# Electromagnetic Waves

## EXERCISE

### 14.0 : Introduction

**Q.1. Define electromagnetic waves.**

**Ans:** i. Electromagnetic waves are time varying electric and magnetic fields, propagating in space.

eg. Infrared rays, microwaves, radio waves, ×–rays, UV rays etc.

ii. Electromagnetic waves are produced by accelerated electric charges.

### 14.1 : Electromangetic waves and their characteristics :

**Q.2. Explain Hertz's experiment for the production of electromagnetic waves.**

**OR**

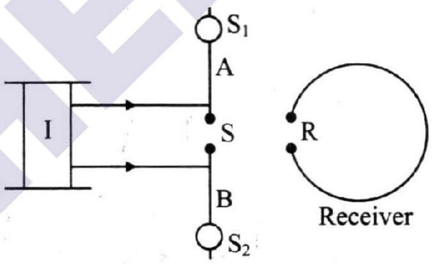
**Explain how electromagnetic waves are generated.**

**Ans: Production of electromagnetic waves:**

i. An experimental setup used by Hertz to produce and detect electromagnetic waves is as shown in the figure.

ii. The transmitter consists of two spheres $S_1$ and $S_2$ located near the ends of two straight rods A and B separated by a spark gap S.

iii. With the two rods connected to an induction coil I, sparks jump across the gap S, giving rise to an oscillatory current in A and B. The spheres $S_1$, $S_2$ act as the plates of a capacitor and the rods A and B provide inductance. Hence, the transmitter acts as an oscillator circuit.




Hertz Experimental setup

**Hertz Experimental setup**

| | | |
|---|---|---|
| **I** | **:** | **Induction coil** |
| **A, B** | **:** | **Straight rods** |
| **S** | **:** | **Gap between A and B** |
| **R** | **:** | **Gap between loop of wire** |
| **$S_1S_2$** | **:** | **Spheres{Capaciters)** |

iv. The receiver or detector, consists of a single loop of wire with a tiny spark gap at R.

v. This circuit too, is an oscillating circuit with the spark gap acting as a capacitor and the loop providing the inductance.

vi. Tuning the transmitter frequency to that of the receiver is done by sliding the spheres $S_1$, $S_2$ along the rods A and B. When the two circuits are tuned, a spark appears across R, whenever a spark passes across S.

vii. Wavelengths of electromagnetic waves were found to be about 6 m.

viii. These waves undergo reflection, refraction, interference etc. similar to light.

**Q.3. State the main characteristics of electromagnetic waves.**

**Ans: Characteristics of electromagnetic waves:**

i. Electric field vector and magnetic field vector vibrate perpendicular to each other and also to the direction of propagation of wave i.e., electromagnetic waves are transverse in nature.

ii. E.M. waves propagate in the form of time varying electric and magnetic fields.

iii. Electromagnetic waves are produced by accelerated electric charges or in a nuclear transition or in the annihilation of an electron and a positron.

iv. Electromagnetic waves do not require any material medium for their propagation. They can travel through vacuum as well as through solids, liquids and gases.

v. The relation between the velocity (c), frequency (v), and wavelength ($\lambda$) of electromagnetic waves in vacuum (i.e., free space) is given by $c = v\lambda$.

vi. Electromagnetic waves travel with the speed of light in vacuum and their velocity (c) is given by,

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.85 \times 10^{-12}}}$$

$$= 3 \times 10^8 \text{ m/s}$$

where, $\varepsilon_0$ and $\mu_0$ are the permittivity and permeability of free space.

vii. In a given material medium, the velocity ($v_m$) of electromagnetic waves is given by,

$$v_m = \frac{1}{\sqrt{\mu \varepsilon}}$$

where $\mu$ = Permeability of the given medium
$\varepsilon$ = Permittivity of the given medium

viii. Electromagnetic waves obey the principle of superposition of waves.

ix. The momentum transported by electromagnetic waves is given by,

$$P = \frac{U}{c}$$

where, U is energy transported by electromagnetic waves in a given time and c is speed of electromagnetic waves in free space. As a result, the electromagnetic waves exert pressure on the surface on which they strike.

×. The electromagnetic waves obey the laws of reflection and refraction. Also, they exhibit phenomena of interference, diffraction and polarisation.

xi. Electric and magnetic fields in electromagnetic waves vibrate in phase.

xii. The ratio of the amplitudes of electric and 'magnetic fields is always constant and it is equal to velocity of the electromagnetic waves $\left(c = \frac{E}{B}\right)$

xiii. The energy of electromagnetic waves is equally distributed among the electric and magnetic field vector.

xiv. The low frequency electromagnetic waves are unaffected by external electric and magnetic fields.

## 14.2 : Transvers nature of electromagnetic waves :

**Q.4. Explain the transverse nature of electromagnetic waves.**

**Ans:** i. The electromagnetic waves are produced by accelerated electric charges. An accelerated charge produces a magnetic field in the surrounding region which gives rise to an electric field.

ii. The electric and magnetic fields are mutually perpendicular to each other. If the accelerated charge is oscillating, both the electric and magnetic fields vary with time and they travel outwards from the charge in the form of electromagnetic waves.

iii. If E is along the Y–axis and B is along the Z–axis, the direction of propagation is along Ex B i.e., along the ×–axis as shown in figure (a).

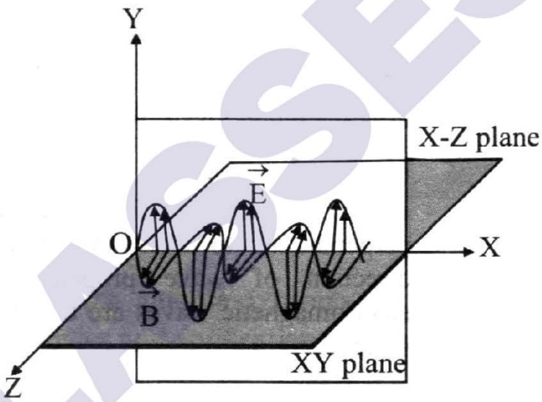



**Figure (a) Electromagnetic wave propagating along × axis**

iv. A single electromagnetic wave propagating perpendicular to both electric and magnetic fields in magnified form is as shown in figure (b).

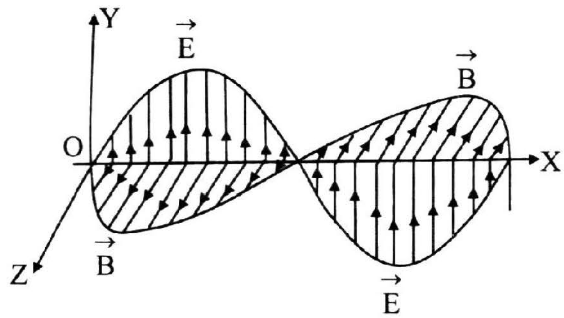



**Figure (b) E.M. Wave**

v. The electric field and magnetic field vary sinusoidally with × and is given by,

$B_y = E_o \sin(kx - \omega t)$

$B_z = B_o \sin(kx - \omega t)$

where,

$E_o$ = amplitude of electric intensity E.

