Physics Notes

Contents

Chapter 1: Measurements

Physical Quantities

- Quantities that can be measured, consists of a numerical magnitude and a unit.

Prefixes

Prefix	Symbol	Standard Form
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	µ	10^{-6}
Nano	n	10^{-9}

Conversion of km/h to m/s

- $km/h \div 3.6 = m/s$

Sizes of well-known objects:

- Radius of Earth: 6378000m (6.378×10^{6})
- Size of atom: 0.0000000001m (10^{-10})

Instruments

Vertier Calipers

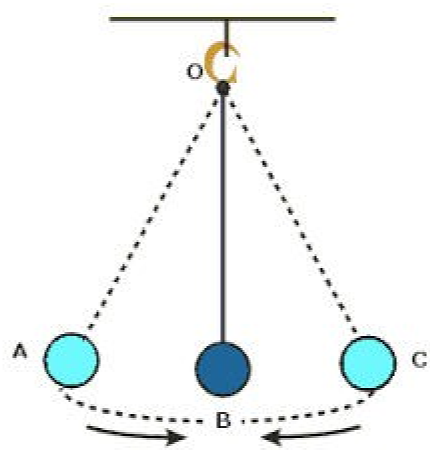
- Precision: 0.01cm
- Read the main scale until the immediate left of the zero mark on the vernier scale, then add the marking which coincides with the marking on the main scale.
- Zero Errors:
    - Positive
        - Zero mark of Vernier is slightly to the right of the main scale.
    - Negative
        - Zero mark of Vernier is slightly to the left.

Micrometre Screw Gauge

- Precision: 0.01mm
- Read main scale, then read thimble reading
- Zero Errors
    - Positive
        - Zero marking on thimble scale is below datum (centre) line.
    - Negative
        - Zero marking on thimble scale is above datum line.

Pendulums

- Oscillation
    - One complete to-and-fro motion (A->C->A)/(B->C->B->A->B)



- Period
    - Time taken for one complete oscillation

Chapter 2: Kinematics

Scalar Quantities

- Quantities with only magnitude
- Distance, Speed, Mass, Energy, Time

Vector Quantities

- Quantities with both magnitude and direction
- Displacement, Velocity, Acceleration, Force

Distance

- Total distance travelled.

Displacement

- Total distance travelled in a straight line.

Speed

- The distance moved per unit time (m/s).

Velocity

- The rate of change of displacement (m/s).

Acceleration

- The rate of change of velocity (m/s^2).
- $a = \frac{v-u}{t}$

Important Information

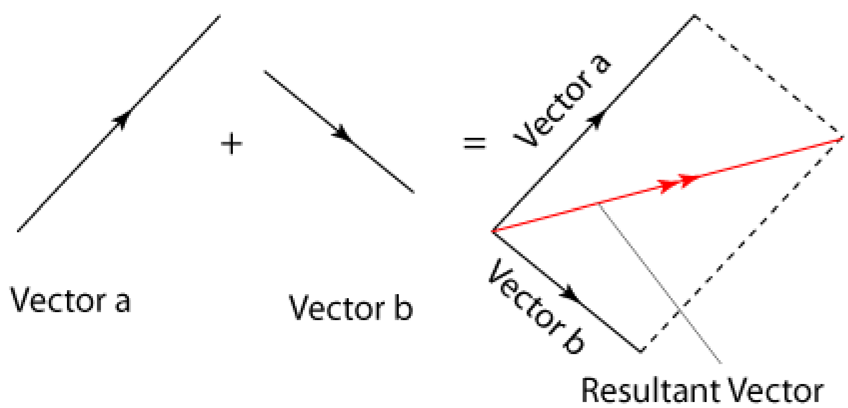
- The gradient of a displacement-time graph of an object is its velocity.
- The gradient of a velocity-time graph of an object is its acceleration.
- The area under a velocity-time graph of an object is its displacement.
- Acceleration due to Gravity = 10 m/s^2

Chapter 3: Forces

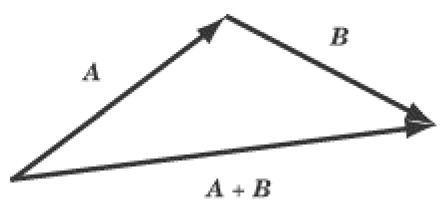
- Newton (N)

Vector Diagrams

- In a vector diagram, if all 3 arrows form a complete loop, the forces are in
- equilibrium.
- Parallelogram method



- Tip-to-tail method



Newton's Laws of Motion

First Law

- Every object will continue in its state of rest or uniform motion in a straight line unless a resultant force acts on it.

Second Law

- When a resultant force acts on an object of constant mass, the object will accelerate in the direction of the resultant force. The product of the mass and acceleration of the object gives the resultant force.

Third Law

- If body A exerts a force F_{AB} on body B, then body B will exert an equal and opposite force F_{BA} on body A.

Friction

- The contact force that opposes or tends to oppose motion between surfaces in contact.

Reducing friction

- Wheels, Ball bearings, Lubricants, Air Cushions

Increasing friction

- Treads, Parachute, Chalk

Chapter 4: Mass, Weight and Density

Mass

- The amount of matter in a body.
- Measured with a beam balanced.
- Kilograms (kg).

Weight

- The gravitational force, or gravity, acting on an object.
- Measured with spring balance.
- Newton (N).

Gravitational field

- A region in which a mass experiences a force due to gravitational attraction.

Gravitational field strength

- The gravitational force acting per unit mass.

Relation Between Mass and Weight

$$w = mg$$

Inertia

- The reluctance of the object to change its state of motion due to its mass.

Density (kg/m^3): $p = \frac{m}{v}$

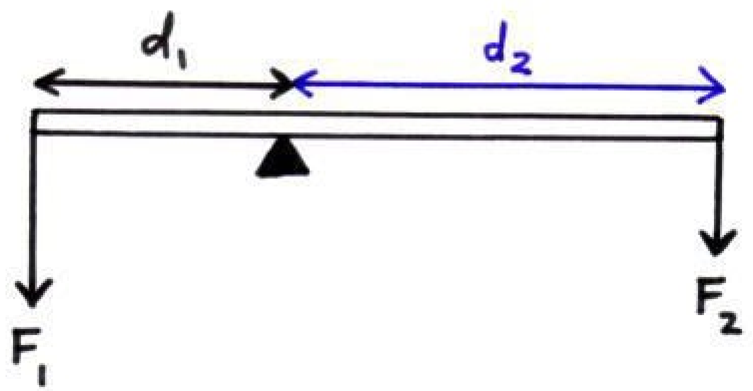
Chapter 5: Turning Effect of Forces

Moments

- Moment of a force (torque, Nm): the product of the force F and the perpendicular distance from the pivot to the line of action of the force.

