Introduction to Electricity

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Force

- A force: the quantity that makes an object with mass m to change its velocity, i.e., to accelerate with a.
- Force is a vector quantity, which means that it has a magnitude and direction.

$$\bar{F} = m\bar{a} \ \ (N), \tag{1}$$

- Unit of force is Newton (N).

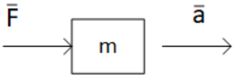


Figure: Force

Work & Energy

- Work:

$$W = Fd \quad (J), \tag{2}$$

where d=distance.

- Unit of work is Joules (J).

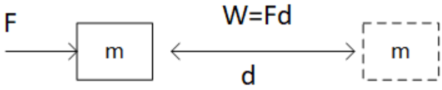


Figure: Work

Work & Energy

- Energy: the capacity to do work

$$E = W \quad (J), \tag{3}$$

where the object does not have to move, it can have a potential of work (energy).

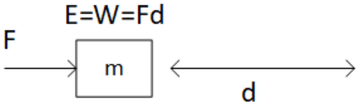


Figure: Energy

Electric Charge

- Electric charge: Electrons, protons.
- 6.2415x1018 proton= 1C.
- 6.2415x1018 electron= -1C.
- Unit of charge is Coulomb (C).

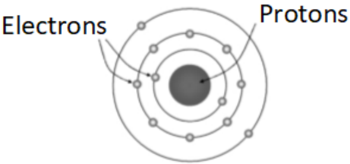


Figure: Bohr's atomic model

Electric Potential (Voltage)

- Electric Potential: Potential energy of 1C of charge.

$$V = \frac{W}{Q} \ (V), \tag{4}$$

where W=Work (Energy) in J, Q=Charge in C, and the voltage in V (Volts).

- Potential energy of charges is the result of the Coulomb's force:

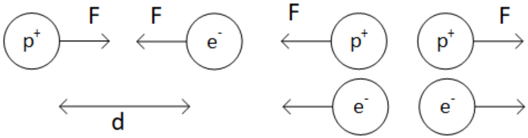


Figure: Coulomb's force of attraction and repulsion

Example:

A battery is a device that separates + charges from - charges, and collects them on its terminals. For the given battery of 1.5V, there are total of 7200C at each terminal. Find the total electric potential energy of the battery ?

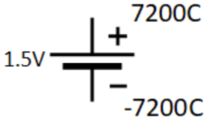


Figure: Coulomb's force of attraction

Answer:

- The electric potential energy for 1C of charge is the voltage (electric potential), which is 1.5 V. Thus, for 7200C of charge at a terminal

$$V = \frac{W}{Q} \tag{5}$$

or

$$W = VQ = (1.5)(7200) = 10800J. = 10.8kJ. \tag{6}$$

- This is the total electric potential energy of the battery.

Electric Properties of Materials

- Materials can be grouped in terms of their electrical characteristics as: Conductors, Insulators,and semi-conductors.
- Conductors: contains lots of free charges (charges that are loosely bound to the atomic core- usually outer orbit electrons). Free e^{-}'s can move easily from orbit to orbit even under small forces. All metals are conductors.
- Insulators: do not contain free charges. Electrons are tightly bound to the core (inner orbit e^{-}'s), high energy is required to separate electrons for motion. Air, plastic, glass can be given as examples of insulators.
- Semi-conductors: In between conductors and insulator. They act as insulators, but when connected to a voltage source, they act as conductors. Silicon is an example to semi-conductors. They are used in the production of electronic components such as diodes and transistors.

Electric Current

- Electric current: The amount of charge moving in per unit time (1 sec.).
- The unit of electric current is Ampere (A).

$$I = \frac{Q}{t} \ (A) \tag{7}$$

- Conduction current occurs through the motion of electrons in a conductor.
- Types of electric current: DC(Direct current), AC (Alternating current).

