TOPIC # 5
ELECTROMAGNETIC ENERGY

PART 1 of the KEY to unlocking the topics of: OZONE DEPLETION, The GREENHOUSE EFFECT, & GLOBAL WARMING !

Class Notes: re-cap of Quantum Behavior of Electrons in Atoms pp 24, 29-30 then onto pp 31- 33

GOAL for this week:

To understand the differences between:

Shortwave
SOLAR radiation
&
Longwave
TERRESTRIAL radiation

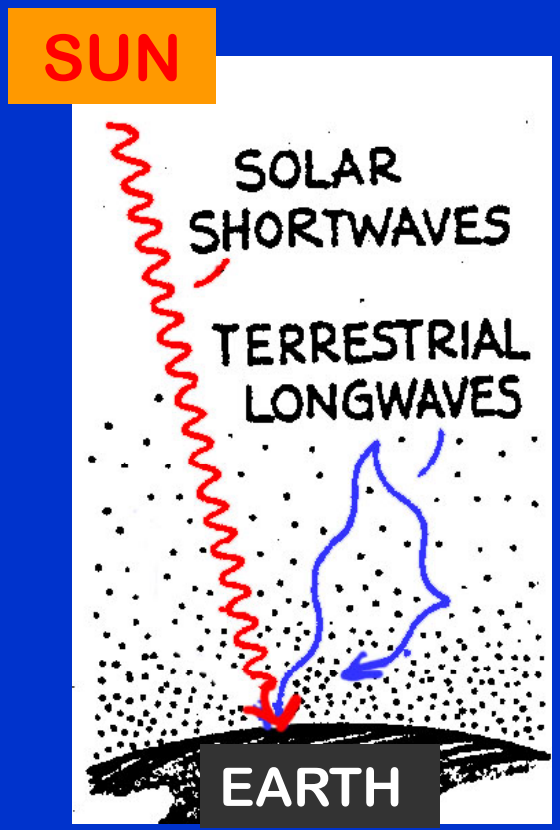
and how these differences drive GLOBAL CHANGE processes

One “cartoon” view
of Solar vs Terrestrial radiation:

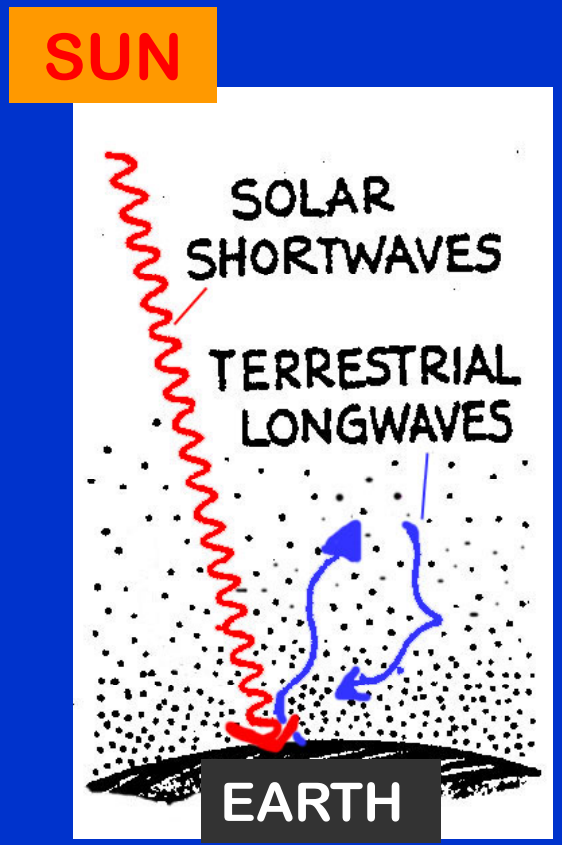
NOT TO
SCALE!!!

Both Sun & Earth are radiating energy . . . .

Other "cartoon" views of Solar vs Terrestrial radiation:



A



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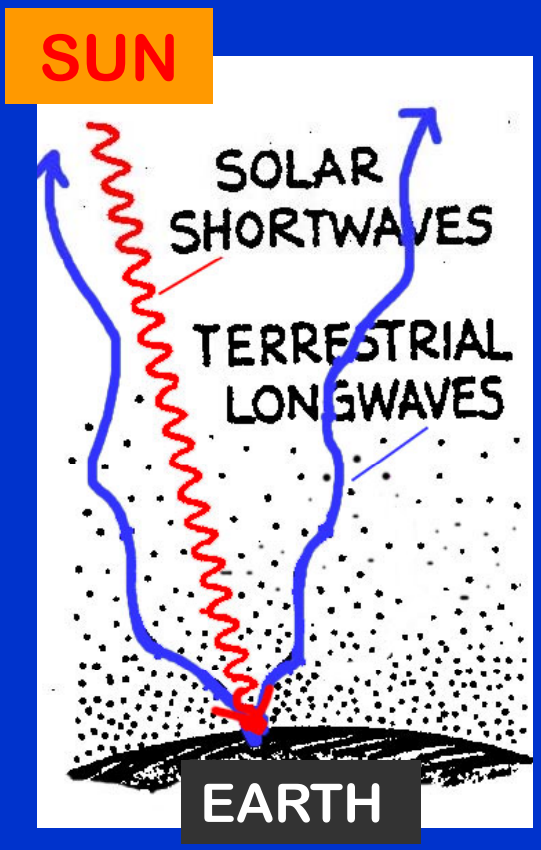
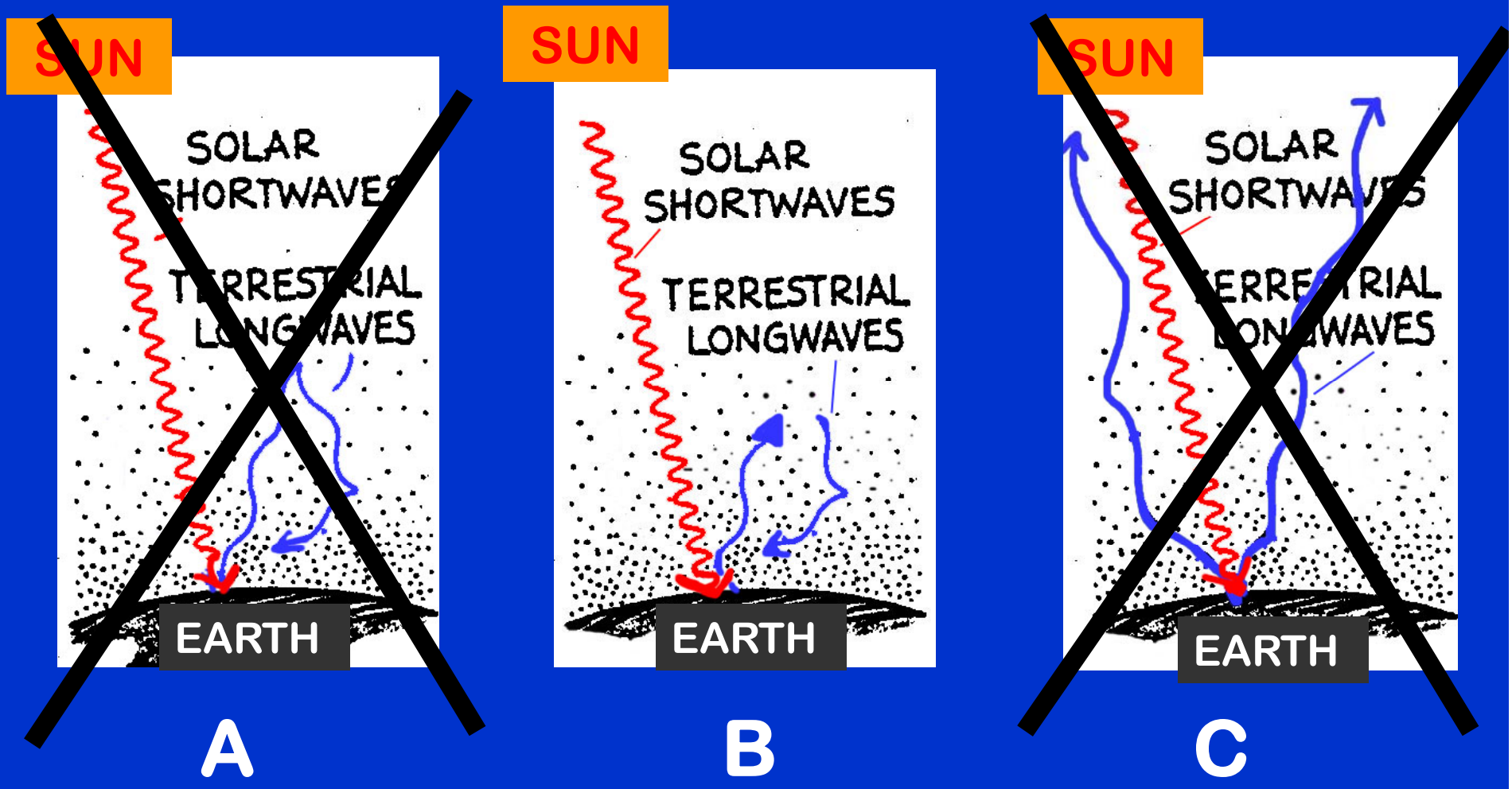


C

Which one is the <u>more accurate</u> depiction of the Greenhouse Effect??

Other “cartoon” views of Solar vs Terrestrial radiation:



B is better than the others!!!!!

but WHY?

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 - turn back to p 24

QUICK REVIEW: The quantum model of the atom states that:

electrons can exist only in discrete allowed places within shells (or energy levels) and not in between.

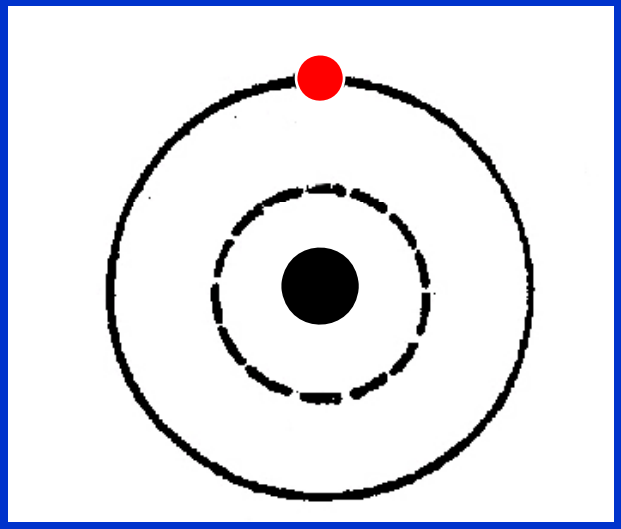
The electrons move -- NOT according to Newtonian laws of motion

-- but according to **quantum mechanics**.

Review (see p 24)

An electron moves between shells or energy levels by "quantum leaps,"

i.e., it disappears from one energy level and reappears in another without ever traversing any of the positions in between!



review

- Electrons can be promoted to higher energy levels or even knocked free from their atoms in a variety of ways . . .

One way is critical to global change processes:

it involves a packet of energy called **PHOTON**

review

Energy in the form of **PHOTONS** is absorbed or emitted as electrons change energy levels within the structure of an atom.

Photons, NOT protons!

review

Photon =

A particle-like unit of electromagnetic energy (light), emitted or absorbed by an atom when an electrically charged electron changes state.

