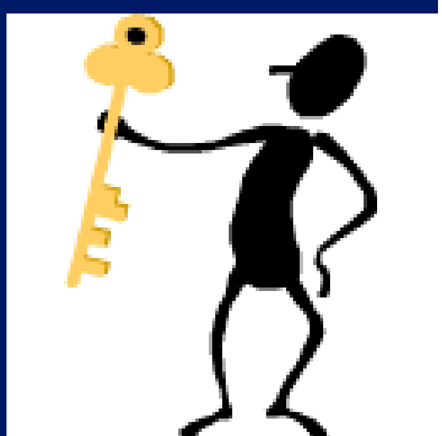
TOPIC # 6
THE ELECTROMAGNETIC SPECTRUM

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



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

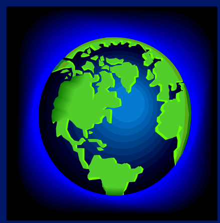
GOAL for this week:

To understand the differences between:

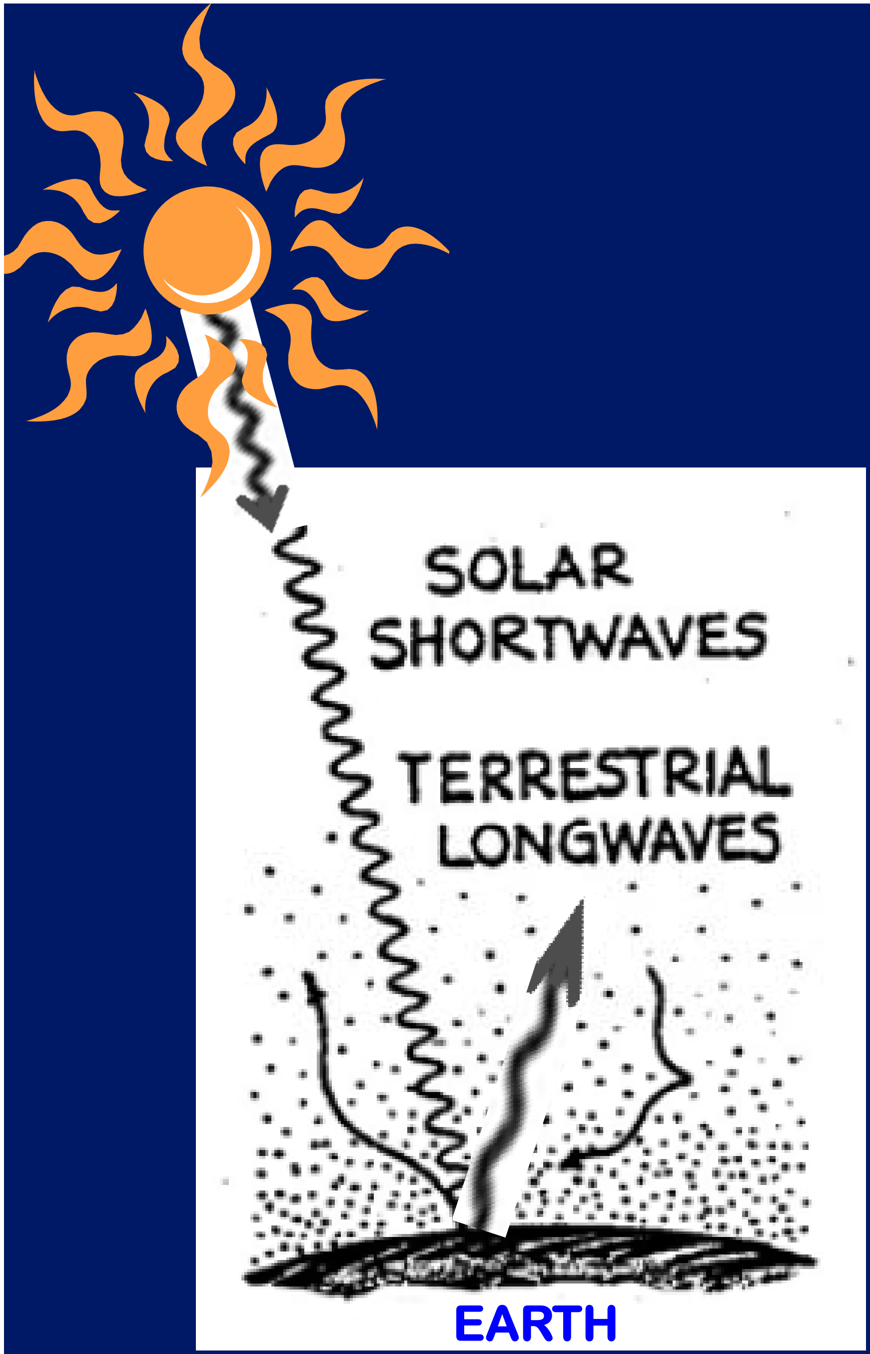
Shortwave
SOLAR radiation

&

Longwave
TERRESTRIAL radiation



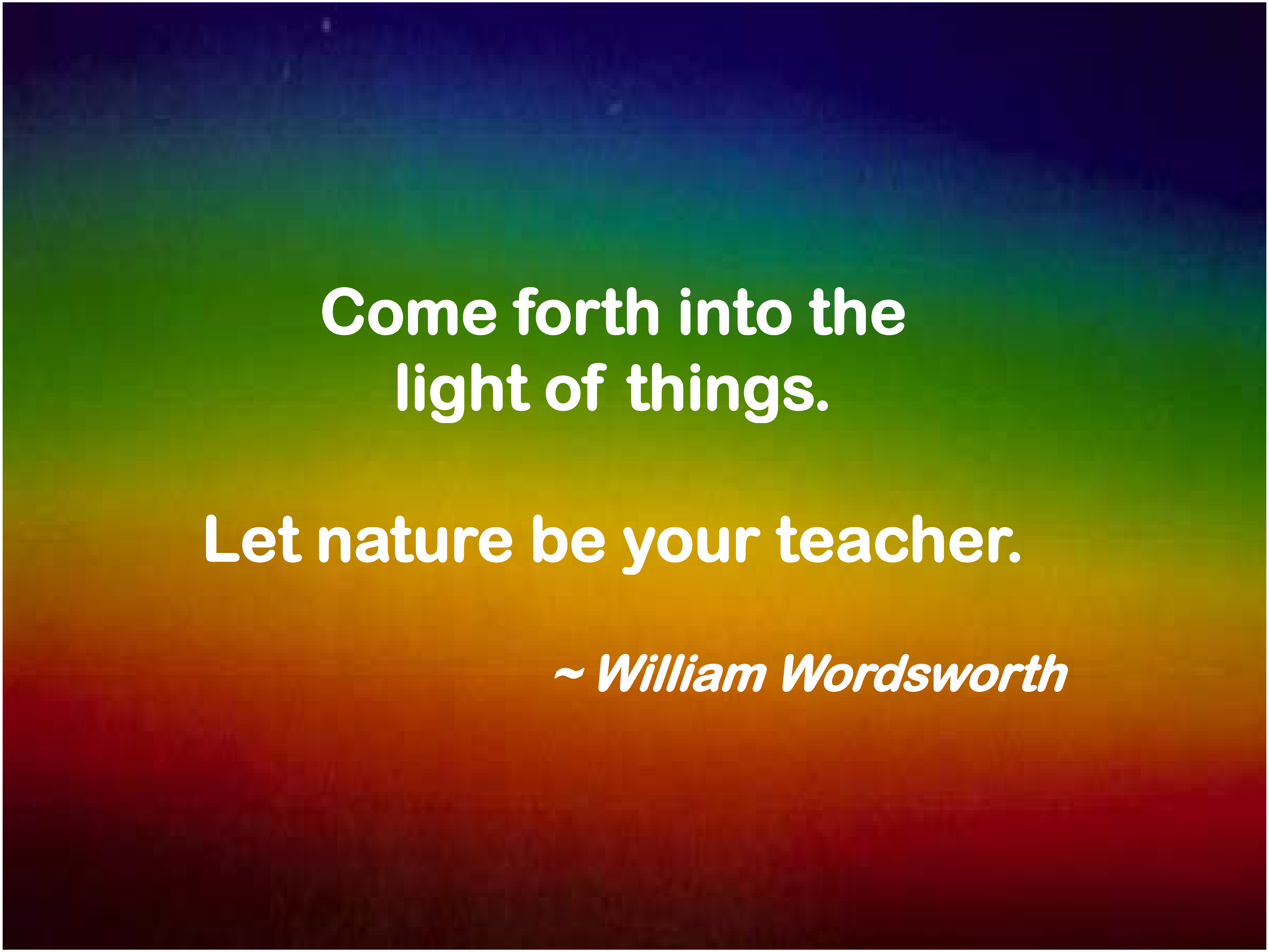
and how these differences drive GLOBAL CHANGE processes



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

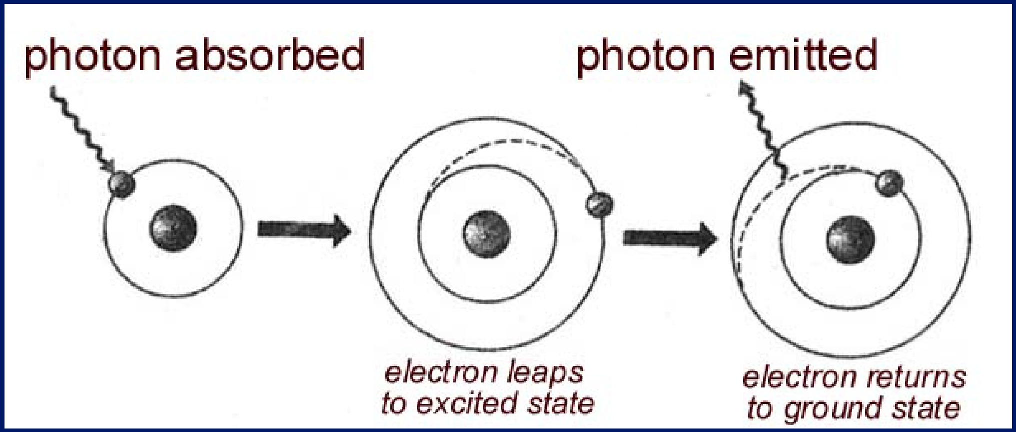
Energy emitted from the sun (i.e, electromagnetic radiation) exhibits both a wave-like (electromagnetic wave) and particle-like (photon) nature.

