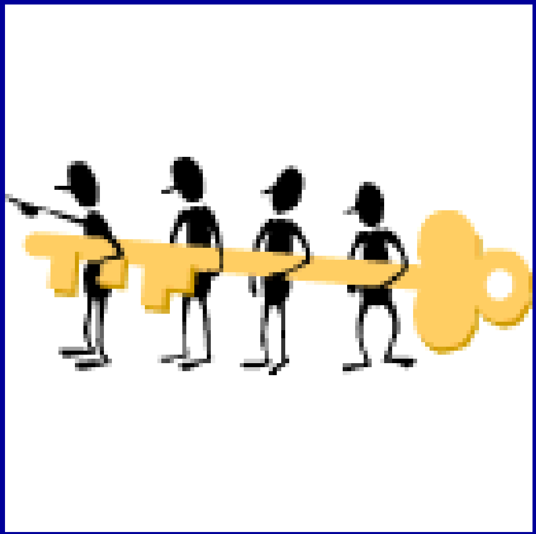
TOPIC # 7
The RADIATION LAWS

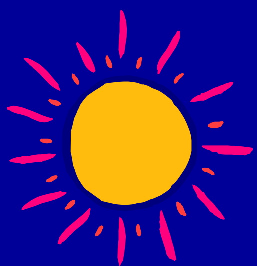
More KEYS
to unlocking the topics of:
The GREENHOUSE EFFECT,
GLOBAL WARMING &
OZONE DEPLETION!

Topic #7
pp 35-38



OBJECTIVES:

To understand more essentials about the key differences between



Solar radiation

&

Terrestrial radiation

based on the principles of the "Radiation Laws."

One “cartoon” view of Solar vs Terrestrial radiation:

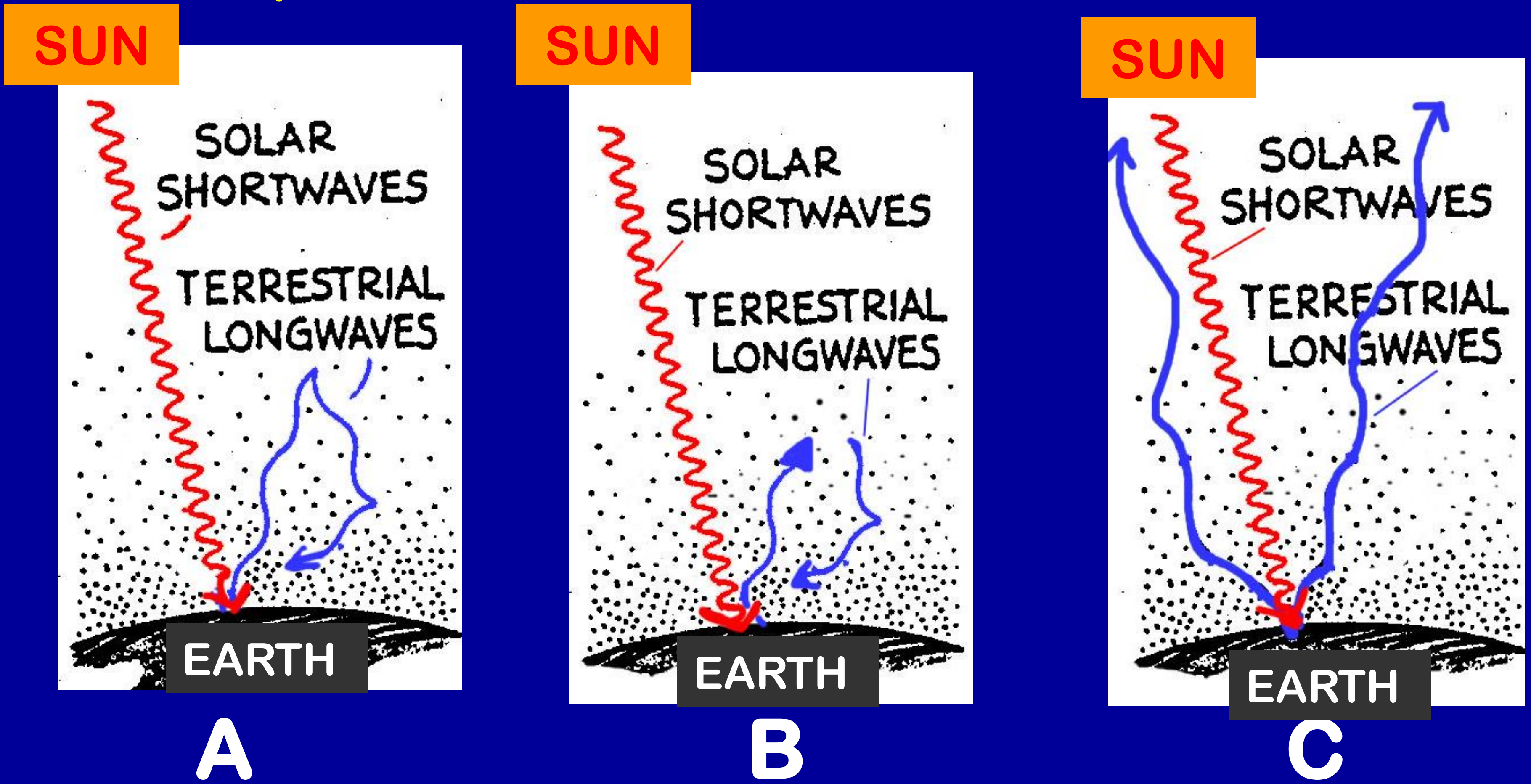
Both Sun & Earth are radiating energy . . . .

NOT TO SCALE!!!

Fire up your clickers . . . . Channel 40

☺

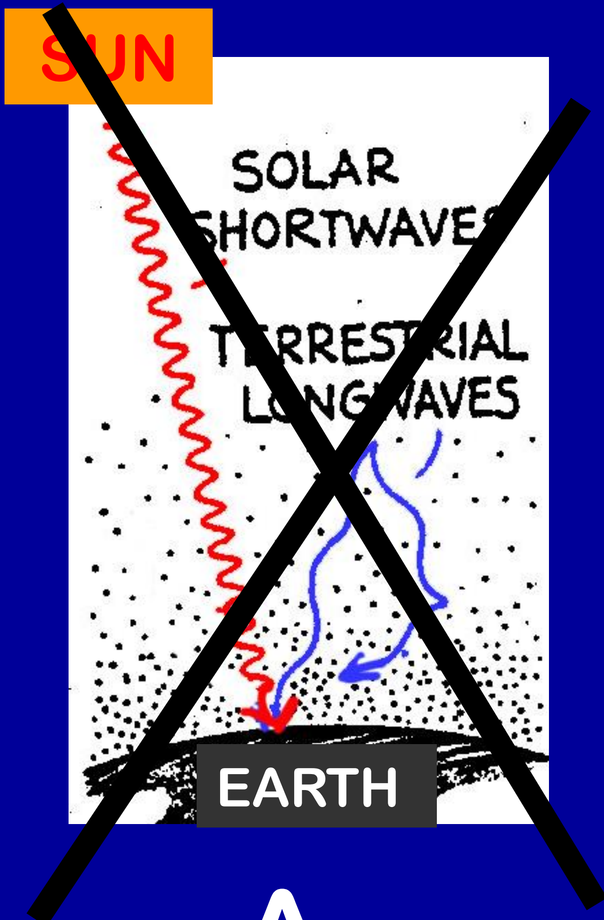
Q1- Which one is the most accurate depiction of the Greenhouse Effect??



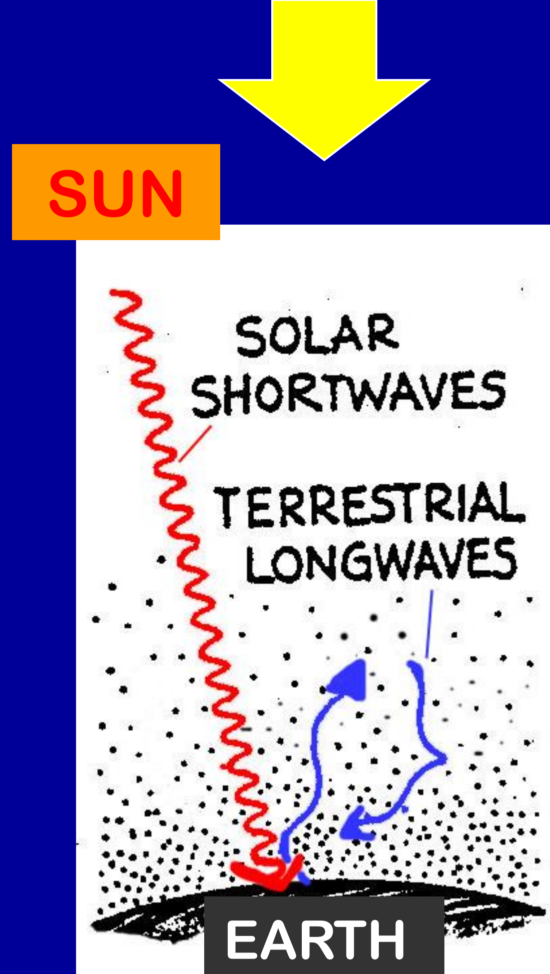
In these & upcoming figures, for convenience:

= solar (shortwave) radiation (High Energy)

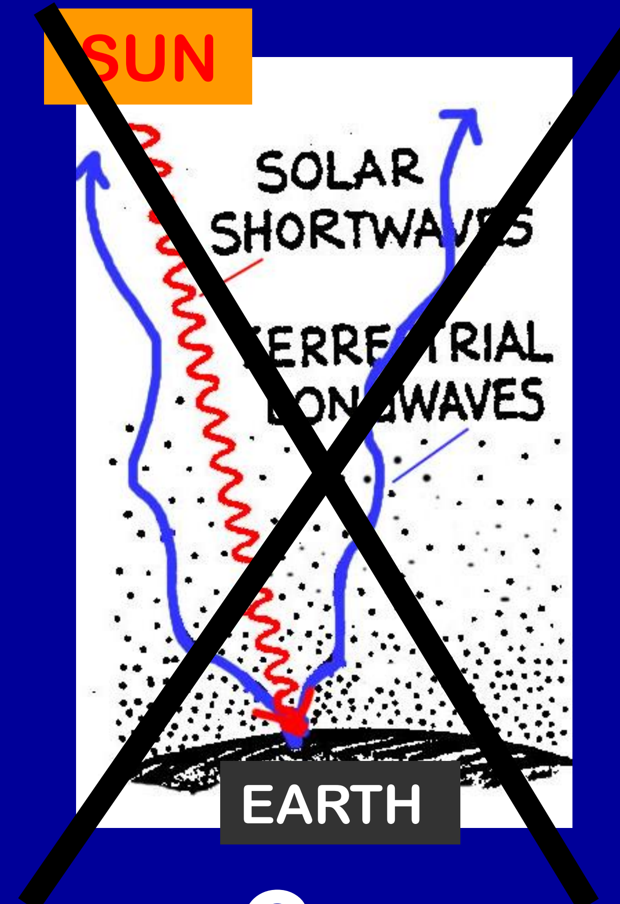
= terrestrial (longwave) radiation (Lower Energy)



A



B



C

IMPORTANT: None of these is exactly correct, and we will learn why soon. . . .

