PHYS 1P92 Electromagnetism, Optics, and Modern Physics

Key Ideas from PHYS 1P91

- If $\vec{v}$ is in the direction of acceleration then it is speeding up
- If $\vec{v}$ is opposite to the acceleration then it is slowing down.
- Newtons Second Law: $a = \frac{f}{m}$, f is the cause, m is the response function, and a is the effect.
- Newtons First Law: If $\vec{f} = 0$, then $\vec{a} = 0$ and the objects trajectory is a straight line constant speed.
- Newtons Third Law: Forces come in pairs.
- Conservation of Mechanical Energy.
  - Kinetic Energy → $KE = \frac{1}{2}mv^2$
  - Potential Energy → $PE = U = -W_c$
  - Total mechanical energy is conserved when the work done by non-conservative forces is 0.
- Conservation of Linear Momentum
  - $p = m\vec{v}$
  - Momentum is conserved when the sum of the exterior forces is zero.

Oscillations and Waves.

Net force

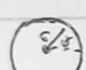
- Net force determines an objects trajectory.
-

F_{net}	
Constant	Straight line is $\vec{v}$ is $\parallel$ to $\vec{F}$, parabola if not
Centripetal	Circular (F_n has constant magnitude but center facing at all times)
Spring force (Size + Direction change)	Produces Oscillations.

Spring force

- Refer to Hooke's Law
- $F = -Kx$, where x is the displacement from equilibrium, and K is the spring constant $\left(\frac{N}{m}\right)$
- Spring force produces oscillations.

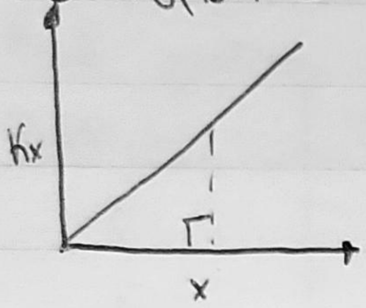
Uniform Circular Motion

- 
- Position, $\theta = \omega t$, where ω is ~~the~~ angular velocity $\left(\frac{rad}{s}\right)$
- $\omega = 2\pi f$, f is frequency $\left(\frac{cycles}{time}\right)$ and is measured in Hz $\left(\frac{1}{s}\right)$
- Velocity, $\vec{v} = -A\omega \sin(\omega t)$, A = amplitude (m)
- Acceleration, $\vec{a} = -\omega^2 A \cos(\omega t)$

Important formula

- $m\omega^2 = K$.
- Many substitutions can be made, i.e. $(\omega = 2\pi f)$

Energy in Simple Harmonic Oscillators.

- We cant use $W = \vec{F} d \cos\theta$ because it is an oversimplification for work
- And Since the force is constant changing we cannot accurately define it using that equation.
- Derivation of Energy in SHO and in Springs.
- 

$$A = \frac{1}{2} bh \rightarrow W = \frac{1}{2} x (Kx)$$
$$W = \frac{1}{2} K x^2$$

} Graphically

- $E_{TOT} = K + U$

$$= \frac{1}{2} mv^2 + \frac{1}{2} Kx^2 \rightarrow \frac{1}{2} m(-A\omega \sin(\omega t))^2 + \frac{1}{2} K(A \cos(\omega t))^2$$
$$= \frac{1}{2} \cancel{m} A^2 \cancel{\omega^2} \sin^2(\omega t) + \frac{1}{2} K A^2 \cos^2(\omega t)$$
$$= \frac{1}{2} K A^2 \sin^2(\omega t) + \frac{1}{2} K A^2 \cos^2(\omega t)$$
$$= \frac{1}{2} K A^2 (\sin^2(\omega t) + \cos^2(\omega t))$$
$$= \frac{1}{2} K A^2$$ ← This means that when, m, is at A, all energy is potential

- Never use Kinematic equations when dealing with SHO, $\vec{a}$ is not constant.