Review

RECAP: Electromagnetic Radiation

(under <u>certain higher-energy conditions</u>, e.g. **LIGHT**)

Electromagnetic radiation
exhibits a particle-like nature which we call **PHOTONS**.

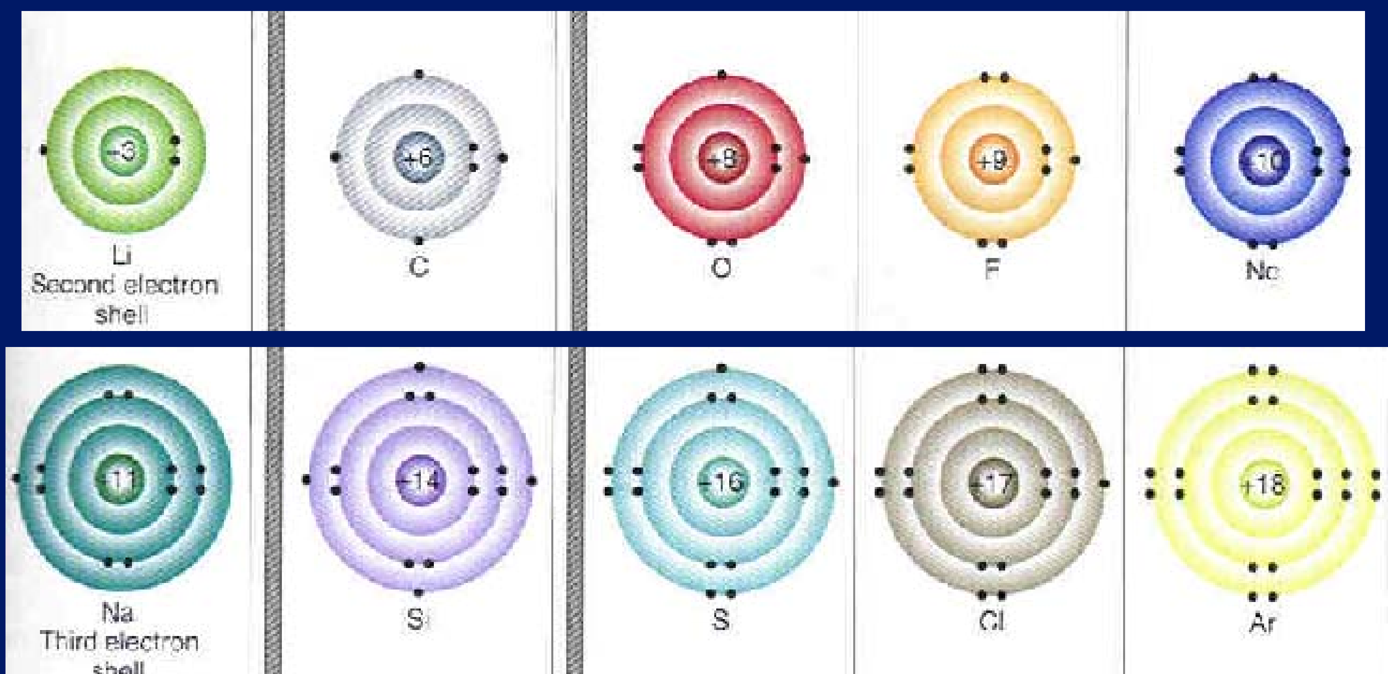


Photons are energy packets having a well-defined wavelength and frequency

Review

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

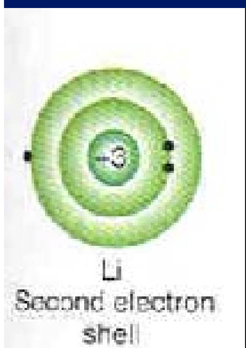
Each atom type (e.g. H, He, etc.) will ABSORB energy over a PARTICULAR set of ELECTROMAGNETIC FREQUENCIES & WAVELENGTHS.

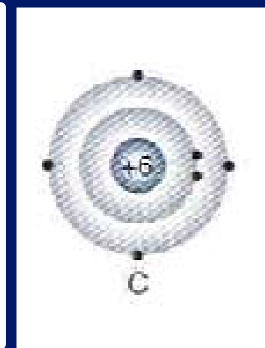


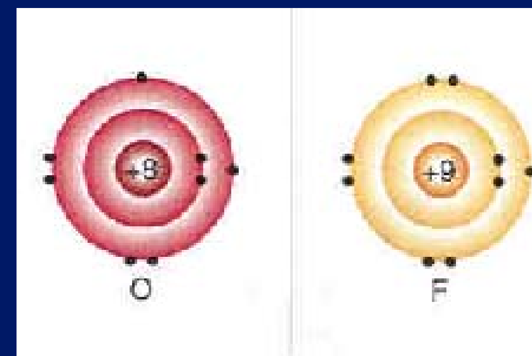
REVIEW:
The Periodic Table is organized by # of shells (rows)
&
# of electrons in the <u>outer</u> shell (columns)

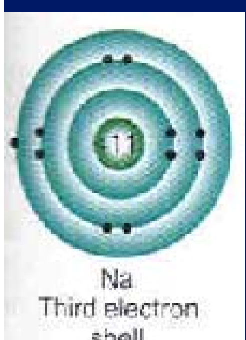
Review

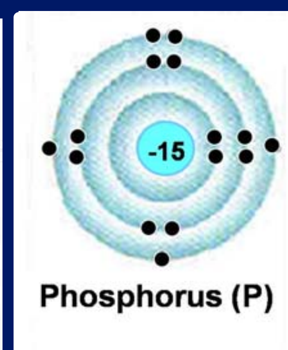
What energy shell & electron properties will the elements in these boxes: ? have?

