Physics 124
Exam 2 Spring 2021

Name: ____

For grading purposes (do not write here):

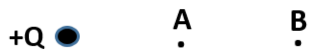
Question	Problem
1.	1.
2.	2.
3.	3.

Include a statement and signature that you have followed the honor code and not cheated on this exam.

Answer each of the following questions and each of the problems. Points for each question and problem are indicated in red with the amount being spread equally among parts (a,b,c etc). Be sure to show all your work.
Use the back of the pages if necessary.

For remote students: Write you solutions and answer on a separate piece of paper (unless you print the exam). Be sure to label each question and problem clearly (example – Q1 a) b) etc). Take photos of each page and email to shapiro@wfu.edu within two hours of being sent the exam. Write legibly but conserve space. Clearly mark your final answer (like put a box around it).

Question 1. (10 points) Consider a single, positive point charge Q of 2 C as shown below. (a) Where is the electric potential higher at point A or at point B?

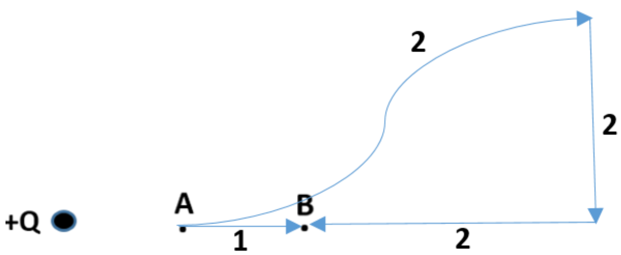


Solution: Point A is at a higher potential. The electric field points from high to low potential and E goes outward radially from Q

(b) Rank the potential energy from highest to lowest for the following scenarios
(i) A positive charge of + 2 nC at A 1
(ii) A positive charge of + 2 nC at B 2
(iii) A negative charge of - 2 nC at A 4
(iv) A negative charge of - 2 nC at B 3

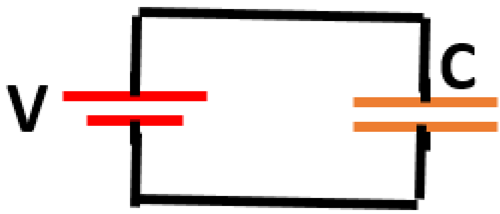
Solution. The rank is shown above in red. This can be seen by the amount of work needed to achieve these configurations (like lifting a ball near the surface of the earth). It takes the most work to push a positive charge close to Q. Likewise it takes work to move a negative charge away from Q. Mathematically, the energy is $U = \frac{kQq}{r}$. So it is highest (positive) with like charges and a small distance. It is lowest with opposite charges and a small distance.

(c) Compare the work done by the electric field in moving a positive charge of 2 nC from A to B along path 1 vs path 2 shown below. Along which path does the field do more work or are they the same?



Solution: Since the electrostatic force is conservative, the work done is independent of the path so they are the same.

Question 2. (10 points) A parallel plate capacitor is hooked up to a power supply that supplies a constant voltage V. The system is allowed to reach steady state.



(a) If the voltage supplied by the power supply is doubled to 2V, what happens to the capacitance of the capacitor (increase, decrease, or remain the same)?

With the voltage constant (now at 2V) a Teflon dielectric is inserted between the plates of the capacitor. The system reaches steady state.

(b) What happens to the capacitance of the capacitor?
(c) What happens to the voltage across the capacitor (compare before and after the dielectric is inserted)?
(d) What happens to the charge on the capacitor (compare before and after the dielectric is inserted)?
(e) What happens to the energy stored by the capacitor (compare before and after the dielectric is inserted)?

Solutions

(a) The capacitance **stays the same**. It is a function of the device.
(b) The capacitance **increases** now. You have modified the device. $C = \kappa C_0$
(c) The voltage **remains the same** because the capacitor is hooked up to teh same power source which supplies a constant voltage.
(d) The charge **increaes**, same voltage, bigger capacitance.
(e) The energy stored increases, $\frac{1}{2}CV^2$ and C increases.

Question 3. (10 points) In the circuit shown below, there is a capacitor at point A, and bulbs at points B, C, and D. There are two switches, one at S1 and one at S2. Bulbs B,C, and D are all identical.

Assume that S1 has been closed and S2 open for a long time.

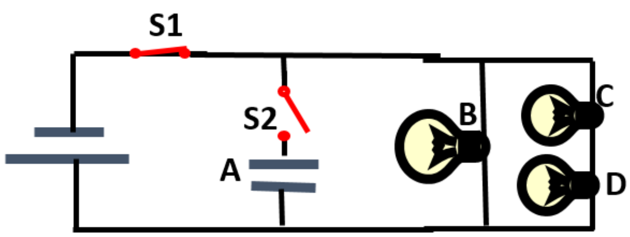
(a) Rank the brightnesses of bulbs B, C, and D.