Electrostatics

Atoms

- Made of nucleus, protons, neutrons, electrons.
- protons and neutrons are in the nucleus.
- Atomic Number is the number of protons
- # of protons ≈ # of neutrons.
-

Particle	Charge	Mass
p	+e	1.67×10^{-27}
e^-	$-e$	9.11×10^{-31}
n	0	$m_n \approx m_p$

Charge and Properties of Charge

- Charge is the state a molecule is in due to its count of p and e^-.
- 4 Properties of Charge
  1. Charge can either be +/-
  2. Charge is quantized
     - Elementary Charge = $e = 1.602 \times 10^{-19}$ C
  3. Charge is conserved (Net charge of a system is constant).
  4. The force felt by charges that was discovered by Coulomb is calculated by $|\vec{F}| = k\frac{q_1 q_2}{r^2}$ or $\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$

Nuclear/Particle Physics Reaction

- Electron-Positron Annihilation
- Positron is the antiparticle to e^- (same mass but opposite charge)
- $e^- + e^+ \Rightarrow$ Gamma ray photon (Particle of light).
- 

Coulombs Law

- Like charges repel, unlike charges attract
- $\vec{F}_E = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \rightarrow \frac{k q_1 q_2}{r^2}$, where k and ε_0 are constants, q is the point charge(s), and r is the distance between them
- $\varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{Nm^2}$, $k = 8.99\times10^{9}\ \frac{Nm^2}{C^2}$

Comparing the Size of the Electric Force to Gravity

- Assume e^- performs uniform circular motion
- 

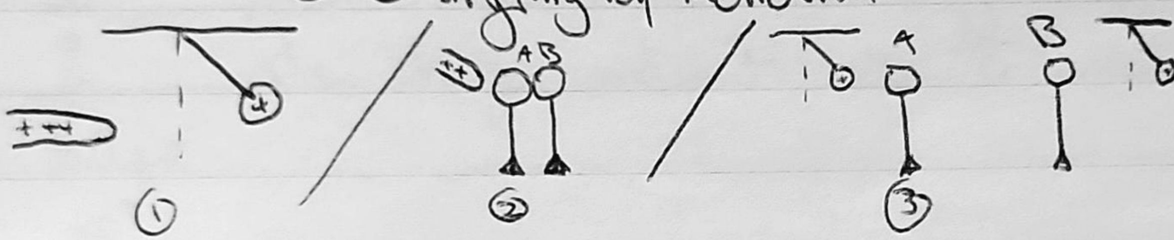
- $\vec{F}_g = \frac{G m_e m_p}{r^2}$ $\quad \vec{F}_E = \frac{k q_1 q_2}{r^2}$
- $\frac{F_E}{F_g} = \frac{kq^2}{G m_E m_p} \approx 10^{39}$

Metals and Insulators

Materials

- Metal - Some e^- are free to move
- Insulators - e^- are not free to move
- Charging Objects - or transfer of e^- (not p)

Charging Processes

- 2 Types: ① Charging by friction
  ② Charging by induction
- 

- ① ~~A~~ A positively charged rod repels the positively charged ball
- ② When the positively charged rod is brought close to the 2 neutral spheres, the free electrons move to the charged
  ③ When the balls are ~~separ~~ separated, they are now charged and either attract or repel the ball depending on their charge

18.4 Electric Fields

Concept of a field.

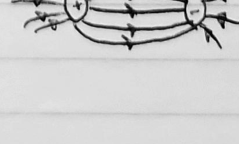
- A field is a way conceptualizing and mapping a force that surrounds any object and acts on another object at a distance without apparent physical contact.
- In Columbs Law, $F = \frac{kq_1q_2}{r^2}$ depends on a point charge and on a test charge.
- The simplify things we prefer that the field depends on the point charge rather than the test charge.
- $\vec{E} = \frac{F}{q}$, where F is the electrostatic force, and q is the charge, and units are $\frac{N}{C}$.
- $\vec{E} = \frac{kQ\cancel{q}}{\cancel{q}r^2}$

$\vec{E} = \frac{kQ}{r^2}$

18.5 Electric Field Lines.

- Drawing lines to represent electric fields around charged objects are useful in visual strength and direction since it is a vector.
- For an electric charge, if it is negative they point radially inward.