$B_o$ = amplitude of magnetic induction B.

$k = \frac{2\pi}{\lambda}$ = Propagation constant and

A is wavelength of oscillations

$\omega = 2\pi v$ = Angular frequency of oscillations.

vi. Both the electric and magnetic fields attain their maximum and minimum values at the same time and at the same point in space i.e., they oscillate in same phase with same frequency.

vii. Energy is equally distributed between electric vector E and magnetic vector B vibrating in same phase.

viii. From the figures, it is observed that propagation of electromagnetic field is in the direction of E × B. As the electric and magnetic fields are mutually perpendicular to each other and to the direction of wave propagation, the electromagnetic waves are transverse in nature.

**Q.5. A plane electromagnetic wave travels in vaccum along z–direction. What can you say about the directions of its electric and magnetic field vectors? If the frequency of the wave is 30 MHz, what is its wavelength? (NCERT)**

**Ans:** Since the electromagnetic waves are transverse in nature, the electric and magnetic field vectors, are mutually perpendicular to each other as well as perpendicular to the direction of propagation of wave.

As the wave is travelling along z–direction, E and B are in XY plane.

For v = 30 MHz = $30 \times 10^6$ Hz

$$\text{Wavelength } \lambda = \frac{c}{v} = \frac{3\times10^8}{30\times10^6} = 10 \text{ m.}$$

**Q.6. Is it possible to polarise the electromagnetic waves?**

**Ans:** Yes, electromagnetic waves can be polarised. A beam of electromagnetic waves is unpolarised, but if the vibrations of the electric field vector are confined to one plane containing the direction of propagation, then the waves are said to be plane polarised or linearly polarised.

## 14.3 : Electromagnetic spectrum :

**Q.7. What is electromagnetic spectrum?**

**Ans:** i. The orderly distribution (i.e., sequential arrangement) of electromagnetic waves according to their wavelengths (or frequencies) in the form of distinct groups having different properties is called the electromagnetic spectrum.

ii. The main parts of the spectrum are: gamma radiation, ×–rays, ultraviolet radiation, visible light, infrared radiation, microwaves, radio waves.

iii. The spectrum of electromagnetic radiations has no upper or lower limits i.e., sharp boundaries. All regions overlap.

iv. The known electromagnetic waves have wavelength ranging from $6 \times 10^{-13}$ m to more than $10^4$ m.

**Q.8. State various units of electromagnetic waves.**

**Ans:** SI unit of frequency of electromagnetic waves is hertz (Hz). Higher frequencies are represented by kHz, MHz, GHz etc.

1 kHz = $10^3$ Hz, 1 MHz = $10^6$ Hz,
1 GHz = $10^9$ Hz.

**Q.9. State different units of wavelength of electromagnetic waves.**

**Ans:** The SI unit of wavelength of electromagnetic waves is metre (m). Small wavelengths are represented by micrometre (urn), angstrom (A), nanometre (om) etc.

1 μm = $10^{-6}$ m, 1 A = $10^{-10}$ m = $10^{-8}$ cm,
10 m = $10^{-9}$ m.

**Q.10. Given below are some famous numbers associated with electromagnetic radiations in different contexts in physics. State the part of the electromagnetic spectrum to which each belongs.**

**a. 21 cm (wavelength emitted by atomic hydrogen in interstellar space).**

**b. 1057 MHz (frequency of radiation arising from two close energy levels in hydrogen; known as Lamb Shift).**

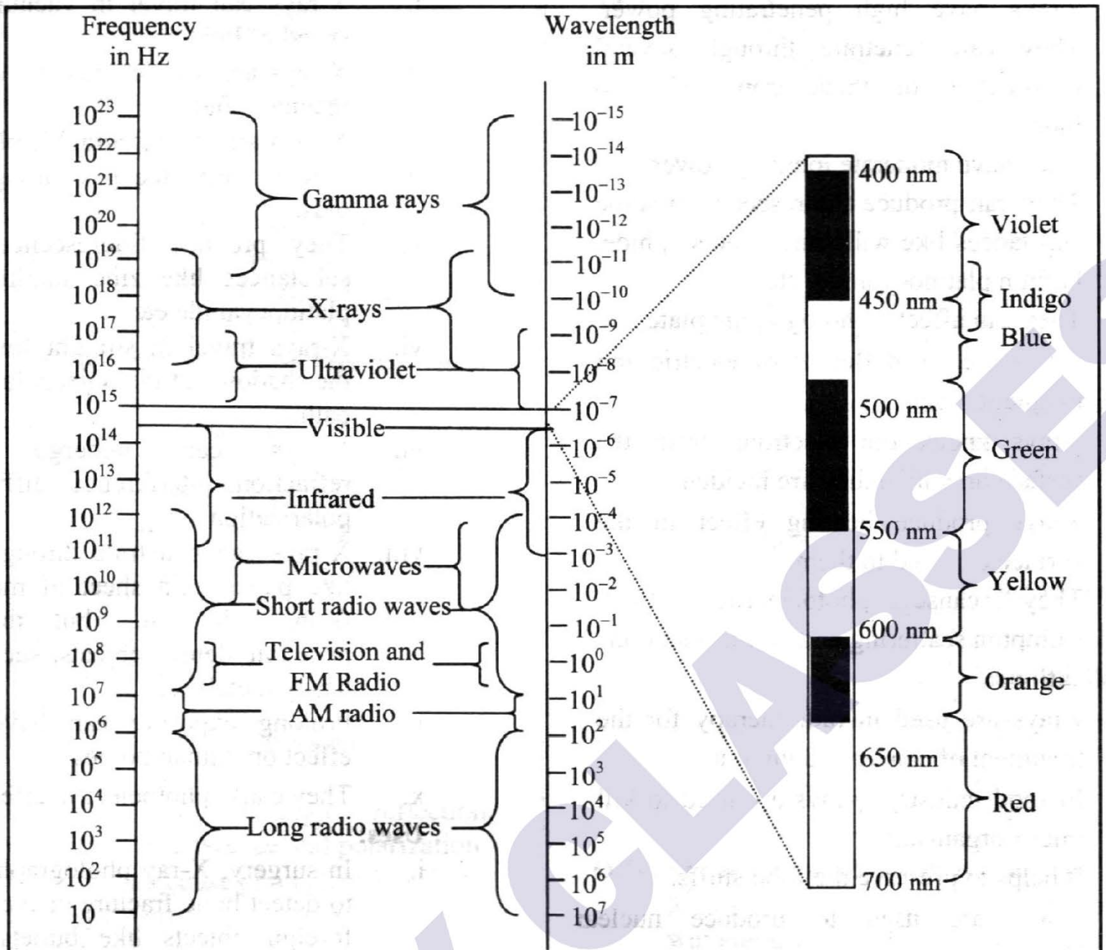
**c. 5890 Å – 5896 Å [double lines of sodium]**

**(NCERT)**

**Ans:** a. Radio waves (short wavelength or high frequency end)

b. Radio waves (short wavelength or high frequency end)

c. Visible region (yellow light)




Electromagnetic spectrum

**Q.11. Draw neat labelled diagram of electromagnetic spectrum.**

**Ans:**

**Q.12. What are gamma (γ) rays? Explain the properties and application of gamma rays.**

**Ans:** i. Gamma rays are electromagnetic waves having wavelength ranging nearly from $10^{-15}$ m to $10^{-10}$ m.

ii. The gamma rays are high energy electromagnetic waves having very high frequency ranging nearly from $3 \times 10^{18}$ Hz to $5 \times 10^{20}$ Hz.

iii. Gamma rays are detected with Geiger counter, photographic plate, fluorescence.

iv. These gamma rays are emitted from the nuclei of some radioactive elements such as uranium, radium etc.

v. Gamma rays were discovered by Paul Ulrich Villard.