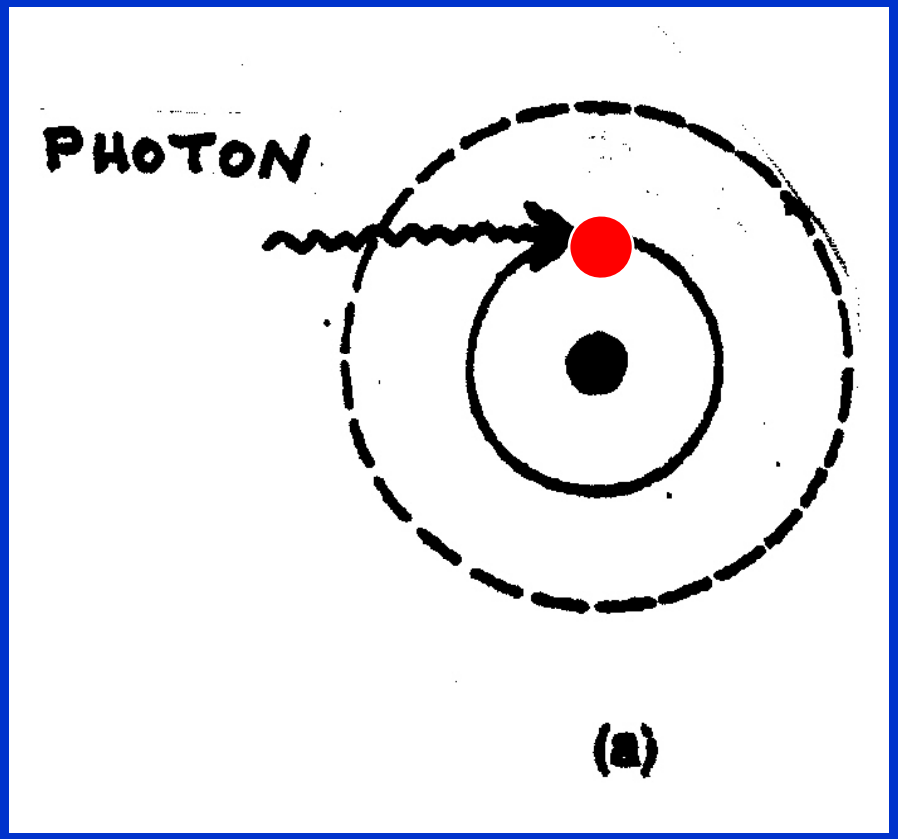
Link to today's topic:

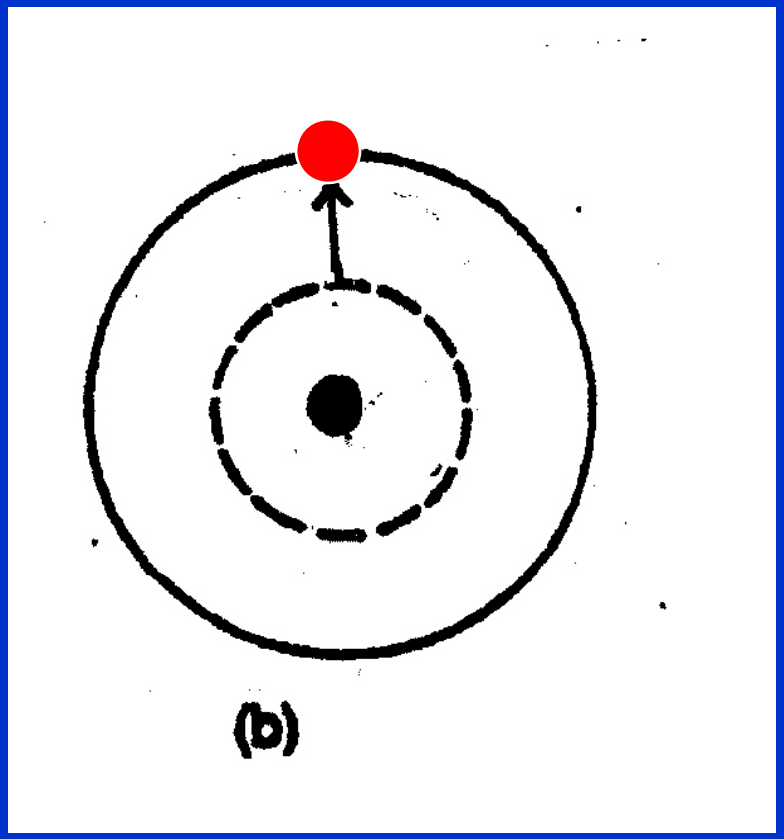
A photon is also the form of a single packet of electromagnetic radiation having a certain wavelength & frequency

review

WHAT HAPPENS WHEN ELECTRONS CHANGE LEVELS:

As an electron receives & absorbs electromagnetic energy (in form of a photon), it jumps from a Lower → Higher energy state (level).





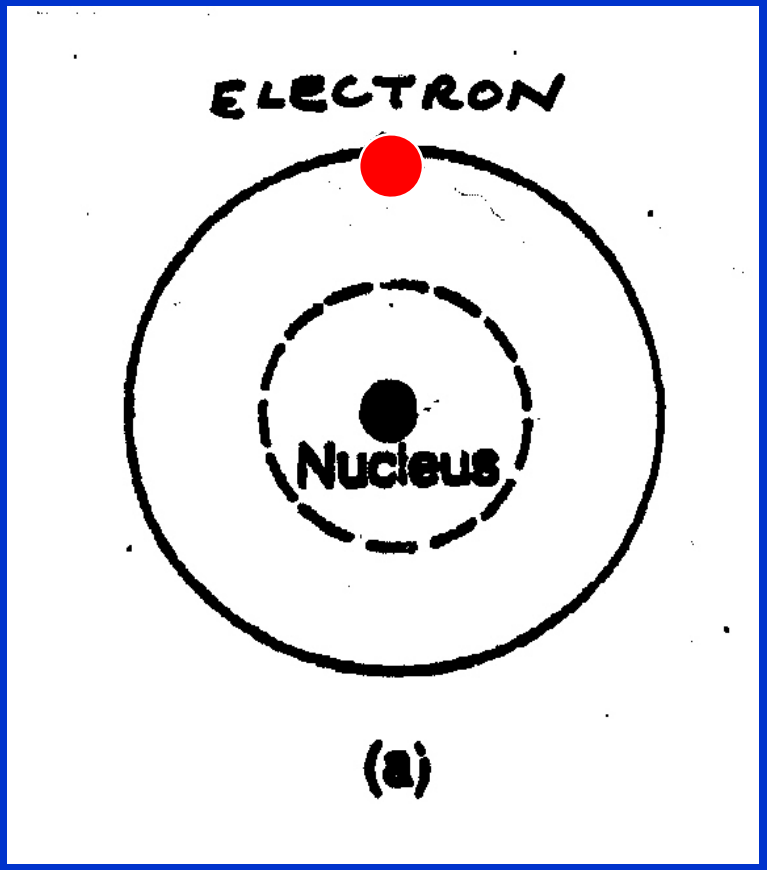
(a) An electron in its ground state, about to absorb a photon

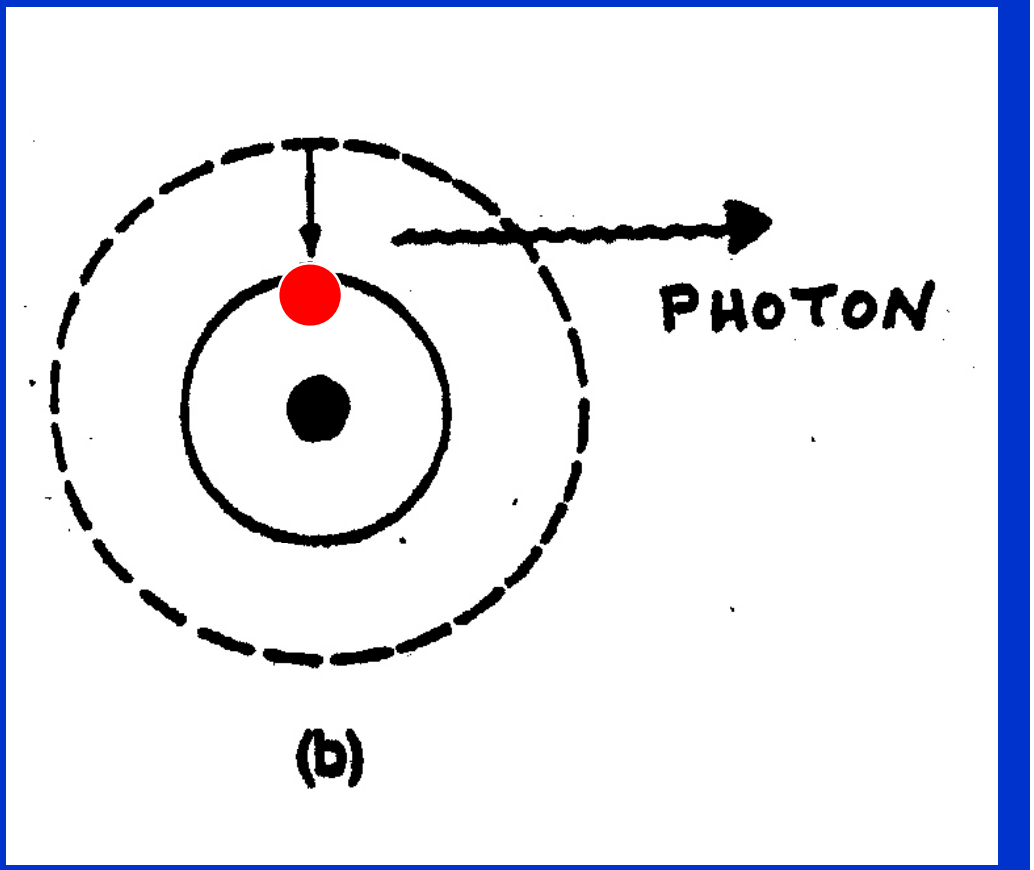
(b) The electron leaps to a higher level as the photon is absorbed

WHAT HAPPENS WHEN ELECTRONS CHANGE LEVELS:

As an electron emits or "gives off" electromagnetic energy (in form of a photon),

it jumps from a Higher → Lower energy state (level)





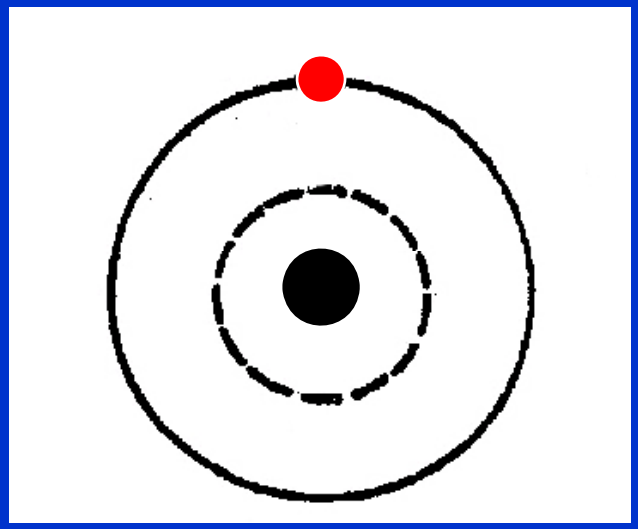
(a) An electron in an excited state.

(b) When the electron drops to a lower level, a photon is emitted.

