Physics 111

Exam #1

September 28, 2018

Name_____

Please read and follow these instructions carefully:

- Read all problems carefully before attempting to solve them.
- Your work must be legible, and the organization clear.
- You must show all work, including correct vector notation.
- You will not receive full credit for correct answers without adequate explanations.
- You will not receive full credit if incorrect work or explanations are mixed in with correct work. So erase or cross out anything you don't want graded.
- Make explanations complete but brief. Do not write a lot of prose.
- Include diagrams.
- Show what goes into a calculation, not just the final number. For example $|\vec{p}| \approx m|\vec{v}| = (5kg) \times (2\frac{m}{s}) = 10\frac{kg \cdot m}{s}$
- Give standard SI units with your results unless specifically asked for a certain unit.
- Unless specifically asked to derive a result, you may start with the formulas given on the formula sheet including equations corresponding to the fundamental concepts.
- Go for partial credit. If you cannot do some portion of a problem, invent a symbol and/or value for the quantity you can't calculate (explain that you are doing this), and use it to do the rest of the problem.
- All multiple choice questions are worth 3 points and each free-response part is worth 9 points

Problem #1	/24
Problem #2	/24
Problem #3	/24
Total	/72

I affirm that I have carried out my academic endeavors with full academic honesty.

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1. Point Charges

a. Alex the point charge has a mass m and a charge $+q$. Samantha, her sister, has a mass of $\frac{3}{4}m$ and a charge $-2q$. Since they have opposite signs for their charges they attract. Which is attracted more to the other and by how much?

1. Alex is attracted more to Samantha and by twice as much.
2. Samantha is attracted more to Alex and by twice as much.
3. Alex is attracted more to Samantha and by four times as much.
4. Samantha is attracted more to Alex and by four times as much.
5. Alex and Samantha attract each other by the same amount.

b. Suppose that point charges Alex and Samantha were initially very far away from each other. If each was brought in from very far away and was forced to stand a distance L apart, how much work was done to assemble the collection of two point charges?

Work done to place Alex:

$$W_A = -q_A \Delta V = 0$$

Work done to place Samantha:

$$W_S = -q_S \Delta V_A = -(-2q)\left[\frac{kq}{L} - 0\right] = \frac{kq^2}{L}$$

The work done to build the distribution of charges:

$$W_{net} = W_A + W_S = \frac{kq^2}{L}$$

c. Suppose that point charges Alex and Samantha were at the following locations; Alex is at the point $(x,y)=(0,0)m$ while Samantha is at the point $(x,y)=(L,0)m$. In this configuration, point charges Alex and Samantha start arguing with each other. Now, suppose that a third point (let's call her Mom) is placed at a point $(x,y)=(0,\frac{L}{2})m$. What force would Mom feel because of Alex and Samantha? Assume that Mom has a mass $2m$ and a charge $4q$.

$$F_{net,x}=F_{M,S}\cos\theta=\frac{kQ_MQ_S}{r_{M,S}^2}\cos\theta=\frac{8kq^2}{\frac{5}{4}L^2}\left(\frac{2}{\sqrt{5}}\right)=\frac{64kq^2}{5\sqrt{5}L^2}=5.7\frac{kq^2}{L^2}$$

$$F_{net,y}=F_{M,A}-F_{M,S}\sin\theta=\frac{kQ_MQ_A}{r_{M,A}^2}-\frac{kQ_MQ_A}{r_{M,A}^2}\sin\theta=\frac{16kq^2}{L^2}-\frac{8kq^2}{\frac{5}{4}L^2}\left(\frac{1}{\sqrt{5}}\right)=13.1\frac{kq^2}{L^2}$$

$$F_{net}=\sqrt{F_{net,x}^2+F_{net,y}^2}=\sqrt{(5.7)^2+(13.1)^2}\,\frac{kq^2}{L^2}=14.3\frac{kq^2}{L^2}$$

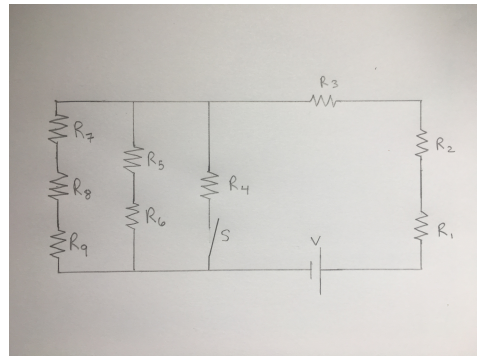
$$\phi=\tan^{-1}\left(\frac{F_{net,y}}{F_{net,x}}\right)=\tan^{-1}\left(\frac{13.1}{5.7}\right)=66.5^0$$

d. Suppose that point charge Mom has had enough of point charges Alex and Samantha and decides to leave her position and move very far away. At her former position, the electric field due to point charges Alex and Samantha (still in their original locations) would have a magnitude and a direction given by which of the following?