**Properties:**

i. $\gamma$ –rays have high penetrating power. They can penetrate through several centimetres of thick iron and lead blocks.

ii. They have moderate ionizing power.

iii. They can produce fluorescence in some substances like willemite, zinc sulphide, barium platinocyanide, etc.

iv. They can affect a photographic plate.

v. $\gamma$ –rays are not deflected by electric and magnetic fields.

vi. $\gamma$ –rays knock out electrons from the surface on which they are incident.

vii. $\gamma$ –rays produce heating effect in the surface exposed to them.

viii. They cause photoelectric effect, Compton scattering and pair production.

**Applications:**

i. $\gamma$ –rays are used in radiotherapy for the treatment of cancer and tumour.

ii. In food industry, $\gamma$–rays are used to kill micro–organisms.
iii. It helps to preserve the food stuffs.
iv. $\gamma$–rays are used to produce nuclear reactions.
v. Gamma ray astronomy.

**Q.13. What are ×–rays? Explain the properties and uses of ×–rays.**

**Ans:** i. ×–rays are electromagnetic waves having very short wavelength ranging nearly from $10^{-11}1$ m to $10^{-8}$ m.
ii. The frequency range of ×–rays is from $1 \times 10^{16}$ Hz to $3 \times 10^{19}$ Hz.
iii. They are produced, when fast moving electrons (Cathode rays) are suddenly stopped by an obstacle.
iv. ×–rays are produced in the laboratory by using Coolidge ×–ray tube.
v. ×–ray were discovered by Wilhelm Konrad Rontgen in 1895.
vi. ×–rays are detected by ionisation chamber, photographic plate, scintillation counters, semi–conductor detector, etc.

**Properties:**
i. ×–rays can travel in vacuum with the speed of light.
ii. ×–rays are not deviated by electric and magnetic fields.
iii. ×–rays affect photographic plates.
iv. ×–rays ionize the gas through which they pass.
v. They produce fluorescence in many substances like zinc sulphide, barium platinocyanide etc.
vi. ×–rays travel in straight line, they cast the shadows of the objects falling in their path.
vii. ×–rays can undergo reflection, refraction, interference, diffraction and polarization.
viii. ×–rays can penetrate through materials like paper, thin sheet of metal, wood, flesh, skin, etc., but they cannot penetrate denser objects, such as bones, heavy metals, etc.
ix. Prolong exposure can have injurious effect on human bodies.
×. They cause photoelectric effect.

**Uses:**
i. In surgery, ×–ray photographs are useful to detect bone fracture or the presence of foreign objects like bullets or hidden metal in a human body.
ii. They are used for detecting faults, cracks, flaws and gaps in metals.
iii. They are used to distinguish real diamonds, gems from artificial ones.
iv. ×–rays are used to detect the structure of crystals.
v. ×–rays are used to cure skin diseases and to destroy tumours in the body of a patient.
vi. They are used for the detection of explosives opium etc.

**Q.14. Define photoelectric effect?**

**Ans:** When electromagnetic radiation of very short wavelength is incident on metal surfaces, electrons are emitted from these surfaces. This phenomenon is called photoelectric effect.

**Note:** Energy of photon = $h\nu = h\frac{c}{\lambda}$

where h is Planck's constant.
$h = 6.63 \times 10^{-34}$ J/s.

**Q.15. State why long exposure to ×–ray is harmful.**

**Ans:** ×–rays can kill living plant and animal tissues and exposure for a long period increases the risk of cancer. Hence, long exposure to ×–rays is harmful.

**Q.16. What are ultraviolet rays? Explain the properties and applications of UV–rays,**

**Ans:** i. Ultraviolet rays are electromagnetic waves of short wavelengths ranging from nearly $10^{-8}$ m to $3.9 \times 10^{-7}$ m.
ii. Their wavelengths are shorter than those of violet light.
iii. They can be produced by the arcs of mercury and iron. They can also be obtained by passing discharge through hydrogen and xenon, UV laser diodes.
iv. The sun is the most important natural source of UV–rays.
v. Ultraviolet rays were discovered by Johann Wilhelm Ritter in 1801.

**Properties:**
i. UV–rays can travel in vacuum with the speed of light.
ii. UV –rays can undergo reflection, refraction, interference and polarization.
iii. UV–rays can cause photoelectric effect.
iv. UV–rays produces fluorescence in certain materials.
v. UV–rays cannot pass through glass but they

can pass through quartz, fluorite, rock salts etc.

vi. UV–rays possess the property of synthesizing vitamin D when the skin is exposed to sunlight.

**Appllcatlonsr :**

i. Ultraviolet rays are used for checking the mineral samples.

ii. They are used to study molecular structure.

iii. Ultraviolet rays destroy bacteria and hence they are used for sterilizing surgical instrument.

iv. Being invisible, UV–rays are used in burglar alarms.

v. They are used in high resolving power microscopes.

vi. They are used to distinguish real and false gems.

vii. They are used in the analysis of chemical compounds.

**Q.17. Write a short note on visible light.**

**Ans:** i Visible rays are narrow part of electromagnetic spectrum which is detected by human eyes.

ii. The wavelength range varies between $3.9 \times 10^{-7}$ m to $7.5 \times 10^{-7}$ m.

iii. The frequency range of visible light is $8 \times 10^{14}$ Hz to $4 \times 10^{14}$ Hz.

iv. Visible light is produced when excited atoms return to their normal states.

v. Visible light consists of different colours ranging from red to violet.

vi. Different wavelengths give rise to different colours. The cvelength of red colour being largest while that of violet colour being least. Wavelength range of various parts of visible rays are as follows:

| **Colour** | **Wavelength ranze in m** |
|---|---|
| Violet | $4 \times 10^{-7}$ to $4.5 \times 10^{-7}$ |
| Blue | $4.5 \times 10^{-7}$ to $5 \times 10^{-7}$ |
| Green | $5 \times 10^{-7}$ to $5.7 \times 10^{-7}$ |
| Yellow | $5.7 \times 10^{-7}$ to $5.9 \times 10^{-7}$ |
| Orange | $5.9 \times 10^{-7}$ to $6.2 \times 10^{-7}$ |
| Red | $6.2 \times 10^{-7}$ to $7.5 \times 10^{-7}$ |

**Q.18. What physical quantity is the same for ×–rays of wavelength $10^{-10}$ m, red light of wavelength 6800 Å and radiowaves of wavelength 500 m? (NCERT)**

**Ans:** The speed in vacuum is the same for all i.e., $c = 3 \times 10^{8}$ m $s^{-1}$.

**Q.19. What are infrared rays? State its properties and uses.**

**Ans:** i. Infrared rays are electromagnetic waves which are responsible for heat radiation.

ii. All hot bodies are sources of infrared rays.

iii. The wavelengths ranges nearly from $7 \times 10^{-7}$ m to $10^{-3}$ m.

iv. The frequency ranges from $4 \times 10^{14}$ Hz to $3 \times 10^{11}$ Hz.

v. About 60% of solar radiations are infrared in nature.

vi. It was discovered by Sir Frederick William Hershell in 1800.

