

WRAP UP OF TOPIC #5 . . .

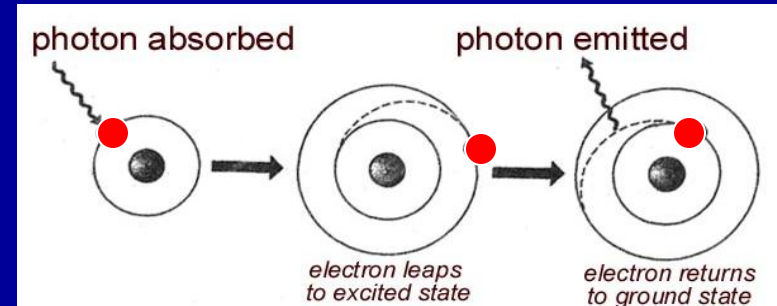
**ELECTROMANGETIC
RADAITAION
&
THE ELECTROMAGNETIC
SPECTRUM**

ATOMS vs MOLECULES

Quantum leap of electrons

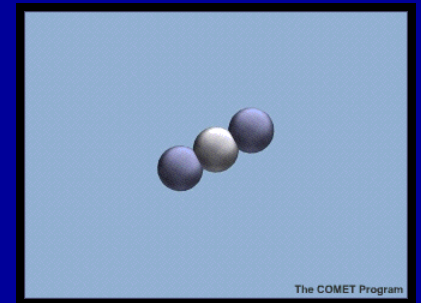
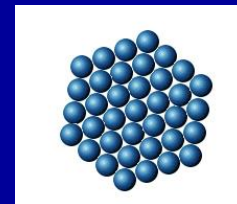
WITHIN an ATOM

when photons are
absorbed or emitted →



Quantum MOLECULAR MOTION

behavior when photons are
absorbed or emitted

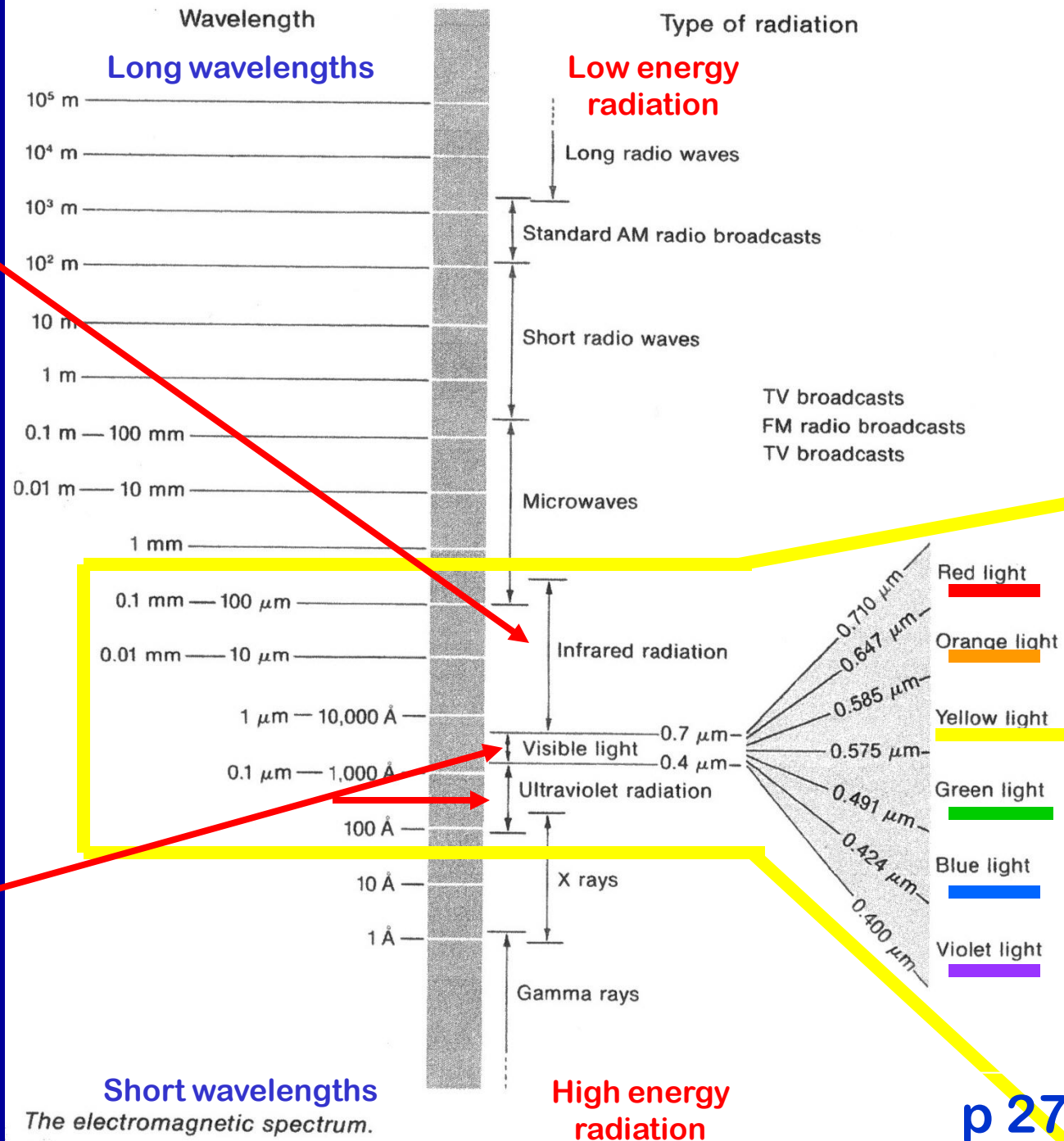


Review p 26

Longwaves (LW)


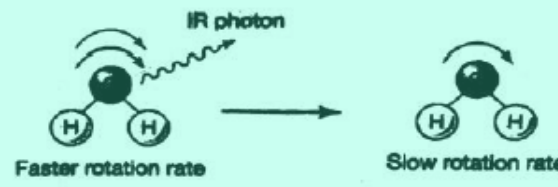
The Electromagnetic Spectrum (another view)

Shortwaves (SW)



Details on the spectrum: UV Vis IR

Visible Light range = 0.4 – 0.7 micrometers

Type of Electromagnetic Radiation	Range of Wavelengths (in units indicated)	Additional Information
Gamma rays	10^{-16} to 10^{-11} in meters (m) using scientific notation	Involve high-energy processes <u>within a nucleus</u> caused by the strong force
UV Ultraviolet radiation UVC .20 - .29 UVB .29 - .32 UVA .32 - .40	.0001 to 0.4 in micrometers (μm)	Involve electrons moving (quantum leaps) <u>within atoms</u> 
VIS Visible light Solar	0.4 to 0.7 in micrometers (μm)	
IR Infrared radiation	0.7 to ~30 (up to 1000) in micrometers (μm)	Involve chaotic thermal <u>kinetic motion of molecules</u> due to their thermal energy 
IR Near Infrared radiation Longwave	0.7 - 1.0 in micrometers (μm)	
IR Far Infrared Infrared	1.0 - ~30 (up to 1000) in micrometers (μm)	
Microwaves	10^{-4} to 10^{-2} in meters (m) using scientific notation	occur in nature & also electronically produced by a "magnetron" in a microwave oven
AM Radio waves	10 to 10^2 in meters (m) using scientific notation	occur in nature & also electronically produced in human-made electrical circuits

What is the relationship between . . .

ENERGY E and **FREQUENCY ν**

OF PHOTONS ?

KEY CONCEPT #1:

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

\propto = “is proportional to”

$$E \propto \nu$$

What is the relationship between . . .

ENERGY E and **WAVELENGTH λ**

OF PHOTONS ?

KEY CONCEPT #2:

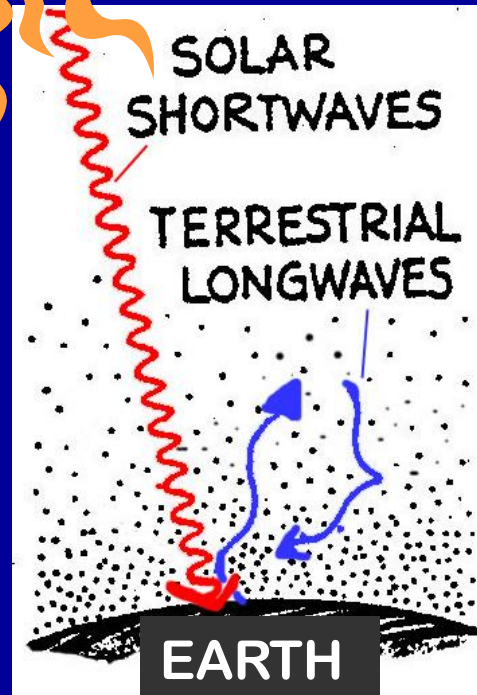
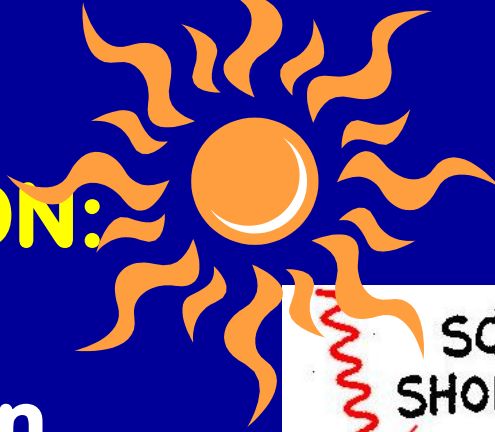
The **Energy E** of photons is **inversely**
proportional to their **wavelength λ**

$$E \propto c / \lambda$$



$c = \text{speed of light} = \text{a constant}$

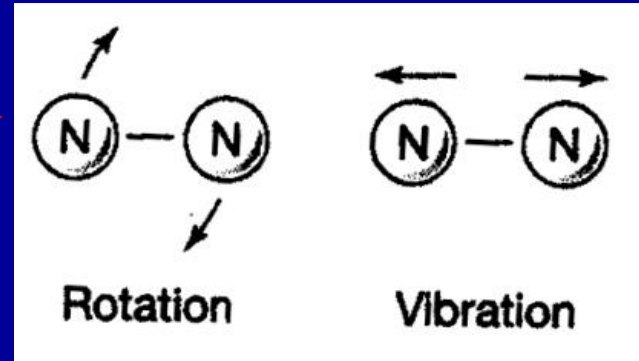
SOLAR RADIATION:
greatest intensity in **SHORT** wavelengths
(high energy & frequency)