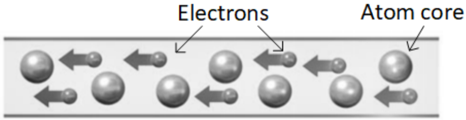


Figure: Conduction current

Resistance

- Resistance: how much a matter opposes against the electric current.
- Unit is ohms (Ω).
- Resistance of a conductor is given as

$$R = \frac{l}{\sigma S} \ (\Omega), \tag{8}$$

where l=Length of the conductor, S=Cross sectional area, and σ=Conductivity constant (in the order of 10^7 for conductors).

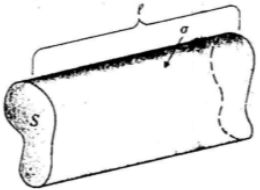


Figure: Resistance of a conductor

Power

- Power: The energy consumed (or generated) by a resistor (or a generator) in per unit time (1 sec.).
- The unit is Watts (W).

$$P = \frac{W}{t} \ (W), \tag{9}$$

- The power consumed in a resistor is

$$P = \frac{W}{t} = (VQ)\left(\frac{I}{Q}\right) = VI \ (W), \tag{10}$$

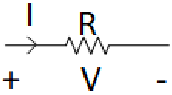


Figure: Power consumed by a resistor

Electric Circuits

- Electric Circuit: The connection of batteries and resistors through conducting wires.
- Ohms law: In a closed electric circuit, $V = IR \ \ (V)$,
- The power consumed in a resistor: $P = IV \ \ (W)$,
- The consumed energy by a resistor in time t: $E = Pt \ \ (kWh)$.

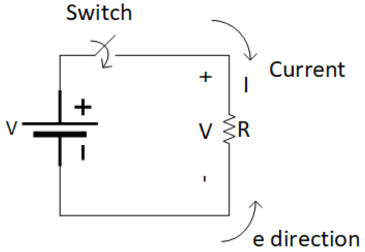


Figure: Electric circuit

Ans

Example

60W light bulb is used for 2 hours everyday. How much total energy is consumed in a month in kWh ?

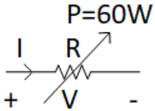


Figure: Example circuit

Ans:

$$E = Pt = (60W)(2h)(30) = 3600kWh. \quad (11)$$

DC and AC Currents

- There are two types of currents: DC (Direct Current) and AC (Alternating Current).
- DC current does not vary in time.
- DC current always flows in the same direction in a conductor.
- DC current is obtained from batteries.

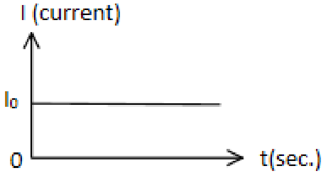


Figure: DC current graph

AC Current

- AC current is the current that changes in time periodically.
- AC current is obtained from turbines that converts mechanical energy into electrical energy in the form of a trigonometric function (sine or cosine).

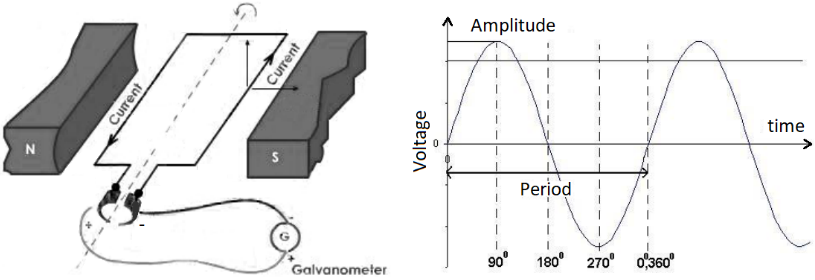


Figure: AC current generation and time graph

Definitions of AC current

- Period (T): is the time it takes for the current to complete a full cycle.
- Frequency (f): is the number of cycles in 1 sec. (f=1/T Hz.)
- Amplitude: The peak value of the current or voltage is called the amplitude.