**Properties:**

i. Infrared rays obey laws of reflection and refraction.

ii. They can produce interference and polarization.

iii. They affect the photographic plates.

iv. When infrared rays are allowed to fall on the material surface, its temperature increases.

v. I.R. rays are strongly absorbed by glass.

vi. Thermocouple, thermopile, bolometer etc are used to detect infrared rays.

vii. They can penetrate through thick columns of fog and mist.

**Uses:**

i. Infrared rays are used in long distance photography. (photographs can be taken in complete darkness by using the infrared film).

ii. They are used in diagnosis of superficial tumours and varicose veins.

iii. They are used to cure infantile paralysis (polio) and to treat sprains, dislocations and fractures.

iv. They are used in solar water heaters and solar cookers.

v. Infrared rays are used in medicine.

vi. Special infrared photographs of the body, called thermograms, can show up diseased parts because they radiate less heat than the healthy parts, which is sensitive to infrared rays.

vii. They are used to keep green house warm.

viii. They are used in remote controls of T.V., V.C.R. etc.

**Q.20. What are microwaves? Explain its properties and uses.**

**Ans:** i. Microwaves are the electromagnetic waves of short wavelength ranging from nearly $1 \times 10^{-4}$ m to 0.3 m.

ii. Frequency range of microwaves is $5 \times 10^9$ Hz to $10^{12}$ Hz.

iii. Microwaves are produced by special vacuum tubes called klystrons, magnetrons and gunn diodes.

**Properties:**

i. They obey the laws of reflection and refraction.

ii. They travel in vacuum with the speed of light.

iii. They heat an object on which they are incident.

iv. Their absorption by water, fats, sugar can produce heat.

v. They can penetrate haze, light rain and snow, clouds and smoke.

**Uses:**

i. Microwaves are used in radar system for the location of distant objects like ships, aeroplanes etc.

ii. Microwaves are used in wireless communication, long distance telephone communication system and satellite communication for TV broadcasting.

iii. Microwave ovens are used for cooking.

iv. Microwaves are used in the study of atomic and molecular structure.

v. Microwaves are used for the transmission of TV signals.

**Q.21. What are radio waves? State properties and uses of radio waves.**

**Ans:** i. Radio waves are electromagnetic waves having very long wavelengths ranging from about 10 centimetres to a few hundred kilometres.

ii. Radio waves are produced by oscillating electric circuits containing an inductor and a capacitor.

iii. Radio waves have frequencies from 3 kHz to 300 GHz.

iv. The frequency of the waves produced by the circuit depends upon the magnitudes of the inductance and the capacitance. So by choosing suitable values of the inductance and the capacitance, microwaves or radio waves of any desired frequency can be produced.

**Properties:**

i. They obey laws of reflection and refraction.

ii. Radio waves get diffracted from obstacles coming in their path. The size of the obstacle should be large as radio waves are having quite larger wavelengths.

iii. They can penetrate through rain, snow, clouds.

**Uses:**

i. Radio waves are used for wireless communication purposes.

ii. They are used for radio broadcasting and transmission of TV signals.

iii. Cellular phones use radio waves to transmit voice communication in the ultra high frequency (UHF) band.

iv. Radio astronomy.

## 14.4 : Propagation of electromagnetic waves in the atmosphere :

**Q.22. Define is atmosphere.**
**Explain different layers of atmosphere.**

**Ans: Atmosphere:**

The earth is surrounded by various layers of gases. The envelope of these gases around the earth is called atmosphere. Earth's atmosphere is due to gravitational attraction of earth.

There are different layers of earth's atmosphere.

**a. Troposphere:**

i. It is the lower layer of the earth's atmosphere close to earth's surface.

ii. It extends upto about 12 km above the surface of the earth.

iii. This layer plays an important role in the weather–phenomena that affects our environment.

iv. Most of the water vapour in the atmosphere is present in the troposphere. It is the source of air.

v. Dust, smoke, pollen grains, salt, organic materials are present in it.

vi. The temperature of this layer decreases from about 280 K to 220K.

vii. The density ranges from 1.0 to $10^{-1}$ $kg/m^2$ which decreases as height increases.

**b. Stratosphere:**

i. It is the next layer to troposphere which extends to about 50 km above the surface of the earth.

ii. It contains very little moisture and dust.

iii. The density of air in this layer ranges from $10^{-1}$ kg/m$^3$ to $10^{-3}$ kg/m$^3$ and, temperature increases with height from 220 K to 280 K.

iv. The region between 15 km to 50 km in stratosphere contains ozone gas. This layer is called ozone layer.

**c. Mesosphere:**

i. The layer above the stratosphere is called the mesosphere.

ii. It extends from 50 km to 80 km above the earth's surface.

iii. In this layer, the temperature of the layer decreases with increase in height.

iv. At a height of 80 km, temperature is about 290 K to 180 K.

**d. Ionosphere:**

i. It is the part of atmosphere that extends from 80 km to thousands of kilometres.

ii. Beyond the mesosphere, the temperature begins to rise due to the partial absorption of solar radiations by the molecules of air. This layer is called thermosphere.

iii. When the molecules of air absorb solar energy, they emit electrons so that neutral molecules of air get converted into positively and negatively charges particles called Ions.

iv. The ionosphere consist of the Dlayers which is the innermost layer. The electron concentration becomes very large between 80 km to 140 km. This layer is known as E–layer. The layer between 250 km to 400 km of highest electron density is known as F–layer.

v. The F–layer plays an important role in radio communications and telecommunications.

**e. Exosphere:**

The exosphere is the outermost atmospheric region from the Earth's surface. It is the transitional zone between the earth's atmosphere and inter–planetary space. The pressure in exosphere is very low.

