IB Physics SL/HL 1 Study Guide

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Fundamental Constants: Quantity / Symbol

- Acceleration of free fall / g
- Gravitational constant / G
- Avogadro's constant / N_A
- Gas constant / R
- Boltzmann's constant / k_B
- Stefan-Boltzmann constant / σ
- Coulomb constant / k
- Permittivity of free space / ϵ_0
- Permeability of free space / μ_0
- Speed of light in vacuum / c
- Planck's constant / h
- Elementary charge / e
- Electron rest mass / m_e
- Proton rest mass / m_p
- Neutron rest mass / m_n
- Unified atomic mass unit / u
- Solar Constant / S
- Fermi radius / R_0

Measurement

- SI Units- Standard units of measurements consisting of the following:
    - Length/ Meter/ m
    - Time/ Seconds/ s
    - Amount of substance/ Mole
    - Electric Current/ Ampere/ A
    - Temperature/ Kelvin/ K
    - Luminous Intensity/ Candela/ cd

  - Mass/ Kilogram/ kg
- From here, units are derived, such as Joules, which is force*distance, so $N * m$

Kinematics in One Direction

- Position of a particle is the position in respect to the origin, the unit being "s"
- This is called displacement, different from distance
  - Displacement is a vector quantity, if it's positive it has moved in the positive direction, and if it's negative it has moved in the negative direction
- $Average\ Speed = \frac{total\ distance}{Total\ Time}$
- Instantaneous Velocity is the velocity at the given moment

$$v = lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- Average Acceleration

$$a_{avg} = \frac{\Delta v}{\Delta t}$$

- Average Velocity

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

- Constant acceleration (more equations to solve)

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

$$s = \frac{1}{2}(u + v)t$$

- Free Fall Acceleration
  - We refer to motion vertically, and replace acceleration with g, which is the magnitude of the free-fall acceleration

$$g = 9.8m/s^2$$

Vectors

- Scalers only contain magnitude
- Vectors have both magnitude and direction, and obey the rules of algebra
- Components of a Vector

- Components are given by: $a_x = a\cos\theta$, and $a_y = a\sin\theta$
- We can also find magnitude and orientation of vector a with: $a = \sqrt{{a_x}^2 + {a_y}^2}$

Kinematics in Two and Three Directions

- Projectile Motion is the motion of a particle that is launched with an initial velocity
- During its flight, the particle's horizontal acceleration is 0, and it's vertical acceleration is -g

$$s_x = (u\cos\theta)t$$
$$s_y = (u\sin\theta)t - \frac{1}{2}gt^2$$
$$v_y = u\sin\theta - gt$$

- Uniform Circular Motion
    - If a particle travels along a circle or circular arc of radius r at constant speed v, it is in uniform circular motion and has an acceleration of constant magnitude

$$a = \frac{v^2}{r}$$

    - The direction of acceleration is towards the center of the circle or circular arc, and the acceleration is centripetal
    - T is the time for the particle to complete the circle, also called the period of revolution, or period

$$T = \frac{2\pi r}{v}$$

- Relative Motion
    - When 2 frames of reference A and B are moving relative to each other at constant velocity, the velocity of particle P as measured by an observer in frame A usually differs from measured from frame B

$$v_{PA} = v_{PB} + v_{BA}$$

Force and Motion

- Force is a vector quantity
- Net force is the vector sum of all the forces acting on the body
- Newton's First Law

- An object in motion stays in motion, and an object at rest stays at rest unless acted upon by an external, unbalanced force

- Newton's Second Law
  - The rate of change of momentum of a body is directly proportional to the force applied.
  - A free body diagram is a stripped down diagram in which only one body is considered, the external forces on the body are drawn
  - A gravitational force on a body is a pull by another body, usually the earth

$$F_g = mg$$
$$W = mg$$

  - A normal force is the force on a body from the surface against which the body presses, always perpendicular to the surface
  - A Frictional force is the force on a body when the body slides along a surface, always parallel to the surface
- Newton's Third Law
  - If object *A* exerts a force $\mathbf{F}_A$ on a object *B*, then *B* simultaneously exerts a equal but opposite force $\mathbf{F}_B$ on *A*,
- Friction
  - When a force tends to slide a body along a surface, a frictional force acts upon the body
  - If the body does not slide, the frictional force is a static friction
  - If the body does slide, the frictional force is kinetic
  - The magnitude of $F_s$has a maximum value, given by

$$f_{smax} = \mu_s F_N$$

    - Where $\mu_s$is the coefficient of static friction

$$f_k = \mu_k F_N$$

    - Where $\mu_k$is the coefficient of kinetic friction
- Uniform Circular Motion
  - Net centripetal force