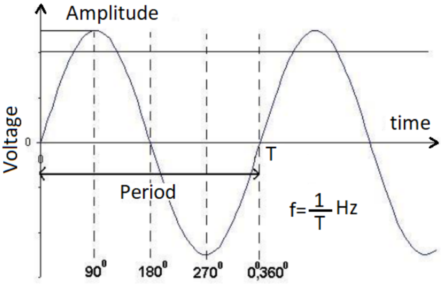


Figure: AC current definitions

Where do we use DC and AC power ?

- DC power is used in all battery powered electronic devices such as radios, notebooks and mobile phones.
- AC power is used in power lines, wireless telecommunication systems such as mobile phones, satellite communication and radars.

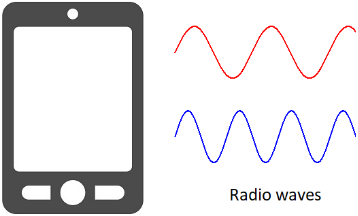


Figure: DC and AC power usage

Why do we use AC in electric energy usage ?

- Easy to generate.
- Easier to transfer energy to long distances than DC.
- Installation Costs and line losses are less than DC.
- It is possible to use transformers with AC.

Figure: AC power lines.

Transformers

- Transformer: Electric device that is made of two windings of wires around an iron core. It is used for increasing or decreasing voltage or current at one of its terminals with respect to the other.

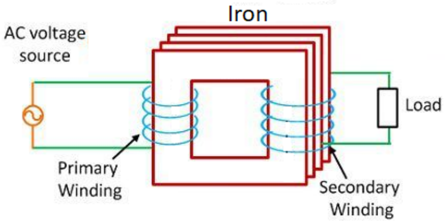


Figure: Transformers

Transformer Applications I

- Adapters: There are transformers inside adapters that are used for decreasing voltage amplitude (120 V) at the electric socket to a lower value such as 20 V to be used for an electronic device such as a notebook.

Figure: Adapters.

Transformer Applications II

- City transformer plants: These transformers are used to decrease high voltage (kV's) to low voltage (120 V city voltage) which is distributed to houses, factories, any other consumer facilities.
- High voltage (kV's) is generated at the power plants (thermal, hydro, nuclear, etc.)

Power plant (kV's)

Transformer plant

City electricity (120V)

Figure: Transformer applications

Electrical Energy generation

- Electrical energy sources:
- Renewable: sun, water, wind, ...
- Non renewable: (fossil based) coil, oil, natural gas, nuclear...

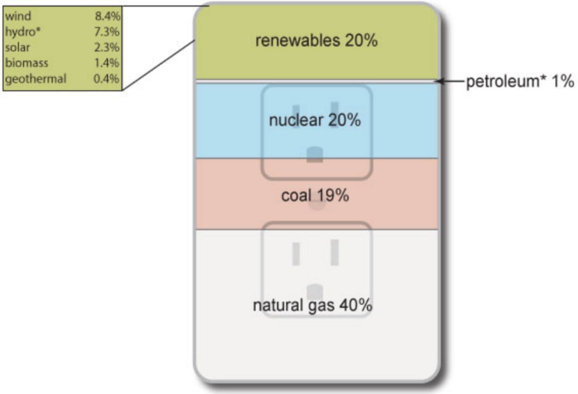


Figure: Sources of U.S. electricity generation, 2020, Total=4.12 trillion kWhrs.

