Electromagnetic Spectrum

Visible Spectrum

 Frequency (Hz)
Wavelength (nm)

$10^4$ $10^6$ $10^8$ $10^{10}$ $10^{12}$ $10^{14}$ $10^{16}$ $10^{18}$ $10^{20}$

700 nm 400 nm

am radio  microwave  ultraviolet  gamma rays
fm radio, TV  infrared  x-rays
Radiation

- Transfer of energy through empty space in the form of waves

Diagram with labels:
- Wavelength
- Crest
- Amplitude
- Undisturbed state
- Trough
- Direction of wave motion
Wavelength ($\lambda$)
- the distance from crest to crest, or trough to trough
- measured in meters
Amplitude
- maximum departure from an undisturbed state
Wave Period
- time it takes 2 crests (or troughs) to travel past the same point in space

Frequency
- number of waves passing a given point per unit of time

\[
\text{Wave frequency} = \frac{1}{\text{Wave Period}}
\]

A period of 2 seconds = a frequency $\frac{1}{2}$ wave per second

Frequency units are Hertz (Hz) which are the number of cycles per second
Comparison of wave properties

- Shorter Wavelength
- Longer Wavelength
- Low Amplitude Radio Waves
- High Amplitude Radio Waves
- High frequency radio waves
- Low frequency radio waves
Wave Traveling through Space

The small circle shows the amplitude of the wave as it goes by us.

The frequency of oscillation of the dot is the frequency of the wave.

http://www.upscale.utoronto.ca/GeneralInterest/Harrison/Spectra/Spectra.html
Waves are formed as a result of a disturbance of electrically charged particles... electrons and protons

Disturbances from heating or collision, for example can create vibrations which send radiation waves through space
- Moving electric charges create magnetic fields.
- Hence every changing electric field has a corresponding magnetic field.
- So all accelerating charges create changing electric and magnetic fields.
Electromagnetic Radiation
is carried in the form of fluctuating electric and magnetic fields which are perpendicular to each other.
- Range of electromagnetic radiation from radio waves to gamma rays

- Each type is defined by the specific wavelength and frequency

- All travel at the same speed… the speed of light (186,000 miles/sec or 300,000 km/sec)

- Wavelength x frequency = velocity
### Size of Electromagnetic Spectrum of Radiation

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Wave Length</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Radiation (γ)</td>
<td>$10^{-3}$</td>
<td>nanometer</td>
</tr>
<tr>
<td>X-ray Radiation (X)</td>
<td>$10^{-6}$</td>
<td>micrometer</td>
</tr>
<tr>
<td>Ultraviolet (UV)</td>
<td>$10^{-6}$</td>
<td>micrometer</td>
</tr>
<tr>
<td>Visible Light</td>
<td>$10^{-8}$</td>
<td>millimeter</td>
</tr>
<tr>
<td>Infrared and Heat</td>
<td>$10^{-3}$</td>
<td>meter</td>
</tr>
<tr>
<td>Millimeter Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>Centimeter Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>Decimeter Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>VHF Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>Short Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>Medium Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
<tr>
<td>Long Waves</td>
<td>$10^{3}$</td>
<td>1 kilometer</td>
</tr>
</tbody>
</table>

- **Synchrotron Radiation**

- **Atomic nucleus**
- **Atom**
- **Protein**
- **Virus**
- **Cell**
- **Fly**
- **Human**
- **Building**
<table>
<thead>
<tr>
<th>Region</th>
<th>Wavelength (Angstroms)</th>
<th>Wavelength (centimeters)</th>
<th>Frequency (Hz)</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td>&gt; 10^9</td>
<td>&gt; 10</td>
<td>&lt; 3 x 10^9</td>
<td>&lt; 10^{-5}</td>
</tr>
<tr>
<td>Microwave</td>
<td>10^6 - 10^9</td>
<td>10 - 0.01</td>
<td>3 x 10^9 - 3 x 10^{12}</td>
<td>10^{-5} - 0.01</td>
</tr>
<tr>
<td>Infrared</td>
<td>10^6 - 7000</td>
<td>0.01 - 7 x 10^{-5}</td>
<td>3 x 10^{12} - 4.3 x 10^{14}</td>
<td>0.01 - 2</td>
</tr>
<tr>
<td>Visible</td>
<td>7000 - 4000</td>
<td>7 x 10^{-5} - 4 x 10^{-5}</td>
<td>4.3 x 10^{14} - 7.5 x 10^{14}</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>4000 - 10</td>
<td>4 x 10^{-5} - 10^{-7}</td>
<td>7.5 x 10^{14} - 3 x 10^{17}</td>
<td>3 - 10^{3}</td>
</tr>
<tr>
<td>X-Rays</td>
<td>10 - 0.1</td>
<td>10^{-7} - 10^{-9}</td>
<td>3 x 10^{17} - 3 x 10^{19}</td>
<td>10^{3} - 10^{5}</td>
</tr>
<tr>
<td>Gamma Rays</td>
<td>&lt; 0.1</td>
<td>&lt; 10^{-9}</td>
<td>&gt; 3 x 10^{19}</td>
<td>&gt; 10^{5}</td>
</tr>
</tbody>
</table>
Wavelength Units

Nanometer (nm) preferred
10^9 nanometers in 1 meter

Angstrom 1 Å = 10^{-10} m = 0.1 nm

Visible Light Spectrum
400-700 nm or 4000 to 7000 Å

- Our eyes are most sensitive to the middle range 550 nm (yellow–green)

- Sun emits most of its electromagnetic energy within this range

Radio Waves

- Range in size from .001 meters to thousands of meters
Radio waves and visible light are the only wavelengths transparent to the atmosphere, so observations can be made from the Earth’s surface in these wavelengths.