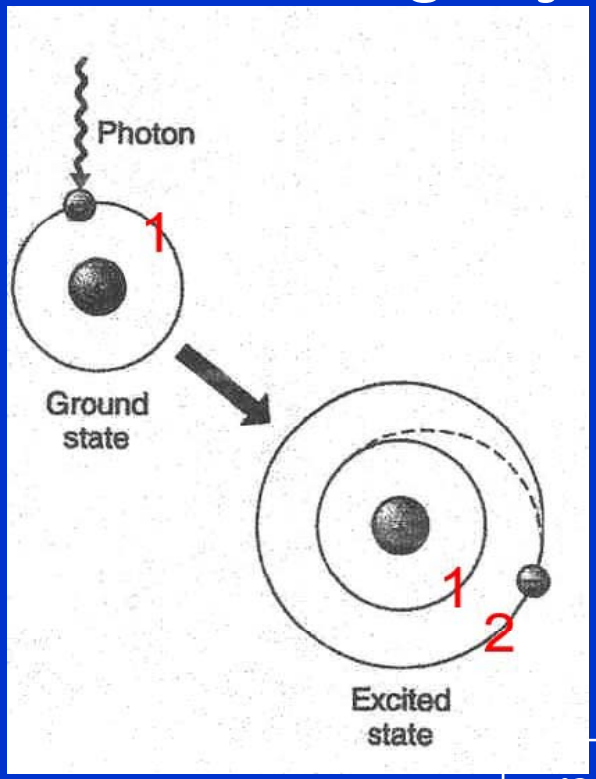
SUMMARY:

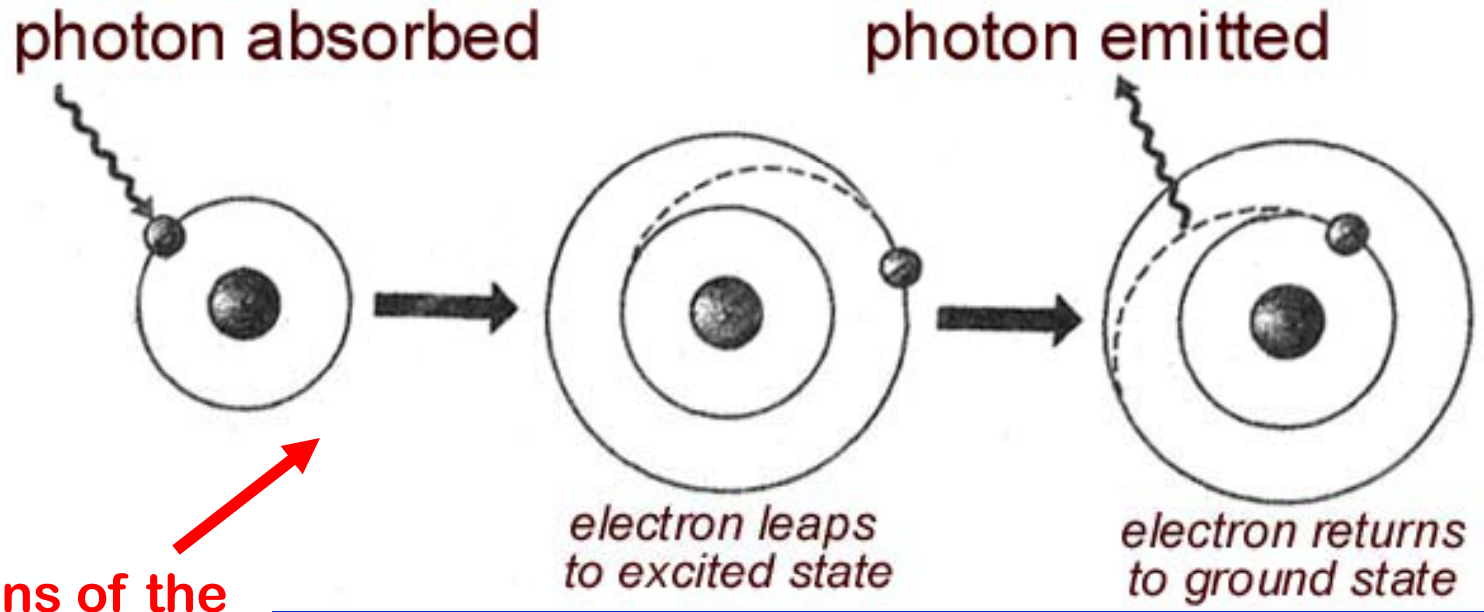
An electron moves between shells or energy levels by "quantum leaps,"

i.e., it disappears from one energy level and reappears in another without ever traversing any of the positions in between!

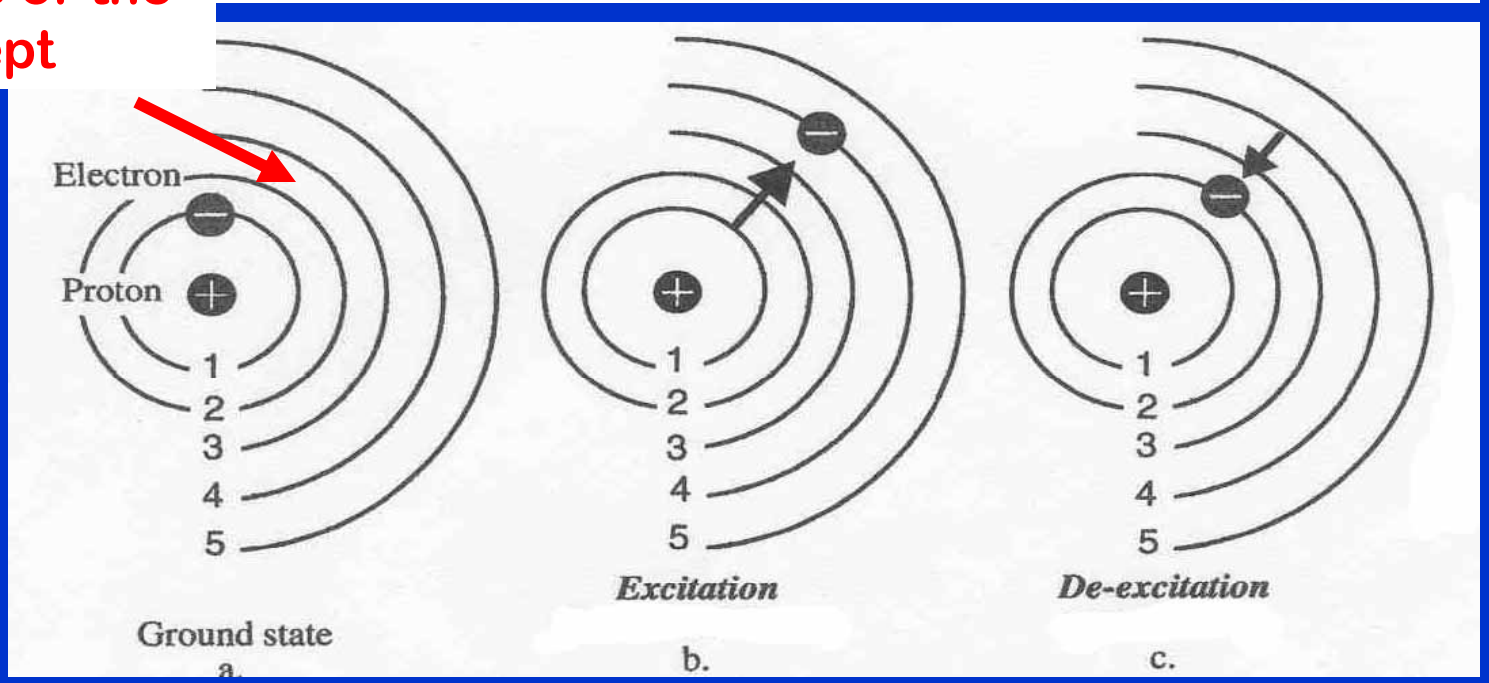


Another depiction →



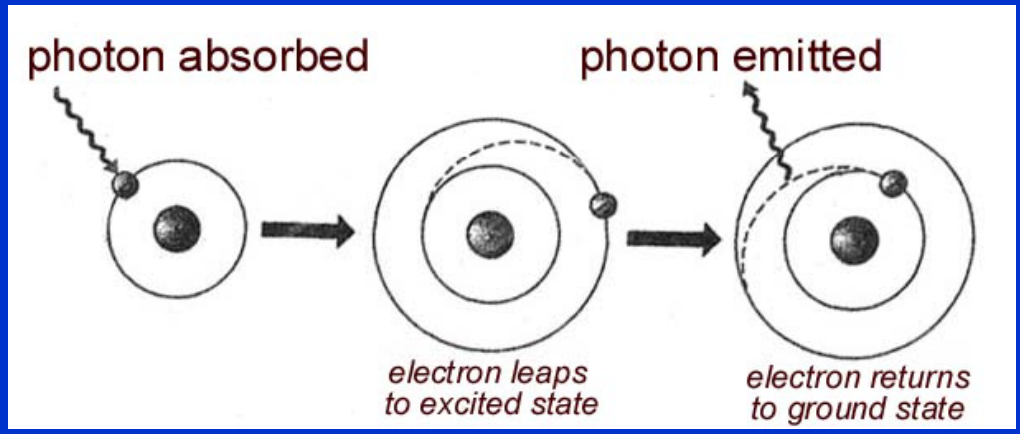


2 depictions of the same concept



RECAP: Electromagnetic Radiation

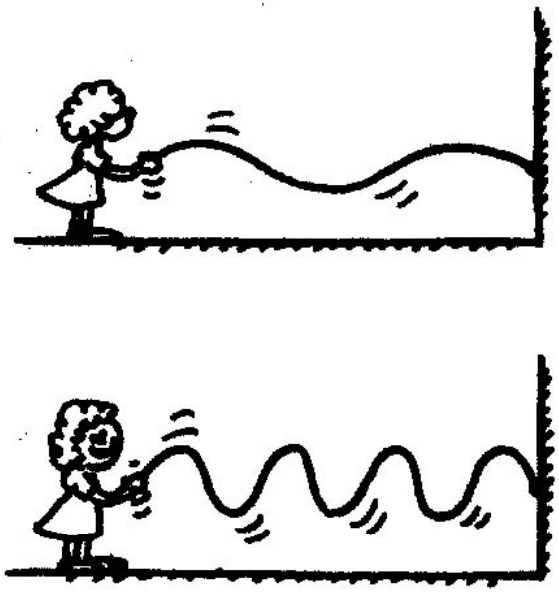
(under certain higher-energy conditions, e.g. light) exhibits a particle-like nature which we call PHOTONS.



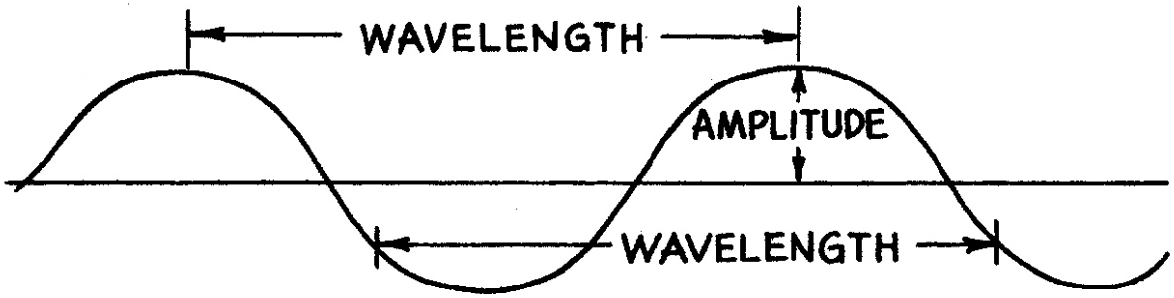
Photons are energy packets having a well-defined wavelength and frequency

