TOPIC # 5 - Part II
THE
ELECTROMAGNETIC SPECTRUM

Class Notes:
pp 27-28
Come forth into the light of things.

Let nature be your teacher.

~ William Wordsworth
Frequency, Wavelengths & Energy of Photons

Energy emitted from the sun (i.e., electromagnetic radiation) exhibits both a wave-like (electromagnetic wave) and particle-like (photon) nature.
Both Sun & Earth are radiating energy . . . .

. . . at different electromagnetic wavelengths

. . . . and at different frequencies

Figure on p 27
Richard Feynman, Quantum Physicist
There's this tremendous mess

Of waves all over in space

Which is the light bouncing around the room

And going from one thing to the other
Wavelengths
Quantifying Frequency & Wavelengths

Terminology for describing the WAVE-like behavior of electromagnetic energy:

**Wavelength** = distance between adjacent crests (or troughs) (symbol = \( \lambda \))

**Frequency** = how fast the crests move up and down (symbol = \( \nu \) or \( \chi \) in E-Text)

**Speed** = how fast the crests move forward (symbol = \( c \) in E-text)

\( c = \) the speed of light
Another view:

A
- Relatively longer wavelength
- crest or maximum
- trough or minimum

B
- amplitude
- Relatively shorter wavelength

C
- 1, 2, 3, 4
Wavelength & Frequency

“The shorter the wavelength
the GREATER the energy
&
the HIGHER the frequency”

NOTE: Shorter wavelengths are produced when the rope is shaken more vigorously.
These are the wavelength ranges most critical to global change processes!
The Electromagnetic Spectrum (another view)

Longwaves (LW)

- Low energy radiation
- Long wavelengths
- Long radio waves
- Standard AM radio broadcasts
- Short radio waves
- TV broadcasts
- FM radio broadcasts
- TV broadcasts

Shortwaves (SW)

- High energy radiation
- Short wavelengths
- Ultraviolet radiation
- Visible light
- Infrared radiation
- Microwave radiation
- Microwaves
- TV broadcasts
- FM radio broadcasts
- TV broadcasts

The electromagnetic spectrum.
Another (flipped) view:

Typical Sources That Send out Waves at This Frequency:

<table>
<thead>
<tr>
<th>Low energy radiation</th>
<th>High energy radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processes by protons and neutrons in atomic nuclei</td>
<td></td>
</tr>
<tr>
<td>Electrons in atoms, high-energy processes</td>
<td></td>
</tr>
<tr>
<td>Electrons in atoms, low-energy processes</td>
<td></td>
</tr>
<tr>
<td>Thermal vibrations of molecules</td>
<td></td>
</tr>
<tr>
<td>Microwave oven</td>
<td></td>
</tr>
<tr>
<td>Radar antenna</td>
<td></td>
</tr>
<tr>
<td>FM radio, TV antenna</td>
<td></td>
</tr>
<tr>
<td>AM radio antenna</td>
<td></td>
</tr>
<tr>
<td>60-Hz power-line radiation</td>
<td></td>
</tr>
</tbody>
</table>

Frequency, Hz

Short wavelengths

Gamma ray

X ray

Ultraviolet

Visible

Infrared

Typical Object Whose Size Is the Same as This Wavelength:

Nucleus tiny |

Atom |

DNA molecule |

Amoeba |

Fine dust particle |

Millimeter |

Centimeter |

Meter |

Soccer field |

Kilometer |

Earth huge |
What are the “sources” of different wavelengths of electromagnetic radiation?