1. The magnitude of the electric field would be given by $\left|\vec{E}\right| = E = \frac{F}{4q}$ and the direction would point in the same direction of the net force on point charge Mom.
2. The magnitude of the electric field would be given by $\left|\vec{E}\right| = E = \frac{F}{4q}$ and the direction would point in the opposite direction of the net force on point charge Mom.
3. The magnitude of the electric field would be given by $\left|\vec{E}\right| = E = \frac{F}{q}$ and the direction would point in the same direction of the net force on point charge Mom.
4. The magnitude of the electric field would be given by $\left|\vec{E}\right| = E = \frac{F}{q}$ and the direction would point in the opposite direction of the net force on point charge Mom.
5. The electric field in both magnitude and direction would be zero because point charge Mom is no longer at the point in question.

2. Circuits

a. Consider the resistor circuit on the right in which a collection of resistors is wired in combination to a battery. The battery is rated at $V_B = 22V$ and each resistor is $R = 100\Omega$. What is the equivalent resistance of the circuit and the total current produced by the battery? Assume that the switch S is closed for this question.



R_7, R_8, and R_9 are in series: $R_{789} = R_7 + R_8 + R_9 = 100\Omega + 100\Omega + 100\Omega = 300\Omega$.

R_5, and R_6 are in series: $R_{56} = R_5 + R_6 = 100\Omega + 100\Omega = 200\Omega$.

R_4, R_{56}, and R_{789} are in parallel:

$$\frac{1}{R_{456789}} = \frac{1}{R_4} + \frac{1}{R_{56}} + \frac{1}{R_{789}} = \frac{1}{100\Omega} + \frac{1}{200\Omega} + \frac{1}{300\Omega} = \frac{11}{600\Omega} \rightarrow R_{456789} = \frac{600\Omega}{11} = 54.5\Omega$$

R_1, R_2, R_3, and R_{456789} are in series:

$R_{eq} = R_{123456789} = R_1 + R_2 + R_3 + R_{456789} = 100\Omega + 100\Omega + 100\Omega + 54.5\Omega = 354.5\Omega$.

The total current produced by the battery:

$$V = I_T R_{eq} \rightarrow I_T = \frac{V}{R_{eq}} = \frac{22V}{654.5\Omega} = 0.0621A = 62.1mA.$$

b. What is the total energy dissipated as heat and light across the portion of the circuit containing resistors $R_4 \rightarrow R_9$ if the circuit is energized (connected to the battery) for $32s$? Assume that the switch S is closed for this question.

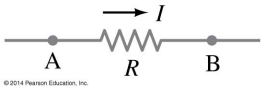
$$V_{R_{456789}} = V - V_{R_1} - V_{R_2} - V_{R_3}$$
$$V_{R_{456789}} = V - I_T R_1 - I_T R_2 - I_T R_3$$
$$V_{R_{456789}} = V - 3I_T R_1$$
$$V_{R_{456789}} = 22V - (3 \times 0.621A \times 100\Omega) = 22V - 18.6V = 3.4V$$

$$P = \frac{\Delta E}{\Delta t} = \frac{V_{R_{456789}}^2}{R_{456789}} = \frac{(3.4V)^2}{54.5\Omega} = 0.21W$$
$$\Delta E = P\Delta t = 0.21W \times 32s = 6.67J$$

c. Suppose that the switch S in the circuit above were left open. In this case the total current and the energy per unit time produced by the battery would change according to which of the following?

1. Both the total current and energy per unit time produced by the battery would increase.
2. The total current would decrease and energy per unit time produced by the battery would increase.
3. Both the total current and energy per unit time produced by the battery would remain constant at their original values.
4. The total current would increase and energy per unit time produced by the battery would decrease.
5. The total current would decrease and energy per unit time produced by the battery would decrease.

