Physics 111

Exam #1

January 20, 2023

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. Two equal and opposite point-charges are placed at equal distances above and below the x-axis. The point charges have magnitude $|q| = e$ and are separated by a distance $d = 2nm$ between their centers as shown on the right.

   a. How much work (in electron volts) did it take to assemble this collection of point charges? Assume that each point-charge was brought in one at a time from very far away and placed at their final locations.
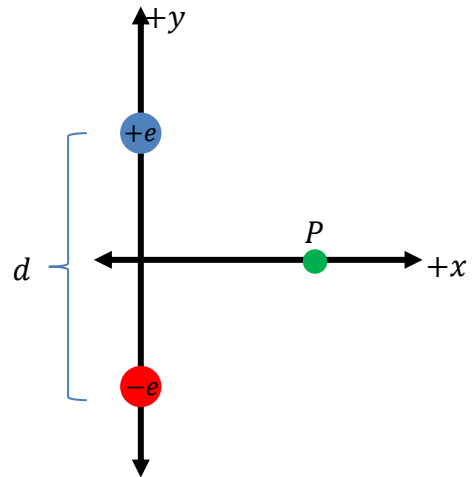
   b. At a point $P = (x, y) = (10,0)nm$, what is the net electric field?

c. Suppose that a point-charge $q = -3e$ was placed at point P. If the charge had a mass $m = 14u$, where $1u = 1.66 \times 10^{-27}kg$, what would be the initial acceleration of the charge?

d. Suppose that you have the situation below in which two positive point charges $(+e)$ are located a distance d apart and are also located equidistant above and below the x-axis. A small negative charge $(-e)$ is placed at the midpoint between the two positive point charges and is given a small kick to the right directly along the x-axis. In as much detail as possible, describe the resulting motion of the negative charge. The two positive point charges cannot move.
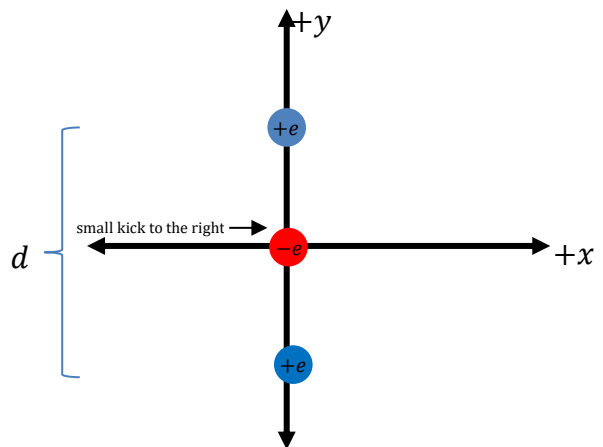
2. Ion beams generated by particle accelerators are routinely used
   in materials analysis, where the composition of an unknown
   material needs to be determined. Suppose that you have the
   accelerator shown below in which an alpha particle (a helium
   nucleus ^4_2He) is accelerated from rest near the left plate and that
   the alpha particle will eventually exit through the hole in the
   right plate. A potential difference $\Delta V = 70V$ exists across the
   plates and the plates are separated by a distance $d = 2m$.
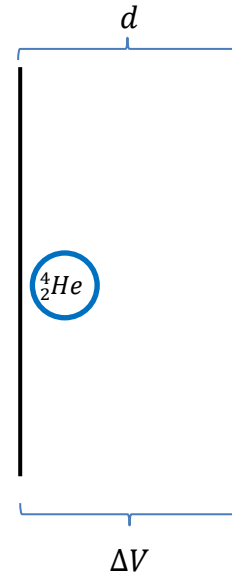
a. When the alpha particle exits through the hole on the right plate, what will be its
   speed?

b. Suppose that after the alpha particle exits the hole in the right plate with speed v_i determined from part a, it passes between a second set of parallel plates shown below. The plates are square with sides of length $L = 15cm$ and are separated by a distance $d = 8cm$. An $80V$ battery across theses plates was used to create an electric field between the plates. What was the magnitude and direction of the electric field between the plates and what plate (the upper or lower plate) is at the higher electric potential? Be sure to explain your choice for the higher potential plate.