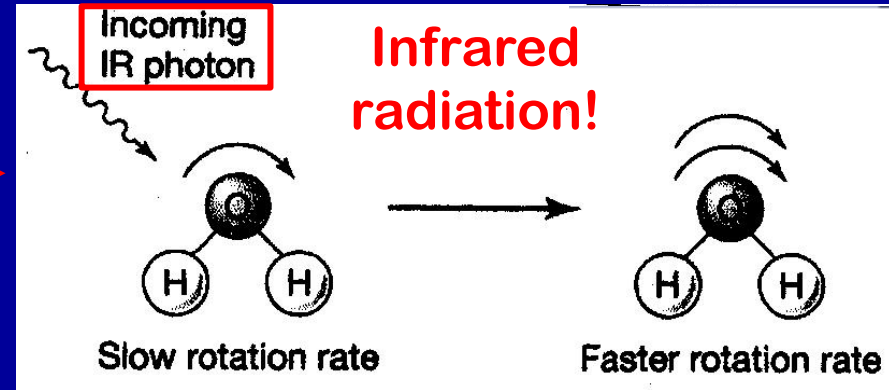
EARTH RADIATION:
entirely in **LONG** wavelengths
(low energy & frequency)

The wavelength determines how the electromagnetic ENERGY (photon) will interact with MATTER !

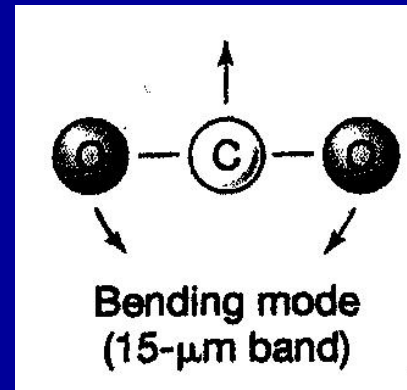
**NITROGEN GAS
MOLECULE**
 N_2



**WATER VAPOR
MOLECULE**
 H_2O



**CARBON
DIOXIDE GAS
MOLECULE**
 CO_2

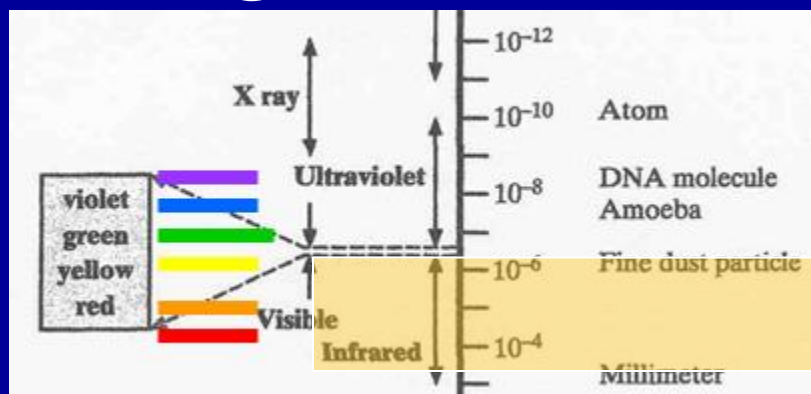


Greenhouse gases!

So what is a **Greenhouse Gas**?

abbreviation we'll use = GHG

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



IR
radiation

> 0.7 - 1000 micrometers



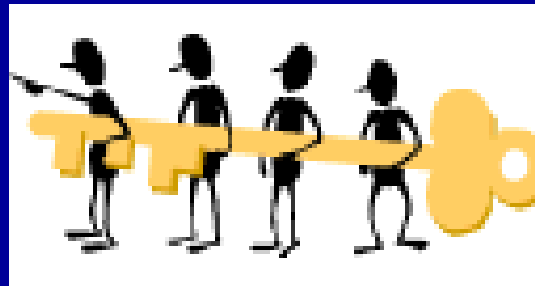
KEY POINT:

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

TOPIC # 6

The RADIATION LAWS

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



TODAY: Topic #6 – Part I
pp 29-31

$$E = \sigma T^4$$

**“The equations we seek
are the poetry of nature
Why is nature that way?”**

$$(1/d^2)$$

**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.”**

$$E = hc/\lambda$$

$$\lambda_m = a/T$$

~ Chen Ning Yang (b. 1922) US physicist

OBJECTIVES FOR TODAY'S CLASS:

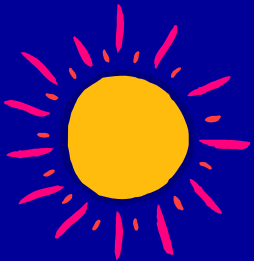
To understand the key
differences between

Solar radiation

&

Terrestrial radiation

based on the principles of
the **“Radiation Laws.”**



FIRE UP YOUR CLICKERS FOR RESPONSE TIME!

Clicker



ResponseWare Device



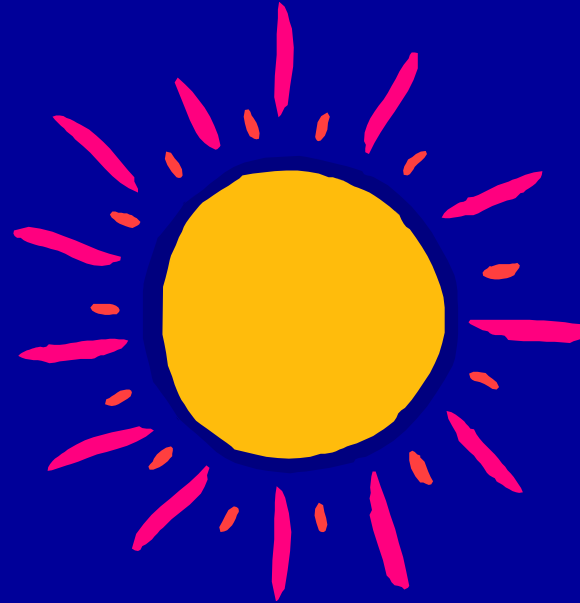
Open your “APP” or
login to: rwpoll.com

**ENTER
CHANNEL = 28**

**ENTER SESSION ID
(see above)**

A “cartoon” view of Solar vs Terrestrial radiation:

**Both Sun & Earth
are radiating
energy**



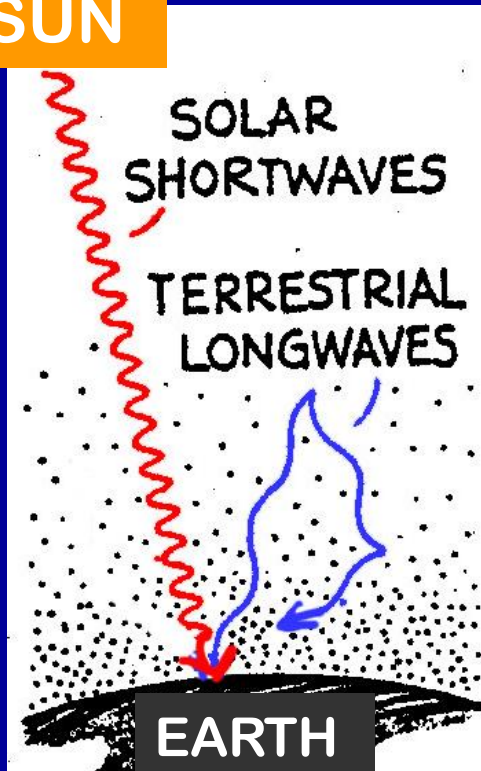
*(Sun & Earth
are NOT shown in proper scale!)*



Warm up question: Which one do you think is the most accurate depiction of the Greenhouse Effect??

