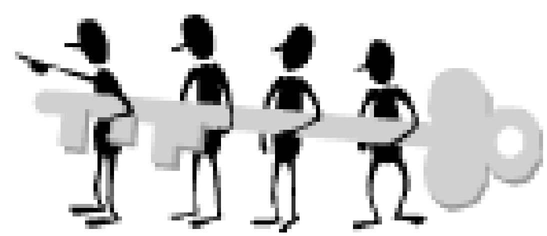
TOPIC # 7
The RADIATION LAWS

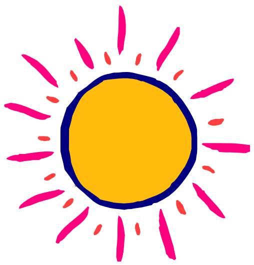
PART 3 of the KEY
to unlocking the topics of:
The GREENHOUSE EFFECT,
GLOBAL WARMING &
OZONE DEPLETION!

Topic #31
pp 31-35



OBJECTIVES:

To understand more essentials about the key differences



between

Solar radiation

&

Terrestrial radiation

based on the principles of the "Radiation Laws."

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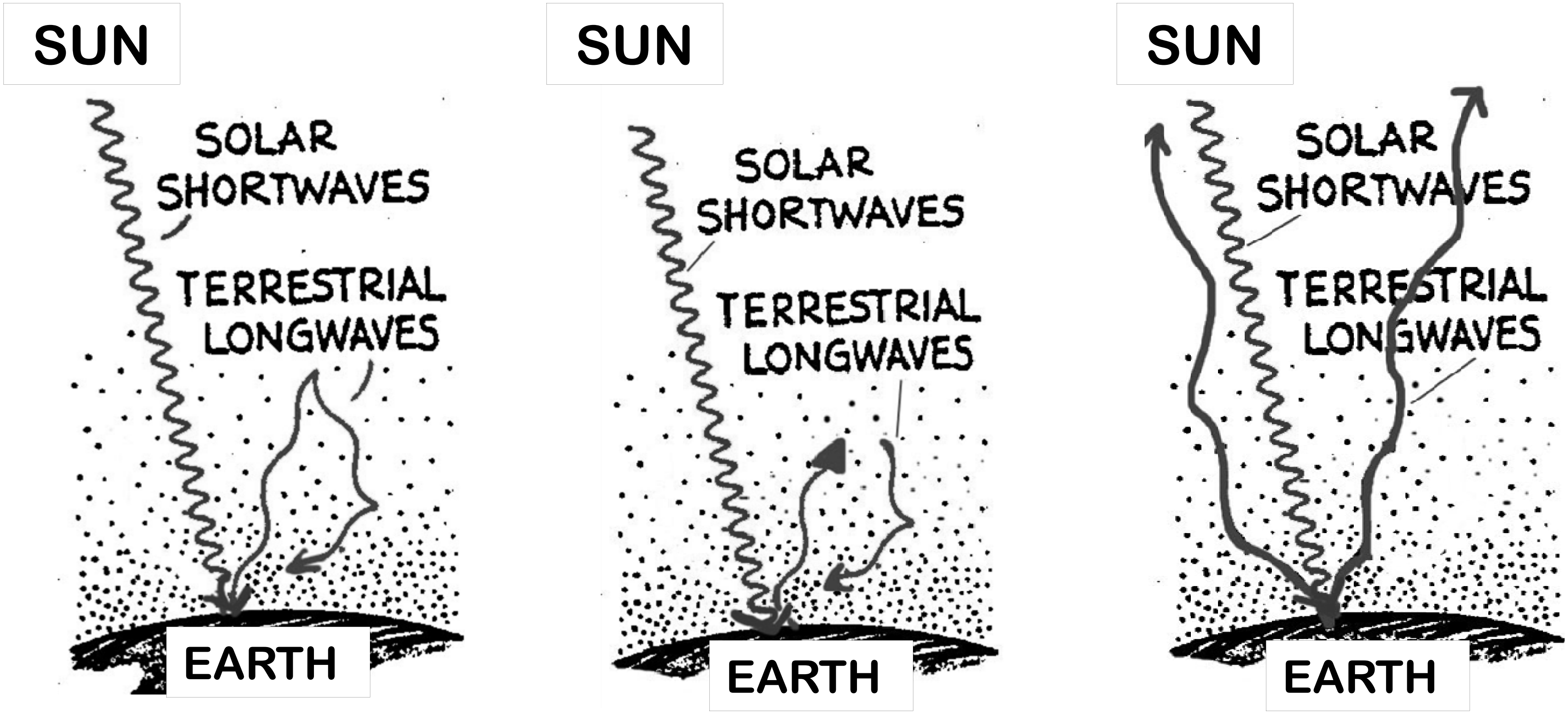
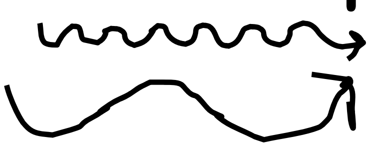
“cartoon” views of Solar vs Terrestrial radiation:



In these & upcoming figures, for convenience:



= solar (shortwave) radiation (High Energy)

= terrestrial (longwave) radiation (Lower Energy)

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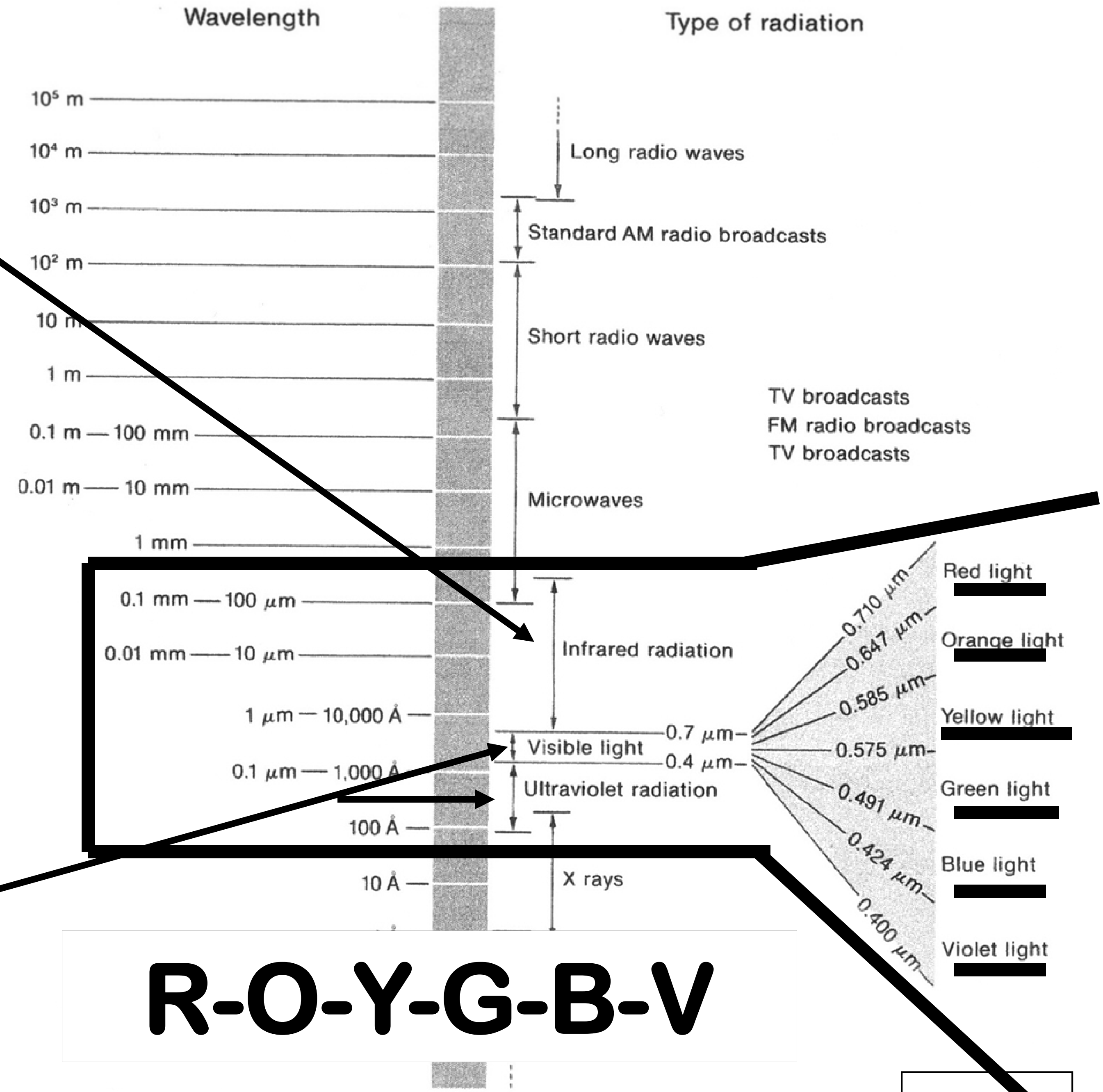
Longwaves (LW)

The Electro-magnetic Spectrum

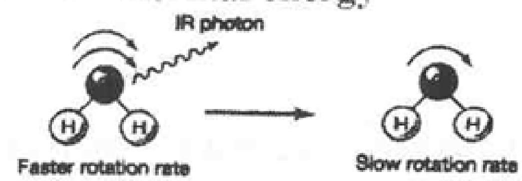
Shortwaves (SW)



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 **Solar**	.0001 to 0.4 in micrometers (µm)	electrons moving (quantum leaps) within individual atoms
Visible light **SW**	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 **Terrestrial LW**	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

Review p 30

$E = \sigma T^4$ $(1/d^2)$

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.

$E = hc/\lambda$ $\lambda_m = a/T$

~ Chen Ning Yang (b. 1922) US physicist

Presenting . . . .

THE RADIATION LAWS !!!

Keys to Understanding the Greenhouse Effect

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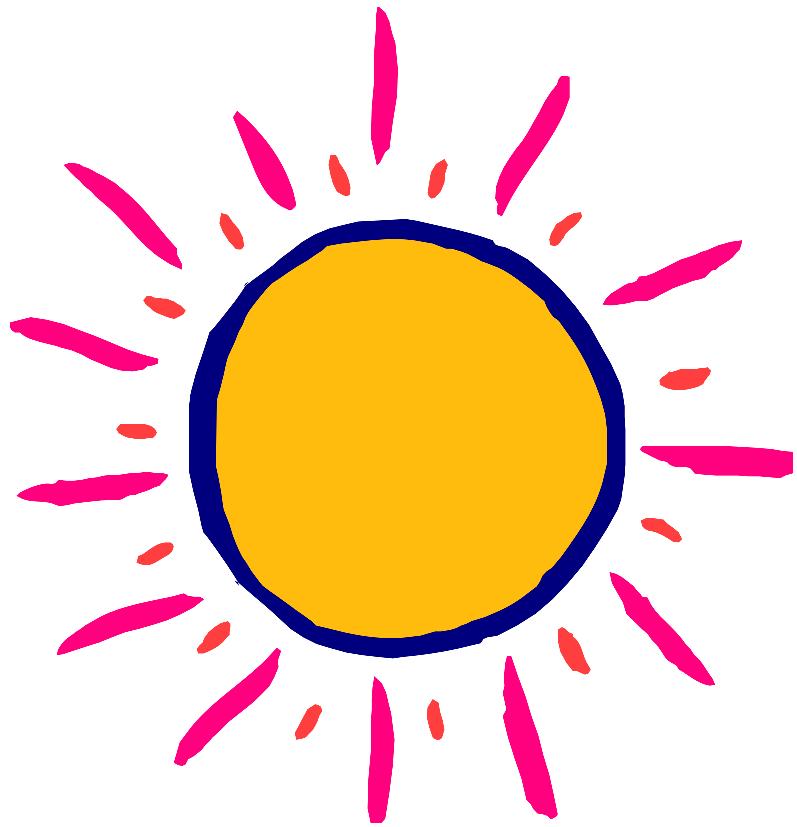
TYING IT ALL TOGETHER: THE RADIATION "LAWS"

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

mostly SW (but also some LW)



