CHAPTER 2:
ELECTROMAGNETIC RADIATION
With the exception of objects at absolute zero, all objects emit electromagnetic radiation (EMR).

Objects also reflect radiation that has been emitted by other objects.

Electromagnetic energy is generated by several mechanisms.

Remote sensing imagery is interpreted based on the interaction of the EMR with the Earth’s objects and the atmosphere.
IMPORTANT CONCEPTS

Incident radiant energy

Reflected

Absorbed

Reflected Solar Radiation (W/m²)

0 700

Emitted Heat Radiation (W/m²)

85 350

Emitted

Retained
**ELECTROMAGNETIC RADIATION**

- It is a way to transfer energy through space, which has properties of wave and particle.

- Every object with a temperature higher than 0 K (-273.15 °C / -459.67 °F) emits electromagnetic radiation.

![Diagram of Electromagnetic Radiation](image)
The fusion process: Nuclear reactions where lightweight chemical elements (like hydrogen) form heavier elements (such as helium and carbon). This process converts matter (i.e. mass of an atom) to energy.

Albert Einstein in 1905 showed that: \( E = mc^2 \)

Where,
- \( E \) = Energy
- \( m \) = mass
- \( c \) = speed of light in a vacuum \((3.0 \times 10^8 \text{ m/s})\)

The Sun produces its energy by two fusion reactions:
1. Proton-Proton (PP) – 88%
2. Carbon-Nitrogen-Oxygen (CNO) – 12%
WAVE PROPERTIES

- James Clerk Maxwell (1864): Theory of Electromagnetic Radiation

- This radiation is made of the electric and magnetic fields, that travel perpendicular to each other along the wave propagation.

- These waves can be described with wavelength and frequency.

- They vary proportional inverse and are related by the following equation:

\[ f = \frac{c}{\lambda} \]

where \( c = \) velocity of light (constant)
FIGURE 2.2. Amplitude, frequency, and wavelength. The second diagram represents high frequency, short wavelength; the third, low frequency, long wavelength. The bottom diagram illustrates two waveforms that are out of phase.
### TABLE 2.1. Units of Length Used in Remote Sensing

<table>
<thead>
<tr>
<th>Unit</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilometer (km)</td>
<td>1,000 m</td>
</tr>
<tr>
<td>Meter (m)</td>
<td>1.0 m</td>
</tr>
<tr>
<td>Centimeter (cm)</td>
<td>0.01 m = $10^{-2}$ m</td>
</tr>
<tr>
<td>Millimeter (mm)</td>
<td>0.001 m = $10^{-3}$ m</td>
</tr>
<tr>
<td>Micrometer ($\mu$m)(^a)</td>
<td>0.000001 m = $10^{-6}$ m</td>
</tr>
<tr>
<td>Nanometer (nm)</td>
<td>$10^{-9}$ m</td>
</tr>
<tr>
<td>Ångstrom unit (Å)</td>
<td>$10^{-10}$ m</td>
</tr>
</tbody>
</table>

\(^a\)Formerly called the “micron” ($\mu$); the term “micrometer” is now used by agreement of the General Conference on Weights and Measures.