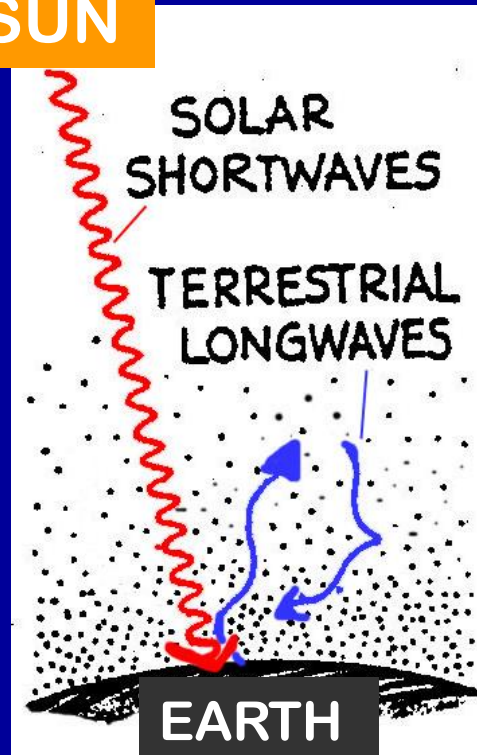
from
SUN

A



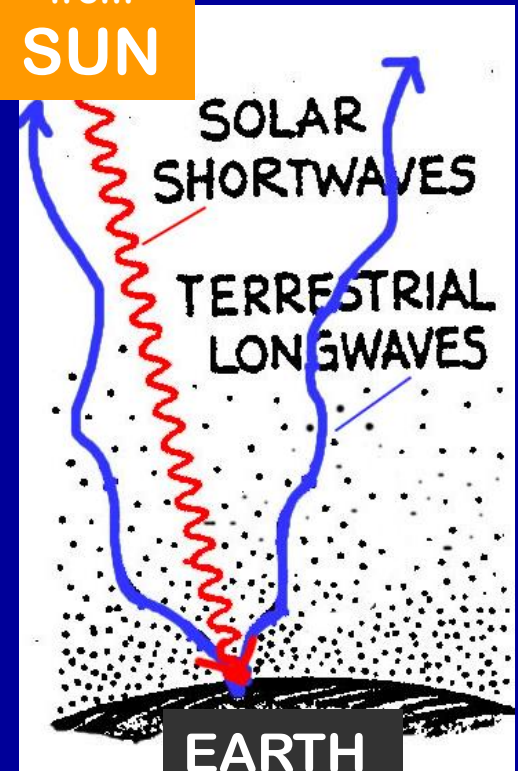
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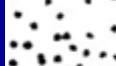
B





from
SUN

C



 = gases in the atmosphere

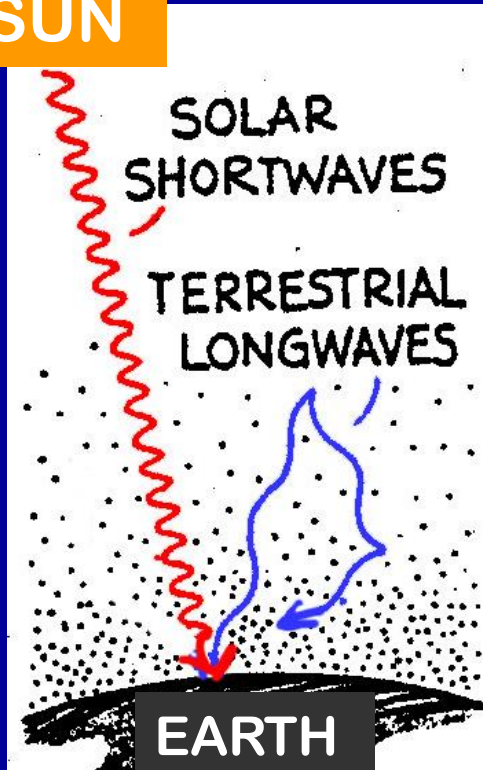
 = solar (shortwave) radiation (High Energy)
 = terrestrial (longwave) radiation (Lower Energy)



Warm up question: **Which one do you think is the most accurate depiction of the Greenhouse Effect??**

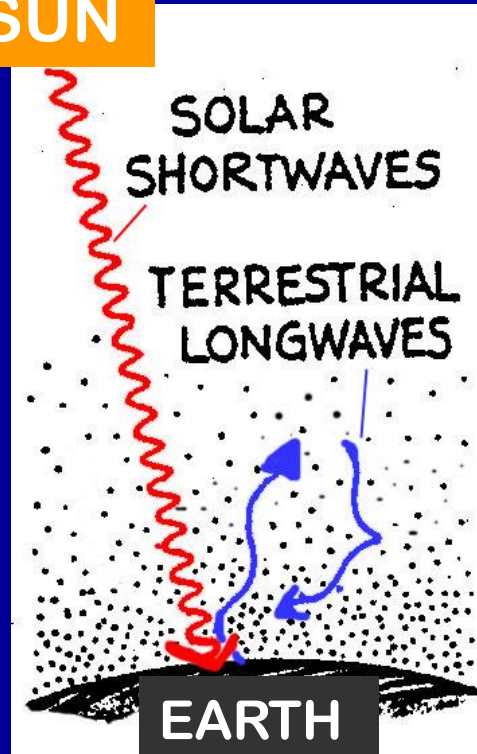
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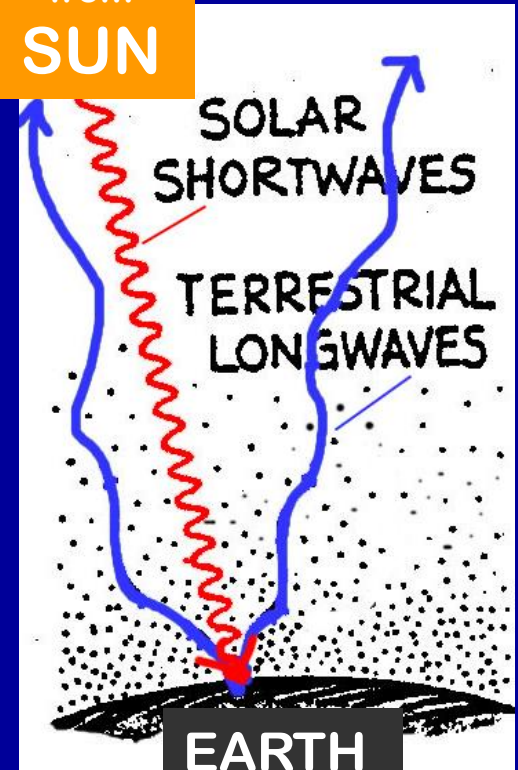
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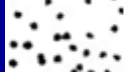
B





from
SUN

C

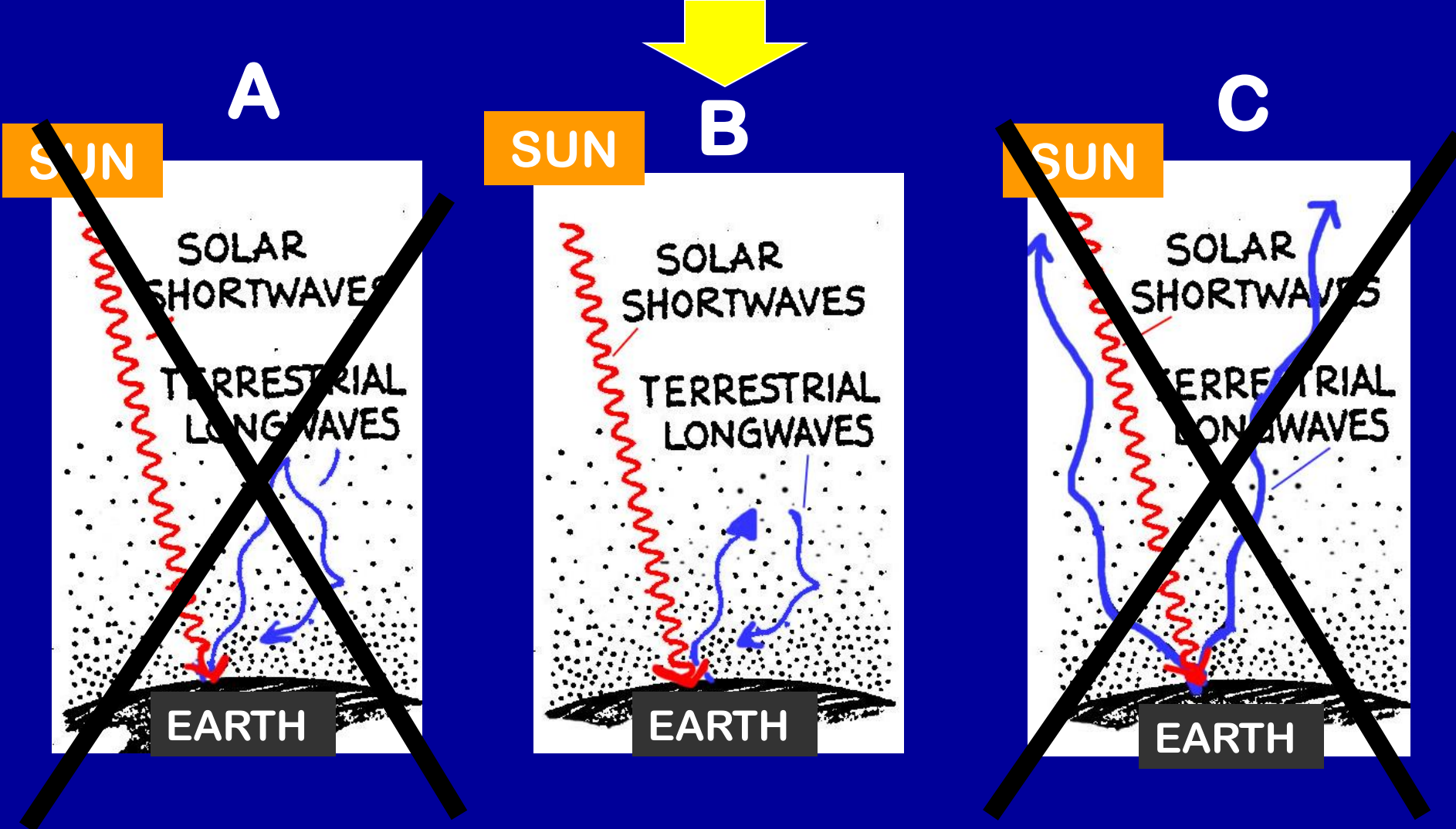


 = gases in the atmosphere

 = solar (shortwave) radiation (High Energy)