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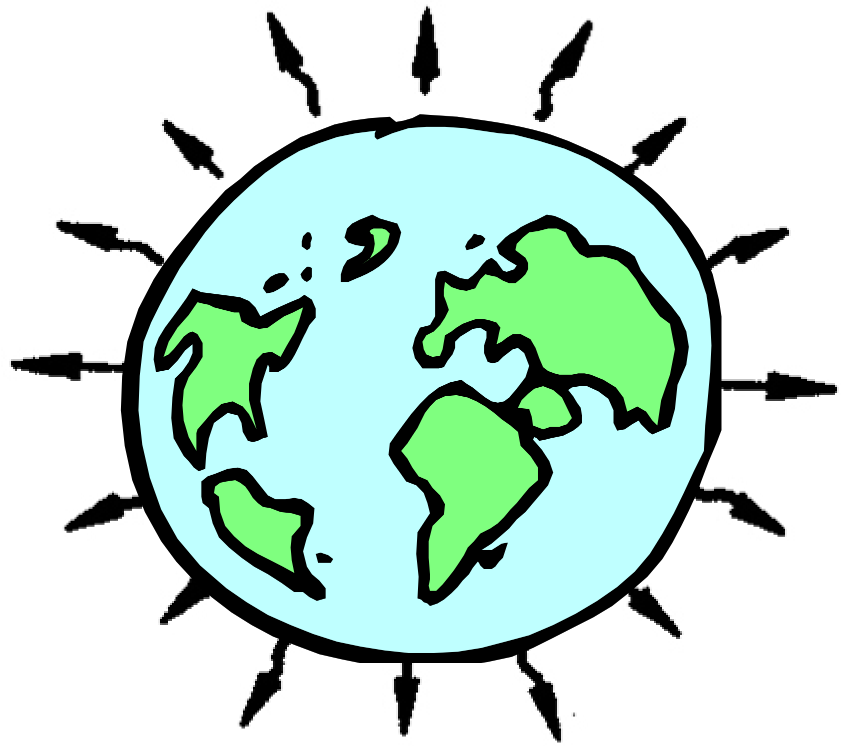
The Earth's energy (terrestrial) is also emitted in the form of electromagnetic wavelengths.



mostly LW

☺

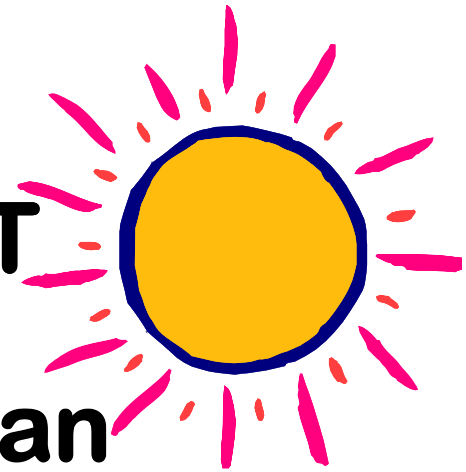
LAW #1

Emission of radiation

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

(-273.15^{o}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 31

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 * 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"

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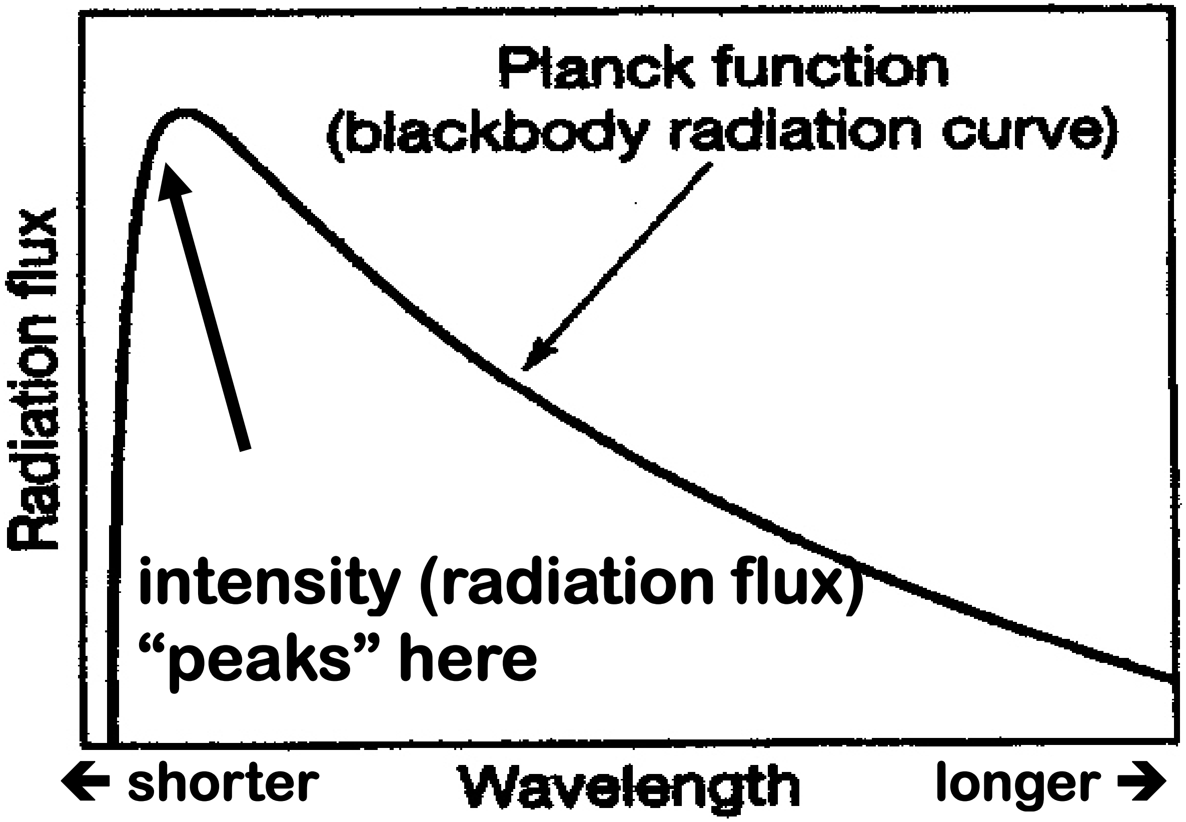
This can be depicted in a graph:



An emitting blackbody’s <u>SHORTER</u> 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"

☺

Dr. H's: "FRUGAL CLICKER TIME" !!
In-Class "SELF CHECK"

(1) PRINT your name on your colored index card

(2) Set up the card this way ➔

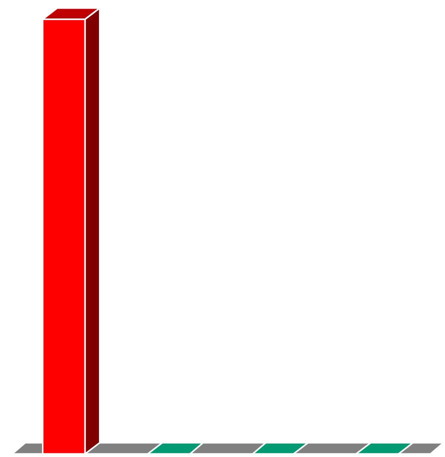
Stella Student Grp # 0
Q1
Q2
Q3
Q4
Q5

(3) Write in PEN only (no changing your "final answer"!)

(4) GRADE YOUR SELF AS YOU GO ALONG . . .

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!



☺ **Record your Q1 answer now**

LAW #3: THE STEFAN-BOLTZMANN LAW:

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

The total AMOUNT of radiation given off is <u>proportional</u> 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)

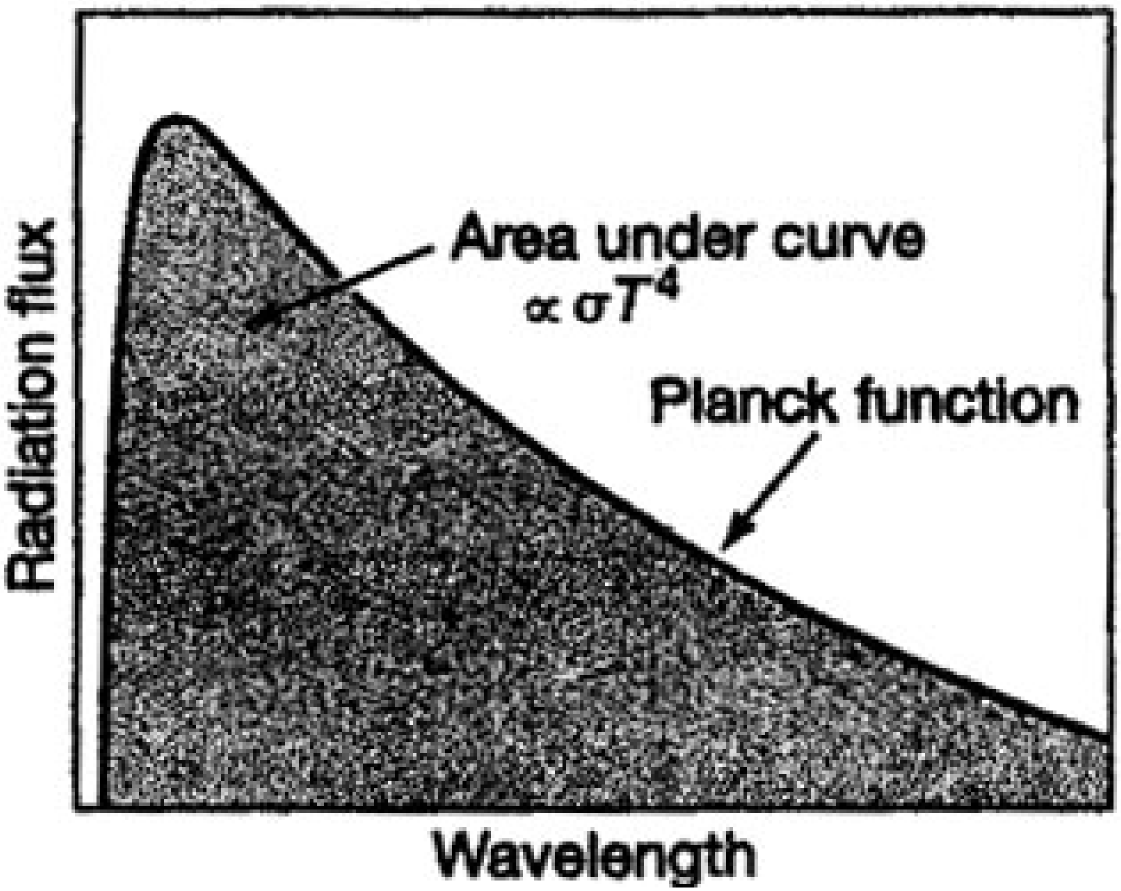
This law links:

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

(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:

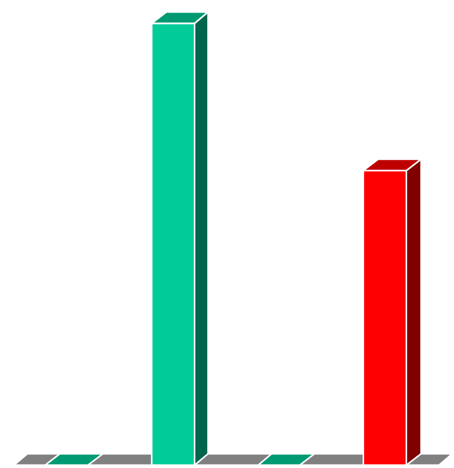
the <u>amount</u> of radiation given off by a body is a very *sensitive* function of its <u>temperature</u>

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?