$Moment\ of\ a\ force = F \times d\ (perpendicular\ distance)$

- Moments are vector quantities, thus must specify both magnitude and direction.
- Principle of Moments: when a body is in equilibrium, the sum of clockwise moments about a pivot is equal to the sum of anticlockwise moments about the same pivot.



Centre of Gravity

- The point through which its whole weight seems to act.

Stability

- The measure of an object's ability to return to its original position after it is slightly displaced.

Equilibrium

- Stable, unstable, neutral

Chapter 6: Energy, Work and Power

Energy

- Energy is the capacity to do work.

Principle of Conservation of Energy

- Energy cannot be created or destroyed, but can be converted from one form to another. The total amount of energy in an isolated system is constant.
- Efficiency is calculated by:

$$\frac{Useful\ Energy}{Total\ Energy} \times 100\%$$

Work done

- Work done by a constant force on an object is the product of the force and the distance moved by the object in the direction of the force.
- Work Done = Energy Transformed
- Work done is calculated by:

$$W = F \times s$$

Kinetic Energy

- Kinetic energy is the energy an object possesses due to its motion.
- Kinetic energy is calculated by:

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

Gravitational Potential Energy

- Gravitational potential energy is the energy an object possesses due to gravity.
- Gravitational potential energy is calculated by:

$$E_p = mgh$$

Power

- Power is the rate of work done or energy conversion.
- Power is calculated by:

$$P = \frac{WD}{t} = \frac{E}{t}$$

Chapter 7: Pressure

- Pressure is defined as the force acting per unit area.

Solids

- Pressure in solids can be calculated by:

$$p = \frac{F}{A}$$

Liquids

- Pressure in liquids can be calculated by:

$$p = h\rho g$$

- Pressure in a hydraulic system is the same everywhere.
- Work done for hydraulic presses can be calculated by:

$$p_1 = p_2$$

$$F_1 \times d_1 = F_2 \times d_2$$

Atmosphere

- Pressure at sea level is 1.013×10^5 Pa or 760 mmHg.

Chapter 8: Temperature

Temperature

- Temperature refers to how hot or cold an object is.
- Kelvin (K)

Heat

- Heat refers to the amount of thermal energy that is being transferred from a hotter to a colder region.
- Joules (J)

Measuring Temperature

Qualities of a good thermometer

- An easy-to-read-scale.
- Responsive to temperature changes.
- Sensitive to small temperature changes.
- Can measure a wide range of temperatures.

Thermometric substances

- Have physical properties that vary continuously and linearly with temperature for the range of temperatures measured.

Physical Property	Example of Thermometer
Volume of fixed mass of liquid	Mercury-in-glass thermometer, Alcohol thermometer.
Electromotive force or electrical voltage	Thermocouple thermometer
Electrical resistance of a piece of metal	Resistance thermometer

Constructing a Thermometer

1) Choose an appropriate thermometric substance to be used in the thermometer.
2) Choose two fixed points which are easily obtainable and reproducible. Usually, the temperature of pure melting ice at one atmosphere and the temperature of steam from boiling water at one atmosphere are used as fixed points.
3) Record the values of the substance level in the thermometer stem at these fixed points.
4) Divide the interval between these two fixed points in 100 equal parts 5. Each of these equal parts on the scale represents a measure of 1 oC

Ice / melting point

- The temperature of pure melting ice at one atmospheric pressure, 0^oC.

Steam / boiling point

- The temperature of steam from boiling water at one atmospheric pressure, 100^oC.

Precautions when calibrating thermometers

- Ice point: Use crushed ice to ensure good contact between the bulb and ice, use a funnel to allow melted ice to flow away so that the thermometer only measures the temperature of the melting ice.
- Steam point: Use a manometer to check if the pressure inside the apparatus is the same as the atmospheric pressure outside. If the pressure is not equal, adjust the flame accordingly.

Chapter 9: Kinetic Model of Matter

- Kinetic model of matter states that the tiny particles that make up matter are always in continuous random motion.

Brownian Motion

- A phenomenon that provides evidence for the continuous and random motion of tiny particles.

Relationship between pressure, volume and temperature

- *At constant pressure,*

$$V \propto T$$

  - At higher temperatures, gas particles have higher kinetic energy. If volume is constant, the frequency of collisions, and hence pressure, will increase. In order for the pressure to remain constant, the distance between the walls of the container must increase so that the average time between each collision is increased. Therefore, at constant pressure, the volume of a gas increases with increasing temperature.

- *At constant temperature,*

$$p \propto \frac{1}{V}$$

  - When volume is increased, the distance between the walls of the container is increased. This causes the average time between each collision of the gas particles to increase, and the frequency of collisions to decrease. Therefore, at constant temperature, the pressure of a gas decreases with increasing volume.

- *At constant volume,*

$$p \propto T$$

  - When temperature increases, the gas particles have greater kinetic energies and move faster. They collide with the walls of the container more frequently and with greater average force. This causes the pressure in the container to increase. Therefore, at constant volume, the pressure of a gas increases with increasing temperature.

Chapter 10: Transfer of Thermal Energy

- Thermal energy always flows from a region of higher temperature to a region of lower temperature. Net flow of thermal energy occurs only when there is a difference in temperature.

Conduction

- The transfer of thermal energy by molecular vibration through a medium without any flow of the medium.
- Particles, when heated, gain kinetic energy and vibrate vigorously about their fixed positions.
- They collide with neighboring particles, making them vibrate more vigorously. The neighboring regions of the object (rod) become hot. Eventually, the particles at the other end of the rod are also set into vigorous vibration.
- Free electron diffusion (metals only): The free electrons at the heated end absorb thermal energy, and hence gain kinetic energy. The free electrons that gain kinetic energy move at greater speeds, and move to the cooler regions of the rod. As these electrons move, they collide with the atoms in the cooler parts of the rod, making them vibrate more vigorously. Thermal energy is transferred via the motion of the free electrons. The cooler end of the rod becomes hot.
- Speed: Solid > Liquid > Gas.
- Distance between particles is inversely proportional to the frequency of collisions.

Convection

- The transfer of thermal energy by means of convection currents in a fluid, due to a difference in density,.
- Involves the bulk movement of the fluid that carries the thermal energy. a. When the flask is heated, the water molecules at the bottom of the flask gain thermal energy through conduction, and thus speed up and expand, hence decreasing in density. As these molecules are less dense than the surrounding water above, they rise. As the upper region of the water is more dense, it sinks to displace the hot water molecules. Hence a convection current is set up, and thermal energy is transferred throughout the water.

