Electromagnetic Spectrum

Oscillation and waves

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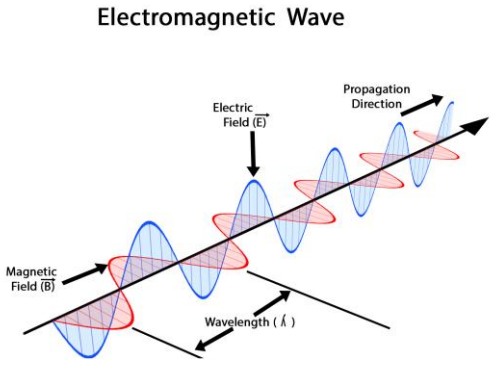
Introduction

In this lesson we are going to:

- Define electromagnetic waves.
- Define electromagnetic spectrum.
- Describe the wave in the electromagnetic spectrum.
- Discuss the sources of electromagnetic waves.
- Analysis of electromagnetic spectrum in terms of energy, frequency, and wavelength.
- List the properties of electromagnetic waves.



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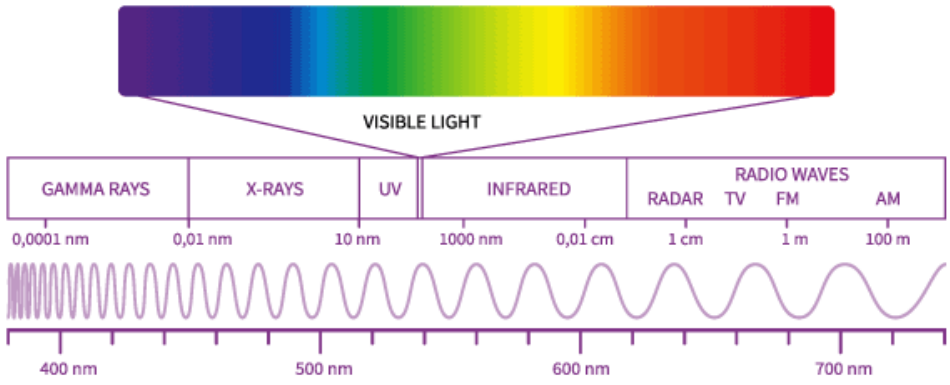
Electromagnetic waves

- Electromagnetic waves are **transverse** waves made up of oscillating **electric** and **magnetic** fields, which are perpendicular to each other and to the direction of wave propagation.
- Electromagnetic waves **does not** require a **medium** to travel through – they propagate through empty space (**vacuum**).
- These waves travel through space at the speed of light.

Electromagnetic Spectrum

- This is the range of all possible types of electromagnetic waves arranges according to **frequency** and **wavelength**.
- The spectrum (range) is arranged in order of increasing frequency and decreasing wavelength of the waves
- The diagram on the slide shows an illustration of the electromagnetic spectrum.

Electromagnetic Spectrum



Note: in general, Electromagnetic waves are emitted when electrically charged particles change energy in the atomic structure.

Uses and sources of Electromagnetic waves

Below is a description of the waves that are found in the electromagnetic spectrum *(from low frequency to high frequency)*:

1. ***Radio Waves:*** waves with longest wavelength, lowest frequency. They are used for communication (radio, TV, Wi-Fi). **Source**: Generated by oscillating electric currents (electrons moving in conductors) in antennas or transmitters.
2. ***Microwaves:*** waves with shorter wavelength than radio waves. They are used in cooking and communication. **Source:** Generated by special transmitters and magnetrons.
3. ***Infrared Rays (IR):*** waves that emit heat. They are felt as heat but invisible to human eye. They are used in remote controls, thermal imaging, and night vision devices. **Source:** Warm of hot objects such as sun and heat lamps.
4. ***Visible light:*** also called the visible spectrum. It is the only part of the spectrum visible to the human eye. It is denoted by the ROYGBIV colors. **Source:** Generated by the sun, fire, and light bulbs.