- For positive charges, they point radially outward.

- Like Charges:  Opposite Charges: 

Eletric field due to 'Continuous' Charge Distribution.

- Uniform line of charge $\lambda = \frac{\text{Charge}}{\text{Length}}$
- Uniform sheet of charge $\sigma = \frac{\text{Charge}}{\text{area}}$
- $\vec{E} = \frac{\lambda}{2\pi\epsilon_0 d}$
- Infinite Plane (Eletric field is perpendicular)

$$\vec{E} = \frac{\sigma}{2\epsilon_0}$$

Motion of e^-, in constant $\vec{E}$

- When an e^- is placed in a constant electric field the we can find its motion ~~or~~ or acceleration from

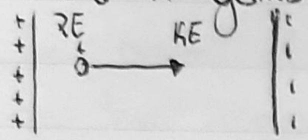
$$\vec{F} = q\vec{E}$$

$$ma = q\vec{E}$$

$$a = \frac{q\vec{E}}{m}$$

19 Electric Potential and Electric field

19.1 Electric Potential Energy: Potential Difference

- When a free charge is accelerated in an electric field it gains kinetic energy.
- 

- The sign on the charge indicates in which way it will accelerate ($+$ charge $\vec{a}$ $-$) ($-$ charge $\vec{a}$ $+$)
- We know $W = Fd\cos\theta$ and $F = qE$, so we define electric potential as $V = \frac{U}{q}$, where U is the potential energy and V is in volts $\left(\frac{J}{C}\right)$
- This is the electrical potential energy per unit charge.
- Electron Volt
  - $1\ eV = 1.602 \times 10^{-19}\ J$

19.2 Electric Potential in a Uniform Electric field

- Parallel plates allow for simple equations to be made.
- For parallel plates, $E = \frac{V}{d}$, where E is the electric field.
- Derivation → $W = qV$

$$\cancel{q}Ed = \cancel{q}V$$

$$E = \frac{V}{d}$$

- This is the relationship of the electric field and voltage for parallel plates and uniform electric field.

19.3 Electrical Potential Due to a Point Charge.

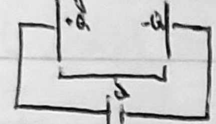
- The electric potential for a point charge is given by $V = \frac{kQ}{r}$, where k is $9\times10^9 \frac{N\,m^2}{C^2}$

19.4 Equipotential Lines.

- Electric fields and electric potential are heavily related.
- We can imagine this graphically by ~~estimating~~ drawing lines where the electric potential is constant.
- Electric field. Electric Potential

- When these two are combined we see that the electric field and the electric potential is perpendicular.
- The Electric potential lines are called equipotential lines.
- Parallel Plates Example.

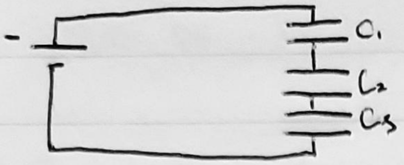
19.5 Capacitors and Dielectrics

- A capacitor is a device that is used to store charge.
- 

- The amount of charge a capacitor can store depends on two major factors, which are the applied voltage and size.
- The parallel plate capacitor is the simplest form of this
- Capacitance can be calculated by the formula
  $C = \frac{Q}{V}$ → where Q is charge, and V is voltage,
  (C units = Farads (F) = $1\frac{C}{V}$)
- Coming back to the parallel plate capacitor, the capacitance ca be found in the equation
  $C = \varepsilon_0 \frac{A}{d}$, where A is Area of the plate, d is the distance between them, an ε_0 is the permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m}$
- Dielectric
  - You can only make the ~~plates~~ distance so small to increase capacitance.
  - The space in between the capacitors can be filled with an insulator called a dielectric to increase capacitance.
  - $C = \kappa \varepsilon_0 \frac{A}{d}$, where κ is the dielectric constant.

19.6 Capacitors in Series and Parallel

- Capacitors in Series.

