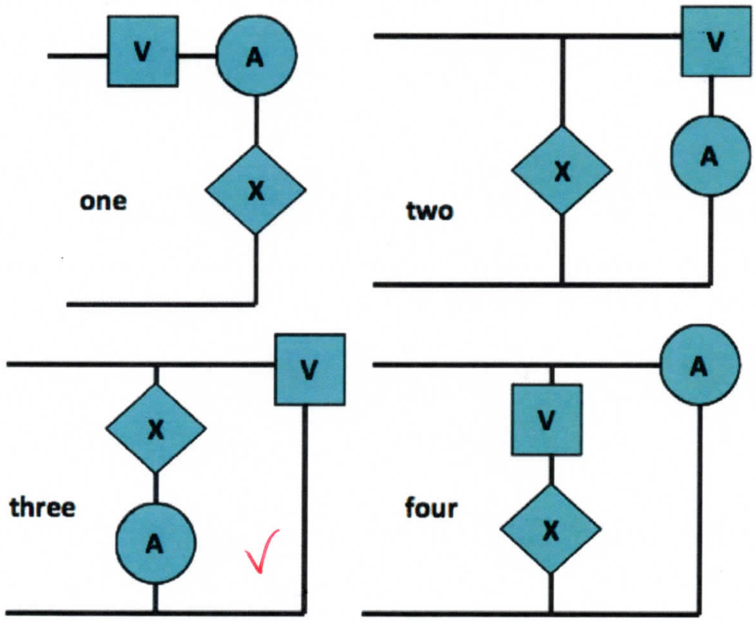
$$\frac{Q_{final}}{2} = Q_{final}\left(1 - e^{-\frac{t}{RC}}\right)$$

$$\frac{1}{2} = 1 - e^{-\frac{t}{RC}} \qquad e^{-\frac{t}{RC}} = \frac{1}{2}$$

$$\frac{t}{RC} = \ln 2 \Rightarrow$$

$$C = \frac{10 \cdot 10^{-3}\,s}{720\,\Omega \ln 2} \simeq 20\,\mu F$$

The figure below shows four different ways that studio groups in previous years have wired up a voltmeter (square box with V) and an ammeter (circle with an A) to perform a simultaneous measurement of the current through and the voltage difference across circuit element X (diamond with an X). Assume "ideal" performance for the voltmeter and ammeter.



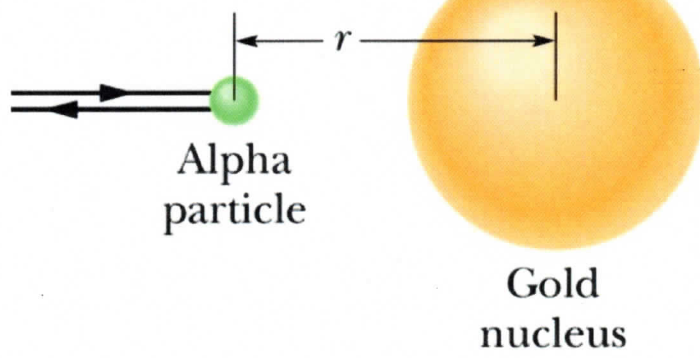
15. (3 points) Which is the only scheme that correctly measures the voltage across X and the current through X?

    (a) one
    (b) two
    (c) three
    (d) four

16. (3 points) Which scheme is most likely to blow a fuse in the ammeter?

    (a) one
    (b) two
    (c) three
    (d) four

Part II: Work out this part in the space provided. Show your work! (52 points total)



17. (14 points) An alpha particle (two protons and two neutrons) moves into a stationary gold nucleus (79 protons and 118 neutrons), as shown in Figure above. The alpha particle momentarily stops when its center is at radial distance $r = 9.23 \cdot 10^{-15}$ m from the nuclear center. Then it moves back along its incoming path. Because the gold nucleus is much more massive than the alpha particle, we can assume the gold nucleus does not move.

(a) (2 points) What are charges of alpha particle and gold nucleus?

α : $2e = 3.2 \cdot 10^{-19} C$ (+1)

Gold : $79e = 1.26 \cdot 10^{-17} C$ (+1)

(b) (4 points) Find the electric potential of the nucleus at the distance r, where the alpha particle comes to a stop. Assume the nucleus to be charged uniformly. If you take any assumptions, describe them below.