$$F = \frac{mv^2}{R}$$

Work and Kinetic Energy

- Kinetic Energy

$$E_k = \frac{1}{2}mv^2$$

- Work is the energy transferred from an object from a force acting on the object

$$W = Fdcos\theta$$

- For a particle, the change in kinetic energy equals the net work done on the particle
- Spring force
  - $F_s = -kx$ (hooke's law)
  - K is the spring constant, and x is the displacement of the spring
- Work done by the spring

$$W_s = \frac{1}{2}kx^2$$

- Power is the rate at which the force does work on an object

$$P_{avg} = \frac{W}{\Delta t}$$

P = Fv

Potential Energy and the Conservation of Energy

- A force is a conservative force is the net work it does on a particle moving around any closed path, from an initial point and then back to the point is zero
- Kinetic frictional force is a non conservative force
- Potential energy is the energy that is associated in which a conservative force acts
- Gravitational potential energy is the potential energy associated with a system consisting of the earth, and a nearby particle is the GPE

$$E_p = mgh$$

  - Where h is the height
- If there is a turning point where the particle reverses its motion, the kinetic energy is equal to 0
- Work done on an external force $W = E_k + E_p$
- Elastic Potential Energy

$$EPE = \frac{1}{2}kx^2$$

- Mechanical Energy

$$E_{mec} = E_k + E_p$$

- Conservation of Energy
  - The total energy E of a system can only chance by amounts of energy that are transferred to or from the system

$$\frac{1}{2}mv^2{}_i + mgh_i = \frac{1}{2}mv^2{}_f + mgh_f$$

    - Where i is initial, and f is final

Linear Momentum

- p = mv
- Impulse

$$J = F_{avg}\Delta t$$

$$F_{avg} = -\frac{\Delta m}{\Delta t}\Delta v$$

- Conservation of Linear Momentum
  - If a system is isolated so that no net external force acts on it, the linear momentum of the system remains constant

$$P_i = P_f$$

- Inelastic Collision in One Dimension
  - In an inelastic collision of 2 bodies, the kinetic energy of the two-body system is not conserved
  - If the system is closed and isolated, the total linear momentum of the system must be conserved

$$P_{1i} + P_{2i} = P_{1f} + P_{2f}$$

  - If the motion of the bodies is along a single axis and the collision is one dimensional:

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

    - If the bodies stick together, the collision is completely inelastic collision and the bodies have the same final velocity
- Elastic Collisions in One Dimension
  - A special type of collision in which the kinetic energy of a system of the colliding bodies is conserved
  - If system is closed and isolated, the linear momentum is also conserved
- Collisions in Two Dimensions

$$P_{1i} + P_{2i} = P_{1f} + P_{2f}$$

- If the collision is also elastic, $K_{1i} + K_{2i} = K_{1f} + K_{2f}$

Rotation

- Angular Position
  - To describe the rotation of a rigid body about a fixed axis, called the rotation axis, we assume there is a reference line in the body, perpendicular to the axis and rotating with the body

$$\theta = \frac{s}{r}$$

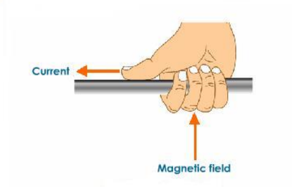
  - 1 revolution = 360° = 2πrad
- Angular Displacement

$$\Delta\theta = \theta_2 - \theta_1$$

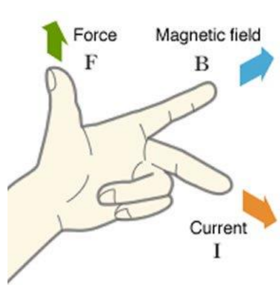
- Angular Velocity and Speed
  - If a body rotates through an angular displacement in a time interval, its average angular velocity is

$$\omega_{avg} = \frac{\Delta\theta}{\Delta t}$$

  - We use the right hand rule to see the direction of the velocity, thumbs up, facing the direction of the current, fingers facing direction of magnetic field



  - Another right hand rule is known as the fleming's right hand rule when force is involved



- Angular Acceleration

$$a_{avg} = \frac{\Delta\omega}{\Delta t}$$

- Work and Rotational Kinetic Energy
  - If the body rotates through an angle, the point moves along an arc with length s given by: $s = \theta r$
  - The linear velocity of the point is tangent to the circle, and the point's linear speed is given by: $v = \omega r$
  - The linear acceleration of the point has both tangential and radial components, the tangential component is: $a_t = \alpha r$
  - The radial component is: $a_r = \omega^2 r$
  - If the point moves in uniform circular motion, the period T of the motion for the point and the body is: $T = \frac{2\pi}{\omega}$