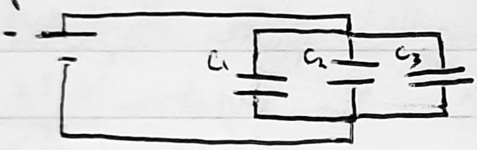


- $V_{TOT} = V_1 + V_2 + V_3$

$$\frac{Q}{C_{TOT}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

- Capacitors in Parallel



- $Q_{TOT} = Q_1 + Q_2 + Q_3$

$$C_{TOT}\cancel{V} = C_1 V + C_2\cancel{V} + C_3 V$$

$$C_{TOT} = C_1 + C_2 + C_3$$

19.7 Energy Stored in Capacitors.

- Capacitors store potential energy
- Its stored in the electric field.
- $U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$
- Q = Charge, V = Voltage, C = Capacitance.

20 Electric Current, Resistance, and Ohm's Law

20.1 Current

- Current is the rate at which charge flows
- $I = \frac{\Delta Q}{\Delta t}$, where Q is ~~columbs~~ charge (C), t is time, and I is measured in Amps ($A = \frac{C}{s}$)
- Drift Velocity
  - Electric signals move very fast, sometimes at around 10^8 m/s
  - The average velocity of the electron is ≈ 0
  - Drift speed is introduced, which tells us the average velocity of the free charges.
  - $v_d = v_i + at$

    $v_d = \frac{qE\tau}{m}$, where q is the charge, E is the electric field, τ is the time inbetween collisions, and m is the mass.
- Drift Velocity and Current have a relationship together.
- $I = nqAv_d$, where n is the number of free charges per unit volume, q is the charge, A is the cross sectional area, and v_d is the drift velocity.

20.2 Ohm's Law: Resistance and Simple Circuits

- Ohms Law
  - German Physicist Georg Simon Ohm demonstrated that current flows through most substances with an applied voltage.
  - He found $I \propto V$

- Resistance and Simple Circuits
  - The electric property that impedes current is called resistance.
  - Resistance is, $I \propto \frac{1}{R}$
  - This gives the relationship $I = \frac{V}{R}$.
  - Resistance is also measured in ohms (Ω) which is equal to $1 \frac{V}{A}$.

20.3 Resistance and Resistivity

- Material and Shape Dependence of Resistance.
- Resistance is proportional to its length, L, and inversely proportional to its area, A.
- ~~Also define~~ $R = \rho \frac{L}{A}$, where ρ is resistivity, L is length, and A is area of the cross section

20.4 Electric Power and Energy

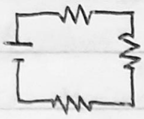
- $P = IV$, $\frac{V^2}{R}$, $I^2 R$, power is in watts.

20.5 Alternating Current vs Direct Current.

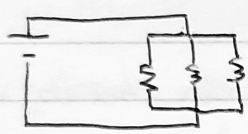
- Direct Current (DC) is the flow of electric charge in one direction
- Alternating Current (AC) is the flow of electric charge that periodically reverses directions.
- Average power $= \frac{IV}{2}$, ...

21 Circuits and DC Instruments

21.1 Resistors in Series and Parallel

- Resistors in Series
  - 
  - $V_{TOT} = V_1 + V_2 + V_3$

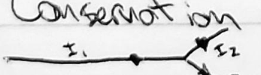
    $\cancel{I} R_{TOT} = \cancel{I} R_1 + \cancel{I} R_2 + \cancel{I} R_3$

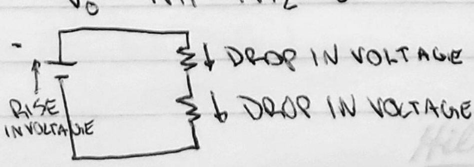
    $R_{TOT} = R_1 + R_2 + R_3$
- Resistors in Parallel
  - 
  - $I_{TOT} = I_1 + I_2 + I_3$

    $\frac{\cancel{V}}{R_{TOT}} = \frac{\cancel{V}}{R_1} + \frac{\cancel{V}}{R_2} + \frac{\cancel{V}}{R_3}$