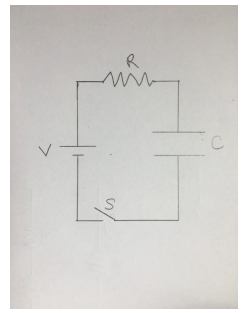
d. We have talked about resistors in class and we have said that electric currents flow through a resistor while electric potential differences occur across a resistor. Consider part of a circuit shown in the figure below where the electric current enters the resistor from point A. For this situation, is the electric potential higher at point A or at point B and is the electric current greater at point A or point B?



1. The electric potential is higher at point A than point B and the electric current is greater at point A than at point B.
2. The electric potential is higher at point B than point A and the electric current is greater at point A than at point B.
3. The electric potential is higher at point A than point B and the electric current is the same at point A as it is at point B.
4. The electric potential is higher at point B than point A and the electric current is the same at point A as it is at point B.
5. The electric potential is higher at point A than point B and the electric current is lower at point A than at point B.
6. The electric potential is higher at point B than point A and the electric current is lower at point A than at point B.

3. Capacitors

A $54\mu F$ capacitor is connected to a 10000Ω resistor and this resistor-capacitor combination is connected to a switch S and a battery with potential V as shown below.



a. At time the switch S is closed and the initially uncharged capacitor begins to charge. In *fractions or multiples of the time constant*, at what time does the potential across the resistor equal three-quarters of that across the capacitor? In other words, at what time does $V_R = \frac{3}{4}V_C$?

$$V = V_R + V_C = V_R + V\left(1 - e^{-\frac{t}{RC}}\right) \rightarrow V_R = Ve^{-\frac{t}{RC}}$$

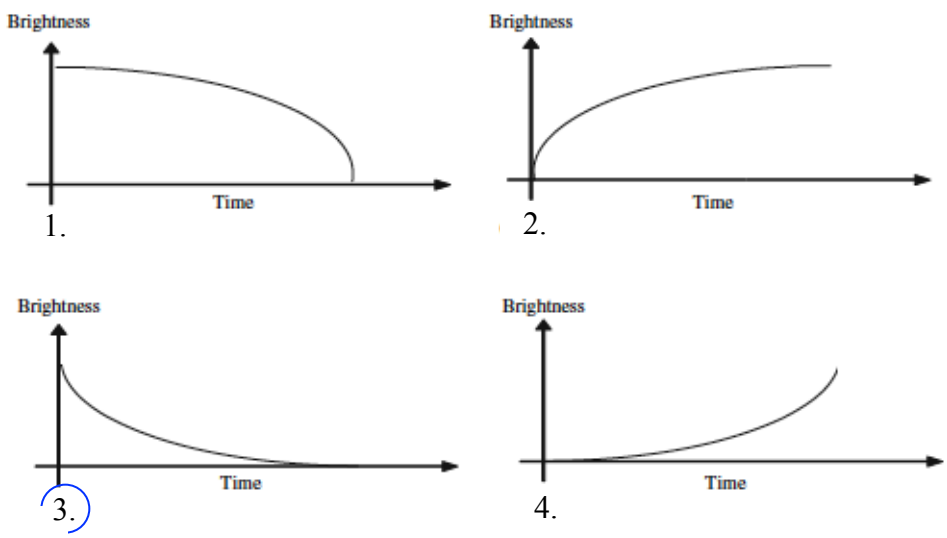
$$V_R = \frac{3}{4}V_C \rightarrow Ve^{-\frac{t}{RC}} = \frac{3}{4}V\left(1 - e^{-\frac{t}{RC}}\right) \rightarrow \frac{7}{4}e^{-\frac{t}{RC}} = \frac{3}{4} \rightarrow t = -RC\ln\left(\frac{3}{7}\right) = -\tau\,\mathrm{n}\left(\frac{3}{7}\right)$$

$$\therefore t = 0.85\tau$$

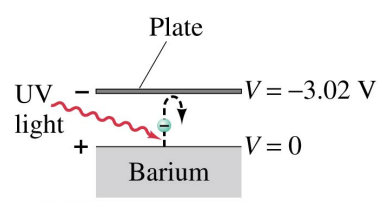
b. Suppose that after a long time has passed, the capacitor is fully charged and that at this point the switch S is opened and the battery and resistor are both removed from the circuit. If the plates of the capacitor are then squeezed together so that the distance between the capacitor plates is one-half of its original distance. In this scenario, which of the following describes the change in the electric field between the capacitor plates and the work done pushing the plates together? In the answers below, let C_o and V_o be the original capacitance of the system and potential difference across the capacitor plates respectively, before you pushed the plates.