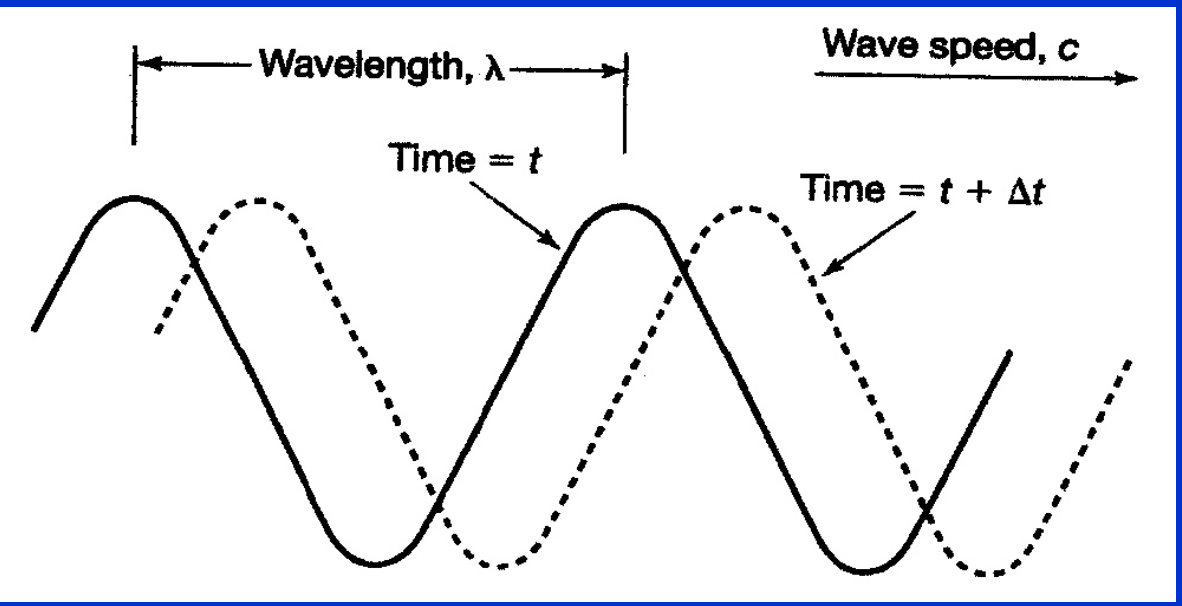
Figure is on bottom of p 31

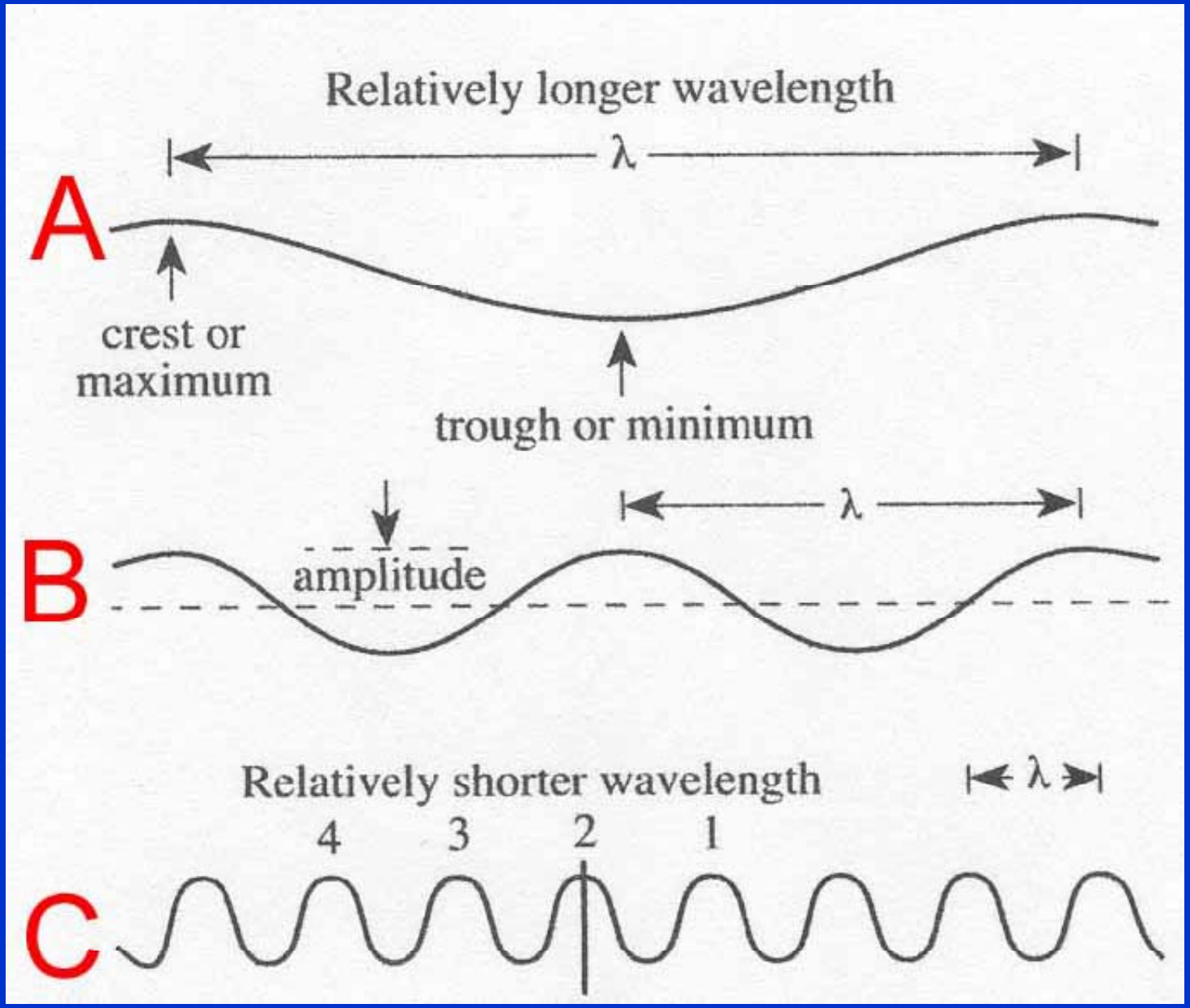
Wavelengths



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






Relatively longer wavelength
λ
A
crest or maximum
trough or minimum
λ
B
amplitude
Relatively shorter wavelength
λ
4
3
2
1
C

Take notes

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)

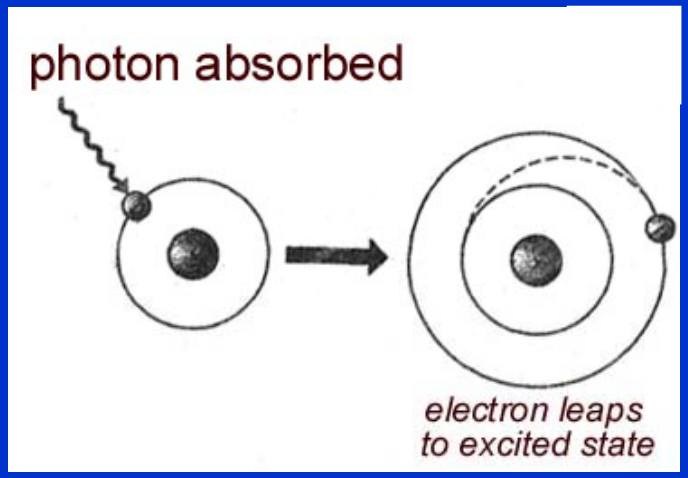
Speed = how fast the crests move forward (symbol = **c** in SGC) the speed of light

Take notes

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

- If a photon of electromagnetic energy strikes an atom,
- and if the **FREQUENCY** of the electromagnetic radiation is such that it is equal to:
  the *difference* in the energy
  of the ground level & the first excited level,
- the electron **ABSORBS** the photon energy and . . .
- the electron is "moved" (quantum leap) to "Level 2"

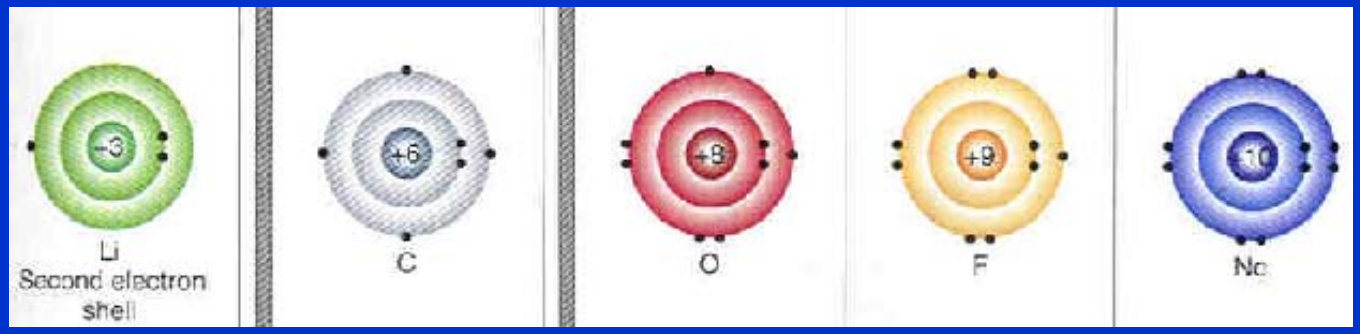
Hydrogen atom:

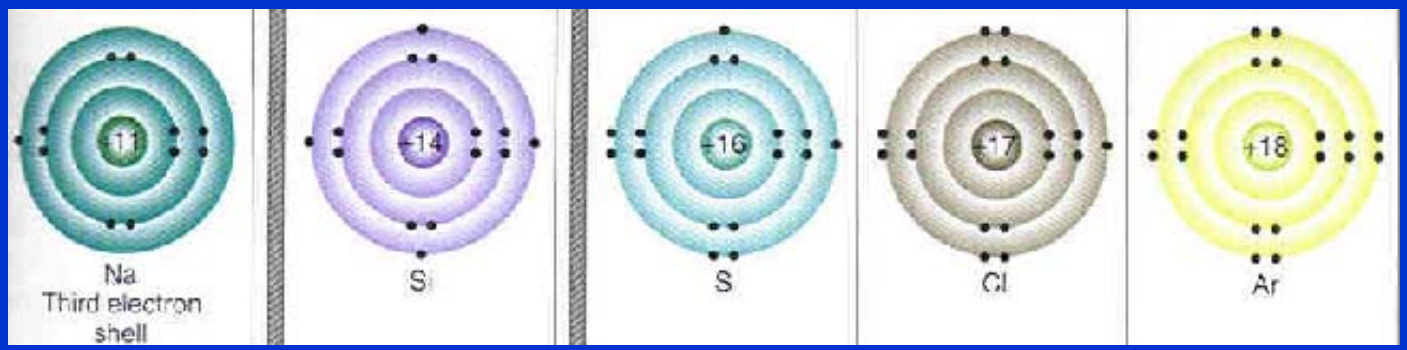


Take notes

KEY POINT → Because each atom type (element) has a unique set of energy levels,

each atom type (e.g. H, He, etc.) **will ABSORB over a PARTICULAR SET OF ELECTROMAGNETIC FREQUENCIES & WAVELENGTHS.**



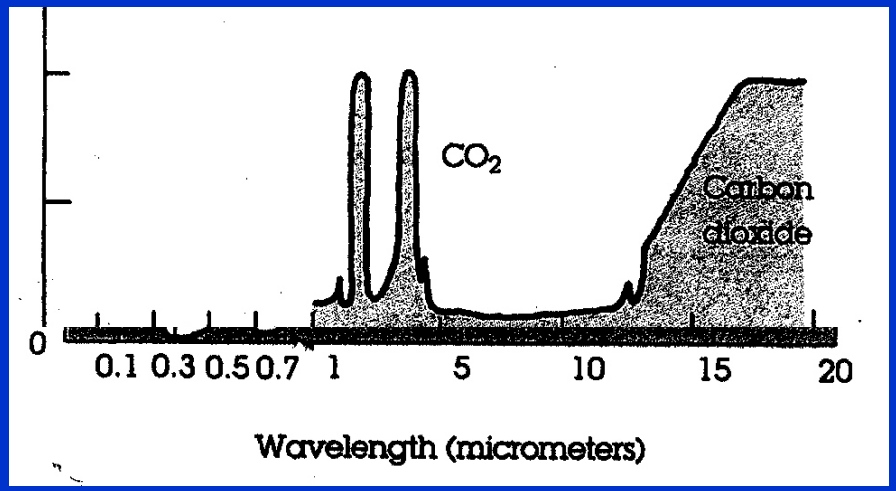


REVIEW:
The Periodic Table is organized by # of shells (**rows**) &
# of electrons in the <u>outer</u> shell (**columns**)

Take notes

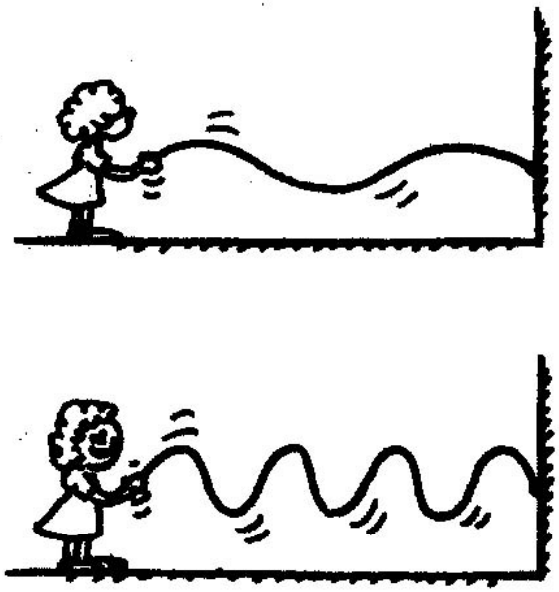
The pattern of wavelengths absorbed by a particular atom (or combination of atoms in, say, a gas molecule of CO_2 or H_2O) is called its ABSORPTION SPECTRUM or its ABSORPTION CURVE (more on this later . .)