Voltage levels

- High voltage > 1000 V
- Low voltage < 1000 V

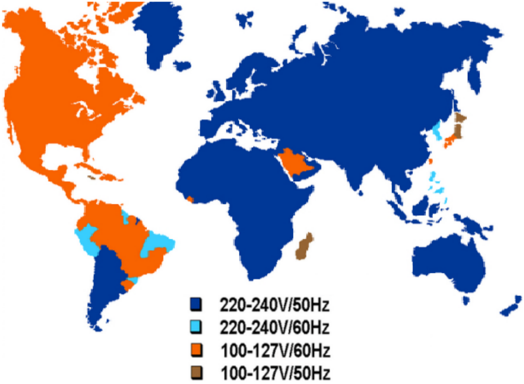


Figure: Voltage levels in the world

Electrical energy transportation

- High voltage (HV) power lines: 115 kV to 230 kV.
- HV lines: P=IV, For the same P, high V means less I which means thinner wires.
- Advantages: Low cost, easy installation, less losses in wires as heat dissipation.

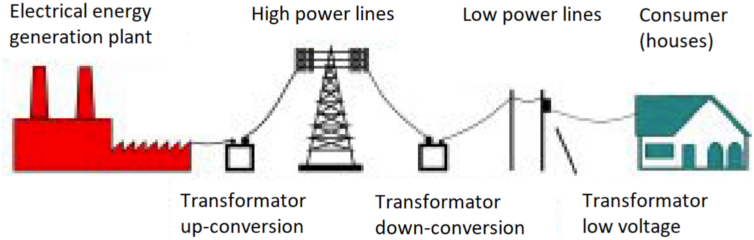


Figure: Electrical energy transportation scheme

High voltage lines

- High voltage lines: 154kV, 380 kV
- Minimum height over highways: 14 m
- Maximum distance of approach: 2-3.5 m
- Isolators (ceramics)
- Warning boals

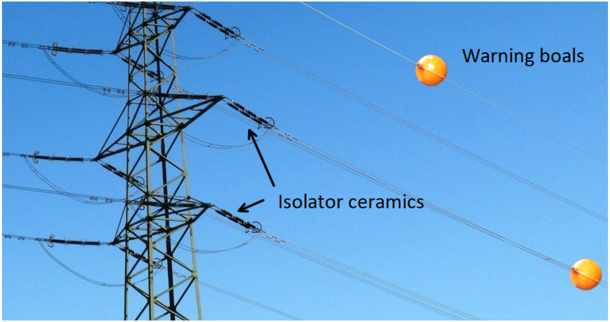


Figure: Electrical energy transportation scheme

Electrical energy distribution structures

- Electrical Power grid: All the cables and air lines from the power plant to the supplier (transformer) and to the consumer facilities.
- Electrical Distribution Network: All the cables and air lines from the current supplier (transformer) to the consumer facility.
- Consumer facility: All the electrical systems that consume electrical energy located after the main disribution panel.

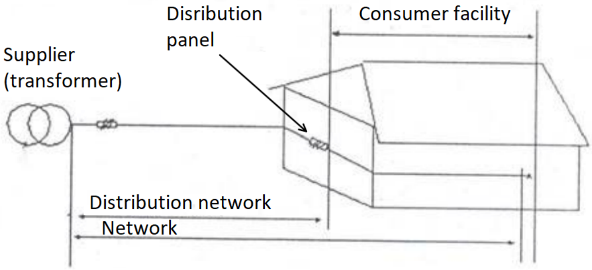


Figure: Electrical energy transportation scheme

Grounded electrical power distribution network

- Grounded type electric networks contain a ground connection both at the supplier and the consumer facility.

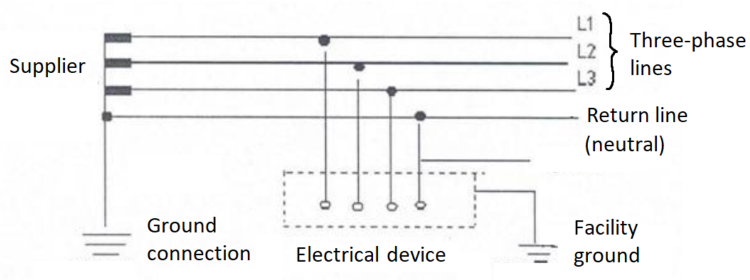


Figure: Electrical power distribution network

Grounded electrical power sockets

- In electric sockets, there are two terminals: the + (phase) and the natural. For facility grounded systems, there is also a ground contact point.

