Physics 5C - Final

Wednesday, June 12, 3-6PM

UCLA / Spring 2024 / Brian Naranjo

NAME ____________________

SIGNATURE ____________________

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- Wait until instructed to begin.
- This exam is closed-book, with no external notes or scratch paper, and no electronic devices.
- Use this coversheet for scratch work. If needed, extra scratch paper is available.
- If your work continues on the scratch page, then make a note in your solution.
- You may unstaple your exam, but please keep the pages in order and include this coversheet.
- Have your photo ID available during the exam.
- Due to exam schedule conflicts, a few students will be taking this exam later this evening. Please do not discuss this exam until after 8AM Thursday.

Electric field

$$k = \frac{1}{4\pi\epsilon_0} \qquad |\mathbf{F}| = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$

$$\mathbf{E}(x,y,z) = \frac{\mathbf{F}_q(x,y,z)}{q}$$

$$|\mathbf{E}| = \frac{1}{4\pi\epsilon_0}\frac{|q|}{r^2} \qquad |\mathbf{E}| = \frac{1}{4\pi\epsilon_0}\frac{|Q_{\text{in}}(r)|}{r^2}$$

$$\sigma = Q/A \qquad |\mathbf{E}| = \frac{|\sigma|}{2\epsilon_0}$$

$$p = qd \qquad \tau = pE\sin\phi$$

$$\mathbf{E}_{\text{axis}} \approx \frac{1}{4\pi\epsilon_0}\frac{2\mathbf{p}}{r^3} \qquad \mathbf{E}_{\text{plane}} \approx -\frac{1}{4\pi\epsilon_0}\frac{\mathbf{p}}{r^3}$$

Electric potential

$$U = qV \qquad E_s \approx -\Delta V/\Delta s$$

$$V = \sum_i \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_i} \qquad U = \frac{1}{4\pi\epsilon_0}\sum_{\text{all pairs}}\frac{q_i q_j}{r_{ij}}$$

$$V = -E_0 x \qquad U = -qE_0 x$$

$$U = -pE\cos\phi \qquad V = \frac{p\cos\theta}{4\pi\epsilon_0 r^2}$$

$$U_0 + K_0 = U_1 + K_1 \qquad 0 = \sum_{\text{loop}}(\Delta V)_i$$

Capacitance

$$Q = VC \qquad C_{\text{plate}} = \frac{\kappa\epsilon_0 A}{d}$$

$$U = \frac{Q^2}{2C} = \frac{QV}{2} = \frac{CV^2}{2} \qquad u_E = \frac{1}{2}\kappa\epsilon_0 E^2$$

$$C_p = C_1 + C_2 + \cdots \qquad 1/C_s = 1/C_1 + 1/C_2 + \cdots$$

$$E = E_0/\kappa \qquad C = \kappa C_0$$

Current and resistance

$$R = \frac{\rho L}{A} \qquad V = IR$$

$$I_{\text{rms}} = I_0/\sqrt{2} \qquad V_{\text{rms}} = V_0/\sqrt{2}$$

$$P = VI = V^2/R = I^2 R$$

$$P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} = V_{\text{rms}}^2/R = I_{\text{rms}}^2 R$$

Circuits

$$\sum I_{\text{in}} = \sum I_{\text{out}} \qquad 0 = \sum \Delta V_i$$

$$\tau = RC \qquad I(t) = I_0 e^{-t/\tau}$$

$$V_d(t) = V_0 e^{-t/\tau} \qquad V_c(t) = V_0(1 - e^{-t/\tau})$$

$$R_s = R_1 + R_2 + \cdots \qquad 1/R_p = 1/R_1 + 1/R_2 + \cdots$$

Mechanics

$$v = v_0 + at \qquad x = x_0 + v_0 t + at^2/2$$

$$v^2 = v_0^2 + 2a(x - x_0) \qquad a_c = v^2/r$$

$$K = mv^2/2 \qquad W = F_x\,\Delta x = -\Delta U$$

Magnetic fields and forces

$$\Delta B = \frac{\mu_0}{4\pi}\frac{I\Delta x\sin\theta}{r^2} \qquad B_{\text{wire}} = \frac{\mu_0 I}{2\pi s}$$

$$B_{\text{loop}} = \frac{\mu_0 I}{2a} \qquad B_{\text{sol}} = \mu_0 n I$$

$$n = N/L \qquad \mathbf{B}_{\text{axis}} = \frac{\mu_0}{4\pi}\frac{2\mathbf{m}}{d^3}$$

$$m = IA \qquad \tau = mB\sin\theta$$

$$U = -mB\cos\theta$$

$$F = |q|vB\sin\alpha \qquad F = I\ell B\sin\alpha$$

$$r = mv/(qB) \qquad f = qB/(2\pi m)$$

Electrodynamics and light

$$\mathcal{E} = -\frac{\Delta\Phi}{\Delta t} \qquad \Phi = AB\cos\theta$$

$$\mathcal{E}_m = v\ell B \qquad c = \lambda f$$

$$E_0 = cB_0 \qquad I = \frac{1}{2}c\epsilon_0 E_0^2$$

$$p_{\text{rad}} = I/c \qquad I_1 = I_0\cos^2\theta$$

$$E_1 = E_0\cos\theta \quad (\mathbf{E_1}\ \text{along filter axis})$$

MP08 and MP09

$$N_i = Ce^{-E_i/(k_B T)} \qquad V_{\text{Nernst}} = \frac{k_B T}{q}\ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right)$$