Radiation

- The transfer of thermal energy in the form of electromagnetic waves such as infrared radiation without the aid of a medium, i.e. in vacuum.
- Thermal energy from infrared radiation is called radiant heat. All objects emit radiant heat.

Factors affecting radiation:

- Colour and texture of the surface: Dull and black materials are better emitters/absorbers of radiant heat.
- Surface temperature: The higher the surface temperature in comparison with the surroundings, the higher the rate of emission.
- Surface area: Objects with larger surface area emit/absorb at a higher rate than objects with smaller surface areas.

Chapter 11: Thermal Properties of Matter

Thermal Energy

$$Q = mc\Delta\theta$$

Internal Energy

- The sum of molecular kinetic and potential energies of the particles of a substance.

Heat capacity

- The amount of thermal energy required to raise the temperature of a substance by 1K or 1^{o}C
- J/^{o}C

Specific heat capacity

- The amount of thermal energy required to raise the temperature of 1 kg of a substance by 1K or 1^{o}C
- J/kg/^{o}C

Melting

- Temperature remains constant as the thermal energy is absorbed to overcome the strong bonds between particles.

Freezing

- Temperature remains constant as there is no change in the kinetic energy of the molecules, as intermolecular bonds are formed during freezing and only the potential energy of the substance's molecules decreases.

Boiling

- Temperature remains constant as thermal energy is absorbed to break the intermolecular bonds between particles, provide energy for particles to push back on the surrounding atmosphere and increase the average space between particles.

Boiling vs evaporation

Boiling	Evaporation
Occurs only at boiling point.	Occurs at any temperature.
Relatively fast.	Relatively slow.
Takes place throughout the liquid.	Takes place only at the surface.
Temperature remains constant.	Temperature usually decreases.
Bubbles formed in the liquid.	No bubbles formed in the liquid.
External thermal energy source needed.	External thermal energy source not needed.

Process of evaporation:

- Molecules of a liquid have different kinetic energies. When they constantly bombard each other, energy is being transferred. At the surface of the liquid, the most energetic molecules can overcome the downward attractive forces of other liquid molecules and the atmospheric pressure to escape from the surface of the liquid, hence evaporation occurs.
- As the less energetic molecules are left behind, the average kinetic energy of the molecules in the liquid decreases, hence the temperature of the liquid decreases.

Factors affecting rate of evaporation

- Surrounding temperature.
- Humidity.
- Pressure.
- Surface area.
- Heat capacity of liquid.
- Wind.

Latent Heat

- Latent heat is the energy released or absorbed by a substance during a change of state, without a change in its temperature.

Latent heat of fusion

- The amount of thermal energy required to change a substance from solid state to liquid state without a change in temperature.

Latent heat of vaporization

- The amount of thermal energy required to change a substance from liquid state to gaseousstate without a change in temperature.

Specific latent heat of fusion

- The amount of thermal energy required to change 1 kg of a substance from solid state toliquid state without a change in temperature.

$$Q = ml_F$$

Specific latent heat of vaporization

- The amount of thermal energy required to change 1 kg of a substance from liquid stateto gaseous state without a change in temperature.

$$Q = ml_V$$

Chapter 12: Light

Reflection

Laws of Reflection:

- *First Law*
    - The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane.
- *Second law*
    - The angle of incidence i is equal to the angle of reflection r.

Normal

- The perpendicular line to the reflecting surface at the point of incidence.

Plane mirror images

- Same size as object, laterally inverted, upright virtual
- Distance from the mirror = Distance of object from mirror

Refraction

Refraction

- The bending of light as light passes from one optical medium to another.

Laws of refraction

- *First Law*
    - The incident ray, the normal and the refracted ray all lie in the same plane.
- *Second Law*
    - For 2 given media, the ratio of sin i to sin r is a constant. (Snell's Law)

Refractive index

- Ratio of speed of light in vacuum to the speed of light in medium.

Critical Angle

- The angle of incidence in an optically denser medium for which the angle of refraction is perpendicular to the plane.

Total Internal Reflection

- The complete reflection of a light ray inside an optically denser medium at its boundary with an optically less dense medium.
- For total internal reflection to occur,
    - The light ray in an optically denser medium strikes its boundary with an optically less dense medium
    - The angle of incidence is greater than the critical angle of the optically denser medium.

Converging lenses

Focal Length

- The distance between the optical centre and the focal point F.

Focal point

- The point at which all rays parallel to the principal axis converge after refraction.

Principal axis

- The horizontal line perpendicular to the vertical plane of the lines passing through the optical centre.

Object distance	Type of Image	Image distance	Uses
∞	Inverted, real, diminished	$v = f$	Object lens of a telescope
$u > 2f$	Inverted, real, diminished	$f < v < 2f$	Camera
$u = 2f$	Inverted, real, same size	$v = 2f$	Photocopier
$f < v < 2f$	Inverted, real, magnified	$v > 2f$	Projector
$u = f$	Upright, virtual, magnified	∞	Spotlights
$u < f$	Upright, virtual, magnified	Behind obj	Magnifying glass

Object between F and 2F

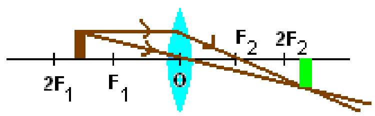


Image beyond 2F

Object at F

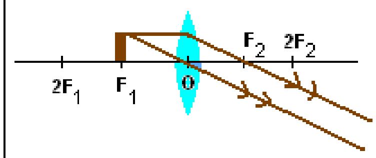


Image at infinity

Object is between F and 2F

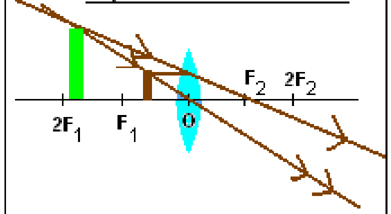


Image on the same side, behind object

Object at 2F

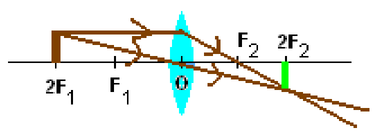


Image at 2F

Object beyond 2F

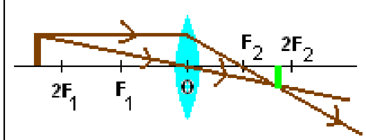


Image between F and 2F

Object at inifiity

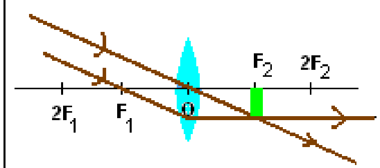


Image at F

Chapter 13: Waves

- A wave is made up of periodic motion.
- Waves transfer kinetic energy without transferring the medium.
- Waves transfer energy from one point to another.
- The source of a wave is a vibration or an oscillation.
- Waves transfer energy from one point to another.