### TABLE 2.2. Frequencies Used in Remote Sensing

<table>
<thead>
<tr>
<th>Unit</th>
<th>Frequency (cycles per second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hertz (Hz)</td>
<td>1</td>
</tr>
<tr>
<td>Kilohertz (kHz)</td>
<td>$10^3$ ($= 1,000$)</td>
</tr>
<tr>
<td>Megahertz (MHz)</td>
<td>$10^6$ ($= 1,000,000$)</td>
</tr>
<tr>
<td>Gigahertz (GHz)</td>
<td>$10^9$ ($= 1,000,000,000$)</td>
</tr>
<tr>
<td>Division</td>
<td>Limits</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>&lt; 0.03 nm</td>
</tr>
<tr>
<td>X-rays</td>
<td>0.03–300 nm</td>
</tr>
<tr>
<td>Ultraviolet radiation</td>
<td>0.30–0.38 μm</td>
</tr>
<tr>
<td>Visible light</td>
<td>0.38–0.72 μm</td>
</tr>
<tr>
<td>Infrared radiation</td>
<td></td>
</tr>
<tr>
<td>Near infrared</td>
<td>0.72–1.30 μm</td>
</tr>
<tr>
<td>Mid infrared</td>
<td>1.30–3.00 μm</td>
</tr>
<tr>
<td>Far infrared</td>
<td>7.0–1,000 μm (1 mm)</td>
</tr>
<tr>
<td>Microwave radiation</td>
<td>1 mm–30 cm</td>
</tr>
<tr>
<td>Radio</td>
<td>≥ 30 cm</td>
</tr>
</tbody>
</table>

**FIGURE 2.3.** Major divisions of the electromagnetic spectrum. This diagram gives only a schematic representation—sizes of divisions are not shown in correct proportions. (See Table 2.3.)
This radiation can be described equally well in terms of waves or in terms of packets of radiant energy called **quanta** or **photons**.

The relationship between these two "forms" of electromagnetic radiation is:

\[ E = hf \]

Where,

- \( E \) = Energy of a photon (joules)
- \( h \) = Planck's constant (joules * s)
- \( f \) = frequency (hertz)

Remember!

\[ \lambda = \frac{c}{f} \]

Therefore, the energy of a photon is directly proportional to the frequency but indirectly proportional to the wavelength.
What is the energy of a photon with a wavelength of 400 nm?

1. Get wavelength (\( \lambda \)) in meters:
   \[ 1 \text{ nm} = 10^{-9} \text{ meters} \]
   \[ ? \text{ meters} = 400 \text{ nm} \left( \frac{10^{-9} \text{ m}}{1 \text{ nm}} \right) = 4 \times 10^{-7} \text{ meters} \]

2. Get the frequency:
   \[ f = \frac{c}{\lambda} \]
   \[ = \frac{3 \times 10^8 \text{ m/s}}{4 \times 10^{-7} \text{ m}} = 7.5 \times 10^{14} \text{ cycles/second (or Hz)} \]

3. Get the energy:
   \[ E = hf \]
   \[ = (6.63 \times 10^{-34} \text{ J*s}) \left( 7.5 \times 10^{14} \text{ /s} \right) \]
   \[ = 4.97 \times 10^{-19} \text{ J} \]
What is the energy of a photon with a wavelength of 500 nm?

1. Get wavelength (\( \lambda \)) in meters:
   \[
   1 \text{ nm} = 10^{-9} \text{ meters}
   \]
   \[
   ? \text{ meters} = 500 \text{ nm} \left( \frac{10^{-9} \text{ m}}{1 \text{ nm}} \right) = 5 \times 10^{-7} \text{ meters}
   \]

2. Get the frequency:
   \[
   f = \frac{c}{\lambda}
   \]
   \[
   = \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{-7} \text{ m}} = 6 \times 10^{14} \text{ cycles/second (or Hz)}
   \]

3. Get the energy:
   \[
   E = hf
   \]
   \[
   = (6.63 \times 10^{-34} \text{ J*s}) (6 \times 10^{14} /\text{s})
   \]
   \[
   = 3.98 \times 10^{-19} \text{ J}
   \]
What is the energy of a photon with a wavelength of 700 nm?

