

Physics 111

Exam #1

January 23, 2026

Name _____

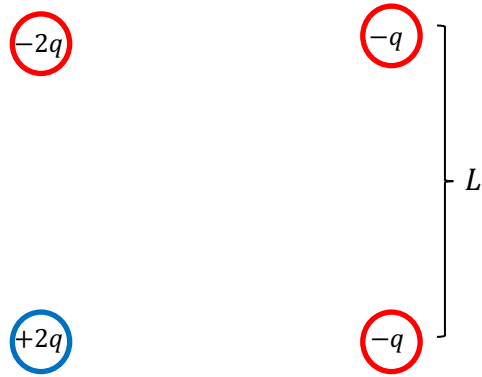
Please read and follow these instructions carefully:

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

1. Consider the following arrangement of four point-charges arranged on the corners of a square. Assume that the square has sides of length L .



- a. How much work was done to assemble this collection of point-charges. Assume each point-charge is brought in one at a time from very far away and put in their final locations.

Starting with the $+2q$ point-charge and proceeding counterclockwise we have:

$$W_{2q} = 0$$

$$W_{-q} = -(-q) \left[\frac{k2q}{L} - 0 \right] = \frac{2kq^2}{L}$$

$$W_{-q} = -(-q) \left[\frac{k(-q)}{L} - 0 \right] - (-q) \left[\frac{k2q}{\sqrt{2}L} - 0 \right] = -\frac{kq^2}{L} + \frac{\sqrt{2}}{2} \frac{kq^2}{L}$$

$$W_{-q} = \left(\frac{\sqrt{2}}{2} - 1 \right) \frac{kq^2}{L}$$

$$W_{-2q} = -(-2q) \left[\frac{k(-q)}{L} - 0 \right] - (-2q) \left[\frac{k(-q)}{\sqrt{2}L} - 0 \right] - (-2q) \left[\frac{k(2q)}{L} - 0 \right]$$

$$W_{-2q} = -\frac{2kq^2}{L} - \frac{2}{\sqrt{2}} \frac{kq^2}{L} + \frac{4kq^2}{L} = \left(2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L}$$

$$W_{net} = W_{2q} + W_{-q} + W_{-q} + W_{-2q}$$

$$W_{net} = 0 + \frac{2kq^2}{L} + \left(\frac{\sqrt{2}}{2} - 1 \right) \frac{kq^2}{L} + \left(2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L}$$

$$W_{net} = \left(2 + \frac{\sqrt{2}}{2} - 1 + 2 - \frac{\sqrt{2}}{2} \right) \frac{kq^2}{L} = 3 \frac{kq^2}{L}$$

- b. What is the electric potential energy in this collection of point-charges? Does the sign of the potential energy make sense? Explain in a sentence or two.

$$W = -\Delta U_e = -(U_{ef} - U_{ei}) = -U_{ef} \rightarrow U_{ef} = -W = -3 \frac{kq^2}{L}$$

- c. What is the net electric field at the center of the square due to the four point-charges on the corners?

$$E_{net,x} = E_{-q,x} + E_{+2qx} - E_{-2qx} + E_{-qx} = 2E_{-qx} = 2 \left(\frac{kq}{L^2/2} \right) \cos 45 = 2\sqrt{2} \frac{kq}{L^2}$$

$$E_{net,y} = E_{-q,y} + E_{+2qy} + E_{-2qy} - E_{-qy} = 2E_{-2qy} = 2 \left(\frac{kq}{L^2/2} \right) \sin 45 = 4\sqrt{2} \frac{kq}{L^2}$$

$$E_{net} = \sqrt{E_{net,x}^2 + E_{net,y}^2} = \frac{kq}{L^2} \sqrt{(2\sqrt{2})^2 + (4\sqrt{2})^2} = \sqrt{40} \frac{kq}{L^2} = 6.3 \frac{kq}{L^2}$$

$$\tan \phi = \frac{E_{net,y}}{E_{net,x}} = \frac{4\sqrt{2} \frac{kq}{L^2}}{2\sqrt{2} \frac{kq}{L^2}} = 2 \rightarrow \phi = 63^\circ \text{ above the positive x-axis.}$$

- d. Suppose that a charge $Q = -4q$ were placed at the center of the square. What net force would Q feel?

$$F_{net} = qE_{net} = 4q \cdot \frac{6.3kq}{L^2} = 25.2 \frac{kq^2}{L^2} \text{ in magnitude @ } \theta = 63^\circ + 180^\circ = 243^\circ$$

measured with respect to the positive x-axis (or 63° below the negative x-axis.)