L

d

^4_2He

v_i

^4_2He

v_f
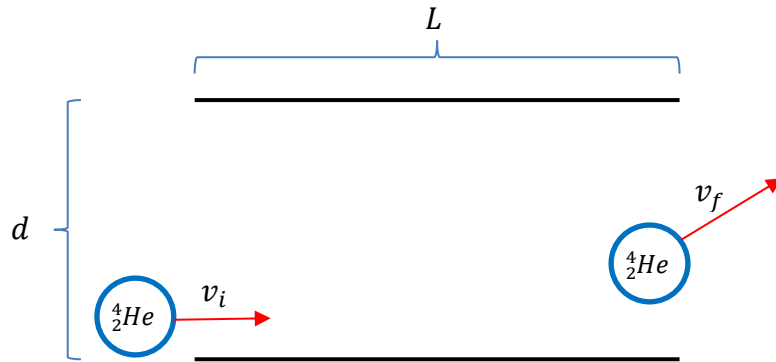
c. What is the magnitude and direction of the final velocity of the alpha particle when it leaves the plates on the right?

d. The alpha particles that emerge from the system in part c are incident on atoms of calcium. How close to the nucleus of a calcium atom does the alpha particle come? Hints: Assume that the proton starts very far away from a calcium nucleus and that calcium has 20 protons in its nucleus.

3. A $m = 1g$ point charge is suspended at the end of an insulating cord of length $L = 55cm$. An external electric field is turned on and the point charge is observed to be in equilibrium this uniform horizontal electric field of magnitude $|\vec{E}| = 15000\frac{N}{C}$ when the pendulum's position is $12cm$ above its lowest vertical position.
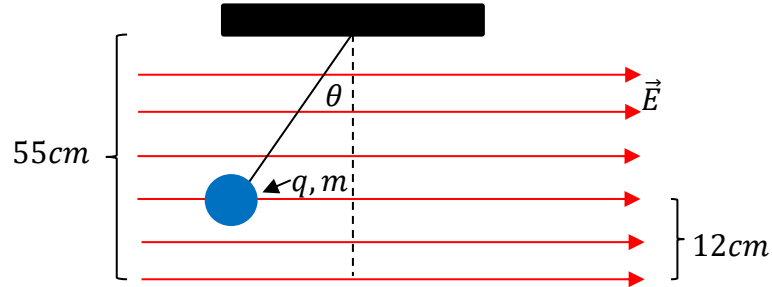
a. What is the magnitude of the tension force in the cord in this configuration?

b. What is the magnitude and sign of the point charge on the end of the cord? Be sure to explain fully your choice for the sign of the point charge and why you chose this as the sign.

c. Suppose that the electric field were generated by a set of parallel circular metal plates with diameter $D = 75cm$ that have equal and opposite charges on them. If the capacitance of the system was $C = 3pF = 3 \times 10^{-12}F$ and the space between the plates is filled with air, how far apart were the plates spaced?

d. What was the voltage of the battery that was used to charge these plates?

Physics 111 Formula Sheet

Electrostatics

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

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

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

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

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

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

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 - Capacitors

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

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

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

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

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

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

$\tau = RC$

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

Electric Circuits - Resistors

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

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

$V = IR$

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

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

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

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

Light as a Wave

$c = f\lambda$

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

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

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

$S = S_0 \cos^2\theta$

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

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

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

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

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

Light as a Particle/Relativity

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

$K_{max} = hf - \phi$

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

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

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

$p = \gamma mv$

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

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

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

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

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

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

$$U_g = mgy$$

$$U_s = \frac{1}{2}ky^2$$

$$K = \frac{1}{2}mv^2$$

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

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

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

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:	$A = \pi r^2$	$C = 2\pi r = \pi$
Spheres:	$A = 4\pi r^2$	$V = \frac{4}{3}\pi r^3$
Triangles:	$A = \frac{1}{2}bh$	
Quadratics:	$ax^2 + bx + c = 0 \rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	

PERIODIC TABLE OF ELEMENTS