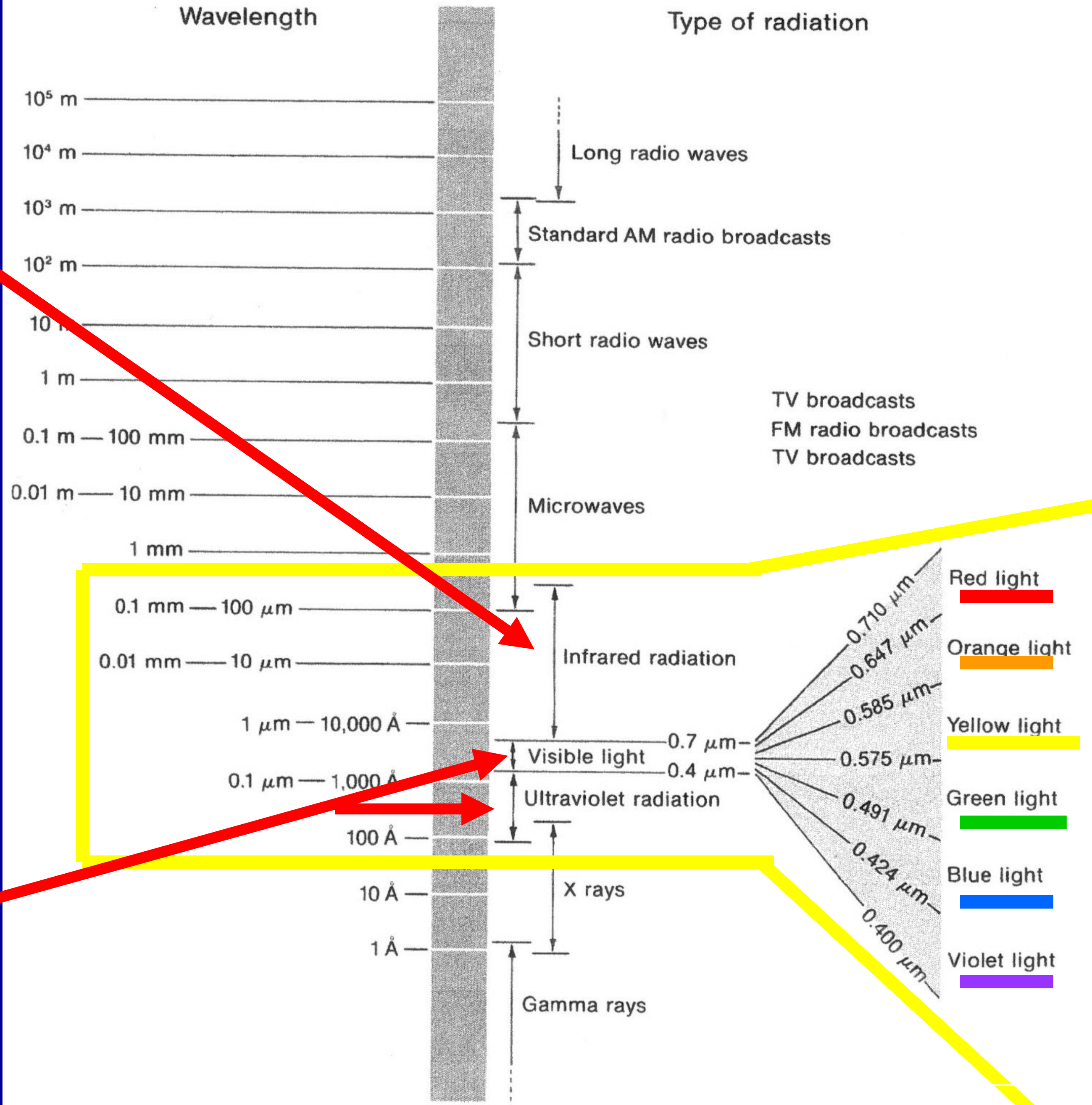
but B is preferred for now.

☺

Longwaves (LW)

The Electro-magnetic Spectrum

Shortwaves (SW)



The electromagnetic spectrum.

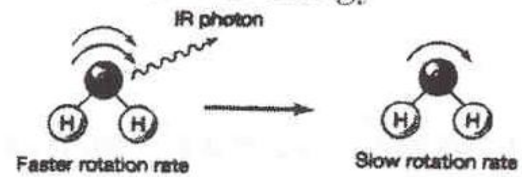
KEY BANDS IN THE SPECTRUM FOR GLOBAL CHANGE:

UV, Visible, IR, NIR,

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	0.7 - 1.0 in micrometers (µm)	
Far Infrared	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

Solar SW (Ultraviolet radiation, Visible light)

Terrestrial LW (Infrared radiation, Near Infrared radiation, Far Infrared)



Review p 34

$E = \sigma T^4$

$(1/d^2)$

**"The equations we seek
are the poetry of nature . . . .
Why is nature that way?
Why is it possible for these powerful
manifestations of forces to be trapped
in a very simple, beautiful formula?"**

**"This has been a question
which many people
have discussed,
but there is no answer."**

$\lambda_m = a/T$

$E = h\,c\,/\,\lambda$

~ Chen Ning Yang (b. 1922) US physicist

Presenting . . . .

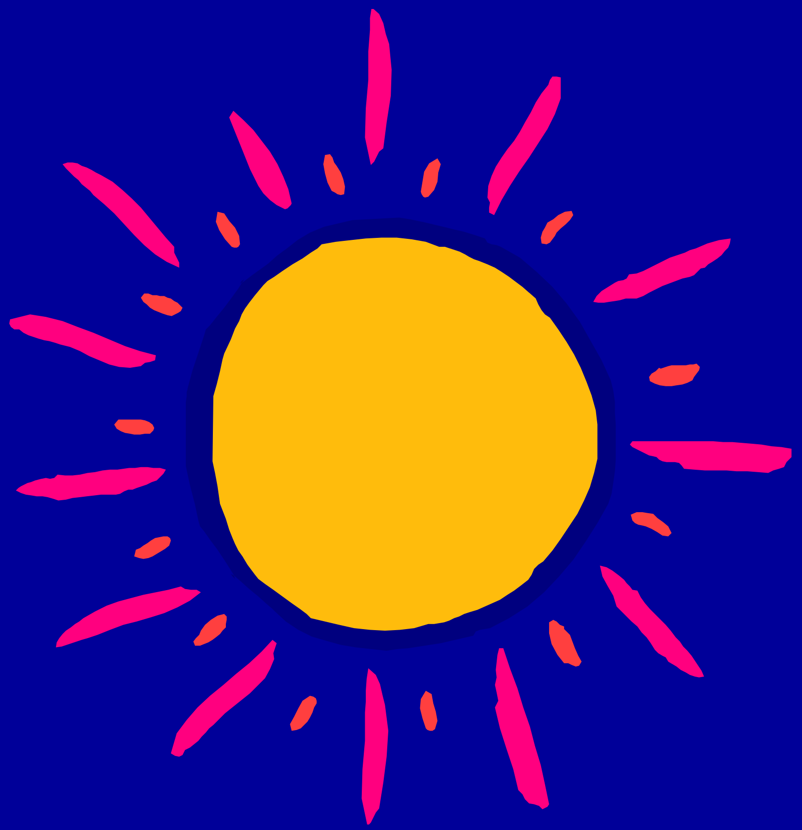
THE RADIATION LAWS !!!

Keys to Understanding the Greenhouse Effect

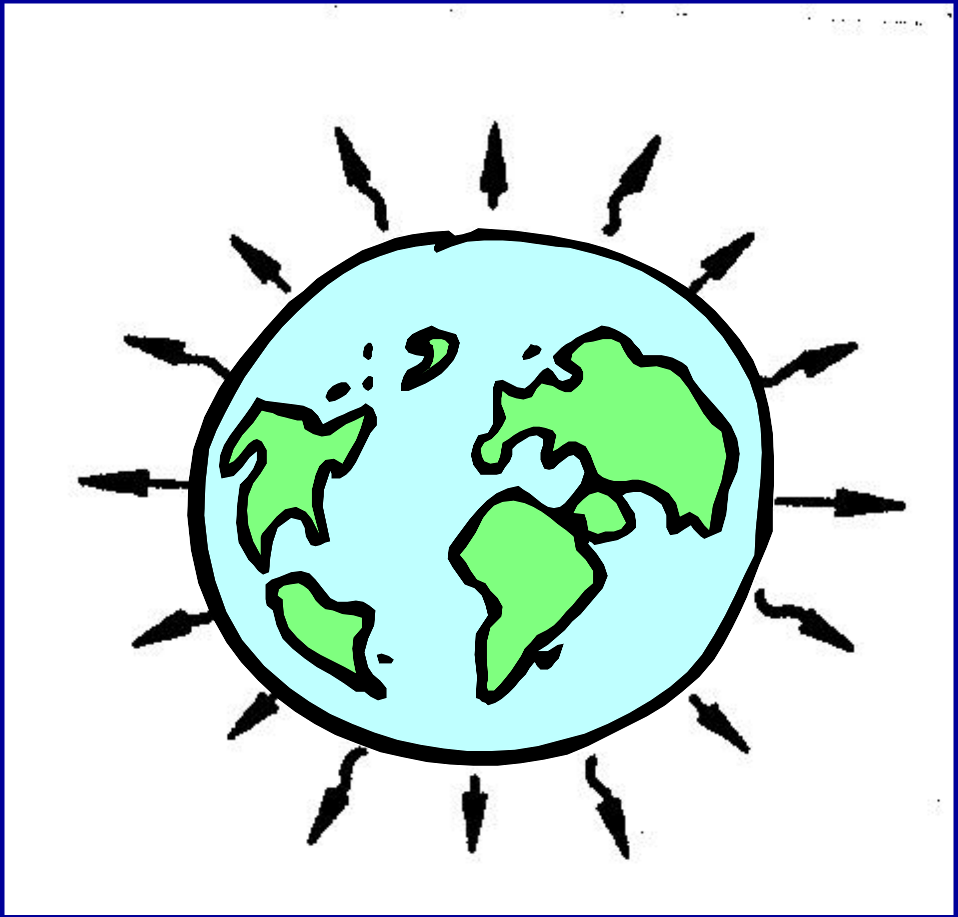
TYING IT ALL TOGETHER: THE RADIATION "LAWS"

