Physics 111

Exam #1

September 22, 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, $|\vec{p}| \approx m|\vec{v}| = (5kg) \times \left(2\frac{m}{s}\right) = 10\frac{kg \cdot m}{s}$
- 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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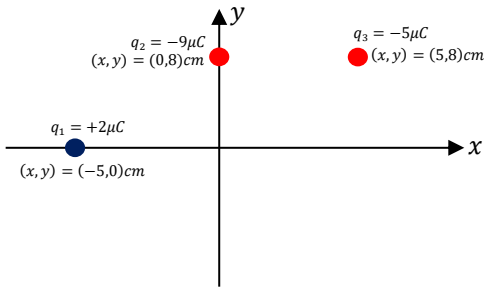
1. Three point-charges are assembled as shown below where each charge is brought in from very far away.

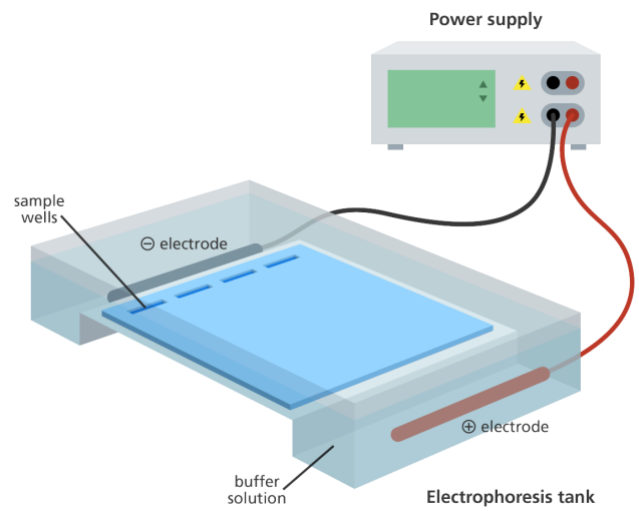
   a. How much work did it take to assemble this collection of point-charges?



   b. At a point $P = (x, y) = (0,0)cm$, what is the net electric field in magnitude and direction?

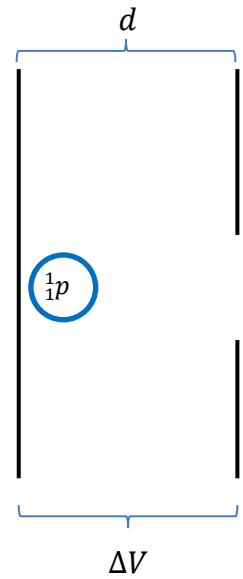
c. Suppose that a point-charge $q_4 = -3\mu C$ was placed at point P, what net force, in magnitude and direction, would q_4 feel?

d. We've said that if you put a charge q into an electric field $\vec{E}$, it will feel a force $\vec{F} = q\vec{E}$. This is a useful technique that can be exploited in something called gel electrophoresis. The main idea of gel electrophoresis is to separate masses of DNA, RNA or protein chains by molecular (or chain) weight based on how far the chain moves through the gel in the presence of an external electric field. The basic setup of gel electrophoresis is shown below. As the segemnt of say DNA moves through the gel due to its charge (assumed for this problem to be $q = -e$ for all chains) it is subject to a drag force $F_d = Cv$, opposite to its velocity v, where C is a constant called the drag coefficient that depends on mass. Suppose that you have a solution of various masses (chain lengths) and the solution of various DNA chains move through the gel at a constant velocity, called the terminal velocity. The DNA sample is inserted into the left most end and the samples migrate toward the right end as they interact with the applied electric field. This interaction separates out the masses into bands that can be used (with a standard) to determine molecular chain weights. Using the figure below, explain the direction of the electric field in the gel, the motion of the DNA strands through the gel, and where you would expect short, medium, and long chain DNA strands end up (in relation to the sample well) and why? Be sure to explain your answer using as many physics ideas as possible and determine an expression for the terminal velocity of a strand.



https://www.yourgenome.org/facts/what-is-gel-electrophoresis/

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 a proton is accelerated from rest near the left plate and that the proton exits through the hole in the right plate. A potential difference ΔV exists across the plates and the plates are separated by a distance $d = 2m$.



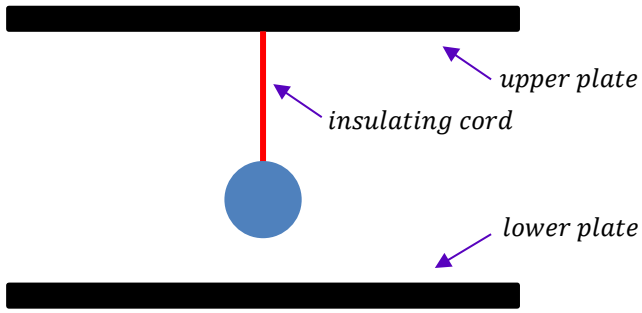
a. If the speed of the proton through the hole on the right plate is $v = 2.1 \times 10^{7}\frac{m}{s}$, what was ΔV?

b. After the proton is accelerated through the potential difference in part a, it is directed at a target composed of a single element with atomic number Z. The proton comes to rest at a distance $r = 4.63 \times 10^{-14}m$ from the nucleus of an atom of the unknown element. What was the element that the target was made from?

c. The accelerator is constructed out of two parallel circular metal plates of diameter $20cm$. What is the capacitance of the system and how much charge was on a plate of this capacitor?

d. Suppose the proton was accelerated through the accelerator from left to right, where the right most circular plate has a small hole so the protons can escape. What is the magnitude and direction of the electric field that accelerated the protons between the plates?

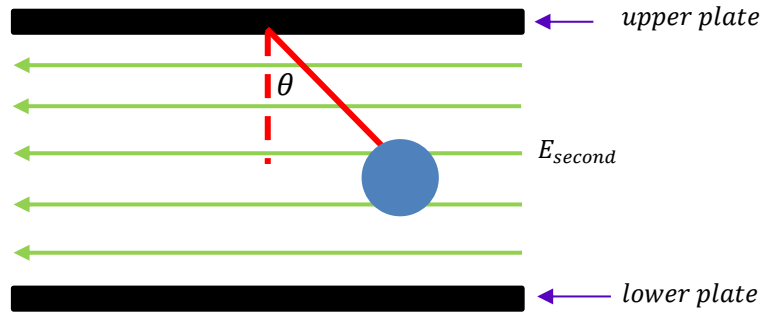
3. A point-charge with mass $m = 400g$ and charge $q = -0.5\mu C$ is suspended at the end of a light insulating cord as shown below. The point-charge is suspended between two metal plates of equal and opposite but unknown charge. The tension in the insulating cord is measured to be $8.6N$.



a. What is the magnitude of the assumed constant electric field between the plates?

b. Explain the direction of the electric field needed in part a to achieve this situation.

c. Suppose that in addition to the electric field in part a, a second electric field (E_{second}) were applied the system as shown below. This second electric field makes the point-charge rise through an angle of $\theta = 28^0$ measured with respect to the vertical. What is the tension in the rope in this situation?



d. What is the magnitude of the second electric field, E_{second}?

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

$c = f\lambda$

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

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

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

$S = S_0\cos^2\theta$

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

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

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

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

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

Light as a Particle/Relativity

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

$K_{max} = hf - \phi$

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

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

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

$p = \gamma mv$

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

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

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

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

$\vec{F} = m\vec{a}; \quad F_G = \frac{GM_1m_2}{r^2}; \quad F_s = -ky; \quad a_c = \frac{v^2}{r}$

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

$U_g = mgy$

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

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

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

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

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

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

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

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

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