    $\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

21.3 Kirchoff's Rules

- Kirchoff's Current Rule (KCR)
  - The sum of all currents entering a junction must equal the sum of all currents leaving the junction.
  - Conservation of charge
  - 

    $I_1 = I_2 + I_3$
- Kirchoff's Voltage Rule (KVR)
  - The algebraic sum of changes in potential around any closed circuit path (loop) must be zero.
  - $V_0 - IR_1 - IR_2 = 0$.
  - 

21.4 DC Voltmeters and Ammeters.

- Voltmeters
  - Voltmeters are connected in parallel with whatever devices voltage is being measured. A parallel connection is used because objects in parallel experience the same potential difference.
  - Volt meters have a very large resistance
  - $V = I(R + r)$, where R is large Resistor and r is the small resistor
- Ammeters
  - Ammeters are connected in series with whatever devices current is being measured. A series connection is used because objects in series have the same amount of current passing through them.
  - Ammeters have small resistances.
  - $\Delta V = \Delta V$

    $I_1 R_1 = I_2 R_2$

    $\frac{I_1}{I_2} = \frac{R_2}{R_1}$

21.6 DC Circuits ~~Con~~taining Resistors and Capacitors.

- RC Circuits
  - An RC circuit is one containing ~~an~~ resistor and a capacitor
  - Charging Capacitors

    $\Delta V_c = V_0 (1 - e^{-\frac{t}{RC}})$, where t is time, RC is resistance and capacitance.
  - Discharging Capacitors

    $\Delta V_c = V_0 e^{-\frac{t}{RC}}$

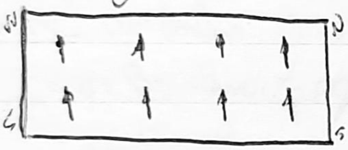
22 Magnetism

22.1 Magnets

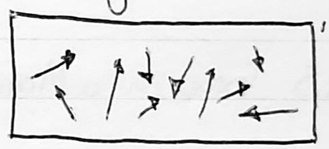
- Magnets have universal characteristics
- Like poles repel, unlike poles attract
- It is impossible to have seperate poles (splitting magnets just makes smaller magnets)
- A bar magnet is a magnetic dipole.

22.2 Ferromagnets and Electromagnets

- Few materials ~~have~~ have strong magnetic effects
- Those materials are ferro magnetic
- Ferro magnets can be magnitized or induced to be made magnetic
- Ferromagnetic Structure



Paramagnetic Structure



- Electromagnetism is the use of current to make magnetic fields and it also makes temporary magnets.
- Current is the source of all magnetism

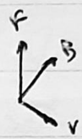
22.3 Magnetic Fields

- 

- 1- The direction of the magnetic field is tangent to the field
  2- The strength of the field is proportional to the closeness of the lines
  3- Magnetic field lines can never cross
  4- Magnetic field lines ~~can never~~ are continuous, no beginning or end.

22.4 Magnetic Field Strength: Force on a Moving Charge.

- It is important to understand that moving charge (current) creates the magnetic field but charge also experiences the magnetic field
- This can be calculated and is seen in the equation $F_{mag} = qvB\sin\theta$, where q is charge, v is velocity, B is the magnetic field strength, and θ is the angle between B and v.
- The direction of the magnetic force can be found by the right hand rule.
- For a positive charge:



f = Palm
B = Fingers
v = Thumb.

- Note: When a vector is shown going into the page it is represented by ⊗ and when it comes out it is represented by ⊙

22.5 Force on a Moving Charge Applications.

- Magnetic force can cause a charged particle to move in a circular path.
- This relation links magnetic force and uniform centripetal motion
- $F_{net} = ma_c$