The Sun's energy is emitted in the form of electromagnetic radiation.

mostly SW (but also some LW)



The Earth's energy (terrestrial) is also emitted in the form of electromagnetic wavelengths.



mostly LW

☺

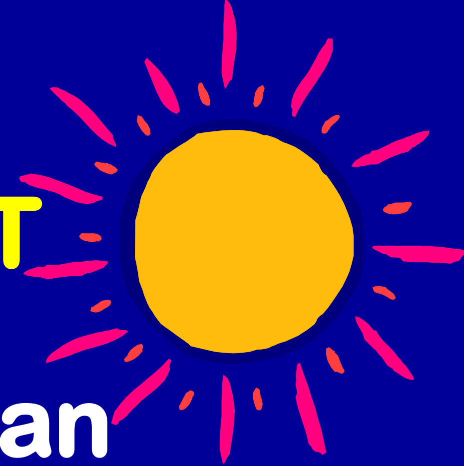
LAW #1

Emission of radiation

<u>All</u> substances emit radiation as long as their temperature is above absolute zero

(-273.15°C or 0 Kelvin).

LAW #2 BLACKBODY & PLANCK FUNCTION CONCEPT



The Sun is very similar to an "ideal emitter" (or "Black body")

(NOTE: the Earth isn't as ideal as a "black body"

Black body (def): **a hypothetical object that absorbs all of the radiation that strikes it. It also emits radiation ("Energy flux") at a maximum rate for its given *temperature.***

p 35

Blackbodies ("ideal emitters") exhibit a *defined relationship* between:

the <u>intensity</u> of radiation <u>energy</u> (E)
(i.e. amount of radiation flux) they give off
&
the <u>wavelength</u> of that radiation.

This relationship is called the <u>Planck function:</u>

E = h * speed of light / wavelength

or

$$E = h\ c\ /\ \lambda$$

(where h is Planck's constant.)

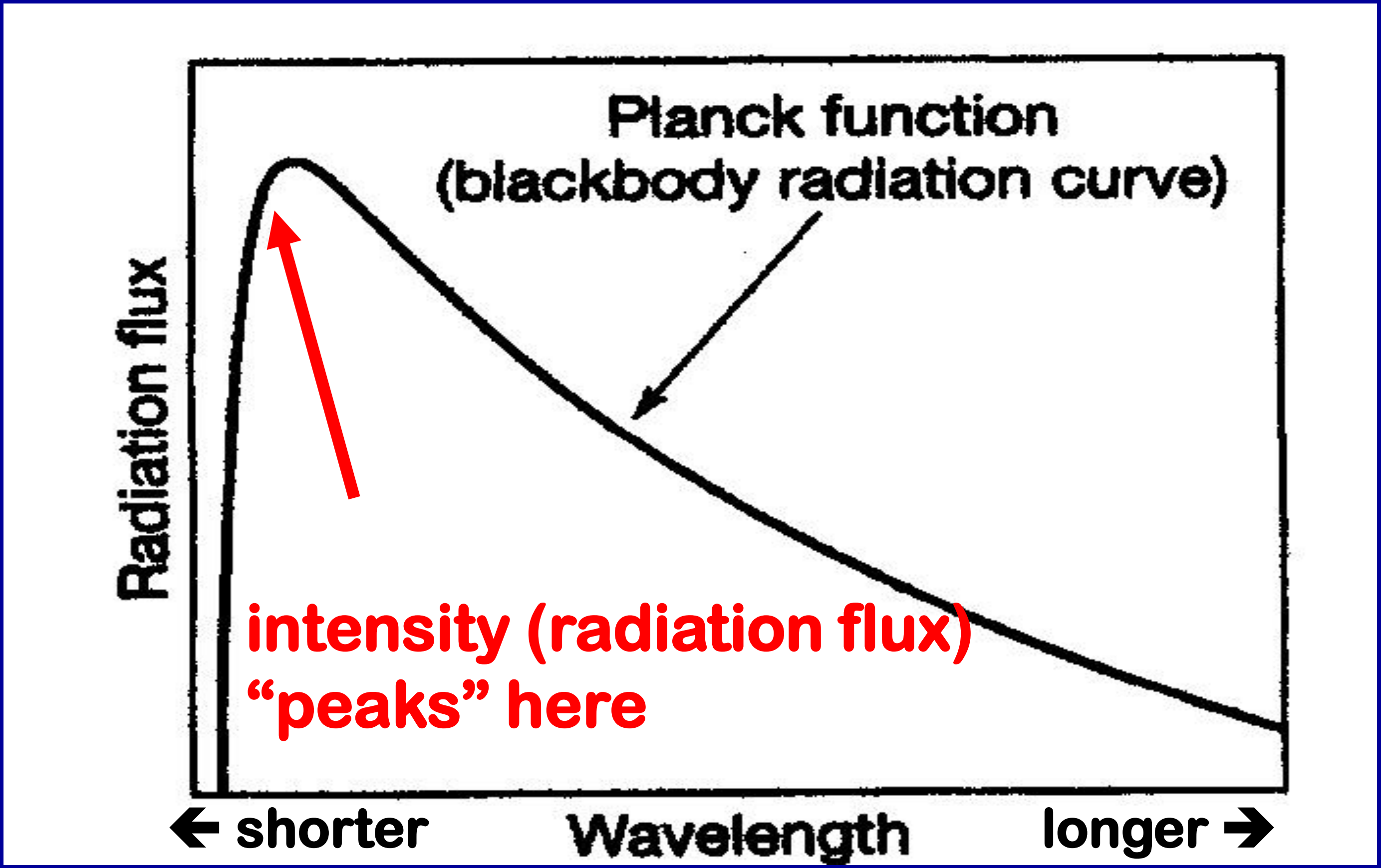
Planck Function:

The Sun emits energy at ALL wavelengths . . .

but the amount of Energy emitted is inversely related to the wavelength of emission

"I radiate at the speed of light like a blackbody; but my energy flux is GREATEST at SHORTER wavelengths"

This can be depicted in a graph:



An emitting blackbody’s SHORTER wavelengths have HIGHER intensity radiation (and greater energy flux) than the LONGER wavelengths

Easy way to remember the PLANCK FUNCTION / BLACKBODY concept:

"The shorter the wavelength, the GREATER the intensity of the energy flux"

☺

Q1 - Gamma radiation involves a <u>greater</u> energy flux than microwave radiation.

1. True
2. False
3. Both wavelength bands have the same energy flux
4. We haven't learned enough yet to answer this!

☺ Record your Q1 answer now

Q1 - Gamma radiation involves a greater energy flux than microwave radiation.

1. True
2. False
3. Both wavelength bands have the same energy flux
4. We haven't learned enough yet to answer this!

LAW #3: THE STEFAN-BOLTZMANN LAW:

If the substance is an ideal emitter (black body),

The total AMOUNT of radiation given off is proportional to the fourth power of its absolute TEMPERATURE.

$$E = \sigma T^4$$

where σ is a constant **(the Stefan-Boltzmann constant)** which has a value of

5.67×10^{-8} W/m^{-2}

(or 5.67×10^{-8} J / m^2)

and T is the absolute temperature (in Kelvin)

$$\text{Energy} = \sigma T^4$$

Stefan-Boltzmann Law (easy way)

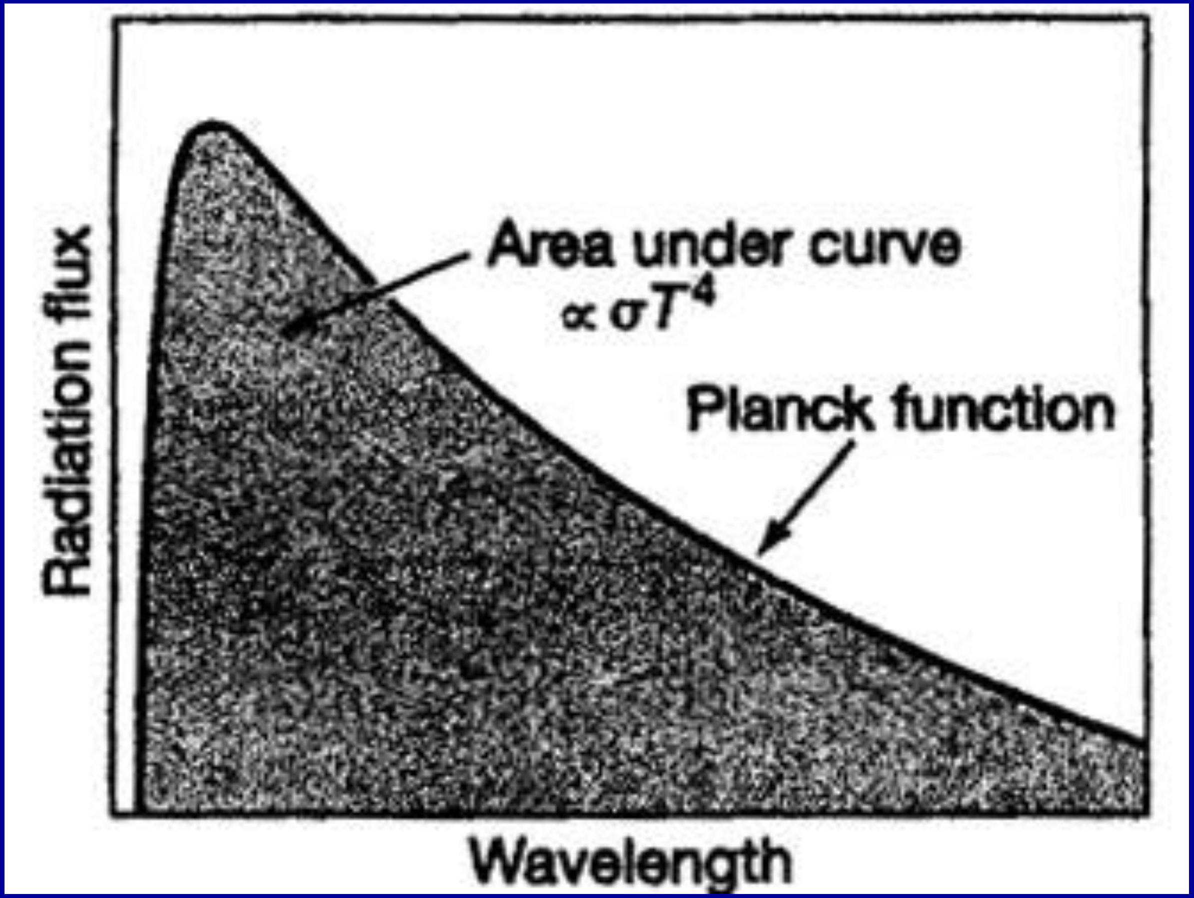
This law links:

the total amount of energy flux that is emitted by a blackbody TO: the body's temperature

(actually, the 4th power of the body's absolute temperature)

"the hotter the body, the (much) greater the amount of energy flux or radiation"

The total amount of energy flux described by the Stefan-Boltzmann Law is proportional to the area under the Planck function curve



See p 40 in SGC-I

Stefan-Boltzmann Law:

"I'm HOT, so I emit LARGE amounts of high intensity energy"

"I'm COOL, so I emit LESSER amounts of energy. *plus* my ENERGY is at a lower intensity than Mr. Hotshot over there!"