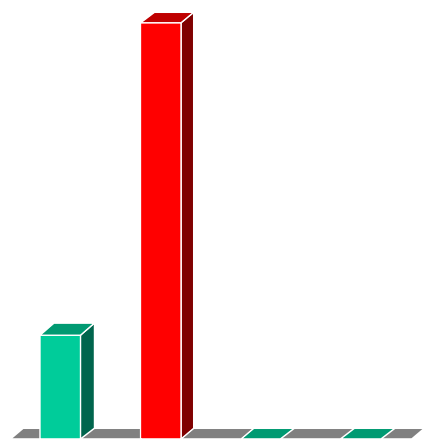
1. The Planck Function
2. The Stefan Boltzmann Law
3. Both of them together
4. Neither one is appropriate because the Earth is NOT a blackbody



☺ **Record your Q2 answer now**

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

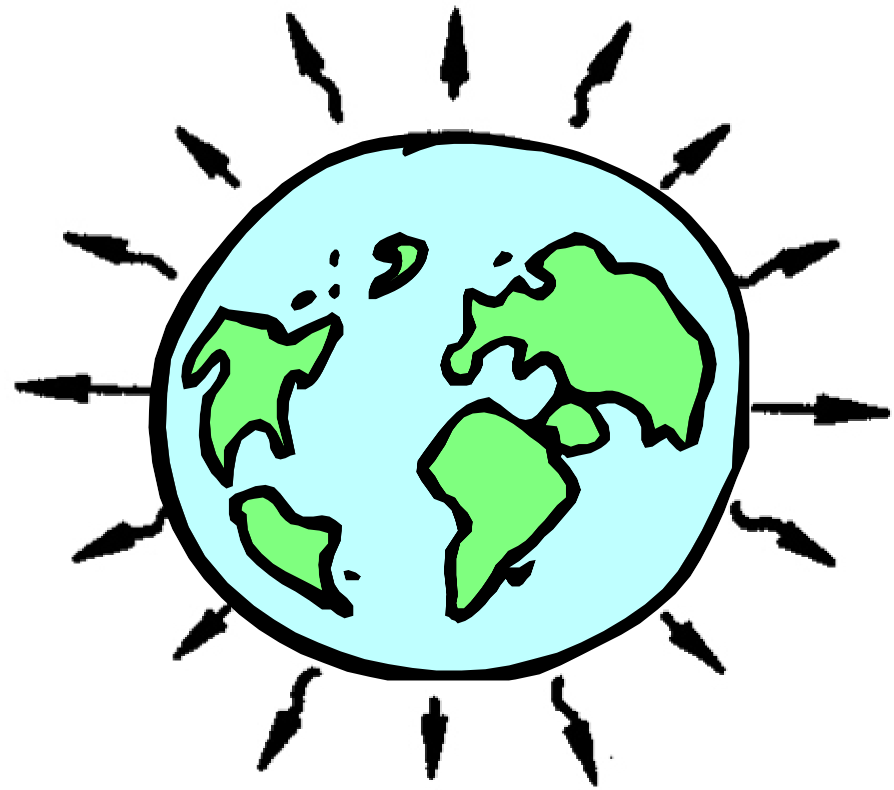


☺ **Record your Q3 answer now**

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

$$4 \prod R^2$$

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

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:

$$\lambda_m = a/T$$

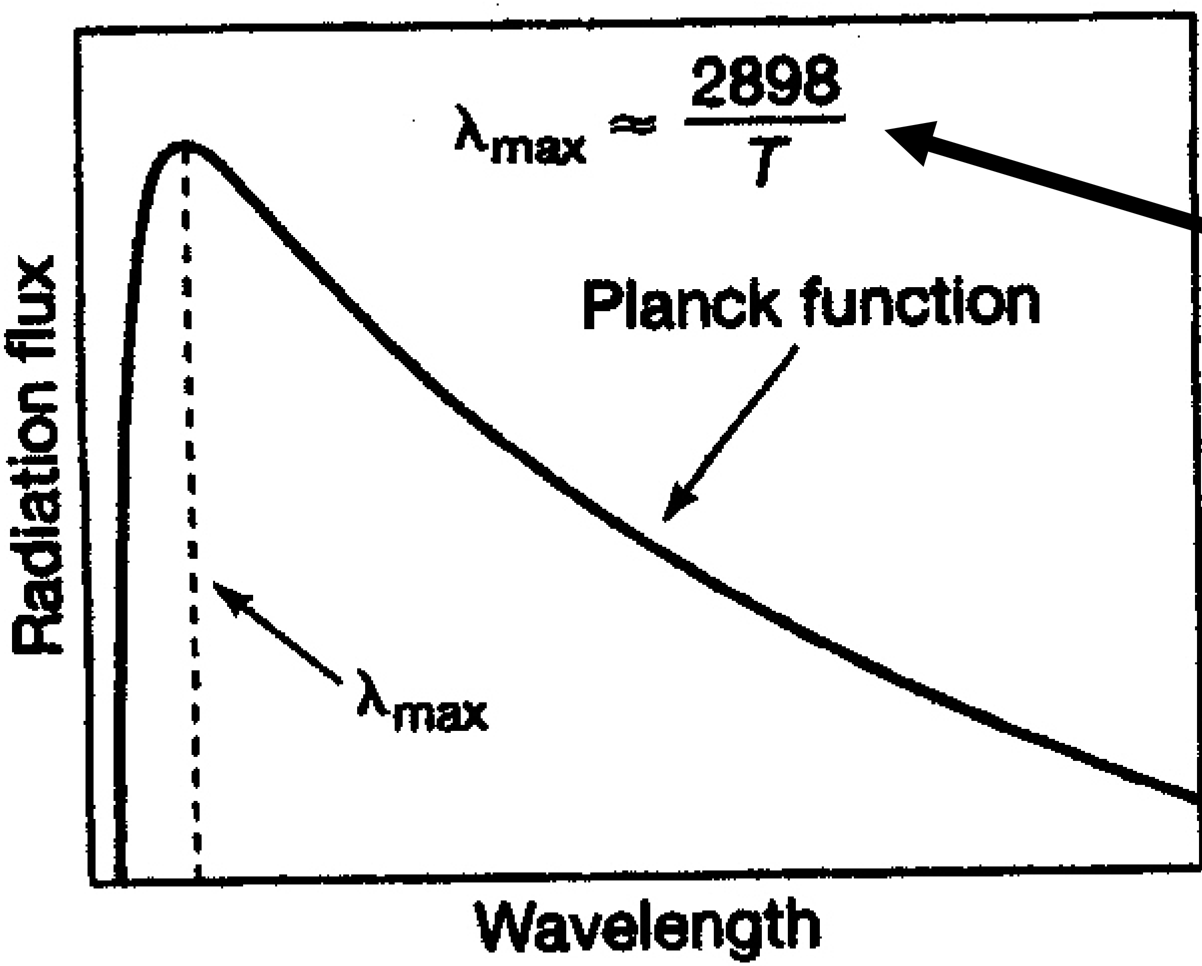
where λ_m is the WAVELENGTH in the spectrum at which the energy <u>peak</u> occurs,

(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 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 & ultraviolet (UV)

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

LW = infrared (IR)

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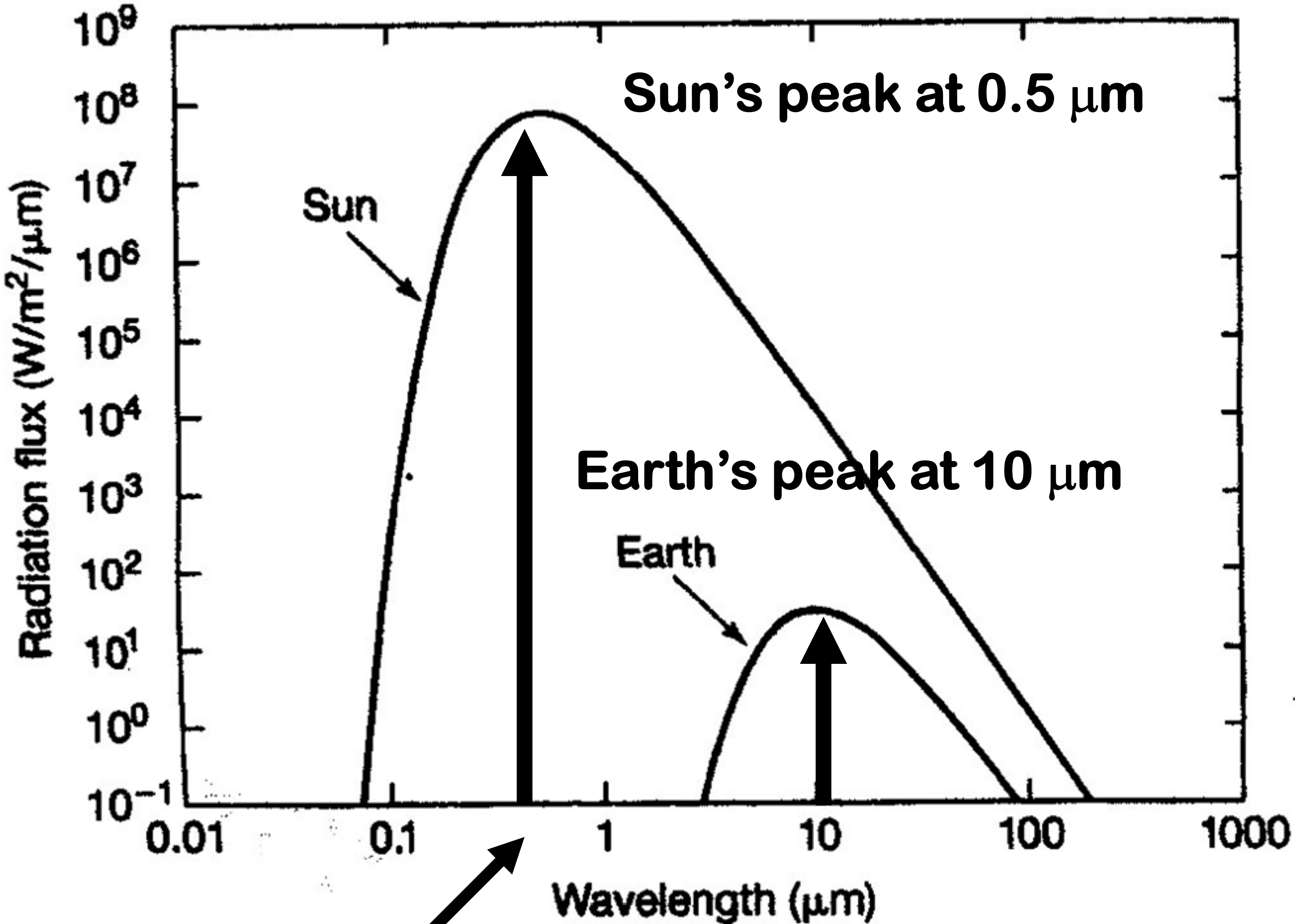
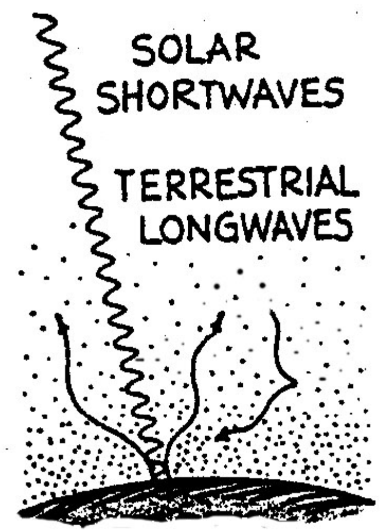
Wein's is the law behind this cartoon (on p 29)