Example of an "absorption spectrum" curve or graph ➔

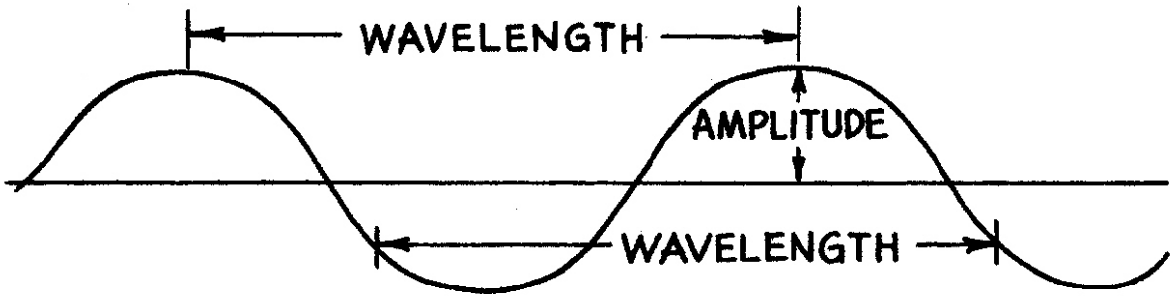


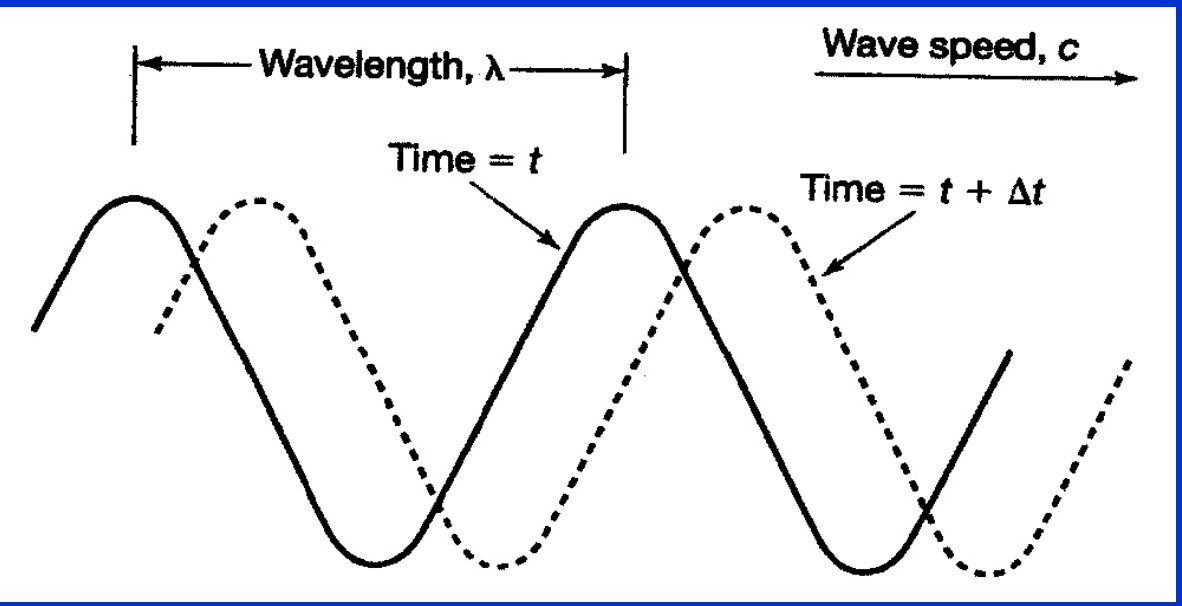
Take notes

Back to Wavelengths

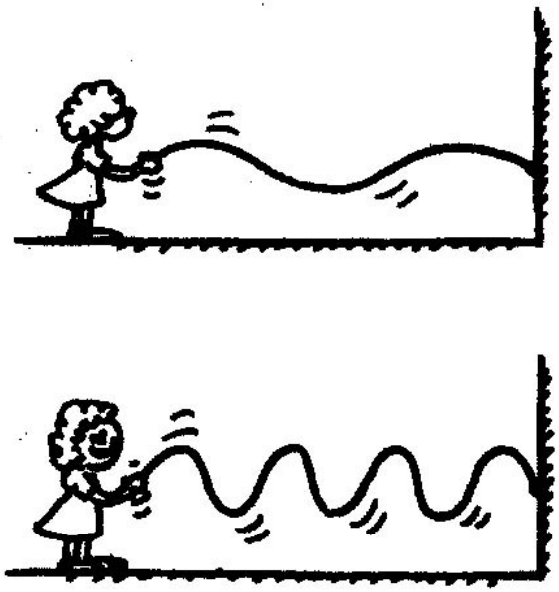


NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**





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 (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:

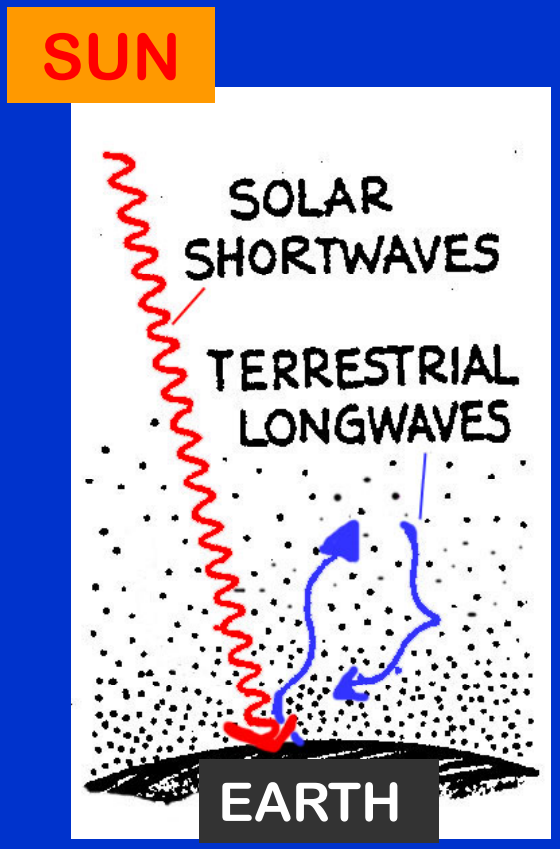
The **Energy (E)** of photons is *inversely* proportional to their **wavelength (λ)**

$$E \propto c / \lambda$$

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:

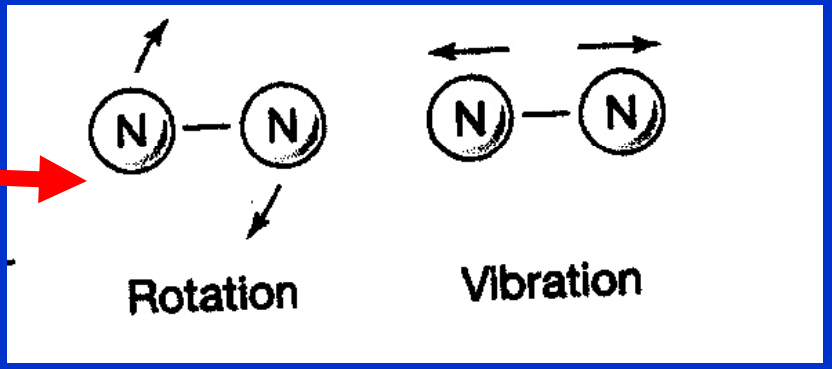
takes place between discrete energy levels (shells) when photons are absorbed or emitted