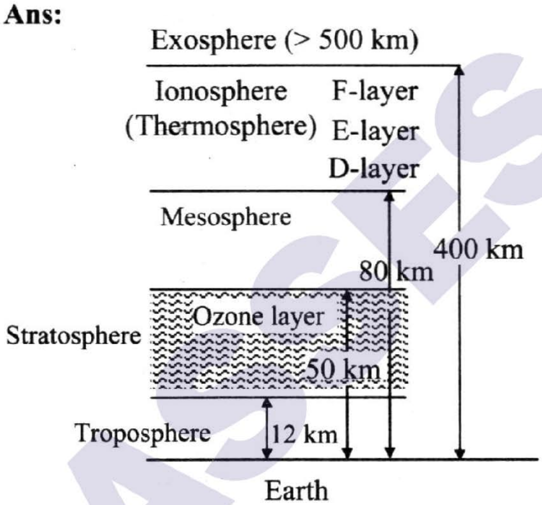
**Q.23. If the earth did not have an atmosphere, would its average surface temperature be higher or lower than what it is now? (NCERT)**

**Ans:** The temperature of the earth would be lower than present because the Green house effect of atmosphere would be absent.

**Q.24. Draw neat and well labelled diag~ to show different layers of atmosphere.**

**Ans:**

**Ans:**




**Different layers of the atmosphere**

**Q.25. What is ozone layer? What important purpose does it serve?**

**OR**

**Write a note on ozone layer.**

**Ans:** i. The part of the stratosphere extending from 15 km to 50 km above the earth's surface contains ozone along with the other gases. This part is called ozone layer.

ii. The ozone layer in the atmosphere absorbs the ultraviolet rays of higher frequencies and prevents them from reaching the earth's surface.

iii. It protects the life on the earth by absorbing the harmful, cancer causing UV radiations coming from sun.

iv. In this way, the ozone layer effectively protects us from the dangerous effects of solar radiation.

v. Now–a–days, rapid industrialization all over the world and the unnecessary use of fossil fuels has resulted in the release of large quantities of polluting gases in the atmosphere. Due to this, the amount of ozone in the ozone layer is decreasing.

vi. The decrease in the ozone layer may allow the ultraviolet rays and the rays of still higher frequencies to pass through it which is harmful to the life on earth.

**Q.26. Explain the role of radio waves in the propagation of electromagnetic waves through communication system.**

**Ans:** i. Radio waves are useful for the transmission of information from one place to another without the help of wires or any material medium between the two places.

ii. The signal to be transmitted is converted into an electrical signal and then superimposed on a high frequency oscillating current flowing through a metallic conductor of suitable shape and size. This conductor (called the transmitting antenna) radiates the corresponding radio waves into the atmosphere.

iii. At the receiving station, there is another metallic conductor of suitable shape and size, called the receiving antenna.

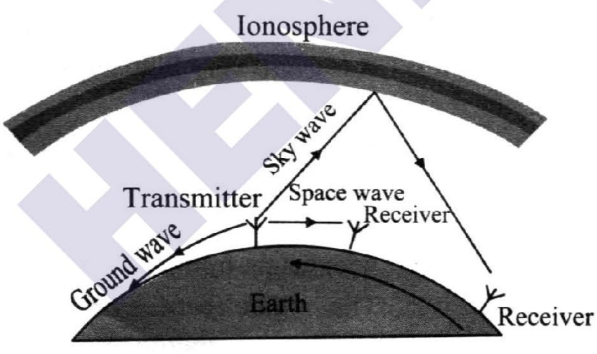
iv. When the radio waves are intercepted by the receiving antenna, a small varying e.m.f. is induced in the antenna. This e.m.f. is amplified and decoded to obtain the information contained in the original signal.

**Q.27. Long distance radio broadcasts use shortwave bands. Why? (NCERT)**

**Ans:** Radio waves from short wave bands get reflected from ionosphere hence are used for long distance communication.

**Q.28. Draw a neat and well labelled diagram of three main modes of propagation of electromagnetic waves.**

**Ans:**




**Three main modes of propagation of electromagnetic waves**

**Q.29. Define the following terms.**

**i. Tropospheric waves**

**ii. Sky waves**

**Ans: i. Tropospheric waves:**

The radio waves reflected from troposphere are called tropospheric waves.

**ii. Sky waves:**

The radio waves having frequencies range 3MHz to 30 MHz are called sky waves.

**Q.30. Write a short note on ground wave propagation.**

**Ans: Ground wave propagation:**

i. When the electromagnetic waves (radio waves) from the transmitting antenna propagate along the surface of the earth so as to reach the receiving antenna, the wave propagation is called ground wave or surface wave propagation.

ii. In ground wave propagation, the electromagnetic waves are actually guided by the earth and follow the curved surface from transmitter to receiver.

iii. The transmitted electromagnetic waves are supported at their lower edge by the ground. They induce current in the ground. If electric field in an electromagnetic wave is parallel to earth, it gets shortened by the conducting earth.

iv. As the wave travels, it is weakened. Therefore, ground waves can travel over limited distances due to absorption by earth.

v. Higher the frequency of waves, larger is the loss of its energy and smaller is the distance covered.

vi. Ground wave propagation is used for the propagation of radio waves of frequency less than 2 MHz (medium frequency band) but for the propagation of TV or FM signal, ground wave propagation can not be used. This is suitable for local broadcasting.

**Q.31. Write a short note on space wave propagation.**

**Ans: Space wave propagation:**

i. When the radio waves from the transmitting antenna reach the receiving antenna either directly or after reflection from the ground or after reflection from troposphere, the wave propagation is called space wave propagation.

ii. The radio waves are reflected from troposphere, hence they are called tropospheric waves.

iii. The radio waves of frequencies greater than

30 MHz can pass through the ionosphere after suffering a small deviation. These waves cannot be transmitted by sky wave propagation.

iv. So TV signals whose frequencies are in range 100 – 200 MHz cannot be transmitted by sky wave propagation.

v. Also, TV signal frequencies being high (100 – 200 MHz) are easily absorbed by the earth, hence cannot be propagated by ground wave propagation.

vi. Transmission of TV signals is possible by using space wave propagation in which the receiving antenna directly intercepts the signals sent out by the transmitting antenna.

vii. Also earth has curved surface, so long distance transmission by means of space wave propagation is not possible. For long distance transmission. long antennae are used. Hence, TV antenna is located at top of high rising building or at greater heights, so as to cover maximum area.

viii. The maximum distance over which the TV signal can reach is called the range. For larger TV coverage, the height of TV antenna should be as large as possible.

**Q.32. Write a short note on sky wave propagation.**

**Ans: Sky wave propagation:**

i. When the radio waves from the transmitting antenna, reach the receiving antenna either directly or after reflection in the ionosphere, the wave propagation is called sky wave propagation.

ii. Radio waves having frequency less than 3 MHz (VH) are absorbed in the ionosphere but frequencies greater than 30 MHz [very high frequency (VHF) and [Ultra high frequency (UHF)] can pass through the ionosphere after suffering a small deviation.

iii. Ionosphere totally reflects the radio waves in the high frequency (HF) band.

iv. The frequencies of these waves are between 3 MHz and 30 MHz. These waves are called the sky waves.

v. These waves can suffer multiple reflections between the ionosphere and the earth and therefore they can be transmitted over large distances.

vi. The two layers of the ionosphere that are important for sky wave propagation are E–layer and F–Iayer of which the Flayer is most useful.