(b) If bulb C is unscrewed, what happens to the brightness of bulbs B and D (increase, decrease, or stay the same)?

Now say that C is screwed back in and switch S2 is closed and a long time passes so that the system reaches a steady state. The switch S1 is then opened

(c) Describe what happens to the brightness of bulb B. Does it remain unchanged, increase in brightness immediately, increase in brightness slowly, go out immediately, decrease in brightness slowly over time and then go out?

Solutions

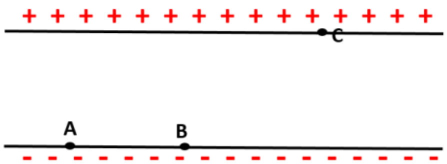


(a) Bulbs D and C have the same current so have the same brightness. Each one has half the voltage across it than bulb B so **B>C=D**.

(b) Bulb D goes out, no current. Nothing happens to bulb B – its has the same voltage.

(c) The capacitor will discharge over time so the brightnesss goes down slowly over time and then goes out.

Problem 1. (15 points) Consider two large parallel, oppositely charged plates separated by a distance d = 0.1 m as shown below. A potential difference of 120 V is applied between the plates. (a) How much work does the electric field do in moving a + 2 mC charge with a mass of 3 Kg a distance of 0.1 m from A to B along the negative plate as shown (b) How much work does the electric field do when moving this charge from B to C, where C is on the positive plate as shown? (c) If the charge is then released from rest at point C, what would its speed be when it reaches the negative plate?



Solutions

(a) The work is zero since the plate is all at the same potential and $W = -q\Delta V$

(b) Here ΔV is 120 V. $W = -q\Delta V = -(2 \times 10^{-3})(120) = -0.24$ J.

(c) Energy is conserved. The initial kinetic energy is zero and the final potential energy is zero.

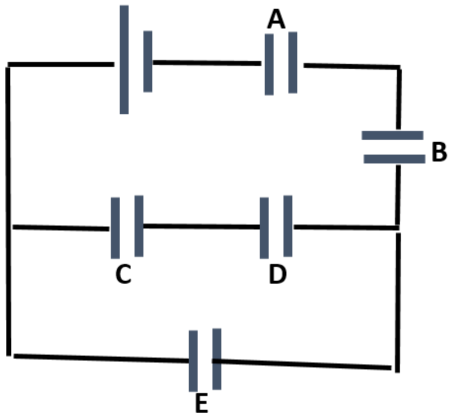
$U_f + K_f = U_i + K_i,\ K_f = U_i$

$\frac{1}{2} mv^2 = qV = (2 \times 10^{-3})(120 = 0.24$

$v^2 = 0.48/3 = 0.16$

$v = 0.4$ m/s

Problem 2. (15 points). A 12 V battery is connected to 5 capacitors labelled A-E as shown below. The capacitances are as follows:



C_A= 3 μF, C_B= 6 μF, C_c= 2 μF, C_D= 2 μF, C_E= 1 μF

(a) (3 points). As drawn, which capacitors are in series and which are connected in parallel?

(b) (5 points). Find the equivalent capacitance

(c) (7 points). Find the charge and voltage across each capacitor. Write you final answers in the Table below (but also show all work).

Solutions.

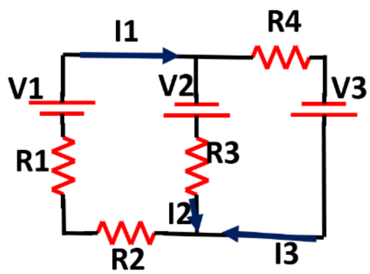
(a) A is in series with B (call that C_{AB}) and C in series with D (call that C_{CD}). As drawn, and without reducing any of these in series, none are in parallel. However, after reducing C and D to a single capacitor C_{CD} it is in parallel with E (call it C_{CDE}). Once those 3 are reduced, it is in series with the reduced C_{AB}.

(b) $C_{AB} = (1/3 + 1/6)^{-1} = 2$ μF. $C_{CD} = (1/2 + 1/2)^{-1} = 1$ μF. $C_{CDE} = 1 + 1 = 2$ μF
$C_{eq} = (1/2 + 1/2)^{-1} = 1$ μF

(c) $Q_{eq} = C_{eq}V = (1)(12) = 12$ μC. This will be the same charge as on and C_{CDE} and C_{AB}. Thus, the voltage across CDE is $V_{CDE} = Q_{CDE}/C_{CDE} = 12/2 = 6$V. The voltage across AB is $V_{AB} = Q_{AB}/C_{AB} = 12/2 = 6$V.
Thus there is 6 V across C_E. The charge on C_E is $Q_E = (6)(1) = 6$ μC.
There is also 6 V across C_{CD}. The charge $Q_{CD} = (1)(6) = 6$ μC.
Since they are in series, $Q_{CD} = Q_C = Q_D = 6$ μC.
$V_C = Q_C / C_c = 6/2 = 3$V. $V_D = Q_D / C_D = 6/2 = 3$V
Since they are in series $Q_{AB} = Q_A = Q_B = 12$ μC.
$V_A = Q_A / C_A = 12/3 = 4$V
$V_B = Q_B / C_B = 12/6 = 2$V

	C_A	C_B	C_C	C_D	C_E
Charge (μC)	12	12	6	6	6
Voltage (V)	4	2	3	3	6

Problem 3. (15 points). Consider the circuit shown below with R1 = 1Ω, R2 = 3Ω, R3 = 2Ω, and R4 = 5Ω. The voltages are given by V1 = 12V, V2 = 20 V, and V3 = 22V.