Figure: Electrical sockets

Electrical devices and faulty connection

- All electrical devices in workplaces are loads.
- AC current path under normal operation is from L to N.
- Deformation of materials.
- Faulty connection.
- Faulty connection is dangerous because it may cause electric shock.

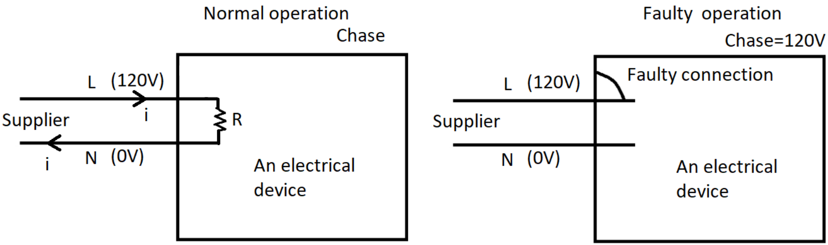


Figure: Electrical device operation and faulty connection

Electric Shock

- It is the current flow over one's body due to a contact with a voltage source usually because of a faulty connection.
- Most often the current enters the body from the hands, passes over the heart and leaves from the feet.
- The current passing through the heart causes it to stop beating (fibrilation).

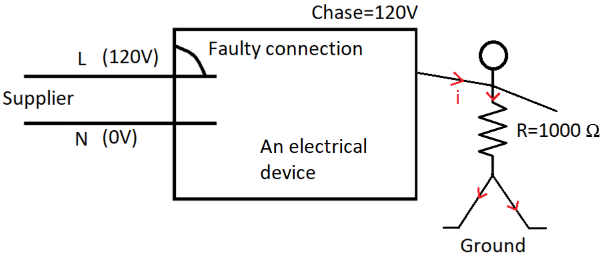
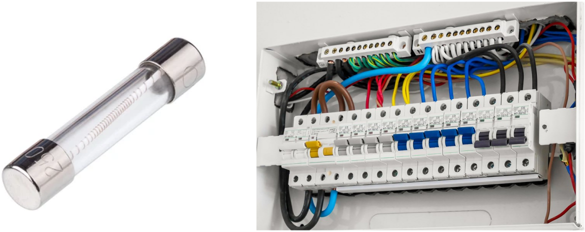


Figure: Electrical shock due to a faulty connection

Electric Fuses + grounding

- Fuses are safety devices against high currents.
- A fuse is a switch that is controlled by current.
- Fuses blow (cuts-off the circuit) when the current exceeds a certain limit.

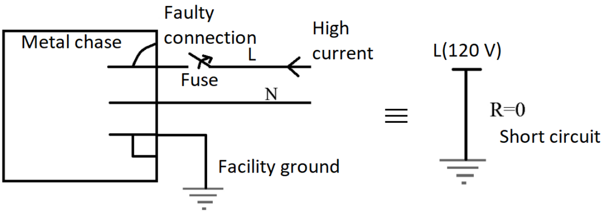


Glass fuse   Fuse box

Figure: Electric fuse

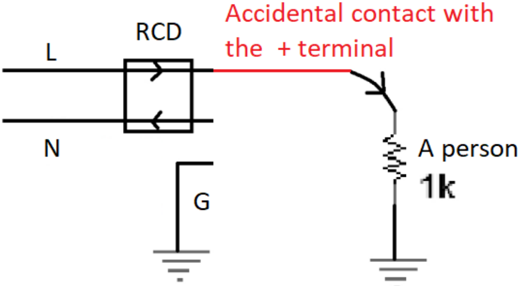
Electric Fuses + grounding

- AC current comes from the positive (live) terminal, passes through the load, and goes back to generator from the natural line, and eventually goes to ground.
- If for any reason the live terminal comes into contact with the natural terminal, an infinite current demand occurs due to V=IR. This is called short circuit.
- Fuses break the circuit when the current exceeds a certain limit, thereby protecting the system from a possible damage, and protecting a person from an electric shock due to faulty connection.



