Physics 208 - Exam II

Fall 2018 (525-528; 531-535; 561-565)   October 15, 2018.

Please fill out the information and read the instructions below, but
do not open the exam until told to do so.

<u>Rules of the exam:</u>
1. You have 75 minutes (1.25 hrs.) to complete the exam.
2. Formulae are provided to you with the exam on a separate sheet. Make sure you have one before the exam starts. You may not use any other formula sheet.
3. Check to see that there are 6 numbered (3 double-sided) pages plus a blank page for additional work if needed, in addition to the scantron-like cover page. Do not remove any pages.
4. If you run out of space for a given problem, the last page has been left blank and may be used for extra space. Be sure to indicate at the problem under consideration that the extra space is being utilized so the graders know to look at it!
5. You will be allowed to use only non-programmable calculators on this exam.
6. **NOTE** that you **must** show your work clearly to receive full credit.
7. Cell phone use during the exam is strictly prohibited. Please turn off all ringers as calls during an exam can be quite distracting.
8. Be sure to put a box around your final answer(s) and clearly indicate your work. Credit can be given only if your work is legible, clearly explained, and labelled.
9. All of the questions require you show your work and reasoning.
10. Have your TAMU ID ready when submitting your exam to the proctor.

Fill out the information below and sign to indicate your understanding of the above rules

Name:_____   UIN:_____
(please print legibly)

Signature:_____   Section Number: _____

Instructor: Webb   Kocharovskaya
(circle one)

1

A. A DC battery maintains a constant voltage V_0 on a parallel plate capacitor. The plates have an area A and the distance between plates is d. The battery remains connected to the capacitor throughout this problem. Answer the following in terms of the constants given.
   a) If there is air between its plates, what (i) charge and (ii) energy does the capacitor store?
   b) If a slab of dielectric constant K would completely fill the space between plates, what (i) charge and (ii) energy does the capacitor store?
   c) If there is any difference of energy between configuration a) and configuration b), explain this difference.

$$C = \frac{\epsilon_0 A}{d} \qquad \text{so} \qquad Q = V_0 C$$

a)(i) $Q_{AIR} = V_0 C = V_0 \frac{\epsilon_0 A}{d}$

(ii) $U_{AIR} = \tfrac{1}{2} C V^2 = \tfrac{1}{2}\frac{\epsilon_0 A V_0^2}{d}$

(b)(i) $Q_K = V_0 C_K = V_0 \frac{K \epsilon_0 A}{d}$

$U_K = \tfrac{1}{2} C_K V^2 = \tfrac{1}{2}\left(\frac{K \epsilon_0 A}{d}\right) V_0^2$

(c) The energy stored increases by a factor of K since work was done in inserting the dielectric slab between the plates.

LO	P	F
28.1		
29.1		
28.2		
31.1		
28.3		
31.2		
32.1		
34.1		

B. A 120-V, 60-W light bulb, a 120-V, 120-W light bulb, and a 120-V, 240-W light bulb are connected in series as shown and connected to a 120 V DC power source. In this configurations, which bulb will have the greatest voltage drop?

R_1 (120 V, 60 W)

R_2 (120 V, 120 W)

R_3 (120 V, 240 W)
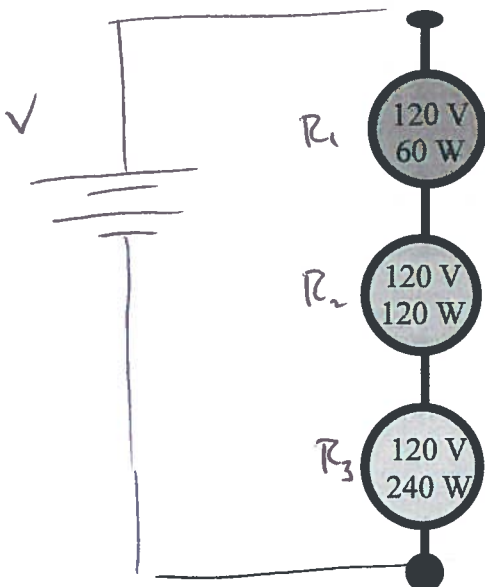
$P_{60} = \frac{V^2}{R_1} = \frac{(120)^2}{R_1}$ so $R_1 = 240\,\Omega$