Quantum theory also involves the *behavior of molecules*

Take notes

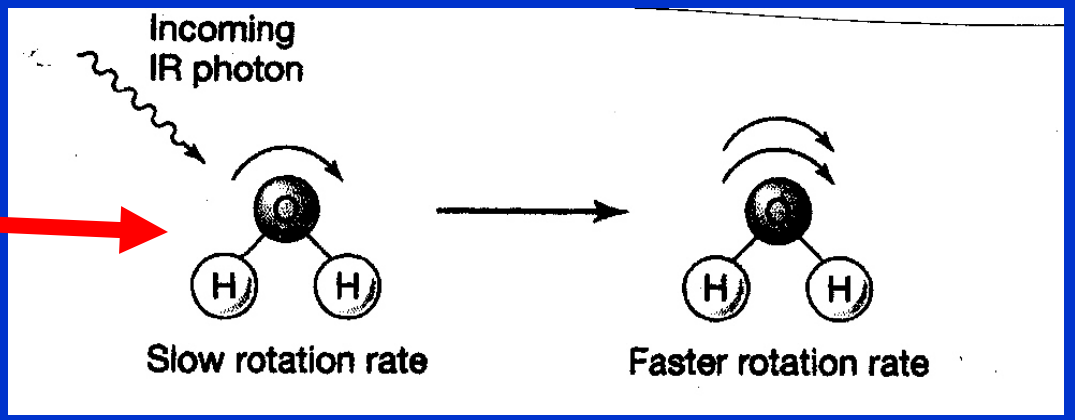
NITROGEN GAS MOLECULE

N_2



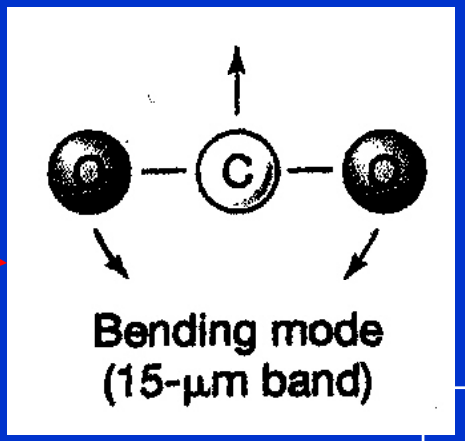
WATER VAPOR MOLECULE

H_2O



CARBON DIOXIDE GAS MOLECULE

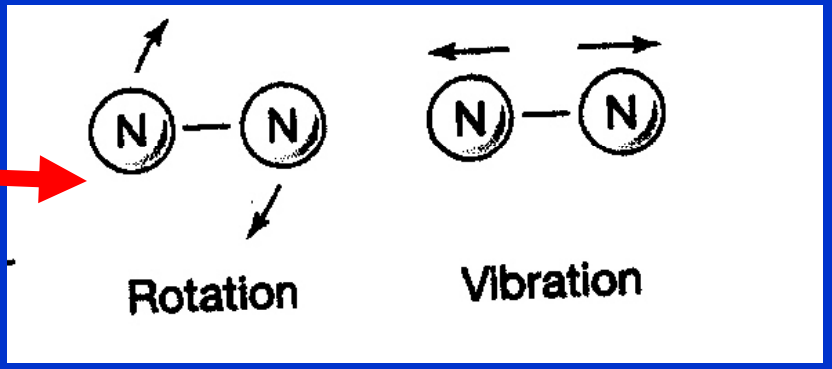
CO_2



Take notes

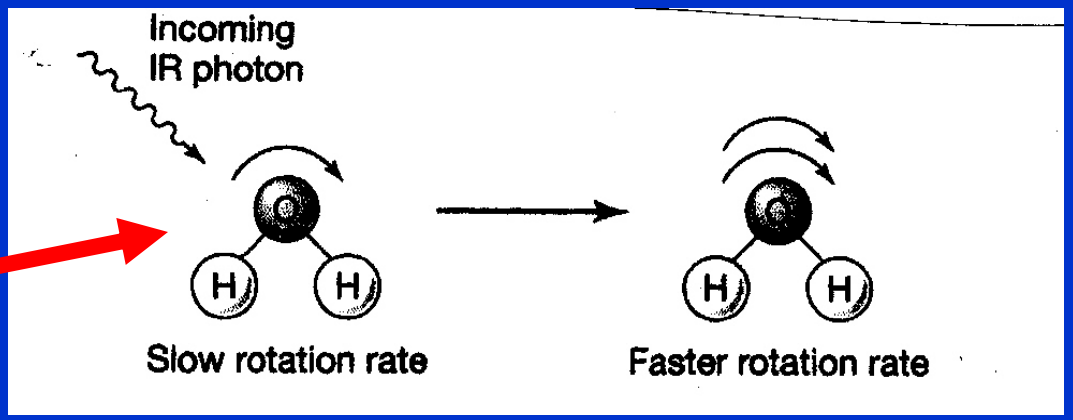
NOT a GREENHOUSE GAS

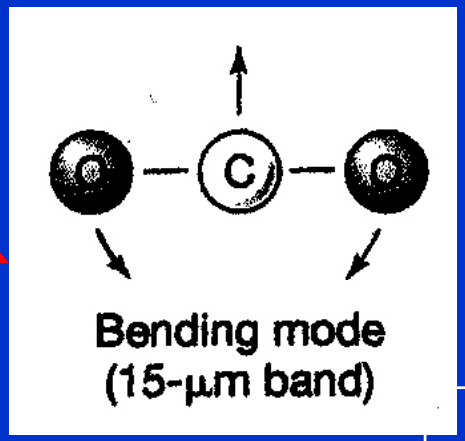
N_2



GREENHOUSE GASES

H_20 & CO_2

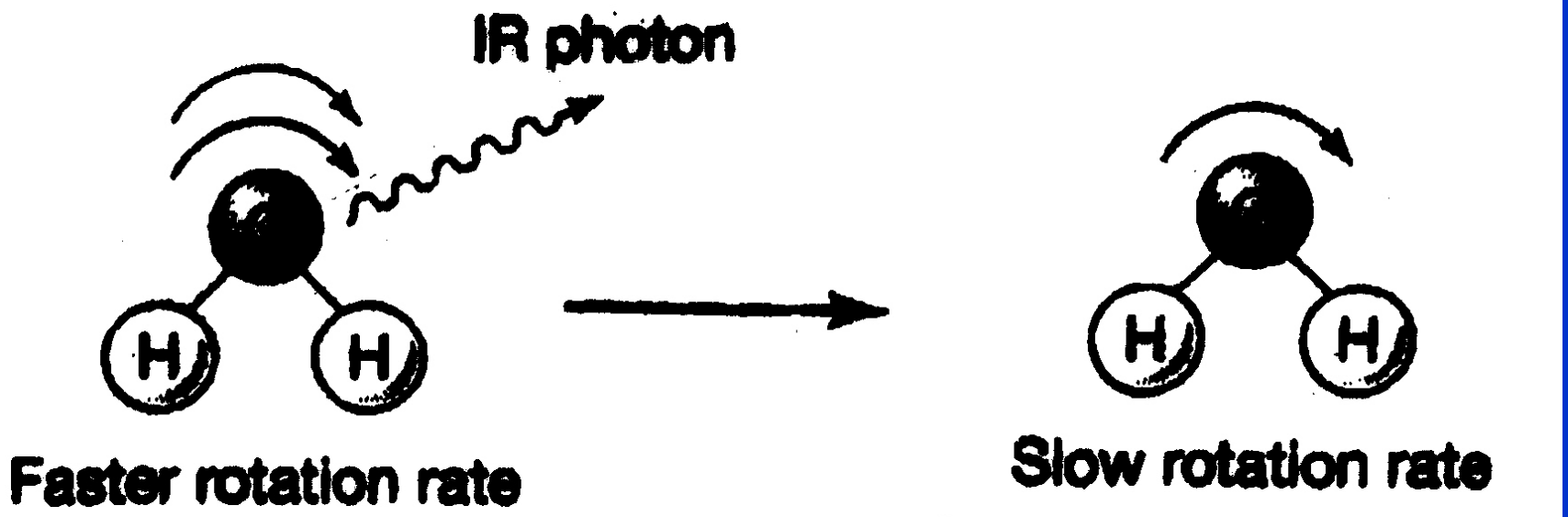




Take notes

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

When it absorbs a photon, the rotation rate increases.



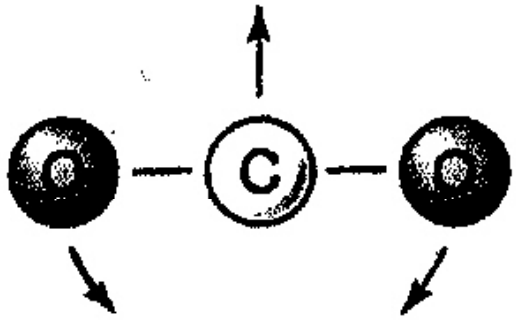
Take notes

- **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

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



Bending mode
(15-μm band)

SGC-Kump Chapter 3

FIGURE 3-14

The bending mode of vibration of the CO_2 molecule.

Take notes

THIS QUANTUM BEHAVIOR OF THE MOLECULES IS THE REASON THAT GREENHOUSE GASES ARE GREENHOUSE GASES!!

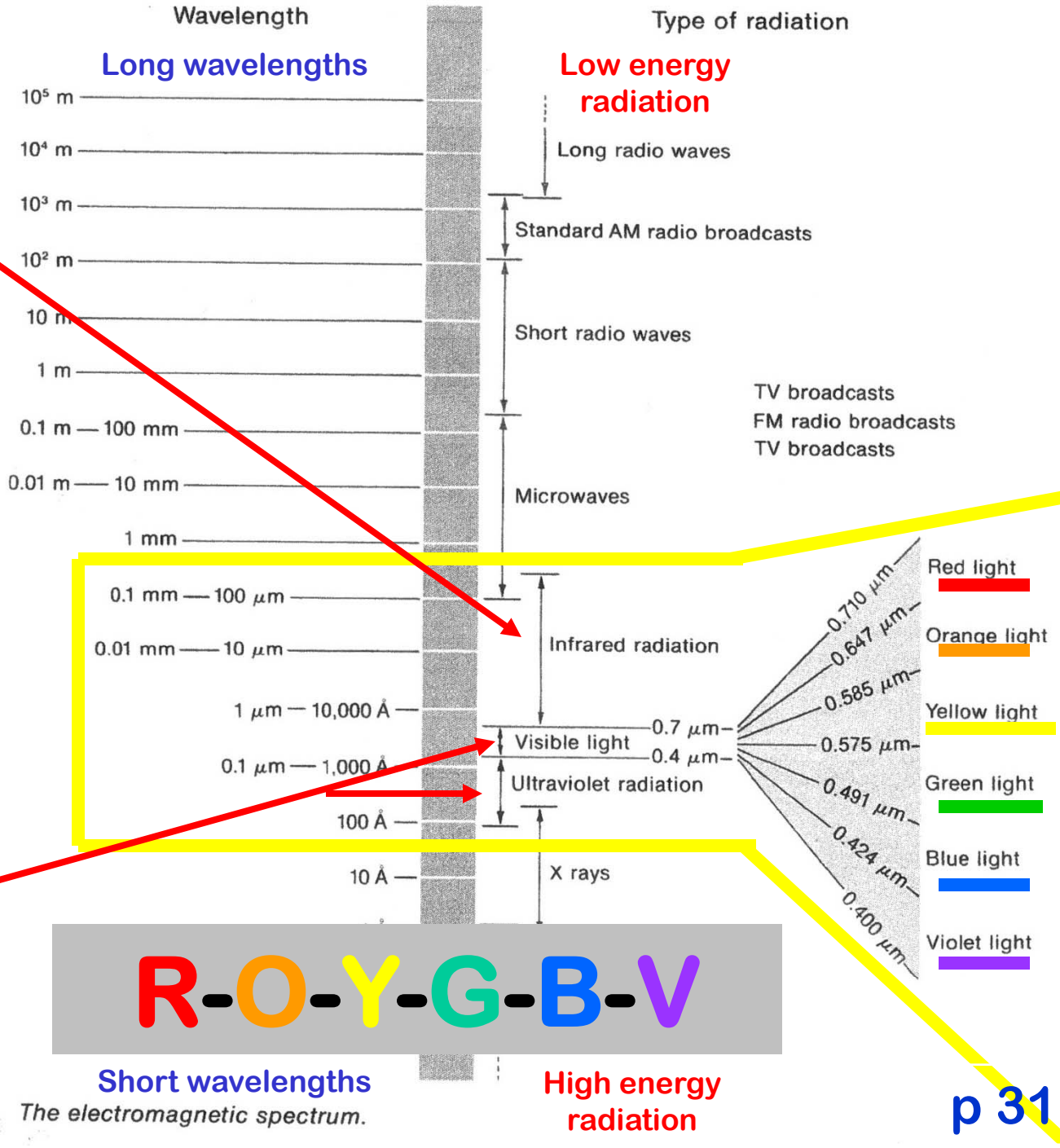
Hence energy given off by both the Sun and Earth has both a particle-like (photon) and wave-like behavior and emits radiation at electromagnetic wavelengths