1. The electric field would increase and the work done pushing the capacitor plates together would be given by $W = -\frac{1}{4}C_oV_o^2$.
2. The electric field would increase and the work done pushing the capacitor plates together would be given by $W = +\frac{1}{4}C_oV_o^2$.
3. The electric field would remain constant and the work done pushing the capacitor plates together would be given by $W = -\frac{1}{4}C_oV_o^2$.
4. The electric field would remain constant and the work done pushing the capacitor plates together would be given by $W = +\frac{1}{4}C_oV_o^2$.
5. The electric field would decrease and the work done pushing the capacitor plates together would be given by $W = -\frac{1}{4}C_oV_o^2$.
6. The electric field would decrease and the work done pushing the capacitor plates together would be given by $W = +\frac{1}{4}C_oV_o^2$.

c. A light bulb is connected in series to a switch, a battery, and an uncharged capacitor. At time $t = 0$, the switch is closed. Which of the following best describes the brightness of the light bulb as a function of time?



In an experiment called the photoelectric effect, light is shown onto a metal surface and if there is sufficient energy in the light, electrons can be ejected from the metal surface. To measure the maximum energy of the emitted electrons, a second plate is placed above the metal surface and is kept negative enough so that the electrons are just repelled from the upper plate as shown on the right.



d. If barium metal is illuminated with ultraviolet light ejecting electrons, what was the maximum speed of the ejected electrons and what electric field was between the barium surface and the upper plate if $\Delta y = 1cm$? The spectroscopic information for barium is ${}^{137}_{56}Ba$.

$$W = \Delta K \rightarrow -q\Delta V = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2 \rightarrow -q\Delta V = -\tfrac{1}{2}mv_i^2$$

$$v_i = \sqrt{\frac{2q\Delta V}{m}} = \sqrt{\frac{2\times\left(-1.6\times10^{-19}C\right)\times\left(-3.02V\right)}{9.11\times10^{-31}kg}} = 1.03\times10^{6}\,\tfrac{m}{s}$$

$$E = -\frac{\Delta V}{\Delta y} = -\left(\frac{-3.02V - 0V}{0.01m - 0m}\right) = 302\,\tfrac{V}{m}$$

or $302\,\tfrac{V}{m}$ in the positive y-direction.

Physics 111 Equation Sheet

Electric Forces, Fields and Potentials

$$\vec{F} = k\frac{Q_1Q_2}{r^2}\hat{r}$$

$$\vec{E} = \frac{\vec{F}}{q}$$

$$\vec{E}_Q = k\frac{Q}{r^2}\hat{r}$$

$$PE = k\frac{Q_1Q_2}{r}$$

$$V(r) = k\frac{Q}{r}$$

$$E_x = -\frac{\Delta V}{\Delta x}$$

$$W = -q\Delta V = -q\left[V_f - V_i\right]$$

Magnetic Forces and Fields

$$F = qvB\sin\theta$$

$$F = IlB\sin\theta$$

$$\tau = NIAB\sin\theta = \mu B\sin\theta$$

$$PE = -\mu B\cos\theta$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\varepsilon_{induced} = -N\frac{\Delta\phi_B}{\Delta t} = -N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