A part of the infrared spectrum is visible from earth.

A very small amount of Ultraviolet rays reach the Earth and can give you a sunburn.

Gamma rays, x-rays, and ultraviolet radiation must be recorded by satellites above the Earth’s atmosphere.
Atmosphere window of electromagnetic radiation
Black Body Spectrum

- All macroscopic objects (above absolute zero) emit radiation.
  
  You, fire, ice, stars, the floor all emit radiation all the time.

-Electrons in atoms are constantly in random motion, and whenever charged particles change their motion electromagnetic radiation is emitted.

**Temperature** is a direct measure of the amount of microscopic movement.

- The greater the movement the hotter the temperature

- The most important property use to identify the type of radiation emitted is **Temperature**.
Intensity (Brightness) of Radiation

- amount and strength of radiation at any given point in space
- spread over a range of frequencies across the electromagnetic spectrum

Blackbody

- theoretical object that is a perfect absorber and emitter of radiation

- Blackbody (or Planck) curve shows the distribution of intensity of the radiation emitted by an object
Blackbody

- As temperature increases there is a shift toward higher frequencies (shorter wavelengths) and greater intensities.
Again, you can see that as an object’s temperature increases, the frequency and intensity of emitted radiation also increase.
Peak Emissions for different objects
By measuring the wavelength at the peak of a star’s spectrum, we can calculate the surface temperature of the star.
Wien’s Law

- Wavelength of peak emission is a function of temperature

- The hotter objects emit most of their radiation at shorter (bluer) wavelengths

- The cooler objects emit most of their radiation at longer (redder) wavelengths

\[
\frac{\lambda_{\text{max}}}{T} = 2.9 \\
\text{Wavelength of Maximum Intensity (cm)} = \frac{2.9}{\text{T (°K)}}
\]
Wien’s Law
(Peak Wavelength) $\lambda = 0.29 \text{ cm}/\text{K}$

Examples

1. Your body emits radiation at $300^\circ \text{ K}$. What would the size and type of your emitting wavelength be?

   $\lambda = \frac{0.29 \text{ cm}}{300}$

   $\lambda = 0.001 \text{ cm}$ infrared radiation

2. What is the surface temperature of the sun if its peak wavelength is 500 nm?

   $500 \text{ nm} = \frac{0.29 \text{ cm}}{\text{K}}$

   $0.29 / 0.0005 = 5800^\circ \text{ K}$
Stefan-Boltzmann Law

- As an object’s temperature increases, the total energy it radiates (over all the frequencies) increases by a power of four.

  Total energy radiated is proportional to temperature$^4$

Example

- Doubling the temperature will cause the total energy radiated to increase by a factor of 16.
Look at the peak wavelength emissions for the following four stellar objects.

What type of peak wavelength do they each have?

(a.) Radio
(b.) Infrared
(c.) visible
(d.) ultraviolet
Spectral Lines

Spectroscope

- instrument used to analyze visible light
3 Types of Spectra

- Continuous, Emission and Absorption Spectra
3 Types of Spectra

- Continuum Spectrum
- Emission Line Spectrum
- Absorption Line Spectrum
Continuous Spectrum

- Spectrum is continuous over all the frequencies of visible light
Emission Spectrum

- Bright line spectrum which is discontinuous
- Low density hot gases emit the bright lines.
- Emission Lines are characteristic of the particular atoms (in the gas) emitting the photons, indicating the chemical composition of the gas
Absorption Lines

- Low density cool gas absorbs certain wavelengths of the continuous spectrum and leaves dark lines.

- These lines are exactly at the same wavelength as emission spectrum, which are produced by that gas (atoms in that gas) at a higher temperature.
Example of the Sun’s Spectrum
Radio Waves

- Radio waves viewed on Earth from space have a much larger window on the electromagnetic spectrum.
- Although you can’t “see” radio waves, you see them in use everyday.
- Can you brainstorm a list of radio waves used around you:
  - AM and FM radio broadcasts
  - Cordless phones
  - Garage door opener
  - Wireless networks
  - Radio controlled toys
  - TV broadcasts
  - GPS receivers
  - Ham radios
  - Police radios
  - Wireless clocks
  - Satellite communications
  - Baby monitors
  - Microwave ovens
  - Radar
  - Scanners
How can all these things use radio waves and not overlap?

- They all run on different frequencies.
- There are thousands of different radio waves.
- The FCC (Federal Communications Commission) decides who uses what frequency

Spectrum of Radio Waves
Basic radio wave technology

- Waves are sent by a **transmitter** and received by a **receiver**

  Both use antennae to radiate and to capture
AM radio stations frequencies are kHz (thousands of cycles per second)

FM radio stations frequencies are MHz (millions of cycles per second)

AM radio waves use amplitude modulation to sent data

FM radio waves use frequency modulation to sent data
Radio Astronomy

- The transmitters in radio astronomy are stellar and interstellar objects
- The receivers are placed at the focus of the reflecting parabolic dish

A radio telescope reflects radio waves to a focus at the antenna.
Radio Waves in Space

-Radio waves are used for looking at long wavelength and low temperature sources

Examples:

- Center of the Milky Way is a radio source
- Background radiation from the Big Bang
- Pulsars
- Mapping the rotation of the Milky Way Galaxy
- Expansion of the Universe (red shifting)
- Pinpoint CO emissions which show molecular clouds (birth places of stars)
- SETI uses radio to look for intelligent signals
Comparative view of radio and visible images of the galaxy

Radio Wave view of the Milky Way

Visible light view of the Milky Way