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

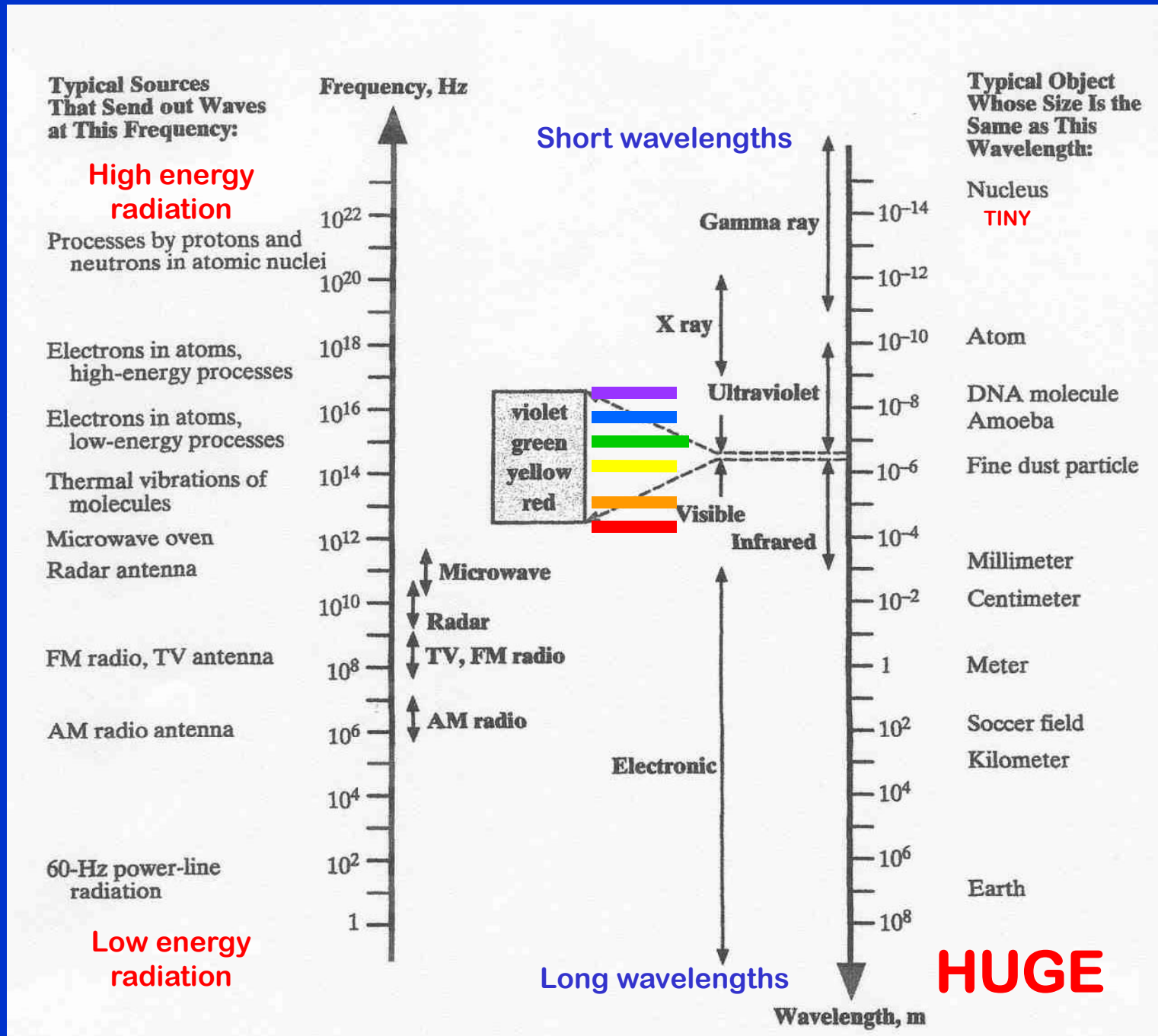
Longwaves (LW)

The Electro-magnetic Spectrum

Shortwaves (SW)



The electromagnetic spectrum.


Typical Sources That Send out Waves at This Frequency:
High energy radiation
Processes by protons and neutrons in atomic nuclei
Electrons in atoms, high-energy processes
Electrons in atoms, low-energy processes
Thermal vibrations of molecules
Microwave oven
Radar antenna
FM radio, TV antenna
AM radio antenna
60-Hz power-line radiation
Low energy radiation
Frequency, Hz
10^{22}
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
1
Short wavelengths
Gamma ray
X ray
Ultraviolet
violet
green
yellow
red
Visible
Infrared
Microwave
Radar
TV, FM radio
AM radio
Electronic
Long wavelengths
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
10^{6}
10^{8}
Wavelength, m
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

Two useful websites:

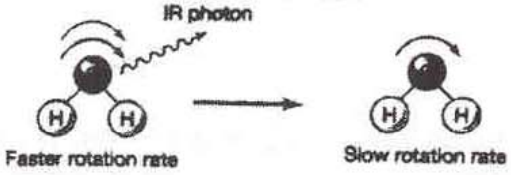
ELECTROMAGNETIC SPECTRUM JAVA APPLET:

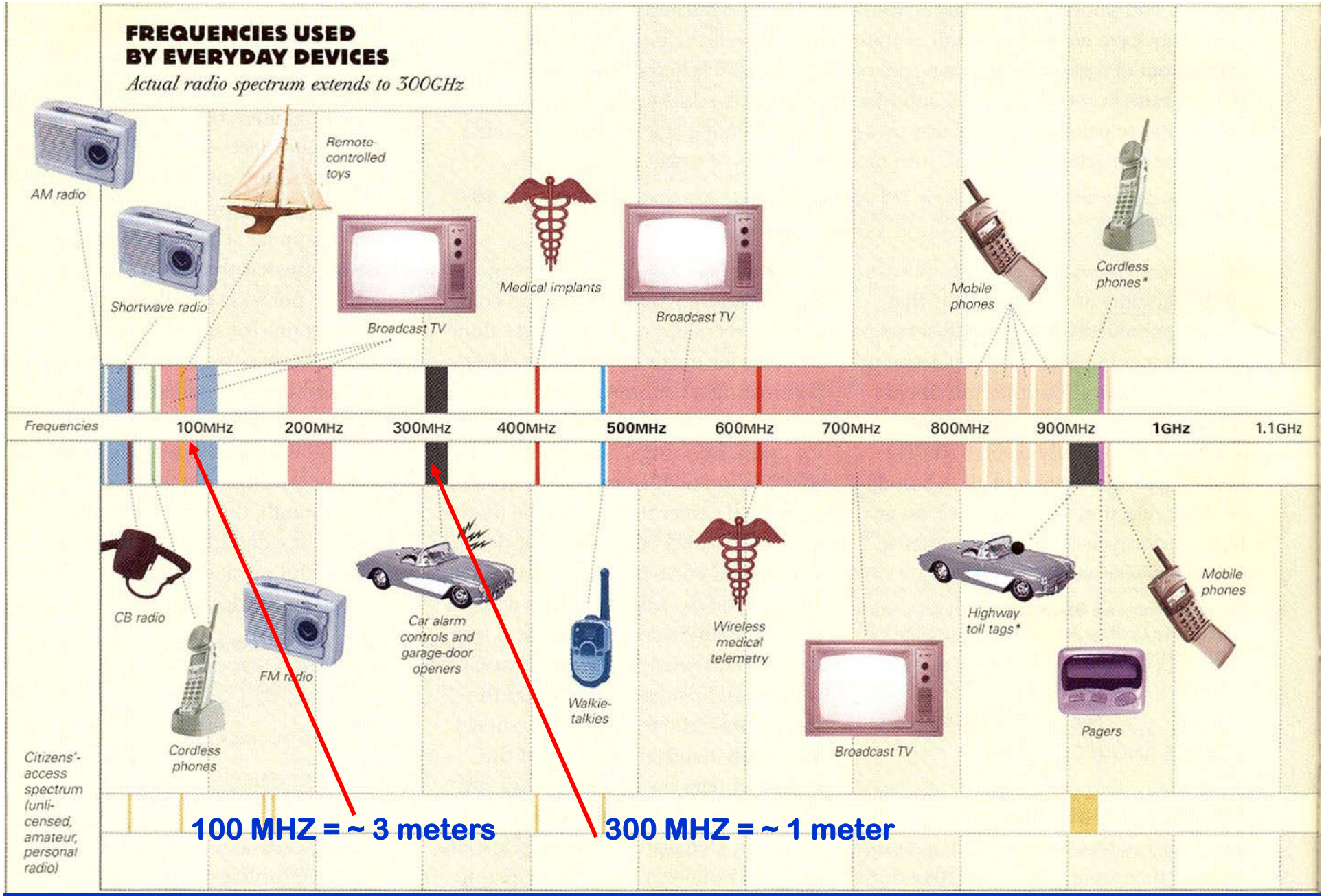
http://lectureonline.cl.msu.edu/~mmp/applist/Spectrum/s.htm

ELECTROMAGNETIC SPECTRUM CONVERTER:

http://oldsite.vislab.usyd.edu.au/photonics/revolution/history/SpectrumTuner/index.html

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-Hobson p 197	0.7 - 1.0 in micrometers (μm)	
Far Infrared See SGC-Hobson 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

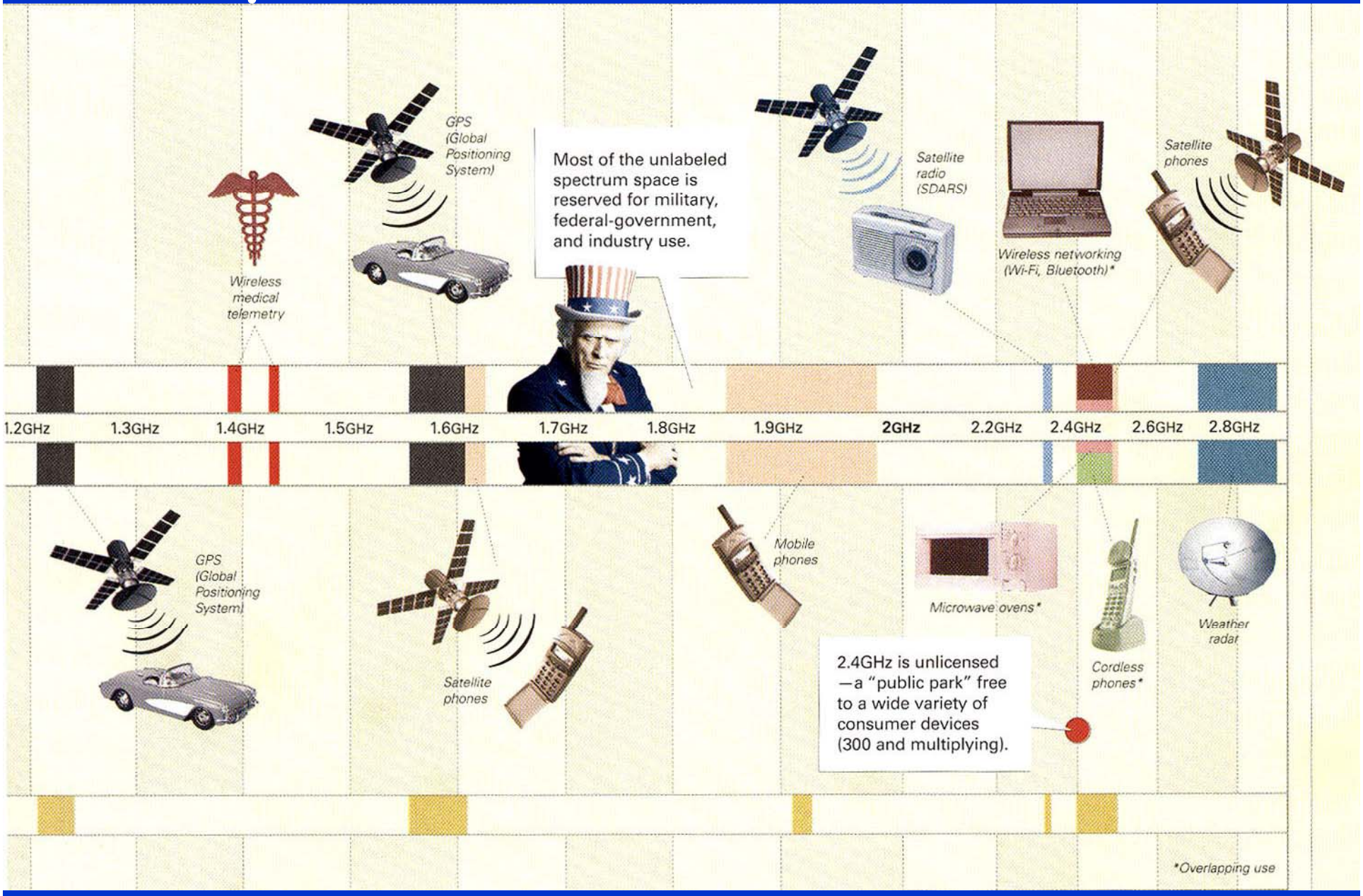
Frequency (def) = The number of times per second that a signal fluctuates.

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 . . .

