

Unit 1 Review Sections

Chapter 1

1.1 Basic Rules of Electrostatics

- Charges are positive or negative. Likes charges repel. Unlike charges attract.
- Charge moves freely in conductors, but not in insulators.
- The force between charged particles is larger when the charges are closer together.
- Charge is quantized and conserved.

1.2 Our Understanding of Conductors

- The electrons in conductors are not bound to individual atoms and are therefore free to move through the conductor with very little loss of energy.

1.3 Electrostatic Induction

- Electrostatic induction: When a charged object come closes to a second object, either a conductor or an insulator, charge in the second object is polarized. Since unlike charge in the second object is nearer the first object, the net force is attractive.

1.4 Fundamental Interactions, Virtual Particles, and Geometric Theories

- Forces can be thought to arise from either the exchange of virtual particles (as with QED) or from the modification of the curvature of space-time (as with general Relativity).

1.5 Physical Models

- Physical models are analogies that behave much like systems that can be found in nature. Good models behave very much like physical systems over a lot of applications. Physical models are not necessarily “true.”

1.6 The Thread Model in Electrostatics

- A simplified version of the rules for the threads of a stationary charge:
 1. The head and tail both of a thread come off from the source in the same direction.
 2. The thread moves in a straight line at the speed of light.
 3. Many short threads are emitted in random directions.
 4. The number of threads emitted is proportional to the charge of the source.
 5. For a positive charge, the direction of the thread is away from the source, for a negative charge, it is toward the source.
 6. The direction of the force on a field particle is in the direction of the threads surrounding the field particle if the field particle is positive and opposite the direction of the threads if the field particle is negative.
 7. The force on a field particle is proportional to a) the charge of the field particle, b) the density of threads near the field particle, c) the length of the threads near the field particle.

1.7 Obtaining Coulomb's Law from the Thread Model

- You do not need to reproduce the mathematics that led us to Coulomb's Law.
- Know Coulomb's Law $\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_s q_f}{r_0^2} \hat{r}_0$ and be able to use it.

1.8 Using Coulomb's Law

- Memorize and be able to use the form $\vec{F} = \frac{q_s q_f \vec{r}}{4\pi\epsilon_0 r^3}$
- Be sure to review how to add vectors and to obtain magnitudes and directions!!

1.9 Force, Energy, and Work

- Potential energy and force are related by the equations $U(x) = -\int F dx$, $F = -\frac{dU}{dx}$.
- When potential energy can be defined, $U + K = E$ which is constant.

1.10 Using Potential Energy

- The potential energy of two point charges is $U(r) = +\frac{1}{4\pi\epsilon_0} \frac{q_s q_f}{r}$.
- Potential energy can be defined for any number of charges, as long as they are stationary

Chapter 2

2.1 How Motion Modifies Threads

- Draw a picture of a thread emitted by a moving source particle. Identify the head line, the tail line, and the ray line, and the angles θ and ψ .
- Threads of a moving particle lie along the ray line.
- Threads are shorter in front of a moving particle and longer behind it.
- Threads are more dense in front of a moving particle and less dense behind it.
- These effects balance, making the force on a field particle the same at forward and backward angles ($\psi = 10^\circ$ and $\psi = 170^\circ$, for example).
- Threads clump up near $\psi = 90^\circ$, so the force is larger there.

2.2 Threads and Moving Train Cars

- Just be sure you understand the head line and the ray line for both stationary and moving cars. We'll redo the math using relativity, so the results are not really valid!

2.3 A Little Relativity

- $\beta = v/c$. $\gamma = 1/\sqrt{1-\beta^2}$. Note that $\beta \leq 1$, $\gamma \geq 1$.
- As an object approaches the speed of light, its length shortens, its mass increases, and its clocks slow down, all by a factor of γ .
- The speed of light is a constant with respect to any observer. No object or signal can

travel faster than the speed of light.

- Be able to describe a reference frame and an inertial frame. The laws of physics are the same in all inertial frames.
- Two events that are simultaneous in one inertial frame are not necessarily simultaneous in another.

2.4 The Relativistic Train Car

- Relativity makes the angle ψ closer to 90° than is θ_0 .

2.5 Moving Source and Stationary Field Particle

- By applying relativity to the motion of a source particle, we can calculate the length and the density of stubs produced by a moving source particle.
- You do **not** need to reproduce the arguments.
- Be able to use Equation 2.6.