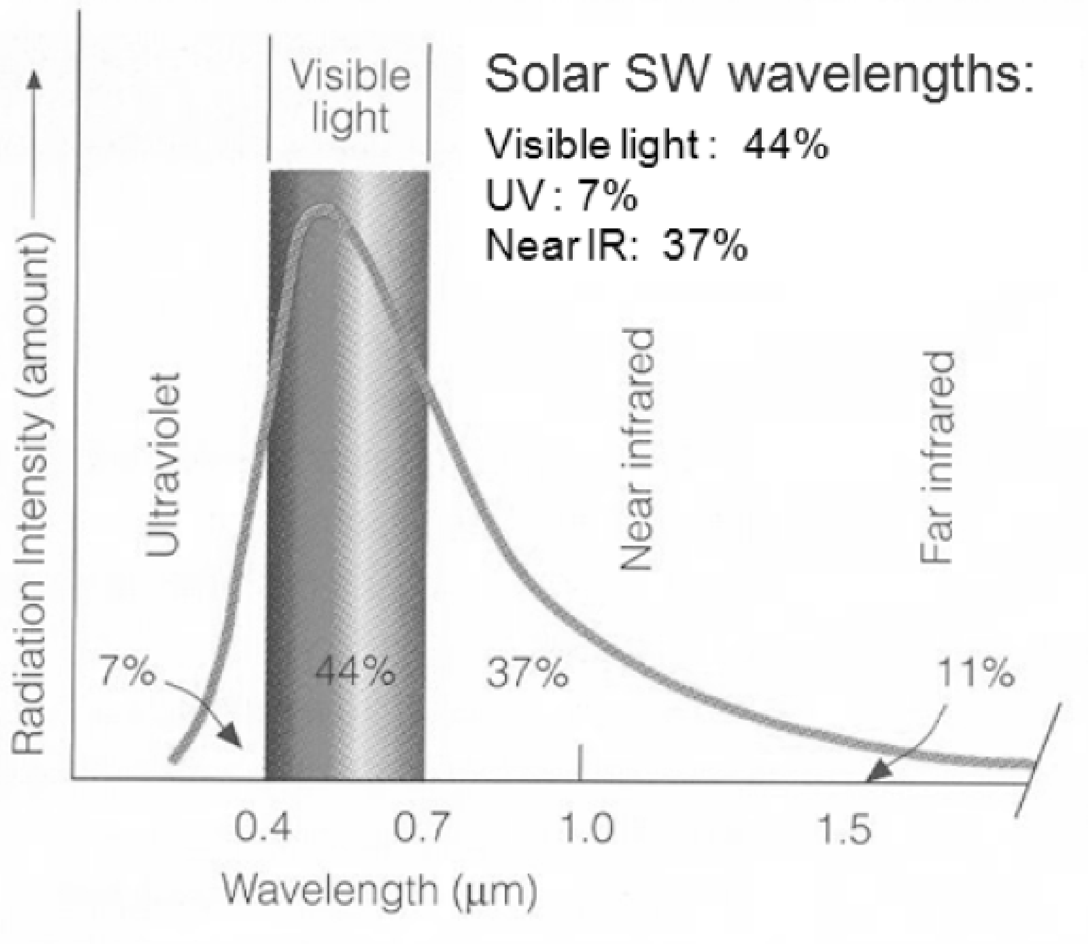


NOTE: this is a logarithmic scale -- values increase exponentially to the right

Shortwave SOLAR radiation
(SW) = UV + VIS + Near IR

Solar SW wavelengths:

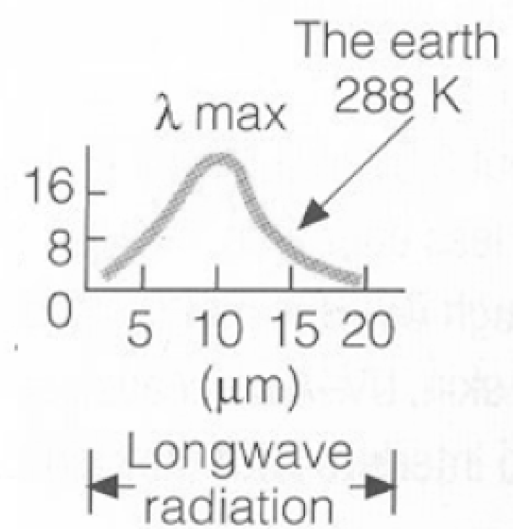
Visible light : 44%
UV : 7%
Near IR: 37%



TERRESTRIAL radiation
(LW) = Far IR

Terrestrial (Earth) radiation wavelengths:

Far IR, with a maximum at ~ 10 μm



THE RADIATION LAWS

Re-cap of Laws # 2 - 4

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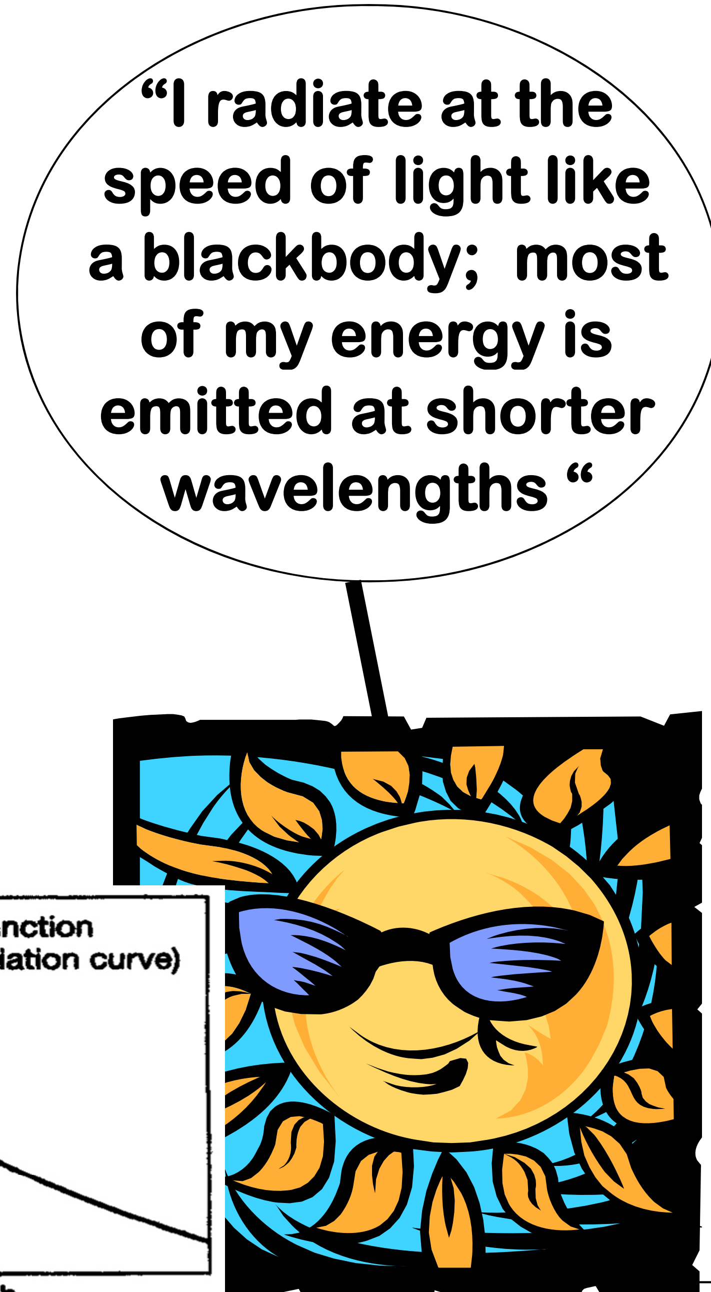
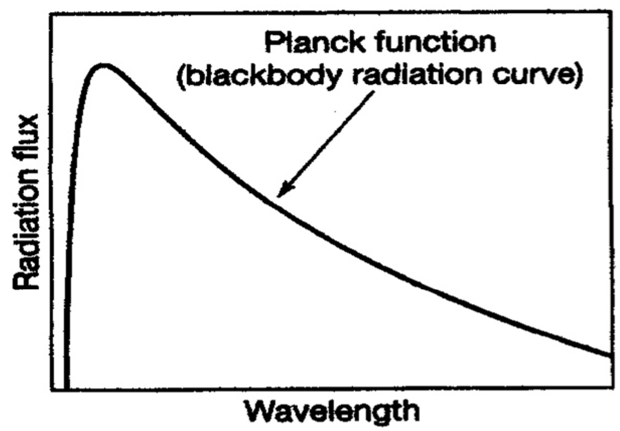
Planck Function:

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

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





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"

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

SW = visible & ultraviolet (UV)

LW = infrared (IR)

☺

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”

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

1. A
2. B
3. C

☺ **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"

☺

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.

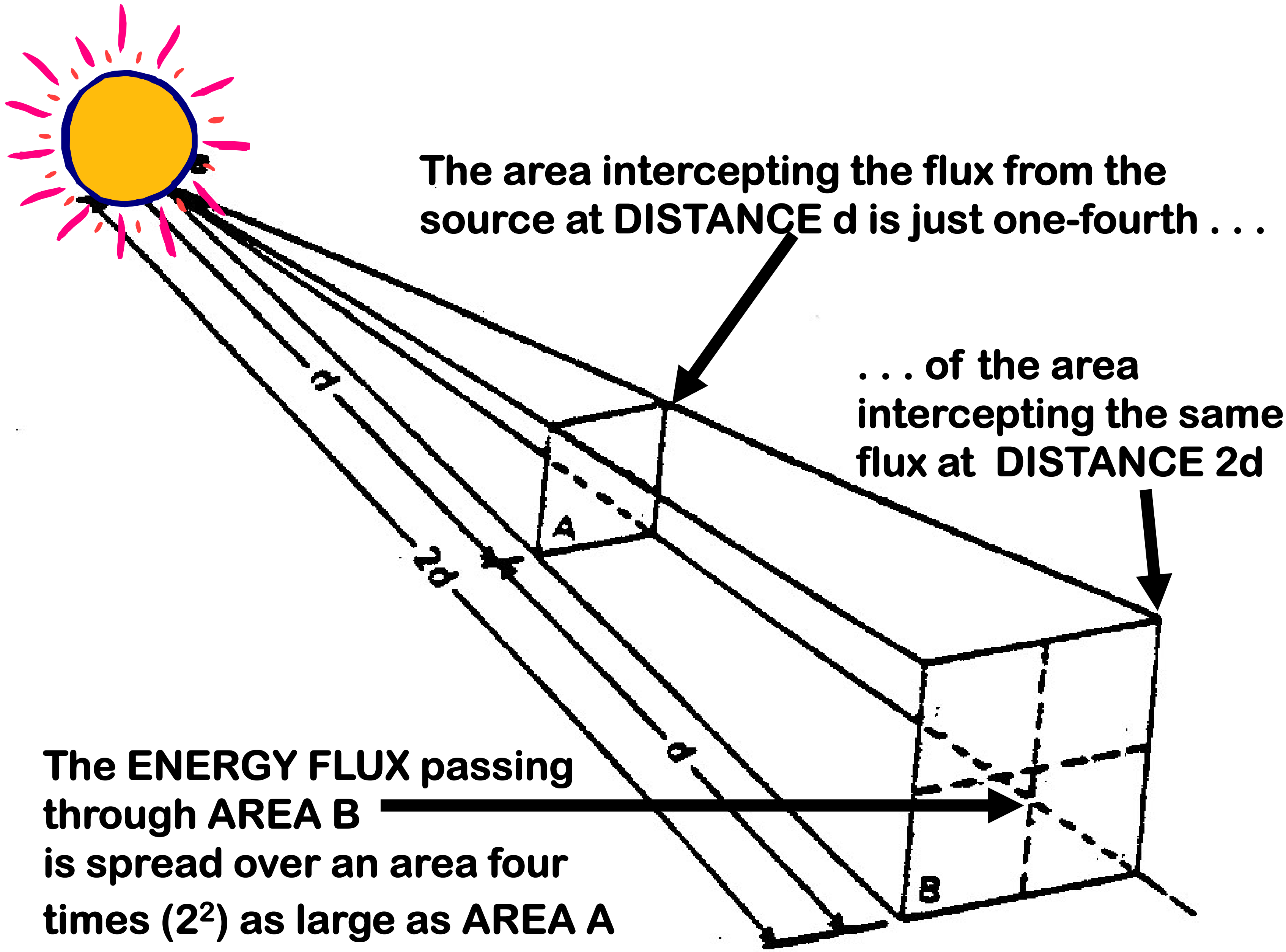
INVERSE SQUARE LAW =

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

$$(1/d^2)$$

p 32


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 (2^2) as large as AREA A
d
2d
d
A
B

p 32

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 <u>reduce</u> the distance from the source to the interception point by a factor of 2 or 3, the intensity of the radiation <u>increases</u> 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.

