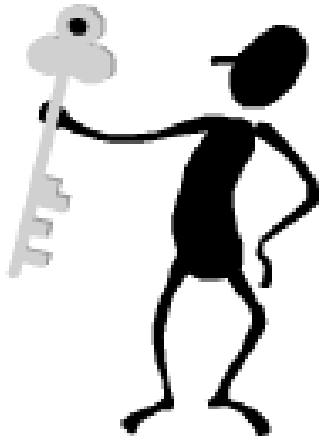
# TOPIC # 6
# THE ELECTROMAGNETIC SPECTRUM

## PART 2 of the KEY
## to unlocking the topics of:
## OZONE DEPLETION,
## The GREENHOUSE EFFECT,
## & GLOBAL WARMING!

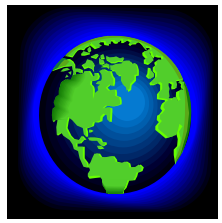


**Class Notes:**
**pp 29-30 ( & 31-32)**

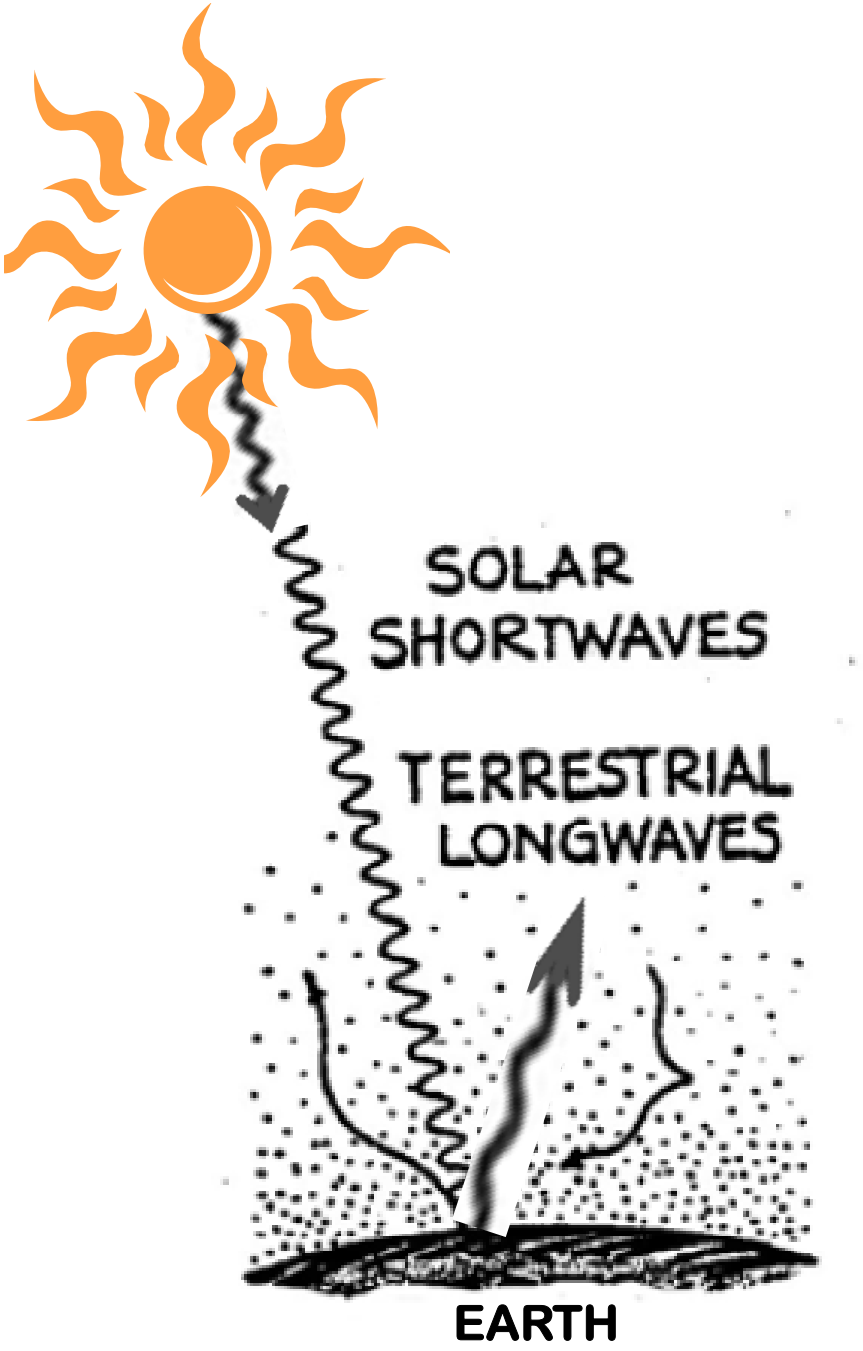
# GOAL for this week:

To understand the differences between:

Shortwave
SOLAR radiation
&
Longwave
TERRESTRIAL radiation



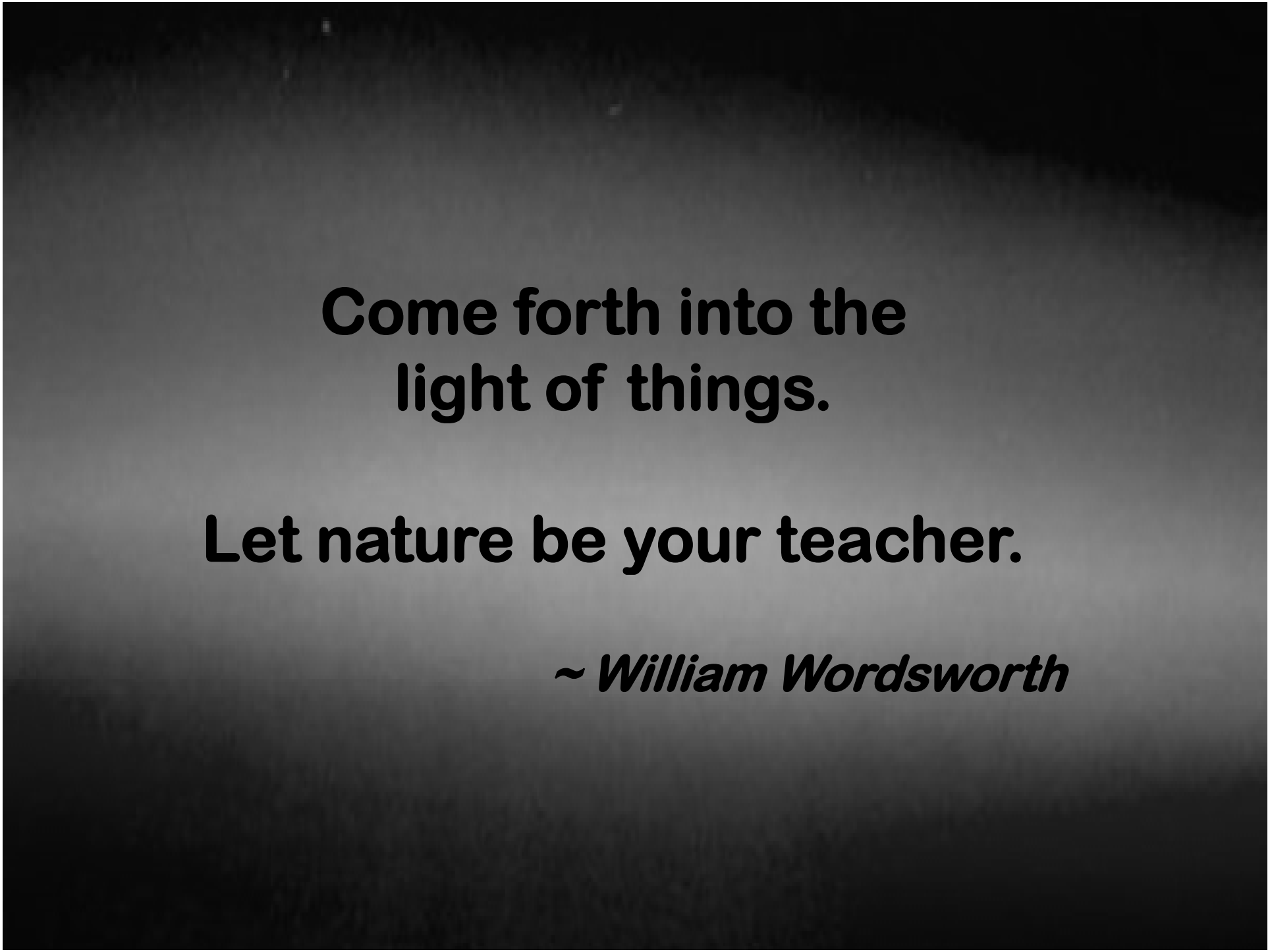
and how these differences drive GLOBAL CHANGE processes




**Both Sun & Earth are radiating energy . . . .**

**. . . at different electromagnetic wavelengths**

**. . . . and at different frequencies**


Come forth into the
light of things.
Let nature be your teacher.
~ William Wordsworth

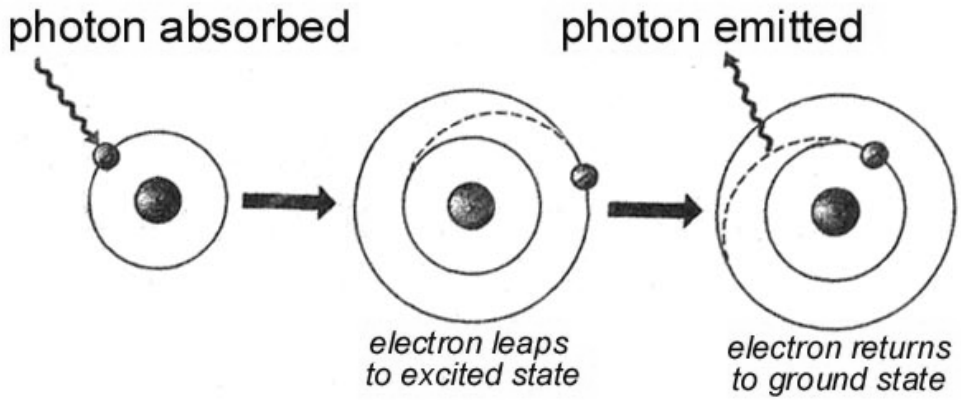
# Frequency, Wavelengths & Energy of Photons

**Energy emitted from the sun (i.e, electromagnetic radiation) exhibits both a wave-like (electromagnetic wave) and particle-like (photon) nature.**

*Review*

# RECAP: Electromagnetic Radiation

**(under certain higher-energy conditions, e.g. LIGHT)**
**Electromagnetic radiation**
**exhibits a particle-like nature which we call PHOTONS.**