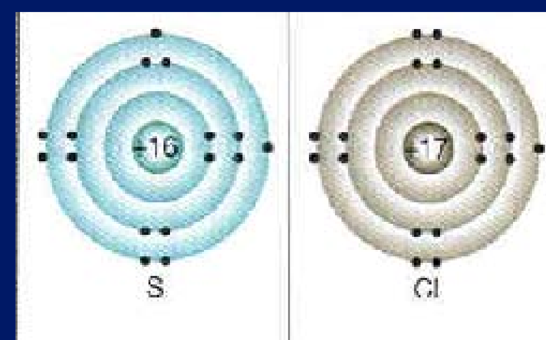




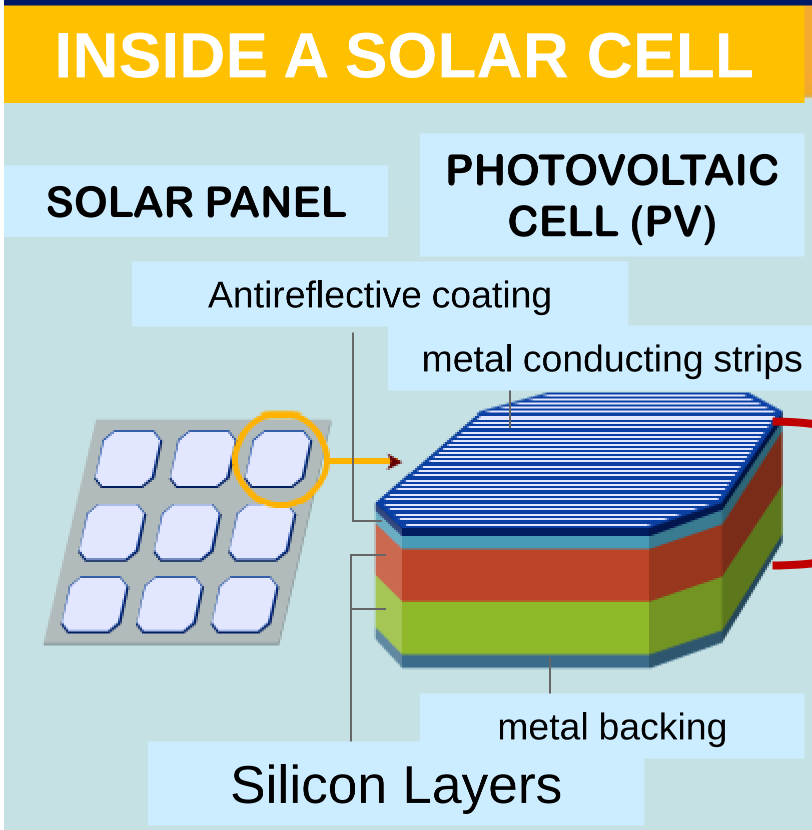


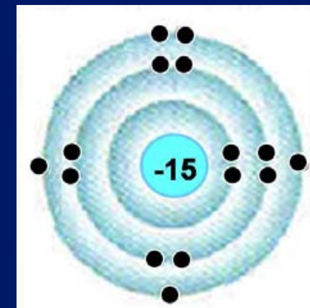




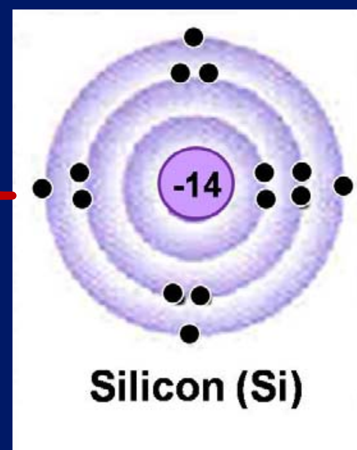


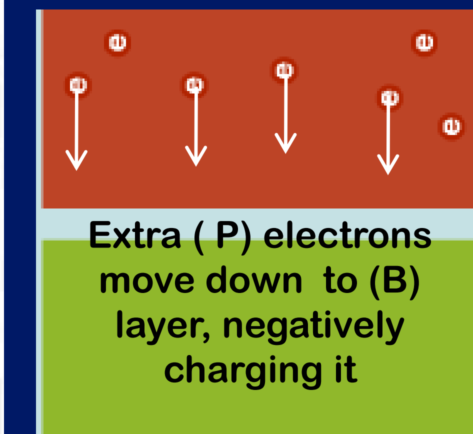
Review



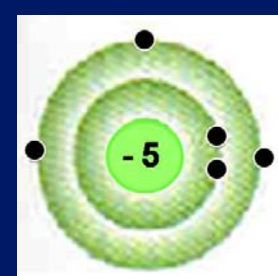


Phosphorus (P)
“doped” Si layer





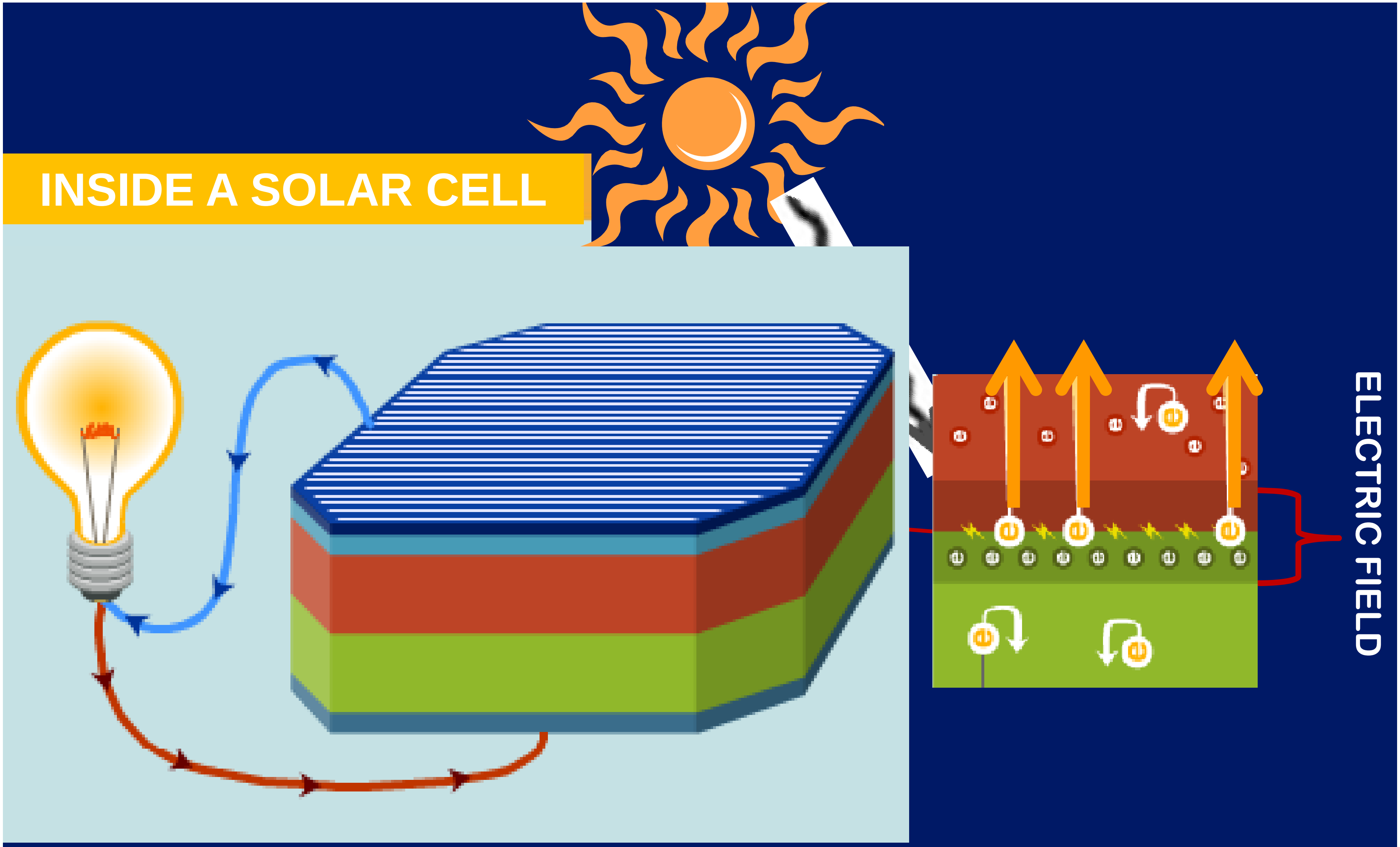
Boron (B)
“doped” Si layer



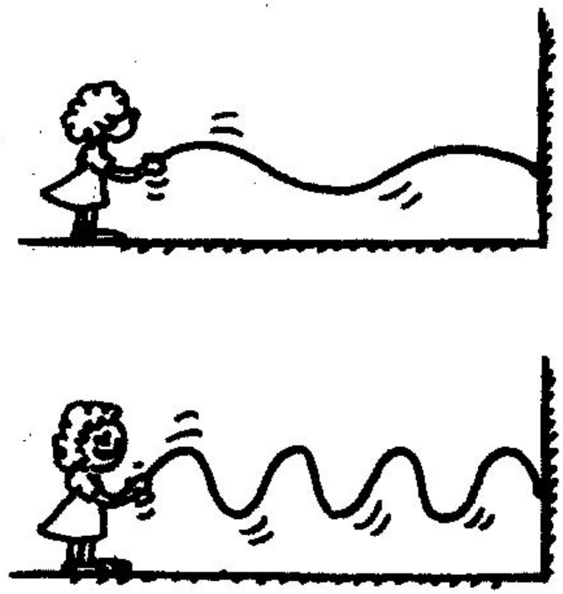
Read this explanation at:

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

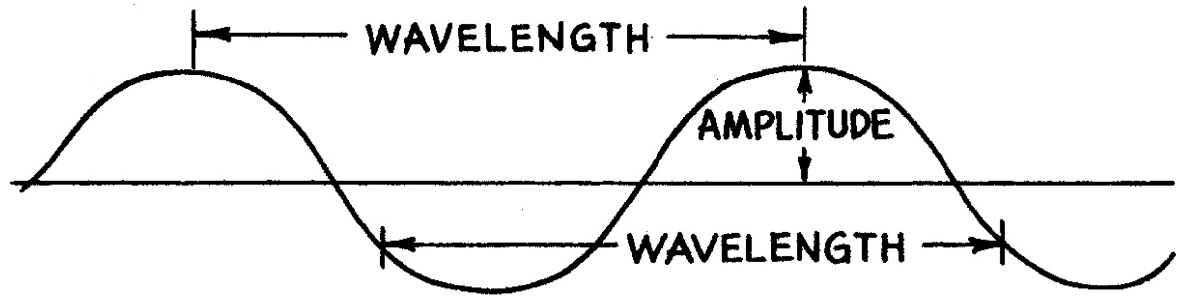
INSIDE A SOLAR CELL

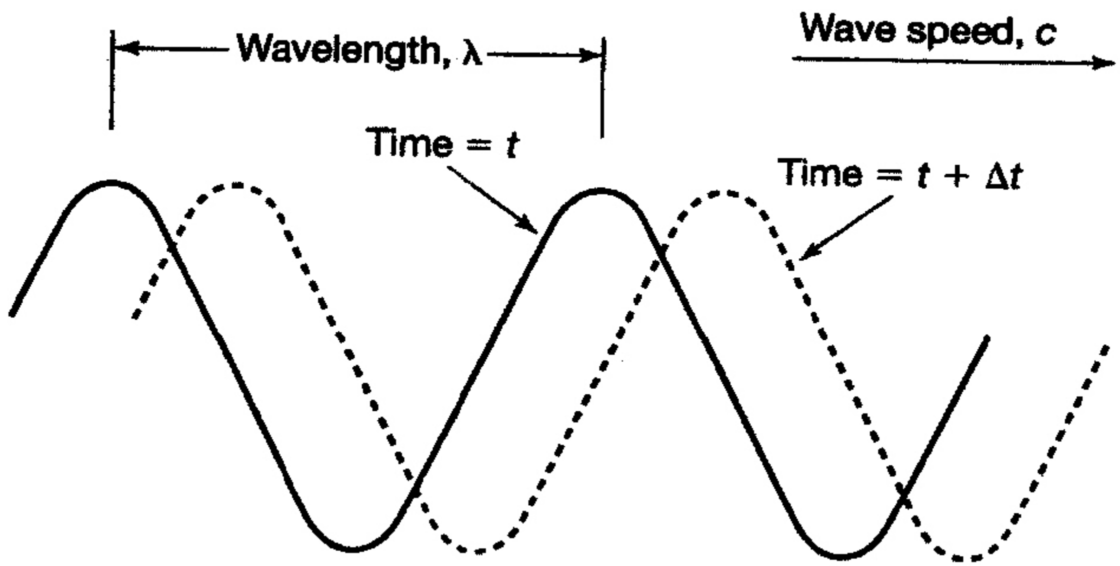


Wavelengths



NOTE: Shorter wave-lengths 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:

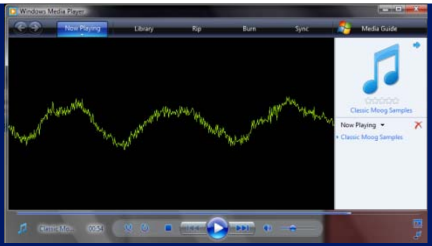
Wavelength = distance between adjacent crests (or troughs) (symbol = **lambda** λ)