Uses and sources of Electromagnetic waves

5. ***Ultraviolet Rays (UV):*** waves with high frequency that the visible light. These waves can cause sunburns and skin damage. They are used in sterilization detecting fake bank notes and tanning. **Source**: Generated by the sun and UV lamps.
6. ***X-rays:*** waves with very short wavelength but high energy that are used in medical imaging and security scanning. **Source:** X-ray tubes and machines.
7. ***Gamma Rays:*** waves with the shortest wavelength and highest frequency and energy. They are used in cancer treatment and medical equipment sterilization. **Source:** Generated from radioactive materials and nuclear reaction.

Note:

- *The electromagnetic spectrum is a continuous spectrum, as such the waves in the spectrum overlaps.*
- *There is **no sharp boundary** between the waves.*

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Energy, frequency, and wavelength of electromagnetic waves.

Energy

- This is the amount of energy carried by the wave. In the spectrum, as we move from **radio waves to gamma rays**, the **energy increases**. This means that gamma rays are the **most energetic**, and radio waves are the **least energetic**.

Frequency

- The number of waves that pass a point in one second (measured in hertz, Hz). In the spectrum, as we move from **radio waves to gamma rays**, the **frequency increases**. This shows that gamma rays have the **highest frequency**, and radio waves have the **lowest**.

Wavelength

- This is the distance between two successive wave crests. In the spectrum the **wavelength decreases** in such a way that**,** radio waves have the **longest wavelength;** gamma rays have the **shortest wavelength**.

Properties of electromagnetic waves

Below are **some** of the properties of electromagnetic waves:

- They are **transverse** waves.
- They carry **no** charge.
- They travel at the **speed of light**.
- They can be **reflected**, **refracted**, and **diffracted**.
- They **do not** require a **medium** to travel through.
- They **transmit energy** from one place to another.
- They obey the wave equation: $c = f \lambda$
- They can be emitted or absorbed by matter.

Methods of detecting Electromagnetic Waves

Oscillation and waves

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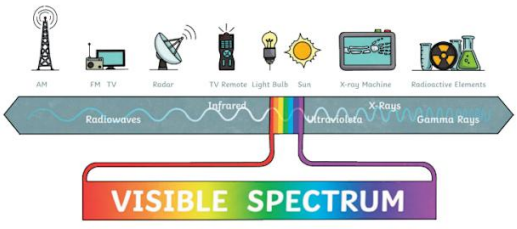
Introduction

In this lesson we are going to:

- Discuss the methods of detecting electromagnetic waves.
- Demonstrate detection of electromagnetic waves – case of infrared Rays (IR)
- Group work



Detecting electromagnetic waves

Electromagnetic waves can be detected in various ways through different instruments:

1. ***Radio waves:*** these waves can be detected by radio receivers and antennas in radios and TVs.
2. ***Microwaves:*** these waves can be detected by microwave antennas (a small dish on satellites) and Schottky diode
3. ***Infrared***: these can be detected by infrared sensors in TVs and motion detectors. Can also be detected by Thermal cameras, and a ***thermopile***.
4. ***Visible light:*** these waves are detected by the human eye, camera, and Photocells in Solar devices.
5. ***Ultraviolet (UV):*** these waves are detected using UV sensors in smartphones and weather station. They are also detected by photodiodes, and photographic films.
6. ***X-rays:*** detected by x-ray films, photographic plates , and fluorescent screens.
7. ***Gamma rays:*** can be detected by the Geiger muller tube, scintillation counters, and photographic plates.

Experiment to demonstrate the detection of electromagnetic waves

Below is an experiment that can carried out to show how one can detect infrared radiations:

Steps

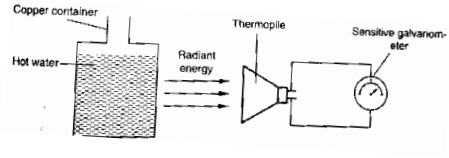
a. Heat some water in a beaker and transfer the water to a metal container.

b. Connect a thermopile to a galvanometer to form a circuit.

c. Bring the thermopile close to the metal container.

d. Observe the galvanometer needle.

Diagram:



Observation

- The galvanometer needle show some deflection.

Explanation

- The thermopile sense the heat from the metal container and sends current through the circuit.

Application of electromagnetic waves

Electromagnetic waves can be used in various ways, some of such ways are:

1. ***Radio waves:*** these waves are used in:

Communication: Used in radio and television broadcasting, mobile phones, and satellite communication.

Radar: Used in air traffic control, weather forecasting, and navigation systems to detect objects and measure distances.