 = terrestrial (longwave) radiation (Lower Energy)

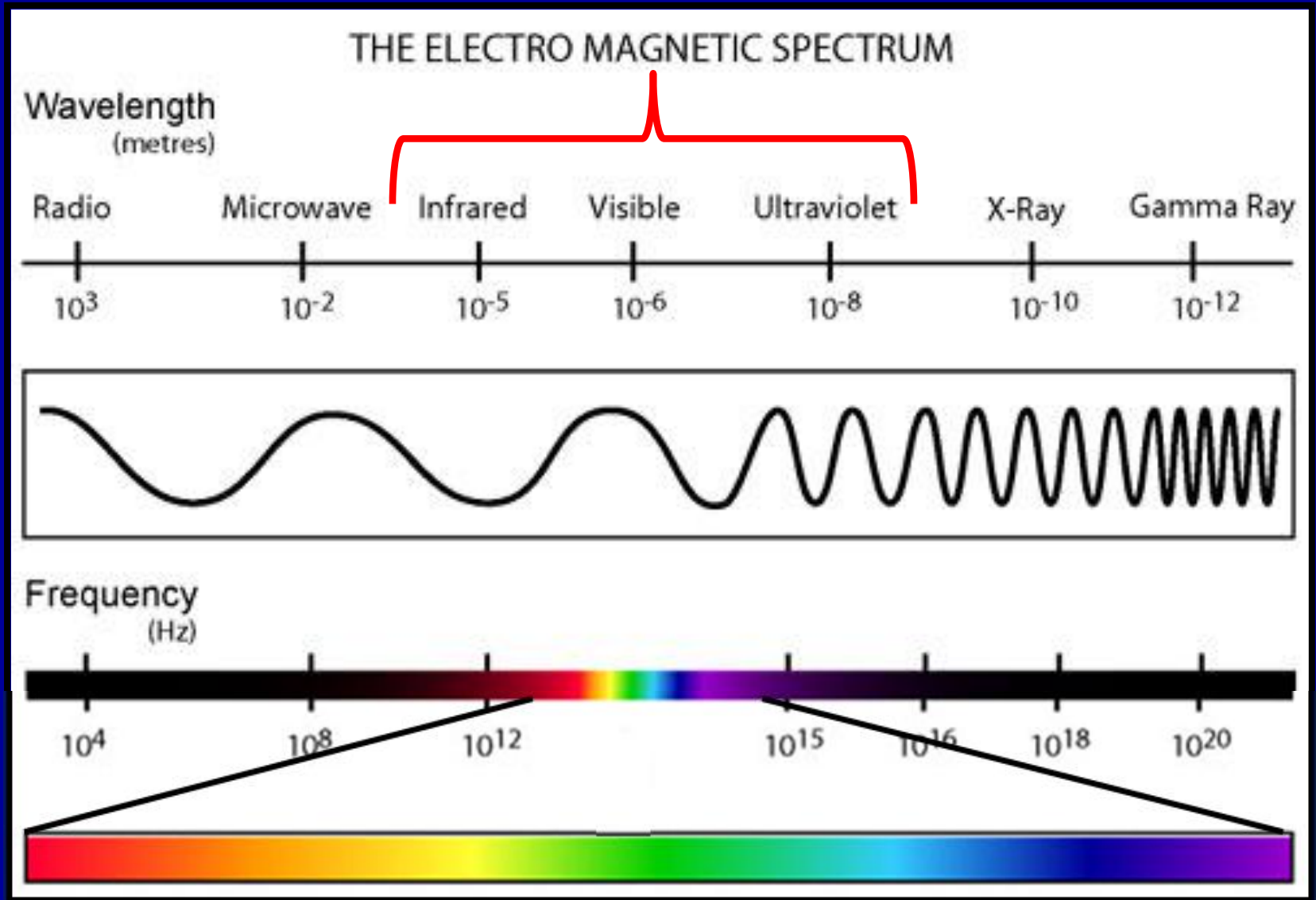




Actually, NONE of these is exactly correct, and we will learn why in a future lecture. . . . but for now, B is the preferred answer see the image on bottom of p 27 in Class Notes.



REVIEW



R

O

Y

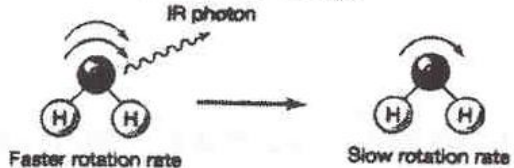
G

B

(I)

V

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	Solar SW .0001 to 0.4 in micrometers (μm)	electrons moving (quantum leaps) within individual atoms
Visible light	0.4 to 0.7	
Infrared radiation	Terrestrial LW (IR)	chaotic thermal kinetic motion of molecules due to their thermal energy
Near Infrared radiation		 <p>Faster rotation rate → Slower rotation rate</p>
Far Infrared		
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

Presenting

THE RADIATION LAWS !!!

**Keys to Understanding
the Greenhouse Effect**



LAW #1

Emission of radiation

All substances emit radiation as long as their temperature is above **absolute zero**

(-273.15°C or 0 Kelvin).

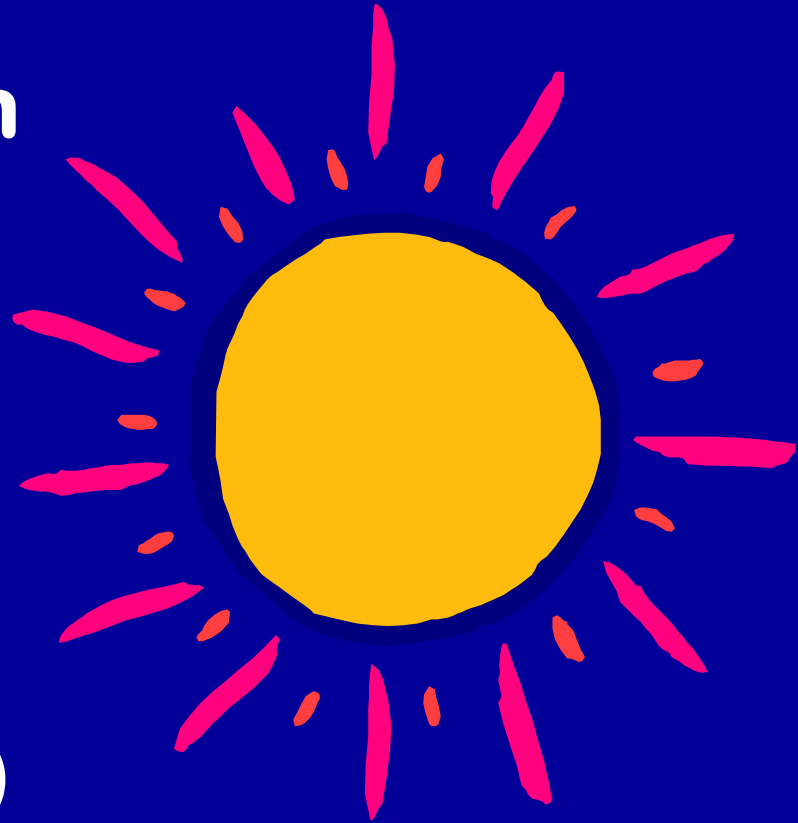
TYING THE RADIATION “LAWS” to GLOBAL CHANGE

The **Sun**'s energy
(**solar**) is emitted in
the form of
electromagnetic
radiation.

mostly

Shortwave (SW)

(but also some LW)

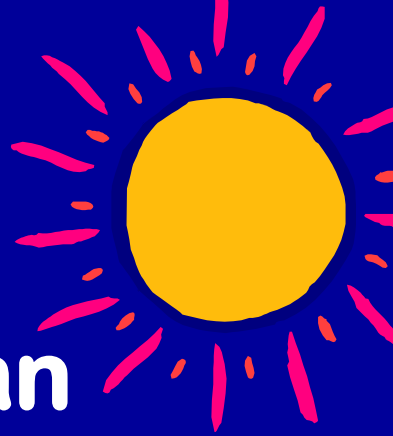


The Earth's
energy
(terrestrial) is
also emitted in
the form of
electromagnetic
wavelengths . . .

