Physics II: Electromagnetism

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Contents

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1 Chapter 21 - Electric Charge

1.1 Charge

1. Matter is composed of specific particles (electrons, protons, and neutrons), each with a property of charge (-ve, +ve, or 0)
   (a) Charge is measured in Coulumbs, generally a unit derived from Amperes for current, such that 1 C = 1 A*s
   (b) Electrons have a charge of $-1.6 * 10^{-19}C$ and a mass of $9.11 * 10^{-31}kg$
   (c) Protons have a charge of $-1.6 * 10^{-19}C$ and a mass of $1.673 * 10^{-27}kg$
   (d) Neutrons have a charge of $0C$ and a mass of $1.674 * 10^{-27}kg$, such that the mass is approximately the sum of that of an electron and proton
   (e) The signs for electrons and protons were chosen by Benjamin Franklin by arbitrary convention
2. The Law of Charges state that like charges repel and unlike charges attract
3. Quantization of Charge states that the charge of any body is equal to the multiple of the charge of an electron/proton, called the elementary charge
   (a) Quantized quantities are those which can only have discrete values of specific integer multiples of some constant, rather than any value
4. Conservation of Charge states that charge is conserved, in all bodies, including subatomic, nuclear, and large-scale
   (a) Thus, in nuclear reactions, charge is either annihilated or pair-produced (producing both charges simultaneously)
5. Materials can be divided into conductors, insulators, and semiconductors
   (a) The distance between the atomic radiuses of each of the atoms in the material determine the type, such that the further the distance, the less conductive, making conductors dense
   (b) Conductors have electrons free to move from orbit to orbit, such as metals or impure water
      i. It is noted that this creates the difference of charged conducting bodies, such that the charges isolate themselves on the edges of the object uniformly dispersed on the outside, unlike insulators which are dispersed evenly throughout
      ii. Thus, conducting spheres act as a spherical shell due to all charges on the outer layer
      iii. Superconductors are conductors without any hindrance to movement of elections
   (c) Insulators have a large energy gap (E_g), such that the electrons are bound to atoms, unable to jump/move, such as wood, glass, rubber, or pure water
   (d) Semiconductors are not free or bound, such that they can be converted to either a conductor or insulator, such as silicon or germanium
      i. Adding impurities to the material through doping allows electrons to jump easier, such that it conducts better
      ii. Increasing temperature increases electron energy, allowing jumps temporarily, while decreasing temperature does the opposite

1.2 Charging

1. Charging by friction is done by rubbing objects together, using the frictional force to force electron transfer to the material with greater attraction to electrons

(a) Valence electrons are the ones lost from the material, specifically called conduction elections when able to be lost (in conductors)
(b) Glass and silk are known for producing positively charged glass
(c) Plastic and fur are known for producing negatively charged plastic

2. Charging by contact is done by contact between two non-insulators, causing the charge to move until equilibrium
3. Charging by induction is done by placing a charged rod near a neutral conductor, such that the material is polarized into a seperation of charges, giving a temporary/induced charge
   (a) If the object is then split up in the case of a conductor, where the polarization is on a super-molecular scale, it can be charged
   (b) If the object is an insulator, such that it is on a dipole molecular scale, it is temporary, but can allow it to be attracted to the object
4. Electroscopes have two flat leaves connected to a rod, which is attached to the ball on top, such that it detects charge by charging by contact, after which the leaves seperate
   (a) It can be discharged by attaching it to a grounding wire, attached to the Earth, which acts as a giant neutral body to neutralize the charges

1.3 Coulomb's Law

1. Coulomb's Law determines the electrostatic force of charged bodies, where electrostatic denotes stationary/negligible-movement charges
2. $F_e = \frac{k|q_1||q_2|}{r^2}$, where the direction of the vector is determined by the law of charges
   (a) $k = 9 * 10^9 \frac{Nm^2}{C^2} = \frac{1}{4\pi\epsilon_0}$
   (b) The overall force must be found before breaking it up into components, rather than in finding it as components first
3. The ratio of electrostatic force to gravitational force on a molecular scale approximates as 10^{40}, such that gravity can be ignored on that scale
   (a) Based on the hydrogen atom, with a radius of 0.53 Angstrom ($0.53 * 10^{-10}m$)
4. Shells of uniform charge density are found to have force interactions with charged point masses outside as if it was concentrated at the center
   (a) Point masses inside the shell have no net electrostatic force acting on it

2 Chapter 22 - Electric Field

2.1 Point Charges

1. The electric field ($\vec{E}$) is a vector field, or a function of vectors at each point on the cartesian grid, allowing a measurement of the influence of a particle on any other particle at that point
   (a) It is related to the number of field lines per unit area, such that lines are drawn from positive to negative
   (b) Electric fields are found by measuring the force on a positive test charge with a small enough size that it doesn't disrupt the surrounding field, though it is noted that fields exist independently of the test charge
2. $\vec{E} = \frac{\vec{F}}{q_0} = \frac{k|q|}{r^2}$, where the direction is determined by the type of charge, where q_0 is the test charge, and q is the charge of the point mass producing the field
   (a) The unit of electric fields is N/C