Due to symmetry of charge distribution, uniformly charged gold nucleus can be substituted with a point-like charge of the same magnitude (+2)

$V = \frac{kQ}{r}$ (+1) $= \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \frac{79 \cdot 1.6 \cdot 10^{-19} \cdot 9 \cdot 10^{9}}{9.23 \cdot 10^{-15}} V = 12.3 \cdot 10^{6} V = 12.3 MV$ (+1)

(c) (4 points) What is the kinetic energy K_i of the alpha particle when it was initially far away?

$K_i + \cancel{U_i} = \cancel{K_f} + U_f$

$K_i = U_f = q \cdot V$

From ~~the~~ conservation of energy initial energy must be equal to the final energy when the α-particle stops (+1)

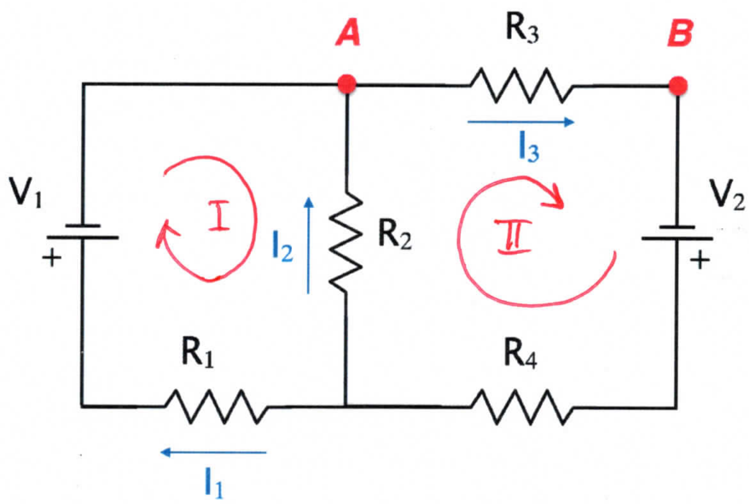
At large distances, potential energy is small, can be neglected (+1)

At $r = 9.23 \cdot 10^{-15}$ particle is at rest → kinetic energy is zero, so (+1) at ∞, total energy is K_i, at r : $Vq = 3.2 \cdot 10^{-19} C \cdot 12.3 MV = 3.94 \cdot 10^{-12} J$ (+1)

(d) (4 points) Use the formula that you derived in (b) written in symbolic form to calculate the magnitude of the electric field at distance r ($|E_r| = |-\partial V/\partial r|$). How does it compare with electric field of the gold nucleus, treated as a single point-like charge?

$|E| = \frac{kQ}{r^2}$ (+2) - exactly what we expect from the point-like charge! (+2)

$E = \frac{9 \cdot 10^{9} \cdot 1.26 \cdot 10^{-17}}{(9.23 \cdot 10^{-15})^2} \frac{N}{C} \approx 1.3 \cdot 10^{21} \frac{N}{C}$



18. (14 points) In the figure above, I_1, I_2, and I_3 are the currents flowing through the resistors labeled R_1, R_2, and R_3, respectively. To help the graders out, use the directions of the currents shown in the figure.

(a) (6 points) Deduce three independent equations for the three unknown currents. Use the symbolic notation for resistances and voltages.

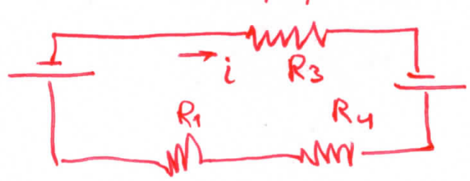
(A) $i_1 + i_2 = i_3$ (+2)

(I) $i_2 R_2 - i_1 R_1 - V_1 = 0$ (+2)

(II) $-i_3 R_3 + V_2 - i_3 R_4 - i_2 R_2 = 0$ (+2)

(b) (5 points) Take $V_1 = 10\text{V}$, $V_2 = 20\text{V}$; $R_2 = 10^6\ \Omega$, and $R_1 = R_3 = R_4 = 10\ \Omega$. Calculate I_1, I_2, and I_3. You can use equations above, or if you can see a simpler path to a very good estimate of the exact answer, use it, explaining whatever approximation you make in one sentence. (*Hint: Wow! R_2 is a very big resistance!*).

