Physics 214/224, Quiz 2

Primary instructor: Yurii Maravin

02/25/2022

KEY

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:

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

Kumarappan (TU 1:30) Blaga (FW 9:30) Maravin (FW 11:30)

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 (34 points total)

1. (2 points) Electric field

   (a) is always perpendicular to equipotential surfaces
   (b) is always parallel to equipotential surfaces
   (c) does not have a specific orientation with respect to equipotential surfaces
   (d) is something I learned in January, but not really sure what it is and how it relates to anything

2. (2 points) An electron volt is

   (a) the force acting on an electron in a field of 1 N/C
   (b) the force required to move an electron 1 meter
   (c) the energy gained by an electron in moving through a potential difference of 1 volt
   (d) the energy needed to move an electron through 1 meter in any electric field
   (e) the work done when 1 coulomb of charge is moved through a potential difference of 1 volt

   $1eV = 1e \cdot 1V$

3. (2 points) The fact that we can define electric potential energy means that

   (a) the electric force is nonconservative
   (b) the electric force is conservative
   (c) the work done on a charged particle depends on the path it takes
   (d) there is a point where the electric potential energy is exactly zero
   (e) Dr. Maravin makes very hard quizzes

4. (2 points) A tiny sphere carrying a charge of 6.5 μC sits in an electric field, at a point where the electric potential is 240 V. What's the sphere's potential energy?

   (a) 2.7×10^{-8} J
   (b) 6.5×10^{-6} J
   (c) 1.6×10^{-3} J
   (d) 240 J
   (e) 3.7×10^{7} J

5. (2 points) The work, required to carry a particle with a charge of 6.0 μC from a 5.0 V equipotential surface to a 6.0 V equipotential surface and back again to the 5.0 V surface is:

   (a) 0 J
   (b) 1.2×10^{-5} J
   (c) 3.0×10^{-5} J
   (d) 6.0×10^{-5} J
   (e) 6.0×10^{-6} J

6. (2 points) Which quantity or quantities take on the same value on all points of a good conductor?

   (a) surface charge density
   (b) normal component of electric field
   (c) voltage
   (d) surface charge density **and** normal component of electric field
   (e) normal component of electric field **and** voltage

7. (2 points) Each plate of a capacitor stores a charge of magnitude 1 mC when a 100 V potential difference is applied. The capacitance is

   (a) 5 μF
   (b) 10 μF
   (c) 50 μF
   (d) 100 μF
   (e) none of these

$Q = CV$

$1 \cdot 10^{-3} C = C \cdot 100 \Rightarrow \quad C = 10 \cdot 10^{-6}\ F$

8. (2 points) If the charge on a parallel-plate capacitor is doubled

   (a) the capacitance is halved
   (b) the capacitance is doubled
   (c) the electric field is halved
   (d) the electric field is doubled
   (e) the surface charge density is not changed on either plate

9. (2 points) Dielectric filling in the capacitor

   (a) reduces the electric field in the capacitor
   (b) increased the electric field in the capacitor
   (c) inserted to protect the capacitor from the discharge
   (d) neither of the above

10. (2 points) A fuse is a piece of conductor designed to run up and break when the current through it exceeds some rated value. To protect a circuit, it should be wired

   (a) in series with the rest of the circuit
   (b) in parallel with the rest of the circuit
   (c) either in series or in parallel, as the fuse will protect the circuit no matter where it is connected
   (d) none of the above

11. (2 points) What is the resistance of the 100W light bulb when operating at V = 120 V?

(a) 60 Ω
(b) 120 Ω
(c) 144 Ω
(d) 240 Ω
(e) none of the above

$P = V \cdot i = V\frac{V}{R} \Rightarrow R = \frac{V^2}{P} = 144\,\Omega$

12. (2 points) A compact fluorescent bulb produces the same light output as a 60 W conventional bulb, but it consumes ten times less power. How many of these bulbs can be put in parallel on a 120 V circuit protected by a 15A circuit breaker?

(a) 3
(b) 30
(c) 300
(d) 3000
(e) 3000000000

$P = 6W$ $\quad i = \frac{P}{V} = \frac{6W}{120V} = 0.05A$

$N = \frac{15A}{0.05A} = 300$

13. (2 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 that battery produces?

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

14. (2 points) The EMF of a battery is equal to its terminal potential difference

(a) under all conditions
(b) only when the battery is being charged
(c) only when a large current is in the battery
(d) only when there is no current in the battery
(e) under no conditions

15. (2 points) "The sum of the currents into a junction equals the sum of the currents out of the junction" is a consequence of

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

16. (2 points) The time constant RC has units of

(a) second/farad

(b) second/ohm

(c) 1/second

(d) second/watt

(e) none of these

17. (2 points) Here is a loop equation: $R\frac{dq}{dt} + \frac{q}{C} = \mathcal{E}$. What does this equation represent?