Gravitation

- The Law of Gravitation

$$F = G\frac{m_1 m_2}{r^2}$$

  - G = 6.67* $10^{-11} Nm^2/kg^2$
- Gravitational Potential Energy
  - The gravitational potential energy of a system of two particles with masses M and m separated by a distance of r
    - GPE= $-\frac{GMm}{r}$
- Gravitational Acceleration

$$a_g = \frac{GM}{r^2}$$

- Kepler's Laws
  - The law of orbits
    - All planets move in elliptical orbits with the sun at one focus
  - The law of areas
    - A line joining any planet to the sun sweeps out equal areas in equal time intervals
  - The law of periods

- The square of the period T of any planet is proportional to the cube of the semimajor axis a of its orbit

$$T^2 = (\frac{4\pi^2}{GM})r^3$$

Oscillations

- Frequency
  - The frequency f is the number of oscillations per second, measured in hertz
- Period
  - The period T is the time required for one complete oscillation or cycle

$$T = \frac{1}{f}$$

- Angular Frequency is related to the period and frequency of the motion by: $\omega = 2\pi f$
- Linear Oscillator
  - A particle with mass m that moves under the influence of a Hooke's law restoring force exhibits simple harmonic motion with
  - $\omega = \sqrt{\frac{k}{m}}$ (angular frequency)
  - $T = 2\pi\sqrt{\frac{m}{k}}$ (period)
- Pendulums
  - Simple Pendulum: $T = 2\pi\sqrt{L/g}$
- Resonance
  - The velocity amplitude of the system is greatest in resonance

Waves

- Transverse and Longitudinal waves
  - Mechanical Waves can only exist in material media and are governed by Newton's laws of motion
  - Transverse mechanical waves are waves in which it oscillates perpendicular to the waves direction of travel
  - Longitudinal waves oscillates parallel to the wave's direction of travel
- Sinusoidal waves

- y = $Asin(kx - \omega t)$ *Notations may differ from textbook to textbook
    - Where A is the amplitude of the wave, k is the angular wave number, $\omega$is the angular frequency, and kx-$\omega t$is the phase
    - The wavelength is: $k = \frac{2\pi}{\lambda}$
    - The wave speed is: $v = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f$
- Resonance
    - Standing waves on a string can be set up by a reflection of traveling waves from the ends of the string
    - If an end is fixed, it must be the position of a node
        - This limits the frequencies at which standing waves will occur on a given string
    - Each possible frequency is a resonant frequency, and the corresponding standing wave pattern is an oscillation mode

$$f = \frac{v}{\lambda} = n\frac{v}{2L}$$

- Sound intensity
    - The intensity I of a sound wave at a surface is the average rate per unit area which energy is transferred by the wave through or onto the surface:

$$I = \frac{P}{A}$$

    - The intensity at a distance r from a point sources that emits sound waves of power P is:

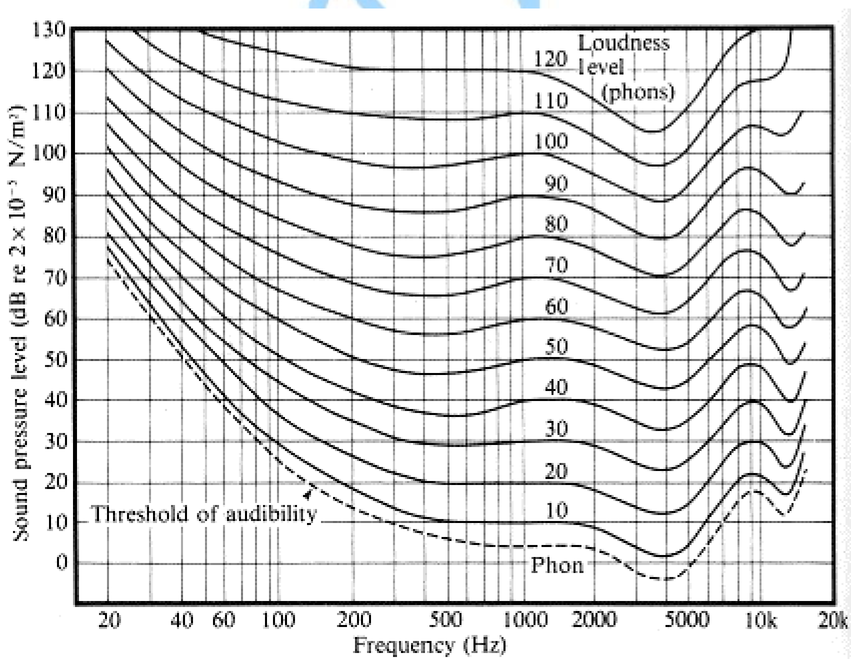
$$I = \frac{P}{4\pi r^2}$$

- Doppler Effect
    - The doppler effect is a change in the observed frequency of a wave when the source or the detector moves relative to the transmitting medium

