Physics 111

Exam #1

January 31, 2024

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.
- Each free-response part is worth 6 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. Three point-charges are assembled along the x-axis with point-charge $q_1 = +9\mu C$ located at $(x_1, y_1) = (-5,0)cm$, point-charge $q_2 = -3\mu C$ at $(x_2, y_2) = (0,0)cm$, and point-charge $q_3 = +2\mu C$ located at $(x_3, y_3) = (+7,0)cm$.

   a. Assuming that each charge is brought in one at a time from very far away and placed in their final respective positions, how much work did it take to assemble the collection of point charges?

   b. What is the net electric force on point-charge q_2 due to point-charges q_1 and q_3?

c. What is the net electric field at the origin, $(x, y) = (0,0)$, due to q_1 and q_3?

d. Suppose that point-charge q_2 were released from rest. What will the speed of point-charge q_2 be when it is at a distance of $2cm$ from point-charge q_1? Assume that the mass of point-charge q_2 is $0.5kg$.

2. As shown in Figure A below, a particle accelerator is used to accelerate a positive point-charge $q = 12e$ and mass $m = 1.66 \times 10^{-26} kg$ from rest near the left plate of the accelerator, through a potential difference ΔV_{acc}. The point-charge exits through a hole in the right plate with a speed v_i. The positive point-charge is then incident at the midpoint between two horizontal plates separated by a distance of $d = 2.8m$ as shown in Figure B. The positive point-charge travels a horizontal distance L between the plates and exits the system with a speed $v_f = 5 \times 10^6 \frac{m}{s}$ directed at an angle $\theta = 30^0$ below the horizontal.

Figure A

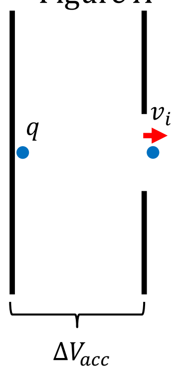
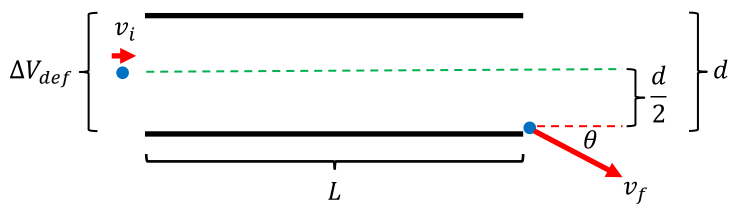


Figure B



a. If the potential difference across the horizontal plates is $\Delta V_{def} = 56000V$, what is the magnitude and direction of the electric field between the horizontal plates and explain which plate (upper or lower) is at the higher electric potential?

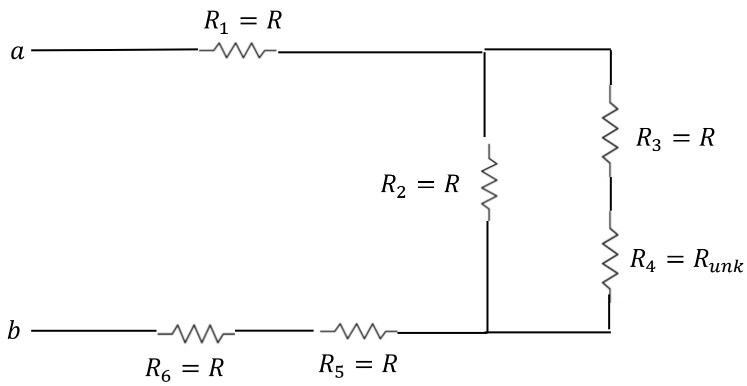
b. If the point-charge was accelerated over a vertical distance of $\frac{d}{2}$, how long was the point-charge interacting with the electric field?

c. What is the length L of the horizontal plates?

d. Through what potential difference ΔV_{acc} was the point-charge initially accelerated?

3. Consider the following part of a circuit shown in Figure C where several resistors are wired together between points a and b. Each resistor has a resistance R except for the unknown resistance R_{unk}.

Figure C



a. If the equivalent resistance between points a and b needs to be $R_{eq} = \frac{19}{5}R$, what is the value of R_{unk} in terms of R? Note, do not use any numerical value of any resistor given in the remainder of the problem to answer this part. Your answer should be of the form $R_{unk} = CR$, where the constant C is either a fraction (number less than 1) or a multiple (number greater than 1) of R and the answer to this question is not required to complete the remainder of the problem.

b. Suppose this network of resistors were wired to an uncharged $30{,}000\mu F$ capacitor and a $12V$ battery. At what time t does the potential difference across the capacitor V_C equal $8V$ if $R = 10{,}000\Omega$?

c. At the time t determined in part b, what is the current I that is flowing in the circuit and what is the potential difference across the equivalent resistor, $V_{R_{eq}}$?

d. For the current I found in part c, what is the drift velocity of the charge carriers in the wire? Assume that the wires in the circuit are made from tungsten (W) with a density $\rho_W = 19250\frac{kg}{m^3}$, molecular mass $M_W = 181\frac{g}{mol}$, have a radius $r = 1mm$, and that tungsten donates 2 charge carriers per tungsten atom.