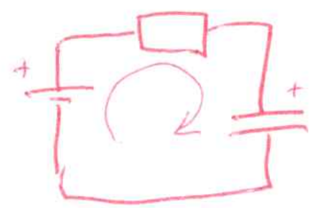
(a) a charging capacitor

(b) a discharging capacitor

(c) a capacitor that has been disconnected

(d) a charging resistor

(e) an oscillating circuit

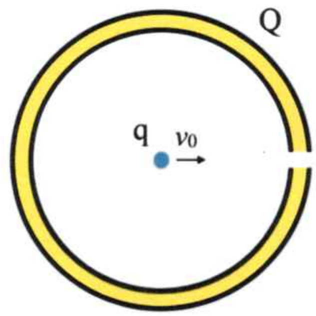


$$\mathcal{E} - iR - \frac{q}{C} = 0$$

$$\mathcal{E} = iR + \frac{q}{C} = R\frac{dq}{dt} + \frac{q}{C}$$

charging cap.

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



18. (9 points) A hollow non-conductive thin shell with radius $R = 1$ m, pictured above, has a positive charge $Q = 1$ C distributed evenly on a surface and a tiny positive charge $q = 1$ μC in the center of the shell. The charge q is pushed off-center with an initial speed $v_0 = 1$ m/sec toward a small opening in the shell from which the tiny charge escapes. The mass of the charge q is $m = 1$ g, and you should assume that the charge Q is fixed in space and cannot move. Assume that the opening does not affect the symmetry of the charge distribution on the shell (assume shell to have a perfectly uniform charge distribution on its surface in your calculations).

(a) (2 points) Does the charge q accelerate while it is moving **inside** the shell or not? Explain why.

No, it doesn't (+1)

(+1) This is because there is no electric field inside the shell (a consequence of radial symmetry of the charge distribution and Gauss law), so $F=0 \Rightarrow a=0$.

(b) (2 points) Does the charge q accelerate as it leaves the shell Q? If yes, is the acceleration constant or not?

Yes, it does (+1)

There's a field outside the shell, the same as that from a point like charge Q at the center of the shell, so $F = k\frac{qQ}{r^2} \Rightarrow a$ is not constant. (+1)

(c) (2 points) Assuming the potential is 0 V at infinity, what is the potential right above the surface of the shell Q?

(+1) $\left\{\right.$ As the sphere acts as a point-like charge due to symmetry and Gauss law:

$$V = \frac{kQ}{R} = \frac{9\cdot 10^9 \frac{Nm^2}{C}\cdot 1C}{1m} = 9\cdot 10^9 \text{ V}$$

(+1)

(d) (3 points) Find a speed of the charge q when it is sufficiently far away from the shell Q.

Initially the total energy is

(+1) $\frac{mv_0^2}{2} + qV_0$, where $v_0 = 1$ m/s (initial speed) and V_0 - potential on the surface.

At the end, PE = 0 and all energy is

(+1) kinetic: $\frac{mv^2}{2} \Rightarrow$

$$\frac{mv^2}{2} = \frac{mv_0^2}{2} + qV_0$$

$$v = \sqrt{v_0^2 + \frac{2qV_0}{m}} = \sqrt{(1\ \mathrm{m/s})^2 + \frac{2 \cdot 1 \cdot 10^{-5}\,\mathrm{C} \cdot 9 \cdot 10^{9}\,\mathrm{V}}{10^{-3}\,\mathrm{kg}}} =$$

(+1) $= 4240$ m/s $= 4.2\ \frac{\mathrm{km}}{\mathrm{s}}$.

19. (8 points) Evil Dr. Maravin needs extra energy to make an extra difficult quiz 2 problem, so he decides to make himself a cup of coffee. Unfortunately, he does not have a water heater in his office, so he decides to make an improvised heating element from a spool of copper wire with a diameter of 2 mm and a length of 20 meters that he rolled into a spiral. For a power source, he uses a car battery of his colleague who made a mistake of leaving his car keys on Dr. Maravin's desk. The battery is in a good condition and provides 12 V of potential difference across the terminals.