R_2 is huge! Consider $I_2 = 0$ and $R_2 = \infty$ (break in a circuit.)
This simplifies the circuit to:



$$i = i_3 = i_1 = \frac{V_2 - V_1}{R_1 + R_3 + R_4} = \frac{20\text{V} - 10\text{V}}{30\Omega} = 0.33\text{A}$$

$i_2 = 0\text{A}$
$i_1 = i_3 = 0.33\text{A}$

Exact solution yields $13.3\,\mu\text{A}$ for i_2, and 0.33A for i_1 & i_3.

(c) (3 points) What is the potential difference between points A and B: $V_B - V_A$?

$$V_B - V_A = \underbrace{-i_3 R_3}_{(+2)} = -0.33\text{A} \cdot 10\Omega = -3.3\text{V} \quad (+1)$$

Similarly $V_B - V_A = i_2 R_2 + i_3 R_4 - V_2$ or $V_1 + i_1 R_1 + i_3 R_4 - V_2$.

Extra paper for calculations

Exact solution for 18.

from (A): $\quad i_1 = i_3 - i_2$

(I) $\quad i_2 R_2 - (i_3 - i_2) R_1 - V_1 = 0 \Rightarrow i_2(R_2 + R_1) - i_3 R_1 = V_1$

(II) $\quad -i_3(R_3 + R_4) - i_2 R_2 + V_2 = 0 \Rightarrow -i_3(R_3 + R_4) - i_2 R_2 = -V_2$

$$\Rightarrow \quad i_3 = \frac{i_2(R_2 + R_1) - V_1}{R_1} \quad \Rightarrow$$

$$-(R_3 + R_4) \cdot \frac{i_2(R_2 + R_1) - V_1}{R_1} - i_2 R_2 = -V_2$$

$$\frac{(R_3 + R_4)(R_2 + R_1) i_2}{R_1} - \frac{V_1(R_3 + R_4)}{R_1} + i_2 R_2 = V_2$$

$$i_2\left(\frac{(R_3 + R_4)(R_2 + R_1)}{R_1} + R_2\right) = V_2 + \frac{V_1(R_3 + R_4)}{R_1}$$

Sub $\quad R_1 = R_3 = R_4 = r$, and $R_2 = R$:

$$i_2\left[\frac{2r(R+r)}{r} + R\right] = V_2 + 2V_1$$

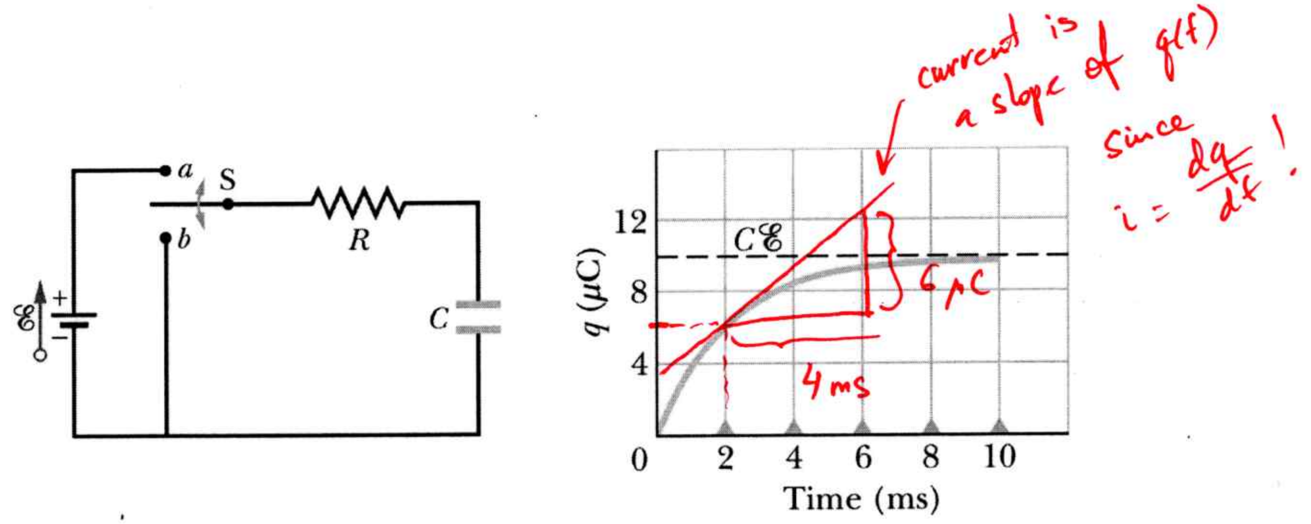
$$i_2 = \frac{(V_2 + 2V_1) r}{2rR + 2r^2 + rR} = \frac{(V_2 + 2V_1)\cancel{r}}{\cancel{r}(2r + 3R)} = \frac{V_2 + 2V_1}{2r + 3R}$$