(b) $\vec{E}_{net} = \sum_i \vec{E}_i$, or the electric field at some point/test charge due to a series of additional charges, such that superposition applies

3. Electric dipoles are created by two point charges of equal magnitude, but opposite charge, seperated by some distance
   (a) Dipole moment $(\vec{P}) = qr$, where r is the distance between them, and q is the charge of each point, where the vector goes from negative to positive
      i. The direction of the dipole is based on the direction of the electric field vectors acting on the point charge for any point on the dipole line
   (b) Thus, $\tau = PxE$ and $PE = -E \cdot P$ for dipole moments
      i. CHECK OUT
   (c) $E_{dipole} = \frac{kP}{r^3}$, where r is the distance from the center of the dipole, where the point is on the dipole axis as r becomes far greater than the distance between the dipole charges
      i. On the other hand, E is proportional to $\frac{1}{r^3}$ at all points on the dipole axis, rather than just at a large distance
      ii. This proportionality is due to the charges canceling each other out faster as the distance gets further

2.2 Solid Bodies

1. $\vec{E} = \sum_i \frac{k\Delta q_i}{r_i^2} = \int \frac{k}{r^2} dq$
   (a) $q = \lambda x, q = \sigma A, q = \rho V$ (depending on the dimensions of the solid body)
   (b) If the density functions are non-uniform, the integral is taken to solve for q, with respect to each dimension variable
   (c) These calculations can be made simpler if one of the dimensions of the field cancels out, but a multiplier of some trig function must be added to the equation to remove that component
2. For parallel, nonconducting plates, $\vec{E} = \frac{\sigma}{\epsilon_0}$, such that the field from each plate is half of that value
   (a) ϵ_0 is the permittivity constant of free space, or $8.854 * 10^{-12} C^2/Nm^2$, and σ is the charge density of the plates
   (b) This is due to all field lines moving in a different direction being cancelled, assuming infinitely long parallel plates (or assumed to exist far from the edge of the plate, creating a uniform electric field
   (c) Uniform electric fields are those with the same magnitude and direction at every point

3 Chapter 23 - Electric Flux

3.1 Electric Flux

1. Electric flux is the number of electric field lines passing through an area, such that $\Phi_E = \vec{E} \cdot \vec{A}_n = \vec{E}\vec{A}_n cos(\theta)$, where $\vec{A}_n$ is the normal to the surface, perpendicular and with a magnitude equal to the area
   (a) For an enclosed object, lines entering the surface of the object is negative, outward is positive
   (b) Thus, positive objects have lines entering but not leaving, negative objects have vice versa

2. $\Phi = \vec{E} \cdot \vec{A}_n$ for uniform surfaces
   (a) $\Phi = \lim_{\Delta A_n \to 0} \sum_i \vec{E}_i \cdot \Delta A_n = \oint \vec{E} \cdot dA_n$

3.2 Gauss's Law

1. Gauss's Law is used to calculate the graviational field at a point, by creating a gaussian surface including that point
   (a) Gaussian surfaces must be closed (compact/effectively-continuous without boundary in any direction), 3D surfaces, such that they are the boundary of a 3D region with a constant field throughout (symmetrical)
   (b) The electric field must also be parallel to the normal of the tangent plane, A_N, on the surface A
   (c) $\Phi_e = \oint \vec{E} dA = \vec{E} \oint dA = \frac{kq_{enc}}{r^2}(4\pi r^2) = \frac{q_{enc}}{\epsilon_0}$, where q_{enc} is the charge of the body inside the surface creating the field, and the surface integral of dA is the surface area
2. This is used to derive the field of a sheet of charge, by creating a cylinder in the center around some area of the sheet of some height, thus calculating the field of the section of the sheet
3. For varying charge density, $q_{enc} = \int \rho dV$ is substituted in, where dV can be converted to cartesian, cylindrical, or spherical depending

4 Chapter 24 - Electric Potential

1. Electric potential energy can be defined in a system from infinity as a reference as the negative work done to move a particle from infinity towards some stationary second charge ($U_r = -W_{\infty \to r}$)
   (a) Electrostatic force is conservative, and thus path independent
   (b) Electric potential (V) is a quantity not dependent on the particle being moved, such that $V_r q_0 = U$, where q_0 is the charge of the moving particle and r is the distance from the stationary particle
   (c) Thus, $V = \int \frac{kdq}{r}$
   (d) ΔV is called the voltage, and measured in Volts, or J/C
2. The work moving a series of charges is equal to the sum of the work to move each charge with respect to the work of the charges moved previously
3. By the relationship of potential energy and force, $E = -\vec{\nabla} V(\vec{r})$ or $\Delta V = \int -E \cdot dr$
   (a) As a result, since $V(\infty) = 0, V(r) = \int_\infty^r -E \cdot dr$
   (b) In this case, the electric field must be found, not just at the point itself, but all points from there to infinity, such that if it is measured by multiple functions at various regions, must be broken up
   (c) This function to find V is commonly used for symmetrical objects by which Gauss's Law can be applied, while the defining function is more commonly used for non-symmetrical ones
4. Equipotential regions/points are those where the electric potential is equal
   (a) By extension, points are equipotential if the work done moving a charge from one to the other is 0, electric field is 0, or the electric field is perpendicular to the movement of the charge