(a)As drawn, state which resistors are in series and which are in parallel, if any.

(b) Use Kirchhoff's first law (Junction rule) to find an equation relating the three currents going through the three batteries.

(c)Use Kirchoff's 2^{nd} law to find two more equations relating these currents.

Solutions.

(a) R1 and R2 are in series. No others are in series or parallel.
(b) I1 = I2 + I3
(c) V1 +V2 –I2*R3-(R1+R2)(I1) = 0
    32-2I2-4I1 = 0
    –V2-R4*I3+V3+I2*R3 = 0
    2-5I3+2I2 = 0

    You did not have to, but if you solve you get I1 = 6 A, I2 = 4A, and I3 = 2 A

Possibly Useful Information

$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$

$\varepsilon_0 = 8.85 \text{ X } 10^{-12} (C^2 / N - m^2)$

$e = 1.6 \text{ X } 10^{-19}$ C

$\vec{E} = \vec{F}/q_0$

$E = \frac{|q|}{4\pi\varepsilon_0 r^2}$, $E = \sigma/\varepsilon_0$

$\varepsilon_0\Phi = \varepsilon_0\oint \vec{E}.d\vec{A} = q_{enc}$

$\Delta x = x_2 - x_1$, $\Delta t = t_2 - t_1$

$\bar{v} = \Delta x / \Delta t$

$\bar{s}$ = (total distance) / Δt

$v = dx/dt$

$\bar{a} = \Delta v / \Delta t$

$a = dv/dt = d^2x/dt^2$

$v = v_o + at$

$g = 9.8 \text{ m/s}^2$

$x - x_o = v_o t + (½)at^2$

$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

$v^2 = v_o^2 + 2a(x-x_o)$

$\Delta\vec{r} = \vec{r}_2 - \vec{r}_1$

$x - x_o = ½(v_o + v)t$

$\Delta\vec{r} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}$

$x - x_o = vt - 1/2at^2$

$\bar{\vec{v}} = \Delta\vec{r} / \Delta t$, $\vec{v} = d\vec{r} / dt$

$\vec{a} = d\vec{v} / dt$

$\bar{\vec{a}} = \Delta\vec{v} / \Delta t$

$\Delta U = U_f - U_i = -W$

$\Delta V = V_f - V_i = -W/q_0 = \Delta U/q_0$

$U = -W_\infty$

$V = -W_\infty/q_0$

$V_f - V_i = -\int_i^f \vec{E}.d\vec{s}$

$V = -\int_i^f \vec{E}.d\vec{s}$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$

$U_f + K_f = U_i + K_i$

$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$

$K = ½ mv^2$

$E = \frac{\Delta V}{\Delta s}$

$U = -W = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$

$Q = CV$

$C = \frac{\varepsilon_0 A}{d}$

$C = 2\pi\varepsilon_0\frac{l}{\ln(b/a)}$

$C = 4\pi\varepsilon_0\frac{ab}{b-a}$

$C = 4\pi\varepsilon_0 R$

$C_{eq} = \sum C_j$ (parallel)

$$\frac{1}{C_{eq}} = \sum \frac{1}{C_j} \text{ (series)}$$

$$U = \frac{Q^2}{2C} = \tfrac{1}{2} CV^2$$

$u = \tfrac{1}{2} \varepsilon_0 E^2$

$C = \kappa C_0$

$I = dQ/dt$

$\rho = 1/\sigma$

$\Delta V = \varepsilon - Ir$

$R = \rho L / A$

$V = IR$

$P = IV$

$P = I^2 R = V^2/R$

$I = \varepsilon / (R + r)$

$P_{emf} = I\varepsilon$

$R_{eq} = \sum R_j$ (series)

$$\frac{1}{R_{eq}} = \sum \frac{1}{R_j} \text{ (parallel)}$$

$q(t) = Q(1 - e^{-t/RC})$

$I = (\varepsilon/R)e^{-t/RC}$

$q(t) = Qe^{t/RC}$

$I = (Q/RC)e^{-t/RC}$, $I_0 = (Q/RC)$

$\lambda = Q/L$, $\sigma = Q/A$, $\rho = Q/V$

$E = \sigma/\varepsilon_o$