but in **LW**
INFRARED (IR)
wavelengths



LAW #2 BLACKBODY & PLANCK FUNCTION CONCEPT



The Sun is very similar to an **“ideal emitter”** (or **“Black body”**)

*(NOTE: the **Earth** is NOT a VERY good “black body” emitter)*

Black body (def): a body that **emits** equally well at **all wavelengths**

(i.e. radiates with 100% efficiency)

It also **absorbs** equally well at all wavelengths and is a **“perfect absorber”**

(hence described as “black”)

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

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

This relationship is called the Planck function :

$$E = h * \text{speed of light} / \text{wavelength}$$

Where (h)
is Planck's
constant.

or

$$E = h c / \lambda$$

Planck Function:

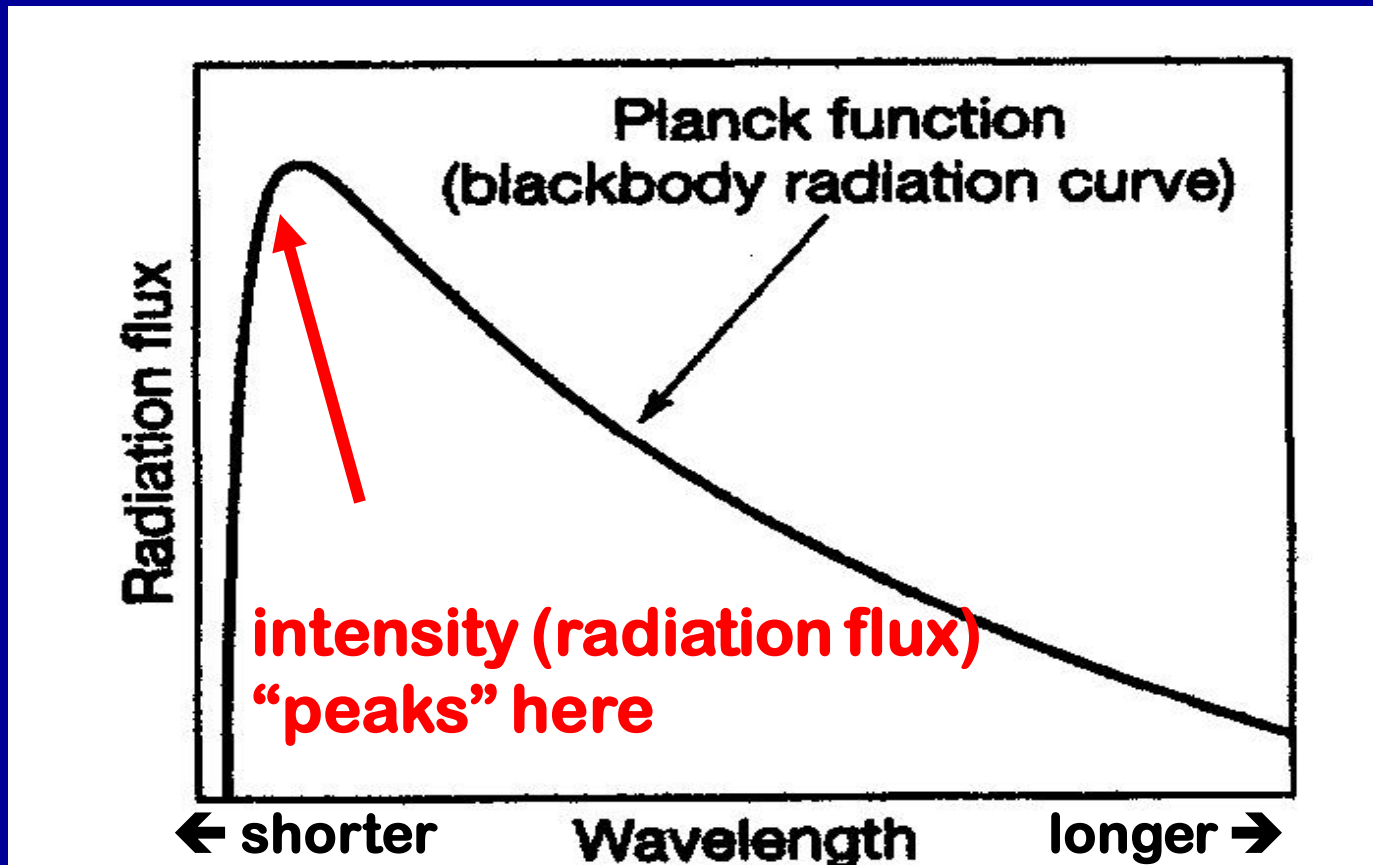
The Sun emits energy at ALL wavelengths . . .

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 greater energy flux than microwave radiation.

1. True

2. False

 **Record your Q1 answer now**

3. Both wavelength bands have the same energy flux

4. We haven't learned enough yet to answer this!

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
 $5.67 \times 10^{-8} \text{ W/m}^2$
(or $5.67 \times 10^{-8} \text{ J/m}^2$)
and T is the absolute temperature
(in Kelvin)

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

Stefan-Boltzmann Law (easy way)

This law links:

(E) the total amount of energy flux that is emitted by a blackbody
& **(T)** the body's temperature

(specifically, 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

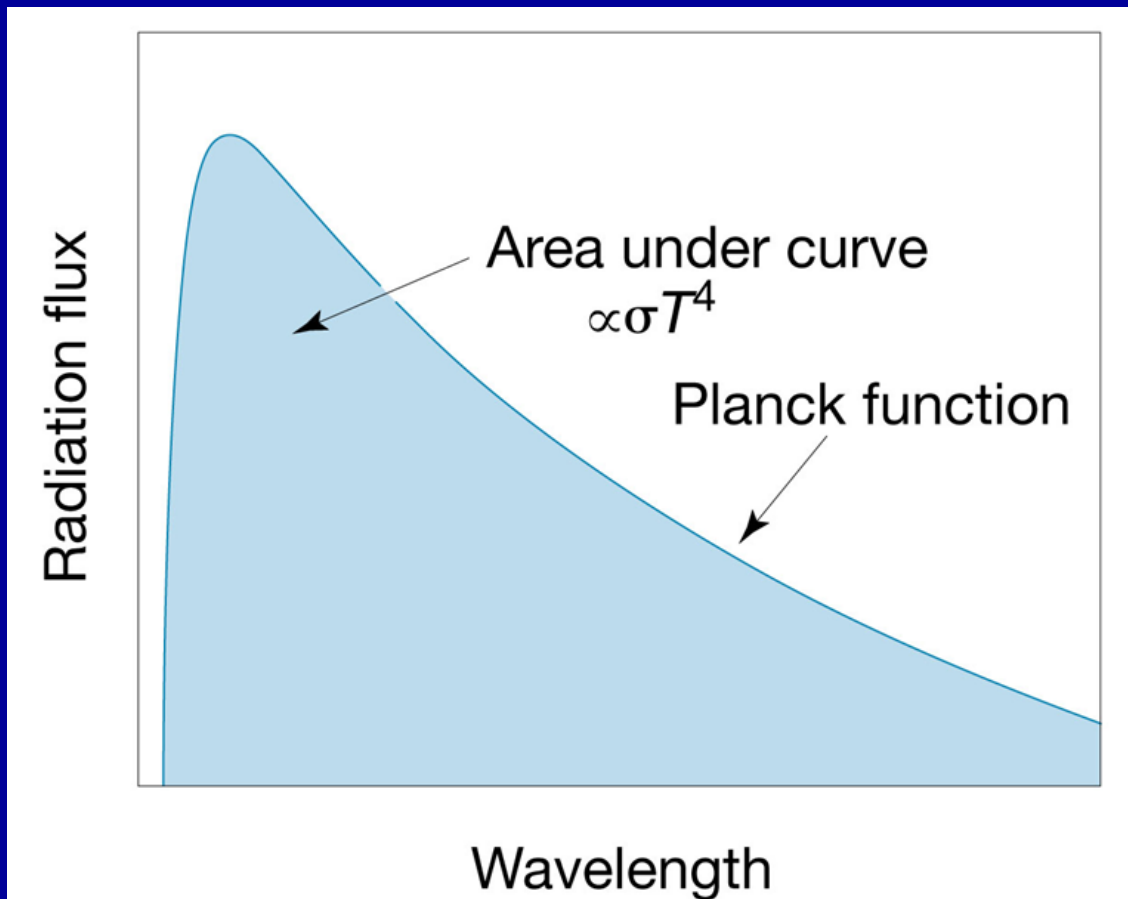


Figure on p 42
in SGC E-text

Stefan-Boltzmann Law:

“I’m HOT, so I emit
LARGE amounts
of high intensity
energy”



“I’m COOL, so I
emit much LESS
energy . . .AND
MY energy is at a
lower intensity
than Mr. Sun over
there!”



Why is this concept important?