Periodic motion

- Motion repeated at regular intervals.

Transverse wave

- Waves that travel perpendicular to the direction of the vibration. (e.g. water waves, electromagnetic waves)

Longitudinal wave

- Waves that travel parallel to the direction of the vibration. (e.g. sound)

Amplitude

- The maximum displacement of a point from its rest position.

Wavelength

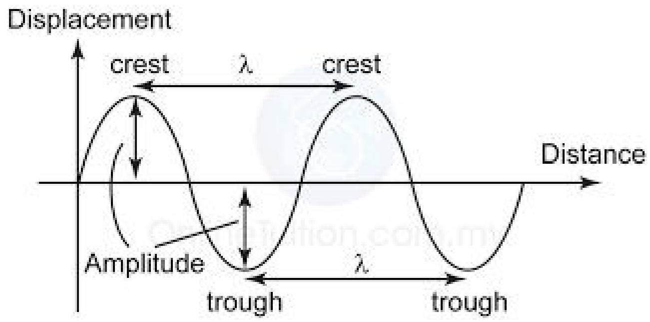
- The shortest distance between 2 points in phase. Wavelength becomes shorter/longer upon entering a denser/less dense medium. However, frequency remains the same in both.

$$\frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2}$$

- 2 points are in phase if they have the same direction of motion, same speed and same displacement from rest position.

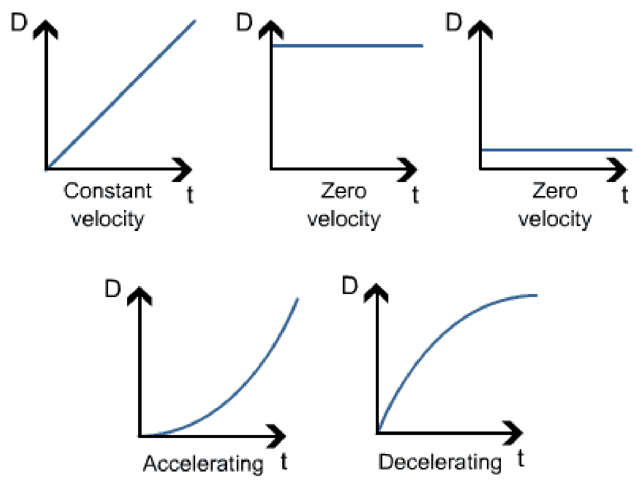
Displacement-distance graph

- Displays the displacements of all particles at a particular point in time.



Displacement-time graph

- Displays the displacement of a particle over time



Period

- The time taken to produce one complete wave.

Frequency

- The number of complete waves produced per second.

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

Wave speed

- The distance travelled by a wave per second.

$$v = f\lambda$$

Wavefront

- Imaginary line on a wave that joins all adjacent points that are in phase.

Chapter 14: Electromagnetic Waves

Electromagnetic Spectrum

- Made up of electromagnetic waves.

← Longer wavelength / Smaller frequency ←				→ Shorter wavelength / Higher frequency →		
Radio waves	Microwaves	Infrared Radiation	Visible Light	Ultraviolet	X-rays	Gamma Rays

Properties of electromagnetic waves:

- They are transverse waves, comprising electric and magnetic fields oscillating 90^{o} to each other.
- Can travel through vacuum.
- Travel at the speed of $3.0 \times 108\ m\ s^{-1}$ vacuum.
- Transfer energy from one place to another.
- Wave speed equation $v = f\lambda$ is applicable to all electromagnetic waves.
- Wavelength and speed changes upon changing medium, but frequency does not.
- Electromagnetic waves obey the laws of reflection and refraction.
- Electromagnetic waves carry no electric charge.

Applications of Electromagnetic Waves

Electromagnetic Wave	Application
Radio Waves	- Radios, over-the-air TV and communications. - AM, FM radio, submarine communication. - Chosen over microwaves as they have longer wavelengths and can hence diffract around obstructions on Earth's surface better that microwaves which have shorter wavelengths.
Microwaves	- Microwave ovens, satellite TV, GPS. - Chosen over Radio Waves as they have a higher frequency and can penetrate the atmosphere and travel through haze, light rain, snow, clouds and smoke to receivers.
Infrared Radiation	- Remote controls, ear thermometers and intruder alarms
Visible Light	- Optical fibres
Ultraviolet (UV) Radiation	- Sunbeds, equipment sterilisation
X-rays	- Radiation therapy, imaging
Gamma Rays	- Radiation therapy - Killing of cancer cells

Effects of Electromagnetic Waves

Infrared heating

- Infrared radiation from e.g. burning charcoal

Ionizing radiation

- Radiation that has enough energy to remove electrons from atoms or molecules
- Can damage biological molecules (e.g. proteins or DNA) and lead to abnormal patterns of cell division
- Causes cancers such as leukemia, or deformation of foetuses

Chapter 15: Sound

- Sound is a form of energy that is transferred from one point to another as a longitudinal wave.
- **In a sound wave,**
    - Compressions are regions where air pressure is higher than the surrounding air pressure.
- Rarefactions are regions where air pressure is lower than the surrounding air pressure.

Transmission of sound

- Can only be transmitted through a medium.
- Cannot be transmitted through a vacuum.
- Speed of sound varies in each medium.
- Speed of sound in gas < Speed of sound in liquid < Speed of sound in solid

Reflection of sound

- An echo is the repetition of a sound due to the reflection of sound.
- Echoes largely obey the rules of light reflection.
- Used to measure large distances or detect the location of objects.

Ultrasound

- Sound with frequencies above the upper limit of the human range of audibility (>20kHz)
- Used for:
    - Quality control
    - Prenatal scanning

Pitch

- Pitch is related to the frequency of a sound wave, the higher the frequency, the higher the pitch

Loudness

- Loudness is related to the amplitude of a sound wave, the larger the amplitude, the louder the sound

Chapter 16: Static Electricity

Electric Charges

- Like-charged objects repel.
- Unlike-charged objects attract.
- Atoms become positively charged and negatively charged when electrons are removed or added respectively to form ions. Only electrons (not protons) can be transferred, however positively charged atoms are mobile.
- Measured in coulombs - Charge carried by an electron or proton is $1.6 \times 10^{-19} C$

	Electrical Insulators	**Electrical Conductors**
Motion of charged particles	Not free to move about.	Free to move about.
Ability to conduct electricity	Low.	High.
Method of charging	Friction: When charged, the electrons remain at the surface where the material has been rubbed as they are unable to move freely within the material.	Induction: When rubbed the electrons can be easily transferred to and away, leaving it electrically neutral.