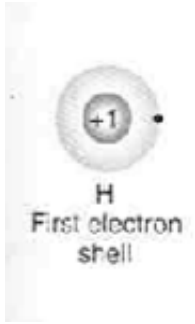


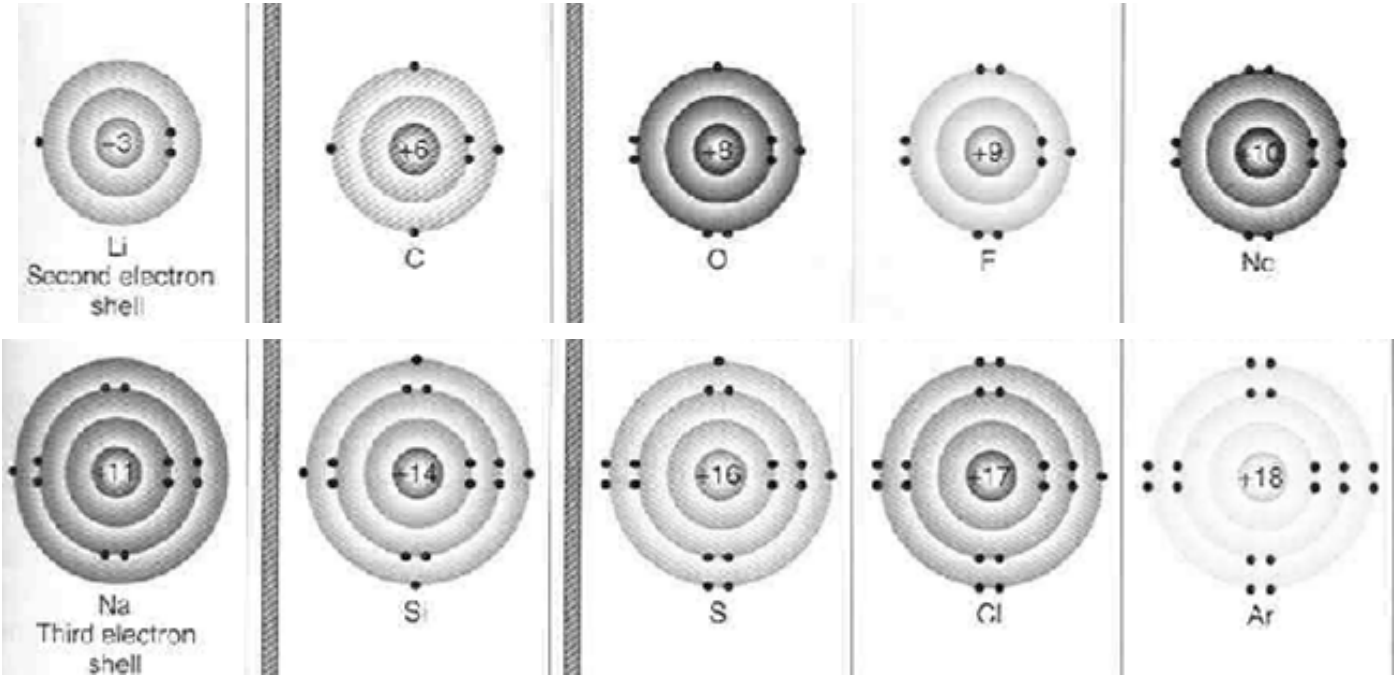

**Photons are energy packets having a well-defined wavelength and frequency**

***Review***

**Because each atom type (element) has a unique set of energy levels with electrons,**

**Each atom type (e.g. H, He, etc.) will ABSORB energy over a PARTICULAR set of ELECTROMAGNETIC FREQUENCIES & WAVELENGTHS.**

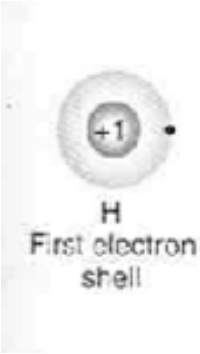


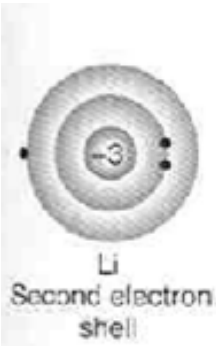

**REVIEW:**
**The Periodic Table is organized by # of shells (rows)**
**&**
**# of electrons in the outer shell (columns)**

***Review***

# What energy shell & electron properties will the elements in these boxes: ? have?

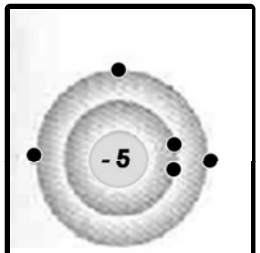



H
First electron shell



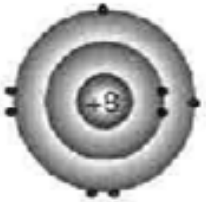

Li
Second electron shell


Na
Third electron shell

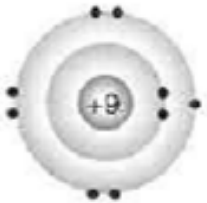



Boron (B)


C




O

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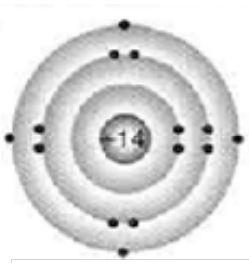
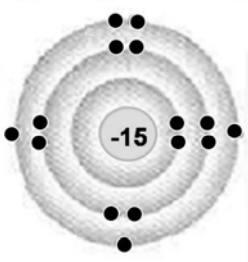
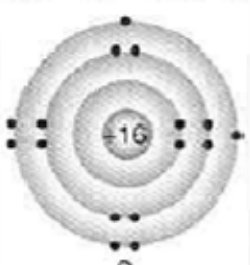



Silicon (Si)




Phosphorus (P)