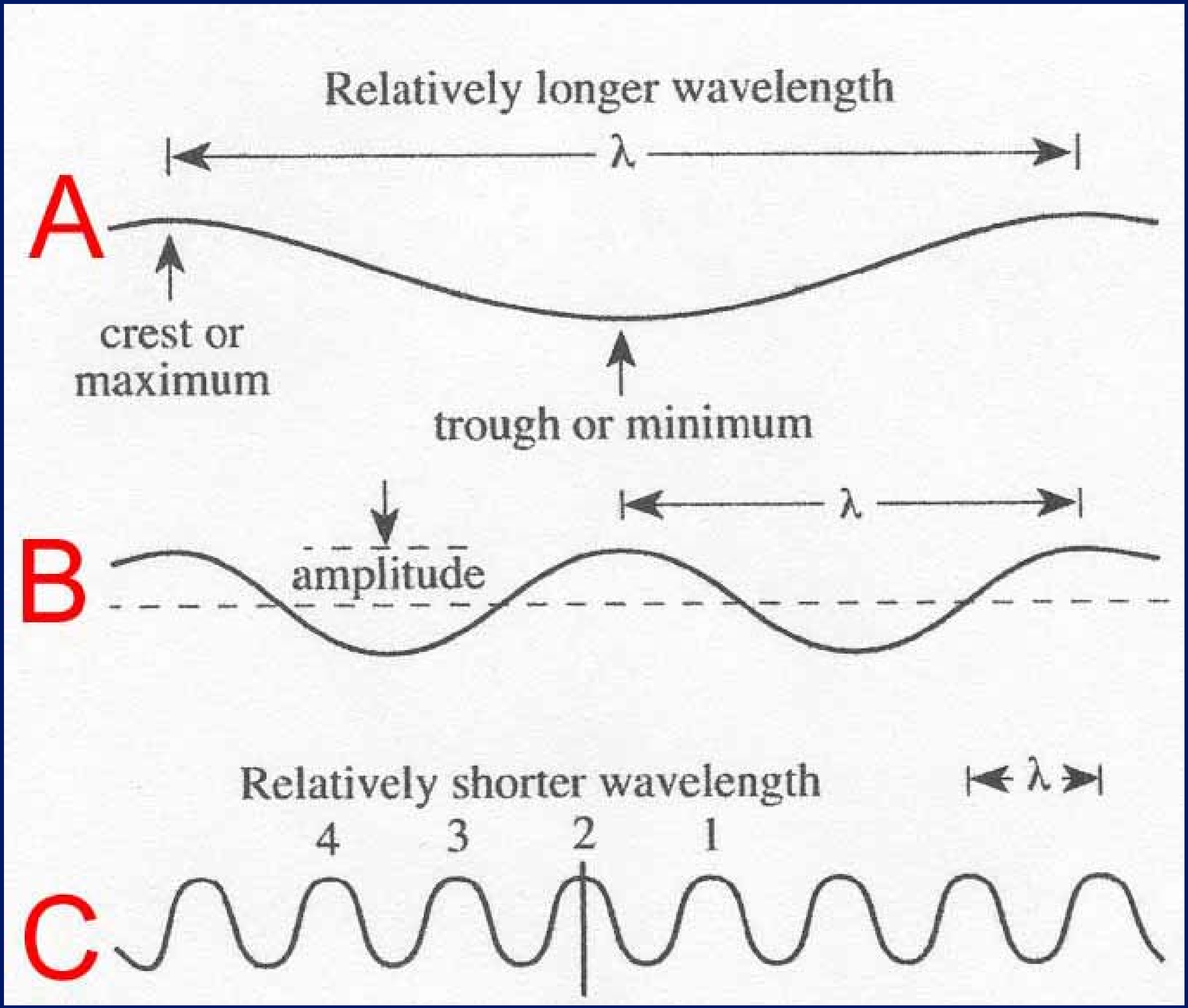
Frequency = how fast the crests move up and down (symbol = **nu** ν in SGC)

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

Take notes

Another view:

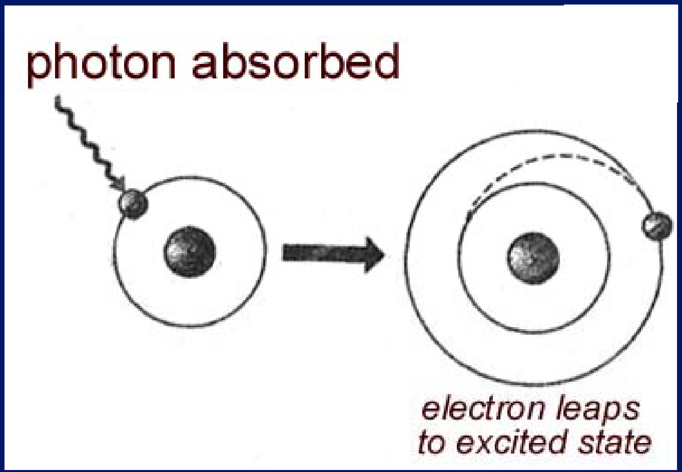




QUANTUM MECHANICS & the LINK to ABSORPTION OF ELECTROMAGNETIC ENERGY AT THE SUBATOMIC SCALE

- 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:

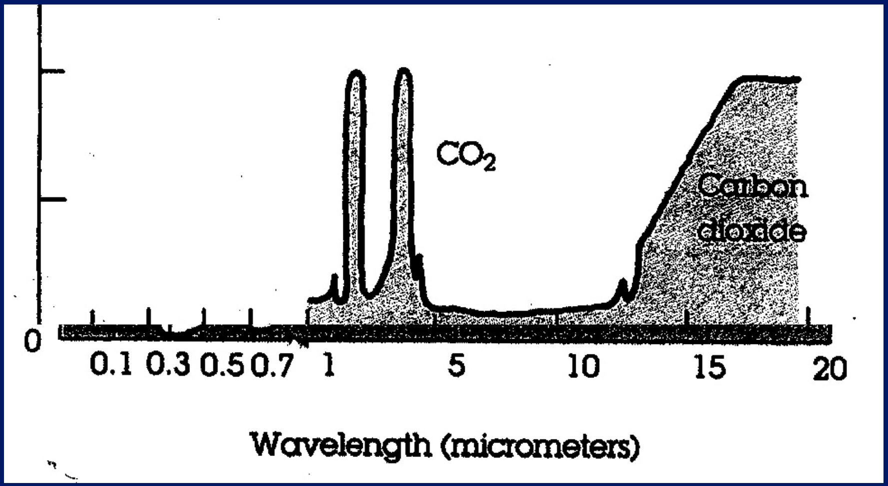


Review

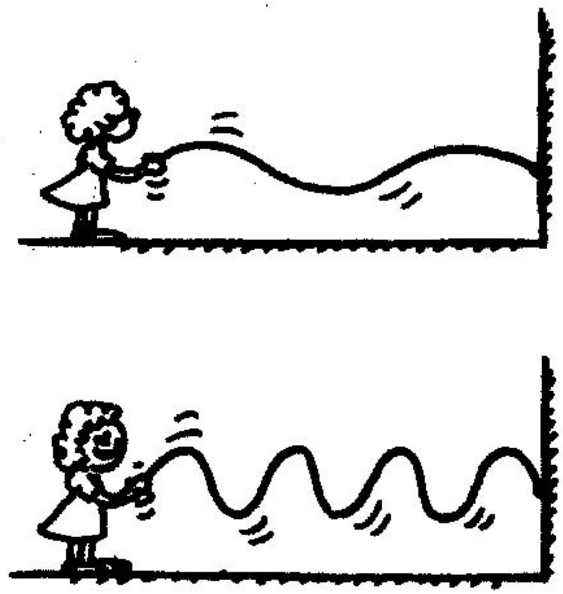
The pattern of wavelengths absorbed by a particular atom or combination of atoms ,
(e.g. a gas molecule of CO_2 or H_2O)

is called its ABSORPTION SPECTRUM or its ABSORPTION CURVE (more on this later . .)

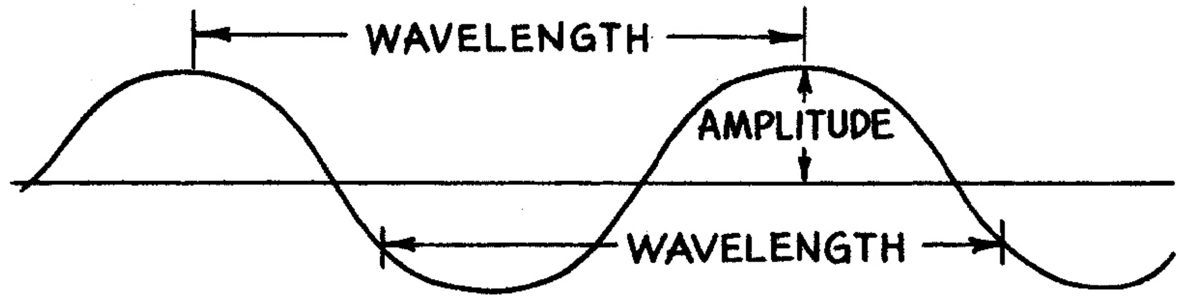
Example of an "absorption spectrum" curve or graph →