$P_{120} = \frac{V^2}{R_2} = \frac{(120)^2}{R_2}$ so $R_2 = 120\,\Omega$

$P_{240} = \frac{V^2}{R_3} = \frac{(120)^2}{R_3}$ so $R_3 = 60\,\Omega$

In a series circuit the same current flows through all resistors so:

$I_1 R_1 > I_1 R_2 > I_1 R_3$
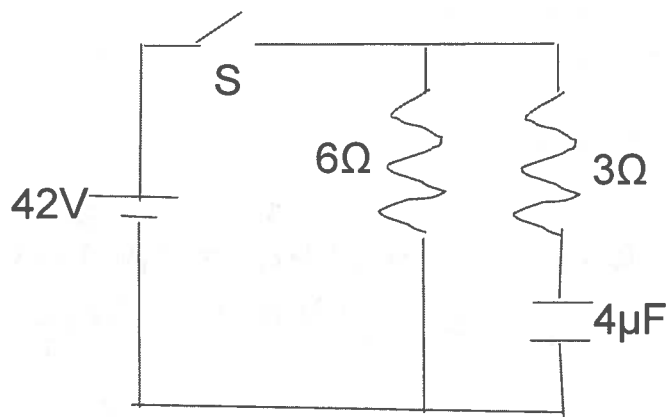
so 60 W bulb has largest voltage drop.

LO	P	F
36.1		
40.1		
36.2		
40.2		
36.3		
40.3		
41.1		

2

C. The capacitor is initially uncharged.
  i)   Immediately after the switch is closed what are the currents through each resistor?
  ii)   The switch was closed for a long time. What are the currents through each resistor?

LO	P	F
3.1		
41.2		
45.1		
3.2		
41.3		
45.2		

(i) When uncharged there is no ΔV across the capacitor
so it looks like a connection with 0Ω.
  The current through the 3Ω resistor will be
$$I_{3\Omega} = \frac{42V}{3\Omega} = 14A$$
$$I_{6\Omega} = \frac{42V}{6\Omega} = 7A$$

(ii) After switch is closed for a long time the capacitor is fully
charged and current stops flowing through it. At this moment
the current through the 3Ω resistor $I_{3\Omega} = 0$ · · and the current
through the 6Ω resistor remains $I_{6\Omega} = \frac{42V}{6\Omega} = 7A$.

3

Problem 1.

The capacitances in the figure below have the values $C_1 = 10\mu F$ and $C_2 = 40\mu F$. The charging battery provides $V_{ab} = 10V$ to this system of two capacitors.
   a) What is the total electric charge stored by this system of two capacitors?
   b) What is the total energy stored by this system of two capacitors?

The battery is now unplugged from the system. The capacitors are disconnected from each other, **without any loss of electric charge**, then reconnected to each other such that the plates of <u>opposite</u> sign are in electric contact.
   c) What is the voltage across each capacitor in this new situation?
   d) What is the total energy stored by the reconfigured system of two capacitors?
Is the energy stored in the reconfigured system equal, greater, or less than the energy calculated in part b)?
   e) If any difference of stored energy, explain where it came from (or went to). If no difference in stored energy, explain why should be so.
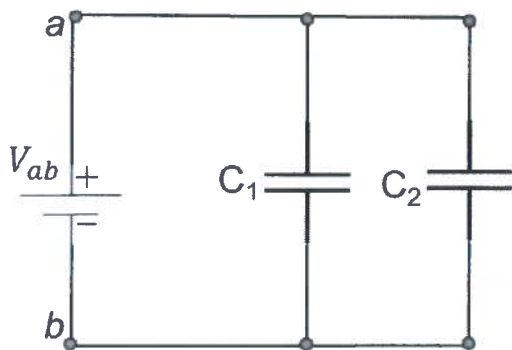
a) $Q_{TOTAL} = Q_{C_1} + Q_{C_2} = C_1 V + C_2 V$
$= (50\mu F)(10V) = 500\mu C$