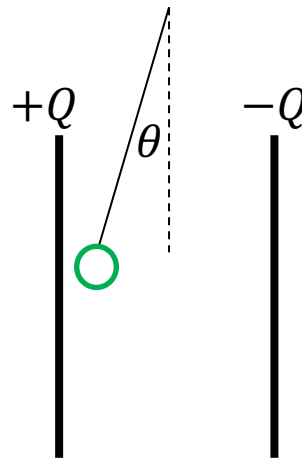
2. A capacitor is constructed out of two circular parallel plates of diameter 10cm separated by an unknown distance d . The initially uncharged capacitor is connected to a resistor and a 1000V battery and charged to its maximum value Q_{\max} where $Q_{\max} = 0.7\text{nC}$.

- a. If the capacitor is air filled, what is the separation between the plates of this capacitor?

$$Q = CV = \left(\frac{\kappa \epsilon_0 A}{d} \right) V \rightarrow d = \frac{\kappa \epsilon_0 A V}{Q}$$

$$d = \frac{1 \cdot 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \cdot \pi (0.05\text{m})^2 \cdot 1000\text{V}}{0.7 \times 10^{-9}\text{C}} = 0.099\text{m} = 0.1\text{m} = 10\text{cm}$$

- b. Suppose the capacitor is oriented as shown on the right. At the midpoint between the plates a point-charge q (the green circle) is suspended from an insulating string of length $L = 75\text{cm}$. The point-charge comes into equilibrium when the string makes an angle $\theta = 20^\circ$ measured with respect to the vertical. What is the magnitude of the electric field between the plates?



$$E = \frac{Q}{\epsilon_0 A} = \frac{0.7 \times 10^{-9}\text{C}}{8.85 \times 10^{-12} \frac{\text{C}^2}{\text{Nm}^2} \cdot \pi (0.05\text{m})^2} = 1 \times 10^4 \frac{\text{N}}{\text{C}}$$

Or,

$$E = -\frac{\Delta V}{\Delta x} = -\left(\frac{0\text{V} - 1000\text{V}}{0.099\text{m} - 0\text{m}} \right) = 1 \times 10^4 \frac{\text{V}}{\text{m}}$$

The direction: From the positive to the negative plate.

- c. What is the sign of the point-charge q ? Explain your choice fully to earn full credit. Simply stating positive or negative will earn minimal credit.

Since the electric field points from the positive to the negative plate and the sphere moves to the left in the direction opposite the electric field, the charge on the sphere must be negative.

- d. What is the magnitude of the point-charge q if $m = 250g$?

$$F_{net,x} = -F_e + F_{Tx} = -F_e + F_T \sin \theta = ma_x = 0$$

$$F_{net,y} = F_{Ty} - F_W = F_T \cos \theta - mg = ma_y = 0 \rightarrow F_T = \frac{mg}{\cos \theta}$$

$$\rightarrow qE = F_T \sin \theta = \left(\frac{mg}{\cos \theta} \right) \sin \theta = mg \tan \theta \rightarrow q = \frac{mg}{E} \tan \theta = \frac{0.25kg \cdot 9.8 \frac{m}{s^2}}{1 \times 10^4 \frac{N}{C}}$$

$$q = 8.9 \times 10^{-5} C = 89 \mu C$$

3. Bismuth ($^{209}_{83}\text{Bi}$) has a nuclear radius r_N given by $r_N = 1.2 \times 10^{-15} \text{m} \cdot A^{\frac{1}{3}}$, where A is the atomic mass in unified (or atomic) mass units. A proton was accelerated from rest when it is initially very far away from a bismuth and acquired a speed v_i . The proton approaches the bismuth nucleus head-on and from this interaction the proton is brought momentarily to rest at a distance of $3r_N$.

- a. What was the initial speed v_i of the proton when it was very far away from the bismuth nucleus?

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

$$-e \left[\frac{kq_{bi}}{r_r} - \frac{kq_{Bi}}{r_i} \right] = -e \left(\frac{k(83e)}{3r_n} \right) = -\frac{1}{2}mv_i^2$$

$$v_i = \sqrt{\frac{166ke^2}{2mr_N}} = \sqrt{\frac{166 \cdot 9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \cdot (1.6 \times 10^{-19} \text{C})^2}{3 \times 1.67 \times 10^{-27} \text{kg} \cdot 1.2 \times 10^{-15} \text{m} \cdot (209)^{\frac{1}{3}}}}$$

$$v_i = 3.3 \times 10^7 \frac{\text{m}}{\text{s}}$$

- b. Through what potential difference was the proton accelerated to give it the speed in part a? Assume the proton started from rest.