**Q.33. Explain the terms: transmitting antenna and receiving antenna.**

**Ans: Transmitting antenna:**

A metallic conductor of suitable shape and size to transmit a desired signal is called a transmitting antenna.

**Receiving antenna:**

A metallic conductor of suitable shape and size to receive the desired signal transmitted from the transmitting antenna is called receiving antenna.

**Q.34. Define the following terms.**

**i. Critical frequency**

**ii. Skip distance**

**iii. Communication satellite**

**Ans: i. Critical frequency:**

The maximum value of the frequency of radio waves reflected back to the earth from the ionosphere, when the waves are directed normally to the ionosphere is called critical frequency.

**ii. Skip distance:**

The shortest distance from a transmitter measured along the surface of the earth, at which a sky wave of fixed frequency (f greater than critical frequency) is returned to the earth is called skip distance.

**iii. Communication satellite:**

Satellite which are used in telecommunications for sending signals over large distance is called communication satellite.

**Q.35. Write a note on geostationary satellite.**

**Ans:** i. An artificial satellite revolving in a circular orbit round the earth in an equatorial plane in the same sense as that of rotation of the earth about its own axis and having a period of 24 hours is called geostationary satellite.

ii. So the satellite always appears to be stationary with respect to the earth. It has zero speed relative to the earth.

iii. Geostationary satellite is useful for sending TV signals over large distances on the earth's surface.

iv. The satellite receives the signals from transmitting station, amplifies them and sends them to the receiving stations on earth.

v. A TV signal from a transmitting station can be sent to a receiving station situated on the diametrically opposite side of the earth with the help of two or more geostationary satellites.

vi. The height of the geostationary satellite above the surface of the earth is about 36000 km.

vii. It is also called as communication satellite because it is used in telecommunications for sending signals over large distances.

**Q.36. Optical and radiotelescopes are built on the ground but ×–ray astronomy is possible only from satellites orbiting the earth. Why? (NCERT)**

**Ans:** i. Optical and radio telescopes operate in visible and radio frequency region of electromagnetic spectrum.

ii. These waves can easily penetrate atmosphere and can be used for the purpose of observation.

iii. ×–ray astronomy is an observation branch of astronomy which deals with study of detection and observation of Xray emitted from celestial bodies.

iv. ×–rays due to their smaller wavelength are absorbed by atmosphere. Hence the instrument to detect ×–rays must be taken to high altitudes.

Thus, we can work with optical and radio telescopes on earth's surface but ×–ray astronomy is possible only from satellites.

**Q.37. Is it possible for one communication satellite to propagate waves all over the world? Explain.**

**Ans:** i. No, It is not possible for one communication satellite to propagate waves all over the world.

ii. A single satellite can send waves which are accessible to approximately onethird of the globe.

iii. Communication satellite is geostationary satellite. It is in equatorial plane with same sense as that of rotation of the earth i.e., 24 hour or one day. It has zero speed with respect to earth.

iv. The satellite receives T.V. signals from the transmitting station, amplifies them and then sends to the receiving station which sends on the earth. This is possible for the areas which are diametrically opposite side of the earth with the help of two or more geostationary satellite and not just one.

v. Then only the transmitted area all over the world will be covered.

vi. Hence, three such geostationary satellite which are uniformly spaced can provide communication link between any two points on earth.

## Formulae :

**1. Velocity of electromagnetic wave:**

i. $c = v\lambda$

ii. $c = \frac{\lambda}{T}$

**2. Velocity of electromagnetic wave in free space:**

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

**3. Velocity of electromagnetic wave in medium:**

$$c = \frac{1}{\sqrt{\mu\varepsilon}}$$

## Solved Examples :

**Example 1**

**A radio wave of frequency of 1.0 × 107 Hz propagates with speed 3 × 108 m/s. Calculate its wavelength.**

**Solution:**

Given : $v = 1.0 \times 10^7$ Hz, $c = 3 \times 10^8$ m/s

To find : Wavelength ($\lambda$)

Formula : $c = v\lambda$.

Calculation : From formula,

$$\lambda = \frac{c}{v} = \frac{3\times10^8}{1.0\times10^7} = \mathbf{30\ m}$$

**Ans:** The wavelength of radio wave is **30 m**.

**Example 2**

**From the given data calculate speed of light in vacuum. [$\mu_0 = 4\pi \times 10^{-7}$, $\varepsilon_0 = 8.85 \times 10^{-12}$ unit]**

**Solution:**

Given : $\mu_0 = 4\pi \times 10^{-7}$, $\varepsilon_0 = 8.85 \times 10^{-12}$ unit

To find : Speed of light (c)

Formula : $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

Calculation : From formula,

$$c = \frac{1}{\sqrt{4\pi \times 10^7 \times 8.05 \times 10^{-12}}}$$

$$= \sqrt{\frac{1}{4 \times 3.14 \times 10^7 \times 8.05 \times 10^{-12}}}$$

$c = 2.99 \times 10^8$ m/s = **$3 \times 10^8$ m/s**

**Ans:** The wavelength of radio wave is **30 m**.

**Example 3**

**A radio can tune in to any station in the 7.5 MHz to 12 MHz band. What is the corresponding wavelength band? (NCERT)**

**Solution:**

Given : $v_1$ = 7.5 MHz = $7.5 \times 10^6$ Hz, $V_2$ = 12 MHz = $12 \times 10^6$ Hz.

To find : Wavelength band

Formula : $\lambda = \frac{c}{v}$

Calculation : From formula,

$$v_1 = \frac{3 \times 10^8}{7.5 \times 10^6} = \mathbf{40\ m}$$

$$v_2 = \frac{3 \times 10^8}{12 \times 10^6} = \mathbf{25\ m}$$

Wavelength band = **40 m to 25 m**

**Ans:** The corresponding wavelength **40 m to 25 m**.

**Example 4**

**The amplitude of the magnetic field part of harmonic electromagnetic wave in vaccum is $B_o$ = 510 nT. What is the amplitude of the electric field part of the wave? (NCERT)**

**Solution:**

Given : $B_o$ = 510 nT = $510 \times 10^{-9}$ T

To find : Amplitude of electric field ($E_0$)

Formula : $E_o = B_0 c$

Calculation : From formula,

$E_0 = 510 \times 10^{-9} \times 3 \times 10^8$

= **153 V/m**

**Ans:** The amplitude of electric field part of the wave is **153 V/m**.

**Example 5**

**Suppose that the electric field amplitude of an electromagnetic wave is $E_0$ = 120 N/C and that its frequency is v = 50.0 MHz. (a) Determine, $B_0$, ω, k, and λ. (b) Find expressions for E and B. (NCERT)**

**Solution:**

For $E_0$ = 120 N/C, v = 50 MHz = $50 \times 10^6$ Hz

a. $\lambda = \frac{c}{v} = \frac{3 \times 10^8}{50 \times 10^6} = \mathbf{6\ m}$

$B_0 = \frac{E_0}{c} = \frac{120}{3 \times 10^8} = \mathbf{4 \times 10^{-7}\ T}$

= 400 nT

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{6} = \mathbf{1.0472\ rad/m}$

$\omega = 2\pi v = 2\pi \times 50 \times 10^6$

$= 3.14 \times 10^8$ rad/s.

b. Assuming motion of cm wave along ×–axis, expression for electric field vector may lie along Y–axis,

$E = E_o \sin(kx - \omega t)$

$= 20 \sin(1.0472\ x - 3.14 \times 10^8\ t)\ \hat{j}$ N/C

Also, magnetic field vector will lie along Z–axis, expression for magnetic field vector,

$B = B_o \sin(kx - \omega t)$

$= 4 \times 10^{-7} \sin$

$(1.0472\ x - 3.14 \times 10^8\ t)\ \hat{k}$ T.