$$i_3 = \frac{i_2(R+r) - V_1}{r} \qquad i_1 = i_3 - i_2 \Rightarrow$$

$i_2 = 13.33\ \mu A$

$i_3 = +0.33\ A$

$i_1 = +0.33 A$



19. (10 points) The left figure above shows a circuit with a switch that can be either in (a) or (b) position. The EMF of the battery is 50 V. The right figure indicates the charge measured on the capacitor of the circuit.

(a) (1 point) The time-dependence of the charge on the capacitor indicates that the switch is flipped to (a) or to (b) position? Explain.

It is charging, so a)   Explanation (+1)

(b) (2 points) What is the RC time constant for this circuit?

$\frac{2}{3}\cdot 10\,\mu C \simeq 6\,\mu C$, so $\tau \simeq 2$ ms

(c) (2 points) What is the capacitance of the circuit?

$$C\mathcal{E} = 10\,\mu C \Rightarrow C = \frac{10\,\mu C}{\mathcal{E}} = \frac{10\,\mu C}{50V} = 0.2\,\mu F$$

(d) (2 points) What is the resistance of the circuit?

$$\tau_{RC} = RC = 2\,ms \Rightarrow R = \frac{2\,ms}{C} = \frac{2\,ms}{0.2\,\mu F} = \frac{2\cdot 10^{-3}s}{2\cdot 10^{-7}F} = 10\,k\Omega$$

(e) (3 points) How much current flows into the capacitor at time $t = 2$ ms? *Hint:* $\frac{dQ}{dt}$?

Charging formula: (+2)
$$\begin{cases} Q(t) = 10\,\mu C\cdot(1 - e^{-\frac{t}{\tau}}) \Rightarrow \\ i(t) = \frac{10\,\mu C}{\tau} e^{-\frac{t}{\tau}} = \frac{10\,\mu C}{2\cdot 10^{-3}s} e^{-\frac{t}{\tau}} \Rightarrow \end{cases}$$

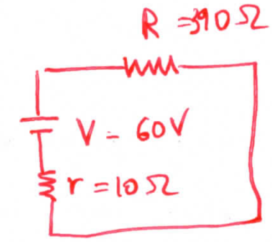
$$i(t) = 5\cdot 10^{-3} A\, e^{-\frac{2ms}{2ms}} \simeq \underline{1.84\,mA}$$ (+1)

Or grafically

$$i \simeq \frac{6\,\mu C}{4\,ms} \simeq 1.5\,mA$$

20. (9 points) A 60 V battery has an internal resistance of 10 Ω. The battery is connected to resistive load with resistance of $R_L = 390\ \Omega$.

(a) (2 points) Show that the battery supplies a current of 0.15 A.



+1 $\begin{cases} R_{eff} = 10\Omega + 390\Omega = 400\Omega \\ i = \dfrac{V}{R_{eff}} = \dfrac{60V}{400\Omega} = 0.15A \end{cases}$ +1

(b) (3 points) What voltage would a very good voltmeter show if you connect the leads to the battery terminals?

$V = \underbrace{60V - ir}_{+2} = 60V - 0.15A \cdot 10\Omega = 58.5V$ +1

(c) (3 points) How long would the circuit need to operate for the battery to absorb 1000 J of heat energy?

Battery provides a steady current of 0.15A, heat is released in the internal resistor +1

$P = i^2 \cdot r = (0.15)^2 \cdot 10\ W = 0.225W$ +1

$Heat = P \cdot t \Rightarrow t = \dfrac{1000J}{0.225W} = 4444s$

(d) (1 point) How much current would the battery need to supply if the load resistance developed a short circuit?

if $R_L = 0 \Rightarrow i = \dfrac{V}{10\Omega} = \dfrac{60V}{10\Omega} = \underline{\underline{6A}}$.

+1