$$f' = f\frac{v \pm v_D}{v \pm v_S}$$

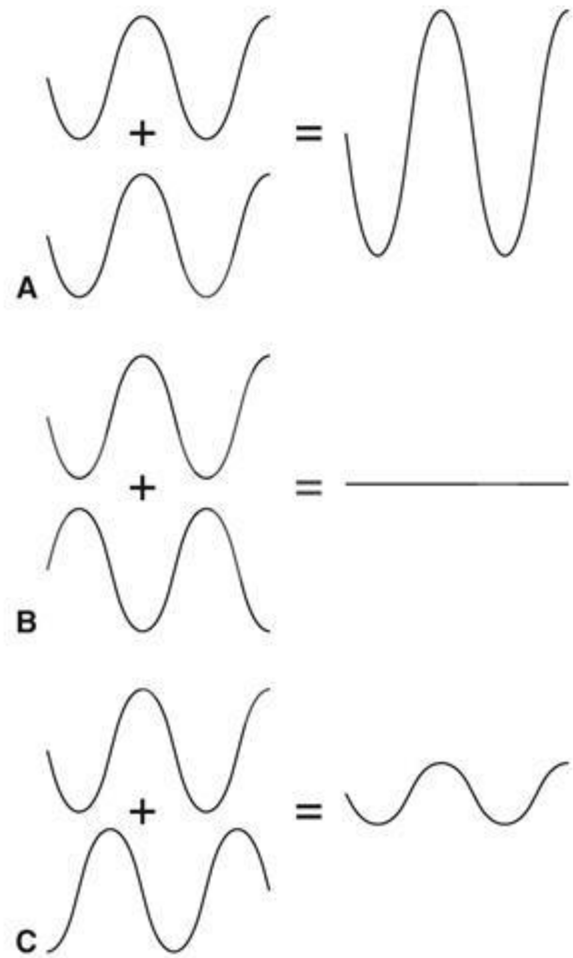
    - Where $v_D$is the speed of the detector relative to the medium, and $v_S$is that of the sources
    - f' tends to be greater for motion towards, and less for motion away
- Simple Harmonic Motion

    - Occurs when something is in its equilibrium point
    - Force is proportional to displacement from equilibrium
- Frequency is the number of sound waves
    - Sound with single frequency is a pure tone
    - Under 20 Hz is infrasonic
    - Above 20 Hz is ultrasonic
    - The pitch is the brain's interpretation of frequency
    - The pressure amplitude is the magnitude of maximum change in pressure measured relatively to undisturbed atmospheric pressure
    - Loudness is the amplitude of the wave
- Application in medicine
    - Ultrasounds, pulses, doppler flow meter
- The sensitivity of the human ear



- The principle of linear superposition
    - When 2 or more waves are present simultaneously at the same place, the resultant disturbance is the sum of the disturbance from the individual waves
- Constructive and destructive interference of sound waves
    - Constructive interference is when 2 waves meet condensation-condensation or rare-rare

  - Destructive interference is when 2 waves meet rare-condensation
- Diffraction is the bending of waves around obstacles
  - Single slit- first medium
    - Sin $\theta = \frac{\lambda}{D}$
  - Circular opening
    - Sin $\theta = 1.22\frac{\lambda}{D}$
- Transverse Standing
  - Each pattern is a transverse wave pattern
  - Nodes = no vibration
  - Antinodes = maximum
- Superposition
  - When 2 or more waves are at the same place and collide and create a resulting wave



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Temperature

- Zeroth Law of Thermodynamics
  - If bodies A and B are each in thermal equilibrium with a third body C (the thermometer), then A and B are in thermal equilibrium with each other
- The Kelvin Temperature Scale
  - Standard SI unit, where the freezing point of water is 273.16 K
- Heat Capacity
  - If heat Q is absorbed by an object, the object's temperature change is related by

$Q = C(T_f - T_i)$ *where* T_f *is the final temperature and* T_i *is the initial temperature*