**Example 6**

**In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of $2.0 \times 10^{10}$ Hz and amplitude 48 $Vm^{-1}$.**

**a. What is the wavelength of the wave?**

**b. What is the amplitude of the oscillating magnetic field?**

**c. Show that the average energy density of the E field equals the average energy density of the B field. (NCERT)**

**Solution:**

For v = $2.0 \times 10^{10}$ Hz, $E_0$ = 48 V $m^{-1}$ and $c = 3 \times 10^8$ $ms^{-1}$

a. $\lambda = \frac{c}{v} = \frac{3 \times 10^8}{2.0 \times 10^{10}} = 1.5 \times 10^{-2}$ m

b. Since, $E_0 = cB_0 \Rightarrow B_0 = \frac{E_0}{c} = \frac{48}{3 \times 10^8}$

$B_0 = 1.6 \times 10^{-7}$ T = 160 nT

c. The average energy density associated with electric field vector is

$$U_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0 \left(\frac{E_0}{\sqrt{2}}\right)^2 = \frac{1}{4}\varepsilon_0 E_0^2 \quad ..(1)$$

Also, the average energy density associated with magnetic field vector is

$$U_B = \frac{1}{2}\frac{B_2}{\mu_0} = \frac{1}{2\mu_0}\left(\frac{B_0}{\sqrt{2}}\right) = \frac{B_0^2}{4\mu_0}$$

$$\text{since } c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \Rightarrow c^2 = \frac{1}{\mu_0\varepsilon_0}$$

$$\Rightarrow \frac{1}{\mu_0} = \varepsilon_0 c^2$$

Also, $E_0 = cB_0 \Rightarrow B_0 = \frac{E_0}{c}$

From equation (2), $U_B = \left(\frac{E_0}{c}\right)^2 \frac{\varepsilon_0 c^2}{4} = \frac{1}{4}\varepsilon_0 E_0^2$

$\therefore$ $\mathbf{U_B = U_E}$

## Additional Theory Questions :

1. Define:
   a. electromagnetic spectrum
   b. Geostationary satellite

**Ans:** a. Refer Q.7. point (i).
b. Refer Q.35. point (i).

2. Write a note an electromagnetic spectrum.

**Ans:** Refer Q.7.

3. Explain properties of:
   a. Gamma rays

**Ans:** Refer Q.12.
   b. X-rays

**Ans:** Refer Q.13.
   c. UV–rays

**Ans:** Refer Q.16.
   d. Infrared rays

**Ans:** Refer Q.19.
   e. Microwave

**Ans:** Refer Q.20.
   f. Radio waves

**Ans:** Refer Q.21.

4. Give applications or uses of
   a. Gamma rays

**Ans:** Refer Q.12.
   b. X-rays

**Ans:** Refer Q.13.
   c. UV–rays

**Ans:** Refer Q.16.
   d. Infrared rays

**Ans:** Refer Q.19.
   e. Microwave

**Ans:** Refer Q.20.
   f. Radio waves

**Ans:** Refer Q.21.

5. Explain how geostationary satellite is useful in the telecommunication system.

**Ans:** Refer Q.35.

6. It is necessary to use satellites for long distance TV transmission. Why? (NCERT)

**Ans:** Refer Q.31.

7. The small ozone layer on top of the stratosphere is crucial for human survival. Why? (NCERT)

**Ans:** Refer Q.25.

## Practice Problems :

**1.** Find the frequency of violet light of wavelength 400 nm in vacuum. [$c = 3 \times 10^8$ m/s]

**2.** Velocity of electromagnetic wave in free space is $3 \times 10^8$ m/s. Determine relative permittivity of the medium assuming $\mu_0 = 4\pi \times 10^{-7}$ Wb/A m.

**3.** Name the part of the electromagnetic spectrum to which waves of following wavelength belongs:
   i. 2 Å
   ii. 1 m
   iii. 7500 Å

# Multipal Choice Questions

1. Which of the following type of radiations are radiated by an oscillating electric charge?
a) Electric b) Magnetic
c) Thermoelectric d) Electromagnetic

2. The theory of electromagnetic waves predicted by Maxwell in 1888 was first confirmed experimentally by
a) Einstein b) Hertz
c) Marconi d) J.C. Bose

3. Whose experiments mark the beginning of the field of communication using electromagnetic waves?
a) Maxwell b) Hertz
c) Marconi d) J.e. Bose.

4. The speed of electromagnetic wave is same for ______
a) odd frequencies
b) even frequencies
c) all frequencies
d) all intensities

5. Frequencies in the UHF range normally propagate by means of ______
a) thermal waves b) sky waves
c) surface waves d) space waves

6. If $\vec{E}$ and $\vec{B}$ are the electric and magnetic field vectors of e.m. waves, then the direction of propagation of e.m. wave is along the direction of
a) $\vec{E}$ b) $\vec{B}$
c) $\vec{E} \times \vec{B}$ d) $\vec{E} \cdot \vec{B}$

7. The unit of expression $\mu_0 \varepsilon_0$ is
a) m / s b) $m^2 / s^2$
c) $s^2 / m^2$ d) s / m

8. According to Maxwell's equation the velocity of light in any medium is expressed as
a) $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ b) $\frac{1}{\sqrt{\mu\varepsilon}}$
c) $\sqrt{\frac{\mu}{\varepsilon}}$ d) $\sqrt{\frac{\mu_0}{\varepsilon}}$

9. The electromagnetic waves do not transport
a) energy b) charge
c) momentum d) pressure

10. The magnetic field out of the parallel plated capacitor is maximum
a) along the wire.
b) on the axis of wire.
c) at distance equal to radius of plated.
d) at distance larger than radius of plates.

11. The amplitude of electric and magnetic fields relate to each other as
a) $E_0 = B_0$ b) $E_0 = c\,B_0$
c) $E_0 = \frac{B_0}{c}$ d) $E_0 = \frac{c}{B_0}$

12. In an electromagnetic wave, the direction of the magnetic induction $\vec{B}$ is
a) parallel to the electric field $\vec{E}$.
b) perpendicular to the electric field $\vec{E}$.
c) antiparallel to the pointing vector $\vec{E}$.
d) random.