Because it means that:

the amount of radiation
given off by a body
is a very sensitive function
of its temperature

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:

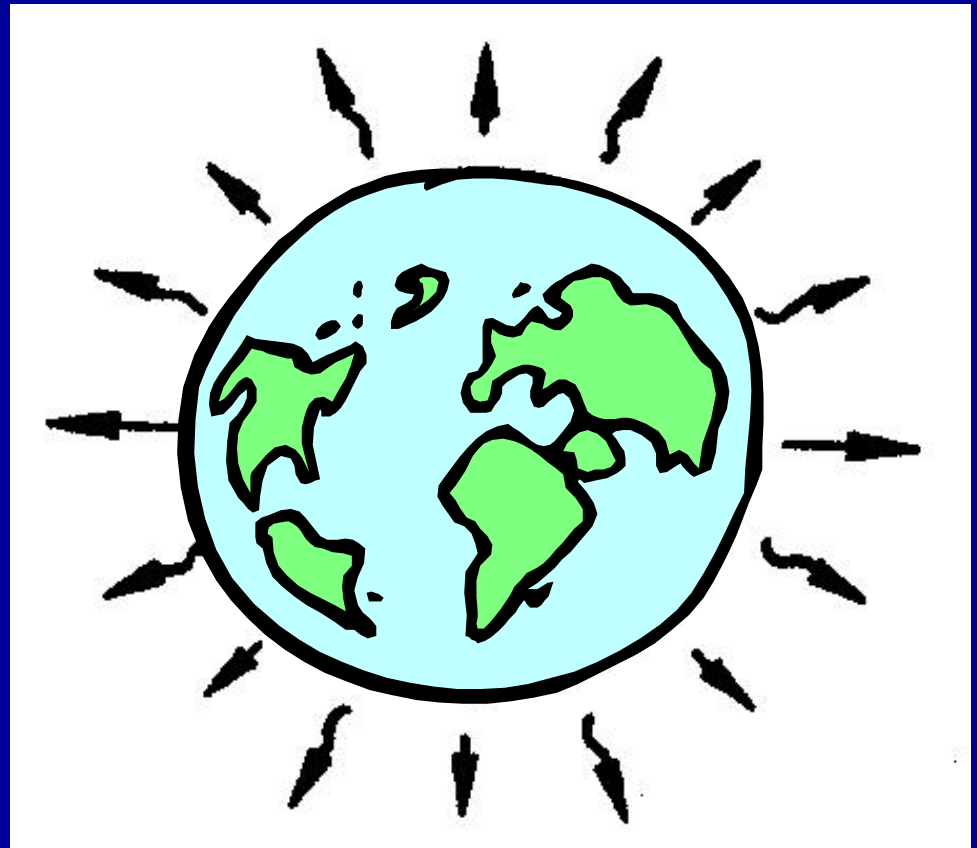
$$E = \sigma T^4$$

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 44 in SGC E-text for more details

10 minute SUSTAINABILITY SEGMENT

more of:



Then . . . **MORE CLICKER
PARTICIPATION POINTS**

Breaking news on gas and coal-fired plant regulations!

EPA to revise climate rule for new power plants; will still require carbon capture

By Juliet Eilperin, Published: September 11 [E-mail the writer](#) ↩

This month, the [Environmental Protection Agency](#) will propose standards that will establish stricter pollution limits for gas-fired power plants than coal-fired power plants, according to individuals who were briefed on the matter but asked not to be identified because the rule was not public yet.

The revised rule, which would impose [greenhouse gas limits on power plants](#) for the first time, will still require utilities to install costly carbon controls on coal plants.

More health and science news

New EPA climate proposal still tough on coal



Juliet Eilperin SEP 11
EPA will unveil a proposal this month to limit carbon emissions from new coal and gas plants, sources say.

The agency initially proposed that any new power plant emit no more than 1,000 pounds of carbon dioxide per megawatt hour of electricity produced but [decided to overhaul that rule](#) this spring out of concern that it would face a stiff legal challenge.

The average U.S. natural gas plant emits 800 to 850 pounds of carbon dioxide per megawatt, and coal plants emit an average of 1,768 pounds. According to those familiar with the new EPA proposal, the agency will keep the carbon limit for large natural gas plants at 1,000 pounds but relax it slightly for smaller gas plants. The standard for coal plants will be as high as 1,300 or 1,400 pounds per megawatt hour, the individuals

Today's news in
The Washington
Post, The Wall
Street Journal,
and others . . .

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:

$$\lambda_m = a/T$$

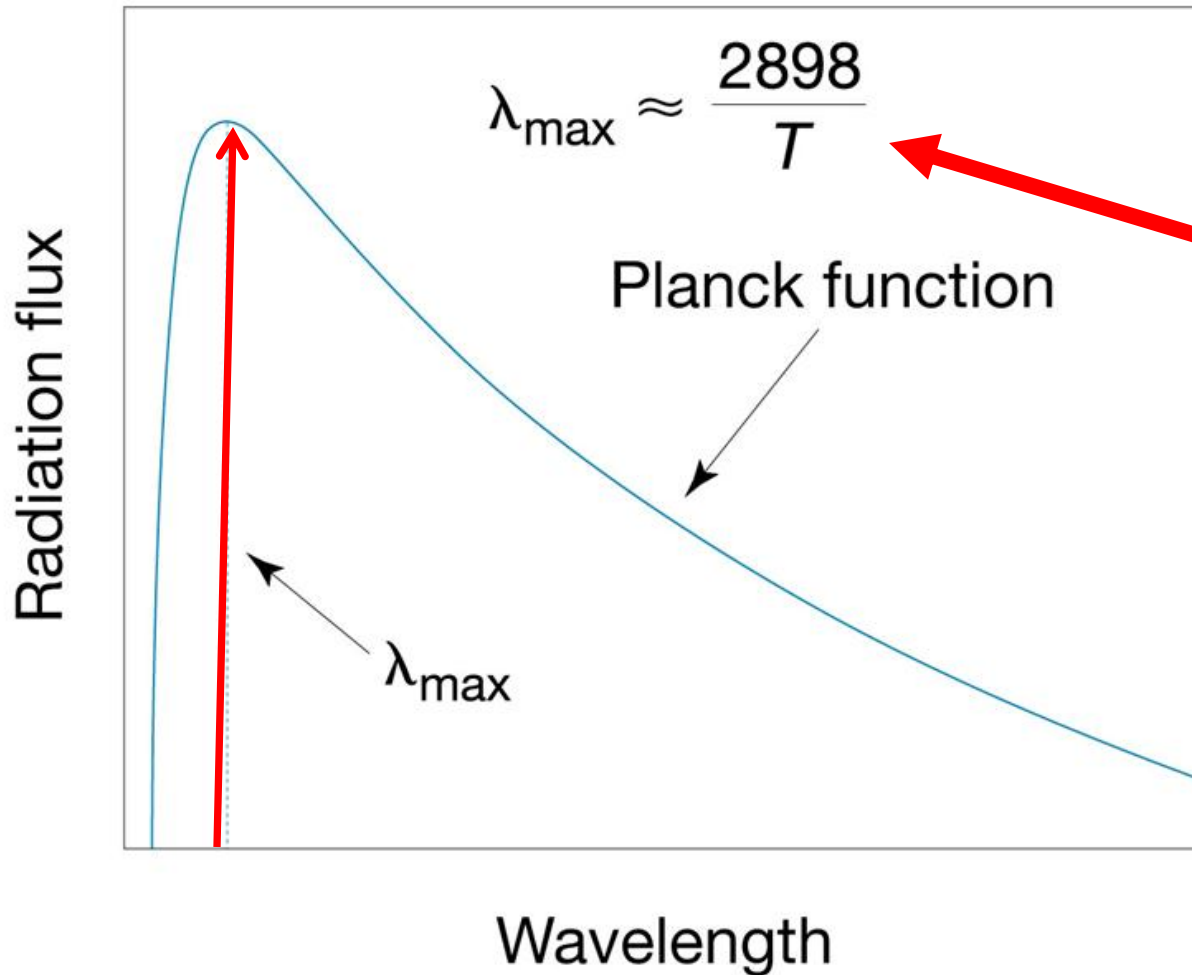
where λ_m is the **WAVELENGTH** in the spectrum at which the energy peak occurs,

(**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 figure on p 42 in SGC

Wien's Law (easy way)

$$\lambda_{\text{max}} = \text{constant} / T$$

(Inverse relationship between wavelength and temperature)

“The hotter the body, the shorter the wavelength”

“The cooler the body, the longer 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"