- If object has mass m, then

$$Q = cm(T_f - T_i)$$

- Celsius and Fahrenheit Scales

    - The celsius temperature scale is defined by: $F_c = T - 273.15$
        - T is in kelvins
    - Fahrenheit temperature is defined by: $T_f = \frac{9}{5}T_c + 32$
- Radiation
    - Radiation is an energy transfer via the emission of electromagnetic energy

$$P_{rad} = \sigma\epsilon AT^4$$

    - Everything with temperature gives us thermal radiation
    - Above absolute zero is vibrational energy

$$Q/t = power = \epsilon\sigma AT^4$$

The Kinetic Theory of Gases

- Average translational kinetic energy per particle

$$KE = \frac{3}{2}kT$$

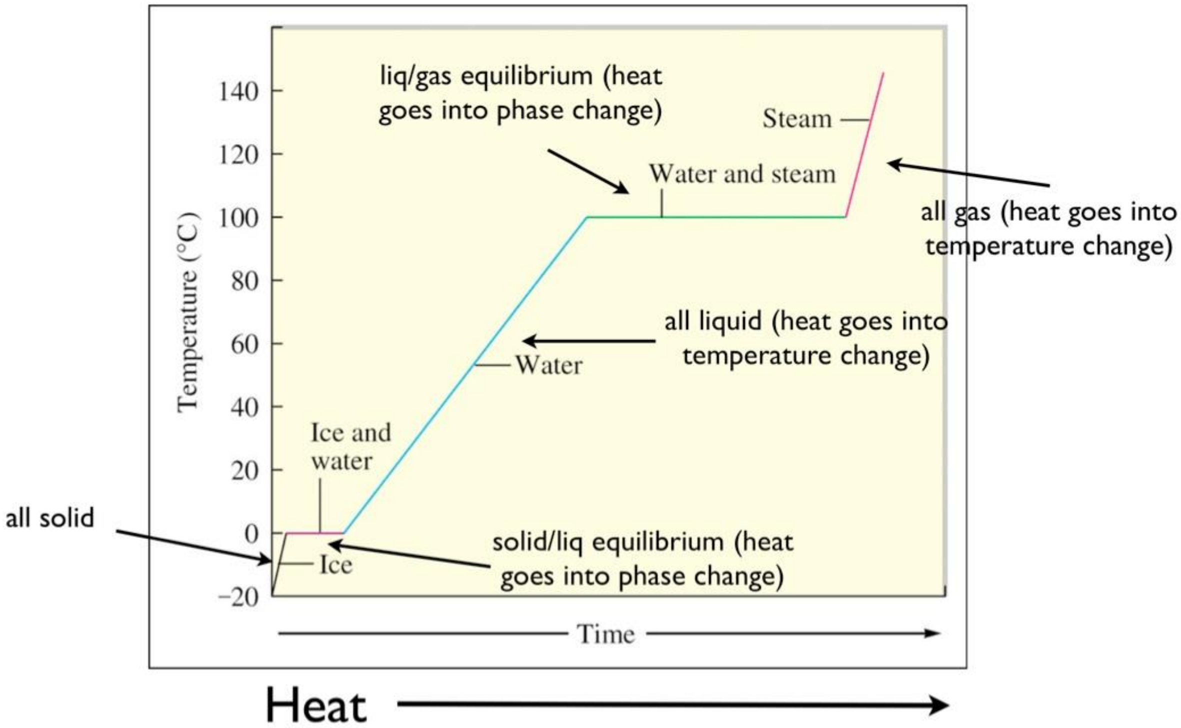
- Internal Energy of a Monatomic ideal gas

$$U = \frac{3}{2}nRT$$

- The distribution of molecular speeds
    - Particles travel at different speeds, but it's possible to have an average particle speed
- Avogadro's Number
    - One Mole of a substance contains N_A elementary units

$$N_A = 6.02 * 10^{23} mol^{-1}$$

- Ideal Gas
    - pV = nRT
    - Can also be written as pV = NkT
        - Where k, the boltzmann constant, is $k = \frac{R}{N_A} = 1.38 * 10^{-23} J/K$
- The number of moles n contained in a sample of mass consisting of N molecules is given by: $n = \frac{N}{N_A} = \frac{M_{sam}}{M} = \frac{M_{sam}}{mN_A}$



Coulomb's Law

- Conductors
    - Materials in which a significant number of electrons are free to move
- Coulomb's Law describes the electrostatic force between two charged particles

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

    - Where $\epsilon_0$is the permittivity constant
- Conservation of Charge
    - The net electric charge of any isolated system is always conserved
- Like charges repel, opposites attract
- Charged objects can be created by friction