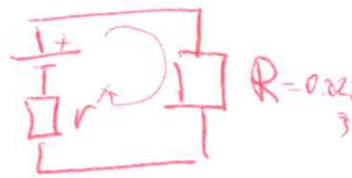
(a) (2 points) Calculate the resistance of the heating element assuming that the resistivity of copper is $1.68 \times 10^{-8}\ \Omega \cdot \mathrm{m}$.

$$\underbrace{R = \rho \frac{\ell}{S}}_{(+1)} = 1.68 \cdot 10^{-8}\ \Omega\mathrm{m} \cdot \frac{20\ \mathrm{m}}{\pi \cdot (0.002\ \mathrm{m})^2} = \underbrace{0.027\ \Omega}_{(+1)}$$

(b) (2 points) When Dr. Maravin plugs the heating element to the car battery he is surprised that the heating elements does not get really hot! Annoyed, he measures the potential difference across the heating element to find out that only 2 V is on the heating element, despite the fact that the battery is rated at 12V. What is the reason for such a small potential difference on the heating element? (*Hint: the car battery is not ideal!*)

(+1): This is due to the fact that the battery is not ideal and it has its own resistance r!

(+1) r must be bigger than 0.027 Ω



(c) (2 points) Calculate the internal resistance of the battery.

If i - current in the circuit:

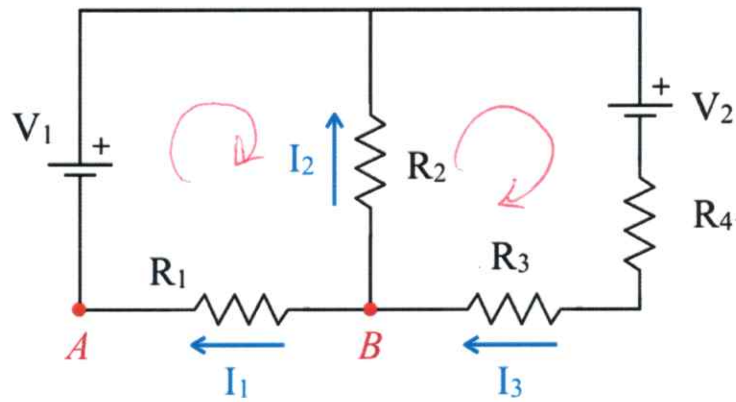
$$2\mathrm{V} = i \cdot 0.027\,\Omega \Rightarrow i = 74\ \mathrm{A}$$

$$10\mathrm{V} = ir \Rightarrow \quad r = \frac{10\ \mathrm{V}}{74\ \mathrm{A}} = 0.135\ \Omega$$

(d) (2 points) What is the power of the thermal energy in the heating element? Compare that to the usual 800W appliance that is commonly used to heat water.

(+1) $P = i^2 \cdot R = (74\mathrm{A})^2 \cdot 0.027\,\Omega = 148\ \mathrm{W}$

(+1) About 4 times smaller, Dr. Maravin has to drink his coffee cold.



20. (11 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) (3 points) Deduce three independent equations for the three unknown currents. Use the symbolic notation for resistances and voltages.

(B): $i_3 = i_1 + i_2$ (+1)

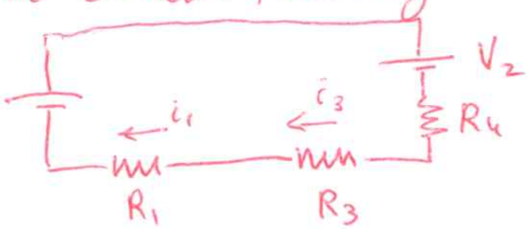
$V_1 + i_2 R_2 - i_1 R_1 = 0$ (+1)

$-V_2 - i_3 R_4 - i_3 R_3 - i_2 R_2 = 0$ (+1)

(b) (6 points) Take $V_1 = 20\text{V}$, $V_2 = 10\text{V}$; $R_2 = 10^6\ \Omega$, and $R_1 = R_3 = R_4 = 100\ \Omega$. 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!*).

Easy way

R_2 is huge, so effectively it serves as a break in the circuit, making it



$i_2 = 0\text{ A}$

$i_1 = i_3$ ⇒

(+1) Correct answers
(+2) Explanation

$V_1 - V_2 = i_1 (R_1 + R_3 + R_4) \Rightarrow$

$20\text{V} - 10\text{V} = i_1 \cdot 300\Omega \Rightarrow i_1 = \frac{10\text{V}}{300\Omega} =$

$= 0.033\text{A} = i_3$

Long way is on a separate sheet.

(c) (2 points) What is the potential difference between points A and B: $V_B - V_A$?