Electrostatics

- The study of static electric charges

Charging by Friction

- Before rubbing, the glass rod and the piece of silk are electrically neutral. As different materials have different affinities (extent of attraction) for electrons, when the glass rod and the piece of silk are rubbed together, the atoms at their surfaces are disturbed and some electrons from the atoms at the surface of the glass rod are transferred to the piece of silk. As the glass rod loses electrons, it becomes positively charged. As the piece of silk gains electrons, it becomes negatively charged.

Induction

- The process of charging a conductor without contact between the conductor and the charging body
- **Charging 2 metal spheres**
    - Place the 2 conductors side by side such that they are touching each other. Bring a negatively charged rod near but not touching sphere A. This causes the electrons in both metal spheres to be repelled to the far end of sphere B. Now, sphere A has excess positive charges which sphere B has excess negative charges. While holding the charged rod in place, pull sphere B away from sphere A. Remove the charged rod. Spheres A and B have an equal number of opposite charges.
- **Charging a single Conductor**
    - Bring a positively charged glass rod near a metal conductor. The free electrons in the metal are drawn towards the positively charged glass rod. Without removing the glass rod, earth the positively-charged end of the metal conductor by touching it to neutralise the positive charges. With the glass rod still in place, remove your hand to stop the earthing and remove the glass rod. The negative charges will redistribute throughout the conductor to make it negatively charged.

Discharging an Insulator

- **Heat**
    - Intense heat from flame ionises air particles which neutralise the excess charges onthe insulator to discharge it.
- **Humidity**
    - Water molecules in the air are conductors hence excess charges will be transferred to the water molecules on the surface of the insulator.

Discharging a conductor

- **Earthing**
    - Providing a path for excess electrons to flow.
    - Providing a path for electrons to flow to the conductor

Electric Field

- An electric field is a region in which an electric charge experiences an electric force.
- An electric force is attractive or repulsive force that electric charges exert on one another.
- The direction of an electric field is the direction of that force that would act on a small positive charge.
- Lines always go from the positive to the negative.
- Lines are curved due to the resultant force exerted by the attraction and repulsion of both charges.
- Strength of the field is indicated by how close the field lines are to one another.

Hazards of Electrostatics

Lightning

- Friction between water molecules and air particles charges the thundercloud. The negative charges which tend to gather at the bottom of the cloud repels electrons on the Earth's surfaces and renders it positively charged by induction. With enough charges the air particles near the cloud will be ionised, forming a conducting path for electrons in the cloud to reach Earth, which will form lightning.
- Tends to strike tall or isolated structures, therefore lightning rods are needed to provide a conducting path for the electrons to flow from the air to the earth to protect tall buildings.
- A current of 0.1 A is sufficient to kill a person.

Electrostatic discharge

- Charges accumulated due to friction between roads and vehicles' wheels may cause sparks and ignite flammable items when suddenly discharged.
- Older trucks have a metal chain at the rear that hangs close to the ground to provide an earthing path for excess charges.
- Antistatic packaging for electronics.

Applications of Electrostatics

- Photocopiers.
- Electrostatic precipitators.
- Spray painting: Charges paint by friction, paint spreads out due to repulsion, attracted to earth object, hence forming a uniform coat of paint.

Chapter 17: Current Electricity

Ampere

- One ampere is the current produced when one coulomb of charge passes a point in the circuit in 1 second.

Electron flow

- Flow of electrons from the negative terminal of the battery to the positive terminal.

Conventional current

- Flow of current from the positive terminal of the battery to the negative terminal.

Electric current

- The rate of flow of electric charge.

$$I = \frac{Q}{T}$$

Ammeter

- Measure the strength of a current.
- Should be connected in series.

Electromotive force

- The electromotive force of an electrical energy source is the work done by the source in driving a unit charge around a complete circuit.

$$\varepsilon = \frac{WD}{Q}$$

Potential difference

- The potential difference across a component in an electric circuit is the work done to drive a unit charge through the component.

$$V = \frac{W}{Q}$$

Resistance

- The resistance of a component is the ratio of the potential difference V across it to the current I flowing through it. R is directly proportional to V (p.d.) and inversely proportional to I.

$$V = IR$$

Ohm's Law

- Ohm's law states that the current passing through a metallic conductor is directly proportional to the potential difference across it, provided that physical conditions (such as temperature) remains constant.

$$I \propto V$$

- The conductor obeys Ohm's law IF and only IF
  - The gradient of the graph is constant.
  - The graph has an origin of 0.

Non-ohmic Conductors

- As the current increases, devices generate more heat and thus their temperatures and the resistance of the device increases.
  - Example: Filament lamp
- Diode: Allows current to flow in the forward direction only

Ammeter

- Connected in series (negligible resistance)
- Ammeter is connected in series to measure the amount of current flowing in the circuit. It has a negligible resistance so as to not increase the total amount of resistance in the circuit and cause the current reading to be inaccurate.

Voltmeter

- Connected in parallel (infinite resistance)
- Voltmeter is connected in parallel to measure the potential difference across a component. It has infinite resistance such that it does not draw any current, which may otherwise affect the value of the voltage.

Resistance of a wire

$$R = \frac{pl}{A}$$

$$p = \frac{RA}{T}$$

- A is usually πr^2 therefore resistance increases at an increasing rate as the radius of the wire increases.
- Low Resistivity = Good conductor.
  - Can be used for wires.
- High Resistivity = Poor Conductor.
- Heating Coils in electric kettles (Nichrome): Produces a lot of thermal energy when a current passes through.
- Light Bulbs (Tungsten).

Chapter 18: D.C. Circuits

Series Circuits

- Current at every point is the same.
- Sum of the potential difference across each component is equal to the p.d. Across the whole circuit and the electromotive force of the battery.
- Resistors of larger resistance will have a higher p.d. than resistors of smaller resistance.
- The effective resistance R is the sum of all the resistances.