Residual current device (RCD)

- The standard fuse does not provide protection against electric shocks that may occur as a result of direct contact with the voltage line. (+ terminal).
- RCD or "leakage current fuse" is legally required, and protects from electric shock even from a direct contact.
- RCD is a fuse that measures the difference between the incoming and outgoing currents in the power line. It blows only when this difference exceeds a limit, usually 20 mA.



Technical Factors in Electric Shocks:

- Type of the current (AC-DC)
- Amount of voltage
- Amount of current
- Frequency
- Time of exposure

Major Factors in Electric Shocks:

- The ground being dry or wet
- Existence of some Insulating objects between the voltage source and victim.
- Current direction and path of flow.
- Body resistance
- Hands being dry or wet.

Causes of electric accidents

- Isolation faults (23%)
- Contact to an electrical device with a faulty connection. (26%)
- Contact by the power lines. (20%)
- Accidents on top of electric poles. (12%)

Effects of electric current on human body

- The amplitude limit for safety is considered to be 30 mA.

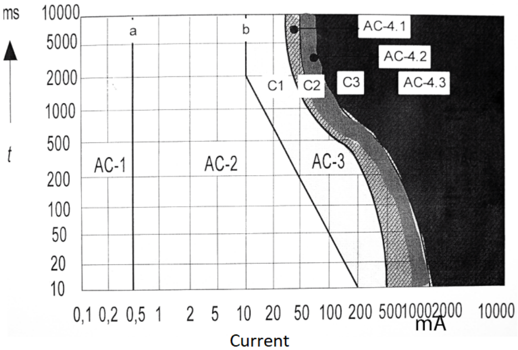


Figure: The effect of time exposure

Body resistance

- The body resistance is 3000 ohms for a dry skin at 120 V.

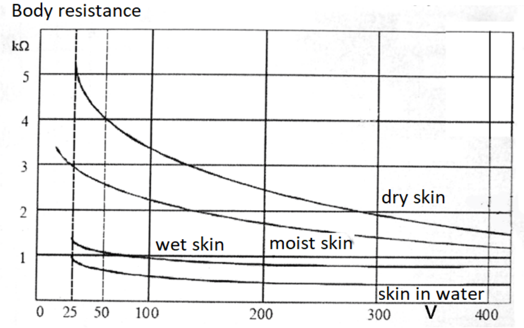


Figure: The effect of time exposure

Safety precautions

- Cutting off the voltage
- Insulation, isolation
- Grounding

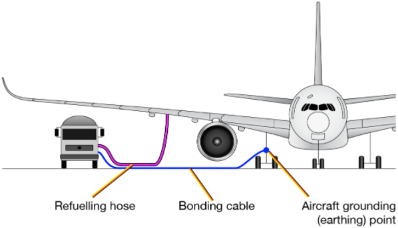
Figure: Safety precautions

Static electricity

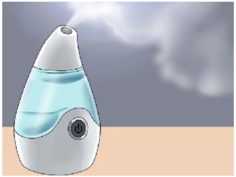
- Static electricity is the separation of charges as a result of friction (movement), creating potential energy.
- It is electrical energy that is generally useless and discharged in the form of arcs.
- Visible static loads are around 6000-7000V. However, the current is very low.
- Risks: In environments where explosive materials and gases are used, there is a risk of explosion and fire due to static energy of tanks or vehicles.