Wi-Fi and Bluetooth: Enable wireless internet and short-range device connectivity.

2. ***Micro waves:*** these waves are used in:

Cooking: Microwave ovens use microwaves to heat food by causing water molecules to vibrate, generating heat.

Telecommunications: Used in satellite communication, GPS, and mobile phone networks due to their ability to transmit data over long distances.

Radar Technology: Used in speed guns by police and in microwave radar for weather monitoring.

Application of electromagnetic waves

3. ***Infrared waves:*** these waves are used in:

Remote Controls: Infrared waves are used in remote controls for TVs, DVD players, and air conditioners.

Thermal Imaging: Used in night-vision cameras and heat-sensing devices to detect heat leaks or living organisms.

Data Transmission: Short-range data transfer in devices like infrared ports in older mobile phones

4. ***Visible light:*** these waves are used in:

Photography and Videography: Cameras use visible light to capture images and videos.

Optical Fibers: Used in high-speed internet and telecommunications, transmitting light signals over long distances.

Illumination: Light bulbs and LEDs provide visible light for homes, streets, and displays.

Application of electromagnetic waves

5. ***Ultraviolet (UV) Rays:*** these waves are used in:

Sterilization: UV rays are used to disinfect water, air, and medical equipment by killing bacteria and viruses. Example: UV lamps in water purifiers eliminate pathogens.

Tanning and Skin Treatment: Controlled UV exposure is used in tanning beds and to treat skin conditions like psoriasis.

Astronomy: UV telescopes study stars and galaxies, as UV radiation is emitted by hot celestial objects

6. ***X-Rays:*** these waves are used in:

Medical Imaging: X-rays are used to image bones and internal organs, helping diagnose fractures or diseases.

Security Scanning: Used in airports to scan luggage for hidden objects.

Material Analysis: X-rays are used in crystallography to study the structure of materials.

Application of electromagnetic waves

7. ***Gamma Rays:*** these waves are used in:

Cancer Treatment: Gamma rays are used in radiotherapy to target and destroy cancer cells. Example: A cobalt-60 source emits gamma rays to treat tumors.

Sterilization: Used to sterilize medical equipment by killing microorganisms.

Nuclear Industry: Used to inspect welds and detect flaws in materials.

Problems associated with electromagnetic waves

Electromagnetic waves can be detected in various ways through different instruments:

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Problems associated with electromagnetic waves

Health Risks

- **UV Rays**: Prolonged exposure can cause skin cancer, cataracts, and sunburn..
- **X-Rays and Gamma Rays**: High exposure can damage cells and DNA, potentially causing cancer.
- **Microwaves**: Overexposure to high-intensity microwaves can cause burns or tissue damage, though household microwave ovens are safe when used correctly.

Environmental Concerns

- **Interference**: Radio waves and microwaves from multiple sources (e.g., Wi-Fi routers, cell towers) can interfere with each other, causing signal loss.
- **Example**: Overlapping Wi-Fi signals in crowded areas can reduce internet speed.
- **Wildlife Impact**: Some studies suggest that EM radiation from cell towers may affect bird navigation or bee behavior, though evidence is inconclusive.

Solving problems using the wave equation: $c = f * \lambda$

The Wave Equation

The speed of an electromagnetic wave in a vacuum is constant and is given by the formula:

$$c = f * \lambda$$

Where:

- c = speed of light (3.00×108 m/s)
- f = frequency (in hertz, Hz)
- λ = wavelength (in meters, m)

Example 1:

A radio wave has a wavelength of **2.0 m**. Calculate its frequency.

Given: λ = 2.0 m, c = 3.00 × 10^8 m/s

f = c / λ

f = (3.00 × 10^8)(2.0)

The frequency is 1.5 × 10^8 Hz

Thus: **150 MHz**

Solving problems using the wave equation: $c = f * \lambda$

Solve the following:

a. An X-ray has a frequency of 3.0 × 10^18 Hz. What is its wavelength?

b. A microwave has a frequency of 2.45 GHz. Verify if its wavelength is approximately 0.122 m.

c. An infrared wave has a wavelength of 0.0001 m. Calculate its frequency.

d. A radio station broadcasts at 98.5 MHz. What is the wavelength of the signal?