2.6 Stubs and the Stub Force

- Stubs are used to account for the motion of field particles.
- The definition of a stub is: $\vec{s} = \hat{r}_h \times \vec{\ell}$
- The stub causes a force that is proportional to the charge of the field particle, the thread density, and $\vec{\beta}_f \times \vec{s}$.

2.7 Electric and Magnetic Forces and Fields

- Electric and magnetic fields are understood in terms of forces. If a field particle is at rest, only electric forces act on the particles. When both the source particle and field particle are in motion, magnetic fields act on them.
- The Lorentz force equation is $\vec{F} = q_f \vec{E}_s + q_f \vec{v}_f \times \vec{B}_s$.
- The electric field depends on thread length and thread density. The magnetic field depends on stub length and thread (or stub) density.
- Know how to use Eqs. (2.16) and (2.17). You do not need to memorize these equations.

2.8 Visualizing Threads, Stubs, and Field Lines

The electric field lines point away from the source along the ray lines. If the source were negative, they would point back toward the source.

- There are more threads in the forward direction than in the backward direction.
- The threads are shorter in the forward direction than in the backward direction.
- The electric field lines are similar in the forward and backward directions, pointing out that the electric field is the same.
- The stubs are at right angles to the threads and form a circular magnetic field lines.
- The direction of the stub for a positive source particle is given by a right-hand rule. Point the thumb of your right hand in the direction of the velocity, and your fingers curl around in the direction of the stubs. If the source were negative, the stubs point in the opposite direction. This is also the direction of the magnetic field lines around the wire. (This is just a consequence of the definition $\vec{s} = \hat{r}_h \times \vec{\ell}$.)

2.9 Finding Forces of Moving Charges (ignore this Fall 2007)

- Be able to reproduce the examples in this section. This may be the hardest thing you have to do for the entire course! I do **not** expect you to do any other similar problems at this point – these examples are hard enough. But try to learn the examples with understanding, don't just memorize the steps.

2.10 The Magnetic Force and Relativity: An Intuitive Example

- If an object moving in the y direction experiences a force in the x direction, the y component of its momentum remains unchanged. Since its mass increases, the y component of its velocity decreases. This is called “mass braking.”
- If the motion of this same particle is viewed from the frame in which the particle is initially at rest, the particle accelerates in the $-y$ direction. In this frame, we have to attribute the motion to a velocity-dependent force. This force is the “stub” or “magnetic” force.

Chapter 3

3.1 The Electric Field of a Stationary Point Charge

- We define the electric field by the relation $\vec{F} = q_f \vec{E}$
- If a field particle is positive, the force on it is in the direction of the electric field. If the field particle is negative, the force is opposite in direction to the electric field.
- The electric field of a point charge is given by Coulomb's Law $\vec{E} = \frac{q_s}{4\pi\epsilon_0 r^2} \hat{r}$
- We can use Coulomb's Law to calculate the electric fields of several point charges by evaluating the electric field from each source charge *at a given field point* and adding the fields vectorially.

3.2 The Fields of Uniformly-Moving Point Charges

- The magnetic field of a point charge can be obtained from its electric field: $\vec{B} = \frac{1}{c} \hat{r}_h \times \vec{E}$
- The force on a charge in an electric and magnetic field is given by the Lorentz Force Law: $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$
- The direction of the magnetic force is given by the cross product of \vec{v} and \vec{B} when the field particle is positively charged and opposite that direction when it is negatively charged. The direction is always perpendicular to both the velocity and the magnetic field.
- Source charges must be in motion to produce a magnetic field.
- Field particles must be in motion to feel the magnetic force.
- Uniform magnetic fields cannot change the kinetic energy of a charge.

3.3 Electric Potential and Voltage

- Electric potential can be defined only for static distributions of charge.

- The electric potential of a charge q is defined as $V = \frac{U}{q}$, so electric potential or voltage

is closely related to potential energy.

- We can obtain the electric potential from the electric field by

$$V(x) = -\int E dx, V(r) = -\int E dr.$$

- We can obtain the electric field from the electric potential by

$$E_x = -\frac{dV(x)}{dx}, E_r = -\frac{dV(r)}{dr}.$$

- More generally $\vec{E} = -\nabla V$. The magnitude of the gradient tells us how rapidly a scalar function varies in space. The direction of a gradient tells us in which direction the function increases most rapidly.