  $qvB = \frac{mv^2}{r}$

- Since $v = \frac{2\pi r}{T} \Rightarrow T = \frac{2\pi m}{qB}$

22.6 The Hall Effect

- Magnetic field effects charges moving in a conductor
- The voltage across a current carrying conductor by a magnetic field ~~area~~ is known as the Hall Effect
- $qE = qvB$
- $E = vB$ $\qquad E = \frac{V}{l}$

$$\frac{V}{l} = vB$$

$V = vBl$, where V is the hall emf, and l is the width of the conductor

22.7 Magnetic Force on a Current-Carrying Conductor.

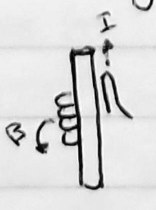
- The magnetic force on charge moving in a conductor is transmitted to the conductor itself
- $F_{mag} = qvB\sin\theta$ $\qquad v = \frac{d}{t} = \frac{L}{t}$

$$= \frac{qL}{t} B\sin\theta$$

$$= \frac{q}{t} L B\sin\theta \qquad \frac{q}{t} = I \text{ current.}$$

$$F_{mag} = ILB\sin\theta$$

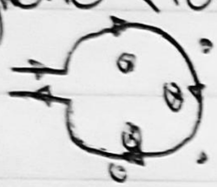
- Direction magnetic field is found by the corkscrew rule



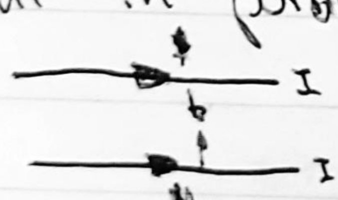
Thumb points parallel and in the direction of the current, fingers curl in direction of B.

22.9 Magnetic Fields Produced by Currents

- Magnetic field Created by a Long Straight Wire
  - Same concept as corkscrew rule
  - $|\vec{B}| = \dfrac{\mu_0 I}{2\pi r}$, where μ_0 is $4.7\times10^{-7}\,\frac{Tm}{A}$, I is current, and r is the distance from the wire
  - 

- Magnetic field Created by a Single Loop
  - 
  - $|\vec{B}| = \dfrac{\mu_0 I}{2R}$, where R is the radius of the loop
- Magnetic field Created by a Solenoid
  - $|\vec{B}| = n\mu_0 I$, where n is the number of turns per unit length $\left(\frac{turns}{m}\right)$.
- Note: Current in parallel but opposite directions repel

Current in parallel but like directions attract



23 Electro magnetic Induction, and AC Circuits

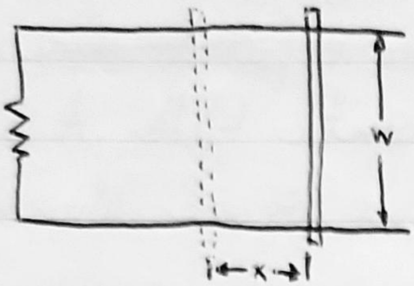
23.1 Induced Emf and Magnetic flux

- Magnetic flux is a measurement of total magnetic field which passes through an area ~~with respect to time~~.
- $\Phi = BA\cos\theta$, where B is the magnetic field, A is the area and θ is the angle between B and the normal.
- The three ways to change flux would be by changing the size of B, changing the area, or changing the angle.
- Magnetic flux also produces an emf or voltage/potential difference
- V or $\mathcal{E} = -\dfrac{\Delta\Phi}{\Delta t}$, Φ = flux, t = time
- This is called faraday's law and is described as the change in flux over time.

23.2 Faraday's Law of Induction: Lenz's Law

- Faraday's law = $\mathcal{E} = -N\dfrac{\Delta\Phi}{\Delta t}$, where N is the number of turns in the coil.
- The negative sign in the equation was introduced by Lenz's law which states the direction of the current induced by a changing magnetic field will create a field that opposes it.
- If Φ increasing, induced B in opposite direction
- If Φ decreasing induced B in same direction