Why is this concept important?

Because it means that:

the <u>amount</u> of radiation given off by a body is a very *sensitive* function of its <u>temperature</u>

Therefore . . . small changes in temperature can lead to BIG changes in the amount of radiation given off.

$$E = \sigma T^4$$

Q2 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to accurately compute
the total amount of ENERGY
emitted to space by planet Earth?

1. The Planck Function
2. The Stefan Boltzmann Law
3. Both of them together
4. Neither one is appropriate because the Earth is NOT a blackbody

☺ **Record your Q2 answer now**

Q2 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to accurately compute
the total amount of ENERGY
emitted to space by planet Earth?

1. The Planck Function

2. The Stefan Boltzmann Law

3. Both of them together

4. Neither one is appropriate because the Earth is NOT a blackbody

Q3 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to compute the total amount of energy
emitted to space by planet Earth,
IF you assume the Earth emits like a blackbody
& you know the Earth's temperature?

1. The Planck Function

2. The Stefan Boltzmann Law

3. Neither one is appropriate because you would need to know the wavelengths of radiation the Earth emits

4. Don't know

☺ **Record your Q3 answer now**

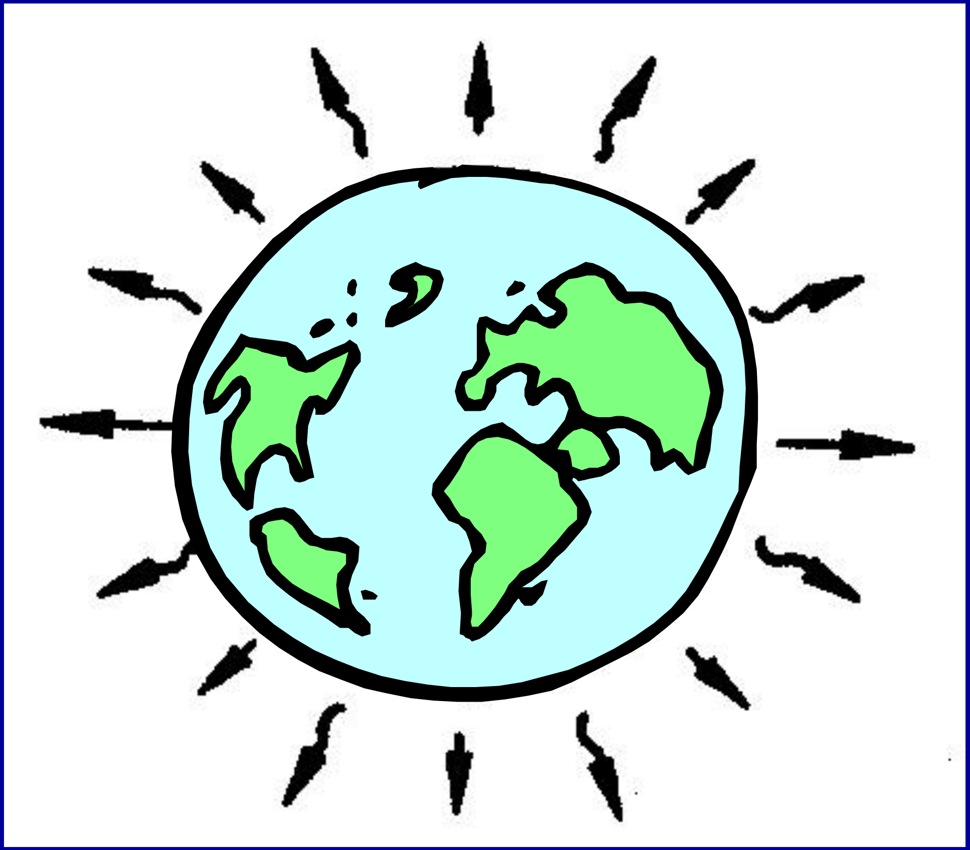
Q3 – Which would you use:
the Planck Function or the Stefan-Boltzmann Law
to compute the total amount of energy
emitted to space by planet Earth,
IF you assume the Earth emits like a blackbody
& you know the Earth's temperature?

1. The Planck Function
2. The Stefan Boltzmann Law
3. Neither one is appropriate because you would need to know the wavelengths of radiation the Earth emits
4. Don't know

How to do it:

$$E = \sigma T^4$$

E = **Energy per unit area**, so all we need to know is the **AREA** of the emitting Earth's surface + what T is.



From geometry: Do you remember the formula for computing the area of a sphere?

The area of a sphere of radius R is
$$4 \pi R^2$$

$$E = 4 \pi R^2 \times \sigma T^4$$

See box on p 42 in SGC for more details

LAW # 4: Temperature and wavelength

As substances get HOTTER, the wavelength at which radiation is emitted will become SHORTER.

This is called Wien's law.

Wien's Law can be represented as:

$$\lambda_m = a/T$$

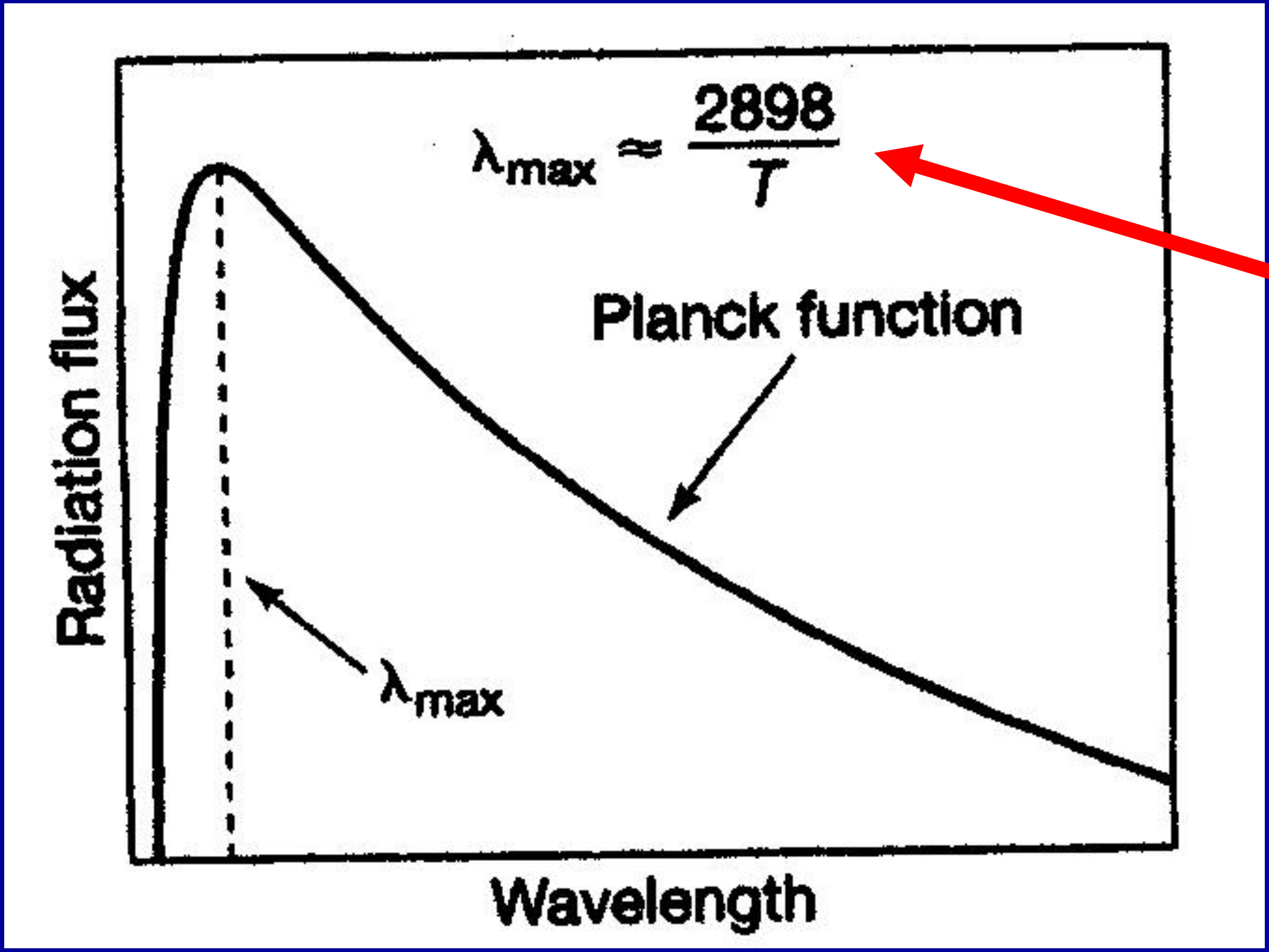
where λ_m is the **WAVELENGTH** in the spectrum at which the energy <u>peak</u> occurs,

(m indicates "max")

T is the absolute **TEMPERATURE** of the body, and

a is a **constant** (with a value of 2898)

(if λ_m is expressed in micrometers.)