<table>
<thead>
<tr>
<th>Type of Electromagnetic Radiation</th>
<th>Range of Wavelengths (in units indicated)</th>
<th>Typical Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rays</td>
<td>$10^{-16}$ to $10^{-11}$ in meters (m) using scientific notation</td>
<td>high-energy processes within nucleus caused by the strong force</td>
</tr>
<tr>
<td>Ultraviolet radiation</td>
<td>0.0001 to 0.4 in micrometers (μm)</td>
<td>electrons moving (quantum leaps) within individual atoms</td>
</tr>
<tr>
<td>Visible light</td>
<td>0.4 to 0.7 in micrometers (μm)</td>
<td></td>
</tr>
<tr>
<td>Infrared radiation</td>
<td>0.7 to ~30 (up to 1000) in micrometers (μm)</td>
<td>chaotic thermal kinetic motion of molecules due to their thermal energy</td>
</tr>
<tr>
<td>Near Infrared radiation</td>
<td>0.7 - 1.0 in micrometers (μm)</td>
<td></td>
</tr>
<tr>
<td>Far Infrared</td>
<td>1.0 - ~30 (up to 1000) in micrometers (μm)</td>
<td></td>
</tr>
<tr>
<td>Microwaves</td>
<td>$10^{-4}$ to $10^{-2}$ in meters (m) using scientific notation</td>
<td>electronically produced by microwave oven</td>
</tr>
</tbody>
</table>

THE GREENHOUSE EFFECT
ELECTROMAGNETIC SPECTRUM

JAVA APPLET:

http://lectureonline.cl.msu.edu/~mmp/applist/Spectrum/s.htm

Applet: Spectrum

Wavelength = 1.643e-6 m = 1642.9 nm
Frequency = 1.825e14 Hz = 182482.3 GHz
Energy = 1.209e-19 J = 0.754 eV

Infrared, heat radiation

Origin: Molecular vibrations
Detection: Bolometer
What is the relationship between . . .

ENERGY $E$

FREQUENCY $\nu$ and

WAVELENGTH $\lambda$

OF PHOTONS?

KEY CONCEPT #1:

The Energy $E$ of photons is **directly proportional** to their frequency $\nu$

$\propto = "\text{is proportional to}\”$

$E \propto \nu$
What is the relationship between . . .

ENERGY \( E \)

FREQUENCY \( \nu \) and

WAVELENGTH \( \lambda \)

OF PHOTONS?

**KEY CONCEPT #2:**

The Energy \( E \) of photons is **inversely** proportional to their **wavelength** \( \lambda \)

\[
E \propto \frac{c}{\lambda}
\]
SOLAR RADIATION: greatest intensity in **SHORT** wavelengths (high energy & frequency)

EARTH RADIATION: entirely in **LONG** wavelengths (low energy & frequency)

The wavelength determines how the electromagnetic ENERGY (photon) will interact with MATTER!
The quantum leap of electrons takes place **WITHIN an ATOM** between discrete energy levels (shells) when photons are absorbed or emitted . . .

Quantum theory also involves the *behavior of molecules*
When *some molecules* absorb and emit *certain wavelengths* of electromagnetic energy they bend, rotate, and spin in a specific way.
Greenhouse gases!

- Nitrogen gas molecule ($N_2$)
- Water vapor molecule ($H_2O$)
- Carbon dioxide gas molecule ($CO_2$)

Infrared radiation!

- Rotation
- Vibration

Slow rotation rate
Faster rotation rate

Bending mode (15-μm band)

Infrared radiation!

Figures on p 26
So what is a **Greenhouse Gas**? abbreviation we’ll use = GHG

**GHG** = a gas than can absorb and emit (re-radiate) **INFRARED** wavelengths of Electromagnetic Radiation

IR radiation

> 0.7 - 1000 micrometers
KEY POINT:

The QUANTUM BEHAVIOR of CERTAIN MOLECULES with respect to INFRARED RADIATION is the REASON THAT GREENHOUSE GASES ARE GREENHOUSE GASES!!
And NOW another...
More of:


Starring:

Silicon (Si)
INSIDE A SOLAR CELL

SOLAR PANEL

PHOTOVOLTAIC CELL (PV)

Antireflective coating

metal conducting strips

metal backing

Silicon Layers

Phosphorus (P) “doped” Si layer

Extra (P) electrons move down to (B) layer, negatively charging it

Boron (B) “doped” Si layer

Read this explanation at:

Silicon Layers
Antireflective coating
Metal conducting strips

Inside a solar cell

Solar panel
Photovoltaic cell (PV)

Electric field