Static electric

- Precautions:
- Grounding, Moistening, Ionization



Grounding



Humidifier

Ionization

Figure: Safety precautions for static electricity

Lightning

- Clouds are formed when warm air condenses at high altitudes.
- In the ionizing atmosphere, mutual charges create an electric potential difference.
- For E=100-160 V/m, 10^5 to 10^6 V occurs between the cumulonimbus clouds (1-2 km) and the ground.
- Electrons fall from the cloud to the earth.

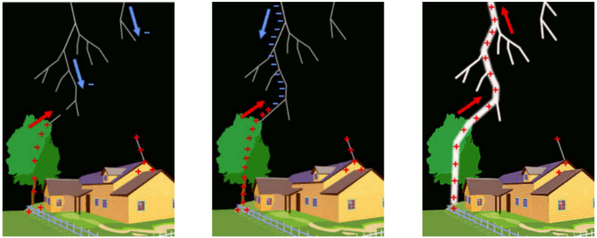


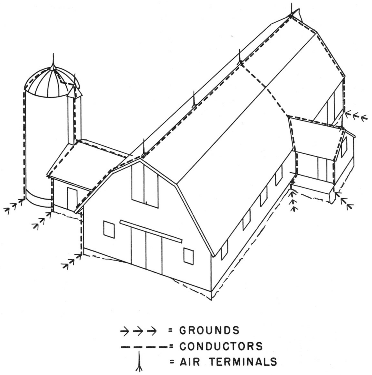
Figure: Lightning

Precautions against Lightning

- Do not stand still.
- Do not stay close to places that are higher than their surroundings.
- Do not stay in open areas.
- Umbrellas should not be opened.
- Do not talk on the cell phone.
- If there is a car, one should get inside.
- It should not be sheltered under trees.
- Water should be avoided. (sea, lakes etc..)

Lightning protection systems

- Lightning rod (Franklin Rod) which is a pointed metal rod attached to a building's roof.
- The lightning conductor with meshed cage (Faraday cage).
- Active lightening rod is an ionizing lightning rod which attracts lightning.



Radiation

- Radiation is defined as energy that can move in space and matter.
- In general, we can divide radiation into two groups: Ionizing and non-ionizing radiation.
- Microwaves and radio waves with a frequency lower than the frequency of light are examples of non-ionizing radiation.
- X and gamma rays are ionized radiation that occur as a result of changes in the structure of the atom.

Radiation

- The AC current flowing on the conductor is the source of the non-ionizing radiation.
- X and gamma rays are produced by the disintegration of the atomic structure generated in nuclear reactors. These are high-energy and dangerous radiations.

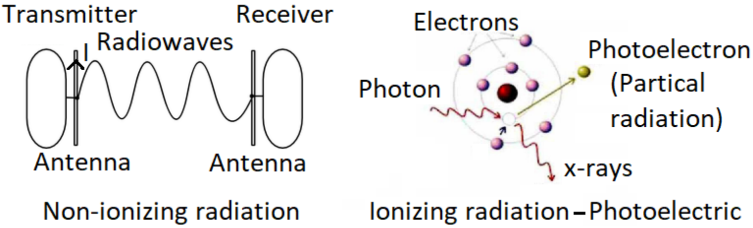


Figure: Lightning

The effects of non-ionizing radiation on human health

- If the amplitude of the source current is high, high energy is radiated.
- In such a case, being near the transmitting antenna may result in electric shock.
- Even if a person is not very close, continuous exposure to radiowaves for long periods of time can also lead to diseases such as cancer.
- There are standards in the world for the approach distance with respect to the exposure time of radio waves.

The effects of ionizing radiation on human health

- It disrupts DNA structure, causes cancer.
- 1 Sievert = 1 Joule/kg
- Limit value = 100 mSv/year
- A flight at 40000 feet gives 0.035mSv radiation exposure. This amount of radiation is less than the amount of radiation we receive from one chest x-ray.
- In general, a person receives 1 to 10 mSv of radiation from the air and soil in a year.
- A chest x-ray, for example, delivers 0.1 mSv, while a chest CT delivers 7 mSv.