Note the INVERSE relationship between wavelength and temperature

See p 40 in SGC-I

Wien's Law (easy way)

λ_{max} = constant / T

(Inverse relationship between wavelength and temperature)

"The <u>hotter</u> the body, the <u>shorter</u> the wavelength"

"The <u>cooler</u> the body, the <u>longer</u> the wavelength"

Wien's Law -- Why is this concept important?

Because it means that **very HOT objects** (like the sun) that radiate like blackbodies will radiate the maximum amount of energy at **SHORT wavelengths**,

while **COOLER** bodies will radiate most of their energy at **LONGER wavelengths.**

Wein's Law:

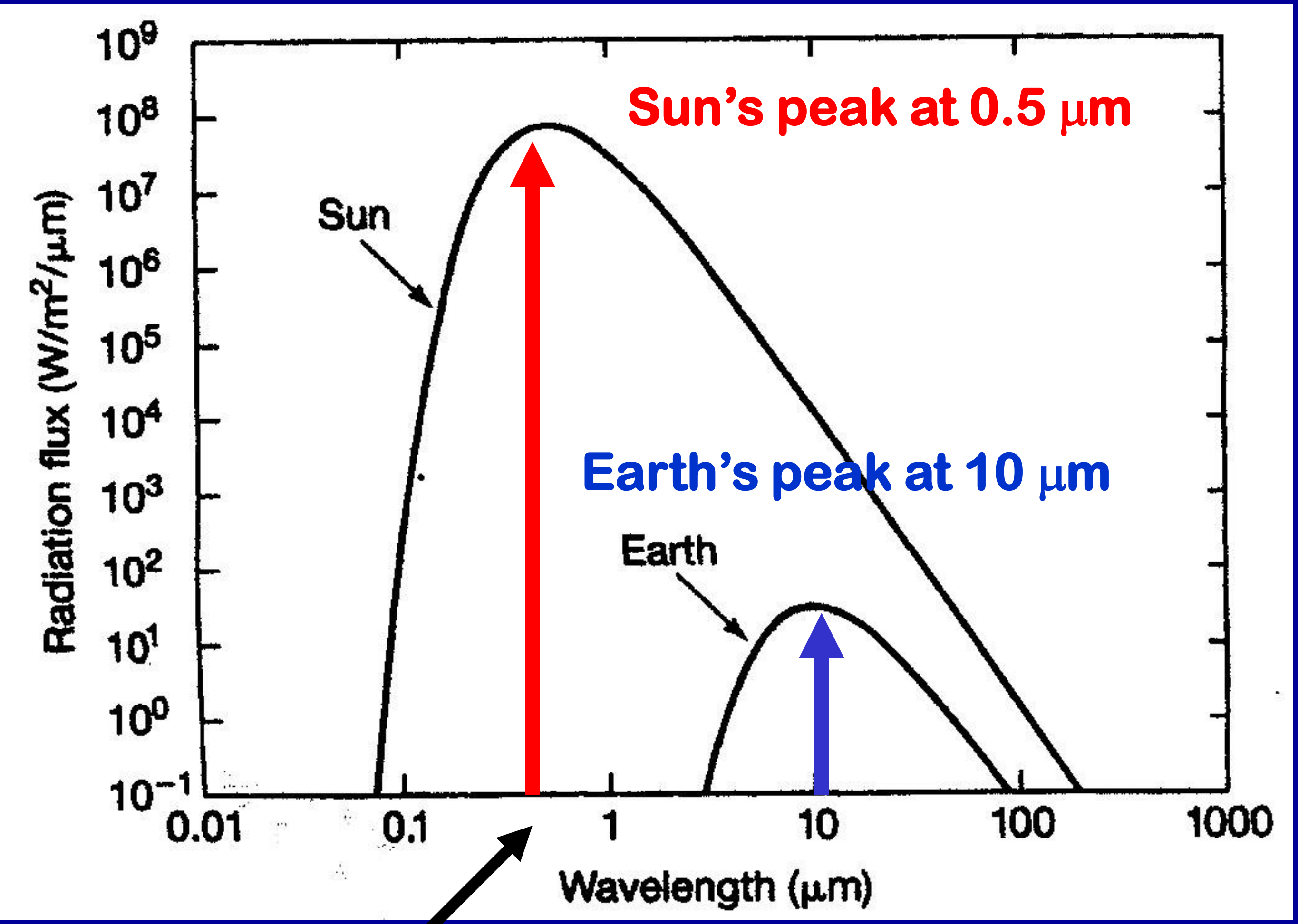
"I'm HOT, so I emit my maximum amount of radiation at SHORTER wavelengths"

SW = visible & ultraviolet (UV)

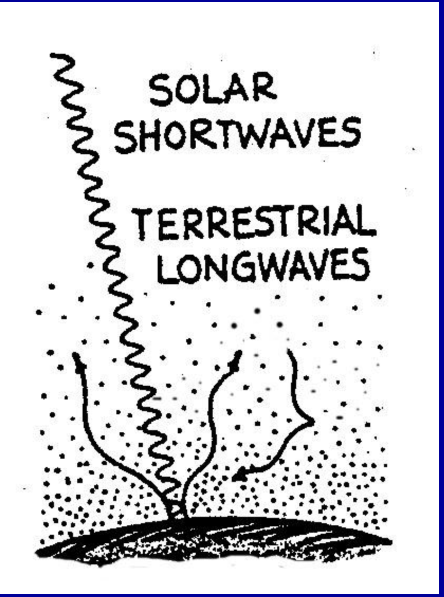
"I'm COOL, so I emit my maximum amount of radiation at LONGER wavelengths"

LW = infrared (IR)

☺



Wein's is the law behind this cartoon (on p 33)



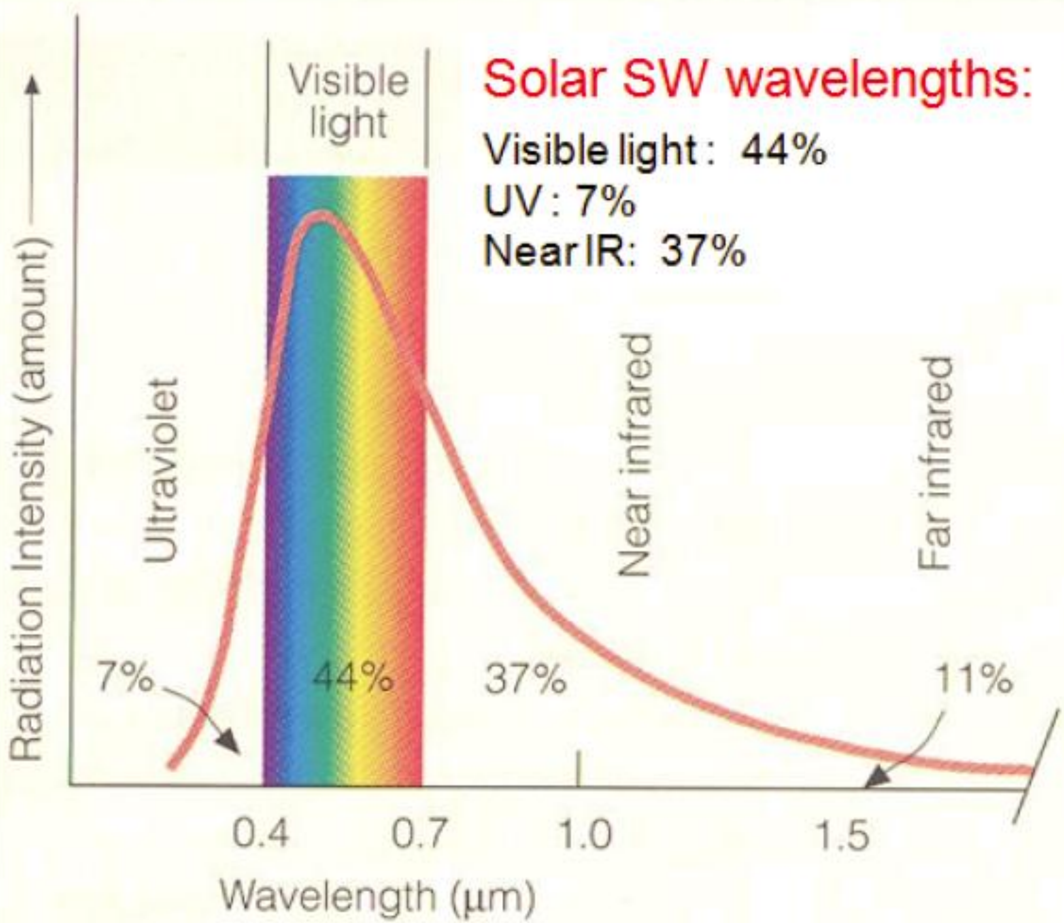
NOTE: this is a logarithmic scale -- values increase exponentially to the right

Shortwave SOLAR radiation

(SW) = UV + VIS + Near IR

TERRESTRIAL radiation

(LW) = Far IR

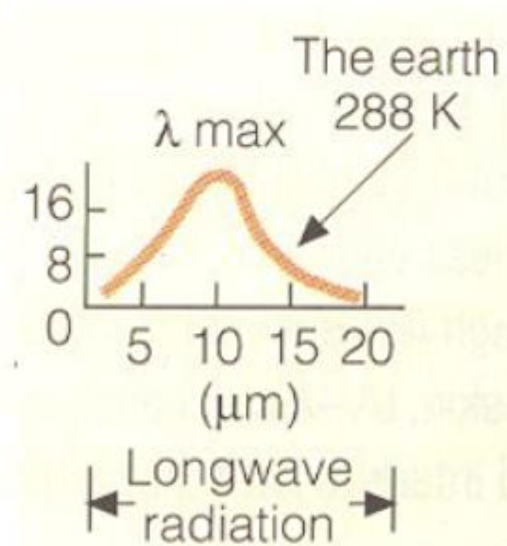


Solar SW wavelengths:

Visible light : 44%
UV : 7%
Near IR: 37%

Terrestrial (Earth) radiation wavelengths:

Far IR, with a maximum at ~ 10 μm



THE RADIATION LAWS

Re-cap of Laws # 2 - 4

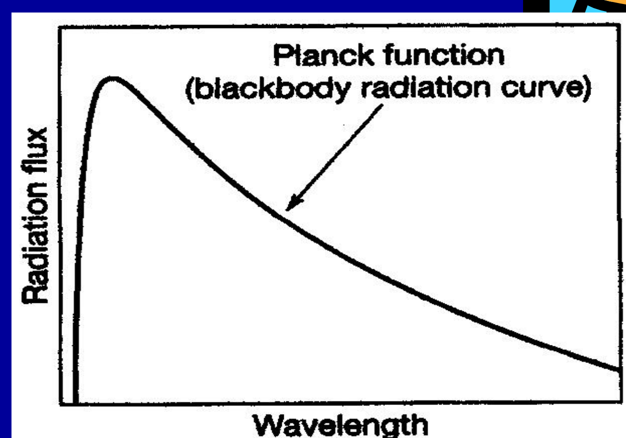
☺

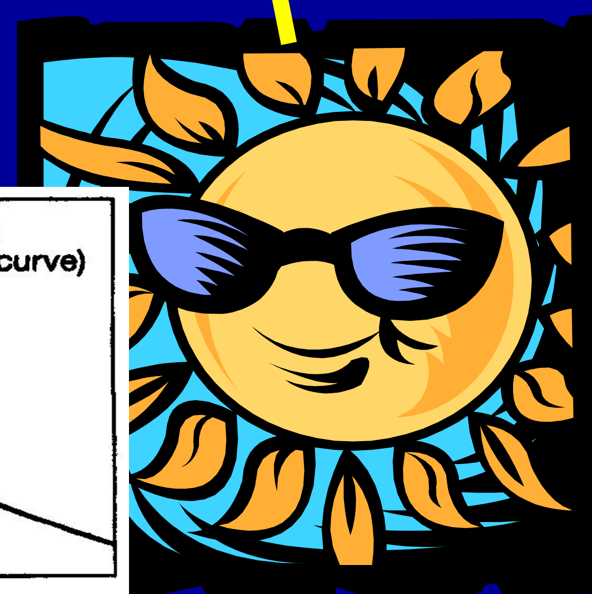
Planck Function:

$$E = h c / \lambda$$

The Sun can emit energy at ALL wavelengths, but the amount of energy emitted is inversely related to its wavelength.

“I radiate at the speed of light like a blackbody; most of my energy is emitted at shorter wavelengths “





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Stefan-Boltzmann Law:

$$E = \sigma T^4$$

"I'm HOT, so I emit LARGE amounts of high intensity energy"

"I'm COOL, so I emit LESSER amounts of energy; *plus* my ENERGY is at a lower intensity than Mr. Hotshot over there!"

Wein's Law: $\lambda_m = a / T$

"I'm HOT, so I emit my maximum amount of radiation at SHORTER wavelengths"

SW = visible & ultraviolet (UV)

"I'm COOL, so I emit my maximum amount of radiation at LONGER wavelengths"

LW = infrared (IR)

☺

Q4 – Which choice correctly matches the Stefan-Boltzmann LAW with its "mantra" (A, B, C):

A "The hotter the body, the shorter the wavelength"
The cooler the body, the longer the wavelength"

B "SHORTER wavelengths have HIGHER intensity radiation than LONGER wavelengths "

C "The hotter the body, the (much) greater the amount of energy flux or radiation"

☺ Record your Q4 answer now

(A) Wein's Law: $\lambda_m = a / T$

"The hotter the body, the shorter the wavelength"
The cooler the body, the longer the wavelength"

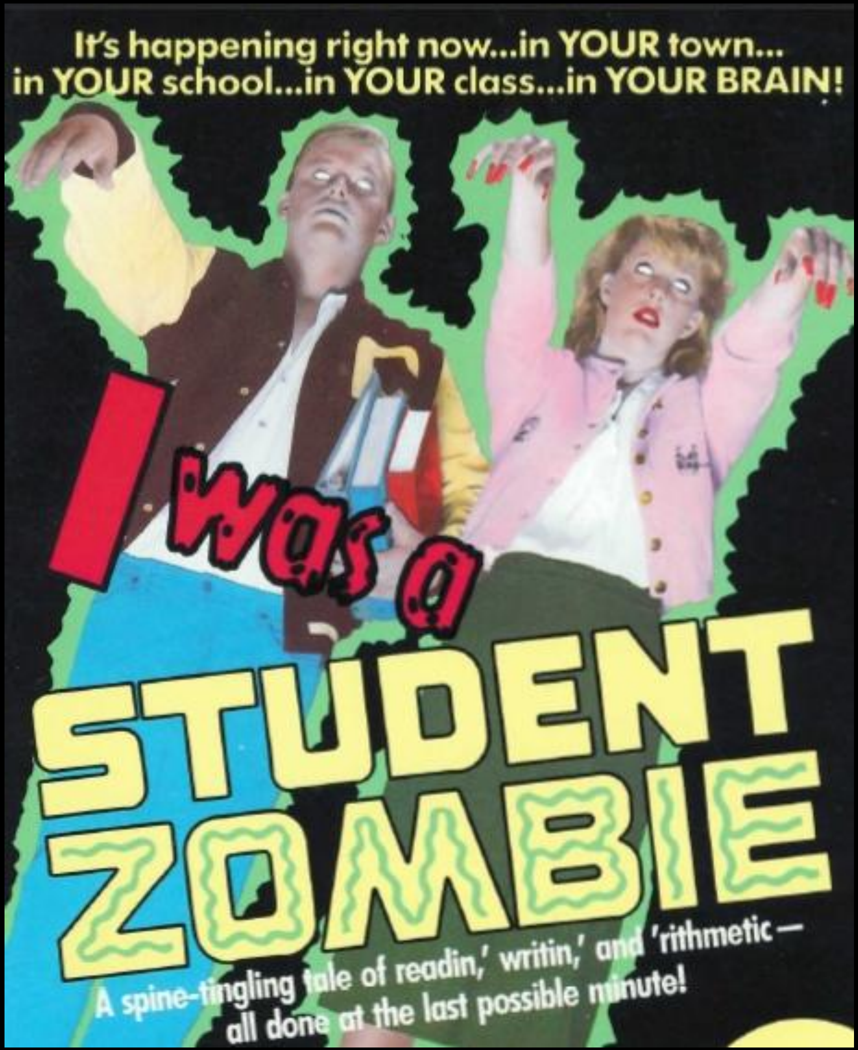
(B) Planck Function: $E = h c / \lambda$

"SHORTER wavelengths have HIGHER intensity radiation than LONGER wavelengths"

(C) Stefan-Boltzmann Law: $E = \sigma T^4$

"The hotter the body, the (much) greater the amount of energy flux or radiation"

☺



ZOMBIE BREAK !

SUSTAINABILITY SEGMENT

more of:

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

LAW #5: Radiation & distance -- the inverse-square law

The inverse square law describes:

how solar **FLUX of ENERGY**
decreases
with increasing **DISTANCE**
from the source of
the flux (i.e., the radiation),
the Sun.

INVERSE SQUARE LAW =

The amount of radiation passing through a particular unit area is:

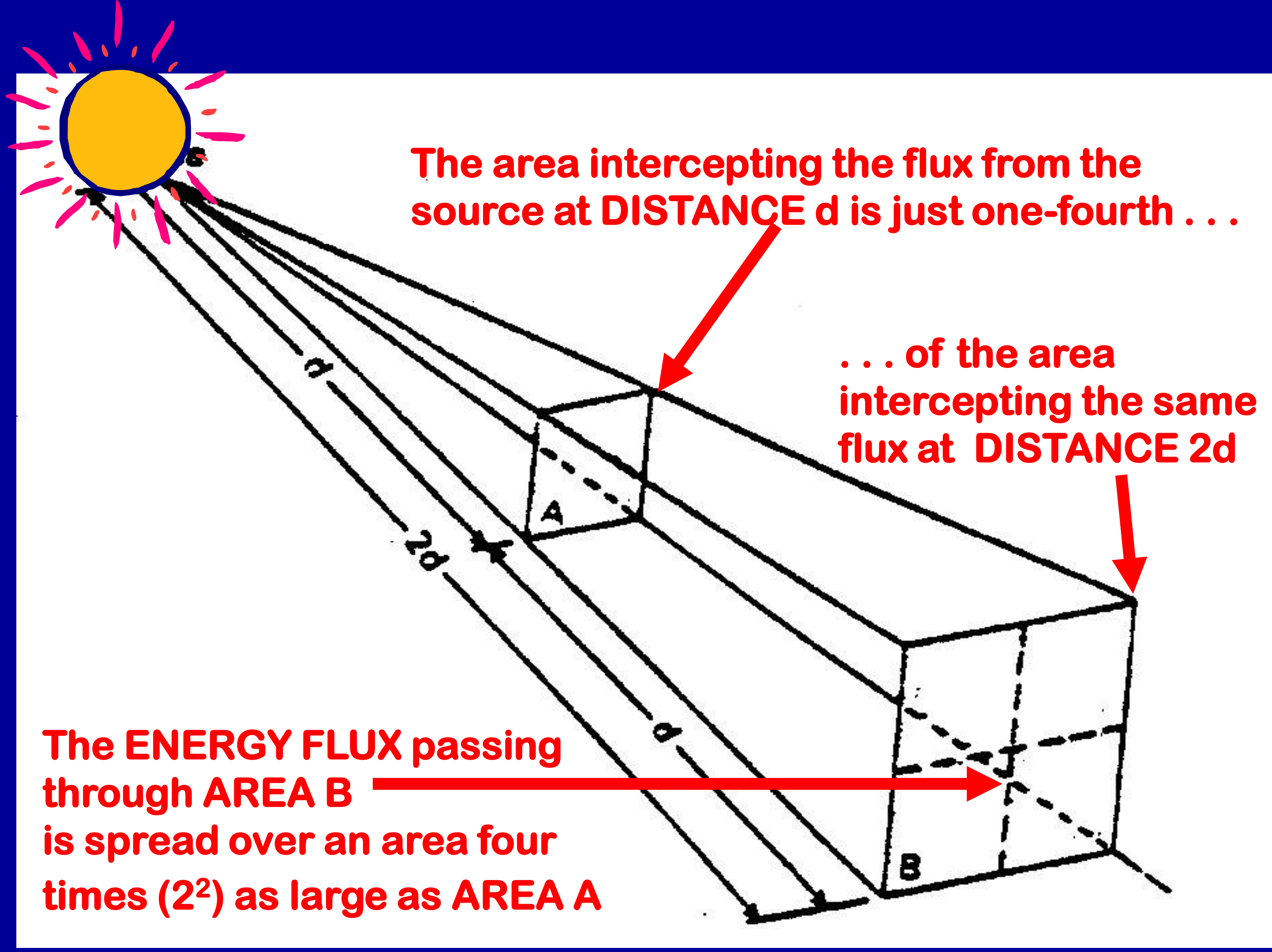
INVERSELY PROPORTIONAL

to the

SQUARE of the distance

of that unit area from the source

$$(1/d^2)$$


The area intercepting the flux from the source at DISTANCE d is just one-fourth . . .
. . . of the area intercepting the same flux at DISTANCE 2d
The ENERGY FLUX passing through AREA B is spread over an area four times (2²) as large as AREA A
d
2d
d
A
B

