Final for Algebra-Based Physics: Electricity and Magnetism (PHYS135B)

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1 Equations and constants

1. Coulomb force: $\vec{F}_C = k\frac{q_1 q_2}{r^2}\hat{r}$.
2. Centripetal force: $\vec{F} = \frac{mv^2}{r}$
3. Definition of electric field: $\vec{F}_C = q\vec{E}$.
4. Voltage and electric field, one dimension, uniform field: $|E| = -\frac{\Delta V}{\Delta x}$.
5. Charge and capacitance: $Q = CV$.
6. Definition of current: $I = \Delta Q/\Delta t$.
7. Parallel plate capacitor: $C = \frac{\epsilon_0 A}{d}$.
8. Ohm's Law: $V = IR$.
9. Adding resistors *in series*: $R_{tot} = R_1 + R_2$ *in parallel*: $R_{tot}^{-1} = R_1^{-1} + R_2^{-1}$.
10. Adding capacitors *in parallel*: $C_{tot} = C_1 + C_2$ *in series*: $C_{tot}^{-1} = C_1^{-1} + C_2^{-1}$.
11. Electrical power: $P = IV = I^2 R = V^2/R$.
12. Magnetic dipole moment: $\vec{\mu} = I\vec{A}$, where $\vec{A}$ is the area vector. $\mu = NIA$ if there are N loops.
13. Torque on a magnetic dipole: $\tau = \vec{\mu} \times \vec{B}$. The magnitude is $\tau = \mu B \sin(\theta)$.
14. Hall voltage: $emf = Blv$.
15. Definition of magnetic flux: $\phi_m = \vec{B} \cdot \vec{A}$. The units are T m^2, which is called a Weber, or Wb.
16. Faraday's Law: $emf = -N\frac{\Delta\phi}{\Delta t}$.
17. Faraday's Law using **Inductance**, M: $emf = -M\frac{\Delta I}{\Delta t}$.
18. Typically, we refer to *mutual inductance* between two objects as M, and *self inductance* as L.
19. Magnetic permeability: $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}
20. Units of inductance: V s A^{-1}, which is called a Henry, or H.
21. Coulomb constant: $k = 8.9876 \times 10^9$ N m^2 C^{-2}.
22. Fundamental charge: $q_e = 1.602 \times 10^{-19}$ C.
23. Speed of light: $\approx 3 \times 10^8$ m/s.
24. Permittivity of free space: $\epsilon_0 = 8.85 \times 10^{-12}$ N^{-1} C^2 m^{-2}.

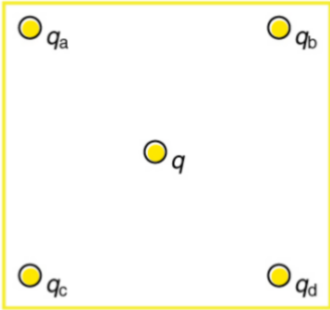

Figure 1: Five charges arranged in a square with one in the middle.

2 Exercises

1. **Chapter 18: Electrostatics**

   (a) Five charges are arranged as in Fig. 1, and the side length is 1 mm. (a) If $q_a = q_b = q_c = q_d$, what is the net force on the central charge, q? (b) If $q_a = q_b = 1$ nC, and $q_c = q_d = -1$ nC, what is the *electric field* at the center where q is located? (c) If $q = 2$ nC, what is the magnitude and direction of the force on q?

   (b) Draw the electric field of the charge distribution in Fig. 1 if (a) all charges have +1 nC, and (b) if q_b and q_c have -1 nC but the other three have +1 nC. (c) Assuming q_a and q_b have +1 nC but the other three have -1 nC, in which direction would the system spin if an external electric field were pointed to the right?

2. **Chapter 19: Voltage and Capacitance**

   (a) How far apart are two conducting plates that have (a) an electric field strength of 5 kV/m between them, if their potential difference is 15.0 V? (*Pay attention to the units*). (b) Assuming the distance d between the plates found in part (a), and a plate area of $A = 1$ cm^2, what is the capacitance? (c) For 15.0 V, how much charge is stored in this capacitor?