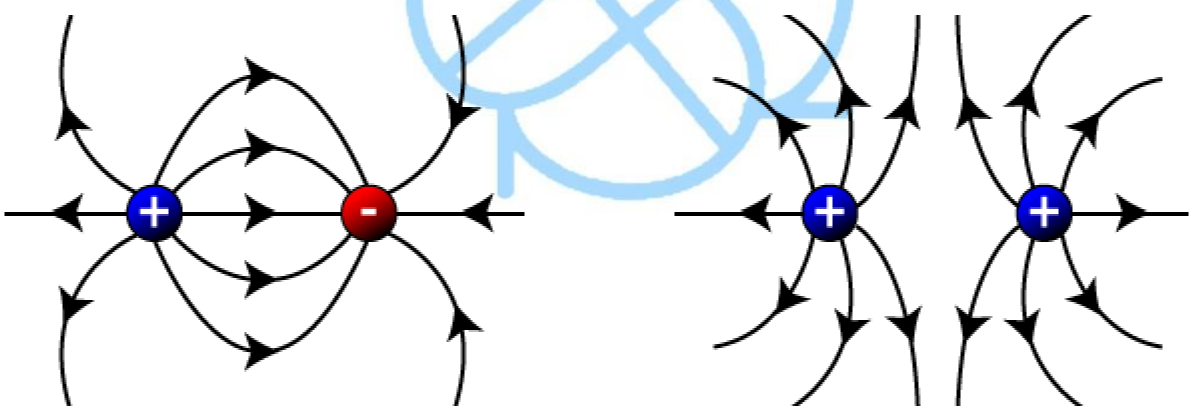
Electric Fields and Electric Forces

- Like mass, electric charge is an intrinsic property $e = 1.6 * 10^{-19} C$
- Law of conservation of electric charge
    - During any process, the net electric charge of an isolated system remains constant

- Conductors and Insulators
    - Conductors are substances that readily conduct
        - Ex. metal
    - Insulators are materials that conduct charge poorly
        - Ex. plastic, rubber
- Charging by contact and induction
    - Contact is directly touching
    - Induction is charging without physical contact

$$E = \frac{F}{q_0}$$

- Electric Field Lines
    - Help visualize the direction and magnitude of electric fields
    - The field vector at any point is tangent to a field line through that point
    - The density of field lines in any region is proportional to the magnitude of the electric field in that region
    - From positive charges to negative charges



- Field due to a point charge

$$E = \frac{1}{4\pi\epsilon_0} = \frac{q}{r^2}$$

- Force on a point charge in an electric field

$$F = qE$$

Electric Potential Energy and Electric Potential

- The electric potential v at a given is the EPE of a small test charge q situated at that point divided by the charge itself

$$v = \frac{EPE}{q}$$

- Relation between charge and potential difference for a capacitor
    - Magnitude q of the charge on each plate of a capacitor is directly proportional to the magnitude v of the potential difference between places

$$q = cV$$

- The electric potential difference
    - $F = q_0 E$is the electric force
    - The work depends on charge q_0

$$\frac{W_{AB}}{q_0} = \frac{EPE_A}{q_0} - \frac{EPE_B}{q_0}$$

- A positive charge accelerates from a region of higher EPE towards a region of lower EPE
    - 1 electron volt is the amount by which the potential energy of an electron changes when the electron moves through the potential difference of 1 volt

$$1eV = 1.60 * 10^{-19} J$$

- The EP difference created by point charges

$$W_{AB} = \frac{kqq_0}{r_A} - \frac{kqq_0}{r_B}$$

$$\rightarrow$$

$$V_B - V_A = \frac{-W_{AB}}{q_{)}} = \frac{kq}{r_B} - \frac{kq}{r_A}$$

- Potential of a point charge $v = \frac{kq}{r}$
    - When 2 or more charges are present, the potential due to all the charges is obtained by adding together the individual potentials
- Equipotential surfaces and their relation to the electric field
    - An equipotential surface is a surface where EP is the same everywhere
    - The net force does 0 work as charge moves on the equipotential surface
    - EF is everywhere perpendicular to associated equipotential surfaces and points in the direction of the decreasing potential
- Capacitors and Dielectrics

- A capacitor: 2 or more conductors, no physical contact
- Dielectric: Electrically insulating material
    - Dielectric constant $k = \frac{E_0}{E}$

Electric Currents

- Electromotive force and current
    - The mas potential difference is the electromotive force (EMF)
    - Flow of chart = electric current