$$E = hf \qquad P = Rhf$$

$$\lambda = h/(mv) \qquad E_n = \frac{h^2 n^2}{8mL^2}$$

$$eV_{\text{stop}} = K_{\text{max}} = hf - \Phi_0$$

$$f_{\text{precess}} = \gamma B$$

Miscellaneous

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} \quad \cos\theta = \frac{\text{adj}}{\text{hyp}} \quad \tan\theta = \frac{\text{opp}}{\text{adj}}$$

$$a^2 + b^2 = c^2 \ ; \ a^2 + b^2 - 2ab\cos\gamma = c^2$$

$$\text{Sphere:} \quad A = 4\pi r^2 \quad V = (4/3)\pi r^3$$

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

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

Charge : C

Electric field : N/C = V/m

Electric potential : V = J/C

Capacitance : F = C/V

$$\text{M} = 10^6, \text{k} = 10^3, \text{m} = 10^{-3}, \mu = 10^{-6}$$

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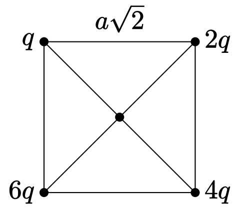
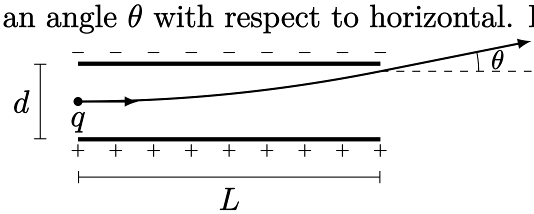
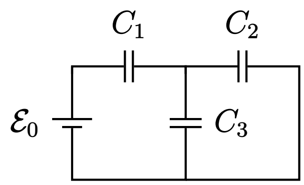
1) (10 points) Four charges are arranged at the corners of a square of side length $a\sqrt{2}$, as shown. Find the *magnitude* of the electric field at the center of the square, taking $q > 0$.



2) (10 points) A particle of positive charge q and kinetic energy K is traveling horizontally when it enters a region between two horizontal parallel plates, as shown. The plates, of length L, are separated by a gap d and have a potential difference ΔV. Upon exiting the gap, the particle makes an angle θ with respect to horizontal. Find an expression for θ.



3) (10 points) In the circuit below, $\mathcal{E}_0 = 3$ V, $C_1 = 6$ µF, $C_2 = 2$ µF, and $C_3 = 1$ µF. Find each capacitor's potential difference, charge, and energy.



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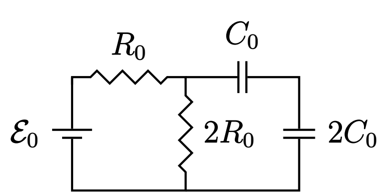
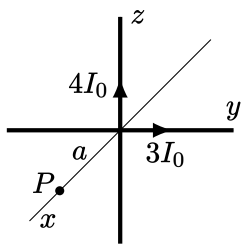
4) (10 points) Consider a spherical conducting shell of resistivity ρ, radius r_1, and shell thickness d_1. When we apply a potential difference between the shell's inner and outer surfaces, a radial current flows. **a)** Assuming a thin shell thickness $d_1 \ll r_1$, find the electrical resistance R_1 to radial current flow through the shell. **b)** We uniformly stretch the sphere out to a larger radius r_2 with a thinner shell thickness d_2 so that the new resistance is R_2. Find an expression for R_2/R_1 in terms of r_2 and r_1.

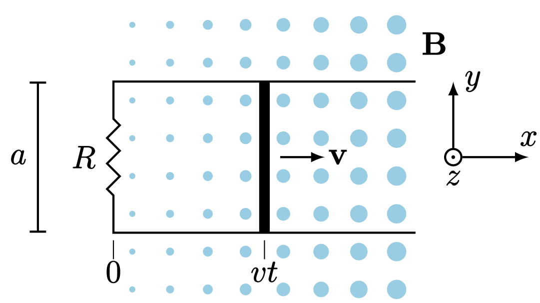
5) (10 points) After installing the battery in the circuit below, we wait a long time for the capacitors to fully charge. Find the the fully charged potential difference across each capacitor.



6) (10 points) A current $4I_0$ flows along the z-axis and a current $3I_0$ flows along the y-axis, as shown. Find the *magnitude* of the resulting magnetic field at point P.



7) (10 points) A slidewire is in nonuniform magnetic field $|\mathbf{B}| = \alpha x$, where α is a positive constant. You pull on the slidewire with constant velocity v, as shown. **a)** Find the magnitude and direction of the resulting current. **b)** Find the magnetic drag force and the mechanical power your hand must provide to maintain the velocity.



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8) (10 points) A semipermeable membrane of thickness d allows an ion species of positive charge q to freely diffuse into and out of a cell while preventing all other species from passing. At temperature T, the ion concentrations are in equilibrium, and it is noted that, inside the membrane, there is a strong electric field E_0 directed inward, into the cell. **a)** Find an expression for $c_{\text{out}}/c_{\text{in}}$ in terms of the given quantities.**b)** Is the ion concentration larger inside or outside the cell? Using physical reasoning, including a sketch, briefly explain why this is so.

9) (10 points) In a photoelectric demonstration lab, the maximum kinetic energy of photoelectrons is K_0. Reducing the wavelength of the incident light to half of its initial value increases the maximum photoelectron kinetic energy to K_1. **a)** What is the work function of the cathode? **b)** What was the initial wavelength?

10) (10 points) A particle of mass m is in a box of length L. The system is in contact with a heat reservoir at temperature T. At what value of T is the particle exactly twice as likely to be in the ground state rather than in the first excited state?