# Physics 111

# Exam #1

# September 23, 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, $\left|\vec{p}\right| \approx m\left|\vec{v}\right| = (5kg)\times\left(2\,\frac{m}{s}\right) = 10\,\frac{kg\cdot m}{s}$
- 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.

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|---|---|
| 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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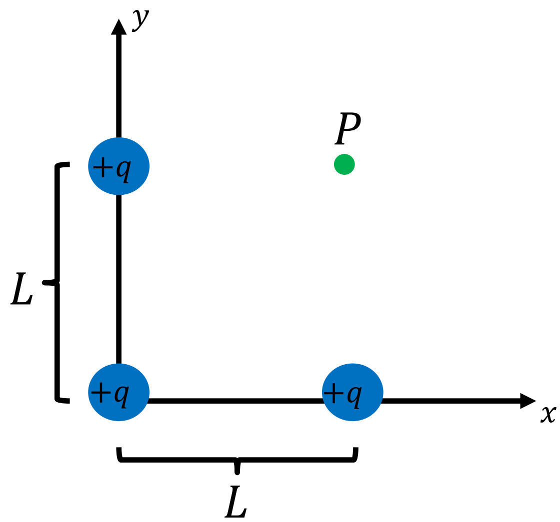
1. Suppose that a collection of point-charges is assembled in a plane, as shown below. Each point-charge is brought in, one at a time, from very far away and placed in their final positions. Each of the point-charges below are positive with magnitude $q$.

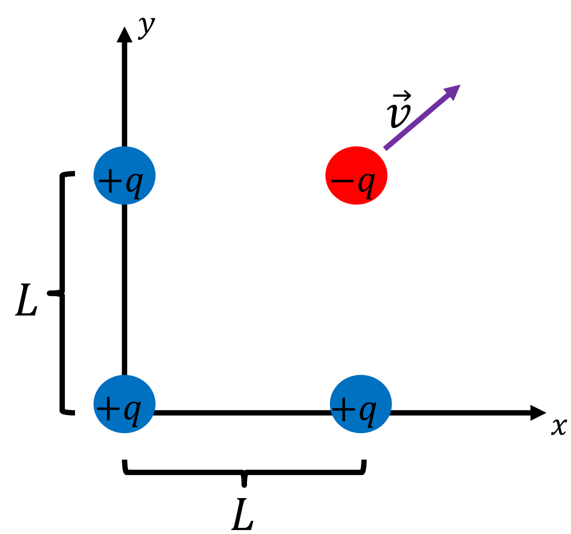



   a. How much work did it take to assemble the collection of point charges?

   b. At a point $P = (x, y) = (L, L)$, what is the net electric field?

c. Suppose that a point-charge $-q$ were placed at point $P = (x, y) = (L, L)$. What net force would the point-charge feel?

d. Describe the changes to the kinetic and potential energy for the point-charge $-q$ if the point-charge were thrown from away point $P = (x, y) = (L, L)$ along the diagonal of the square as shown below.



2. An air-filled capacitor $(\kappa = 1)$ is constructed out of two square metal plates of length $L = 25cm$ separated by a distance of $d = 1\mu m$. The initially uncharged capacitor is connected to a $R = 1M\Omega$ resistor and a $V = 30V$ battery.

   a. How much charge can be stored on the plates of the capacitor and what is the magnitude and direction of the electric field between the plates?

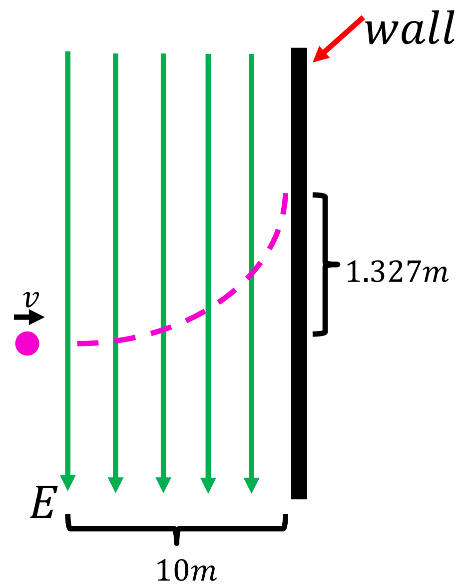
   b. How much energy is stored in the electric fields of the fully charged capacitor?

c. Suppose that after the capacitor is fully charged, the battery is removed and the fully charged capacitor is connected to the resistor and allowed to discharge. After a time, equal to ***two*** time constants, what fraction of the initial stored energy remains to be dissipated?

d. After a time, equal to ***two*** time constants, how much current is flowing through the resistor and what would be the voltage measured across the resistor at this time?

3. An unknown charged particle of mass $m = 200g$ was accelerated horizontally by an accelerator (not shown) and exits the accelerator with a speed $v$ directed horizontally to the right. Immediately after the charged particle exits the accelerator it encounters a $10m$ wide region of space with a uniform electric field pointing vertically down. The motion of the charged particle through the electric field is shown in the diagram below.

   a. What must be the sign of the unknown charged particle? Explain your reasoning with a few sentences. Simply stating positive or negative with no explanation will earn no credit.




   b. As the unknown charged particle travels through the electric field, it will eventually strike the wall on the right. The unknown charged particle is seen to strike the wall $0.42s$ after it enters the electric field on the left. What was the incident speed of the unknown charged particle?

c. With respect to the vertical height that the unknown charged particle enters the electric field, it strikes the wall at a vertical distance of $132.7cm$. If the particle has a magnitude of charge $|q| = 70nC$, what is the strength of the uniform electric field?

d. Through what difference in electric potential does the charged particle rise and does the electric potential energy of the charged particle increase, decrease, or remain the same? Justify your choice for the change in electric potential energy with a sentence or two.

# 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

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

$K_{max} = hf - \phi$

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

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

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

$p = \gamma mv$

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

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

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

## 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

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

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

$U_g = mgy$

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

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

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

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

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

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