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

    - If the charge moves in the same direction, the current is direct current
    - If the charge mores in 1 direction, then switches directions, it's in an alternating current
    - The conventional current is a hypothetical flow of positive charges that would have the same effect in a circuit as the movement of negative charges
- Ohm's Law
    - Resistance = voltage / current
        - Current is in Ampere A
        - Voltage is in Volts V
        - Resistance is in Ohms Ω
- Electric Power
    - The power is equal to the current multiplied by the voltage
- Alternating current

$$P = \frac{v^2}{R}$$

- Series Writing
    - Devices are connected in a way so that there is same electric current in each device

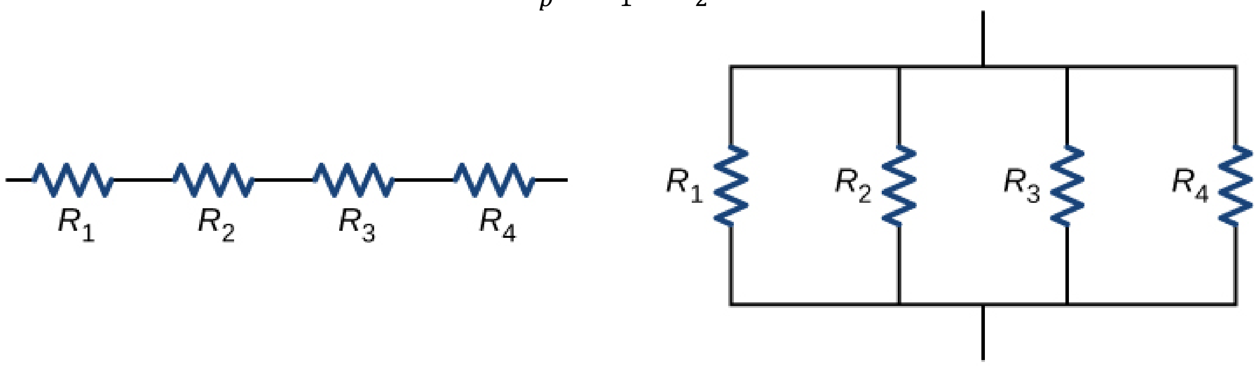
$$V = V_1 + V_2 = IR_1 + IR_2 = I(R_1 + R_2) = R_s$$

    - R_s =equivalent resistance
    - Series resistor = $R_S = R_1 + R_2 \ldots$

- Parallel writing
    - Devices are connected so that voltage is the same

$$I = V\frac{I}{R_p}$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \dots$$

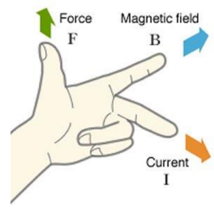


(a) Resistors connected in series (b) Resistors connected in parallel

- Kirchhoff's rules
    - Junction rule
        - At any junction in the electrical circuit, the sum of the currents flowing into the junction is equal to the sum of the currents flowing out of the junction
    - Loop rule
        - Around closed circuit loop, the sum of the potential drop is the sum of the potential rise

Magnetic Fields

- North magnetic pole vs south magnetic pole, opposites attract and likes repel
- The force that a magnetic field exerts on a moving charge
    - The charge must be moving
    - Velocity must have component that is perpendicular to direction of the magnetic field

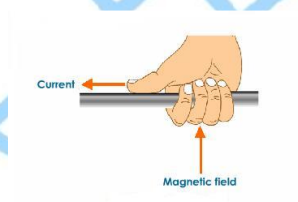


- The motion charged particle in a field
    - Charged particle is perpendicular to the field
    - Magnetic force is perpendicular to the velocity and directed towards center