$V_B - V_A = -i_1 R_1 = -0.033\text{A} \cdot 100\text{V} = -3.3\text{V}$

Sign correct (+1)

Answer correct (+1)

Extra paper for calculations

20(b) Difficult way. Solving

$$i_3 = i_1 + i_2$$
$$V_1 + i_2 R_2 - i_1 R_1 = 0$$
$$-V_2 - i_3 R_4 - i_3 R_3 - i_2 R_2 = 0.$$

$i_1 = i_3 - i_2 \Rightarrow$

$$\begin{cases} V_1 + i_2 R_2 - (i_3 - i_2) R_1 = 0 \\ -V_2 - i_3 (R_3 + R_4) - i_2 R_2 = 0 \end{cases} \Rightarrow \begin{matrix} V_1 + i_2 R_2 - i_3 R_1 + i_2 R_1 = 0 \\ -V_2 - i_3 (R_3 + R_4) - i_2 R_2 = 0 \end{matrix}$$

Since $R_1 = R_3 = R_4 = R$, and:

$$V_1 + i_2 (R_2 + R) - i_3 R = 0$$
$$-V_2 - 2 R i_3 - i_2 R_2 = 0 \Rightarrow$$

$$i_2 = -\frac{V_2 + 2 R i_3}{R_2} \Rightarrow V_1 - \frac{V_2 + 2 R i_3}{R_2} (R_2 + R) - i_3 R = 0$$

$$V_1 R_2 - (V_2 + 2 R i_3)(R_2 + R) - i_3 R R_2 = 0$$

$$V_1 R_2 - V_2 (R_2 + R) - 2 R i_3 (R_2 + R) - i_3 R R_2 = 0$$

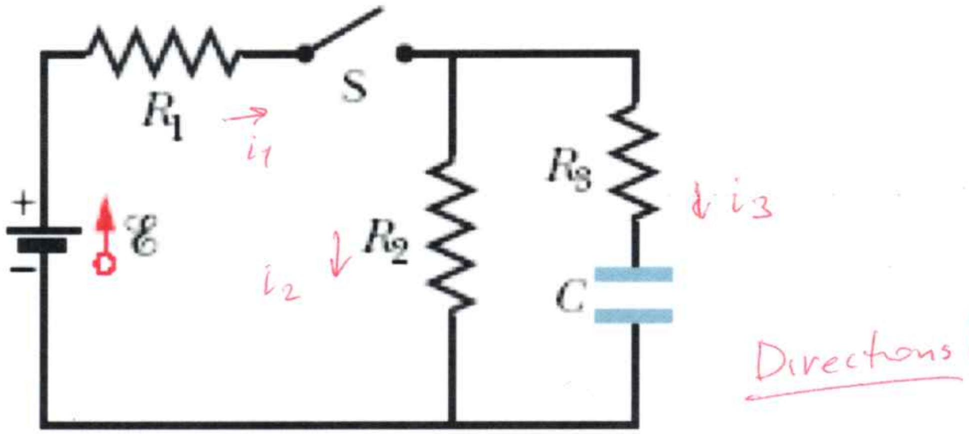
$$i_3 = \frac{V_1 R_2 - V_2 (R_2 + R)}{2 R R_2 + 2 R^2 + R R_2} = \frac{V_1 R_2 - V_2 (R_2 + R)}{3 R R_2 + 2 R^2} =$$

$$\underline{= 0.033\ A}$$

$$i_2 = -\frac{V_2 + 2 R i_3}{R_2} = -1.67 \cdot 10^{-5}\ A$$

$$\underline{i_1 = i_3 - i_2 \simeq 0.033\ A}.$$

Solving with matrix method or mesh method is OK



21. (11 points) In the circuit of the figure above, $\mathcal{E} = 12$ V, $R_1 = R_2 = R_3 = 1000\ \Omega$. With the capacitor C completely uncharged, the switch S is suddenly closed (at $t = 0$).

(a) (6 points) At $t = 0$, what are the currents through the resistor R_1, R_2, and R_3? Indicate the direction of the current in each case on the circuit diagram.

When the circuit is closed, the capacitor starts charging, so current flows unimpeded. (+1)

Since $R_2 = R_3$, $i_2 = i_3 = \frac{1}{2} i_1$. (+1)

$R_{eff} = R_1 + \frac{R_2}{2} = 1500\,\Omega$ (+1) $\Rightarrow$ $i_1 = \frac{12V}{1500\,\Omega} = 0.008$ A (+1)

$i_2 = i_3 = 0.004$ A (+1)

Directions (+1)

(b) (2 points) What are the currents through the above-mentioned resistors at a very long time $t = \infty$ after the switch is closed?

when the capacitor is charged $i_3 = 0$ A $\Rightarrow$ (+1)

$i_1 = i_2$ $\Rightarrow$ $R_{eff} = 2000\,\Omega$ $\Rightarrow$ $i_1 = i_2 = \frac{12V}{2000\,\Omega} = 0.006$ A

(c) (3 points) What is the potential difference across the capacitor C at time $t = 0$ and $t = \infty$?

At $t = 0$ the capacitor is uncharged, so $V_c = 0$ V (+1)

(+1) At $t = \infty$, the capacitor would have the same voltage as R_2, since there's no current across R_3, so

(+1)

$V_c = i_2 R_2 = 0.006\text{ A} \cdot 1000\,\Omega = 6$ V (half the voltage on the battery)