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

$$\Delta V = -\left(\frac{m}{2q}\right)v_f^2 = -\left(\frac{1.67 \times 10^{-27} \text{kg}}{2 \cdot 1.6 \times 10^{-19} \text{C}}\right)\left(3.3 \times 10^7 \frac{\text{m}}{\text{s}}\right)^2 = -5.6 \times 10^6 \text{V}$$

$$\Delta V = -5.6 \text{MV}$$

- c. Particle accelerators, like those used to accelerate the proton in part b, are modeled as a capacitor. Suppose the maximum charge that was stored on the capacitor used in this particle accelerator when fully charged was $Q_{max} = 42.7\mu C$. If the initially uncharged capacitor was charged through a $R = 120G\Omega$ resistor, what is the time constant for the charging circuit?

$$Q = CV \rightarrow C = \frac{Q}{V} = \frac{42.7 \times 10^{-6} C}{5.6 \times 10^6 V} = 7.6 \times 10^{-12} F$$

$$\tau = RC = 120 \times 10^9 \Omega \cdot 7.6 \times 10^{-12} F = 0.92 s$$

- d. Assuming that the capacitor in part c was initially uncharged, how long does it take to store 84% of the total potential energy in the system?

$$U_f = \frac{1}{2}CV^2 = \frac{1}{2}CV_{max}^2 \left(1 - e^{-\frac{t}{\tau}}\right)^2 = U_i \left(1 - e^{-\frac{t}{\tau}}\right)^2$$

$$0.84U_i = U_i \left(1 - e^{-\frac{t}{\tau}}\right)^2$$

$$1 - e^{-\frac{t}{\tau}} = \sqrt{0.84} = 0.92$$

$$e^{-\frac{t}{\tau}} = 0.08 \rightarrow t = -0.92\tau \ln 0.08 = -0.92 \cdot 0.92 \ln 0.08 = 2.1 s$$

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

$$c = f\lambda$$

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

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

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

$$S = S_0 \cos^2 \theta$$

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

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

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

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

$$M = \frac{d_i}{d_o}; \quad |M| = \frac{h_i}{h_o}$$

Magnetism

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

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

$$V_{Hall} = wv_d B$$

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

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

$$\phi_B = BA \cos \theta$$

Electric Circuits - Resistors

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

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

$$V = IR$$

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

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

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

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

Light as a Particle/Relativity

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

$$K_{max} = hf - \phi$$

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

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

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

$$p = \gamma mv$$

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

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

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

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

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

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

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

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

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

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

Geometry/Algebra

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

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

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

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

PERIODIC TABLE OF ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008	2 He Helium 4.0026																
3 Li Lithium 6.94	4 Be Beryllium 9.0122																
5 Na Sodium 22.990	6 Mg Magnesium 24.305																
7 K Potassium 39.098	8 Ca Calcium 40.078	9 Sc Scandium 44.956	10 Ti Titanium 47.867	11 V Vanadium 50.942	12 Cr Chromium 51.996	13 Mn Manganese 54.938	14 Fe Iron 55.845	15 Co Cobalt 58.933	16 Ni Nickel 58.693	17 Cu Copper 63.546	18 Zn Zinc 65.38	19 Ga Gallium 69.723	20 Ge Germanium 72.630	21 As Arsenic 74.922	22 Se Selenium 78.971	23 Br Bromine 79.904	24 Kr Krypton 83.798
25 Rb Rubidium 85.468	26 Sr Strontium 87.62	27 Y Yttrium 88.906	28 Zr Zirconium 91.224	29 Nb Niobium 92.906	30 Mo Molybdenum 95.94	31 Tc Technetium (98)	32 Ru Ruthenium 101.07	33 Rh Rhodium 102.91	34 Pd Palladium 106.42	35 Ag Silver 107.87	36 Cd Cadmium 112.41	37 In Indium 114.82	38 Sn Tin 118.71	39 Sb Antimony 121.76	40 Te Tellurium 127.60	41 I Iodine 126.90	42 Xe Xenon 131.29
39 Cs Cesium 132.91	40 Ba Barium 137.33	57-71 Lanthanoids (Lanthanides)	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
55 Fr Francium (223)	56 Ra Radium (226)	89-103 Actinoids (Actinides)	104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rf Roentgenium (272)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																	
57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97			
89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)			

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