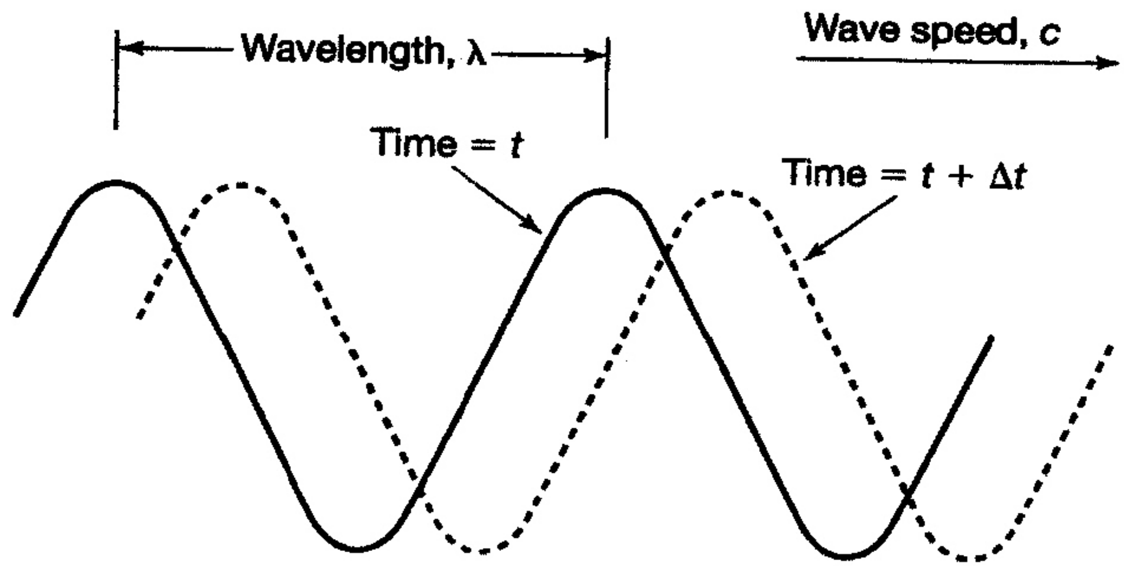


Back to Wavelengths

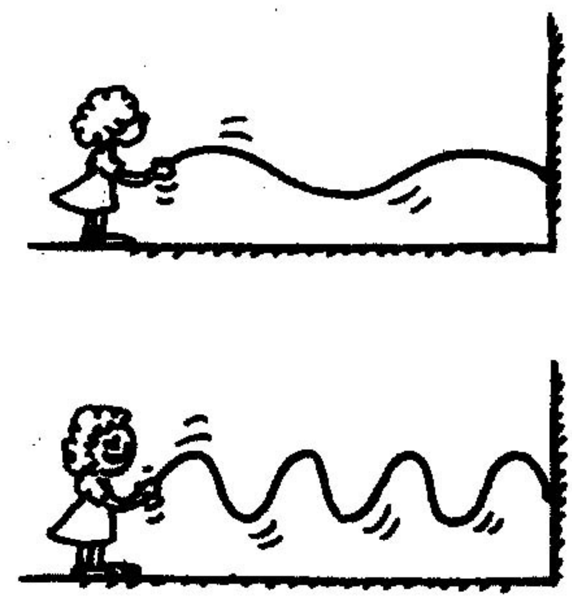


NOTE: Shorter wavelengths are produced when the rope is shaken more vigorously.





Wavelength & Frequency



NOTE: Shorter wave-lengths 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 (ν) , WAVELENGTH (λ), & ENERGY (E) OF PHOTONS:

KEY CONCEPT #1:

The Energy (E) of photons is *directly* proportional to their frequency ν.

$\propto$ = "is proportional to"

$$E \propto \nu$$

Take notes

THE RELATIONSHIP BETWEEN FREQUENCY (ν) , WAVELENGTH (λ), & ENERGY (E) OF PHOTONS:

KEY CONCEPT #2:

The Energy (E) of photons is inversely proportional to their wavelength (λ)

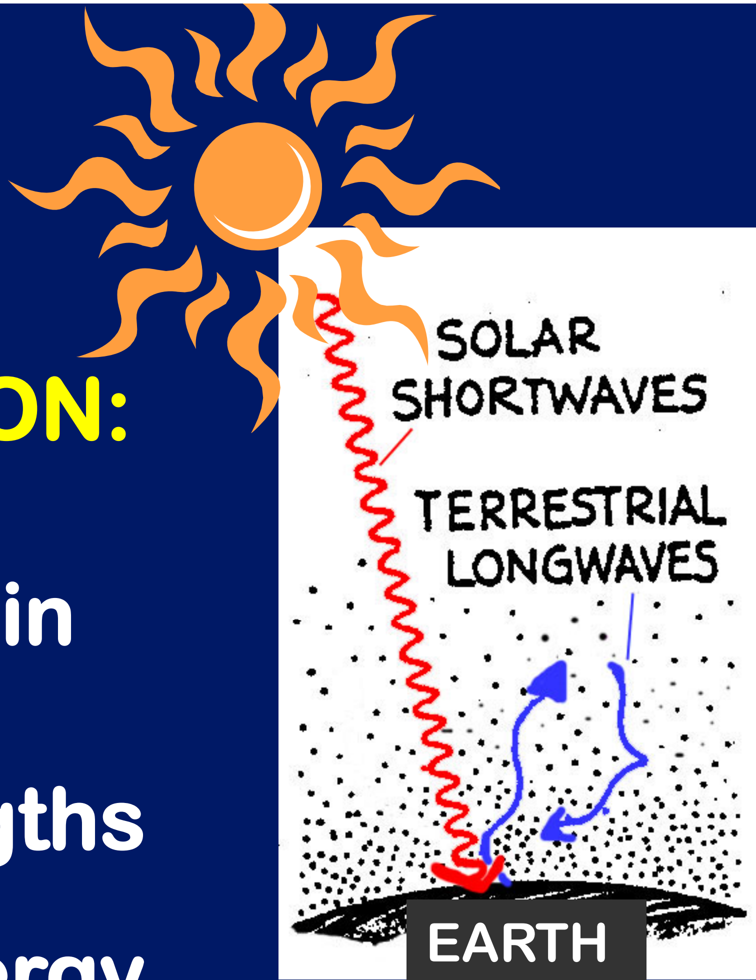
$$E \propto c / \lambda$$

Take notes

SOLAR RADIATION:

greatest intensity in SHORT wavelengths

(high energy & frequency)

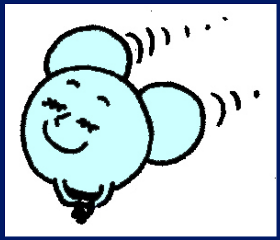


EARTH RADIATION:

entirely in LONG wavelengths

(low energy & frequency)

Quantum Behavior of
MOLECULES



Quantum leap of electrons:

takes place between discrete energy levels (shells) when photons are absorbed or emitted . . .