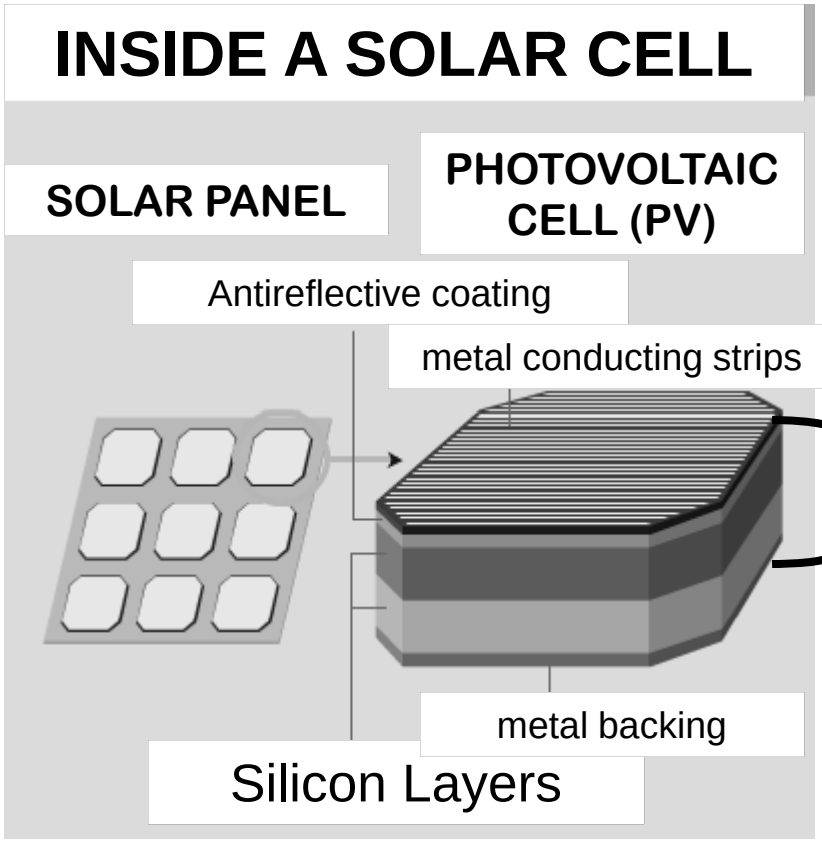


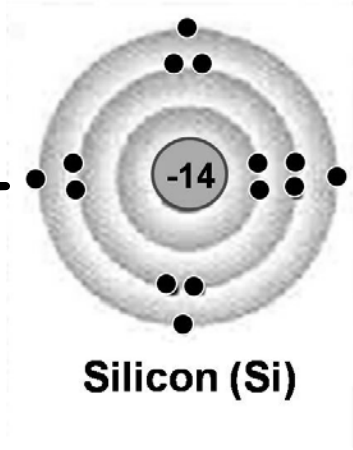

S

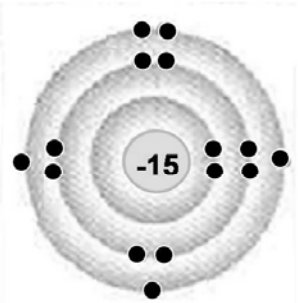

Cl

***Review***

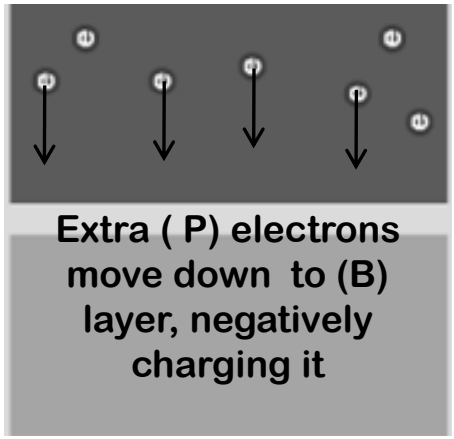
# INSIDE A SOLAR CELL



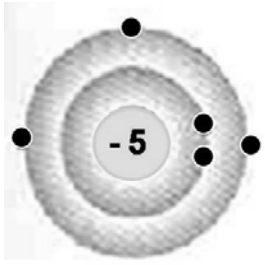




**Phosphorus (P)**
**"doped" Si layer**




**Boron (B)**
**"doped" Si layer**



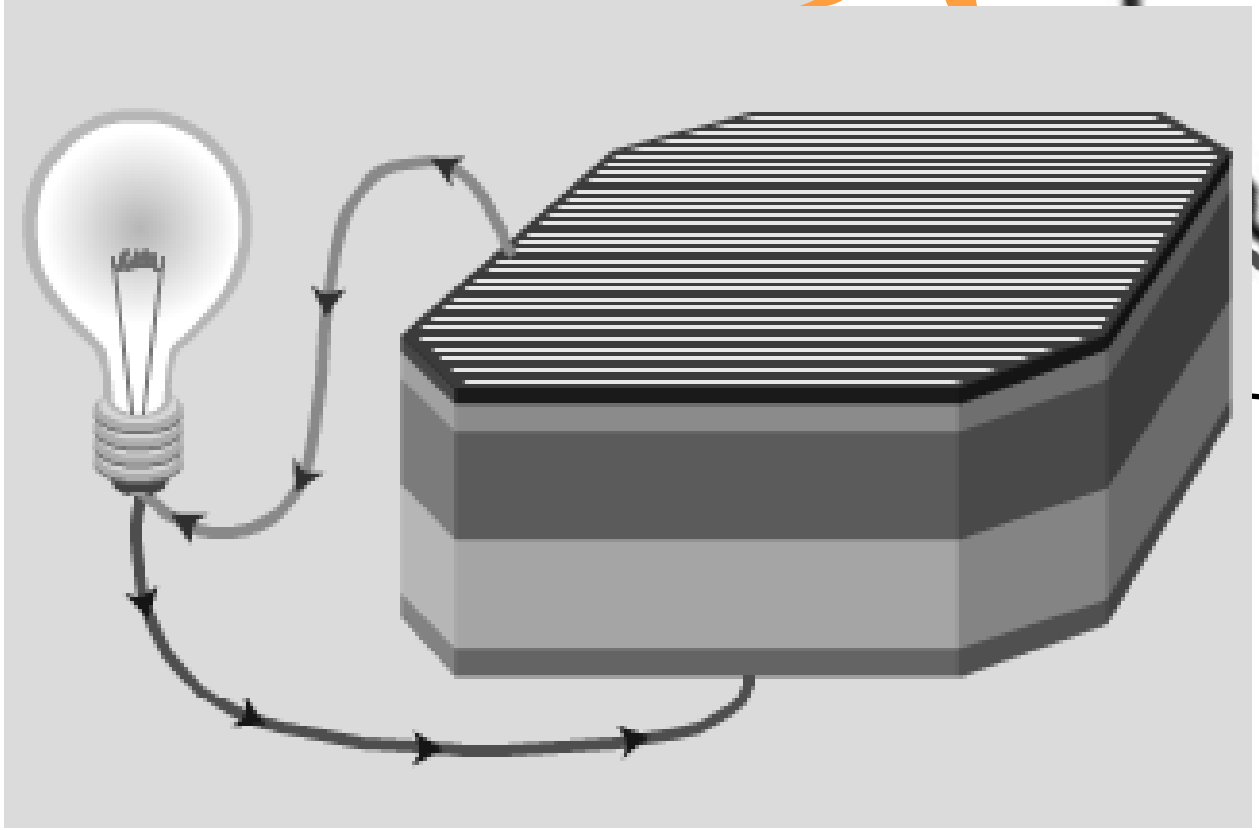


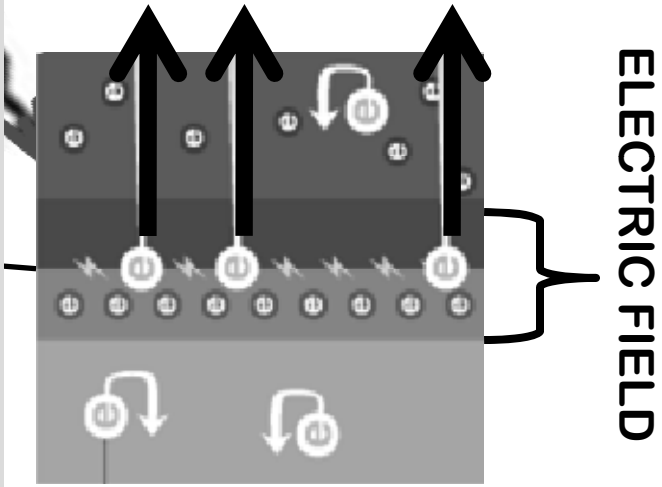
**Read this explanation at:**

**http://www.pbs.org/wgbh/nova/solar/**

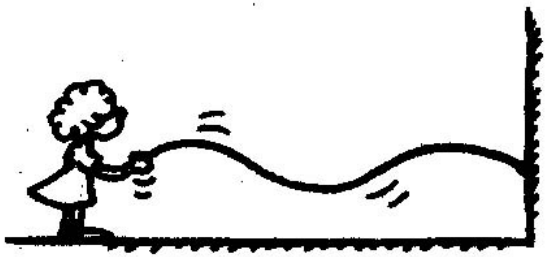
☺

# INSIDE A SOLAR CELL

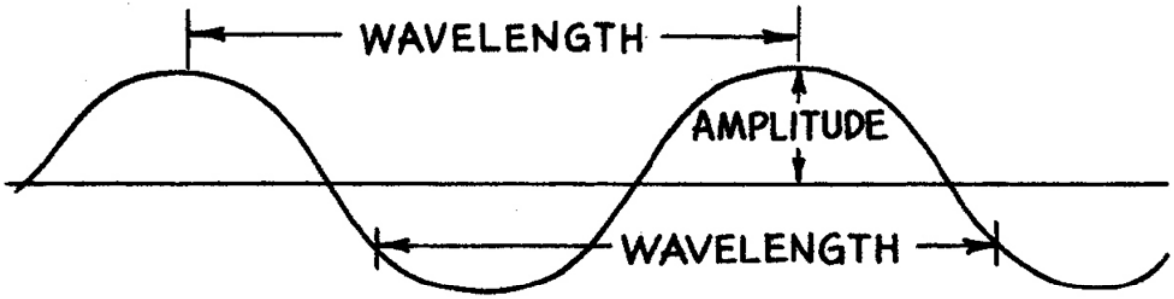


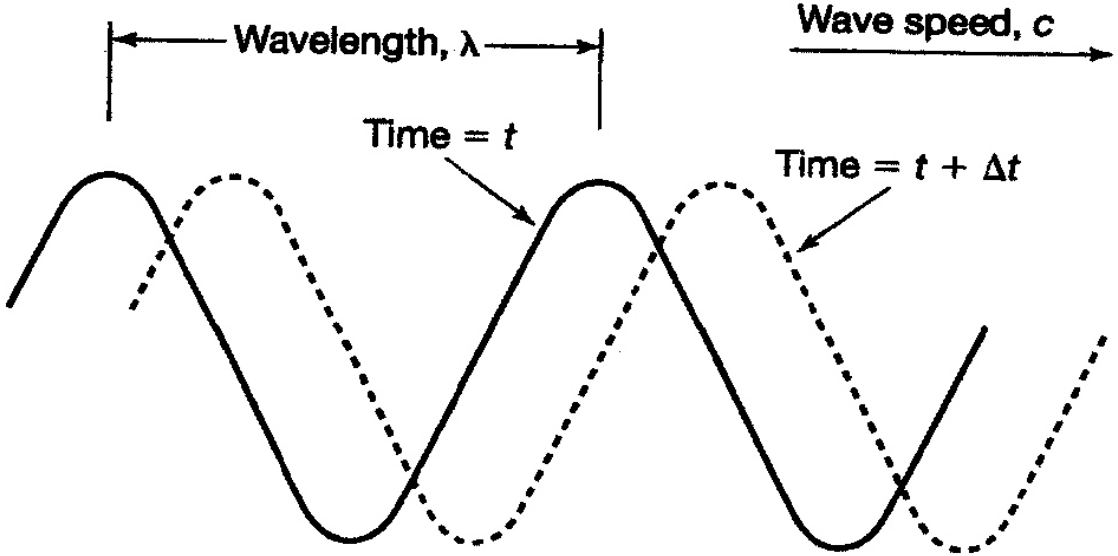


# Wavelengths



NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**



# Quantifying Frequency & Wavelengths

***First we'll talk about the WAVE-like behavior of electromagnetic energy:***

**Wave terminology:**

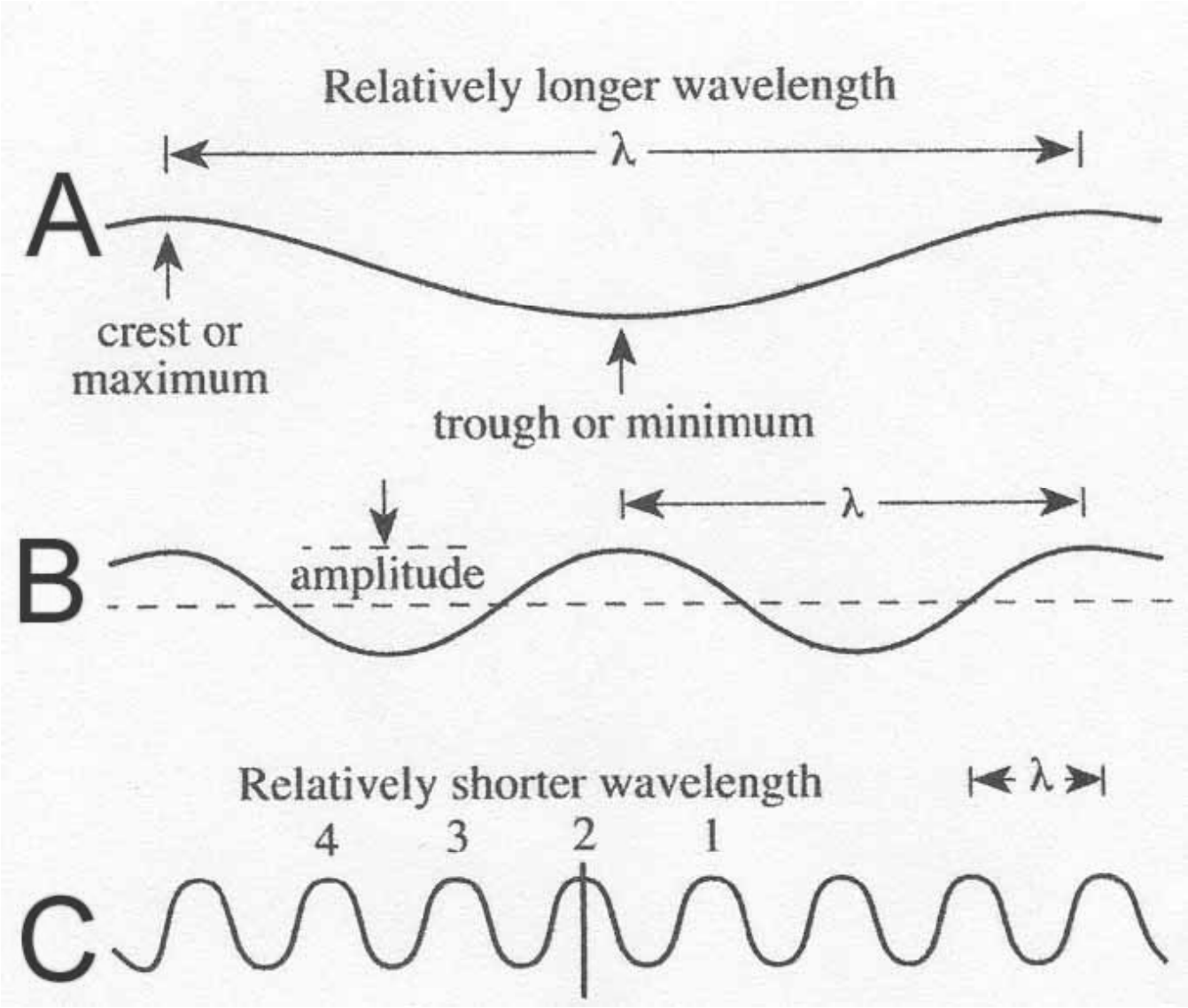
**Wavelength = distance between adjacent crests (or troughs) (symbol = lambda $\lambda$)**