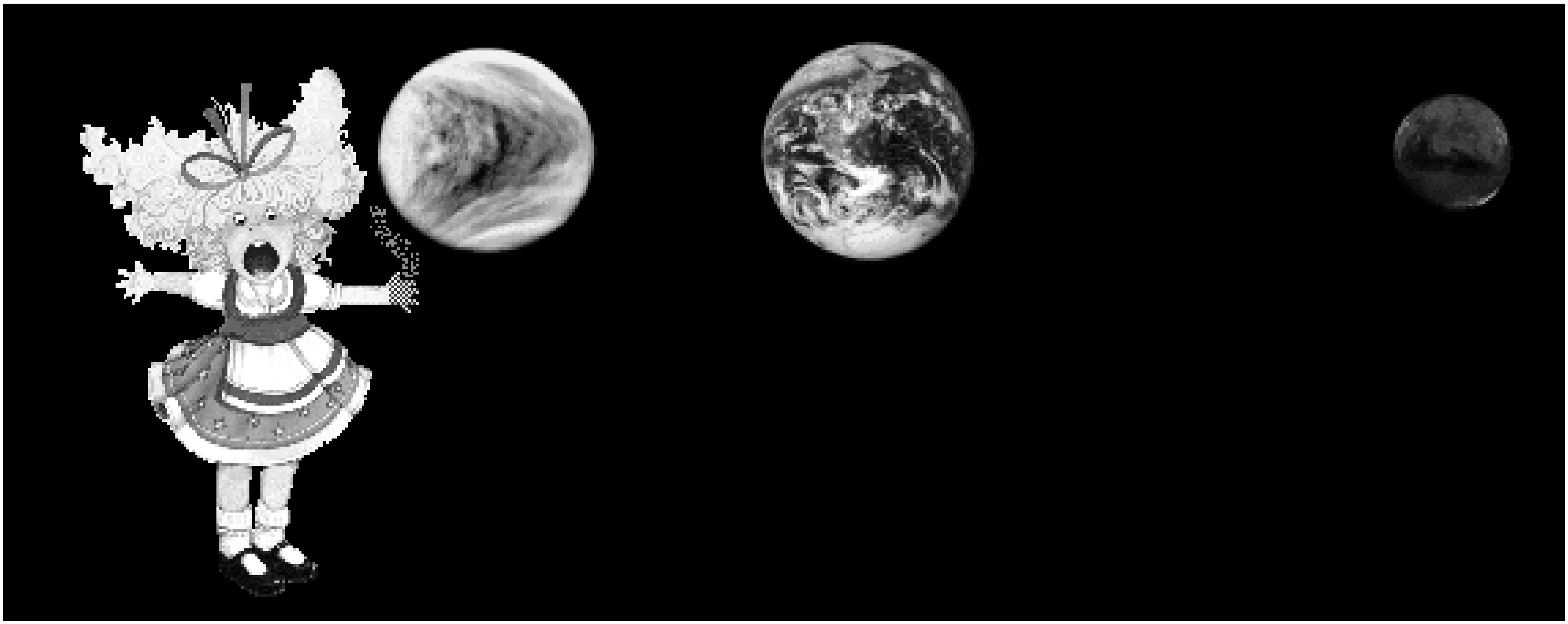
GOLDILOCKS & THE 3 PLANETS

← to Sun

VENUS **EARTH** **MARS**

☺

GOLDILOCKS & THE 3 PLANETS



Yikes! Venus is too HOT!

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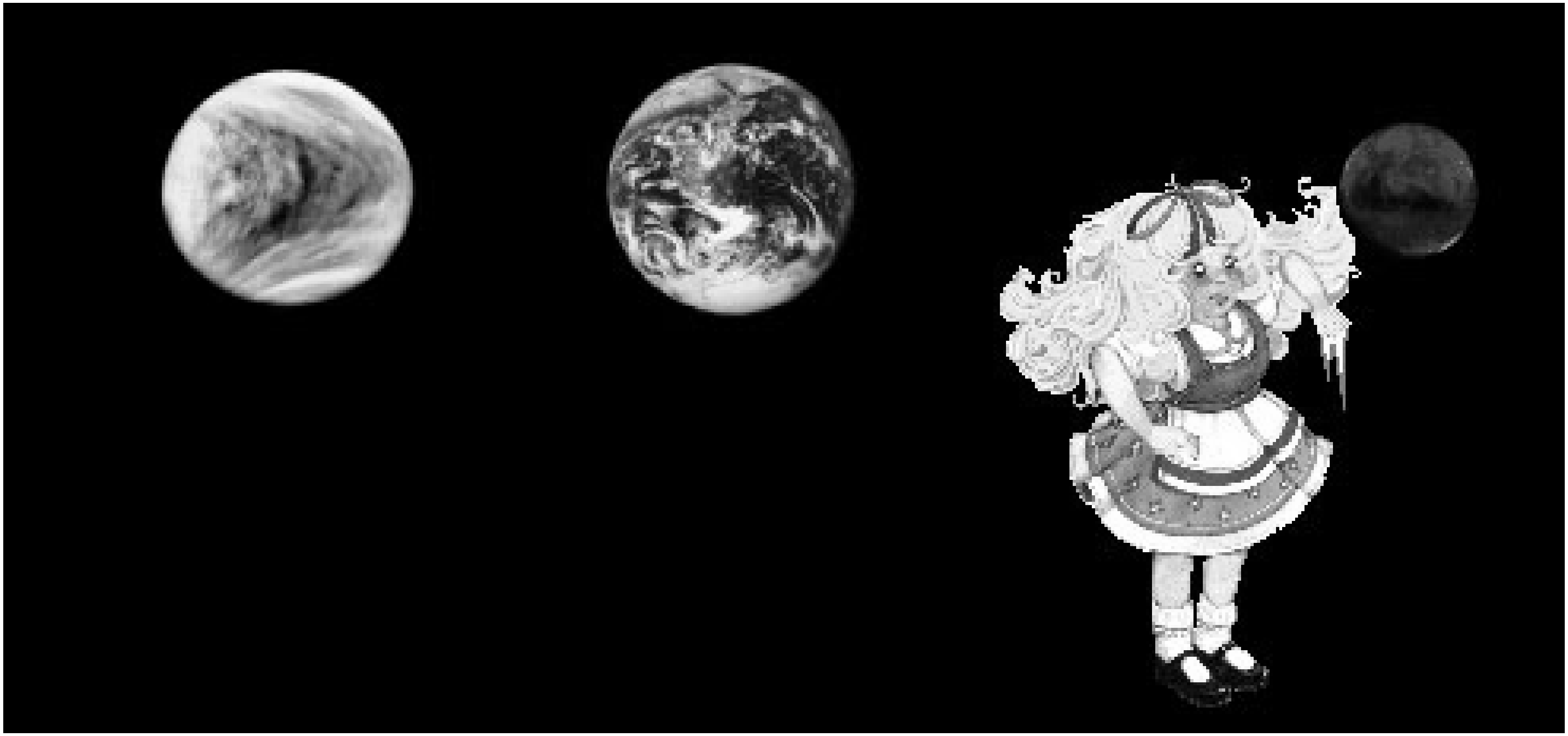
GOLDILOCKS & THE 3 PLANETS



Brrrrrrrrr, Mars is too COLD!!

☺

GOLDILOCKS & THE 3 PLANETS

Ahhhh! Earth is JUST RIGHT!

☺

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!

☺ **Record your Q5 answer now**

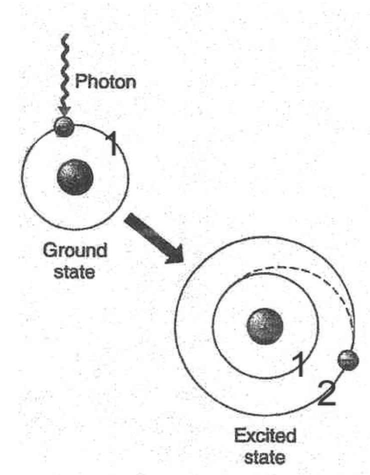
LAW #6: Selective emission and absorption

Some substances emit and absorb radiation at certain wavelengths only.

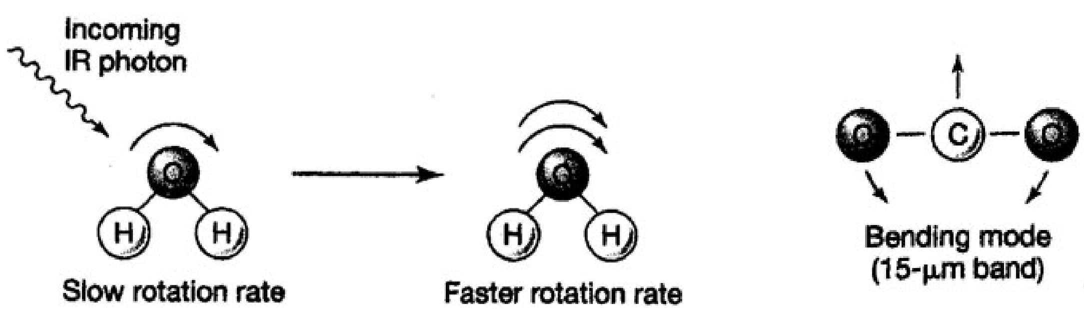
This is mainly true of gases.

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

<u>Substances absorb only radiation of wavelengths they can emit.</u>

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.**

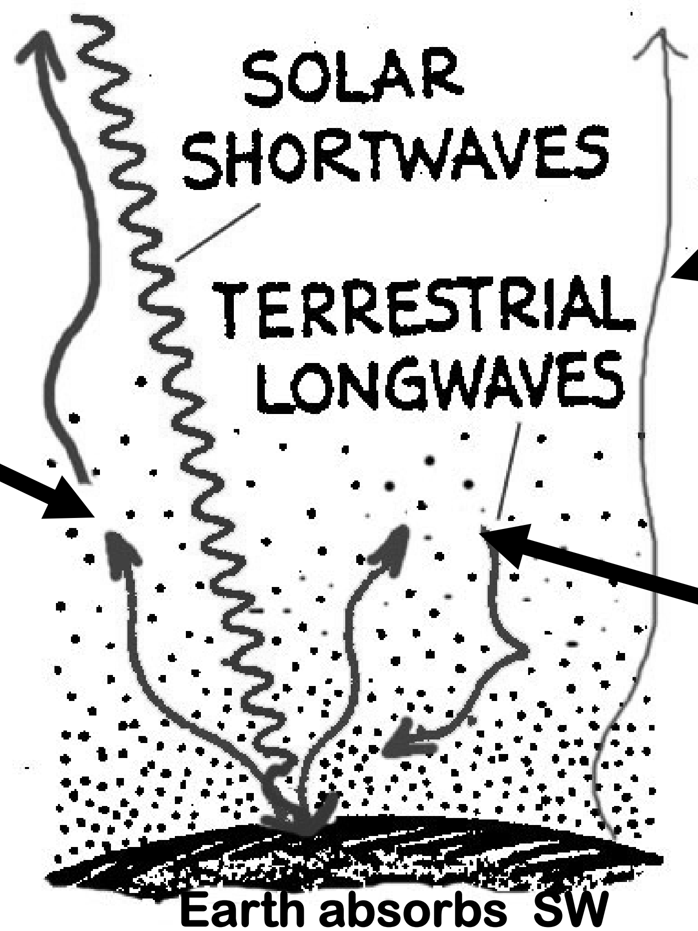
Once IR is absorbed by the greenhouse gases in the atmosphere, it can be emitted back to the Earth's surface to heat it all over again!