Parallel Circuits

- Sum of current in individual branches is equal to to the main current flowing in or out of the parallel branches.
- Branch with the least resistance has the largest current flowing through it.
- Potential difference across separate parallel branches and the total potential difference is the same.
- Reciprocal of the effective resistances of resistors in parallel is equal to the sum of the reciprocal of all the individual resistances.
- Adding additional resistors to a circuit decreases the effective resistance due to the increased current.
- This increases the energy requirement on the energy source.

Advantages of parallel circuits:

- The current flowing through each bulb in a parallel circuit is larger than the current flowing through each bulb in a series circuit, hence bulbs connected in parallel glow more brightly than bulbs connected in series.
- When a bulb in a parallel circuit blows, the other bulbs in the circuit will still work as each parallel branch forms a complete circuit.

Disadvantage of parallel circuits

- The current flowing through the electrical energy source in a parallel circuit is higher than the current flowing through that of a series circuit. Hence the electrical energy source of a parallel circuit provides more power and is thus depleted more quickly than in a series circuit.

	Series Circuit	Parallel Circuit
Current	$I_\varepsilon = I_1 = I_2 = \cdots = I_n$	$I_\varepsilon = I_1 + I_2 + \cdots + I_n$
Potential Difference	$V_\varepsilon = V_1 + V_2 + \cdots + V_n$	$V_\varepsilon = V_1 = V_2 = \cdots = V_n$
Resistance	$R_\varepsilon = R_1 + R_2 + \cdots + R_n$	$R_\varepsilon = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}\right)^{-1}$

Potential Divider

- A line of resistors connected in series. Used to provide a fraction of the voltage of a source to another part of the circuit.

$$V_{out} = \frac{R_2}{R_2 + R_1} \times V_\varepsilon$$

$$V_{out} = \frac{I_2}{I_2 + I_1} \times V_\varepsilon$$

Rheostat vs Potentiometer

- An additional resistor is added to prevent a large current from flowing through the circuit when the variable resistor's resistance is 0, which will cause appliances to overheat.

Input transducers

- Electronic devices that convert non-electrical energy to electrical energy.
    - Thermistor, Light dependant resistor
    - The higher the temperature / light level, the lower the resistivity

Chapter 19: Practical Electricity

Sources of Electrical Energy

Renewable Energy

- Energy from sources that can be replenished naturally.
    - Solar power
    - Hydroelectric power
    - Wind power

Non-renewable Energy

- Energy from sources that cannot be replenished at a sustainable rate.
    - Nuclear power
    - Fossil fuels

Solar Power	Advantage	- Form of clean energy. - Source of energy is free.
	Disadvantage	- Generation of electricity is dependant on the availability of sunlight. - Cost of infrastructure is high.
Wind Power	Advantage	- Form of clean energy. - Source of energy is free.
	Disadvantage	- The construction of wind farms requires large, open areas. - It depends on the availability of wind.
Hydroelectric Power	Advantage	- It is an efficient method of generating electricity as water flow is easily controlled.
	Disadvantage	- It disrupts ecosystems.
Nuclear Power	Advantage	- It is highly efficient as a small amount of uranium is sufficient to generate a large quantity of energy.
	Disadvantage	- Nuclear waste may cause contamination of groundwater.
Fossil Fuels	Advantage	- Most countries have well-established technology and energy distribution systems.
	Disadvantage	- Extensive mining has a negative impact on the ecosystem.

Electrical Power

- Watt (W)

Formulas

$$P = IV$$

$$P = I^2R$$

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

Dangers of Electricity

Damaged insulation

- Insulating materials can become worn with time, and expose the conducting wires inside.
- The exposed conducting wires can cause electric shocks if touched.

Overheating of cables

- Overloaded power sockets: With many appliances in a power socket in parallel, a large current flows.
- Inappropriate wires: Wires which are thin have a higher resistance and produce more heat. Hence when used with appliances which require a lot of power, the wires may overheat.

Damp environments

- Water provides a conducting path with a small resistance for the current to flow.
- Leads to burns, uncoordinated contraction of heart muscles and death
    - Human body can only withstand an alternating current of 0.05 A.

Safety Mechanisms

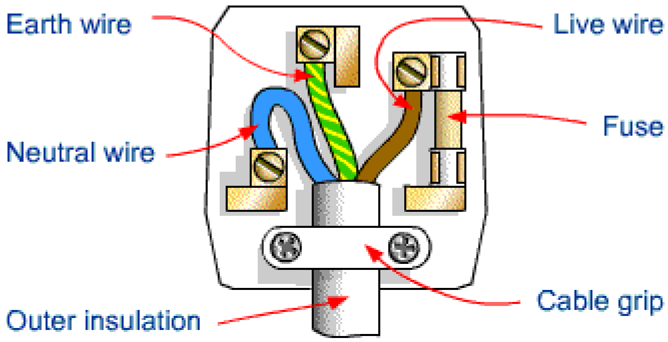
Circuit Breakers

- Switch off energy supply when large current flows.
- Can be reset without being replaced.
- Fault can be located easily without having to inspect each plug.

Fuses

- Prevents excessive current flow.
- Must be replaced after tripping.
- Thin short wire in a casing (low resistance) blows when a large current passes through to open the circuit.
- Slightly higher rated value than normal current.
- Connected to live wire.
  - Casing will be disconnected from live wire, no current flows through person.
  - If on Neutral: Live wire causes metal casing to have high voltage as it is still connected to the metal casing, hence a person will get an electric shock if he touches the casing and a large current flows through him to the earth.
- Mains should be switched off before replacing
- Common fuse ratings: 1A, 3A, 5A, 7A, 10A, 13A.

Earthing



- Earth wire is usually connected to the casing of appliances.
- Without earthing,
  - Electrical fault results in live wire touching metal casing.
  - Metal casing is at high potential (open circuit).
  - When a person touches the casing, circuit is complete and a large current flows through the person.
  - Person gets an electric shock.
- With earthing,
  - Electrical fault results in live wire touching metal casing.
  - Large current flows to the ground through earth wire which has much lower resistance than the person, hence person does not suffer electric shock.
  - Large current exceeds rated value of fuse, hence fuse blows
- Fuse protects the circuit from overheating while Earthing protects users from electric shocks.
- When an electrical fault results in the live wire touching the metal casing, the large current flows to the ground through the earth wire which has a lower resistance than the person. The large current causes a short circuit and exceeds the rated value of the fuse, causing it to blow, hence opening the circuit and cutting off the electricity supply to the appliance.

Double Insulation

- No Earth wire
- Two Levels of Insulation
  - Electric Cables insulated from internal components of appliance.
  - Internal Components insulated from external casing (e.g. plastic casing).