23.3 Motional Emf.

- This chapter shows how a rod in a circuit can be used to calculate things like speed of the rod etc.
- 

$$\mathcal{E} = -\frac{\Delta \Phi}{\Delta t}$$

$$= -\frac{\Delta B \, \Delta A \cos \Delta\theta}{\Delta t}$$

$$= -\frac{B(w\,\Delta x)}{\Delta t}$$

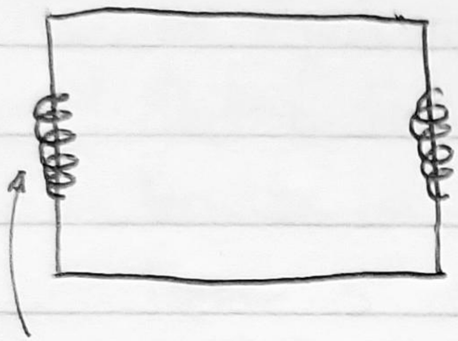
$$= -Bw\frac{\Delta x}{\Delta t}$$

$$\mathcal{E} = -Bwv.$$

23.5 Electric Generators

- Eletric generators turn mechanical energy into electrical energy
- This is all based on changes in the angle.
- $\mathcal{E} = -NBA\omega \sin \omega t$, $\omega = \frac{\Delta\theta}{\Delta t}$, $\omega = 2\pi f$.
- ω is angular frequency.
- Period should be able to be found.

23.7 Transformers

- Transformers do what their name implies, they transform voltages from one value to another.
- They do this by having coils to introduce a flux
- 

Secondary Coil (V_2).
- N_2 turns

Primary Coil (V_1)
- N_1 turns

- The flux in the coils are equal as well, this allows us to write the expression.

$$\frac{V_1}{N_1} = \frac{V_2}{N_2}.$$

- Also if we assume there is no power loss we find the relation

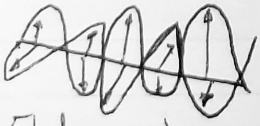
$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}$$

24 Electromagnetic Waves.

24.1 Maxwell's Equations

- James Clarck Maxwell made a set of equation that show the relationship of electromagnetism.
- Maxwells Equations
  1- Electric field lines originate on positive charges and terminate on negative charges. The strength of the force is also related to the electrical constant ϵ_0
  2- Magnetic fields are continuous and magnetic monopoles don't exist. The strength of the magnetic force is related to the magnetic constant μ_0.
  3- A changing magnetic field induces an electric field. and the direction of it opposes the change.
  4- Magnetic fields are generated by moving charges or by changing electric field.
- Maxwell also found that $\frac{1}{\sqrt{\epsilon_0 \mu_0}}$ is equal to the speed of light.
- Heinrich Hertz observed electromagnetic waves by having a transmitter and reciever and both had a spark gap that the current flowed across.

24.2 Production of Electromagnetic Waves.

- 
- 
- Electro and magnetic waves propagate perpendicular to each other.
- Electro magnetic waves are transverse waves.
- $\vec{E} = c\vec{B}$, where E is the electric field, c is the speed of light, B is the magnetic field.

24.3 The Electromagnetic Spectrum

- Frequency, wavelength, and speed have a relationship together.
- It is $c = \lambda f$, where c is the speed of light, λ is wavelength, f is frequency.
-

Type of EM	Production	Applications	f (Hz)
Radio/TV	Accelerating charges	Communications	$10^{0} \to 10^{12}$
Microwaves	Accelerating charges & thermal agitation	Communications, ovens, Radar	$10^{8} \to 10^{12}$
Infrared	Thermal agitations & electronic transmission	Heat Imaging.	$10^{10} \to 10^{14}$
Visible Light	" "	All perrosive	10^{5}
Ultra violet	" "	Cancer Control	$10^{15} \to 10^{18}$
X-Rays	Electronic transitions and collisions	Medical	$10^{16} \to 10^{20}$
Gamma Rays	Nuclear Decays	Medical	$10^{18} \to \ldots$

24.4 Energy in Electromagnetic Waves.

- Energy Density $= \frac{\text{Energy}}{\text{volume}} = \frac{\epsilon E^2}{2} + \frac{B^2}{2\mu_0}$
- Intensity $= \frac{\text{Power}}{\text{Area}} = \frac{\epsilon_0 E^2 c}{2}$

27 Wave Optics

27.1 The Wave Aspect of Light: Interference

- Electromagnetic light obeys the equation $c = \lambda f$.
- It also reacts with the medium its in.
- The wavelength in a medium can be seen as $\lambda_n = \frac{\lambda}{n}$

where n is the index of refraction.