3.4 Field Vectors, Field Lines, and Field Contours

- Given field vectors, know how to construct a field line.
- Field lines always outward from positive and inward toward negative charges.
- Given field lines, know how to construct perpendicular surfaces.
- For field lines, know that the direction of the field is tangent to the field line at a point.
- For field lines, know the following recipe for the magnitude of the field:
Take a section of one perpendicular surface. Count the number of field lines passing through the surface. The magnitude of the field is proportional to the number of field lines piercing the surface section divided by the area of the section
- For field contours, know that the direction of the field is normal to the field contour at a point.
- For field contours, know the following recipe for the magnitude of the field:
Take a segment of one field line. Count the number of field contours pierced by the field line. The magnitude of the field is proportional to the number of surfaces pierced by the segment divided by the length of the segment.

3.5 Static Electric Fields and Potentials in Conductors

- There can be no static electric field inside a conductor.
- The static electric field on the surface of a conductor must be perpendicular to the conductor's surface.
- In the static case, all the charge on a conductor must reside on its surfaces.
- In the static case, the surfaces of a conductor are perpendicular surfaces and equipotential surfaces.

3.6 Force and Motion in Uniform Fields

- The change in kinetic energy of a particle in an electric field is $\Delta K = -q\Delta V$.
- The general motion of a charged particle in a uniform magnetic field is a helical path.
- The cyclotron radius is $p=qBr$. Be able to derive this expression.

3.7 Devices Using Electric and Magnetic Fields

- Be able to describe how linear accelerators, cyclotrons, and mass spectrometers work.
- Knowing the formula for the cyclotron radius, find the cyclotron frequency.

- Given the charge on an ion, the mass of the ion, the accelerating voltage, and the magnetic field, be able to find the radius of curvature for an ion in a mass spectrometer.

Chapter 4

4.1 Electric Fields in Wires

- Current is the rate charge flows through a circuit.

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

- Electrons flow in the opposite direction to current flow.
- The voltage of an electron in a circuit is related to its potential energy by the equation $U = qV$.
- A battery is a device that increases the potential energy of electrons.

4.2 Resistance, Ohm's Law, and power in circuits

- The potential energy of electrons decreases when the electrons lose energy in collision with atoms in matter. Matter is said to have resistance.
- Resistance is defined by the relation $V = IR$. When R is constant, this is termed "Ohm's Law."
- The power dissipated in a resistor is $P = IV$.

4.3 Resistivity and Resistors

- The resistance of a resistor is given in terms of its resistivity as $R = \rho \frac{\ell}{A}$
- Conductivity is the reciprocal of resistivity.
- The temperature dependence of resistance is given by $R = R_0[1 + \alpha(T - T_0)]$

4.4 Resistance Circuits

- Current can flow into (or out of) a "ground" in unlimited amounts without changing the grounds potential energy. We say the earth is at a potential of 0 V.
- The power dissipated by resistors in a circuit is the same as the power provided by the batteries.
- In a resistor, voltage drops in the direction of current flow.

4.5 Resistors in Series and Parallel

- In series and parallel circuits, the current, voltage, and resistance of equivalent resistors is given by:

$$I = I_1 = I_2$$

$$V = V_1 + V_2$$

$$R = R_1 + R_2$$

$$I = I_1 + I_2$$

$$V = V_1 = V_2$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

4.6 Series-Parallel Reduction

- Study this example carefully and be able to apply series-parallel reduction to circuits.

4.7 Real Batteries

- Batteries have internal resistance.
- The voltage of a battery is divided between the load and the internal resistance.
- As batteries age, the internal resistance increases.

4.8 Kirchoff's Laws

- Current coming into a junction must leave the junction.
- The net change in voltage around any closed loop in a circuit must equal zero.
- If there are N junctions, there are $N - 1$ independent junction equations.
- The remaining equations are loop equations. There must be at least one loop covering every circuit element.
- You need to be able to set up a series of equations that can be solved for the currents, but you do not need to solve those equations, except in very simple cases.

4.9 Drift Speed and Electron Velocity

- The drift speed of electrons is very slow ($\sim 10^{-4}$ m/s).