Chapter 20: Magnetism

Magnetic Materials

- Steel
- Iron
- Nickel
- Cobalt

Identifying magnets

- One side is attracted to a side of a known magnet, the other side is repelled from the side of the known magnet.

Magnetic induction

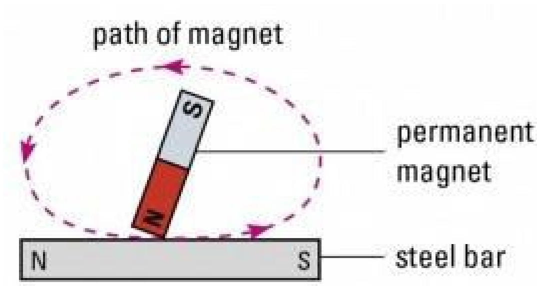
- The process whereby an object made of a magnetic material becomes a magnet when it is near or in contact with a magnet.

Theory of Magnetism

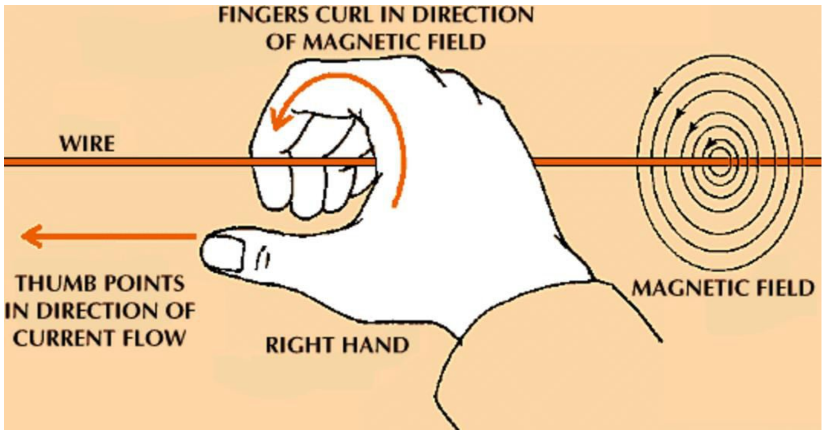
- Every atom is a magnet.
- A magnetic domain consists of a group of atomic magnets pointing in the same direction.

Magnetizing magnetic materials

- *Stroking*
  - Unmagnetised steel bar is stroked several times in one direction with one of the poles of a permanent magnet. Pole at the end of the steel bar where the strokes finish is opposite to the stroking pole used.



- *Electrical method using a direct current*
    - Large direct current aligns the magnetic domains.
    - Right-hand grip rule.
    - Grip solenoid with right hand.
    - Curl fingers in the direction of the current flow
    - Thumb points to the north pole and current flow



Demagnetizing magnets

- *Heating in an east-west direction*
    - Heat causes vigorous vibration of atoms hence causing the magnetic domains to lose their alignment.
- *Hammering in an east-west direction.*
    - Alters the alignment of the magnetic domains.
- *Electrical method using an alternating current*
    - Place the magnet inside a solenoid in an east-west direction.
    - Connect it to an a.c. supply.
    - Withdraw the magnet in an east-west direction while the solenoid is still on.

Magnetic fields

- The region surrounding a magnet in which a body of magnetic material experiences a magnetic force.
- Plotted with sprinkling iron filings/compass.
- Closer lines = Stronger Magnetic Force.
- Earth's geographical North is a magnetic South.

Magnetic shielding

- *Soft magnetic materials*
    - Iron
        - Easily magnetised and demagnetised.
        - Stronger induced magnet.
        - Used to make temporary magnets and for shielding.
- *Hard magnetic materials*
    - Steel
        - Difficult to magnetise and demagnetise.
        - Weaker induced magnet.
        - Used to make permanent magnets.

Uses of magnets

- Magnetic door latches
    - Magnets keep door closed.
- Moving-coil loudspeakers
    - Movement of diaphragm due to alteration between attraction and repulsion between temporary and permanent magnets due to current through a temporarily-magnetic coil.
- Electromagnets
    - Magnets formed when current flows, used for separation of magnetic materials from non-magnetic materials in scrapyards.

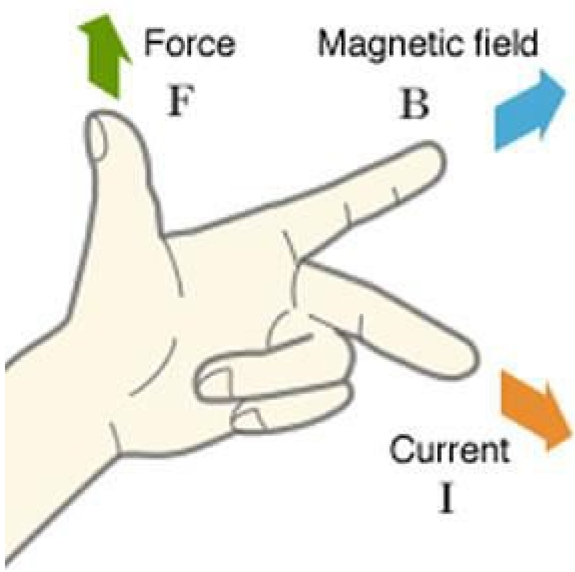
Chapter 21: Electromagnetism

Electromagnetic Effects of a Current

- A current-carrying conductor produces a magnetic field around it.
- Strength of magnetic field increases when the current increases.
- The direction of the magnetic field of a current-carrying wire is reversed when the direction of the current is reversed
- Drawing: Magnetic Field lines should be further apart with increasing distance from the wire

Fleming's Left-hand rule

- To find out the force when a wire is held between 2 poles of a magnet.



- Thumb → Force.
- Index finger → Direction of magnetic field (From North to South).
- Second finger → Direction of current.

Forces between 2 parallel current-carrying conductors

- Conductors carrying currents in opposite direction repel.
- Conductors carrying currents in the same direction attract.

Forces acting on a beam of charged particles in a magnetic field (protons or electrons)

- Direction of current flow is the direction of conventional current, i.e. direction of positive particle flow / opposite to direction of negative particle flow.
    - Point index finger in direction of magnetic field, point middle finger in the direction where the particle would move if undisturbed, resultant movement is between the thumb and middle finger.
- Reversing the direction of the current flow changes the direction of the force acting on the particle.
- Reversing the direction of the magnetic field also changes the direction of the force acting on the particle.
- Opposite Charge = reversed direction.
- Direction of movement of the particle is the resultant of the directions of the force, the current and the magnetic field Current-Carrying Coil Conundrums.