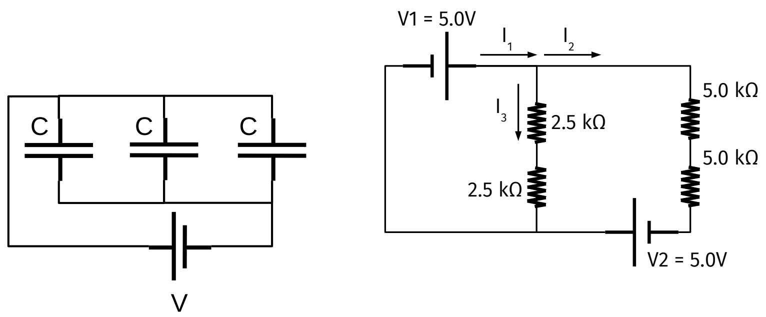

Figure 2: (Left) Three capacitors and a battery in a circuit. (Right) A circuit with two batteries and four resistors.

(b) If $C = 1\mu$F and $V = 12.0$ Volts in Fig. 2 (left), (a) what is the total capacitance, and (b) how much total charge is stored?

3. **Chapters 20-21: Current, Resistance, and DC Circuits**

(a) A couple are renovating a room in their house. They replace three incandescent 50W light bulbs with two 10W LED bulbs that cost $15.00 each. In their area, energy prices are $ 0.16 per kilowatt-hour. (a) Calculate the cost to run the three 50W bulbs for 720 hours (*Pay attention to units*). (b) Calculate the cost to run the two 10W LED bulbs for 720 hours. (c) What is the difference in cost? (d) **Bonus point:** How many hours would it take to have a difference of $30.00, which woud recoup the cost to switch to LEDs?

(b) Solve for the (a) currents in Fig. 2 (right). (b) Using $\Delta Q = I\Delta t$, how much charge is drained from battery $V1$ in 12 hours? (c) How much charge must $V1$ have if we want it to run for 24 hours?

4. **Chapter 22: Magnetism**

(a) A Hall effect flow probe is placed on an artery, applying a 0.2 T magnetic field across it. What is the expected Hall voltage, given that the blood vessel's diameter is 4.0 mm and the blood velocity is 5 mm/s?

(b) An AC motor is built with $N = 500$ coils each having an area of 20 cm^2. The coils are rotating inside a magnet of 0.2 T, and each carry 10.0 A of current. What is the maximum torque achieved by this motor?

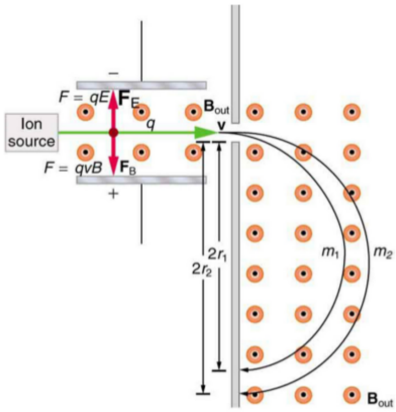

Figure 3: The basic schematic of a *velocity selector*, in which charged particles move through perpendicular E and B-fields. Only particles with $v = E/B$ travel through to the right portion. Once there, centripetal force is provided by the Loretnz force, and particles of different mass curve with different radii.

(c) In Fig. 3 a velocity selector is depicted. If $E = 10^4$ V/m and $B = 10^{-2}$ T, (a) what is the velocity of the particles that travel through to the right portion of the device? (b) If protons traveled at the speed found in part (a) in a B-field that was 1.0 T, what would be the radius of its path? For a proton, $q/m = 95.8 \times 10^6$ C/kg. *Hint: set the centripetal force equal to the Lorentz force.*

5. **Chapter 23: Electromagnetic Induction and Inductance**

(a) Suppose we need an inductor that produces an emf of 5.0 V for a current that changes at a rate of 125 A/s. What inductance do we need?

(b) A large research solenoid has a self-inductance of 25.0 H. What induced emf opposes shutting it off when 100 A of current through it is switched off in 80.0 ms?