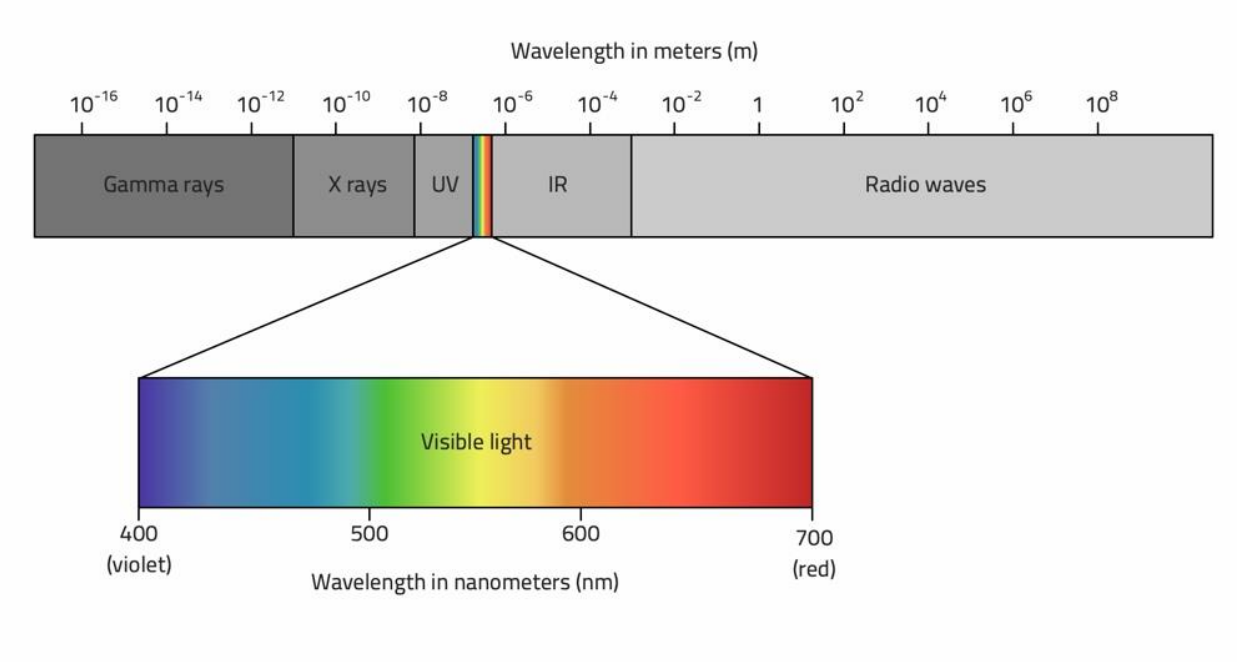
$$r = \frac{mv}{qB}$$

Electromagnetic Waves

- The oscillating current I in the antenna wires create magnetic field B at point P that is tangent to the circle centered on the wires
- The field is directed into the page when the current is upward and out of the page when the current is downwards



- As oscillating current changes, the magnetic field changes accordingly
- An electromagnetic field wave is transverse
    - Can travel through a vacuum or material substance
    - All waves move through vacuum at speed c, which is the speed of light in a vacuum
        - $c = 3.00 * 10^8$m/s
- Electromagnetic spectrum
    - Lower frequency waves generally produced by electric oscillator circuits
    - Higher frequency waves are generated using electron tubes called klystrons



- The energy carried by electromagnetic waves
    - A measure of the energy stored in the electric field E of an electromagnetic wave is provided by the electromagnetic identity
    - As electromagnetic waves move through space, it carries energy
        - The intensity
    - S is the electromagnetic intensity

$$S = \frac{P}{A}$$

    - The volume of space which the wave passes is ctA
    - The total energy in the volume is $S = \frac{c}{\mu_0} B^2$
- Polarization
    - Electromagnetic waves are transverse waves, so they can be polarized
    - Wave is linearly polarized
        - Vibrations always occur in one direction
        - This direction is called the direction of polarization
    - Malus' law
        - Once light has been polarized with a piece of polarizing material, it's possible to use a second piece to change polarization direction and to adjust to the intensity of light

$$S = S_0 cos^2\theta$$

The Refraction of Light, Lenses, and Other Optical Instruments

- The index of refraction
  - Change in speed as ray of light goes from 1 material to another
    - Causes ray to deviate from the "incident direction"
    - This change is called refraction

$$n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ material} = \frac{c}{v}$$

- Snell's law and the refraction of light
  - When light travels from material with refractive index n_1 into a material with refractive index n_2, the refractive ray, the incident ray, and the normal to the interface all lie in the same plane

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

- Apparent Depth
  - An object underwater appears closer than it actually is

$$d' = d\frac{n_2}{n_1}$$

    - Where d' is the apparent depth, d is the actual depth
- Total internal reflection
  - When the angle of incident reaches a certain value, its critical angle is an angle of refraction, 90 degrees
  - The total internal reflection occurs only when light travels from higher to lower medium index
    - Critical angle: $sin\theta_c = \frac{n_2}{n_1}$
- Polarization and the reflection and refraction of light
  - For incident angles other than 0 , unpolarized light becomes partially polarized in reflecting from a nonmetallic surface such as water
  - There is 1 special angle where reflected light is completely polarized parallel to the surface and the reflected ray is only partially polarized: Brewster's angle θ_B
    - Tan $\theta_B = \frac{n_2}{n_1}$
  - The spreading of light into color components is dispersion

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