1. Get wavelength ($\lambda$) in meters:
   
   \[
   1 \text{ nm} = 10^{-9} \text{ meters}
   \]
   
   \[
   ? \text{ meters} = 700 \text{ nm} \left(\frac{10^{-9} \text{ m}}{1 \text{ nm}}\right) = 7 \times 10^{-7} \text{ meters}
   \]

2. Get the frequency:
   
   \[
   f = \frac{c}{\lambda}
   \]
   
   \[
   = \frac{3 \times 10^8 \text{ m/s}}{7 \times 10^{-7} \text{ m}} = 4.28 \times 10^{14} \text{ cycles/second (or Hz)}
   \]

3. Get the energy:
   
   \[
   E = hf
   \]
   
   \[
   = (6.63 \times 10^{-34} \text{ J*s}) (6 \times 10^{14} /\text{s})
   \]
   
   \[
   = 2.84 \times 10^{-19} \text{ J}
   \]
At 400 nm  
\[ E = 4.97 \times 10^{-19} \text{ J} \]

At 500 nm  
\[ E = 3.98 \times 10^{-19} \text{ J} \]

At 700 nm  
\[ E = 2.84 \times 10^{-19} \text{ J} \]
VISIBLE SPECTRUM
FIGURE 2.4. Colors.
INFRARED SPECTRUM

Reflected IR

Emitted IR

Diameter of Human Hair: About 50μm
RADIATION LAWS

- **Planck Law:** Energy and Frequency
- **Kirchhoff Law:** Energy, Wavelength, and Temperature
- **Stefan-Boltzmann Law:** Emitted radiation and temperature
- **Wien Displacement Law:** Wavelength and temperature
Planck discovered that electromagnetic energy is absorbed and emitted in discrete units now called **quanta** or **photons**.

The size of each unit is directly proportional to the frequency of the energy’s radiation.

\[ Q = h \nu \]

Where,

- \( Q \) = Energy of a photon (joules)
- \( h \) = Planck's constant (joules * s)
- \( \nu \) = frequency (hertz)
  - 1 hertz = cycle/second

His model explains the **photoelectric effect**, the generation of electric currents by the exposure of certain substances to light.
The amount of energy and the wavelengths at which it is emitted depend upon the temperature of the object.

The area under each curve may be summed to compute the total radiant energy exiting each object. Thus, the Sun produces more radiant exitance ($M_e$) than the Earth because its temperature is greater. $M_e$ is the ability of a surface to emit radiation.

As the temperature of an object increases, its dominant wavelength ($\lambda_{\text{max}}$) shifts toward the shorter wavelengths of the spectrum.

A blackbody is a hypothetical source of energy. It absorbs all incident radiation and none is reflected. It emits energy with perfect efficiency.
Kirchhoff Law

This law states that the ratio of emitted radiation to absorbed radiation flux is the same for all blackbodies at the same temperature.

It forms the basis for the definition of emissivity ($\varepsilon$):

\[ \varepsilon = \frac{M}{M_b} \]

Where,
\[
\begin{align*}
M &= \text{the emittance of a given object} \\
M_b &= \text{the emittance of a blackbody at the same temperature}
\end{align*}
\]

The emissivity of a true blackbody is 1, and that of a perfect reflector (a whitebody) would be 0. In nature, all objects have emissivities that fall between these extremes (graybodies).
Defines the relationship between the total emitted radiation ($W$) and temperature ($T$).

It states that total radiation emitted from a blackbody is proportional to the fourth power of its absolute temperature.

$W = \sigma T^4$

where $\sigma$ is the Stefan-Boltzmann constant, $5.6697 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$.

It states that hot blackbodies emit more energy per unit area than do cool blackbodies.
This law specifies the relationship between the wavelength of radiation emitted and the temperature of a blackbody.

\[ \lambda = \frac{k}{T} \]

where \( k \) is a constant equaling 2898 \( \mu m \) K, and \( T \) is the absolute temperature in kelvin.

Therefore, as the Sun approximates a 6000 K blackbody, its dominant wavelength (\( \lambda_{\text{max}} \)) is:

\[ \frac{2898 \ \mu m \ K}{6000 \ K} = 0.483 \ \mu m \]
WIEN DISPLACEMENT LAW

- Decrease of $\lambda_{\text{peak}}$ with increase in temperature
- Increase of intensity with temperature and decrease of peak wavelength with temperature.