13. A radiowave has a maximum magnetic field of induction $10^{-4}$ T arrival at a receiving antenna. The maximum electric field intensity of such a wave is
a) zero b) $3 \times 10^4$ V/m
c) $5.8 \times 10^{-9}$ V/m d) $3.3 \times 10^{-13}$ V/m

14. Which of the following electromagnetic waves have the longest wavelength?
a) heat waves b) light waves
c) radiowaves d) microwaves.

15. Beyond which frequency, the ionosphere bends any incident electromagnetic radiation but incident electromagnetic radiation does not reflect it back towards the earth?
a) 50MHz b) 40MHz
c) 30 MHz d) 20MHz

16. Radiowaves do not penetrate in the band of
a) ionosphere b) mesosphere
c) troposphere d) stratosphere

17. The frequency of visible light is of the order of
a) $10^{14}$ Hz b) $10^{10}$ Hz
c) $10^6$ Hz d) $10^4$ Hz

18. X-rays are produced by jumping of
a) electrons from lower to higher energy orbit of atom.
b) electrons from higher to lower energy orbit of

atom.

c) protons from lower to higher energy orbit of nucleus.

d) proton from higher to lower energy orbit of nucleus.

**19.** Which of the following electromagnetic wave has least wavelength?

a) Gamma rays b) X- rays

c) Radiowaves d) microwaves

**20.** X-rays travel in space with the velocity of

a) cosmic rays b) light waves

c) water waves d) ultrasonic waves.

**21.** X-rays and y-rays of same energies are distinguished by their

a) frequencies

b) charges

c) ionizing power

d) method of production

**22.** The energy of X-rays photon is $3.3 \times 10^{-16}$ J. Its frequency is

a) $2 \times 10^{19}$ Hz b) $5 \times 10^{18}$ Hz

c) $5 \times 10^{17}$ Hz d) $5 \times 10^{16}$ Hz

**23.** The wavelength of infrared rays is of the order of

a) $5 \times 10^{-7}$ m

b) $10^{-3}$ m

c) between 'A' and 'B'

d) $10^{-13}$ m.

**24.** If $\vec{E}$ is an electric field and $\vec{B}$ is the magnetic induction, then the energy flow per unit area per unit time in an electromagnetic field is given by

a) $\frac{1}{\mu_0}\vec{E}\times\vec{B}$ b) $\vec{E}\cdot\vec{B}$

c) $E^2 + B^2$ d) $\frac{E}{B}$

**25.** The correct sequence of the increasing wavelength of the given radiation sources is

a) radioactive sources, X-ray tube, crystal oscillator, sodium vapour lamp.

b) radioactive source, X-rays tube, sodium vapour lamp, crystal oscillator

c) X-rays tube, radioactive source, crystal oscillator, sodium vapour lamp

d) X-rays tube, crystal oscillator, radioactive source, sodium vapour lamp

**26.** Out of the X-rays, microwaves, ultra-violet rays, the shortest frequency wave is

a) X-rays b) microwaves

c) ultra-violet rays d) y-rays

**27.** The part of electromagnetic spectrum used in operating radar is

a) y-rays b) visible rays

c) infra-red rays d) microwaves

**28.** The correct sequence of descending order of wavelength values of the given radiation source is

a) radio waves, microwaves, infra-red, yrays

b) y-rays, infra-red, radio waves, microwaves

c) Irrfra-red, radio waves, microwaves, yrays

d) microwaves, y-rays, infra-red, radiowaves

**29.** If the wavelength of electromagnetic wave is doubled, the energy of photon will become

a) half b) same

c) double d) four times

**30.** The ratio of speed of X-rays to y-rays in space is

a) $\frac{1}{4}$ b) $\frac{1}{3}$

c) 1 d) 2

**31.** The ozone layer absorbs following radiations from the sun-rays

a) infra-red b) ultra-violet

c) microwave d) visible range

**32.** The nuclei of atoms of radioactive elements produce _______

a) X-rays b) y-rays

c) microwaves d) ultra-violet rays

**33.** The electronic transition in atom produces

a) ultra violet light b) visible light

c) infra-red rays d) microwaves

**34.** The signals whose frequencies are in the range of 100 – 200 MHz can be transmitted by

a) sky wave propagation

b) space wave propagation

c) mechanical wave propagation

d) direct propagation

**35.** When radiowaves from transmitting antenna reach the receiving antenna directly or after reflection in the ionosphere, the wave propagation is called _______

a) ground wave propagation

b) space wave propagation

c) sky wave propagation

d) satellite propagation

**36.** The radio waves with frequencies are transmitted by ground wave propagation
a) less than 2 MHz
b) greater than 2 MHz
c) between 3 to 5 MHz
d) 4 to 7 MHz

**37.** For TV signals or FM, the propagation which is NOT used is _______
a) sky wave b) space wave
c) ground wave d) All of these

**38.** Troposphere extends between
a) ionosphere and stratosphere.
b) mesosphere and stratosphere.
c) ozone layer and mesosphere.
d) earth's surface and stratosphere.

**39.** Electromagnetic waves in the frequency range of are generally called radiowaves.
a) few $H_2$ to about $10_{11}$ Hz
b) few $MH_2$ to about $10_{11}$ MHz
c) few $H_2$ to about $10_{11}$ MHz
d) few $KH_2$ to about $10_{11}$ KHz

**40.** The photography in complete darkness is possible by using ______
a) ultra violet light b) visible light
c) sunlight d) infra-red light

## Answer Keys

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. d) | 2. b) | 3. c) | 4. d) | 5. c) | 6. c) | 7. c) | 8. b) | 9. b) | 10. a) |
| 11. b) | 12. b) | 13. b) | 14. c) | 15. b) | 16. a) | 17. a) | 18. b) | 19. a) | 20. b) |
| 21. d) | 22. c) | 23. c) | 24. a) | 25. b) | 26. b) | 27. d) | 28. a) | 29. a) | 30. c) |
| 31. b) | 32. b) | 33. b) | 34. a) | 35. c) | 36. a) | 37. c) | 38. d) | 39. a) | 40. d) |

### Answers to Practice Problems :

1. $7.5 \times 10^{14}$ Hz
2. $8.846 \times 10^{-12}$ $C^2/N\ m^2$
3. i. X-rays
ii. Radio wave
iii. Infrared waves

### Hints in Multiple Choice Questions :

**22.** Freuqency $v = \dfrac{\text{Energy}}{\text{Planck's constant}} = \dfrac{E}{h}$

$$= \frac{3.3\times10^{-16}}{6.63\times10^{-34}} \approx 5 \times 10^{17}\ \text{Hz}$$

**29.** Energy $\propto \dfrac{1}{\lambda}$

$$\therefore E_1 \propto \frac{1}{\lambda_1} \text{ and } E_2 \propto \frac{1}{\lambda_2}$$

For $\lambda_2 = 2\lambda_1$

$$\frac{E_2}{E_1} = \frac{\lambda_1}{\lambda_2} = \frac{\lambda_1}{2\lambda_1} = \frac{1}{2}$$