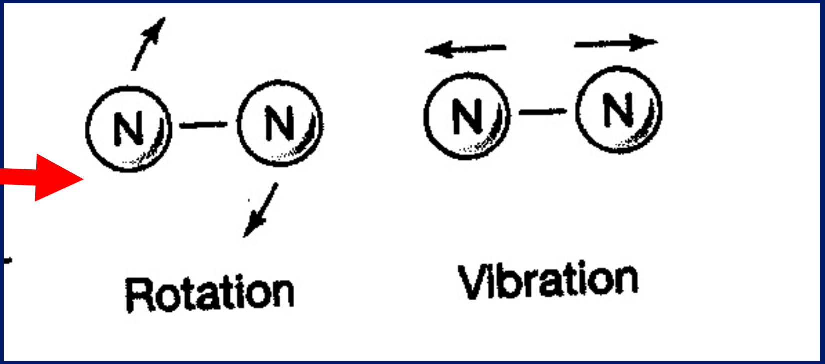
but

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

Review p 29

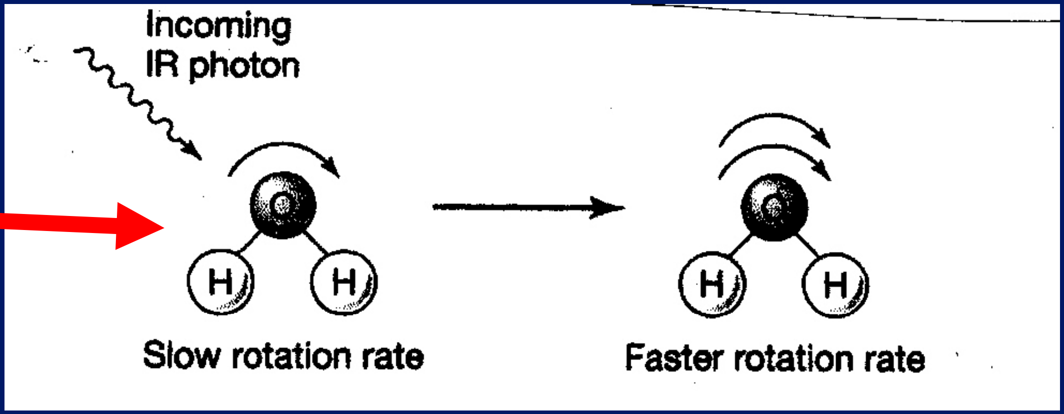
NITROGEN GAS MOLECULE

N_2



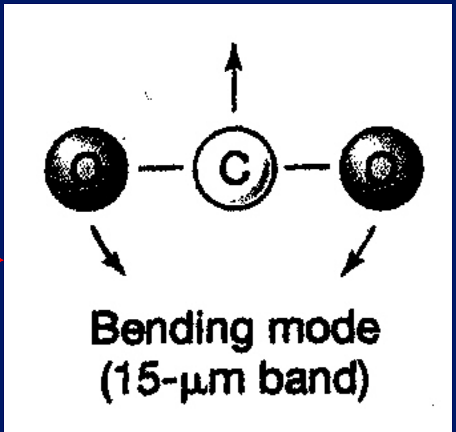
WATER VAPOR MOLECULE

H_20



CARBON DIOXIDE GAS MOLECULE

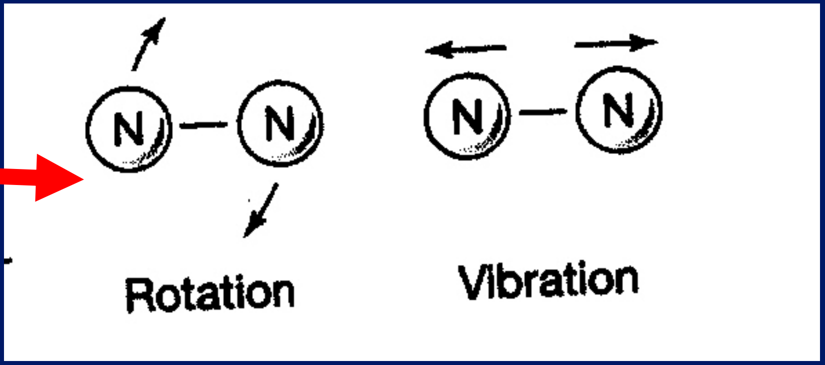
CO_2

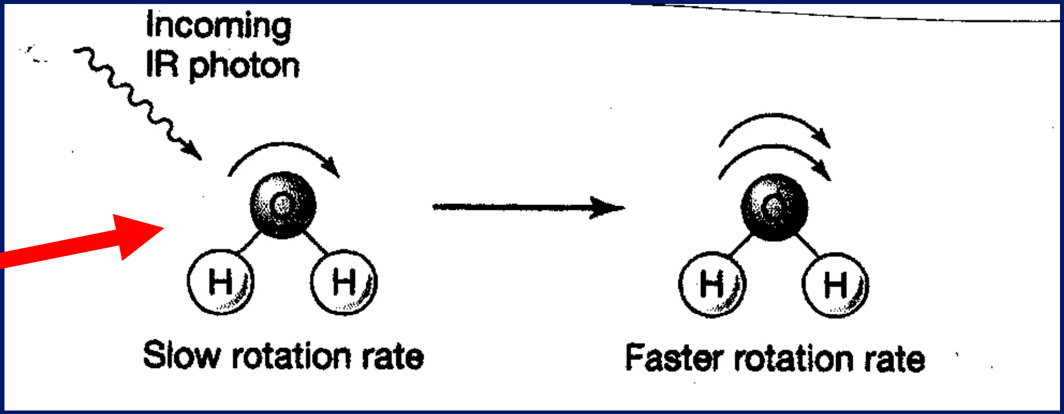


FYI: These figures are on pp 47-48 in SGC-I

NOT a GREENHOUSE GAS

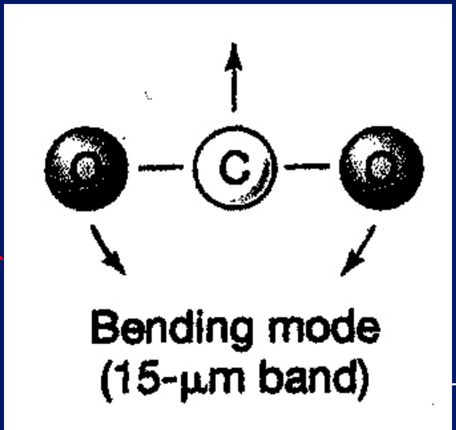
N_2



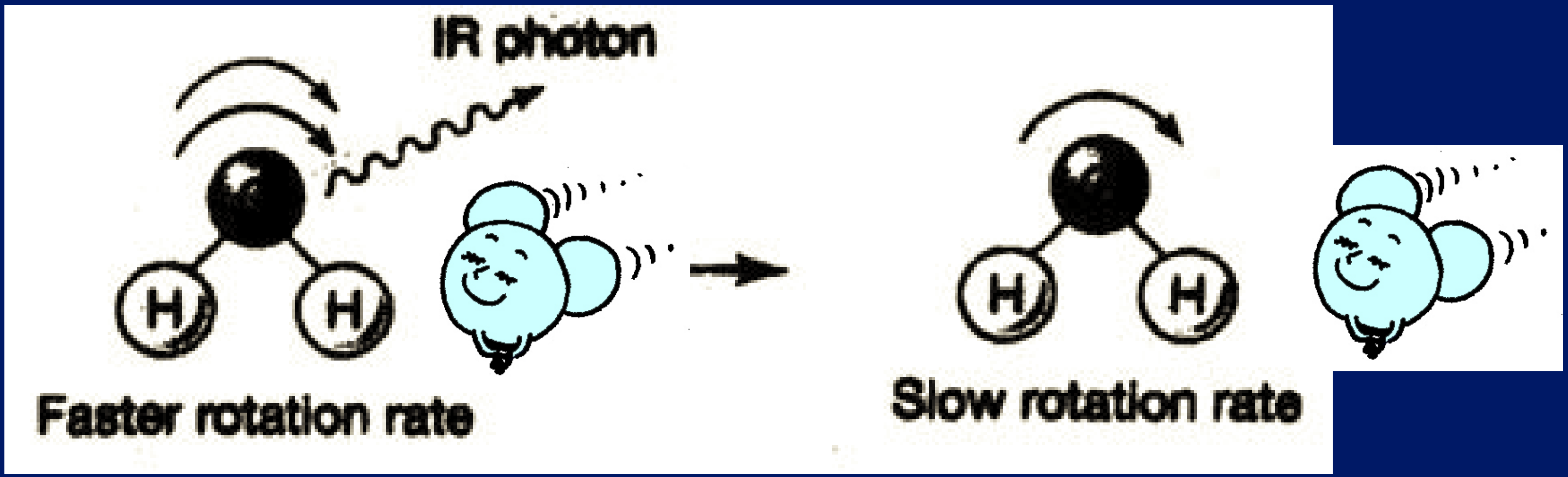


GREENHOUSE GASES

H_20 & CO_2



Take notes



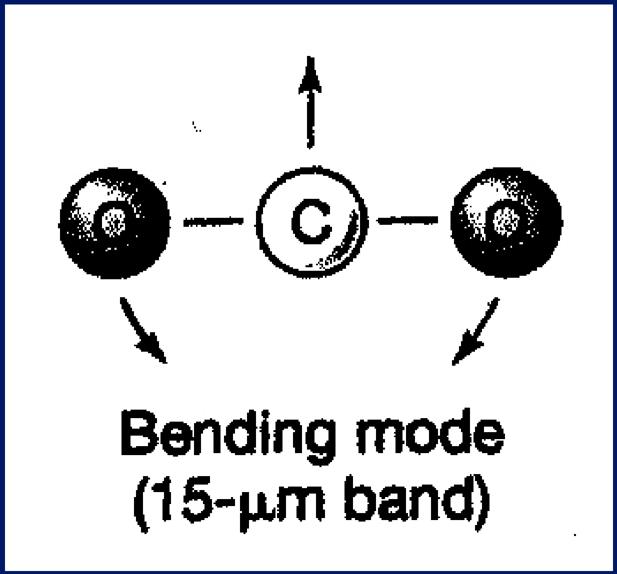
When the H_2O molecule emits a photon, its **rotation rate** decreases;

When it absorbs a photon, the rotation rate increases.

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

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



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 absorb and emit 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

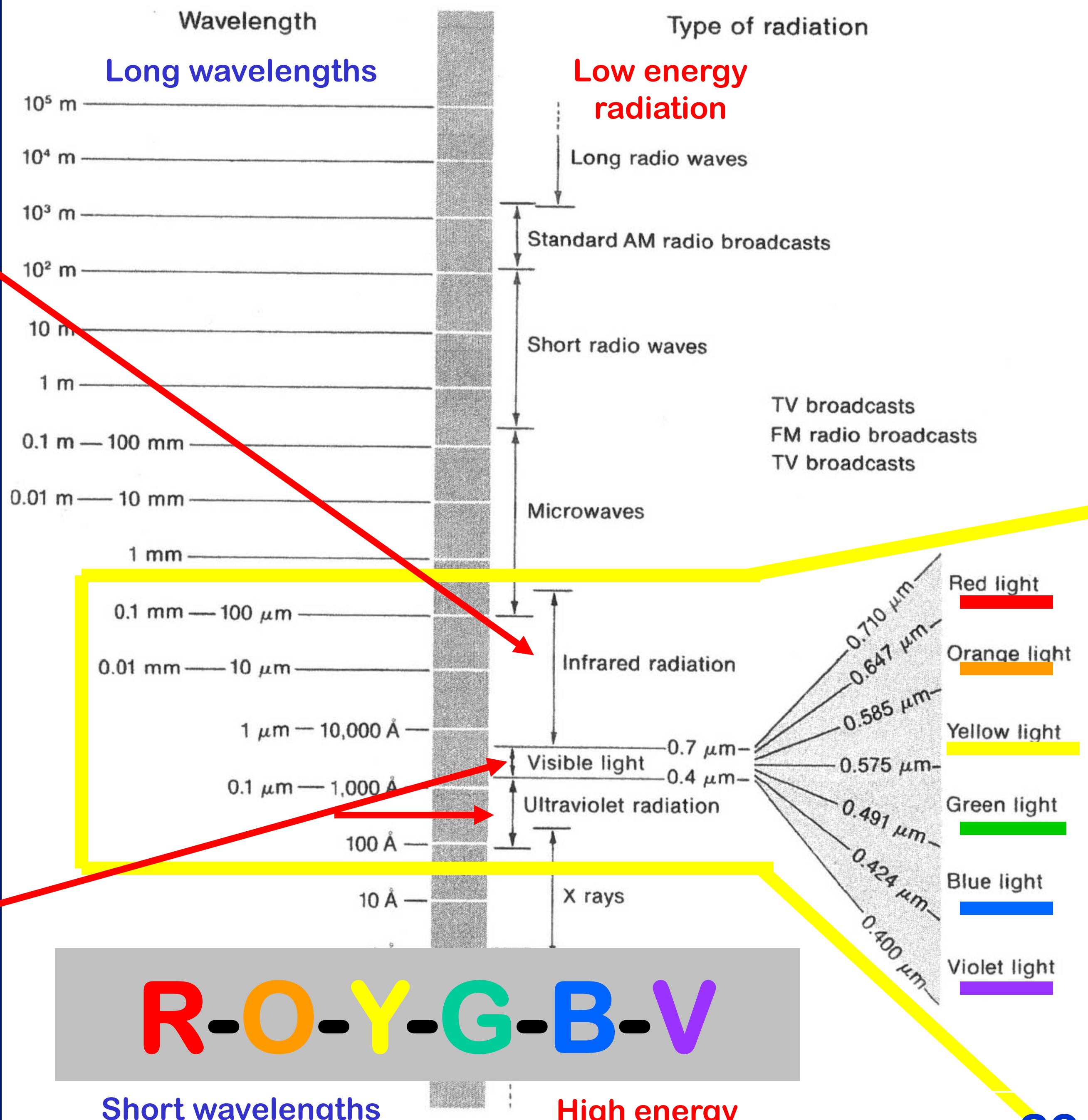
- **but which wavelengths??**
  - **and what difference does it make???**

review

Longwaves (LW)