Compare with Figure 2.5
REMOTE SENSING OF EARTH
INTERACTIONS WITH THE ATMOSPHERE

Very Imp.
EFFECTS OF SCATTERING

Atmospheric Dust Smoke

(b)
FIGURE 2.7. Rayleigh scattering. Scattering is much higher at shorter wavelengths.
\[ I_{\text{total}} = I_S + I_O + I_D \]

Total = Ground + Atmosphere + Diffuse

**FIGURE 2.8.** Principal components of observed brightness. \( I_S \) represent radiation reflected from the ground surface, \( I_O \) is energy scattered by the atmosphere directly to the sensor, and \( I_D \) represents diffuse light directed to the ground, then to the atmosphere, before reaching the sensor. This diagram describes behavior of radiation in and near the visible region of the spectrum. From Campbell and Ran (1993). Copyright 1993 by Elsevier Science Ltd. Reproduced by permission.
Most remote sensors for land studies have bands in the **Visible, IR, and Microwaves**.
FIGURE 2.12. Incoming solar radiation. This diagram represents radiation at relatively short wavelengths, in and near the visible region. Values represent approximate magnitudes for the Earth as a whole—conditions at any specific place and time would differ from those given here.
FIGURE 2.13. Outgoing terrestrial radiation. This diagram represents radiation at relatively long wavelengths—what we think of as sensible heat, or thermal radiation. Because the Earth’s atmosphere absorbs much of the radiation emitted by the Earth, only those wavelengths that can pass through the atmospheric windows can be used for remote sensing.
INTERACTIONS WITH SURFACES

Transmission

Fluorescence

Polarization

Reflection
FIGURE 2.20. Spectral response curves for vegetation and water. These curves show the contrasting relationships between brightness (vertical axis) and wavelength (horizontal axis) for two common surfaces—living vegetation and open water. The sketches represent schematic views of a cross-section of a living leaf (left) and a pond with clear, calm water (right). The large arrows represent incident radiation from the Sun, the small lateral arrows represent absorbed radiation, the downward arrows represent transmitted energy, and the upward arrows represent energy directed upward to the sensor (known as “reflectance”) that form the spectral response patterns illustrated at the top of the diagram. Fuller discussions of both topics are presented in later chapters.
SPECTRAL SIGNATURES

GREEN
RED
INFRARED

47 53 53

37 36 79

35 38 25

23 18 12

24 19 74

26 20 151

SPECTRAL SIGNATURES OF EARTH FEATURES

400 nm 600 nm 800 nm
Wavelength (nm)

Percent Reflectance (Log scale)

Snow and Ice
Clouds
Broadleaf Vegetation
Needleleaf Vegetation
Dry Soil
Wet Soil
Turbid Water
Clear Water

Reflection (%)
LANDSAT-channels (TM)

Pixel-value
LANDSAT-channels (TM)

0.4 0.6 0.8 1.0 1.2
Wavelength (μ)

soil
green vegetation
water

0 10 20 30 40 50

0 50 100 150 200

0.4 0.6 0.8 1.0 1.2
Wavelength (μ)
FIGURE 2.21. Remote sensing using reflected solar radiation. The sensor detects solar radiation that has been reflected from features at the Earth’s surface. (See Figure 2.12.)
FIGURE 2.22. Remote sensing using emitted terrestrial radiation. The sensor records solar radiation that has been absorbed by the Earth, and then reemitted as thermal infrared radiation. (See Figures 2.12 and 2.13.)
FIGURE 2.23. Active remote sensing. The sensor illuminates the terrain with its own energy, then records the reflected energy as it has been altered by the Earth’s surface.
YOUTUBE VIDEO:
THE ELECTROMAGNETIC SPECTRUM

https://youtu.be/cfXzwh3KadE
1. Read Chapter 2 and answer the review questions 4, 8, and 9 (at the end of the chapter).

2. Read Chapters 3 and 4.