Constants

$g = 9.8\,\frac{m}{s^2}$

$1e = 1.6\times10^{-19}C$

$k = \frac{1}{4\pi\varepsilon_o} = 9\times10^{9}\,\frac{Nm^2}{C^2}$

$\varepsilon_o = 8.85\times10^{-12}\,\frac{C^2}{Nm^2}$

$1eV = 1.6\times10^{-19}J$

$\mu_o = 4\pi\times10^{-7}\,\frac{Tm}{A}$

$c = 3\times10^{8}\,\frac{m}{s}$

$h = 6.63\times10^{-34}Js$

$m_e = 9.11\times10^{-31}kg = \frac{0.511MeV}{c^2}$

$m_p = 1.67\times10^{-27}kg = \frac{937.1MeV}{c^2}$

$m_n = 1.69\times10^{-27}kg = \frac{948.3MeV}{c^2}$

$1amu = 1.66\times10^{-27}kg = \frac{931.5MeV}{c^2}$

$N_A = 6.02\times10^{23}$

$Ax^2 + Bx + C = 0 \rightarrow x = \frac{-B\pm\sqrt{B^2-4AC}}{2A}$

Electric Circuits

$$I = \frac{\Delta Q}{\Delta t}$$

$$V = IR = I\left(\frac{\rho L}{A}\right)$$

$$R_{series} = \sum_{i=1}^{N} R_i$$

$$\frac{1}{R_{parallel}} = \sum_{i=1}^{N}\frac{1}{R_i}$$

$$P = IV = I^2R = \frac{V^2}{R}$$

$$Q = CV = \left(\frac{\kappa\varepsilon_0 A}{d}\right)V = (\kappa C_0)V$$

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

$$Q_{\text{charge}}(t) = Q_{\max}\left(1 - e^{-\frac{t}{RC}}\right)$$

$$Q_{\text{discharge}}(t) = Q_{\max}e^{-\frac{t}{RC}}$$

$$C_{parallel} = \sum_{i=1}^{N} C_i$$

$$\frac{1}{C_{series}} = \sum_{i=1}^{N}\frac{1}{C_i}$$

Light as a Particle & Relativity

$$E = hf = \frac{hc}{\lambda} = pc$$

$$KE_{\max} = hf - \phi = eV_{stop}$$

$$\Delta\lambda = \frac{h}{m_e c}(1-\cos\phi)$$

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$p = \gamma mv$$

$$E_{total} = KE + E_{rest} = \gamma mc^2$$

$$E_{total}^2 = p^2c^2 + m^2c^4$$

$$E_{rest} = mc^2$$

$$KE = (\gamma - 1)mc^2$$

Geometry

Circles: $C = 2\pi r = \pi D \qquad A = \pi r^2$

Triangles: $A = \tfrac{1}{2}bh$

Spheres: $A = 4\pi r^2 \qquad V = \tfrac{4}{3}\pi r^3$

Light as a Wave

$$c = f\lambda = \frac{1}{\sqrt{\varepsilon_o\mu_o}}$$

$$S(t) = \frac{energy}{time\times area} = c\varepsilon_o E^2(t) = c\frac{B^2(t)}{\mu_0}$$

$$I = S_{avg} = \tfrac{1}{2}c\varepsilon_o E_{\max}^2 = c\frac{B_{\max}^2}{2\mu_0}$$

$$P = \frac{S}{c} = \frac{Force}{Area}$$

$$S = S_o\cos^2\theta$$

$$v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{c}{n}$$

$$\theta_{inc} = \theta_{refl}$$

$$n_1\sin\theta_1 = n_2\sin\theta_2$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$M_{total} = \prod_{i=1}^{N} M_i$$

$$d\sin\theta = m\lambda \text{ or } (m+\tfrac{1}{2})\lambda$$

$$a\sin\phi = m'\lambda$$

Nuclear Physics

$$E_{binding} = (Zm_p + Nm_n - m_{rest})c^2$$

$$\frac{\Delta N}{\Delta t} = -\lambda N_o \rightarrow N(t) = N_o e^{-\lambda t}$$

$$A(t) = A_o e^{-\lambda t}$$

$$m(t) = m_o e^{-\lambda t}$$

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Misc. Physics 110 Formulae

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t} = \frac{\Delta(mv)}{\Delta t} = m\vec{a}$$

$$\vec{F} = -k\vec{y}$$

$$\vec{F}_C = m\frac{v^2}{R}\hat{r}$$

$$W = \Delta KE = \tfrac{1}{2}m\left(v_f^2 - v_i^2\right) = -\Delta PE$$

$$PE_{gravity} = mgy$$

$$PE_{spring} = \tfrac{1}{2}ky^2$$

$$x_f = x_i + v_{ix}t + \tfrac{1}{2}a_x t^2$$

$$v_{fx} = v_{ix} + a_x t$$

$$v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x$$