Inverse-Square Law (easy way):

If we double the distance from the source to the interception point, the intensity of the radiation decreases by a factor of

$(1/2)^2 = 1/4$

If we triple the distance from the source to the interception point, the intensity decreases by a factor of

$(1/3)^2 = 1/9$

☺

OR if we reduce the distance from the source to the interception point by a factor of 2 or 3, the intensity of the radiation increases by a factor of

$2^2 = 4$

or

$3^2 = 9$

☺

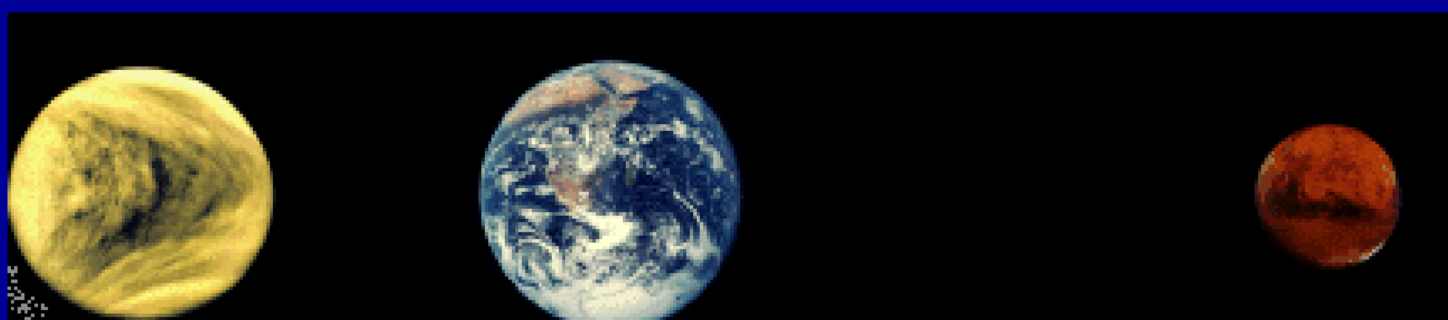
Why is this concept important?

Because it means that <u>relatively SMALL changes in distance</u> from the source of energy (e.g., the Sun)

can result in <u>LARGE changes</u> in the <u>amount of energy</u> received by a planet's surface.

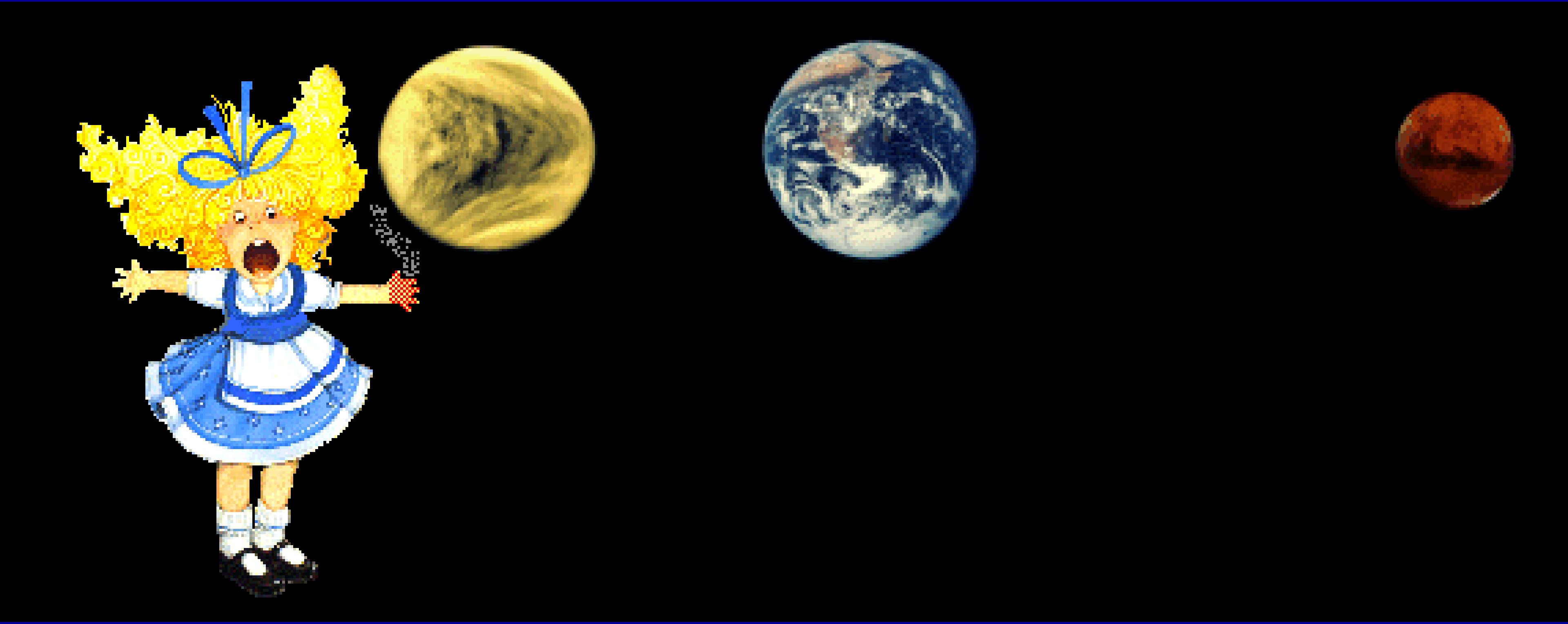
GOLDILOCKS & THE 3 PLANETS

← to Sun



VENUS EARTH MARS

GOLDILOCKS & THE 3 PLANETS



Yikes! Venus is too HOT!

GOLDILOCKS & THE 3 PLANETS

Brrrrrrrrr, Mars is too COLD!!

GOLDILOCKS & THE 3 PLANETS

Ahhhh! Earth is JUST RIGHT!

Q5 The inverse-square law applied to the distance between a planet and the Sun is what determines that planet's temperature. YES or NO?

1. Yes, this is what the Goldilock's Effect is illustrating.

2. No, how much solar energy the planet reflects back must also be taken into account

3. No, whether or not the planet has a greenhouse effect must also be taken into account.

☺ Record your Q5 answer now

Q5 The <u>inverse-square law</u> applied to the distance between a planet and the Sun is what determines that planet's temperature. <u>YES</u> or <u>NO</u>?

1. <u>Yes</u>, this is what the **Goldilock's Effect** is illustrating.

2. <u>No</u>, how much solar energy the planet **reflects back** must also be taken into account

3. <u>No</u>, whether or not the planet has a **greenhouse effect** must also be taken into account.

Both 2 & 3 are correct!

TRICK QUESTION!

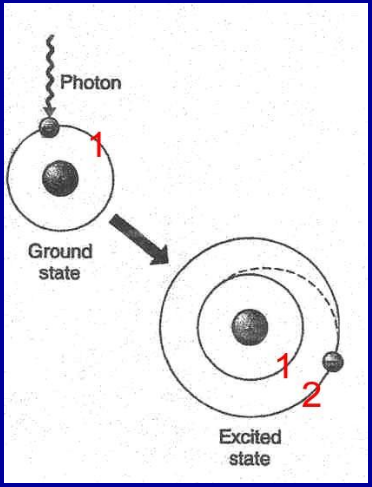
LAW #6: Selective emission and absorption

Some substances emit and absorb radiation at **certain wavelengths only.**

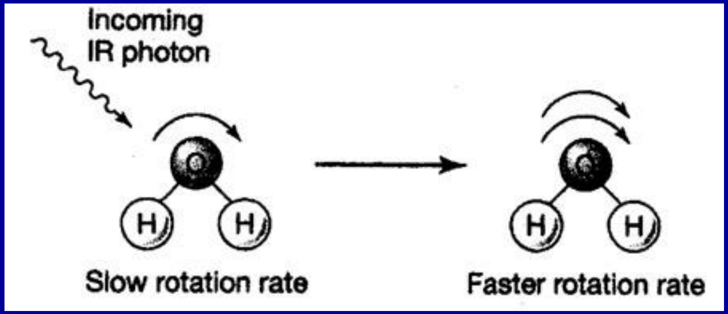
This is mainly true of gases.

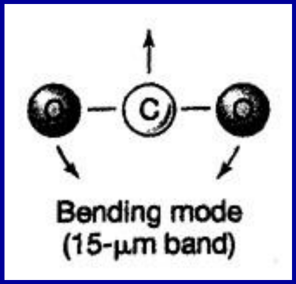
Why?

Recall concept of electron energy states (shells) allowing absorption of photons/wavelengths of **only a specified frequency**,



. . . and concept of certain **gas molecules** allowing absorption of photons/wavelengths of **only specified frequencies** because of how the gas molecules vibrate, bend, and rotate