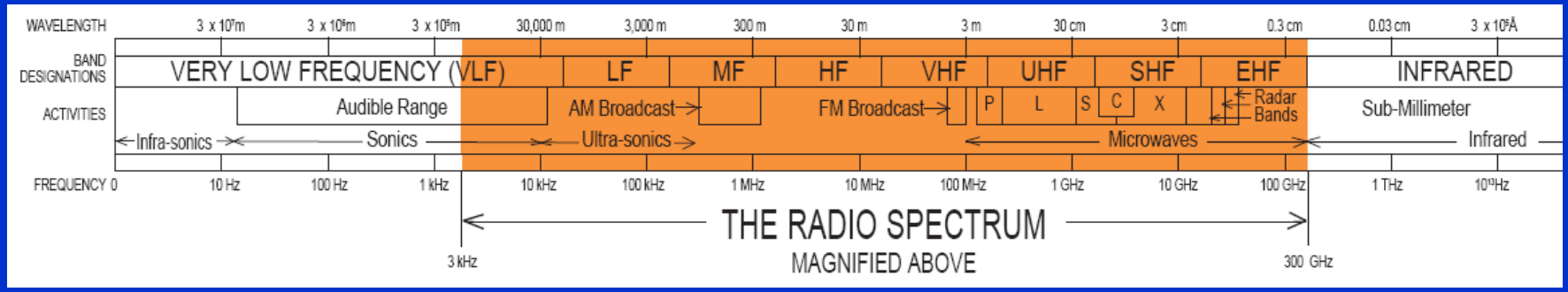


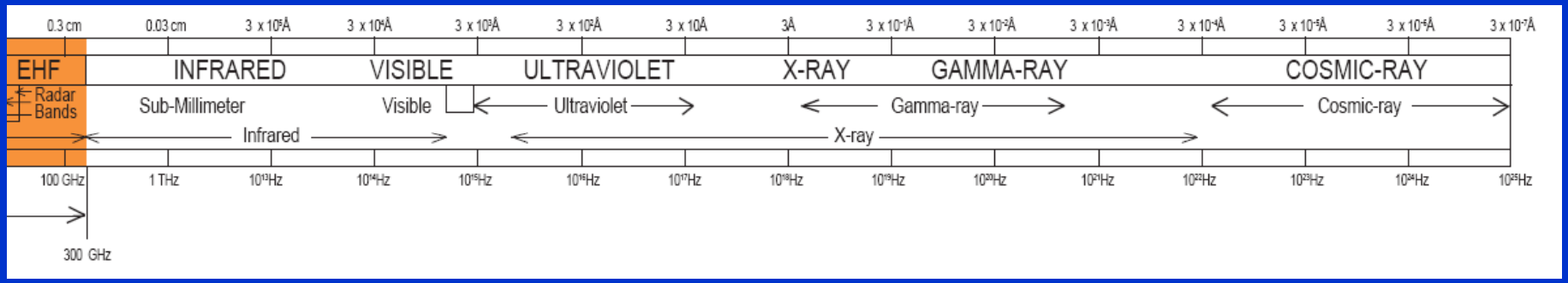
Multicasting:

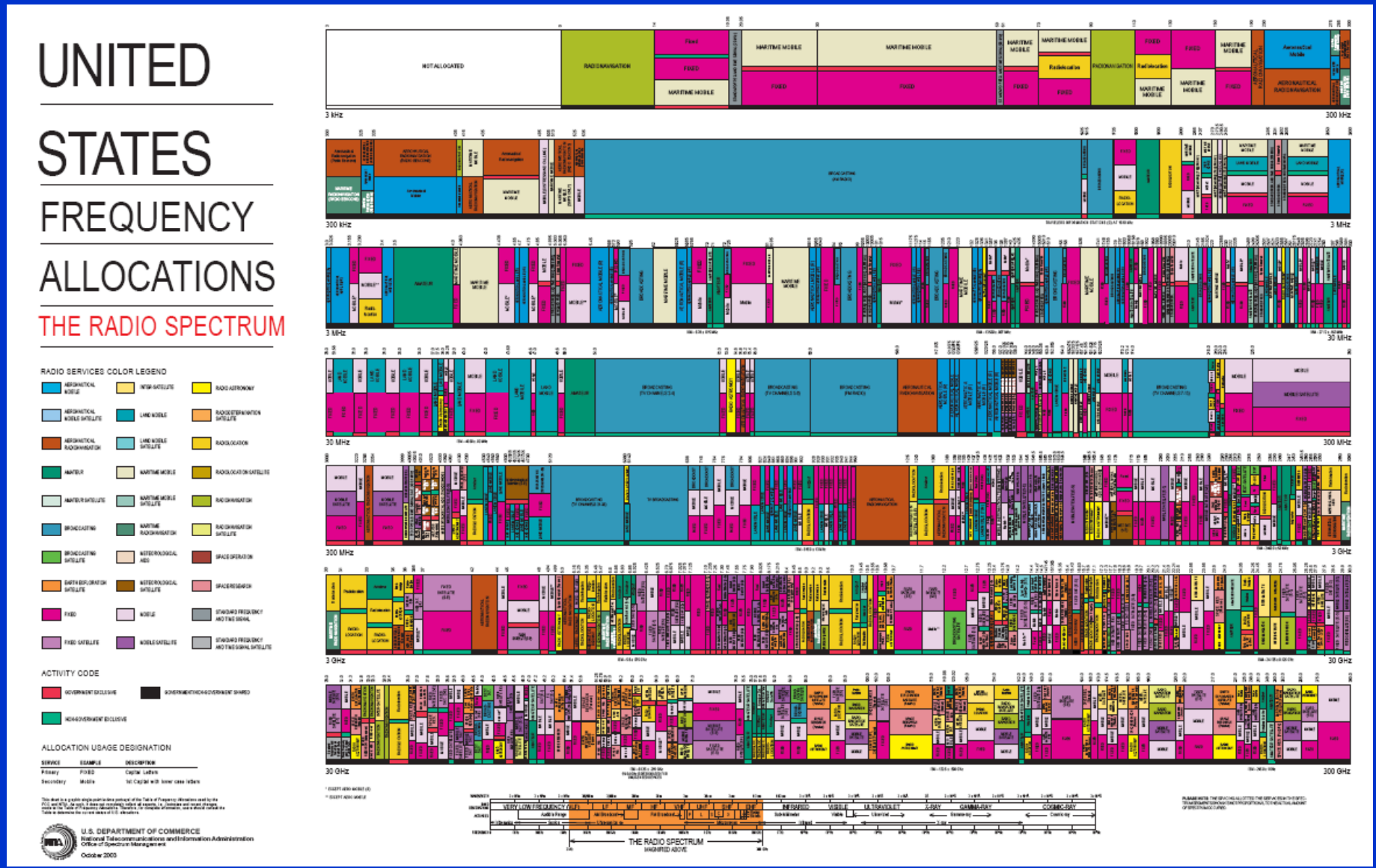
This is the process of transmitting more then one program over the air at the same time on the same channel.

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.

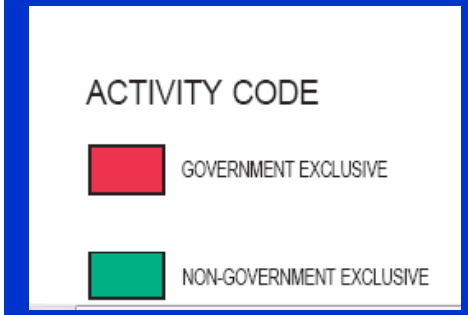

WAVELENGTH
3 x 10⁷m
3 x 10⁶m
3 x 10⁵m
30,000 m
3,000 m
300 m
30 m
3 m
30 cm
3 cm
0.3 cm
0.03 cm
3 x 10⁹Å
BAND DESIGNATIONS
VERY LOW FREQUENCY (VLF)
LF
MF
HF
VHF
UHF
SHF
EHF
INFRARED
ACTIVITIES
Audible Range
AM Broadcast
FM Broadcast
P
L
S
C
X
Radar Bands
Sub-Millimeter
Infra-sonics
Sonics
Ultra-sonics
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 10⁴Å
3 x 10⁵Å
3 x 10⁶Å
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



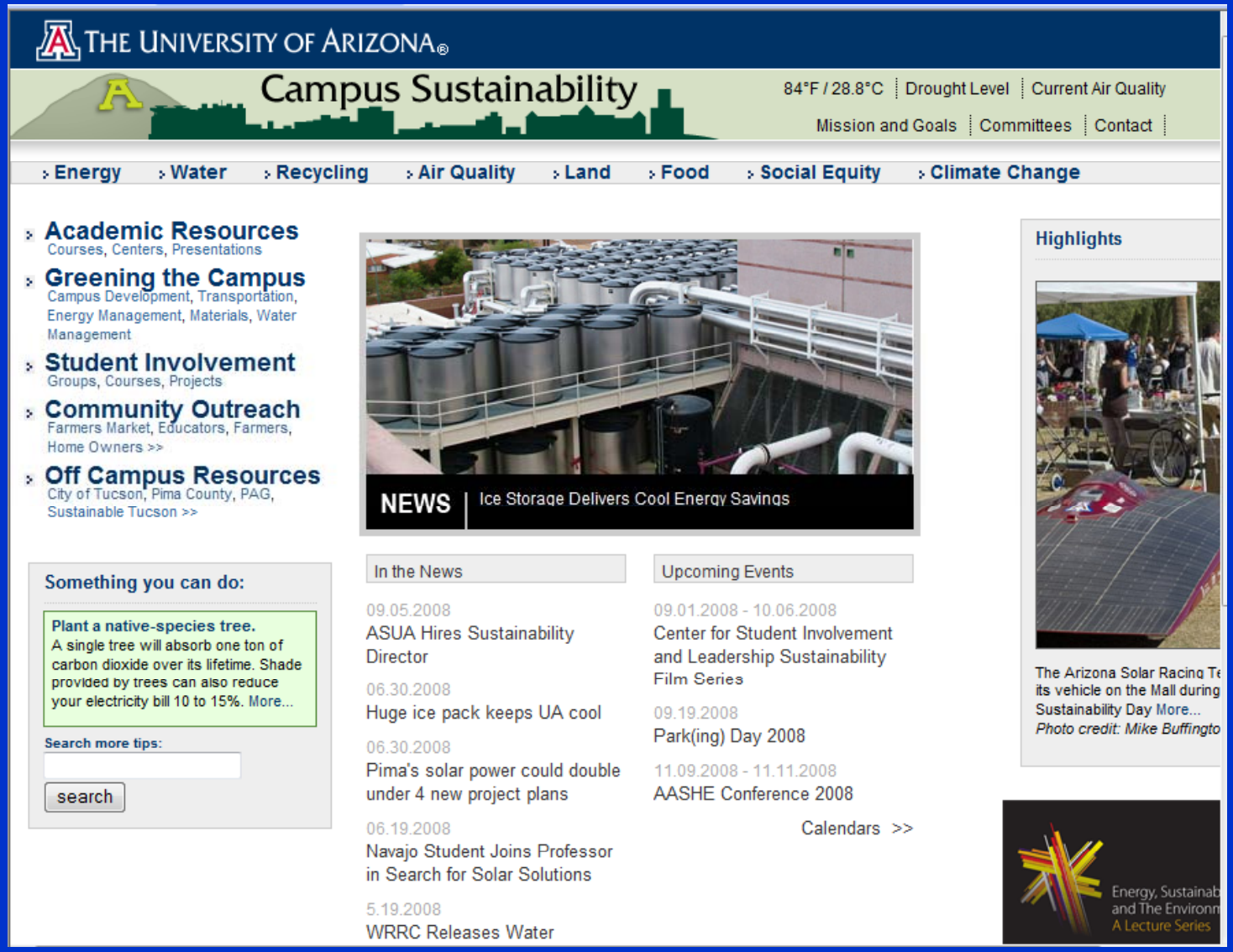
http://www.todaysengineer.org/2005/Dec/spectrum.asp

Who "owns" the spectrum?



UA & SUSTAINABILITY

http://www.sustainability.arizona.edu/



http://uanews.org/node/21365