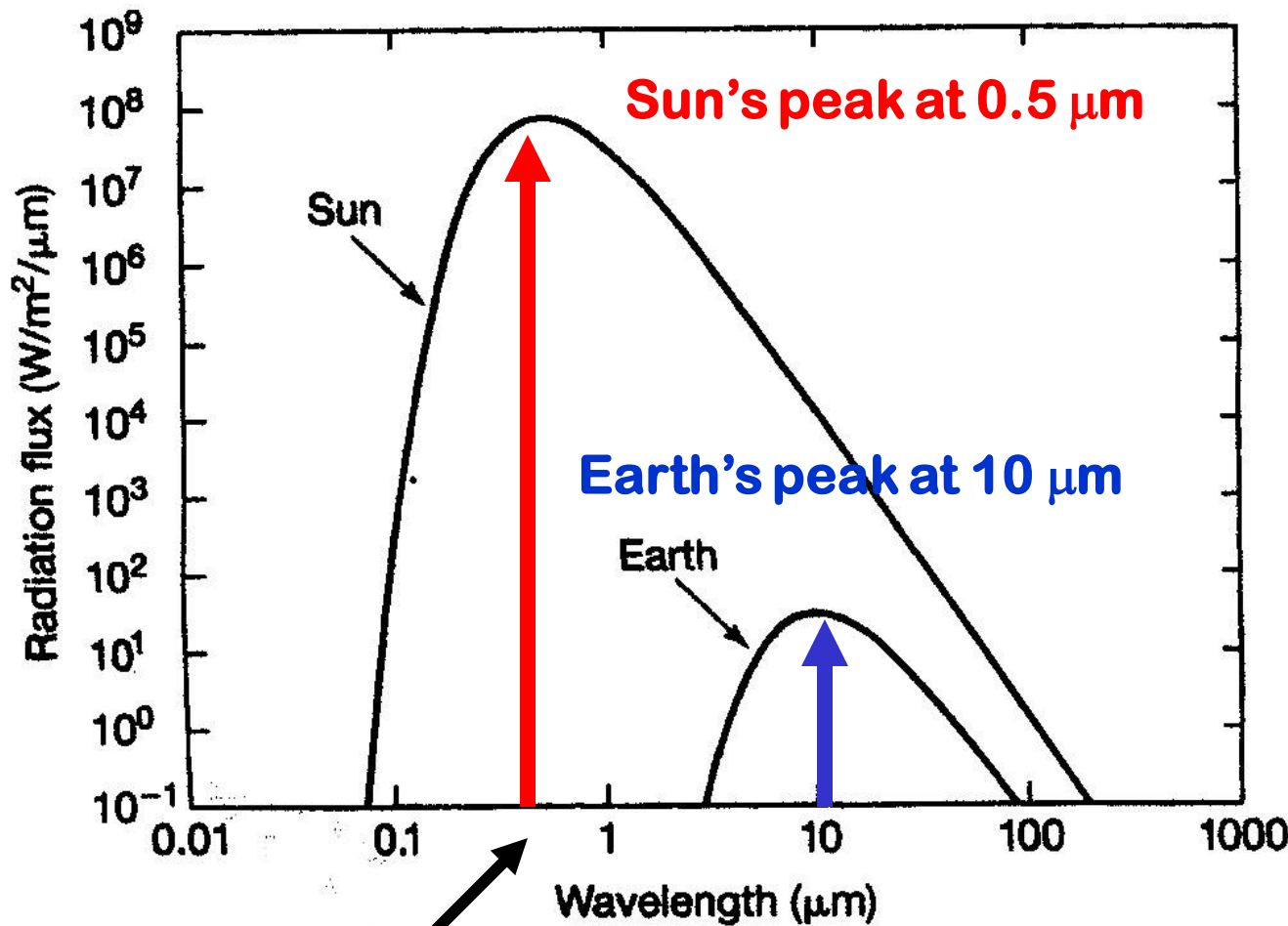
SW = visible (VIS) & ultraviolet (UV)

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

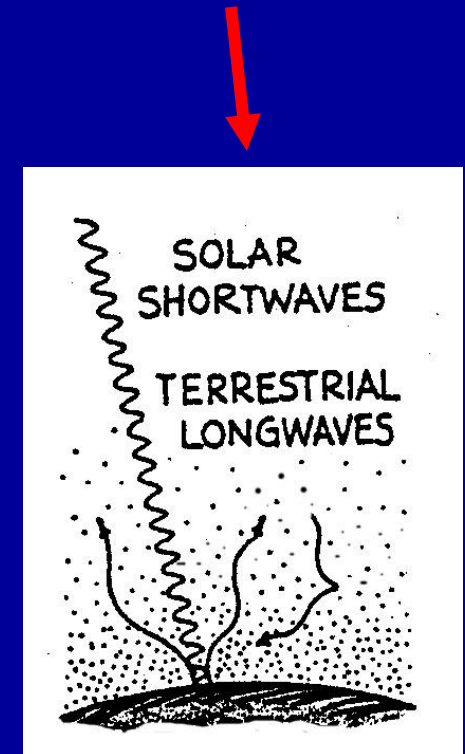


LW = infrared (IR)





Wein's is the law behind this cartoon (back on p 27)

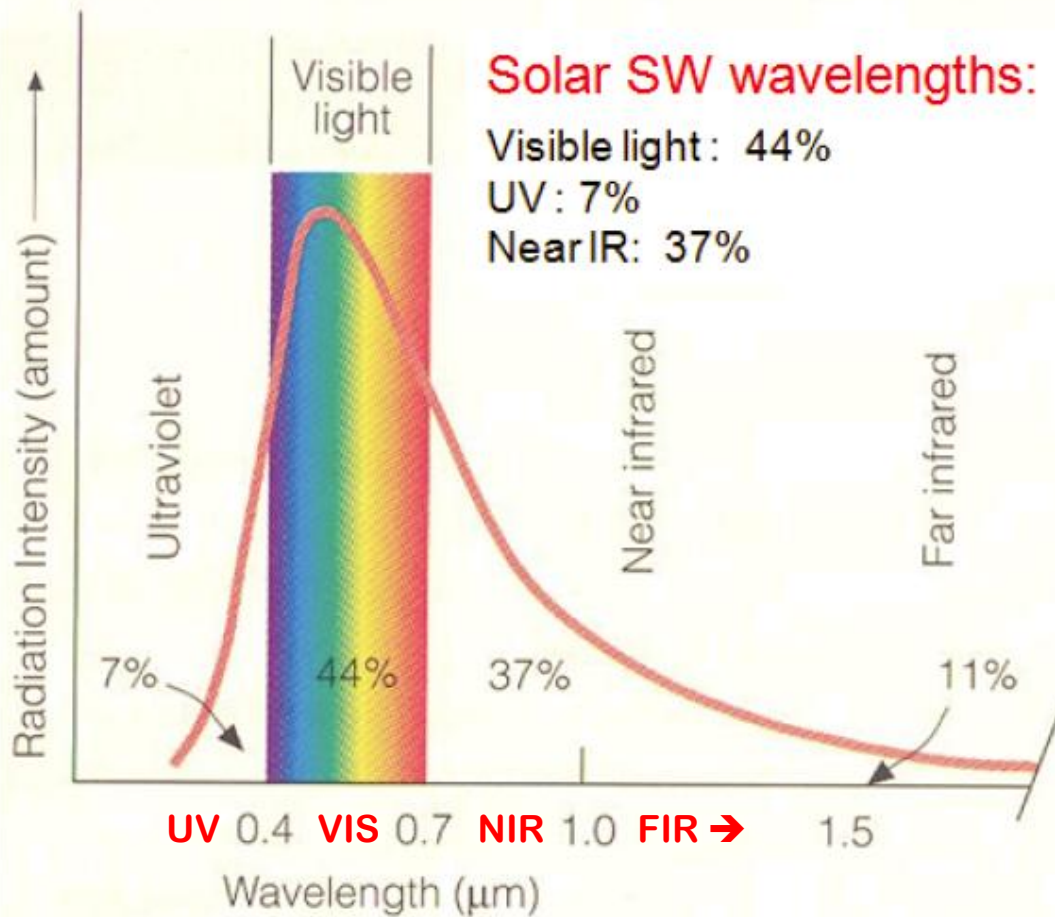


NOTE: this is a logarithmic scale -- values increase exponentially to the right

Another view of the same concept:

Shortwave SOLAR radiation

(SW) = UV + VIS + Near IR

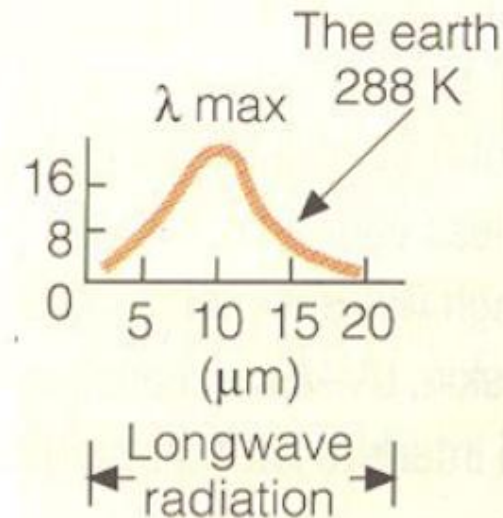


TERRESTRIAL radiation

(LW) = Far IR

Terrestrial (Earth) radiation wavelengths:

Far IR, with a maximum at ~ 10 μm



Know & understand what this figure is illustrating!