b) $U_{TOTAL} = U_{C_1} + U_{C_2} = \frac{1}{2}CV^2$
$= \frac{1}{2}(C_1 + C_2)V^2 = \frac{1}{2}(50\mu F)(10V)^2$
$= 2500 \times 10^{-6}$ Joules

c) After reconfiguring

$Q_T' = Q_1 - Q_2$
$= (C_1 - C_2)V = 300\mu C$

This charge now distributes on the 2 capacitors such that

$Q_1' + Q_2' = 300\mu C$ and

$\frac{Q_1'}{C_1} = \frac{Q_2'}{C_2}$ Solving for Q_1' and Q_2'

let $Q_1' = 300\mu c - Q_2'$ then   or $Q_1' = \left(\frac{C_1}{C_2}\right)Q_2'$

$\frac{(300\mu c - Q_2')}{C_1} = \frac{Q_2'}{C_2}$ or $\left(\frac{C_1}{C_2}\right)Q_2' + Q_2' = 300\mu c$

$\frac{5}{4}Q_2' = 300\mu c$

$Q_2' = \left(\frac{4}{5}\right)300\mu c = 240\mu c$

$Q_1' = 300\mu c - 240\mu c = 60\mu c$

LO	P	F
3.3		
31.3		
3.4		
28.4		
30.1		
4.1		
28.5		
30.2		
28.6		
31.4		
	4	
34.2		

C) $V_{across} = \dfrac{Q_1'}{C_2} = \dfrac{Q_2'}{C_2} = \dfrac{60\mu C}{10\mu F} = 6V$

$$= \dfrac{240\mu C}{40\mu F} = 6V$$

D) Energy Stored in the new configuration

$$U_{TOTAL} = \tfrac{1}{2}C_1 V^2 + \tfrac{1}{2}C_2 V^2 = \tfrac{1}{2}(C_1 + C_2)(6V)^2$$

$$= \tfrac{1}{2}(50\mu F)(36V^2) = 900\mu joules$$

E) Energy went down as work was done moving the charges into the new configuration.

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Problem 2.

In the electric circuit in shown in the figure below, the values are $\varepsilon = 120V$, $r = 1\Omega$, $R = 1\Omega$, $C_1 = 3\mu F$, $C_2 = 3\mu F$, and $C_3 = 6\mu F$. The switch S is initially open and the capacitors are uncharged. Calculate the difference of electric potential between the points (a) and (b), where $V_{ab} = V_b - V_a$ for the following situations.