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 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 out to space

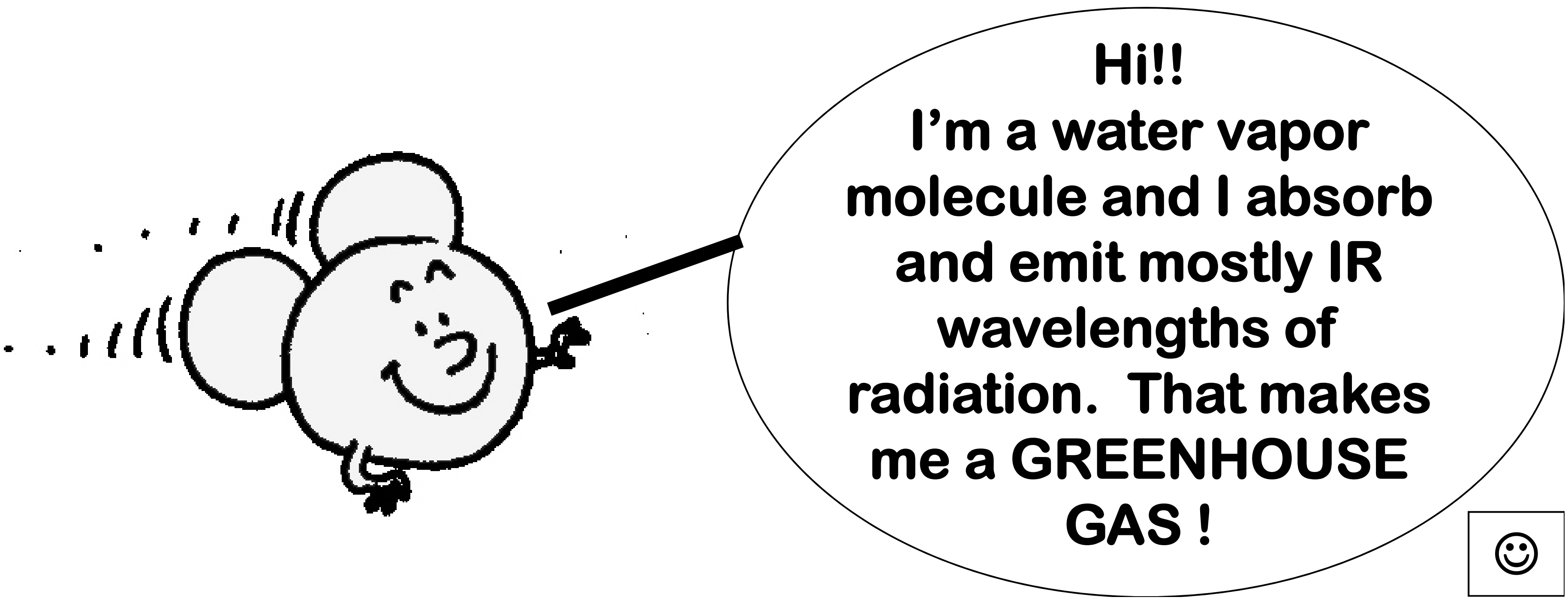


IR radiation is absorbed by GH gases in the atmosphere and emitted back to Earth

Law # 6 says that :

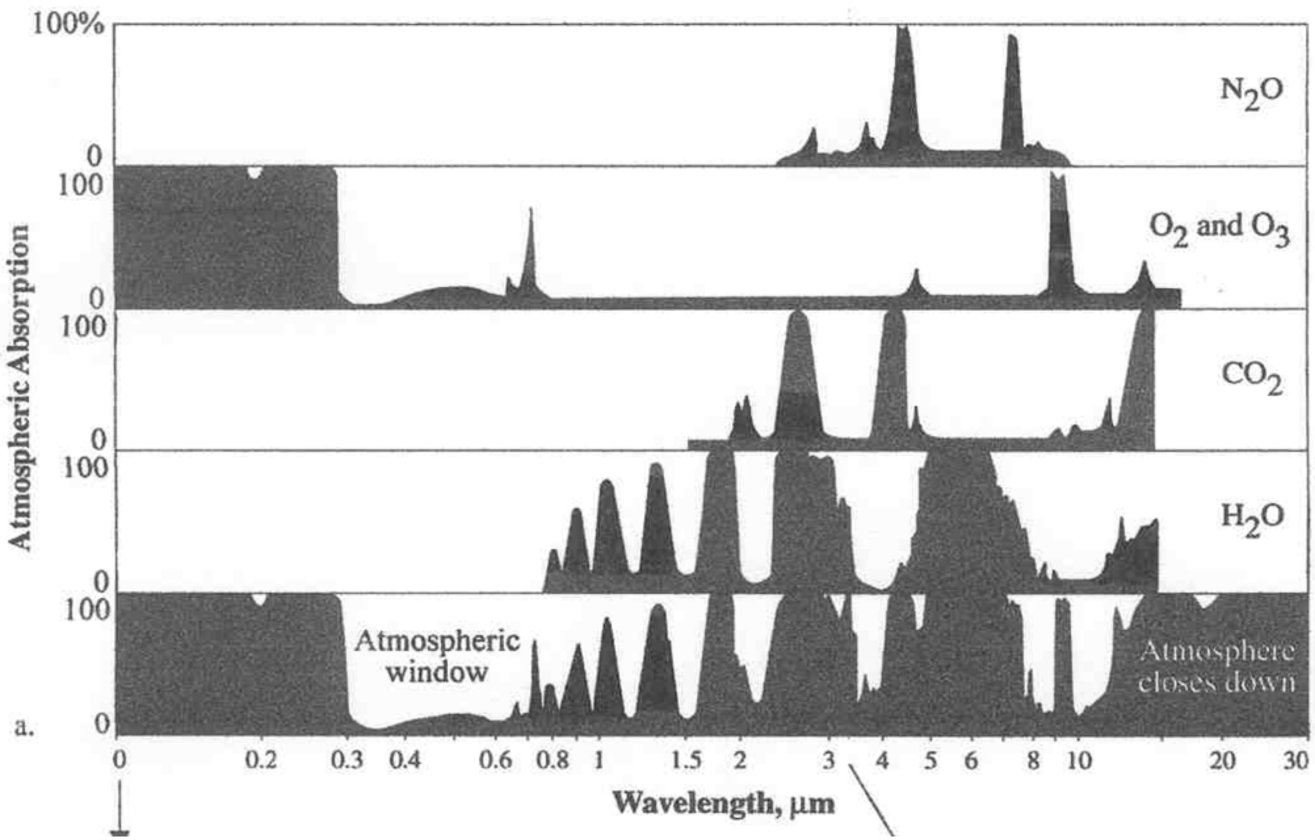
Different gases absorb & emit radiation at different wavelengths

How do we know which wavelengths are absorbed/emitted by different gases?



The pattern of electromagnetic wavelengths that are absorbed & emitted by a particular atom (or combination of atoms)

is called its ABSORPTION SPECTRUM or its ABSORPTION CURVE



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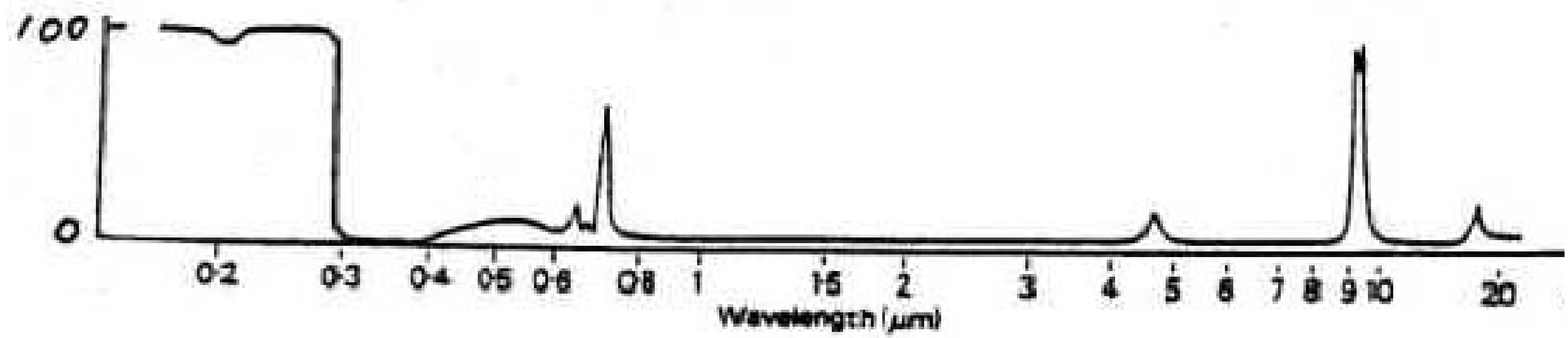
An absorption curve: another view



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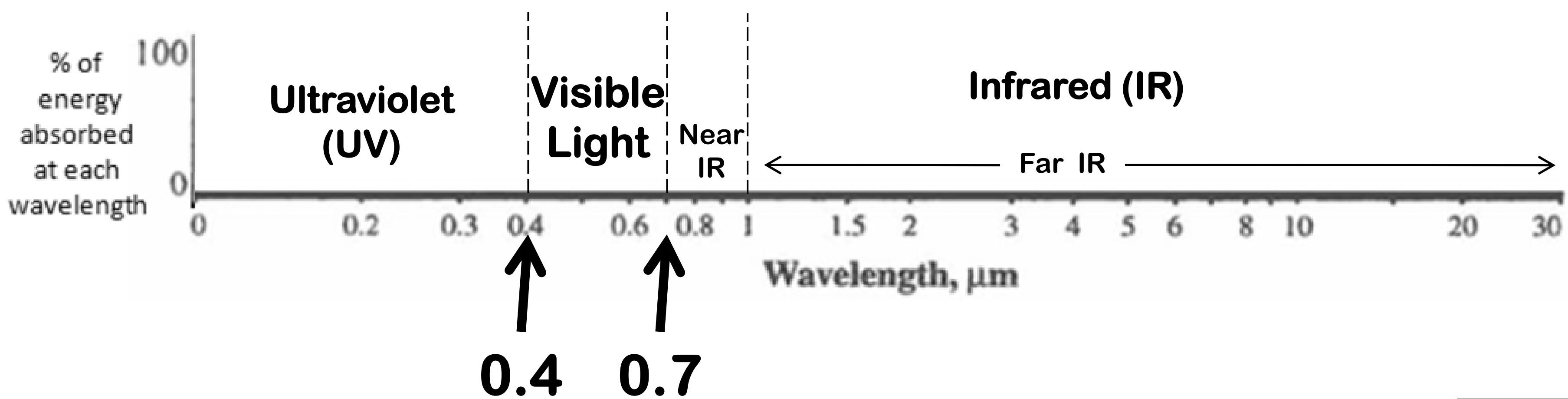
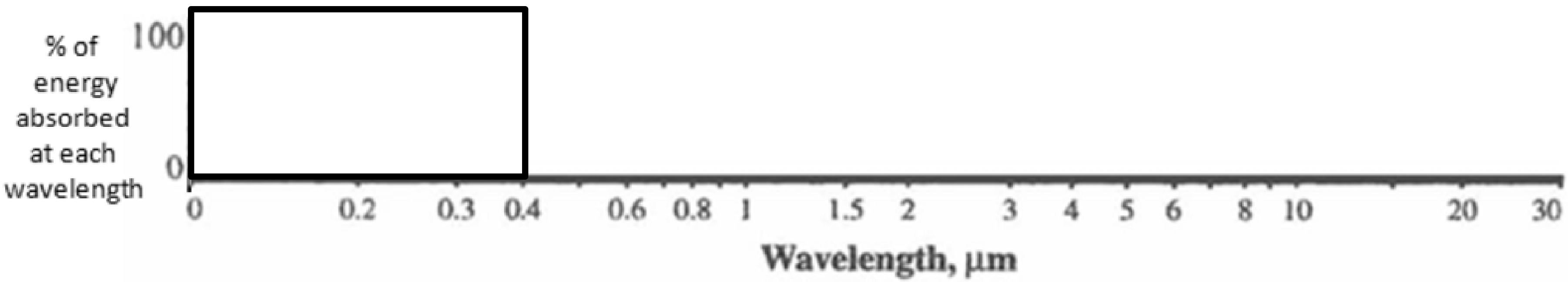
ABSORPTION CURVES

We use an absorption curve to show the relationship between wavelength (along the horizontal axis) and % of energy at a given wavelength that is absorbed (vertical axis):