**Frequency = how fast the crests move up and down (symbol = nu $\nu$ in SGC)**

**Speed = how fast the crests move forward (symbol = c in SGC) the speed of light**

***Take notes***

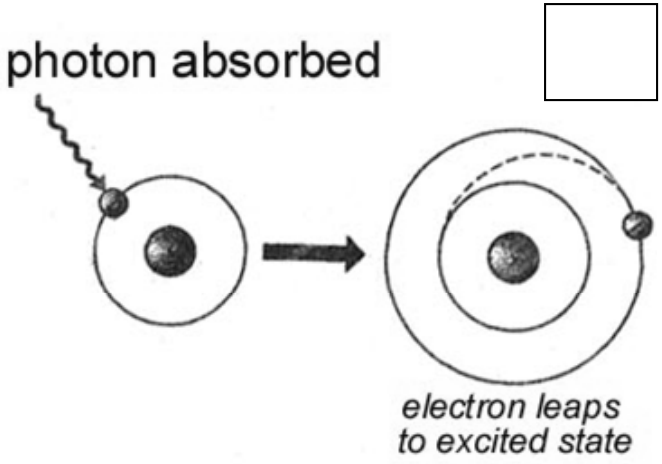
# *Another view:*




# QUANTUM MECHANICS & the LINK to ABSORPTION OF ELECTROMAGNETIC ENERGY AT THE SUBATOMIC SCALE

- If a photon strikes an atom,
- and if the FREQUENCY of the photon's electromagnetic radiation matches the *difference* in the energy of the ground level & the first excited level,
- the electron ABSORBS the photon energy and . . .
- the electron makes a quantum leap to "Level 2"

**Hydrogen atom:**

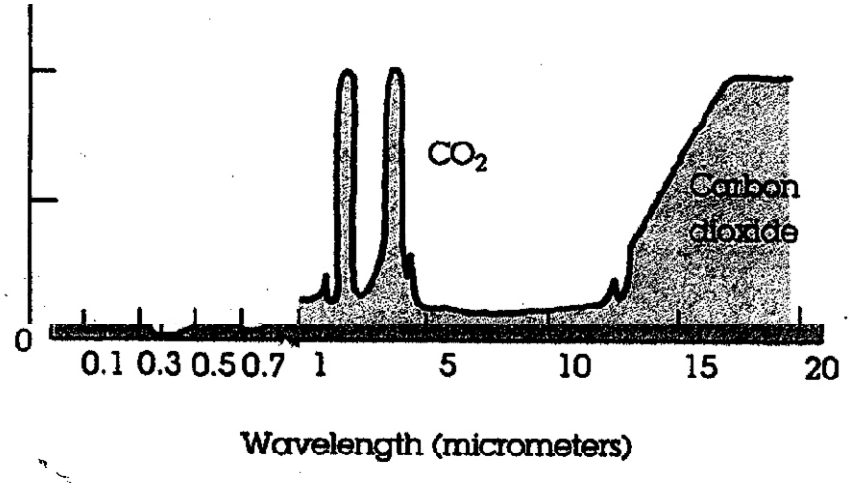




Review

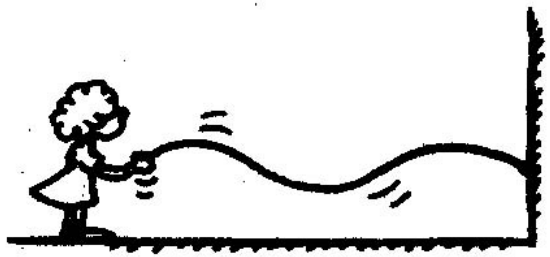
**The pattern of wavelengths <u>absorbed</u> by a particular atom or combination of atoms ,**
**(e.g. a gas molecule of $CO_2$ or $H_2O$)**

**is called its ABSORPTION SPECTRUM or its <u>ABSORPTION CURVE</u>** (more on this later . . )

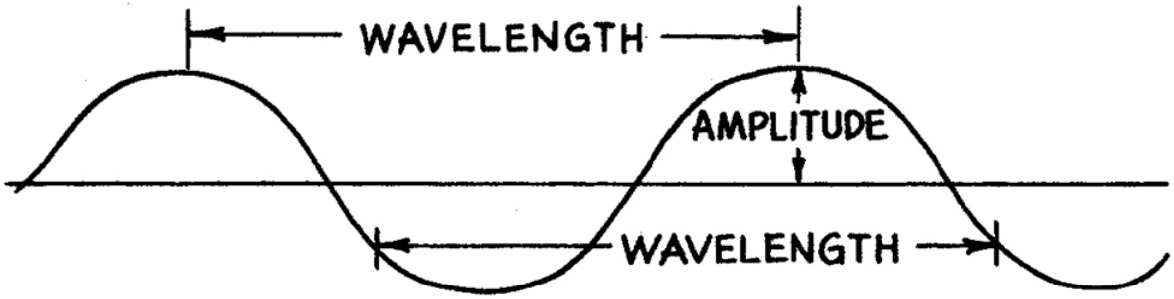
*Example of an "absorption spectrum" curve or graph* ➔

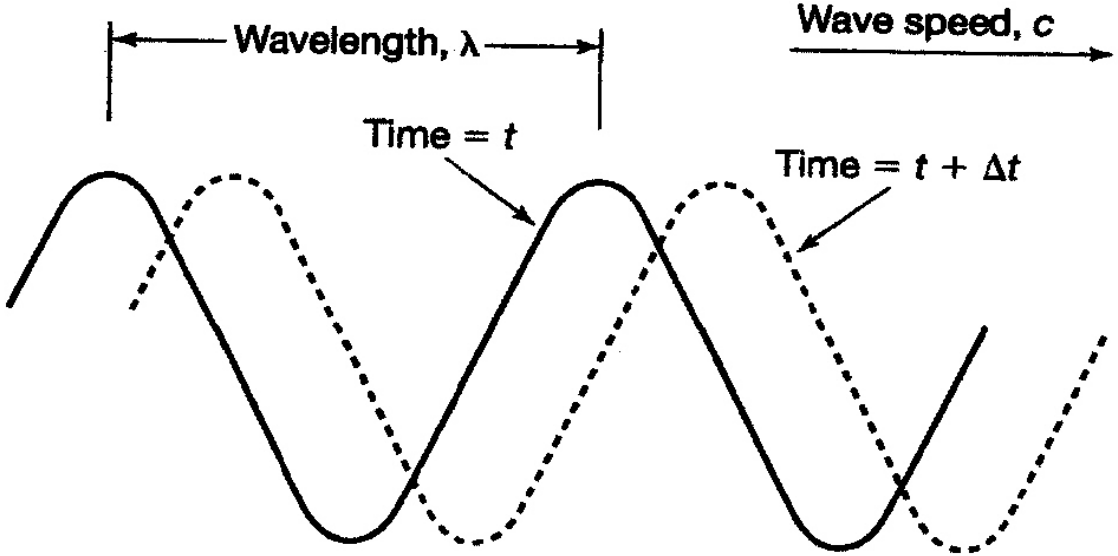



# Back to Wavelengths

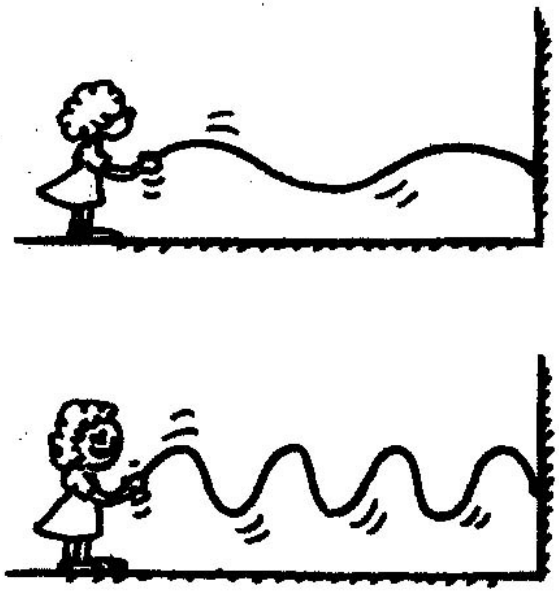


NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**



# Wavelength & Frequency



NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**

*"The **shorter** the wavelength*

*the **GREATER the energy***

*&*

*the **HIGHER the frequency**"*

***THE RELATIONSHIP BETWEEN FREQUENCY ($\nu$) , WAVELENGTH ($\lambda$), & ENERGY (E) OF PHOTONS:***

# ***KEY CONCEPT #1:***

**The Energy (E) of photons is <u>directly</u> proportional to their frequency $\nu$.**

**$\propto$ = "is proportional to"**

$$E \propto \nu$$

***Take notes***

***THE RELATIONSHIP BETWEEN FREQUENCY ($\nu$) , WAVELENGTH ($\lambda$), & ENERGY (E) OF PHOTONS:***

# ***KEY CONCEPT #2:***

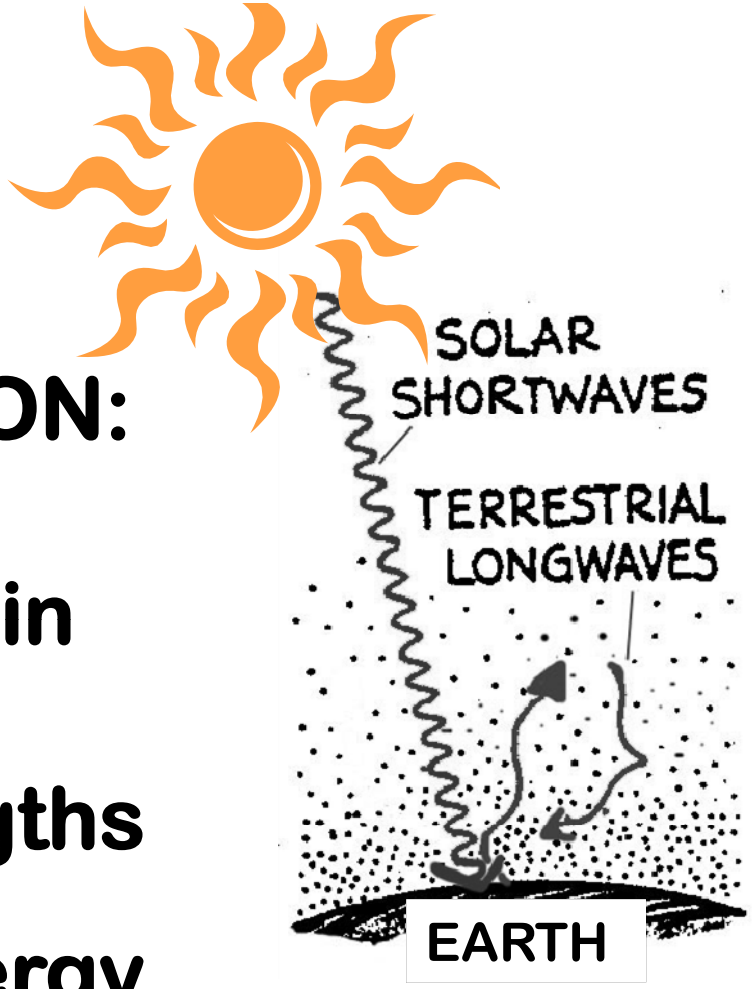
**The Energy (E) of photons is <u>inversely</u> proportional to their wavelength ($\lambda$)**

$$E \propto c / \lambda$$

***Take notes***

**SOLAR RADIATION:** greatest intensity in SHORT wavelengths

(high energy & frequency)