Physics 111 Formula Sheet

Electrostatics

$F = k\frac{q_1 q_2}{r^2}$

$\vec{F} = q\vec{E}; \quad E_{pc} = k\frac{q}{r^2}; \quad E_{plate} = \frac{q}{\epsilon_0 A}$

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

$V_{pc} = k\frac{q}{r}$

$U_e = k\frac{q_1 q_2}{r} = qV$

$W = -q\Delta V = -\Delta U_e = \Delta K$

Electric Circuits - Capacitors

$Q = CV; \quad C = \frac{\kappa\epsilon_0 A}{d}$

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

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

$Q_{charging}(t) = Q_{max}\left(1 - e^{-\frac{t}{\tau}}\right)$

$Q_{discharging}(t) = Q_{max}e^{-\frac{t}{\tau}}$

$I(t) = I_{max}e^{-\frac{t}{\tau}} = \frac{Q_{max}}{\tau}e^{-\frac{t}{\tau}}$

$\tau = RC$

$U_C = \frac{1}{2}qV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$

Light as a Wave

$c = f\lambda$

$S(t) = \frac{\text{Energy}}{\text{time}\times\text{Area}} = c\epsilon_0 E^2(t) = c\frac{B^2(t)}{\mu_0}$

$I = S_{avg} = \frac{1}{2}c\epsilon_0 E_{max}^2 = c\frac{B_{max}^2}{2\mu_0}$

$P = \begin{cases} \frac{S}{c}; & \text{absorbed} \\ \frac{2S}{c}; & \text{reflected} \end{cases}$

$S = S_0\cos^2\theta$

$v = \frac{c}{n}$

$\theta_{\text{incident}} = \theta_{\text{reflected}}$

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

$P = \frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$

$M = \frac{d_i}{d_0}; \quad |M| = \frac{h_i}{h_0}$

Magnetism

$\vec{F} = q\vec{v}\times\vec{B} \rightarrow F = qvB\sin\theta$

$\vec{F} = I\vec{L}\times\vec{B} \rightarrow F = ILB\sin\theta$

$V_{Hall} = wv_d B$

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

$\varepsilon = \Delta V = -N\frac{\Delta\phi_B}{\Delta t}$

$\phi_B = BA\cos\theta$

Electric Circuits - Resistors

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

$I = neAv_d; \quad n = \frac{\rho N_A}{m}$

$V = IR$

$R = \frac{\rho L}{A}$

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

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

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

Light as a Particle/Relativity

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

$K_{max} = hf - \phi$

$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}(1 - \cos\phi)$

$\frac{1}{E\prime} = \frac{1}{E} + \frac{(1-\cos\phi)}{E_{rest}}; \quad E_{rest} = mc^2$

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

$p = \gamma mv$

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

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

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

Nuclear Physics

$N = N_0 e^{-\lambda t}$

$m = m_0 e^{-\lambda t}$

$A = A_0 e^{-\lambda t}$

$A = \lambda N$

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

Constants

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

$1e = 1.6 \times 10^{-19} C$

$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}$

$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$

$1eV = 1.6 \times 10^{-19} J$

$\mu_0 = 4\pi \times 10^{-7} \frac{Tm}{A}$

$c = 3 \times 10^8 \frac{m}{s}$

$h = 6.63 \times 10^{-34} Js = 4.14 \times 10^{-15} eVs$

$N_A = 6.02 \times 10^{23}$

$1u = 1.66 \times 10^{-27} kg = 931.5 \frac{MeV}{c^2}$

$m_p = 1.67 \times 10^{-27} kg = 937.1 \frac{MeV}{c^2}$

$m_n = 1.69 \times 10^{-27} kg = 948.3 \frac{MeV}{c^2}$

$m_e = 9.11 \times 10^{-31} kg = 0.511 \frac{MeV}{c^2}$

Physics 110 Formulas

$\vec{F} = m\vec{a}; \quad F_G = \frac{GM_1 m_2}{r^2}; \quad F_s = -ky; \quad a_c = \frac{v^2}{r}$

$W = -\Delta U_g - \Delta U_s = \Delta K$

$U_g = mgy$

$U_s = \frac{1}{2} k y^2$

$K = \frac{1}{2} m v^2$

$\vec{r}_f = \vec{r}_i + \vec{v}_i t + \frac{1}{2} \vec{a} t^2$

$\vec{v}_f = \vec{v}_i + \vec{a} t$

$v_f^2 = v_i^2 + 2 a_r \Delta r$

Common Metric Units

$nano\ (n) = 10^{-9}$

$micro\ (\mu) = 10^{-6}$

$milli\ (m) = 10^{-3}$

$centi\ (c) = 10^{-2}$

$kilo\ (k) = 10^{3}$

$mega\ (M) = 10^{6}$

Geometry/Algebra

Circles: $A = \pi r^2$ $\quad C = 2\pi r = \pi$

Spheres: $A = 4\pi r^2$ $\quad V = \frac{4}{3}\pi r^3$

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

Quadratics: $ax^2 + bx + c = 0 \rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$