D.C. Motor

- Two Carbon Brushes at XY: Low friction + Path for current to flow.
- Addition of split-ring commutator: Hole cuts off the current when coil is vertical, momentum carries coil forward and allows for another cycle.
    - Reverses the direction of the current every half a revolution to allow it to continue spinning in one direction.
    - Force is greatest when horizontal.
- Rheostat: Set at maximum R before switch is closed and decreased over time to prevent overheating due to large current through small R wire.
- Increasing Turning Effect
    - Increasing number of turns per unit length.
    - Increasing current in coil.
    - Adding a soft iron core.

Chapter 22: Electromagnetic Induction

- The process through which an induced e.m.f. is produced in a conductor due to a changing magnetic field.
- E.m.f: Work done by the source in driving a unit charge around a closed circuit

Faraday's law

- Faraday's law of electromagnetic induction states that the magnitude of the induced e.m.f. in a circuit in directly proportional to the rate of change of magnetic flux (quantity of magnetic field) in the circuit.
- Deals with magnitude, or strength, of the induced current.

Ways to increase the magnitude of the induced e.m.f.

- Increase number of turns per unit length of coil
    - Increases the number of magnetic field lines linked to the coil (magnetic flux linkage)
- Increase the speed at which the magnet moves in / out of the coil.
- Increase the strength of the magnet.

Lenz's law

- Lenz's law states that the direction of the induced e.m.f., and hence the induced current in a closed circuit, is always such that its magnetic effect opposes the motion or change producing it.
    - If magnet enters solenoid south-first, south pole produced by current at end of entry to push away.
    - If magnet leaves solenoid south-first, north pole produced by current at end of entry to pull back.
- Current acts in opposite direction of movement of magnet.
- Galvanometer needle will be deflected in the direction of current.
- Deals with the direction of the induced current.

A.C. Generator

- Transforms mechanical energy into electrical energy.
- Works on principle of electromagnetic induction.
- Current reverses direction, hence "alternating current".
- Parallel Axel = Rate of Change of magnetic flux is maximum.
- When the coil rotates, it cuts across the magnetic field lines and there is a change in magnetic flux in the coil. By Faraday's Law, this change induces an e.m.f. in the coil.

Fleming's right hand rule

- Similar to left-hand rule.
- Used to find out the direction of the current.

Differences between left-hand and right-hand rule

Left-hand rule	Right-hand rule
Applies to D.C. motors.	Applies to A.C. generators.
Gives the direction of resultant force.	Gives the direction of the induced current.

Slip rings

- Ensure that the induced current in the coil is transferred to the external circuit

Ways to increase the magnitude of induced e.m.f.

- Increase number of turns per unit length of the coil.
- Increasing the strength of the permanent magnets.
- Increasing the frequency of rotations of the coil.
- Winding the coil around a soft iron core to strengthen the magnetic flux linking the coil

Fixed coil generator

- An a.c. generator where magnets rotate instead of coils rotate
    - Bike dynamo
- Practically, fixed coil generators are favoured because
    - Does not require carbon brushes, which wear out easily and need to be replaced frequently.
    - They are Less likely to break down from overheating.
        - Does not use slip rings and carbon brushes, eroded connection increases resistance which may cause overheating.
    - More compact

Transformers

- A device that can change a high alternating voltage (at low current) to a low alternating voltage (at high current), or vice versa.
- Used in electrical power transmission from power stations to households.
- Used to regulate voltages for the proper operation of electrical appliances.
- A transformer is based on electromagnetic induction. An a.c. in the primary coil induces a varying magnetic field in the iron core which creates an alternating induced e.m.f in the secondary coil which generates an induced current.

Features of a transformer

- Laminated soft iron core.
  - Comprises of thin sheets of soft iron.
  - Insulated by sheets of lacquer.
- Soft iron is used because it is easily magnetised.
  - Ensure better magnetic flux linkage.
- Lamination reduces heat loss.

Equation of power transmission

$$\frac{V_\varepsilon}{V_p} = \frac{N_\varepsilon}{N_p} = \frac{I_P}{I_s}$$

Types of transformers

- Step up
  - Increases voltage, decreases current.
  - Number of turns in the secondary coil is greater than that of the primary coil.
- Step down
  - Decreases voltage, increases current.
  - Number of turns in the primary coil is greater than that of the secondary coil.

$$V_s = \frac{N_s}{N_p} \times V_p$$

$$I_s = \frac{N_S}{N_P} \times I_p$$

Power transmission

- Ideal transformer has no power loss.
- Equation to calculate efficiency:

$$\frac{P_{out}}{P_{in}} \times 100\%$$

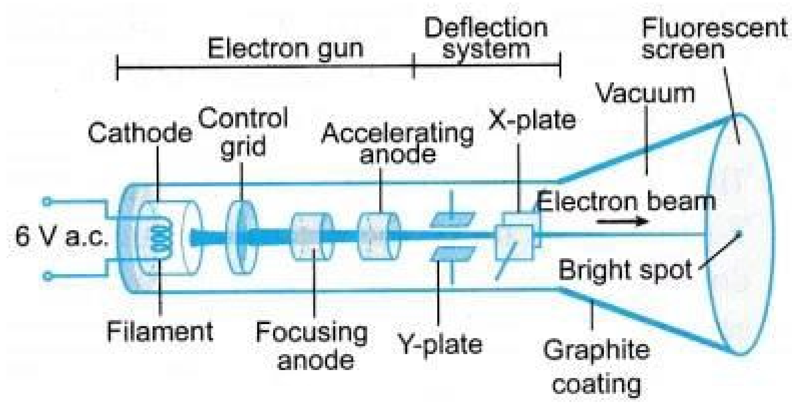
$$\frac{V_s I_s}{V_p I_p} \times 100\%$$

- However, resistance of coils, leakage of magnetic flux in transformers, decrease the efficiency of transformers.

Why are transformers used to transmit electricity over distances?

- Loss of power due to heating of wire.
  - To reduce loss of power, decrease current through step-up.
  - Cannot increase diameter of cables due to increased construction costs.
  - Stepped-down at homes for suitable voltages.

Cathode Ray Oscilloscopes



- Shows a voltage-time graph
- X and Y axis have the unit V/div and ms/div. One division is one square.
- Number of complete cycles can be calculated by:

$$\frac{f_y}{f_x}$$

- Below x-axis: Voltage in opposite direction.
- Y-gain ∝ Amplitude of Graph.
- Timebase ∝ 1/Period of Graph

Notes by:

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