**EARTH RADIATION:** entirely in LONG wavelengths

(low energy & frequency)

# Quantum Behavior of <u>MOLECULES</u>

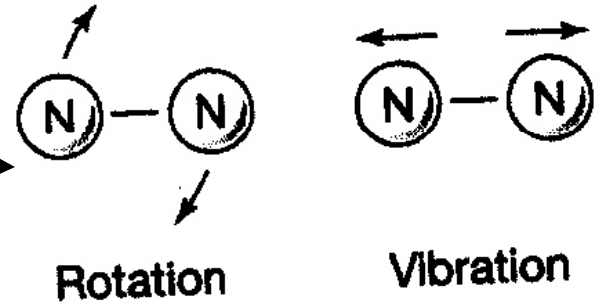
**Quantum leap of electrons:**
**takes place between discrete energy levels (shells) when photons are absorbed or emitted . . .**

**but**

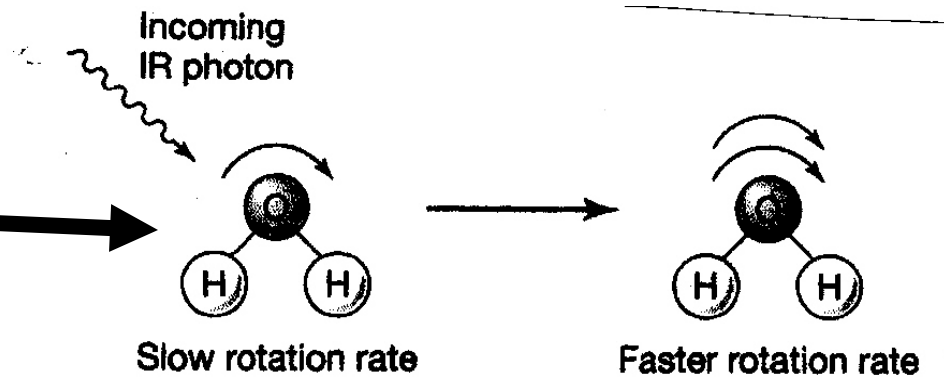
## Quantum theory also involves the *behavior of molecules*

*Review p 29*

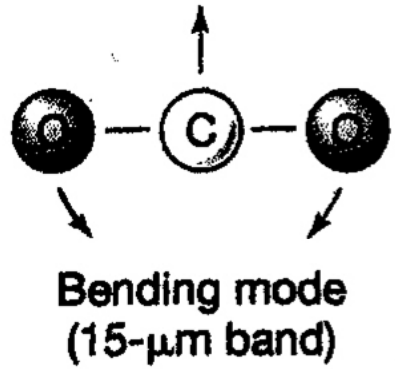
**NITROGEN GAS MOLECULE $N_2$**




**WATER VAPOR MOLECULE $H_20$**

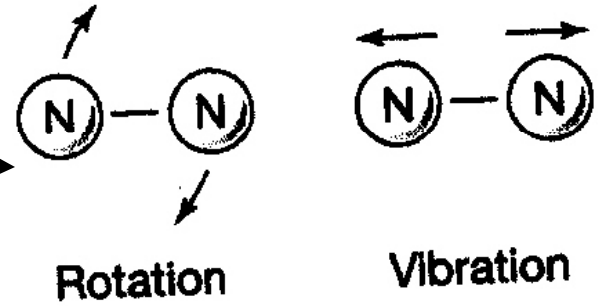



**CARBON DIOXIDE GAS MOLECULE $CO_2$**

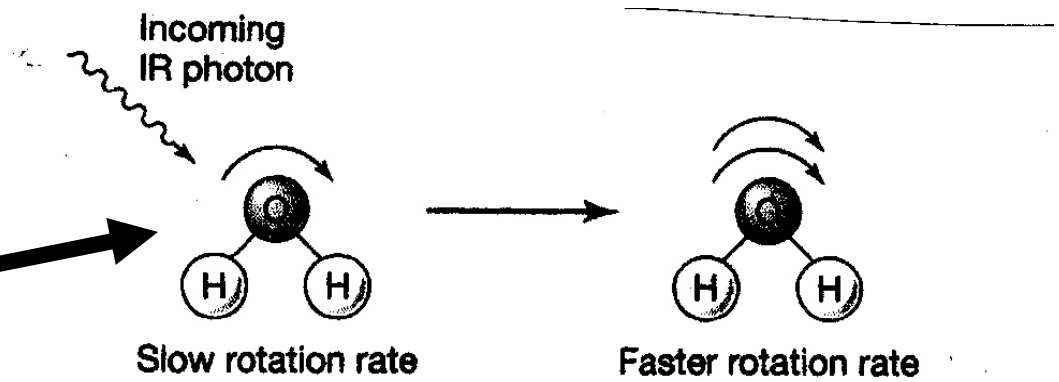


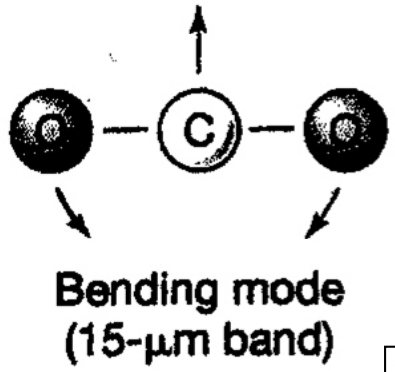

**FYI: These figures are on pp 47-48 in SGC-I**

**NOT a GREENHOUSE GAS**
**$N_2$**

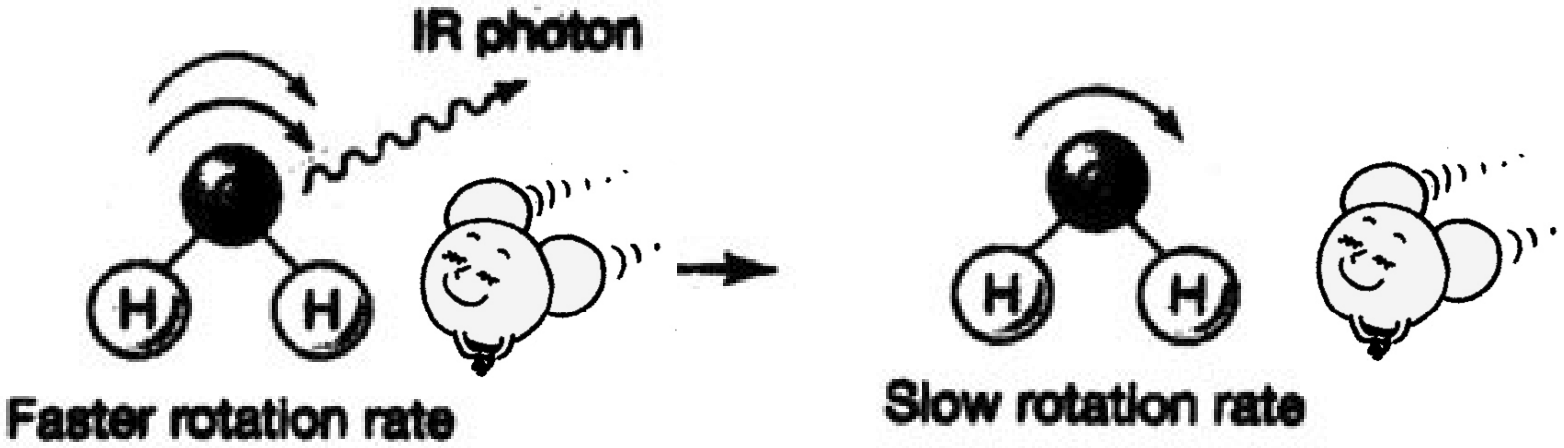



**GREENHOUSE GASES**
**$H_20$ & $CO_2$**




***Take notes***



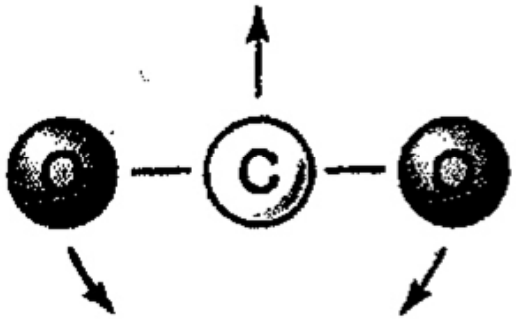

**When the $H_2O$ molecule emits a photon, its rotation rate decreases;**

**When it absorbs a photon, the rotation rate increases.**

- **Molecules can also absorb and emit IR radiation by *changing the amplitude with which they vibrate.***

**If the frequency at which a molecule vibrates matches the frequency of electromagnetic wave, the molecule can absorb a photon and begin to vibrate more vigorously.**

*Take notes*




Bending mode
(15-μm band)

SGC-I Chapter 3

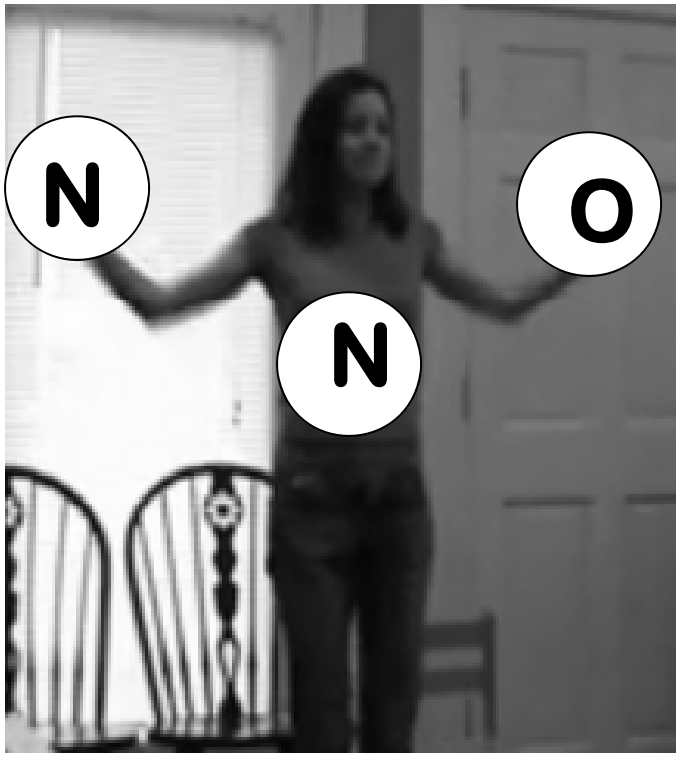
FIGURE 3-14

**As a triatomic molecule, one way that $CO_2$ vibrates is in a "bending mode" that has a frequency that allows $CO_2$ to absorb IR radiation at a wavelength of about 15 micrometers**

**What about another triatomic molecule: $N_2O$ (Nitrous oxide)?**

*Take notes*

# DANCE YOUR PhD !!




$N_2O$ acts as a greenhouse gas through the absorption of radiation in 3 vibrational modes.