a) Immediately after the switch S is closed.
b) After a very long time from the moment when the switch S is closed for $t \to \infty$.
c) When the current through this circuit reaches 1/3 of its maximum possible value.
d) Sketch the current as a function of time on the template below. (Please label important times and current values in your sketch.)
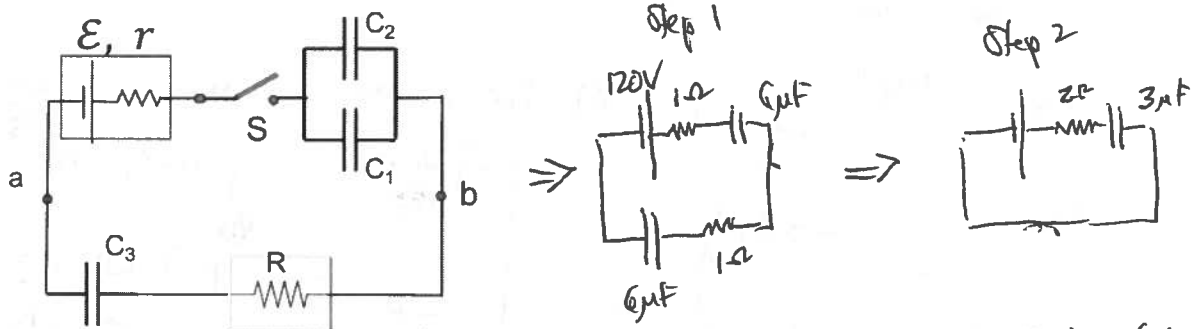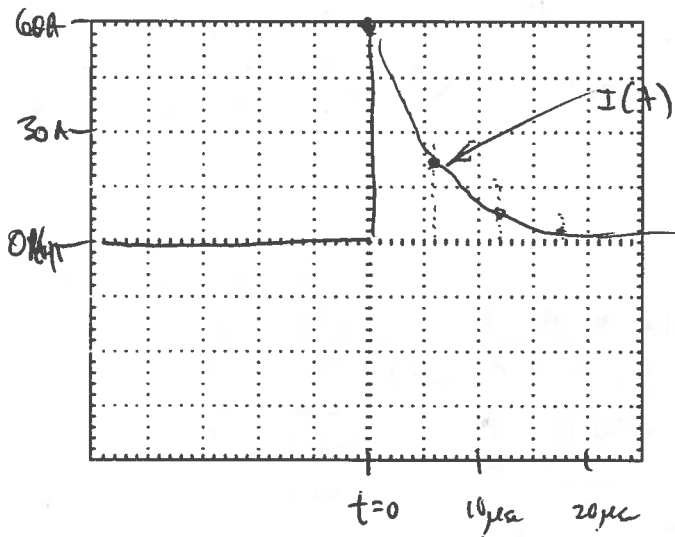

a) Immediately after switch closed $V_a = 0$; $V_b = 120 - 60(1\Omega) = 60V$
   so $\Delta V = 60V = V_b - V_a$

b) After waiting a long time, no current will be flowing or capacitors are fully charged
   again using $V_a = 0$; $V_b = 120V - \frac{Q}{C} = 60V$

c) When $I = \frac{1}{3} I_{max} = 20A$
   again $V_a = 0$; $V_b = 120V - \frac{Q}{C} - I(1\Omega) = 120V - 40V - 20V = 60V$

d) time constant $\mathcal{T} = RC = 2\Omega(3\mu F) = 6\mu sec$

LO	P	F
3.5		
41.4		
30.3		
30.4		
43.1		
45.3		
43.2		
45.4		
43.3		
45.5		
45.6		

Problem 3.
In the electric circuit in figure below, the first battery, emf $\mathcal{E}_1 = 15V$, and has an internal resistance $r_1 = 1.0\ \Omega$. The second battery has emf $\mathcal{E}_2 = 30.0\ V$ and no internal resistance. The ammeters shown in the circuit are *ideal.*

A) When the switch S is open calculate:
1. The currents through the ammeters A_1, A_2, and A_3.
2. The voltage between the points b and c.

B) When the switch S is closed, calculate:
1. The currents through the ammeters A_1, A_2, and A_3.
2. The power output of each battery.
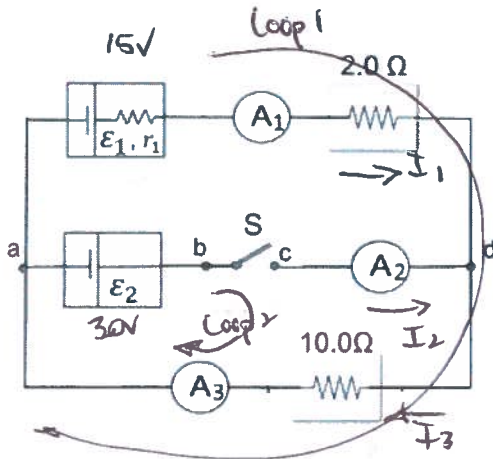
A) switch open   circuit becomes