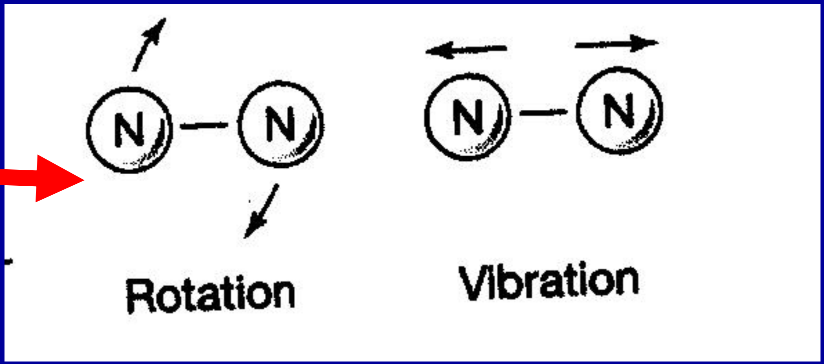




review

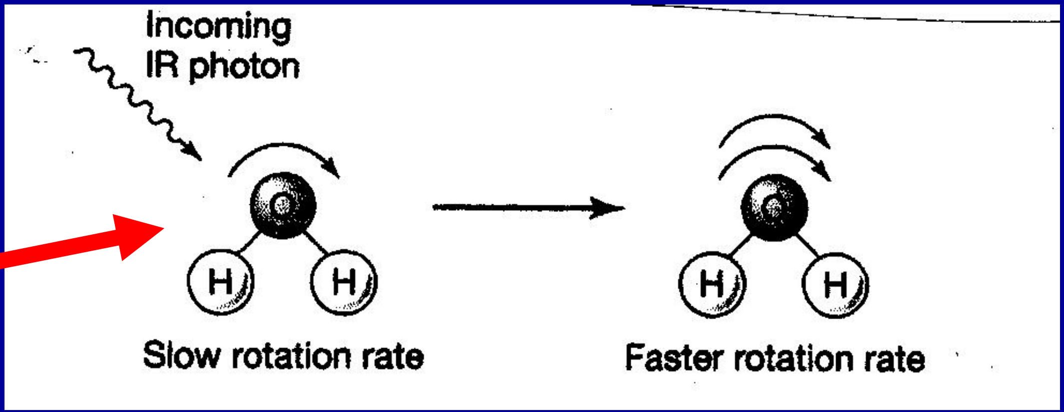
NOT a GREENHOUSE GAS

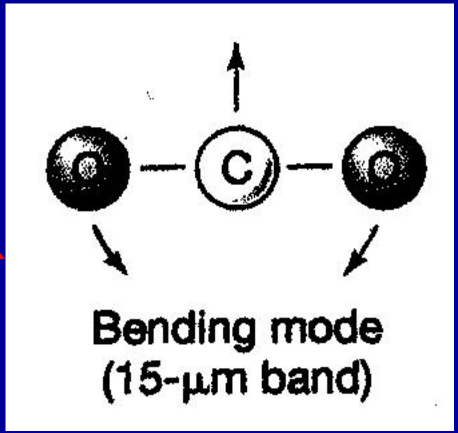
N_2

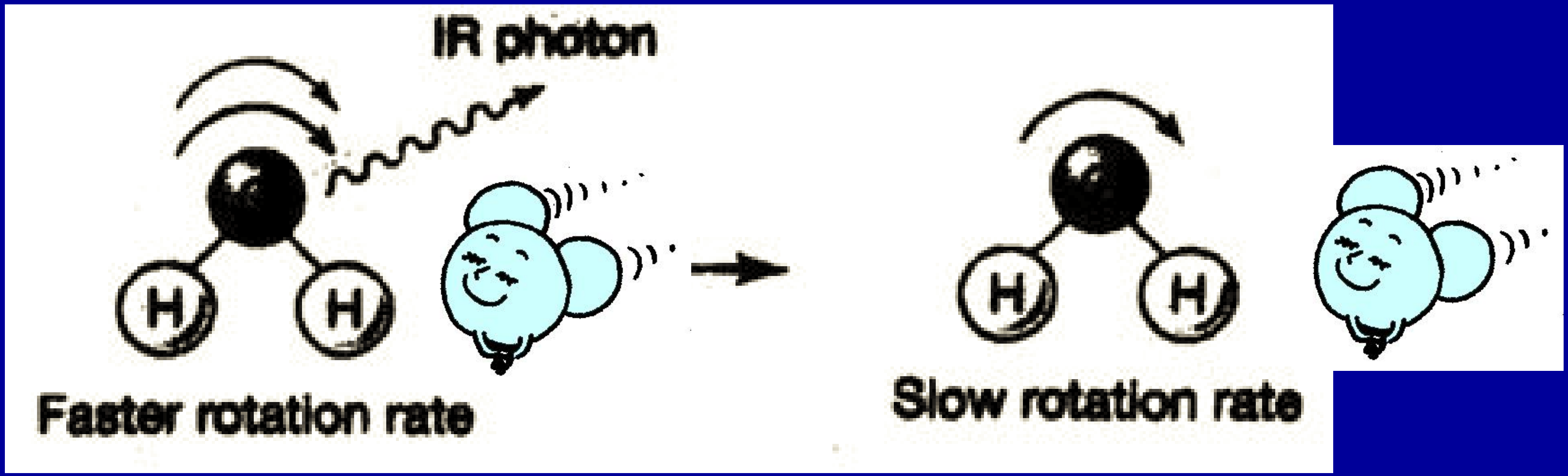


GREENHOUSE GASES

H_20 & CO_2





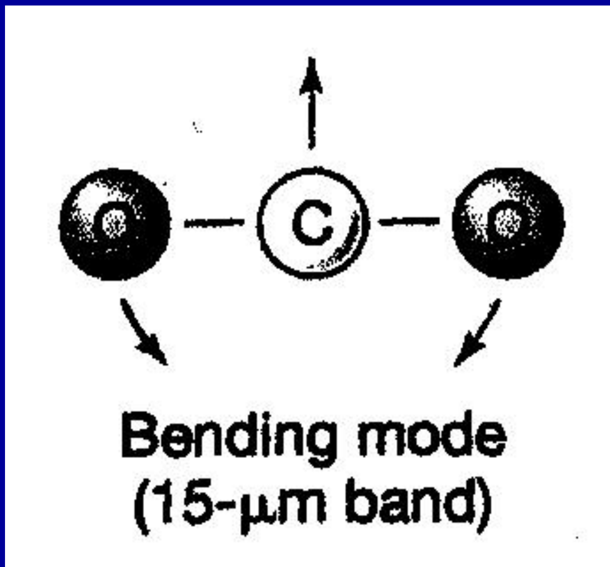


When the H_2O molecule emits a photon, its **rotation rate** decreases;

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.

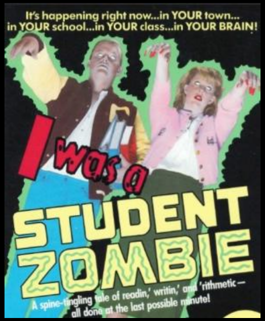


SGC-I Chapter 3

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)?



Mini-
ZOMBIE
BREAK !

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!

Recap: LAW # 6 states that

Substances absorb only radiation of wavelengths they can emit.

The frequency & wavelength of a photon absorbed by a given electron, atom, molecule will be the same as the frequency / wavelength with which it is emitted.

DEFINITION OF GREENHOUSE GASES

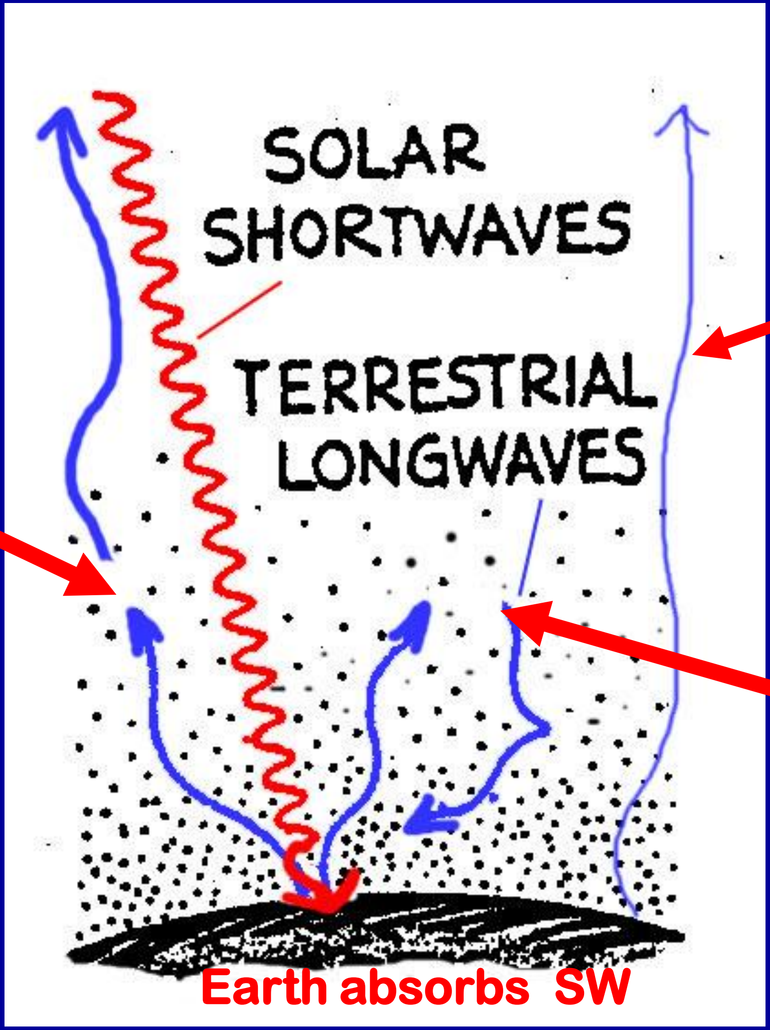
(def): **Greenhouse gases are gases which both absorb and emit electromagnetic radiation in the infrared (IR) part of the spectrum.**

Once IR is absorbed by the greenhouse gases in the atmosphere, it can be emitted back to the Earth's surface to heat it all over again!

Or it can be emitted upward to outer space and be lost from the system altogether.

Modified cartoon representation, showing possible IR pathways:

IR radiation is absorbed by GH gases in the atmosphere and emitted out to space



IR radiation is emitted from the Earth's surface right out to space through "IR window"

IR radiation is absorbed by GH gases in the atmosphere and emitted back to Earth

The **absorbtion** of LW (IR) radiation and **the re-radiation** of LW (IR) energy to the Earth's surface by GH gases is what keeps the Earth in the **"just right" temperature range** for water to be present in all 3 phases and just right for US too!

Without the "Greenhouse Effect," the Earth would be too COLD for life as we know it!

☺

Thanks, Greenhouse Effect!

Law # 6 to be wrapped up next time . . . . .

Come with questions about Assignment I-2 after you read through it!

DON'T FORGET SELF TEST 3 3 & RQ-3 !!

Tuesday Sep 21st

TODAY: SIT ANYWHERE YOU WANT TODAY !

ANNOUNCEMENTS:

- REMINDER: SELF TEST & RQ-3 are DUE THIS WEEK!
  RQ-3 will be cut off Thursday (Sep 23rd) 30 minutes before class!

- ASSIGNMENT I-2 is now posted. It is due one week from today:
  Sep 28th before 11:59 pm in the D2L Dropbox
  Key details in class today – your questions answered on Thursday

- Various grades are being entered in your D2L GRADEBOOK as the grading gets completed, so please check your gradebooks.
  (Assignments I-1 and G-2 are still being graded so do not appear; Test # 1 grades will appear soon.)

- Need specific help? Want to discuss Global Change issues?
  Come to our OFFICE HOURS – we are LONELY! They are held every day of the week (except Friday for this class – see the TEACHING TEAM section of the webpage for when and where.