With one hand as a nitrogen atom, torso as central nitrogen, and the other hand as an oxygen atom, the dancers exhibit the three specific movements of $N_2O$'s vibrational modes.

http://www.youtube.com/watch?v=L5j6BS3XoLc

☺

The $N_2O$ starts in the soil where it is produced by microbial activity and "moves on up" into the atmosphere.

Stepping onto the chairs represents the progression of $N_2O$ to higher levels in the atmosphere (the stratosphere) where it is subject to intense Ultraviolet (UV) radiation from the sun.

This high energy from the bombarding UV radiation is shown in the dancers' high energy, more spastic dancing.

The high intensity UV radiation leads to the destruction of $N_2O$ -- seen as jumping from the chair at the end ➔

**We will learn later that interaction of $N_2O$ in the stratosphere with UV wavelengths is related to OZONE DEPLETION**

**. . . but $N_2O$ also vibrates & bends when absorbing Infrared (IR) wavelengths**

**. . . It is the ability to <u>absorb</u> and <u>emit</u> IR radiation that makes $N_2O$ a GREENHOUSE GAS!**

***Take notes***

# What defines a Greenhouse Gas?

**abbreviation we'll use = GHG**

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

***Take notes***

*KEY POINT:*

**The QUANTUM BEHAVIOR of CERTAIN MOLECULES with respect to INFRARED RADIATION is the REASON THAT GREENHOUSE GASES ARE GREENHOUSE GASES!!**

*Take notes*

# RE-CAP:

**Energy given off by both the Sun and Earth has both a particle-like (photon) and wave-like behavior and emits radiation at electromagnetic wavelengths**

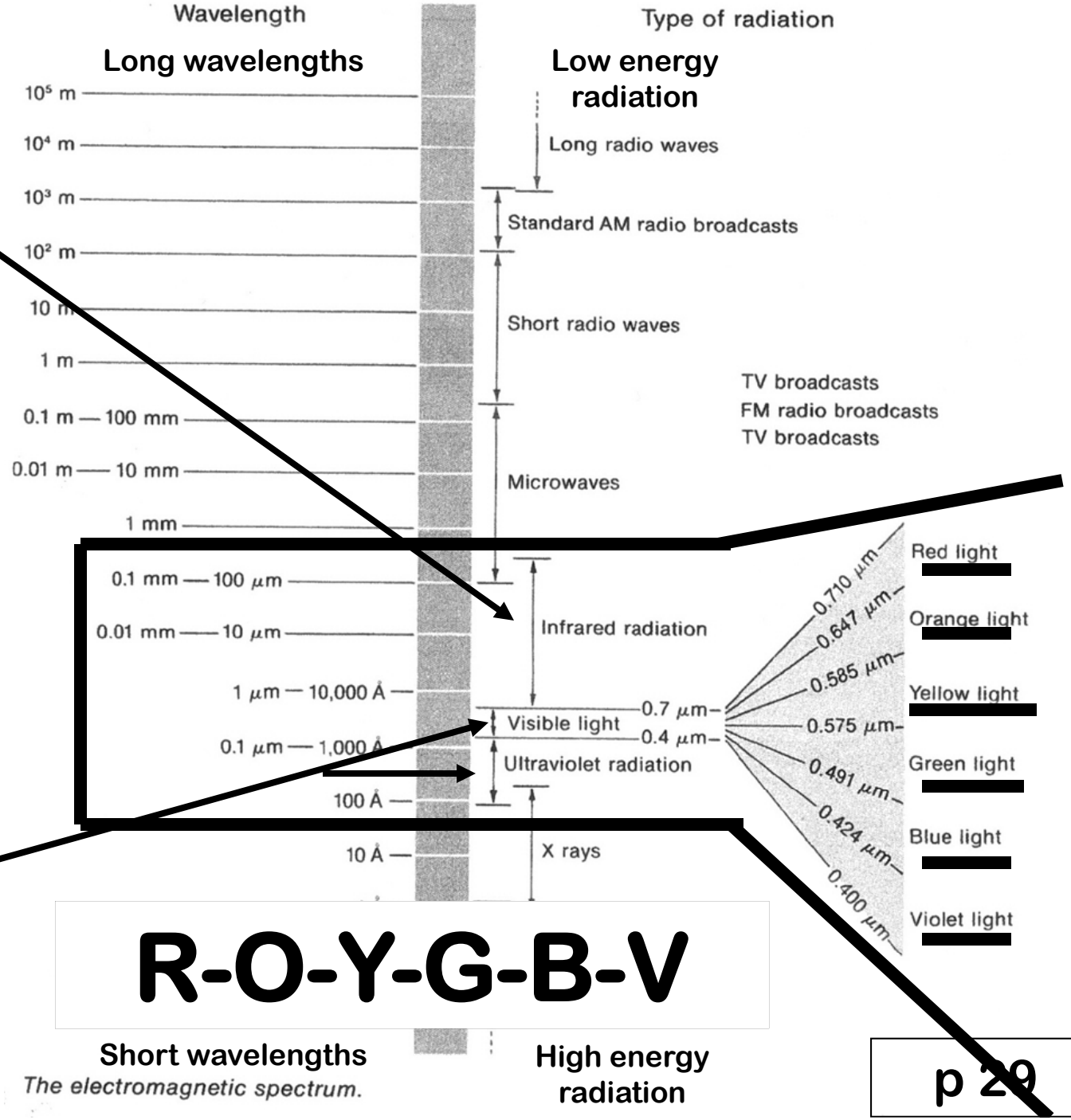
- **but which wavelengths??**
- **and what difference does it make???**