(1) $A_1 = A_3 = \frac{15V}{13\Omega}$; $A_2 = 0$

(2) $\Delta V_{cd} = V_a - V_d =$
$= 0 + 15 - 3\left(\frac{15}{13\Omega}\right)$
$= 15\left(1 - \frac{3}{13}\right) = 15\left(\frac{10}{13}\right)$
$= 11.54$

and $V_b = V_a + 30v$
So $V_b - V_d = 30 - 11.54 = 18.46V$

B) $I_1 + I_2 = I_3$

(1) Loop 1: $15V = I_1 + 2I_1 + 10I_3 = 3I_1 + 10I_3$
    Loop 2: $30V = I_3 10 \implies I_3 = \frac{30}{10} = 3A$

$\to$ Solving $15 = 3I_1 + 10I_3 = 3I_1 + 10(3A) = 3I_1 + 30$
$-15 = 3I_1$ so $I_1 = -5A$

Solving for $I_2 = I_3 - I_1 = 3A - (-5A) = 8A$
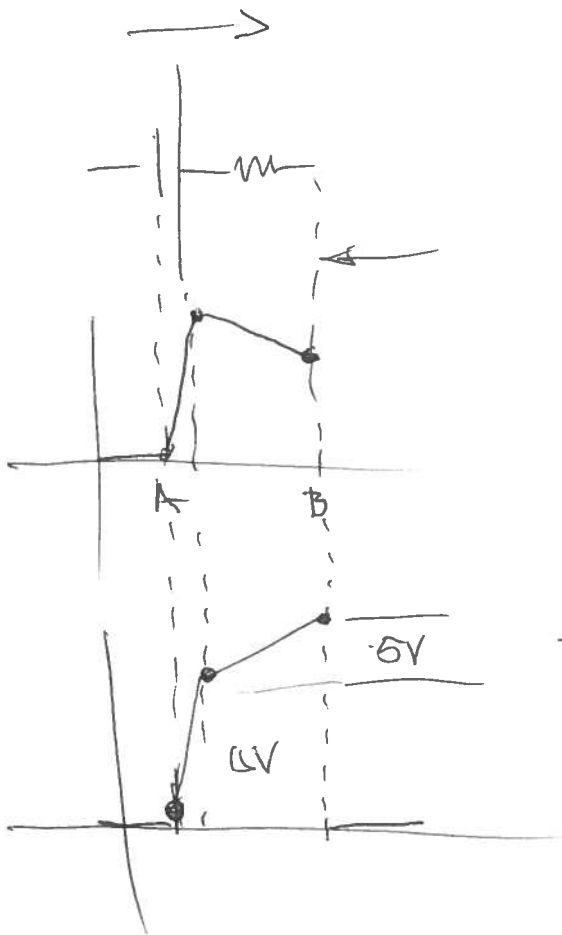
(2) Power output of each battery.
- 30V battery supplies   8A   since this battery has
  no internal resistance   Power out $= IV = (8A)(30V)$
  $= 240\ W$
- 15V battery supplies $-5A$ to the circuit so
  this battery is being charged. Power "out" of terminals
  $P = (V_{term})(-5A) = (20V)(-5A) = -100\ W$ supplied

LO	P	F
3.6		
38.1		
41.5		
43.4		
44.1		
43.5		
4.3		
42.1		
42.2		
42.3		
39.1		
40.4		
40.5		

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B)

(2) continued

Power to resistors

$20\Omega @ 5A) \Rightarrow ^-50 W$

$1.0\Omega @ 5A \Rightarrow - 25 W$
(internal)

$10\Omega @ 3A \Rightarrow -90 W$

Battery

$30V @ 8A \Rightarrow 240 W$

$15V @ -5A \Rightarrow - 75 W$

$+ 240 - [50 + 25 + 90 + 75]$
$\underline{240}$