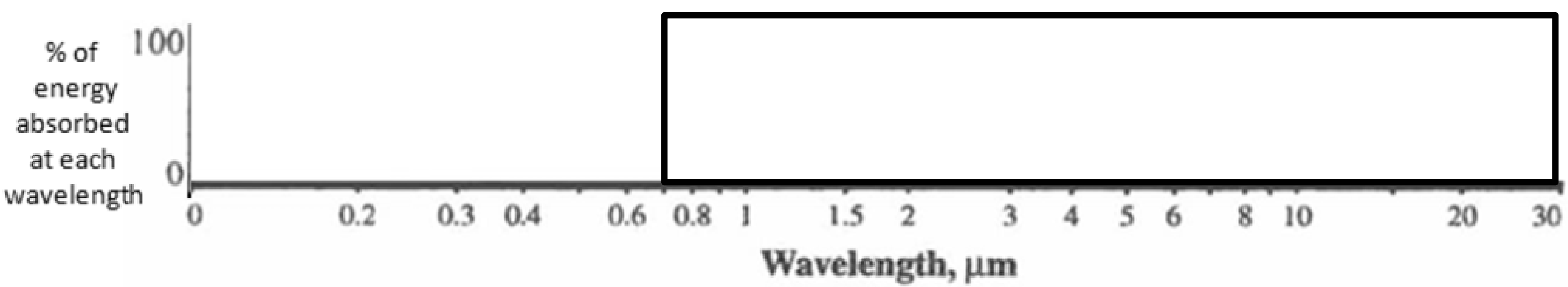


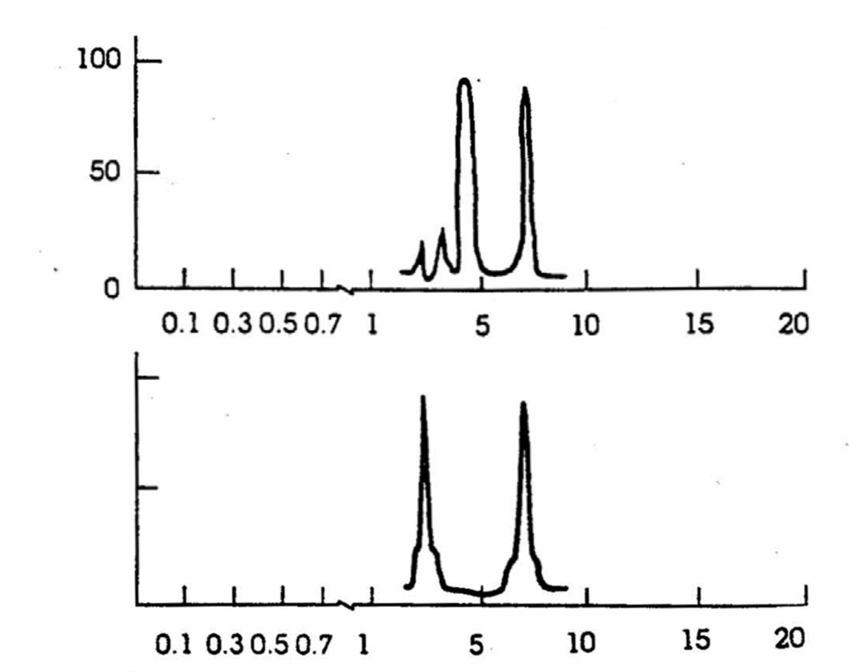
Make-a-sketch question:

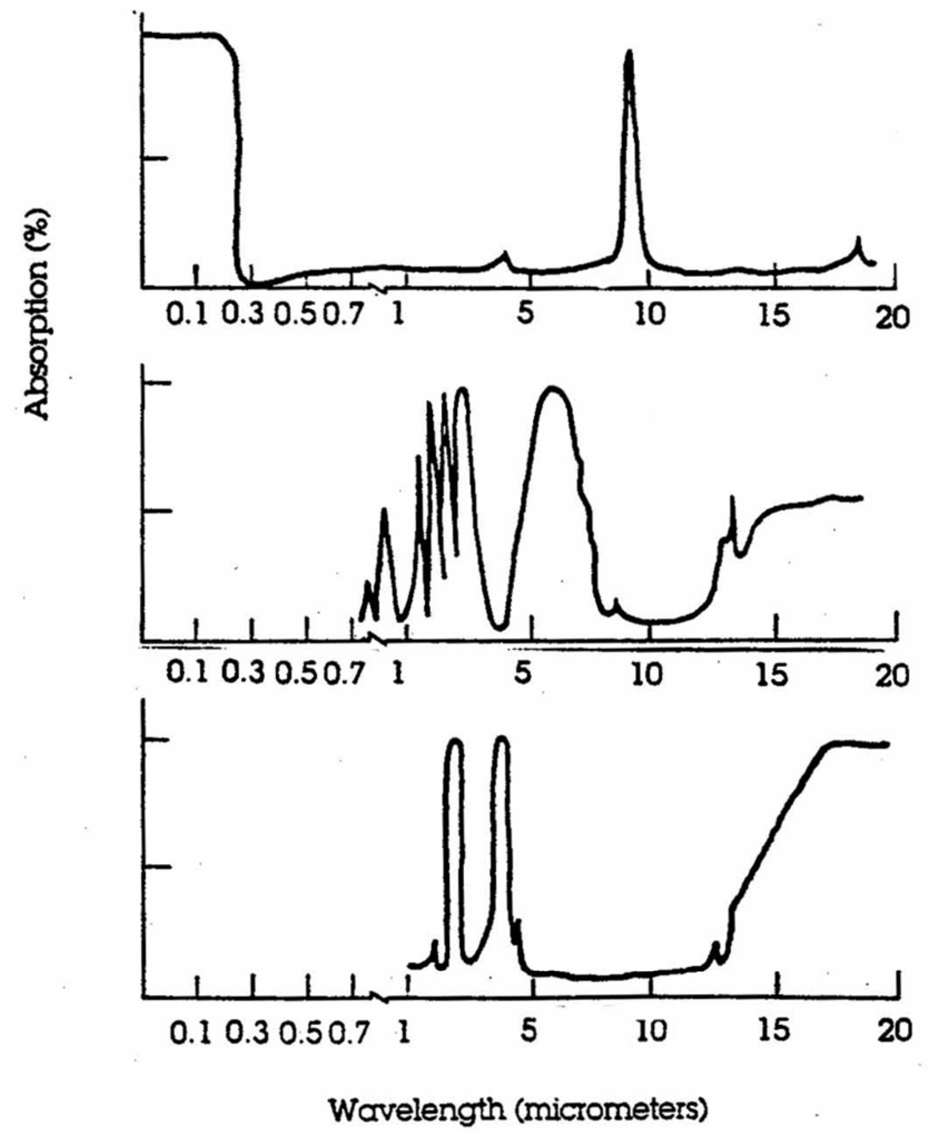
Draw an absorption curve for a hypothetical gas that can absorb ALL UV radiation but zero Visible light and IR:



Draw an absorption curve for a "perfect" greenhouse gas that absorbs ALL IR radiation, but NO visible or UV:

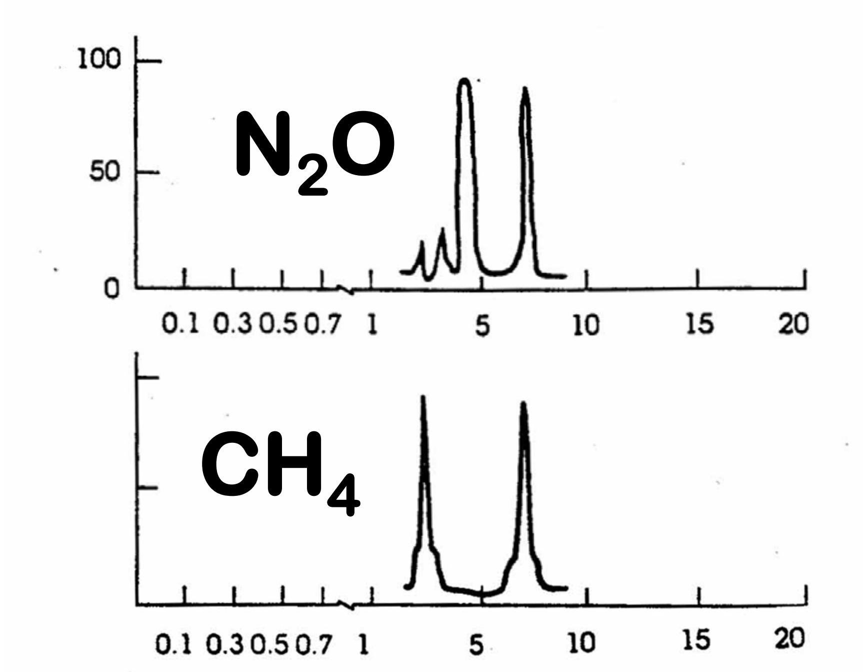


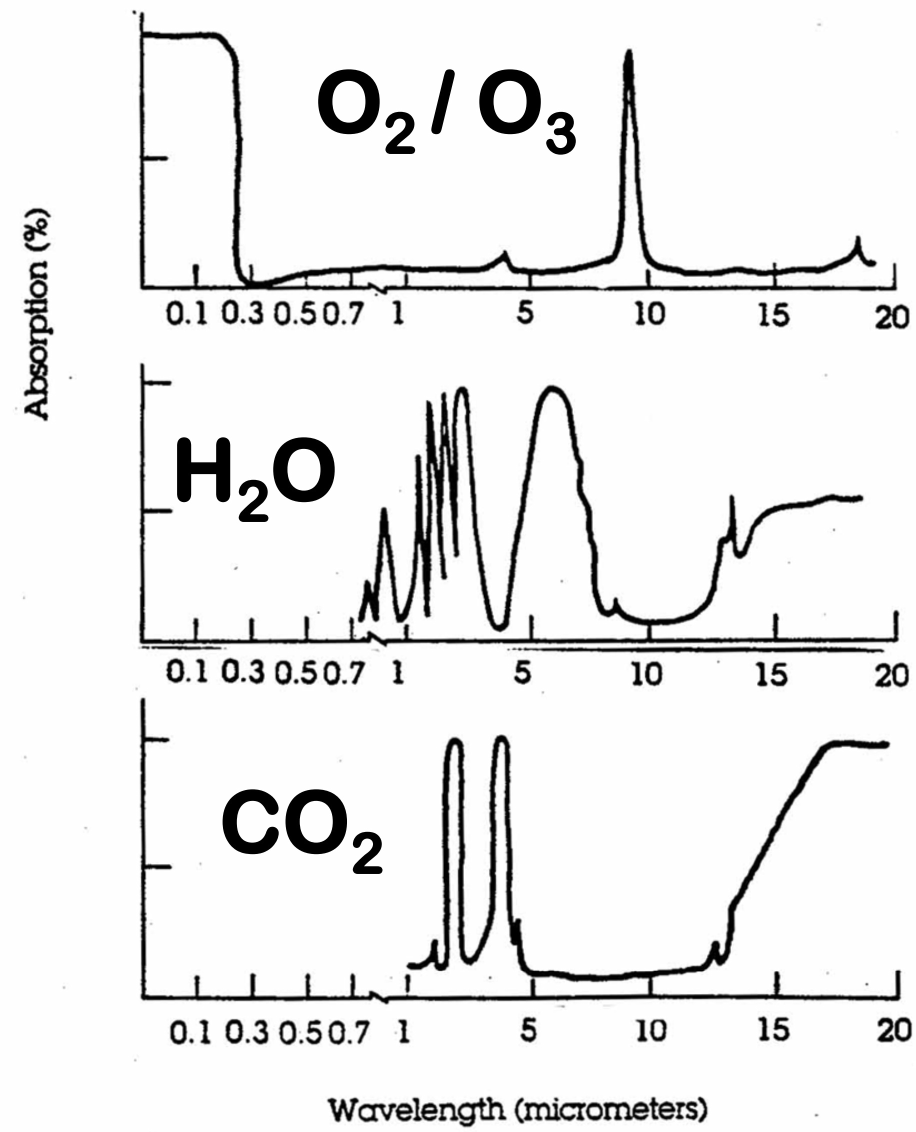




Match the right absorption curve with the right gas:

Choices: **H_2O O_2 / O_3 N_2O CH_4 CO_2**



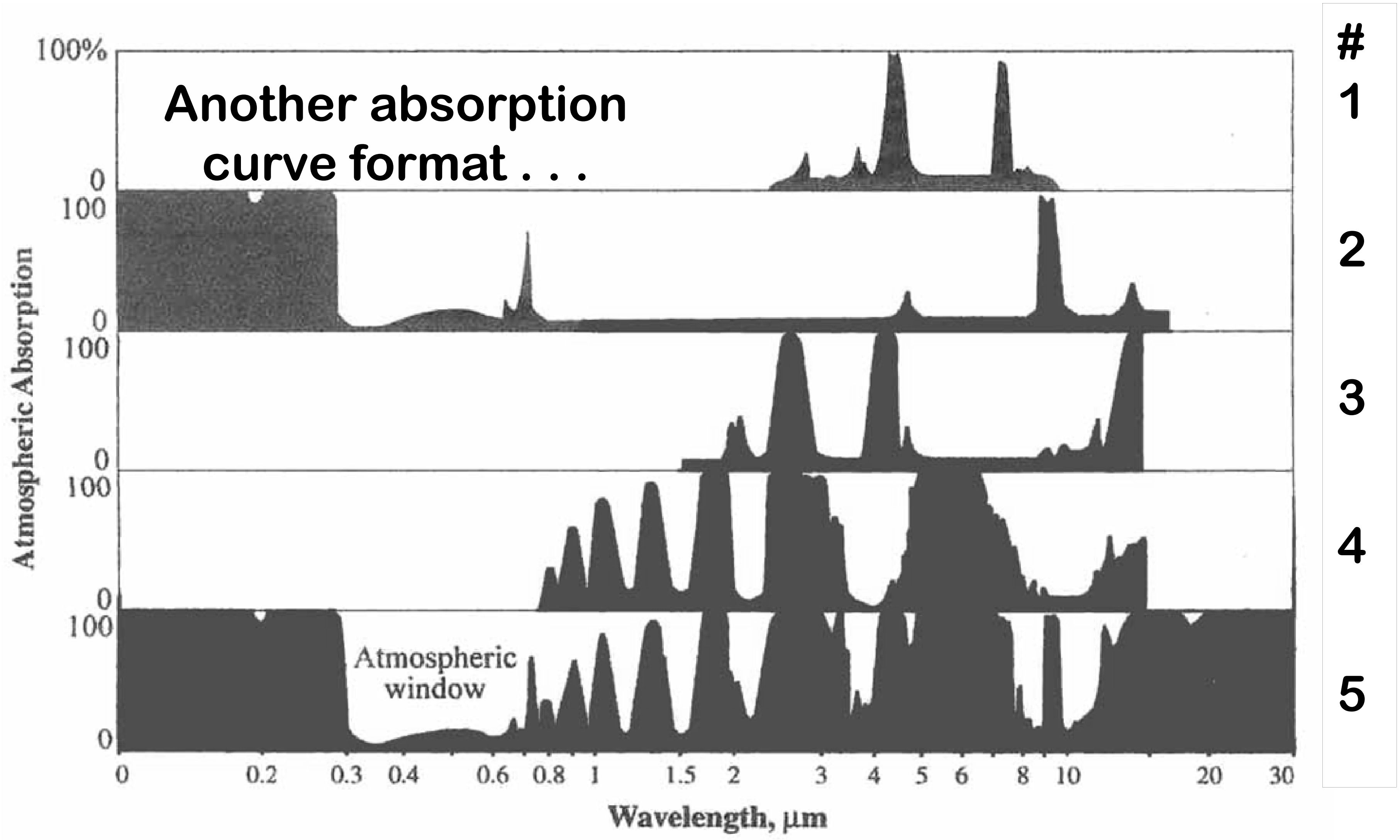


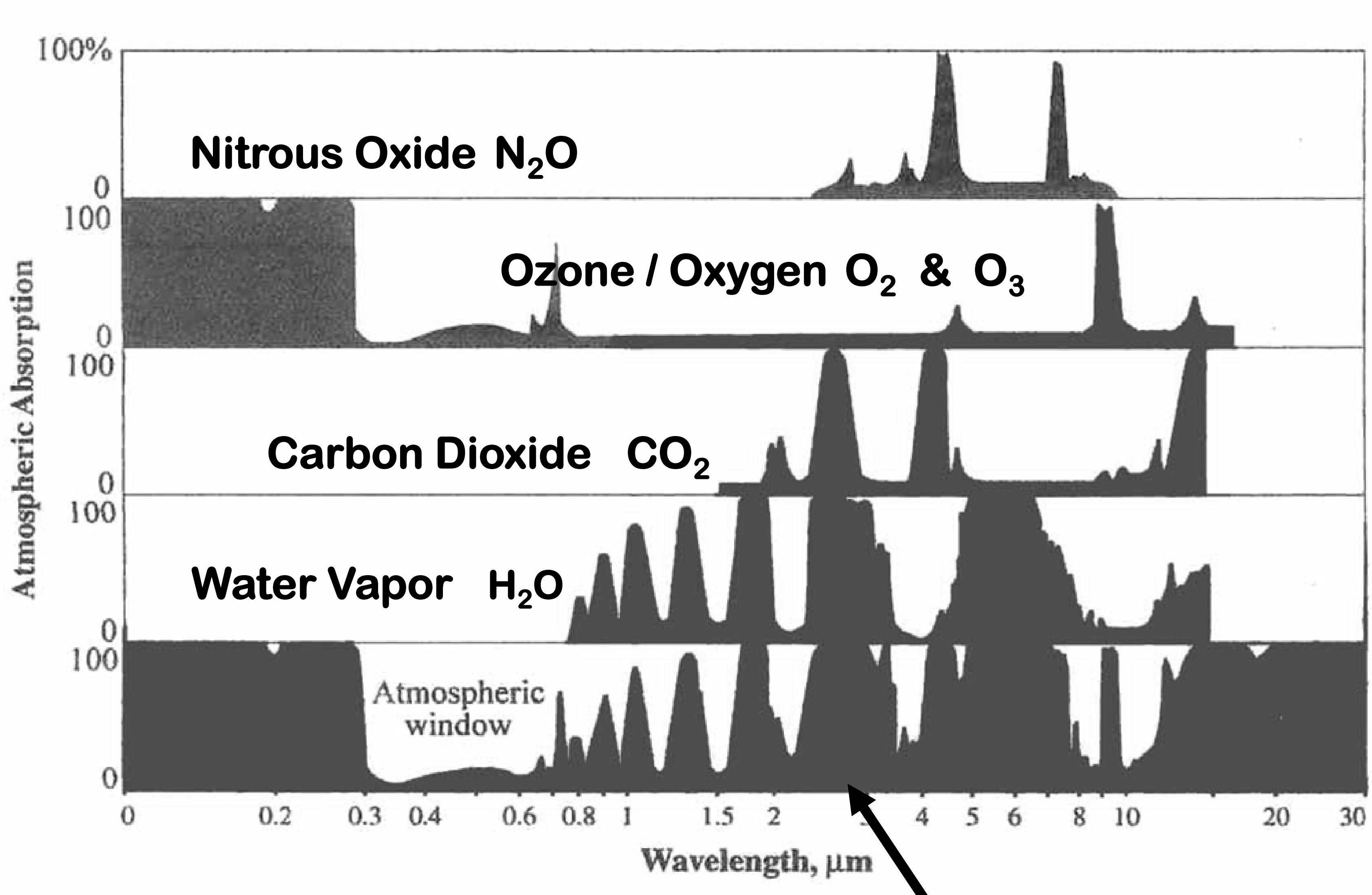
Match the right absorption curve with the right gas:

Choices: H_2O O_2 / O_3 N_2O CH_4 CO_2

Match the GAS with the Absorption Curve #:

CHOICES: CO_2 H_2O O_2/O_3 N_2O & ??

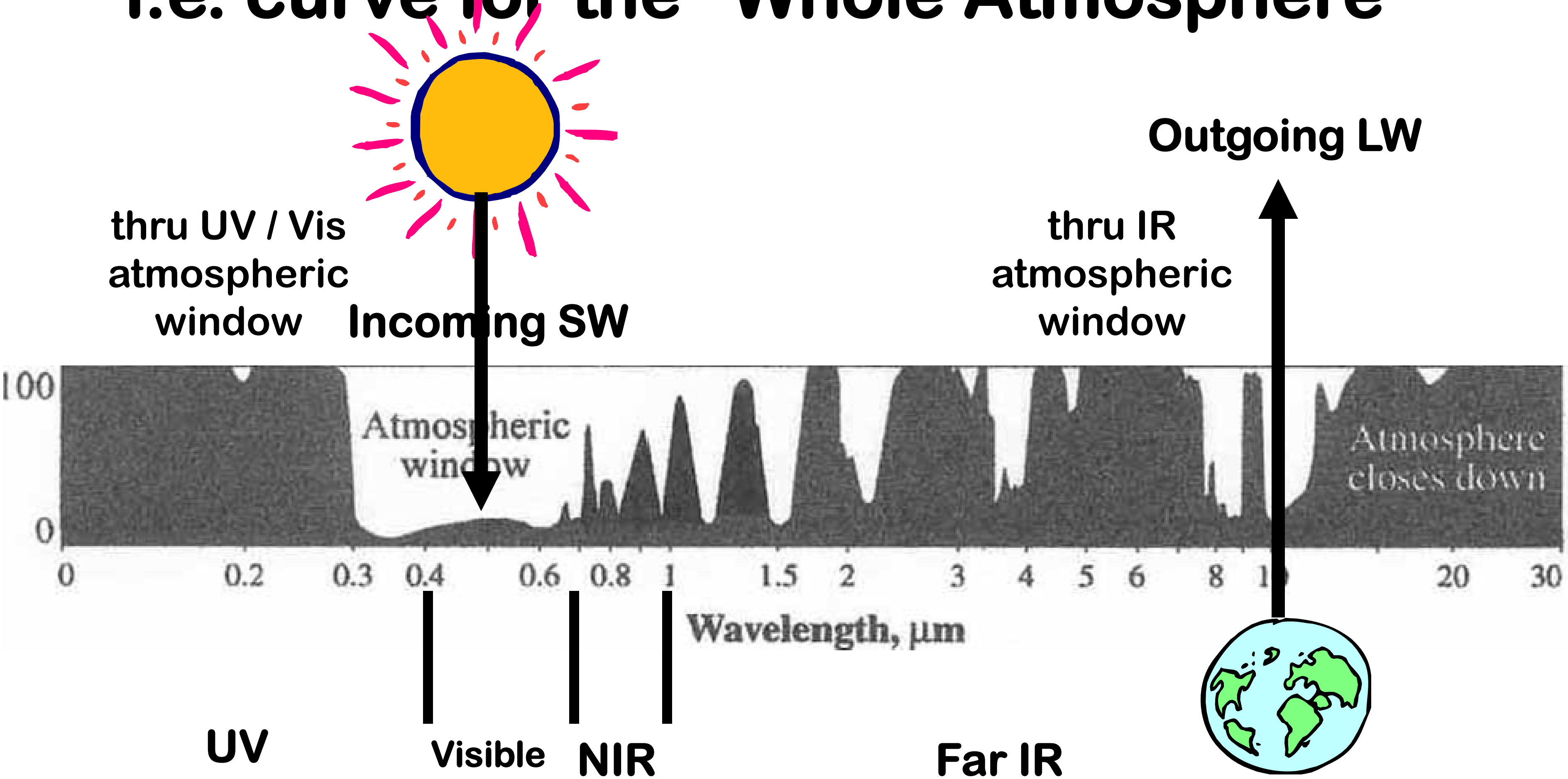




All gases in the atmosphere together!

Absorption by ALL the gases in the atmosphere put together –

i.e. curve for the "Whole Atmosphere"



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KEY CONCEPTS TO GET OUT OF ALL OF THIS:

1. Solar radiation is mostly in shortwave (SW) form (visible and UV).

Most visible & UV wavelengths are TRANSMITTED through the atmosphere but some (esp. harmful UV) are absorbed on their way to Earth's surface by O_2 and O_3.

☺

2. Most of the incoming solar energy absorbed by the Earth and the atmosphere is absorbed *at the EARTH'S SURFACE* which then radiates IR outward to heat up the atmosphere.

Hence, the ATMOSPHERE is HEATED primarily from BELOW (i.e. from terrestrial radiation)

☺

3. Terrestrial radiation is mostly in longwave (LW) form (IR).

Much of the outgoing terrestrial radiation is ABSORBED by H_2O and CO_2 (and other GH gases) before it escapes to space, and it is re-radiated back to the Earth's surface

This is the "Greenhouse Effect".

☺

4. 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!

Turn in your “FRUGAL CLICKER” CARD now !!

PASS YOUR SELF-GRADED CARD TO THE END OF THE AISLE

Stella Student Grp # 0
Q1
Q2
Q3
Q4
Q5

The first 10 randomly selected cards with all answers correct will get a mini-prize at our next class!

PRIZES! PRIZES PRIZES! PRIZES !