*review*

# The Electro-magnetic Spectrum

**Longwaves (LW)**

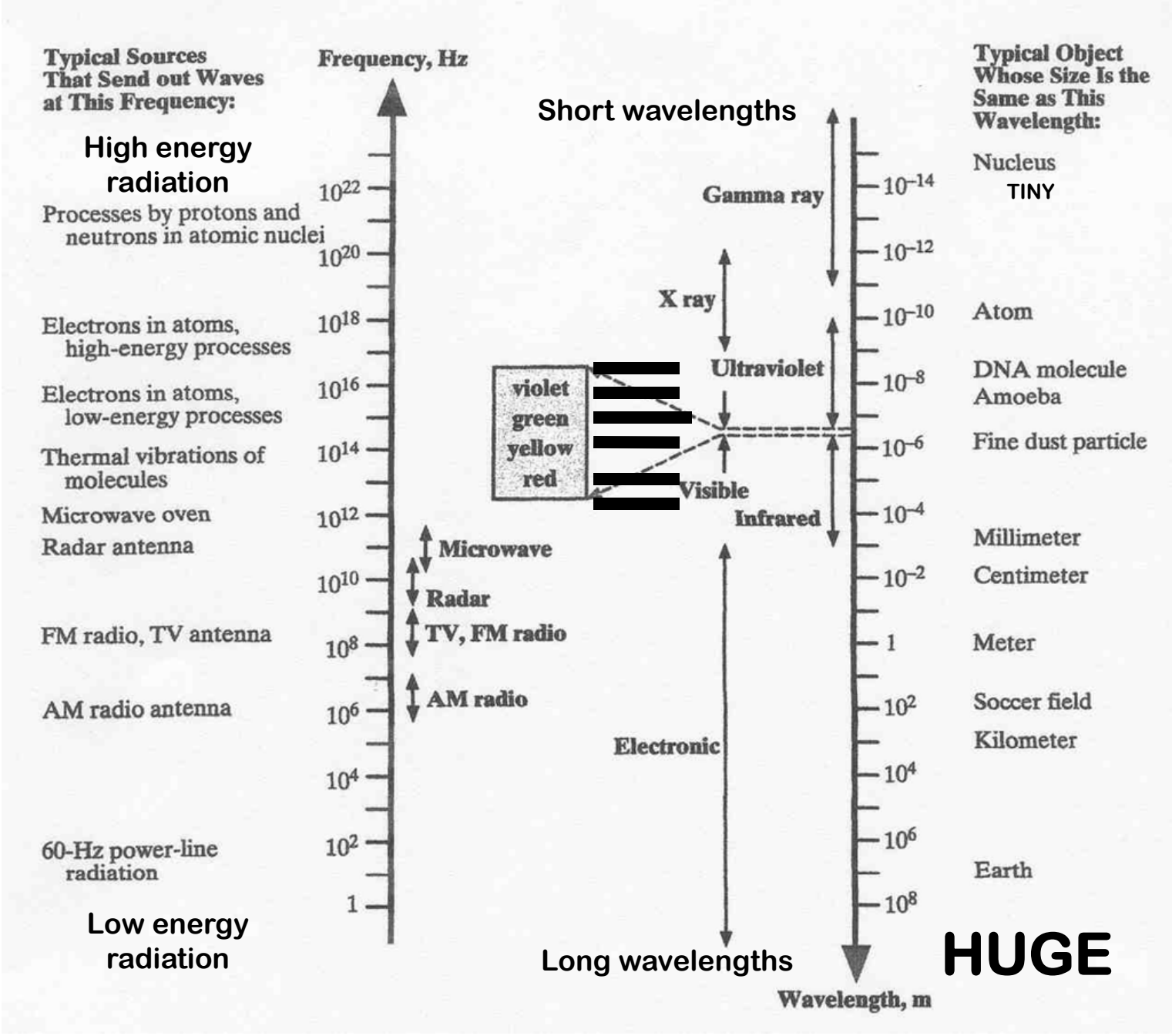
**Shortwaves (SW)**




*The electromagnetic spectrum.*

**R-O-Y-G-B-V**

# *Another (flipped) view:*

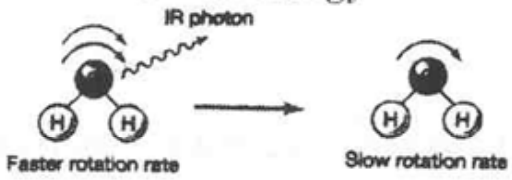


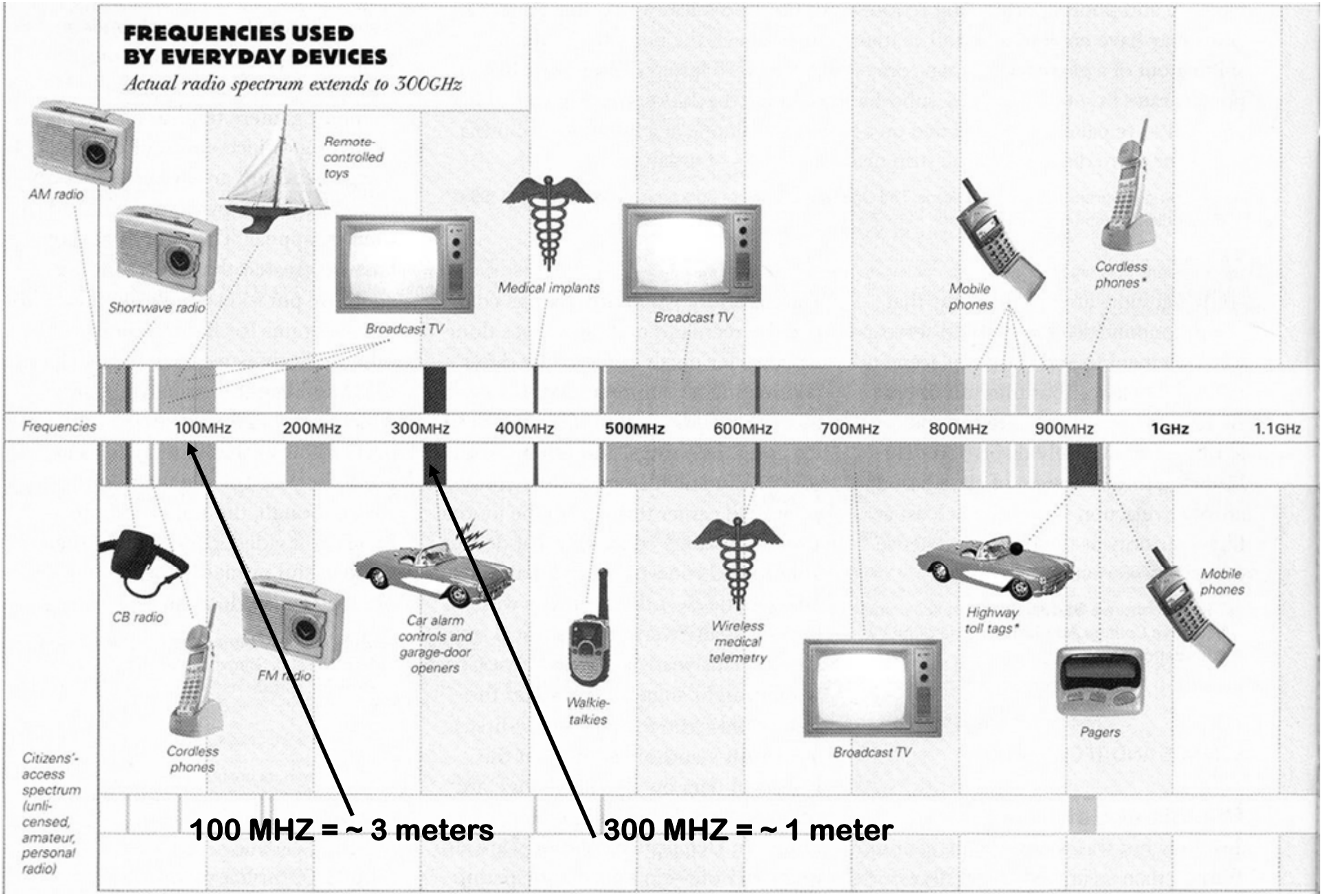
***Neat website:***

# ELECTROMAGNETIC SPECTRUM JAVA APPLET:

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

# What are the "sources" of different wavelengths of electromagnetic radiation?

| Type of Electromagnetic Radiation | Range of Wavelengths (in units indicated) | Typical Source |
|---|---|---|
| Gamma rays | $10^{-16}$ to $10^{-11}$ in meters (m) using scientific notation | high-energy processes within nucleus caused by the strong force |
| Ultraviolet radiation | .0001 to 0.4 in micrometers (μm) | electrons moving (quantum leaps) within individual atoms |
| Visible light | 0.4 to 0.7 in micrometers (μm) | |
| Infrared radiation | 0.7 to ~30 (up to 1000) in micrometers (μm) | chaotic thermal kinetic motion of molecules due to their thermal energy |
| Near Infrared radiation See SGC-II p 197 | 0.7 - 1.0 in micrometers (μm) |   |
| Far Infrared See SGC-II p 197 | 1.0 - ~30 (up to 1000) in micrometers (μm) | |
| Microwaves | $10^{-4}$ to $10^{-2}$ in meters (m) using scientific notation | electronically produced by microwave oven |
| AM Radio waves | 10 to $10^{2}$ in meters (m) using scientific notation | electronically produced -- waves vibrate in human-made electrical circuits |




**Increasing frequency & decreasing wavelength**

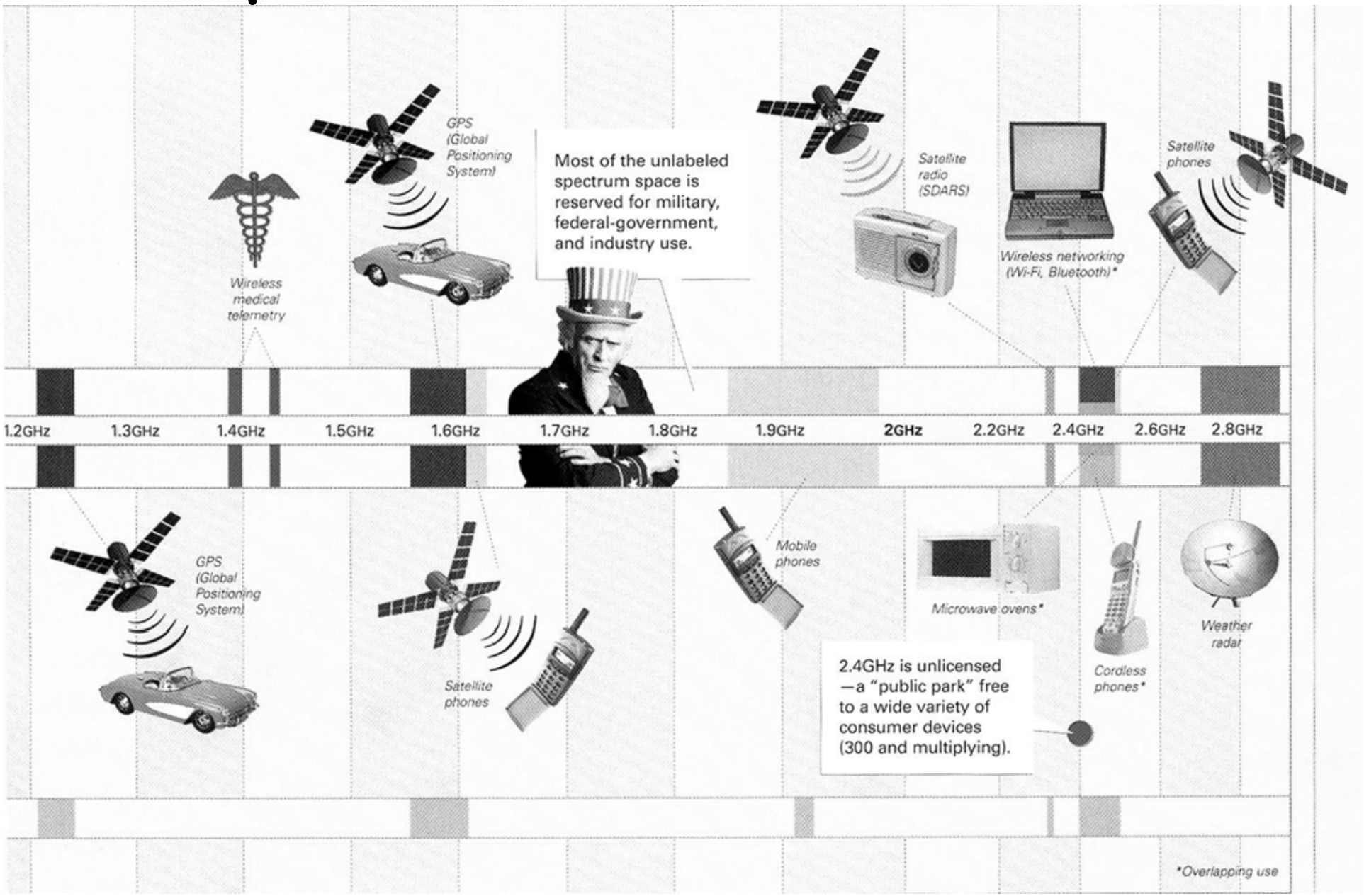
**Frequency** (def) = The number of times per second that a signal fluctuates.

The international unit for frequency is the hertz (Hz).

One thousand hertz equals 1 KHz (kilohertz).
One million hertz equals 1 MHz (megahertz).
One billion hertz equals 1 GHz (gigahertz).

Television is broadcast in frequencies ranging from
54 MHz to 216 MHz (VHF) &
470 MHz to 806 MHz (UHF).

# The spectrum is divided into bands . . .

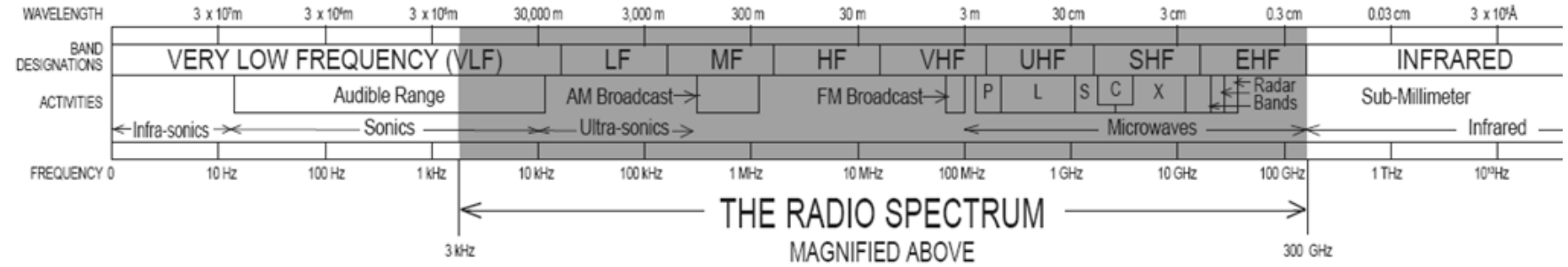


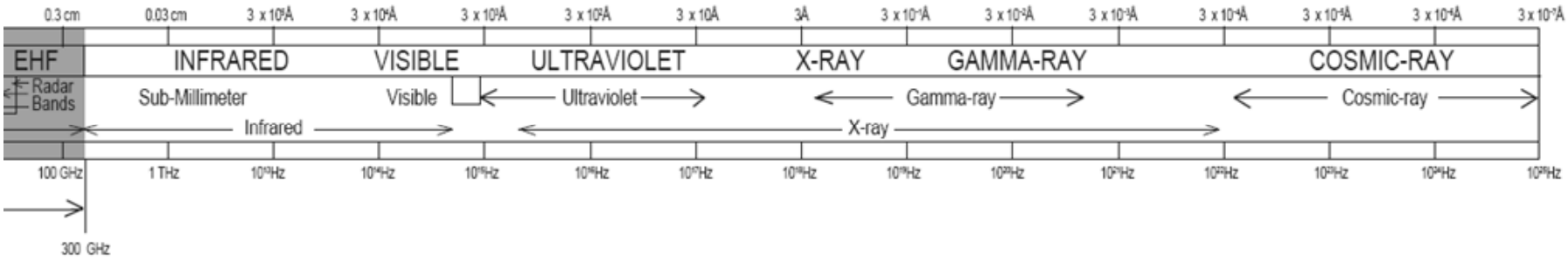
# Multicasting:

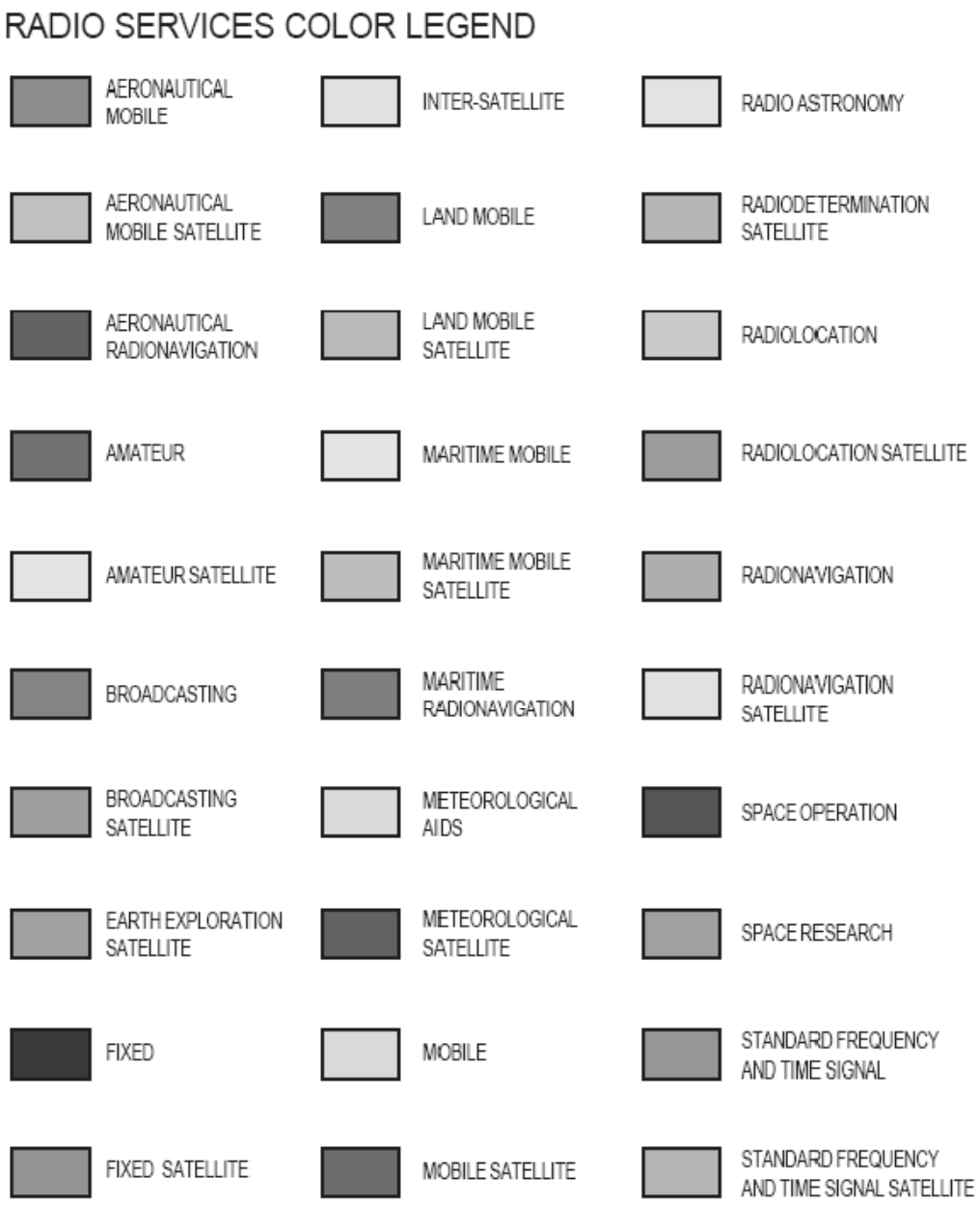
**This is the process of transmitting more then one program over the air at the same time on the same channel.**

**When stations are given their channel for DTV broadcasting they are allocated a specific amount of bandwidth.**

**If they are not using the full amount of bandwidth, they can squeeze more programs OTA through that same channel.**


WAVELENGTH
3 x 10⁷m
3 x 10⁶m
3 x 10⁵m
30,000 m
3,000 m
300 m
30 m
3 m
30 cm
3 cm
0.3 cm
0.03 cm
3 x 10⁴Å
BAND DESIGNATIONS
VERY LOW FREQUENCY (VLF)
LF
MF
HF
VHF
UHF
SHF
EHF
INFRARED
ACTIVITIES
Audible Range
AM Broadcast
FM Broadcast
P
L
S
C
X
Radar Bands
Sub-Millimeter
Infra-sonics
Sonics
Ultra-sonics
Microwaves
Infrared
FREQUENCY 0
10 Hz
100 Hz
1 kHz
10 kHz
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
100 GHz
1 THz
10¹³Hz
THE RADIO SPECTRUM
MAGNIFIED ABOVE
3 kHz
300 GHz


0.3 cm
0.03 cm
3 x 10³Å
3 x 10²Å
3 x 10¹Å
3 x 10⁰Å
3 x 10Å
3Å
3 x 10⁻¹Å
3 x 10⁻²Å
3 x 10⁻³Å
3 x 10⁻⁴Å
3 x 10⁻⁵Å
3 x 10⁻⁶Å
3 x 10⁻⁷Å
EHF
INFRARED
VISIBLE
ULTRAVIOLET
X-RAY
GAMMA-RAY
COSMIC-RAY
Radar Bands
Sub-Millimeter
Visible
Ultraviolet
Gamma-ray
Cosmic-ray
Infrared
X-ray
100 GHz
1 THz
10¹³Hz
10¹⁴Hz
10¹⁵Hz
10¹⁶Hz
10¹⁷Hz
10¹⁸Hz
10¹⁹Hz
10²⁰Hz
10²¹Hz
10²²Hz
10²³Hz
10²⁴Hz
10²⁵Hz
300 GHz




# Who "owns" the spectrum?

# UNITED STATES FREQUENCY ALLOCATIONS

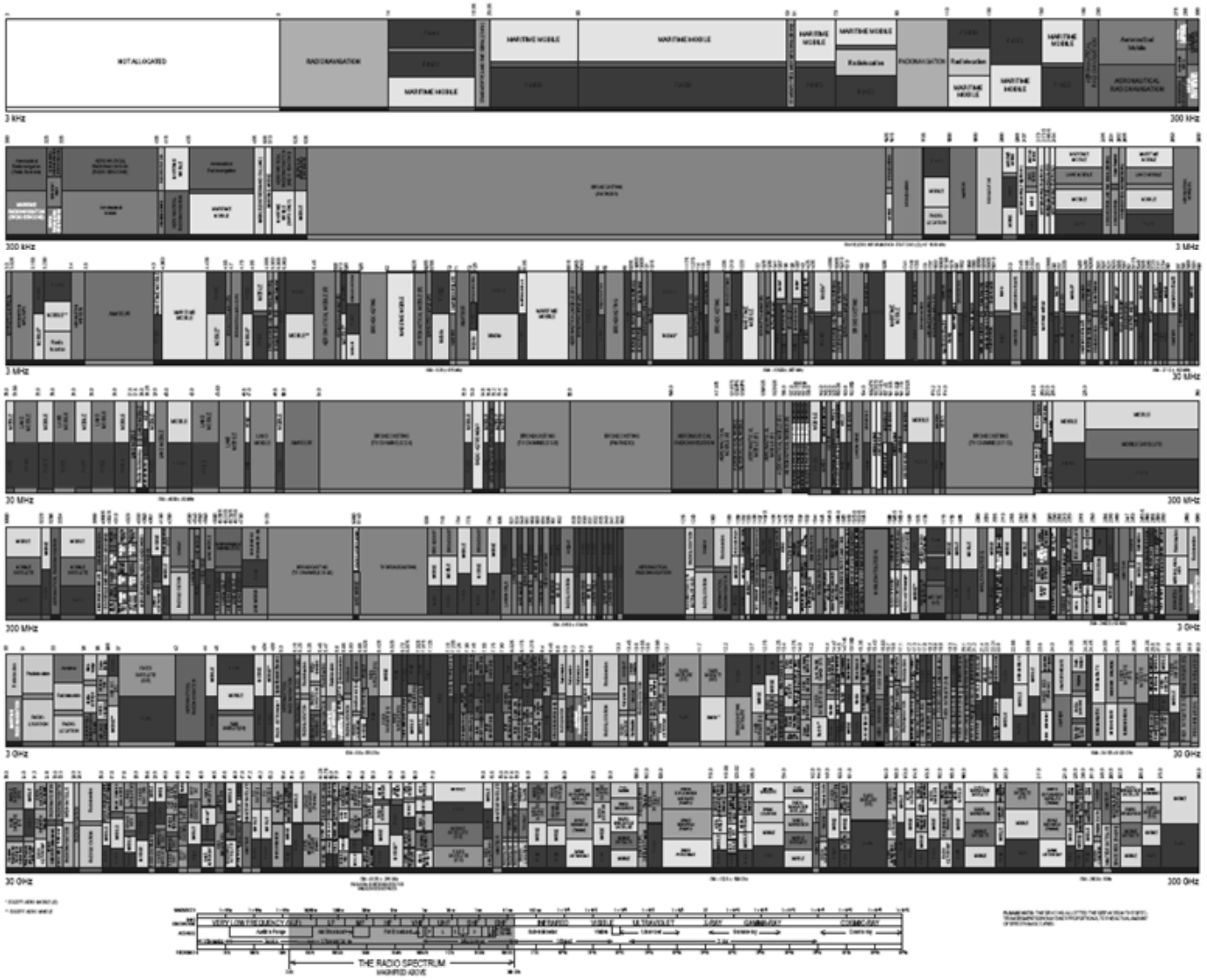
## THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

ACTIVITY CODE

ALLOCATION USAGE DESIGNATION

| SERVICE | EXAMPLE | DESCRIPTION |
|---|---|---|
| Primary | FIXED | Capital Letters |
| Secondary | Mobile | 1st Capital with lower case letters |




U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003

# SUSTAINABILITY SEGMENT

*more of:*


**http://www.pbs.org/wgbh/nova/solar/**

**HAVE A GREAT WEEKEND,**
**BUT STUDY WELL for**
**TEST # 1 next Tuesday**
**&**
**LOOK FOR THE**
**“Top Ten” STUDY GUIDE**
**to be posted**
**on FRIDAY**