The Electro-magnetic Spectrum

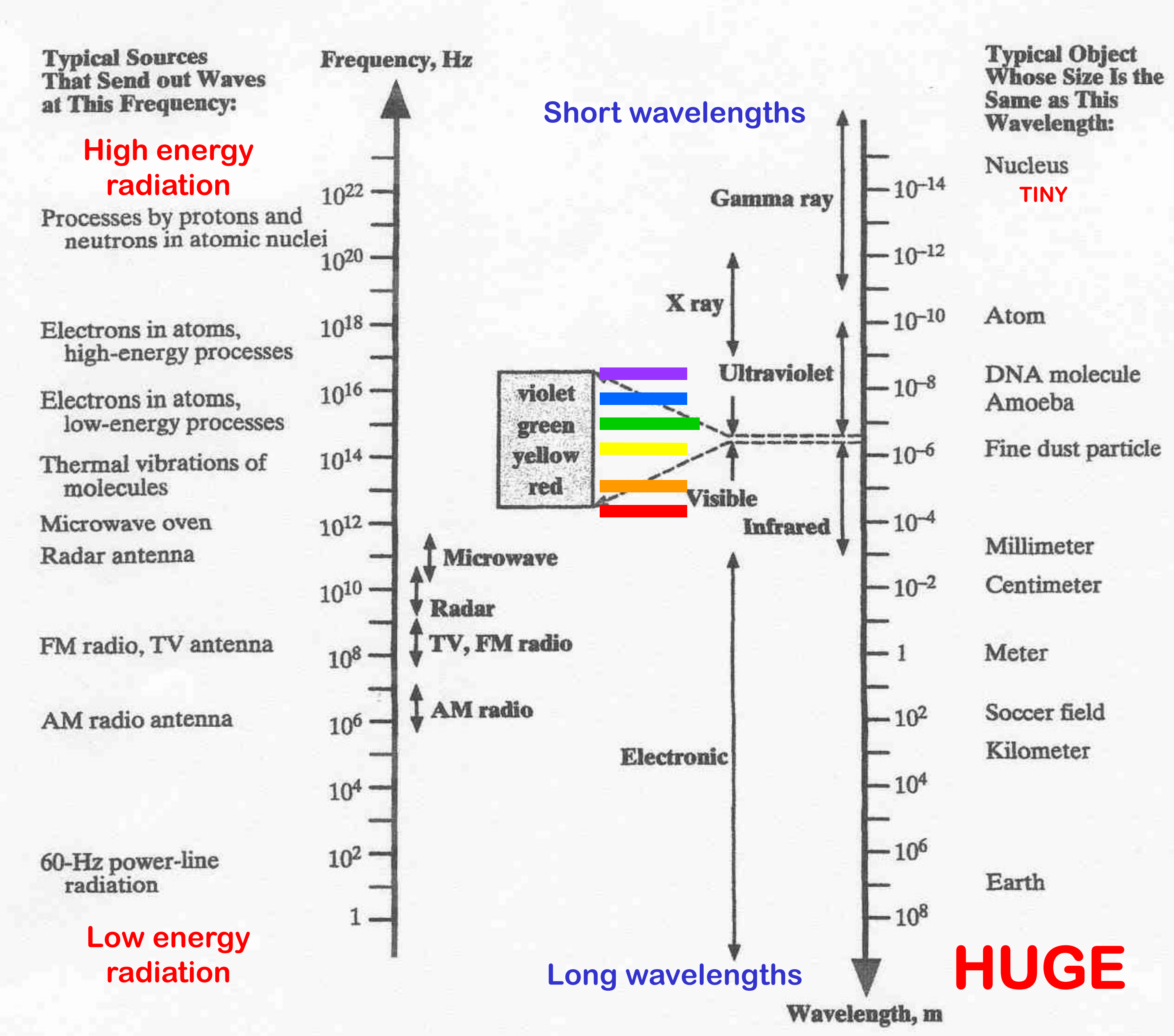
Shortwaves (SW)



The electromagnetic spectrum.

p 29

Another (flipped) view:



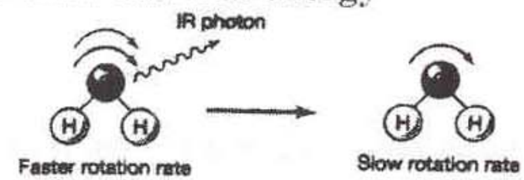
Neat website:

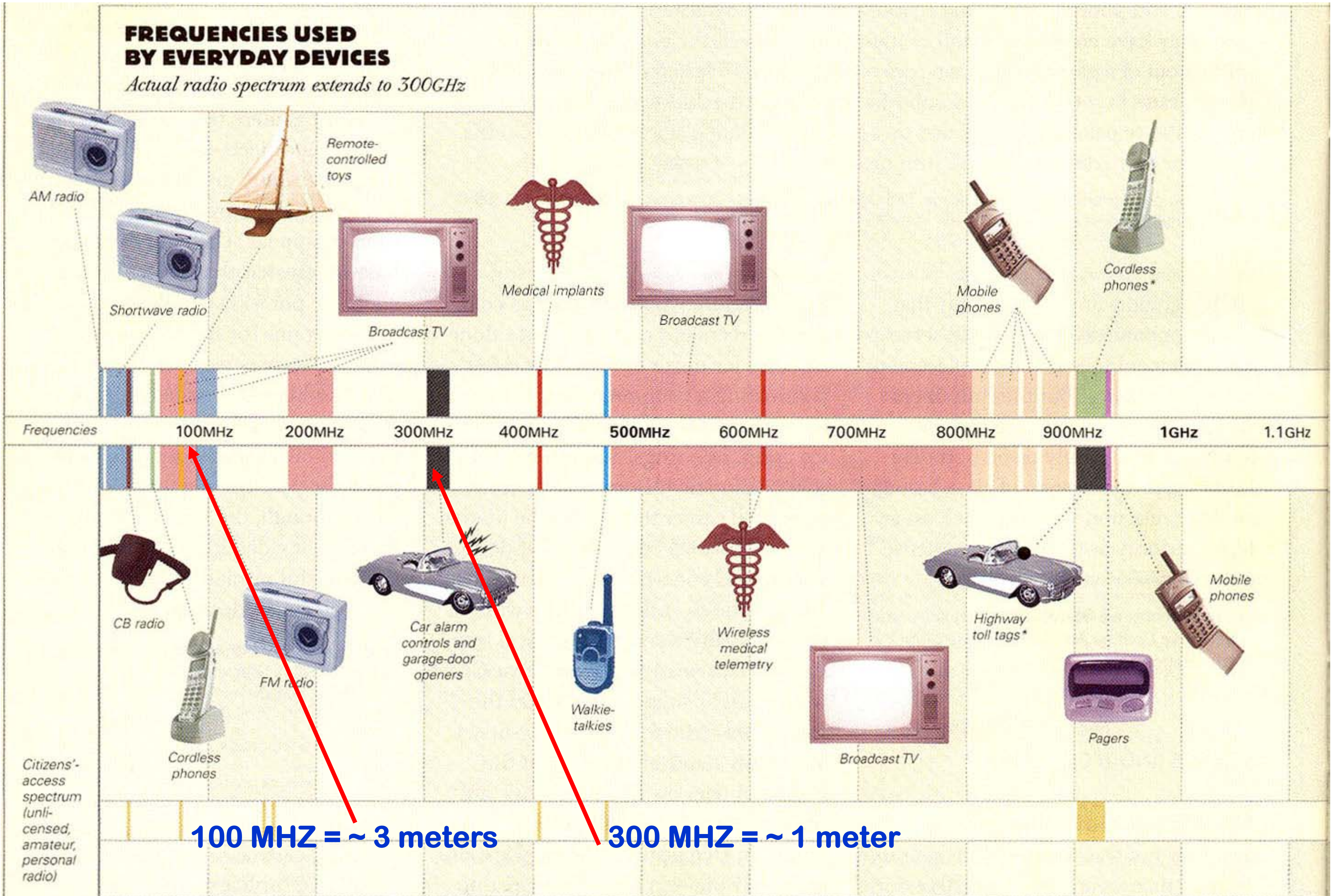
ELECTROMAGNETIC SPECTRUM JAVA APPLET:

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.

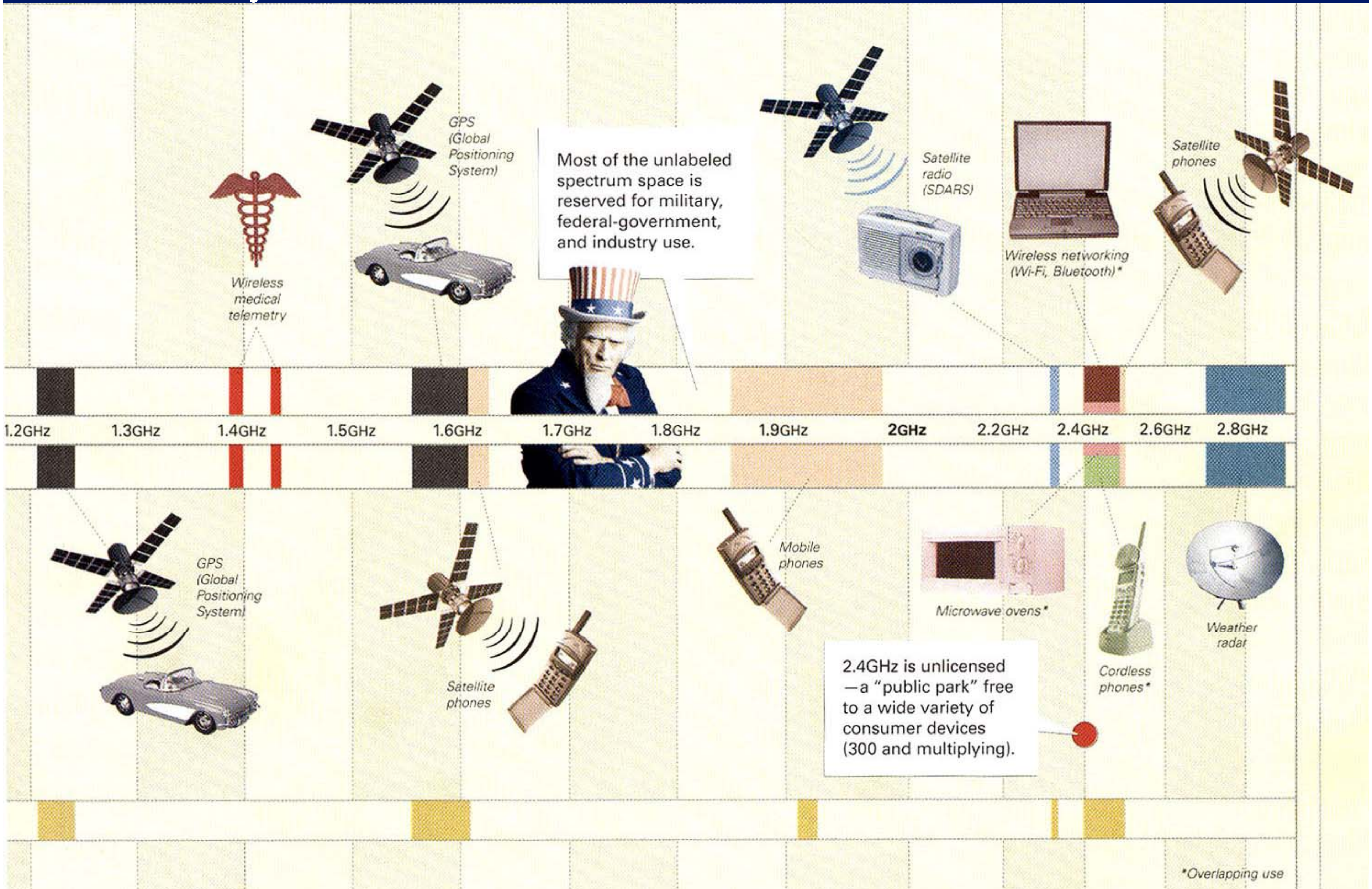
The international unit for frequency is the hertz (Hz).