THE RADIATION LAWS

Re-cap of Laws # 2 - 4

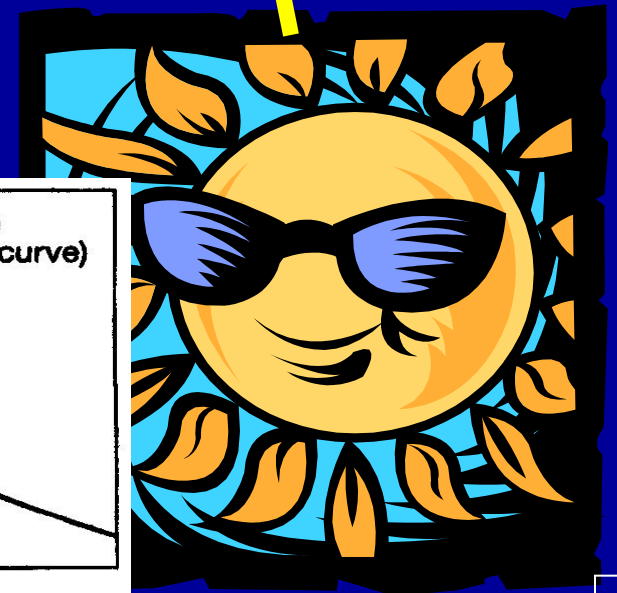
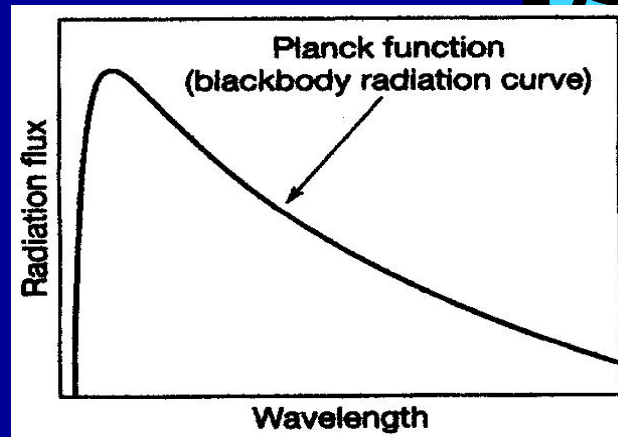


Planck Function:

$$E = h c / \lambda$$

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 “



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”



RADIATION LAWS # 5 and #6

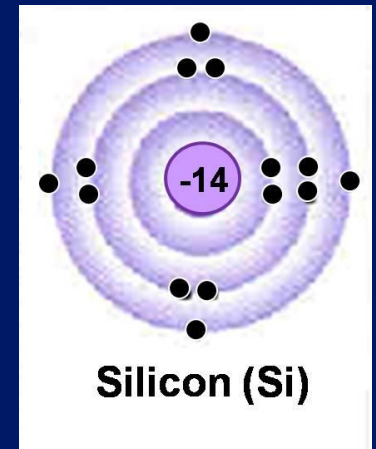
to be continued

Postscript:

Inside a Solar Cell!

From:

Starring:



<http://www.pbs.org/wgbh/nova/tech/saved-by-the-sun.html>

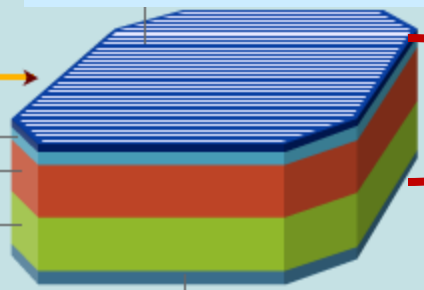
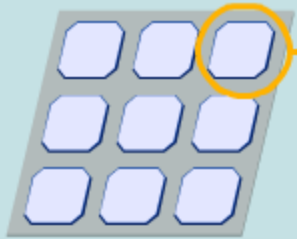
INSIDE A SOLAR CELL

SOLAR PANEL

PHOTOVOLTAIC CELL (PV)

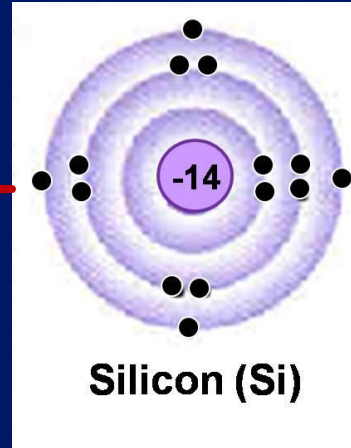
Antireflective coating

metal conducting strips

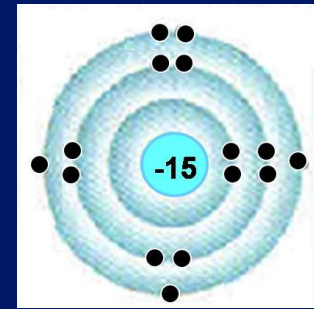


metal backing

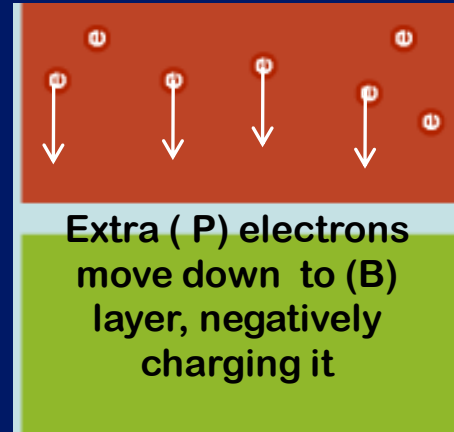
Silicon Layers



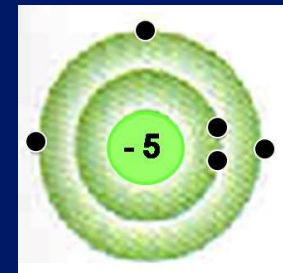
Silicon (Si)



Phosphorus (P)
“doped” Si layer



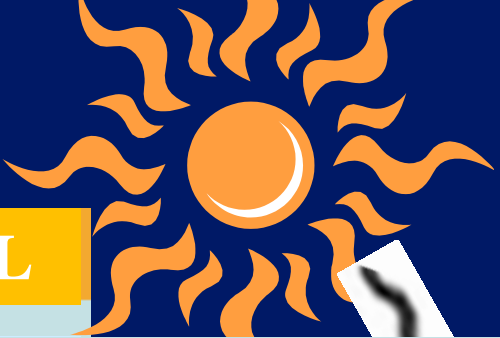
Boron (B)
“doped” Si layer



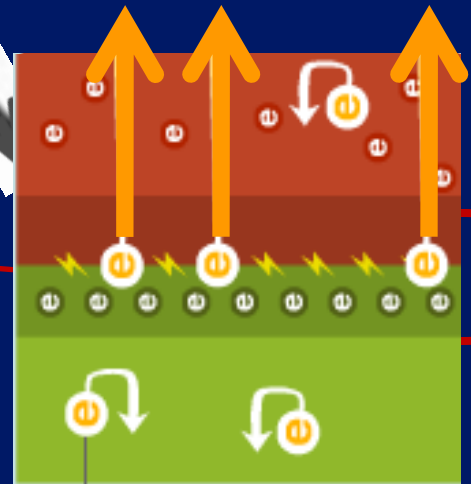
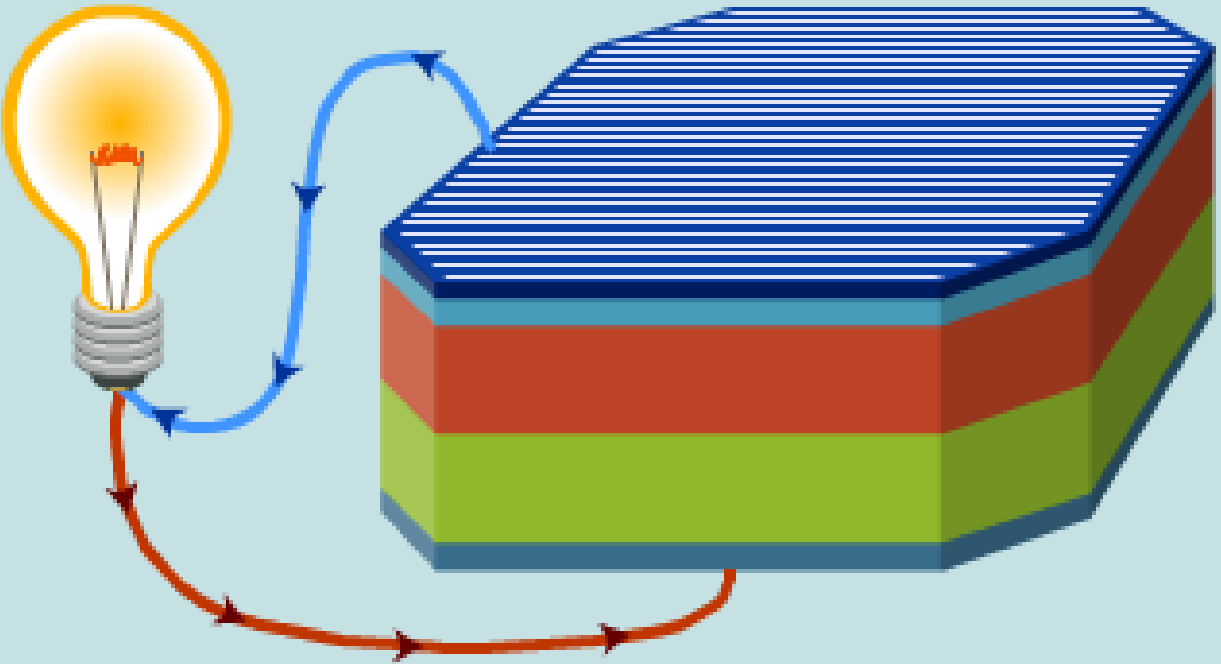
Read this explanation at:

<http://www.pbs.org/wgbh/nova/tech/how-solar-cell-works.html/>





INSIDE A SOLAR CELL



ELECTRIC FIELD



ARIZONA  WILDCATS

GO CATS!