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 . . .



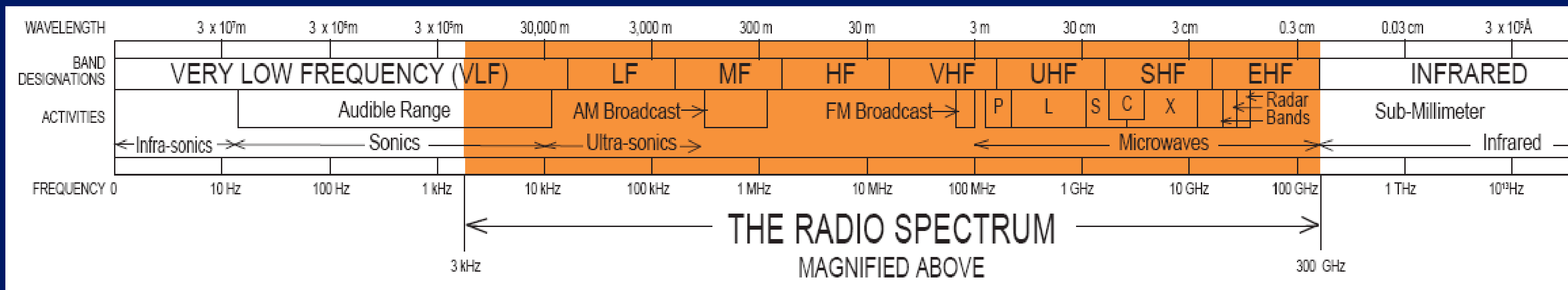
Multicasting:

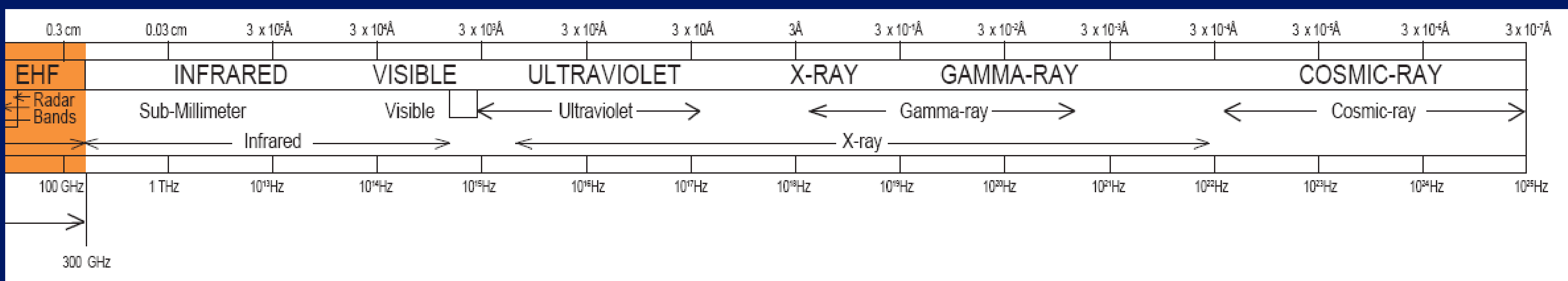
This is the process of transmitting more then one program over the air at the same time on the same channel.

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 10^7m
3 x 10^6m
3 x 10^5m
30,000 m
3,000 m
300 m
30 m
3 m
30 cm
3 cm
0.3 cm
0.03 cm
3 x 10^5Å
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
10^13Hz
THE RADIO SPECTRUM
MAGNIFIED ABOVE
3 kHz
300 GHz


0.3 cm
0.03 cm
3 x 10^5Å
3 x 10^4Å
3 x 10^3Å
3 x 10^2Å
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
10^13Hz
10^14Hz
10^15Hz
10^16Hz
10^17Hz
10^18Hz
10^19Hz
10^20Hz
10^21Hz
10^22Hz
10^23Hz
10^24Hz
10^25Hz
300 GHz

Who "owns" the spectrum?

RADIO SERVICES COLOR LEGEND

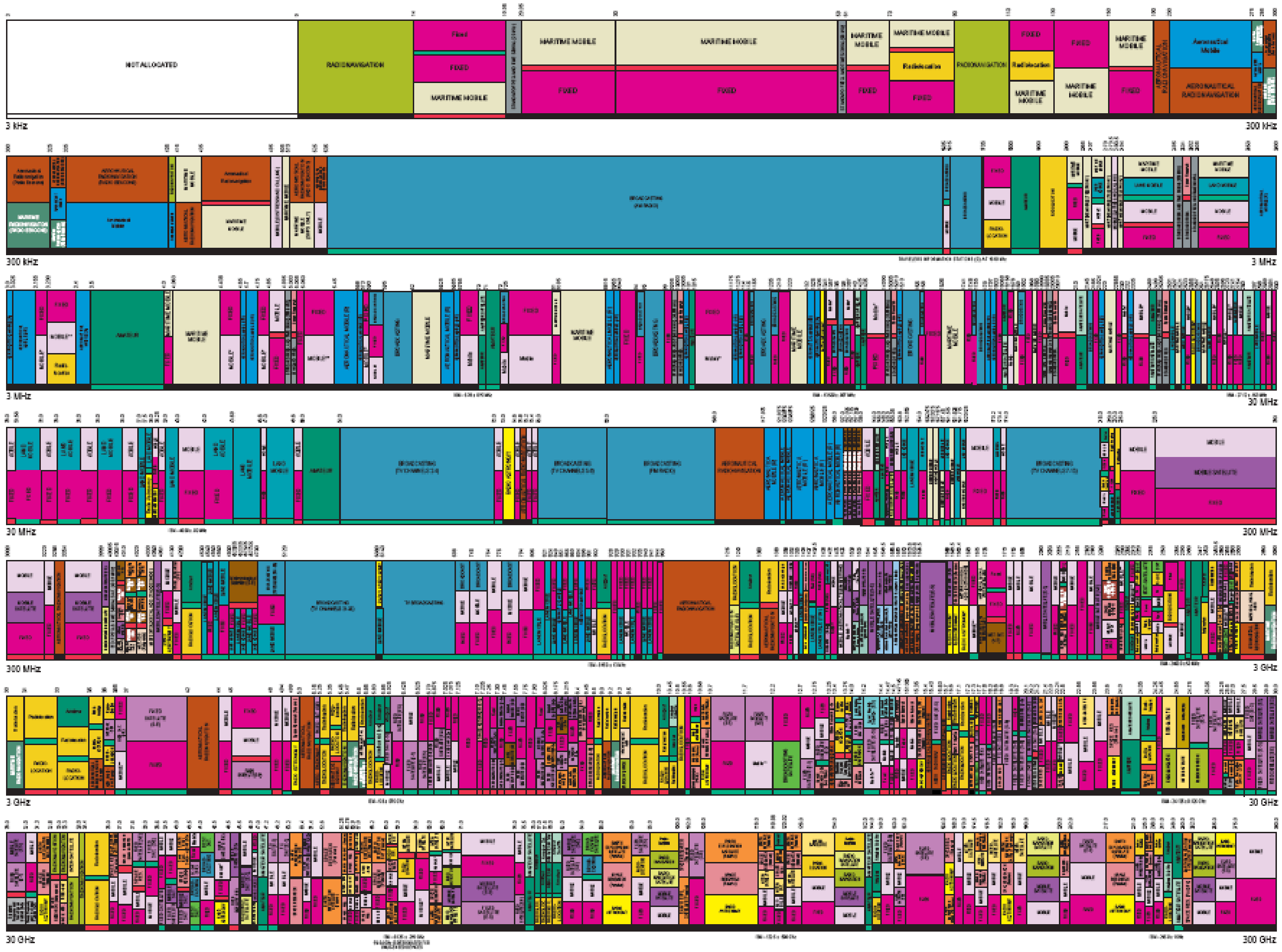
- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

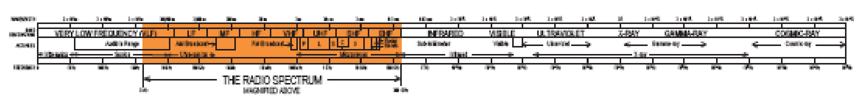
ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- NON-GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM





RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

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